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Natural Fire Regime: A Guide for Sustainable Management of the Boreal Forest

by

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Abstract

The combination of certain features of fire disturbance, notably fire frequency, size and severity, may be used to characterise the disturbance regime any region of the boreal forest. As some consequences of fire resemble the effects of industrial forest harvesting, conventional forest management is often considered as a disturbance that has 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 also has limitations. Short fire cycles generally described for boreal ecosystems do not appear to be universal; rather, important spatial and temporal variations have been observed in Canada. These variations in the fire cycle have an important influence on forest composition and structure at the landscape and regional levels. Size and severity of fires also show a large range of variability. The maintenance of this natural variability should be targeted by forest managers concerned with biodiversity conservation. Current forest management tends to reduce this variability: for example, fully regulated, even-aged management will tend to truncate the natural forest stand age distribution and eliminate over-mature and old-growth forests from the landscape. We suggest that the development of silvicultural techniques that maintain a spectrum of forest compositions and structures at different scales in the landscape is one avenue to maintain this variability. Although we use the eastern boreal forest of Quebec for our examples, it is possible to apply the approach to those portions of the boreal forest whose dynamics are driven by fire.

Keywords : natural disturbance, landscape patterns, coarse filter, harvest pattern, volume retention, historic variability, even-aged management

Introduction

Over the past decade, there has been an increasing interest in the development of forest management approaches that are based on an understanding of natural disturbance dynamics (Attiwill 1994, Bergeron and Harvey 1997, Angelstam 1998). The rationale, which is generally considered sound, is that management that favours the development of stand and landscape compositions and structures similar to those that characterise natural ecosystems should be favourable to the maintenance of biological diversity and essential ecological functions (Franklin 1993, McKenney et al. 1994, Gauthier et al. 1996; Hunter 1999) because indigenous organisms in a given region are probably well adapted to the environmental forces that have been acting over thousands of years.

Despite a certain interest for natural disturbance-based management, the application of the concepts is still not well developed. In effect, most articles treating the subject are limited to providing basic principles, but few go as far as suggesting silvicultural treatments and management strategies that allow practical application of the concepts. In absence of concrete alternatives, forest industry is often hesitant to distant itself from traditional practices that have been proved satisfactory for fibre production.

Application of a management approach based on natural fire regimes has also been constrained by limited knowledge of disturbance dynamics. Understanding of the fire regimes that characterise the boreal forest is still fragmentary and it is inappropriate to generalise from regional studies to the entire boreal zone. This lack of understanding has often lead to abusive generalisations. For example, clear-cutting has been justified for use throughout the boreal forest based on the assumption that the fire regime is characterised by the presence of frequent and severe fires that produced even-aged stands. In fact, it has become increasingly evident that this rule applies only partially to the entire boreal forest and that the situation is considerably more complex (Bergeron et al 2001).

In this article, we explore several avenues that provide greater linkages between natural disturbances, silvicultural practices and forest management strategies. Based on our understanding of the fire regimes that characterise the boreal forest of western Quebec, we illustrate how it is possible to use judiciously a solid understanding of natural forest dynamics in forest management planning and in the development of new silvicultural practices. Although the examples are especially applicable to the boreal forest of western Quebec, it is possible to apply the approach to those portions of the boreal forest where the fire regime favours the development of even-aged stands in burns.

Respecting historic variability of forest conditions

Figure 1 illustrates on three axes (time, size, severity) the possible variability that can characterise forest fires. In the boreal forest, considerable amplitude may exist on each of these axes, and this can vary from region to region. The risk of a fire occurring is such that one site may burn two years in a row whereas another may be spared for several hundred years. Similarly, the area burned by a fire can vary from less than one hectare to 100s or even 1,000s of km^2. Finally, while certain surface fires may only affect ground vegetation, an intense crown fire will kill virtually all trees in its path and may consume the forest humus layer down to the mineral soil. The combination of these characteristics - fire frequency, fire size and fire severity – and others make up the disturbance regime that is proper to an ecosystem or a forest region. Other than the variability imposed by permanent sites features which influence thermal, hydric and nutritional regimes, it is the disturbance regime that is responsible for the variety of forest habitats which occur in a region and thus determines the coarse filter on which maintenance of biodiversity should be based. In contrast, we can represent the variability theoretically created by an intensive forest management regime involving, for example, the wide-spread use of plantations and stand tending treatments. In this context, the interval between harvests, cutover size and their severity constitute a management regime whose variability would be considerably narrower than that of the natural disturbance regime and could even be situated outside of the range of historic variability of the disturbance regime (Figure 1).

Although the objective of ecosystem management is to respect the inherent variability of natural disturbance regimes, in practical terms it is aimed rather at defining a socially and economically acceptable compromise within the limits of historic variability that will reduce the risk of negatively affecting biodiversity. This management target is generally situated somewhere between the great variability generated by the natural regime and the homogeneity generated by a management regime aimed primarily at sustained fibre yield. It should be emphasised here that natural disturbance-based management is not meant to be the sole approach applied to a region but rather the management basis that will affect the major part of the forest mosaic. In this respect and in the perspective of biodiversity maintenance, ecosystem management is intended to complement rather than replace strategies of integral protection areas. In this regard, land-base losses due to the establishment of a network of protected areas could be compensated by an increase in productivity associated with the development of another network of intensive management zones. Regional zoning based on three general categories of management (protection, intensive management, and natural disturbance-based management), Seymour and Hunter's (1992) Triad concept, has been proposed as an integrated solution for maintaining biodiversity in regions managed by the forest industry.

In the following sections we treat each of the three variability axes that characterise fire regimes in the boreal forest, that is, fire frequency, size and severity, and discuss interpretations for the development of new silvicultural and management planning practices. We will illustrate our points with concrete examples from work undertaken in the boreal forest of western Quebec.

Fire frequency and its implications for management strategies and silvicultural practices

When forest rotation age approaches fire cycle, at first glance even-aged management would appear to resemble the natural disturbance regime. However, full even-age regulation does not produce an age class distribution equivalent to the natural distribution, even for forest rotations that are as long as the fire cycle. In effect, in even-aged management a forest is referred to as fully regulated when stand age classes are uniformly distributed throughout a territory. Thus, in theory, after one complete rotation in a region submitted to a 100 year rotation, no stands over the rotation age will exist (Fig. 2a).

The same region submitted to forest fires intense enough to generate even-aged stands will, at equilibrium, present a completely different age class distribution of stands composing the forest. Assuming that the probability of burning is independent of stand age (as is generally reported for studies in the boreal forest; Johnson 1992, Johnson et al. 1998), the forest age structure will, again theoretically, resemble a negative exponential curve, with about 37% of forests older than the fire cycle (Johnson and Van Wagner, 1985; Fig. 2b). This means that for a fire cycle and a forest rotation of similar duration, forest management will not spare any forest that exceeds rotation age whereas fire will maintain over 37 % of the forest in older age classes. This difference is fundamental because it implies that full regulation in an even-age management regime will result in the loss of over-mature and old growth forests, often judged to be essential for the maintenance of biodiversity. Our studies in the forests of western Quebec show that the natural mosaic contains almost 50 % of forests in these categories. Thus diversifying silvicultural practices would appear to be a potential solution to reproducing the diversity of stand structures and compositions of the natural mosaic.

Use of rotations of variable length in proportions similar to those observed in the natural fire regime is a possible alternative (Seymour and Hunter1999; Burton et al. 1999; Fig 3a). However, the approach may be applicable only in ecosystems where species are long-lived and can thus support longer rotations. In boreal forests composed of relatively short-lived species this approach would probably lead to fibre loss and a decrease in allowable cut. This dilemma is not without a solution however. Silvicultural practices aimed at maintaining structural and compositional characteristics of over-aged stands in treated stands could, in boreal regions, guarantee maintenance of habitat diversity while only slightly affecting allowable cut. Thus it would be possible to treat some stands by clear-cutting followed by seeding or planting (or another even-age silvicultural system whose outcome resembled the effect of fire), other stands with partial cuts which approach the natural development of over-aged stands and still other stands with selection cuts in order to reflect the dynamics of old growth stands (Fig 3b).

A simple example illustrating natural dynamics and management of the boreal forest of eastern Canada is presented in Figure 4. The first case (Fig. 4a) illustrates natural succession in the mixedwood forest located in the southern portion of the eastern boreal forest. Following fire, we generally observe an invasion of shade-intolerant hardwoods (birch and poplar) that are gradually replaced in the canopy by shade-tolerant conifers (Bergeron and Dubuc 1989; Bergeron 2000). Thus, during a period of over 200 years, successive replacement of hardwood stands by mixed stands then by softwood stands occurs.

Further north, in the coniferous boreal forest dominated by black spruce (Fig. 4b), stand establishment following fire is often dominated by an initial cohort of spruce which gives rise to a dense, even-aged forest issued principally from seed. At maturity, this stand structure is gradually replaced by a more open forest containing stems originating from the fire and regeneration partly of layer origin. In the prolonged absence of fire, these stands develop into uneven-aged stands maintained by layering and characterised by an even more open and heterogeneous structure. In comparison to the mixedwood forest, tree species composition remains relatively stable in the black spruce forest but the structure is very different between mature, over-mature and old growth stands.

Varying silvicultural practices is intended to recreate a composition and structure comparable to natural stands. Thus the even-aged structure of the first cohort issued from fire could be generated by clear-cutting followed by natural or artificial regeneration. The irregular structure of the second cohort would be maintained or stimulated by partial cutting practised in stands with even or uneven-aged structure. In the case of the uneven structure of the third cohort, it could be generated by selective harvesting to mimic the creation of characteristic gaps of old growth stands. The proportion of stands submitted to each of these treatments will vary depending on the natural disturbance cycle and maximum harvest age.

In a forest system under a natural fire regime, not all stands survive to a mature or old growth stage before again succumbing to fire. In the same way, in the proposed strategy, not all stands should develop to the latter, advanced cohorts. Thus, the reinitiation to a first cohort forest type can occur when forest types in any of the three cohorts are clear-cut and either naturally or artificially regenerated. Figure 3b provides an example of a possible forest age structure where maximum harvest age and fire cycle are both 100 years. The approach provides a means of covering a forest management area with zones of regulated, even-aged forests with proportions of each decreasing in relation with time since the last stand-initiating clear-cut or fire. It should be noted here that the third cohort includes all age classes greater than 200 years. In the case where more time is required to attain a state of quasi-equilibrium, more than three cohorts could be necessary to simulate forest dynamics. In contrast, in regions where fire cycle and forest rotations are short, probably only two cohorts will be necessary. It would thus be possible to partially recreate not only the natural composition and structure of stands, but also to reproduce a forest age structure (proportions of each cohort) that approaches the typical distribution produced by fires (Fig.2b).

This approach can easily be applied to a number of situations; it is only necessary to know the natural fire cycle and maximum harvest age to determine the relative area of each cohort to be maintained over the forest landscape. Silvicultural practices are varied according to the cohort distribution and the disturbance regime of a given forest region. Table 1 presents a framework for determining the proportion of cohorts based on fire cycle and maximum harvest age, the latter considered as the age at which stand break-up begins to occur (i.e., when tree mortality represents significant merchantable volume loss). In this sense, the commercial rotation is generally shorter than maximum harvest age.

In regions where particular site or forest cover conditions generate variable fire frequencies, the model should be applied to homogeneous forest types. This is the case of the ASIO model (Angelstam 1998) for European boreal forests. In the Canadian boreal forest, however, with the exception of situations that are clearly very humid or very dry, it appears that fire is only slightly influenced by the quantity and type of fuel, and that the model can be applied directly to the majority of the territory (Johnson 1992, Johnson et al., 1998).

Fire size and its implications for size and spatial distribution of cutovers

It may appear socially unacceptable to want to use fire size as a basis for developing management directives for cutover size and mean buffer size for even-aged harvesting in the boreal forest. Moreover, in a number of countries, regulations limit clear-cuts in any continuous block to areas under 150 ha in the boreal forest, whereas lightening-caused fires can easily spread over thousands of hectares. While individual cut blocks are clearly much smaller than the mean size of natural burns, they are normally created in a continuous progression and tend to be clustered in a given area. The proximity of numerous blocks over time usually results in the creation of vast areas in regeneration within which remain only fragments of mature forest, essentially in the form of cut block separators, buffer strips and unproductive or inaccessible forest. The spatial and temporal scales for which questions concerning clear-cut size and spacing are to be addressed should correspond to those scales at which these “regeneration areas” are established.

Establishment time for a regeneration area and, consequently its size, will depend on the time required for plants and animals indigenous to the mature forest to be reintroduced into the young forest following harvest, or the time required for the young forest to acquire structural and compositional attributes of the mature forest. Depending on the forest type and specific requirements of each species, 35 to 70 years could pass before the oldest portion of a regeneration area begins to merge into the surrounding mature forest. Over such long periods, the forest

industry has created regeneration areas that exceed tens of thousands of hectares. It is certainly questionable whether these expansive areas of young even-aged forests are situated within the historical limits of variability of burn sizes characteristic of the natural fire regime.
There are relatively few records concerning sizes of past lightening-ignited forest fires. In Quebec, the oldest records are provided by the Ministry of Natural Resources. These records document forest fire events that have occurred in Quebec since the 1940s and provide information concerning their location, origin, ignition date and size.

One of the first things that becomes evident when illustrating frequency of fire occurrence by different size classes is that, whereas the majority of fires are smaller that 1,000 ha, these fires are generally responsible for less than 10 % of the total area burned in western Quebec (Fig. 5a, b). Consequently, it is primarily the large fires (those over 1,000 ha) that are responsible for the natural regeneration of the forest and that permeate a given age structure and configuration (Johnson et al. 1998). At the high end of fire size distribution are fires that cover very large areas. In fact, among those fires over 1,000 ha, the 10 % that are over 20,000 ha are alone responsible for 40 % of total area burned. Considering that these extremely large fires reflect exceptional events (a fire occurring during a particularly dry season, for example), of which we have little effective control, it would appear prudent to exclude these fires from a reference distribution.

Perhaps the most important point of this analysis of fire size distribution is that, over the last 60 years, almost 55 % of area burned in the balsam fir mixedwood forest of western Quebec occurred from fires varying in size from 265 to 15,000 ha. In the black spruce zone of western Quebec for the same period, fires ranging from 950 to 20,000 ha could be considered characteristic. In newly accessed areas of mature and over-mature forests, analysis of fire size distribution suggests that regeneration areas should be limited within the intervals mentioned.

With respect to the spatial distribution of these regeneration areas, or a minimal distance to be maintained between these areas, there is very little existing evidence that fires tend to be clustered in the landscape within a region. A cautious approach would be to maximise the dispersion of regeneration areas in order to limit the cumulative effects that may occur from their juxtaposition. In such a case, guidelines for minimum spacing between regeneration areas could be developed based primarily on fire cycle and its influence on the ratio of even-aged to uneven-aged forest to be maintained in the forest mosaic under management.

To this effect, a fire history map of the boreal forest of western Quebec illustrates the spatial organisation between recent fires (less than 100 years) and older fires (over 200 years) in a region where the average age of the forest is about 150 years (Figure 6a). The overlapping of recent and older fires suggests the application of a fairly complex juxtaposition of clear-cuts (to be favoured in even-aged forests issued from recent fires) with partial and/or selection cuts to be practised in older, uneven-aged forests. In fact, there exists a gradient of heterogeneity of forest mosaics according to the natural disturbance regimes that generated them. At one extremity of this gradient are found mosaics driven by short fire cycles approaching maximum harvest age of stands. These mosaics are relatively homogeneous in terms of composition and distribution of the cohorts because they are largely dominated by even-aged stands (Figure 6b). Old stands, originating from fragments of the oldest fires that have not been effectively erased by more recent fires, are generally sparse and may present a more or less elongated form (Johnson et al., 1998). The use of clear-cutting as the main harvesting regime should be favoured in the case of these mosaics.

At the other extremity of the gradient are forest mosaics in which fires are very infrequent and, consequently, fire cycle greatly exceeds the life span of the first cohort. Here again the forest is relatively homogeneous because it is dominated by uneven-aged and irregular stands characteristic of old age structures (Figure 6c). Management of these forests should favour the use of partial and selection cuts, practices that should more closely resemble natural disturbances (ex. windthrow, stem breakage, gaps dynamics) that occur in the absence of fire.

Even if these two examples characterise extreme situations in which one management strategy, either even-aged or uneven-aged, dominates over the other, there is always place for silvicultural diagnoses prior to harvesting so that the treatments applied are appropriate to stand and site conditions.

Fire severity and its implications for cutting patterns

One of the most tenacious beliefs shared by many foresters in North America is that fires in the boreal forest are generally severe; that is, that they induce the mortality of most trees within their perimeter. Moreover, several studies have shown that only about 5 % of burnovers generally subsists as interior forest islands, untouched by a fire (Eberhart and Woodard, 1987), a figure which may approach the proportion of residual forest left by the forest industry within a cutover. As a corollary, even-aged harvesting is often presented as being no more or no less severe than a fire and, as such, contributes in a similar manner to natural regeneration processes of the forest.

In fact, however, a forest fire, especially if it extends over very large areas and burns for longer than a day, will present variations in severity in its path, leaving green trees following its passage (Kafka, 2000, Turner and Romme, 1994, van Wagner 1983). Fire severity mapping in Quebec recognises de facto the existence of this phenomenon by including the class “mixture of green crowns and reddened crowns with green-crown dominance” in order to designate zones where fire has had a low impact. Far from being a marginal phenomenon, these “low severity zones” may occupy up to 50 % of a burn area, depending on the type of forest burned and, especially, the prevailing weather conditions prior to (Fire weather index) and during the fire. Not only do those trees that survive the passage of a fire appear to play a determining role in regenerating burns (Greene and Johnson, 2000), but they also constitute habitat refuges or shelter in the regenerating forest and contribute to increasing spatial heterogeneity of the forest mosaic resulting from the fire.

Again, we can only conclude that there exist few empirical studies based on detailed mapping of fire severity in the boreal forest. Nonetheless, existing studies tend to attest to the variability of fire severity and would advise caution in drawing similarities between forest conditions created by even-aged harvesting and those prevailing after fire (Nguyen-Xuan et al. 2000). The following example illustrates this variability and the importance of low impact zones within burns. In recent years the Quebec government has encouraged salvage cutting in burns to limit losses of wood volumes following fires. This practice has given rise to a systematic procedure of mapping fire zones in order to guide salvage operations. Although the collection of fire impact maps is limited, it does provide a means of estimating spatial heterogeneity of recent fires.

Figure 7 presents internal composition profiles of 16 fires that occurred during 1995 and 1996. In comparing these profiles, it can quickly be inferred that one of the principal sources of variability is year of fire occurrence. In this example, it is clear that 1995 was particularly favourable for the development of large, severe fires. It was during this year that, among others, the largest fire in 60 years, the Parent Fire, burned almost 67,000 ha. In contrast, the fire weather index during 1996 generally remained within normal historical values. Consequently, fires in 1996 generally burned smaller areas and contained more area of lightly burned forest, roughly 30 to 50 % of their area (Fig. 7). It should be noted that this variability primarily concerns areas slightly affected by the fires, rather than areas that escaped the burn (preserved islands) that were relatively constant around 5 % (Fig. 7). The sustained presence of these lightly burned zones suggests that the mortality pattern generated by fire is notably distinct from that issued from conventional forest harvesting.

In order to reduce the difference between these two disturbance types, retention strategies for cutovers have been increasingly proposed in North America (Cissel et al. 1999, Hebert, per. comm.). The quantity of stems to be left on site raises questions of both an ecological and economic nature. For example, in their article aimed at defining forest ecosystem management targets, Cissel et al. (1999) propose maintaining almost 30 % (on average) of forest cover after harvesting in the Blue River region of Oregon. The impact of this strategy would result in a decrease in wood supply of approximately 17 %. Another example is provided by the company Alberta Pacific, operating in north-eastern Alberta, Canada, which has opted for retention of 6 % of merchantable volume. There are currently no regulations concerning the maintenance of a proportion of green trees in cutovers in the boreal region of Quebec. Our example, however, suggests that almost 5 % of regeneration areas should be dedicated to integral preservation in addition to 30 - 50 % of the area in which variable volume retention should be practised.

Detailed impact mapping of the Lac Crochet Fire, undertaken by Kafka et al. (2000), provides further illustration of the kind of spatial configuration that retention areas could occupy. This 49,070 ha fire that burned in 1995 left a number of zones lightly burned in its passage. These low impact zones appear distributed over the entire burn rather than confined to any particular sector (Fig. 8). Moreover, the preserved (unburned) parcels, averaging 52 ha in size, appear frequently surrounded by low impact zones (Fig. 8). An analysis of their form shows that these islands display a relatively regular form and thus would be expected to incorporate less edge effect than more linear forms. Almost 75 % of their area may be considered as interior habitat (value calculated for an edge effect to 50 m). As a comparison, residual areas left following forest harvesting are most often linear (ex. 100 m cut block separator strips) and thus do not generally preserve interior habitat. Finally, Kafka et al. (2000) calculated that almost 50 % of severely burned zones are found less than 200 m (maximum distance judged adequate for seed dispersal by wind) from a potential seed source in unburned or low impact zones.

In order to minimise economic losses due to the application of retention measures, questions regarding the permanence of retention volumes need to be addressed. Even if we have little data concerning this subject, preliminary data from one fire in Quebec indicate that the mortality rate of residual stems in lightly burned zones can vary from 30 – 50 % two years after fire. Moreover, the dominance of even-aged structures in post-fire boreal stands forest suggests that a portion of residual stems will die over a number of years following the fire. Maintenance of large retention volumes would receive greater economic consideration if a large part of these volumes could be salvaged a number of years following harvesting.

In summary, what we know of fire severity in the eastern Canadian boreal forest should prompt the development of measures aimed at volume retention within even-aged regeneration areas. Between 3 - 5 % of total regeneration areas should be dedicated to preservation. These preserve islands, varying in size from 50 – 200 ha, should be surrounded by a buffer zone (of which the dimensions remain to be determined) where volume retention would be in the order of 30 to 50 %. In total, retention volumes, outside of preserves, should represent 15 – 20 % of initial standing volume and could be harvested at a latter period. If natural inseeding is an objective, composition of these volumes should be made up of forest species known for regenerating from protected seed-trees (ex. balsam fir, white pine and white spruce). Distribution of residual volumes should be such that no part of a regeneration area is farther than 150 m from a potential seed source, a distance, according to Greene et al. (in press), that can still provide moderate stocking. Moreover, given the importance of snags for certain species, a number of stems, especially those with high longevity could be left on site.

Flexibility in applying the approach to different regional realities

Existing work in the Canadian boreal forest has demonstrated the high regional variability in fire regime characteristics and empirical data is still missing to cover all of this variability. Moreover, it is now well established that following future climatic changes, as in the past, fire regime will continue to change (Flannigan et al. 1998). Given this context, it might appear imprudent to want to fix precise management objectives that are inspired from fire regime. While remaining cautious concerning the precision of potential guidelines, it is possible to offer targets for forest managers that are sufficiently wide and allow some flexibility. These targets have the advantage of offering concrete alternatives to current practices, alternatives that move the composition and age structure of managed forest mosaics closer toward their natural state.

In the following section, the applicability and flexibility of the approach described above is illustrated using three regions of Canada that are submitted to contrasting fire regimes. In the boreal forest of western Canada, historically fire cycles have been relatively short (50 – 75 years) and, as a result, the forest mosaic is principally composed of even-aged stands issued from the last fire; a very small area is occupied by over-mature or old growth stands (Johnson 1998). Referring to Table 1, it can be seen that the proportion of first cohort (even-aged) stands should increase in a landscape as maximum harvest age increases relative to fire cycle. In such situations, clear-cutting (and other even-aged silvicultural systems) are to be favoured. Fires affecting forest age structure in western Canada generally cover large areas over 1,000 ha. Almost 50 % of total burned area originates from fires over 10,000 ha (Johnson et al. 1998). Regeneration areas created by forest industry could therefore cover over 10,000 ha, with maximum spacing between areas. Finally, fires that are normally severe will nonetheless preserve some sparsely distributed green trees, either individually or in small groups in the burn (Greene and Johnson 2000). This heterogeneity in the mortality pattern within burns should prompt some volume retention within cut blocks. (See section on severity.)

In contrast, the situation of the mixed or coniferous forest regions of Abitibi, discussed above, shows historically an intermediate fire cycle around 150 years. In this context, forest managers should rely on even-aged management for about 50 % of the region, whereas variable intensities of removal of stand volume (partial and selection cutting) should be applied to the rest of the region (Table 1). As fire size and severity are similar to those in Alberta, management strategies concerning size of regeneration areas as well as quantities of retention could resemble the preceding prescriptions.

Finally, in the more humid climate of eastern Canada, for example in the Quebec North Shore or Labrador, where fire cycles can reach 500 years (Foster 1983), stands are most often irregular or uneven-aged. Consequently, the use of clear-cutting should be considerably diminished and greater use be made of partial and selective harvesting. In this case, it is less the fire regime that offers the most important information for forest management and more other disturbances, such as windthrow and insect outbreaks, that become largely responsible for the make up of the forest mosaic. These disturbances could justify the use of other silvicultural approaches (Bergeron et al 1999).

Conclusion

These examples clearly demonstrate that, for the boreal forest, the universal presence of a frequent and severe fire regime that produces only even-aged stands - as is often used to justify even-aged management - is a myth. This simple understanding has significant implications for changing silvicultural practices, in the context of sustainable forestry, in which uneven-aged management can be expected to assume a greater place in boreal forest management. Although the solutions presented in this paper still remain somewhat theoretical, they do attempt to provide concrete measures for application. These measures should consider the objectives of implementing more sustainable forestry. In effect, we should change our perception of ecosystem management. Rather than consisting of mimicking Nature, ecosystem management should be inspired by our understanding of natural systems in order to maintain their essential functions (ex. productivity, resilience) and their biological diversity. In this sense, the use of so-called “hard practices” such as site preparation and plantations can be justified if they are aimed at reproducing the processes that are essential to assuring forest regeneration and productivity. It is also important to consider the numerous constraints related to forest operations. It is probably easier to adapt proven forest practices than to invent totally new treatments. In this respect, projects aimed at testing new silvicultural approaches inspired by natural dynamics, like a number of projects currently being undertaken in the boreal forest (Harvey et al. in press, Spence et al. 1999), should be initiated throughout the boreal forest. However, we can not wait for the results of these studies in order to change forest practices. In effect, natural forests are disappearing rapidly and we have the responsibility now to manage the forest sustainably. Moreover it is probably much less costly in the long term to establish practices that are based on natural forest dynamics than to attempt to restore forests that have undergone inadequate treatments. We should learn from northern European countries that are currently having to invest in the restoration of their natural forests (Kuuluvainen, this issue).

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Table 1 : Targeted proportions of cohorts according to fire cycle and maximum harvest age.

Note: The third cohort consists of the sum of proportions of all subsequent cohorts.

Maximum Harvest Age	Fire cycle														
	50			**100**			**200**			**400**			**500**		
	cohort (%)			cohort (%)			cohort (%)			cohort (%)			cohort (%)		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
50	63	23	14	39	24	37	22	17	61	12	10	78	10	09	82
100	86	12	2	63	23	14	39	24	37	22	17	61	18	15	67
150	95	5	0	78	17	5	53	25	22	31	21	47	26	19	55
200	98	2	0	86	12	2	63	23	14	39	24	37	33	22	45

Figure 1 : Three dimensional conceptual model of fire regime variability in natural ecosystems (A) and managed ecosystems (B and C). In B, forest management produces a disturbance regime that incorporates little of the diversity of the natural regime. In C, management is illustrated as reproducing natural disturbances but with less variability.

Figure 2 : Theoretical forest stand age class distribution (10 years) as a function of a 100 year even-aged rotation (2a) and a 100 year fire cycle (2b).

Figure 3 : Alternative strategies to the full, even-aged forest regulation strategy. In 3a), a solution proposed by Seymour and Hunter (1999) consists of applying different forest rotation lengths in an area under management. In 3b), management by cohorts consists of diversifying silvicultural practices in order to favour the development and maintenance of stands with even- and uneven-aged structures.

Figure 4 : Natural stand dynamics and silviculture proposed for the boreal mixedwood (4a) and the black spruce boreal zones (4b). The arrows going from left to right represent time since the last fire or clear-cut.

Figure 5 : Size distribution of fires in the boreal forest of western Quebec for the period 1940-1998. 5a) shows the relative frequency of fires and 5b) shows the relative area burned, both according to fire size class.

Figure 6 : Time-since-fire maps illustrating the relative importance of different silvicultural treatments (CC = clear-cut, PC = partial cut, SC = selection cut) in relation to regional fire cycle. 6a) shows a real forest mosaic created under an intermediate fire cycle in the Abitibi region of north-western Quebec; 6b) shows a hypothetical mosaic under a fire cycle (50-80 years) that is shorter than average maximum harvest age; 6c) shows a hypothetical mosaic under a long fire cycle (300-500 years) which greatly exceeds the life expectancy of the first cohort.

Figure 7 : Relative area of preserved zones, lightly burned and severely burned portions of 16 burns that occurred in 1995 and 1996 in the boreal forest of western Quebec.

Figure 8 : Map showing the variability of fire severity in the Lac Crochet Fire.

Figure 1.

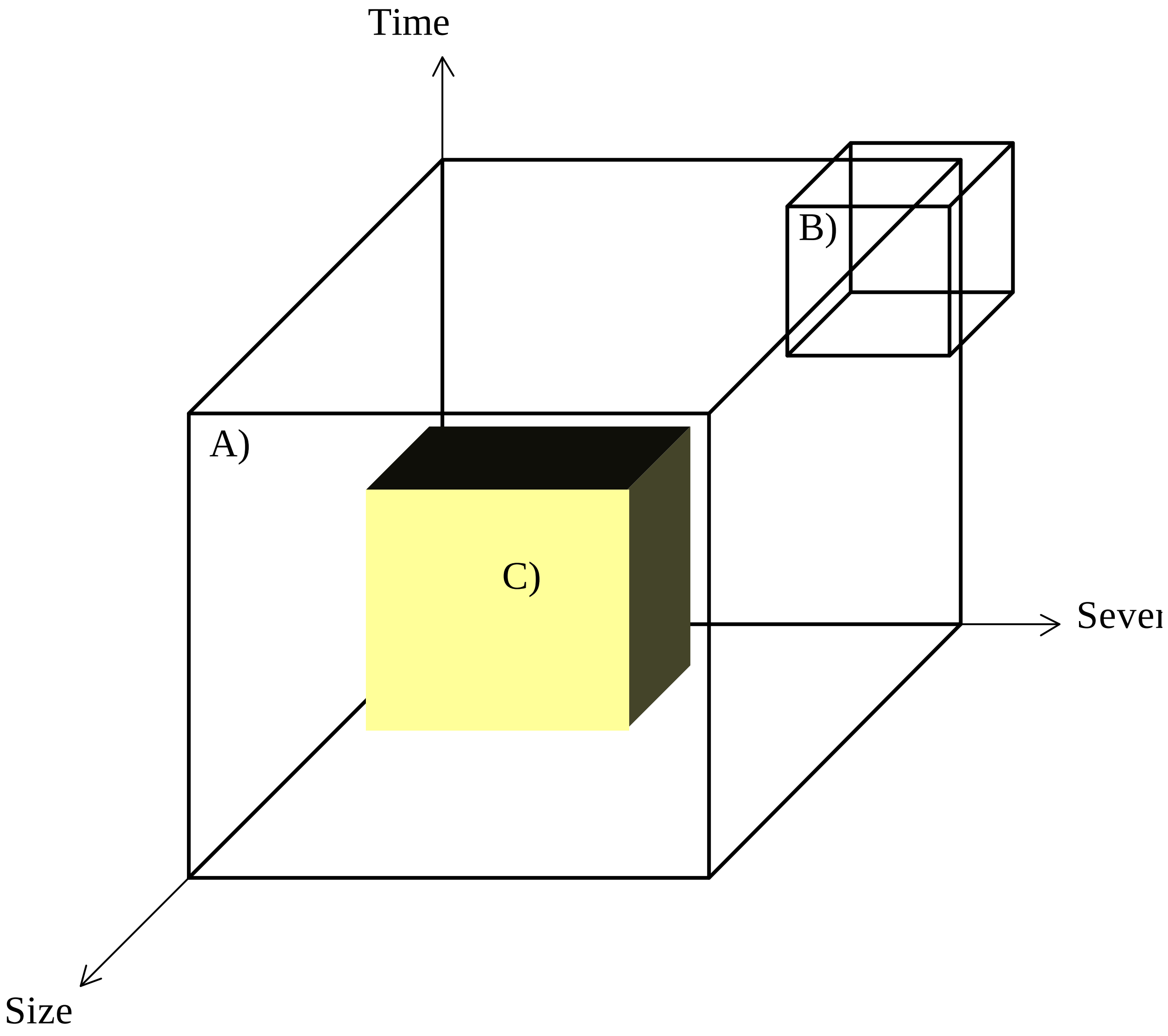


Figure 2.

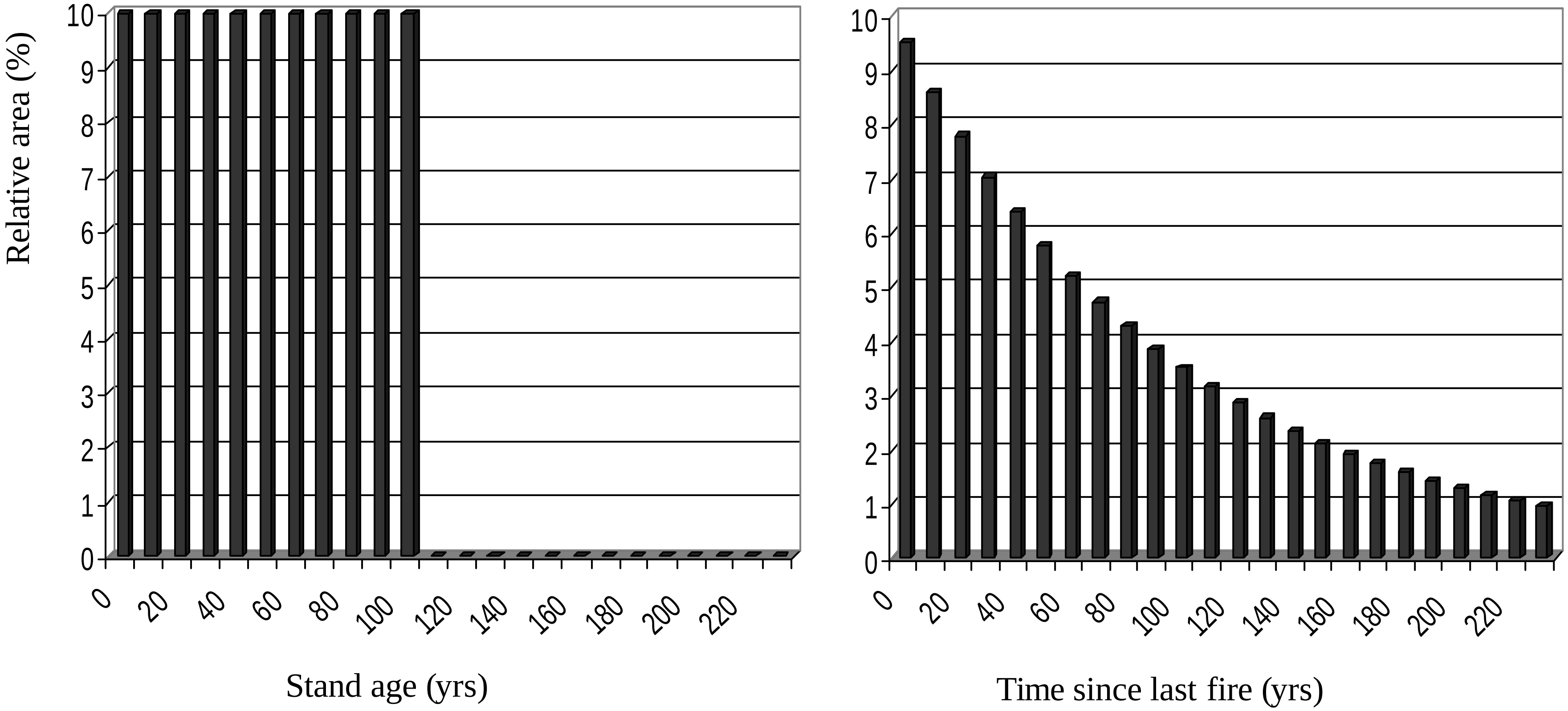
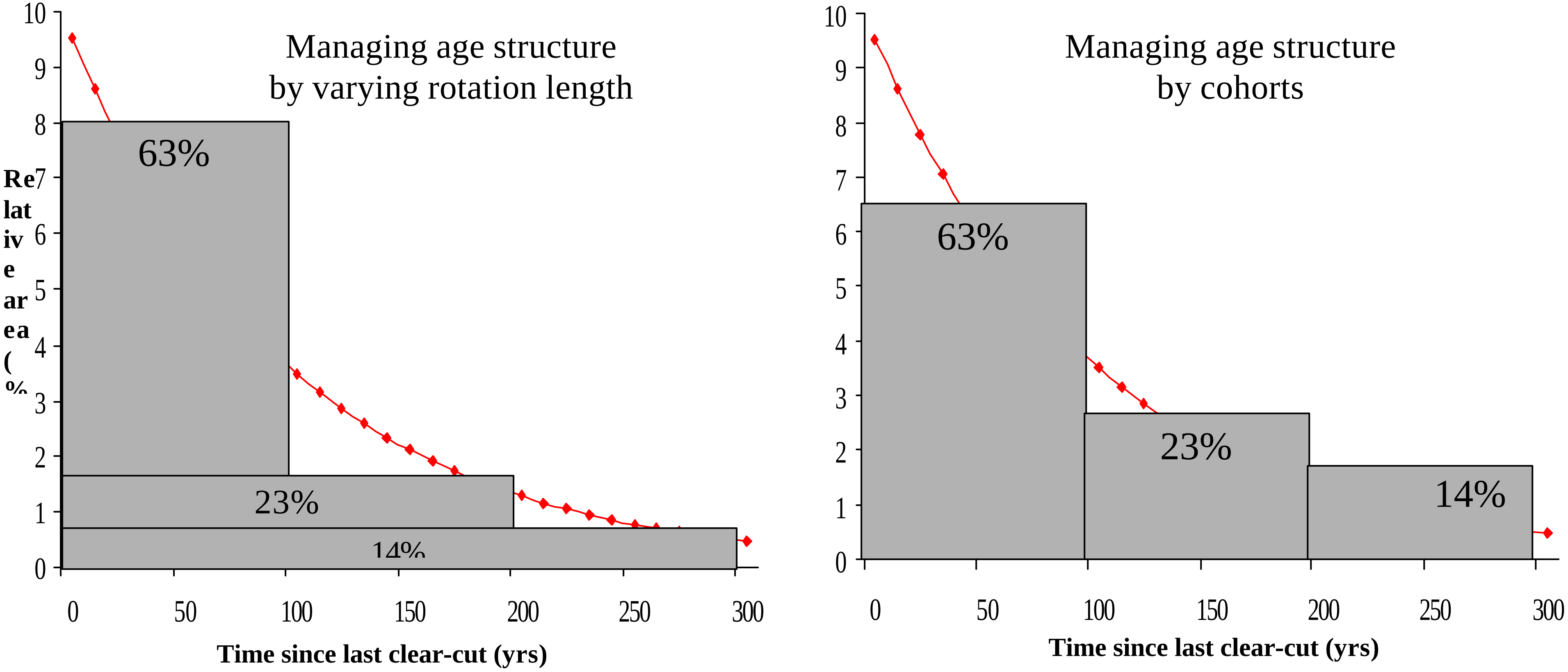

2a)
2b)

Figure 3.



3a) 3b)

Figure 4.

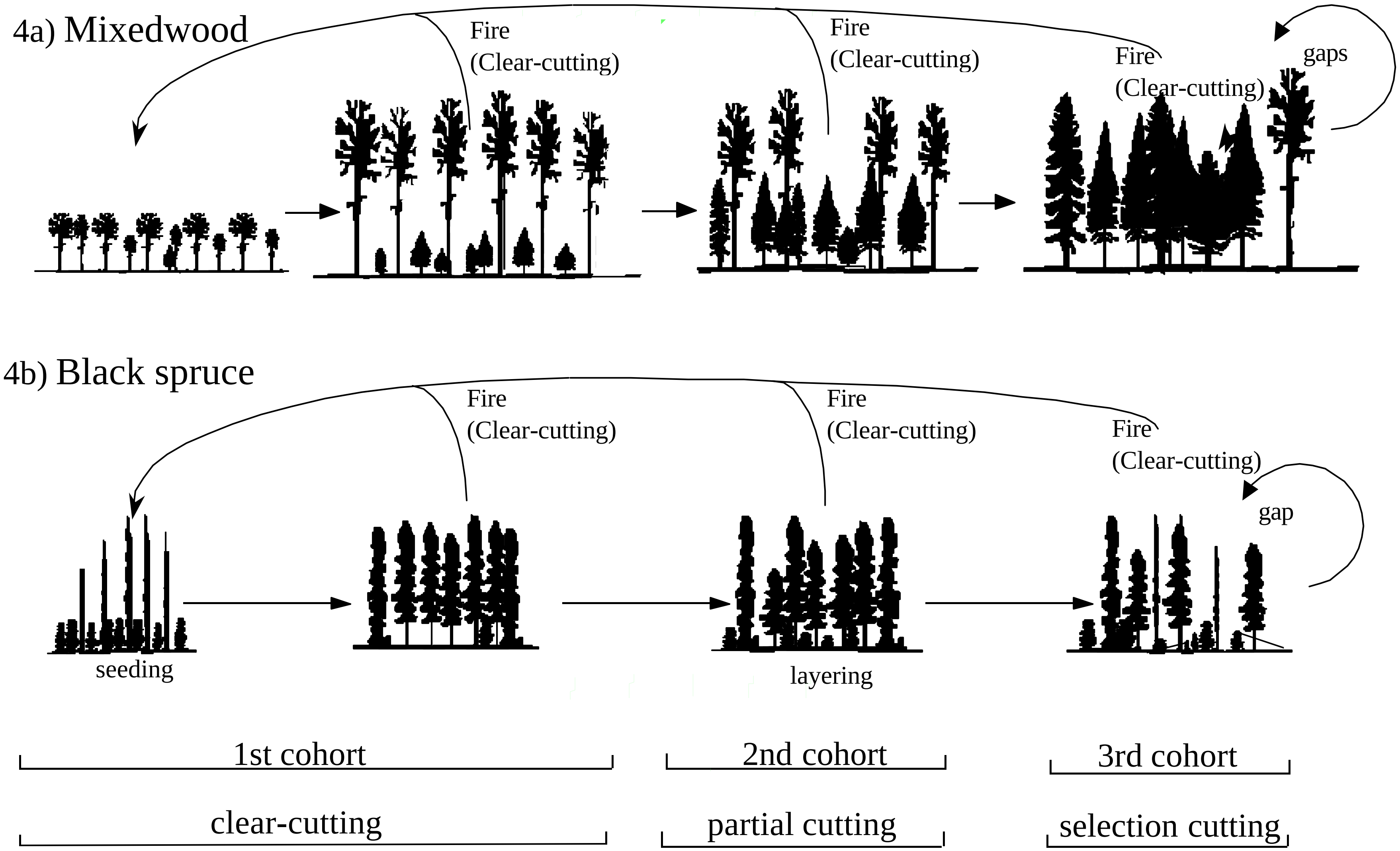

4a) Mixedwood
Fire
(Clear-cutting)
Fire
(Clear-cutting)
Fire
(Clear-cutting)
gaps
4b) Black spruce
Fire
(Clear-cutting)
Fire
(Clear-cutting)
Fire
(Clear-cutting)
gap
seeding
layering
1st cohort
2nd cohort
3rd cohort
clear-cutting
partial cutting
selection cutting

Figure 5.

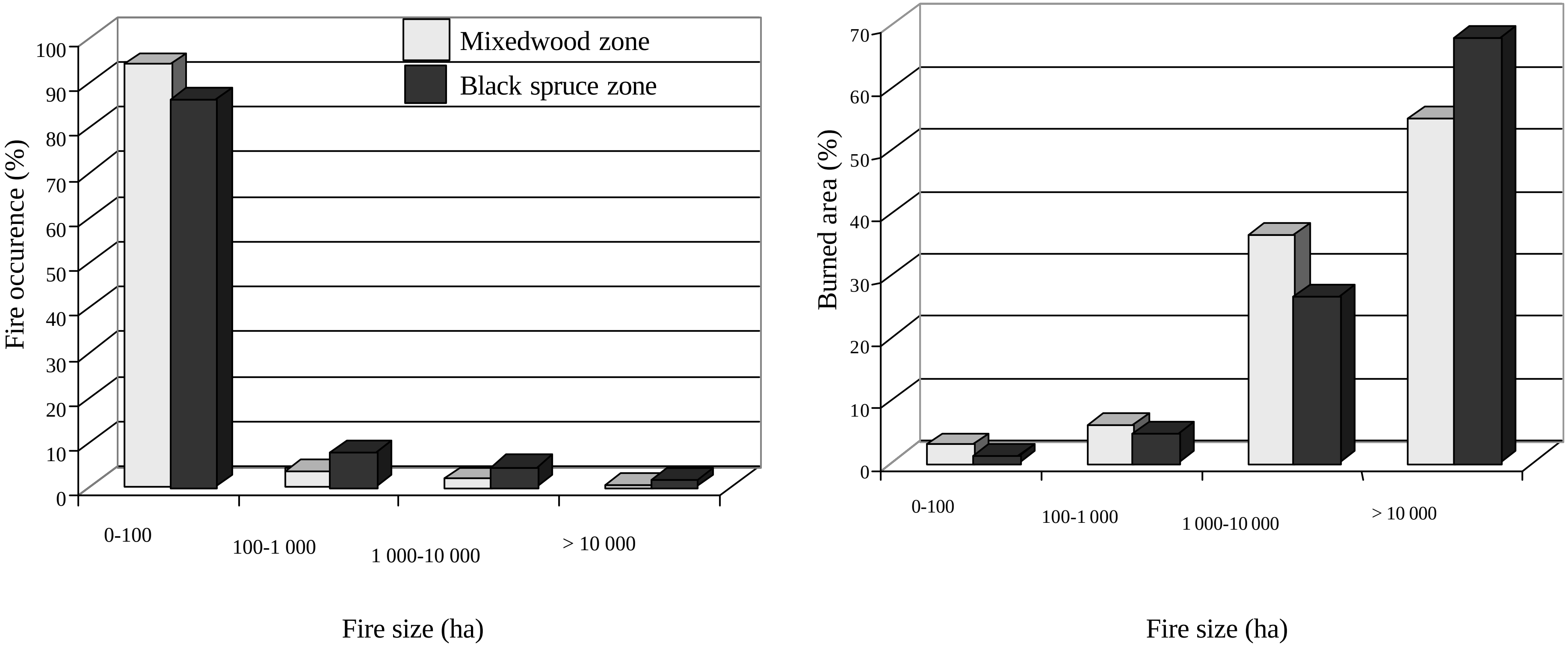

5a) 5b)

Figure 6.

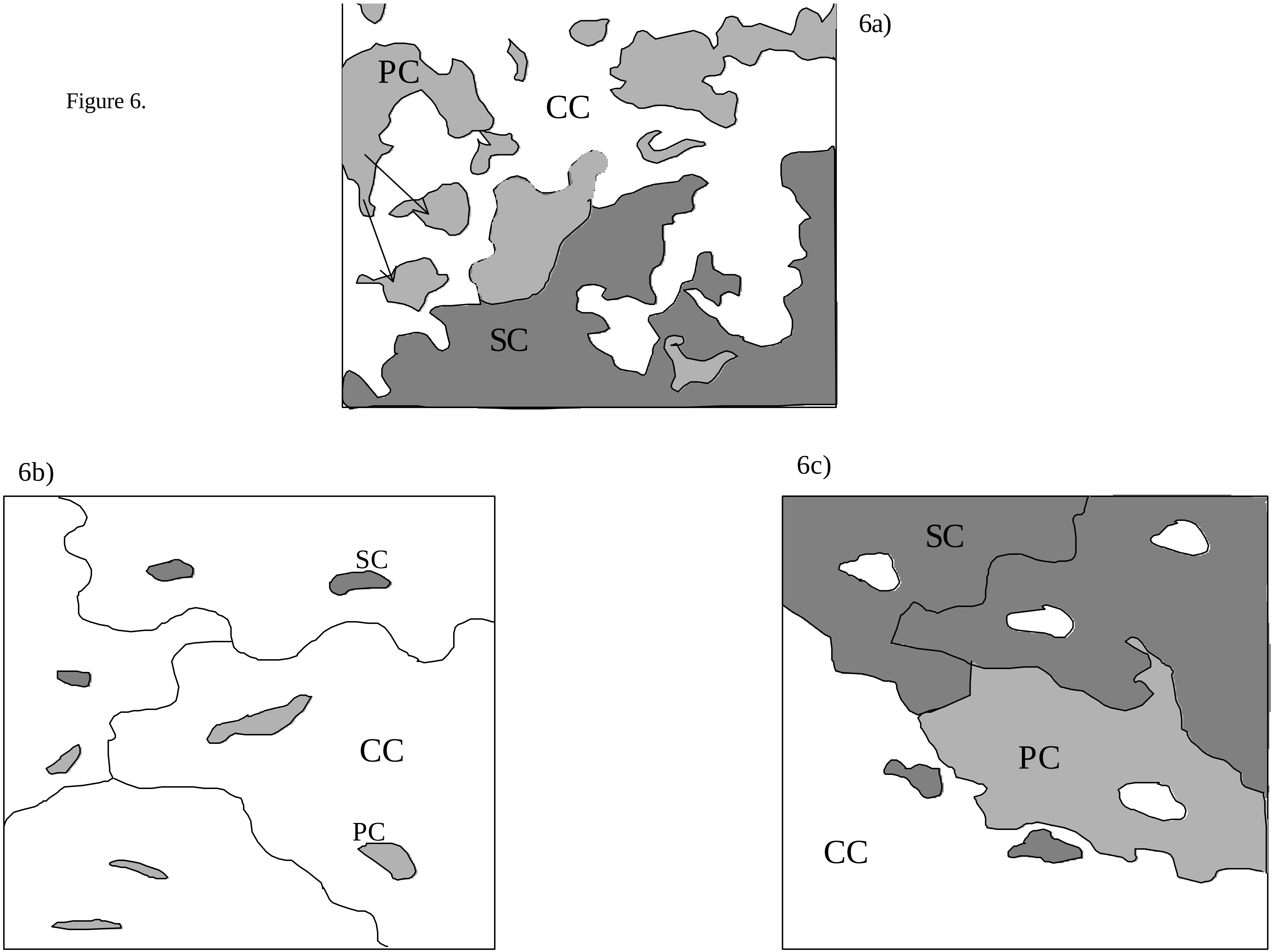


Figure 7.

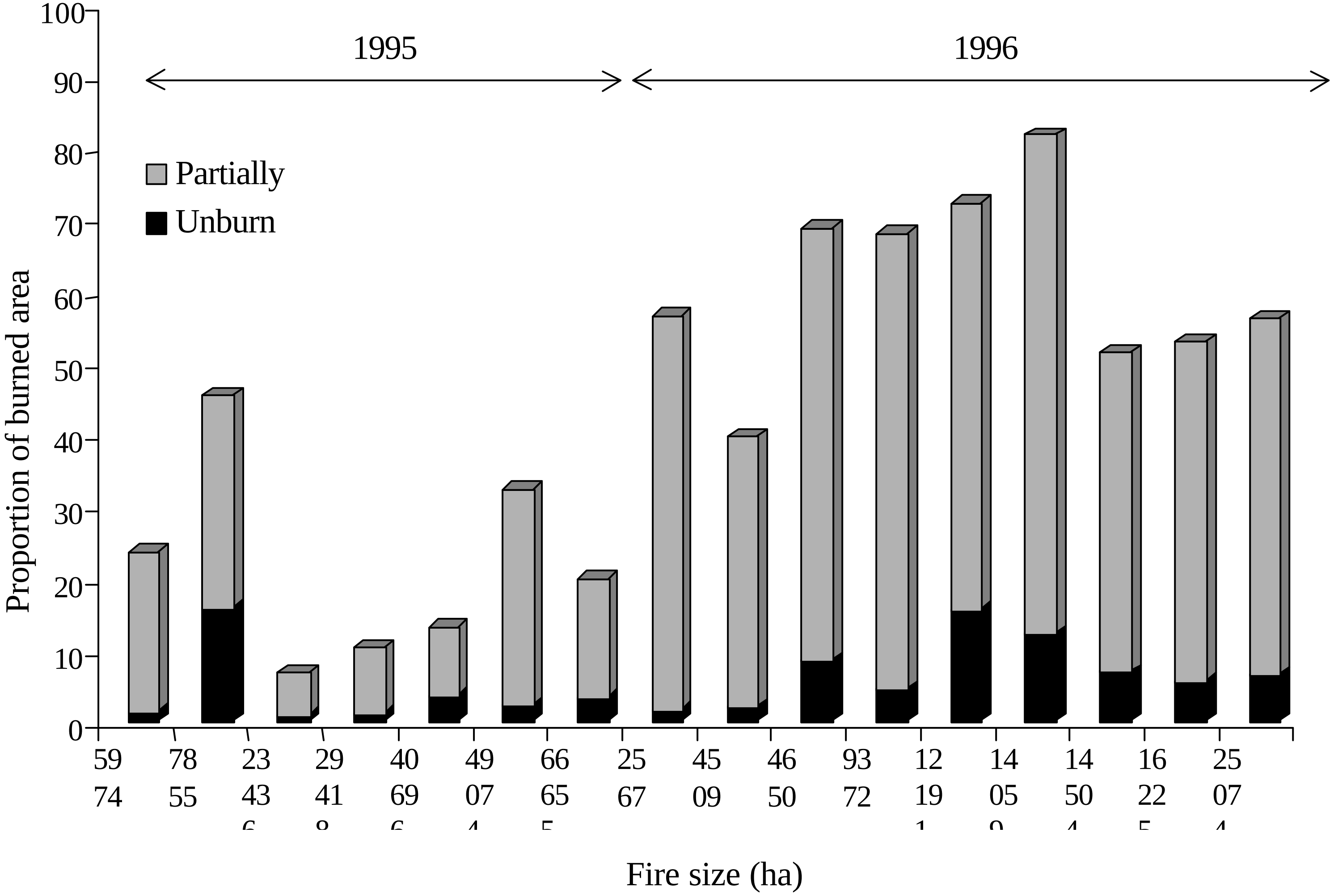
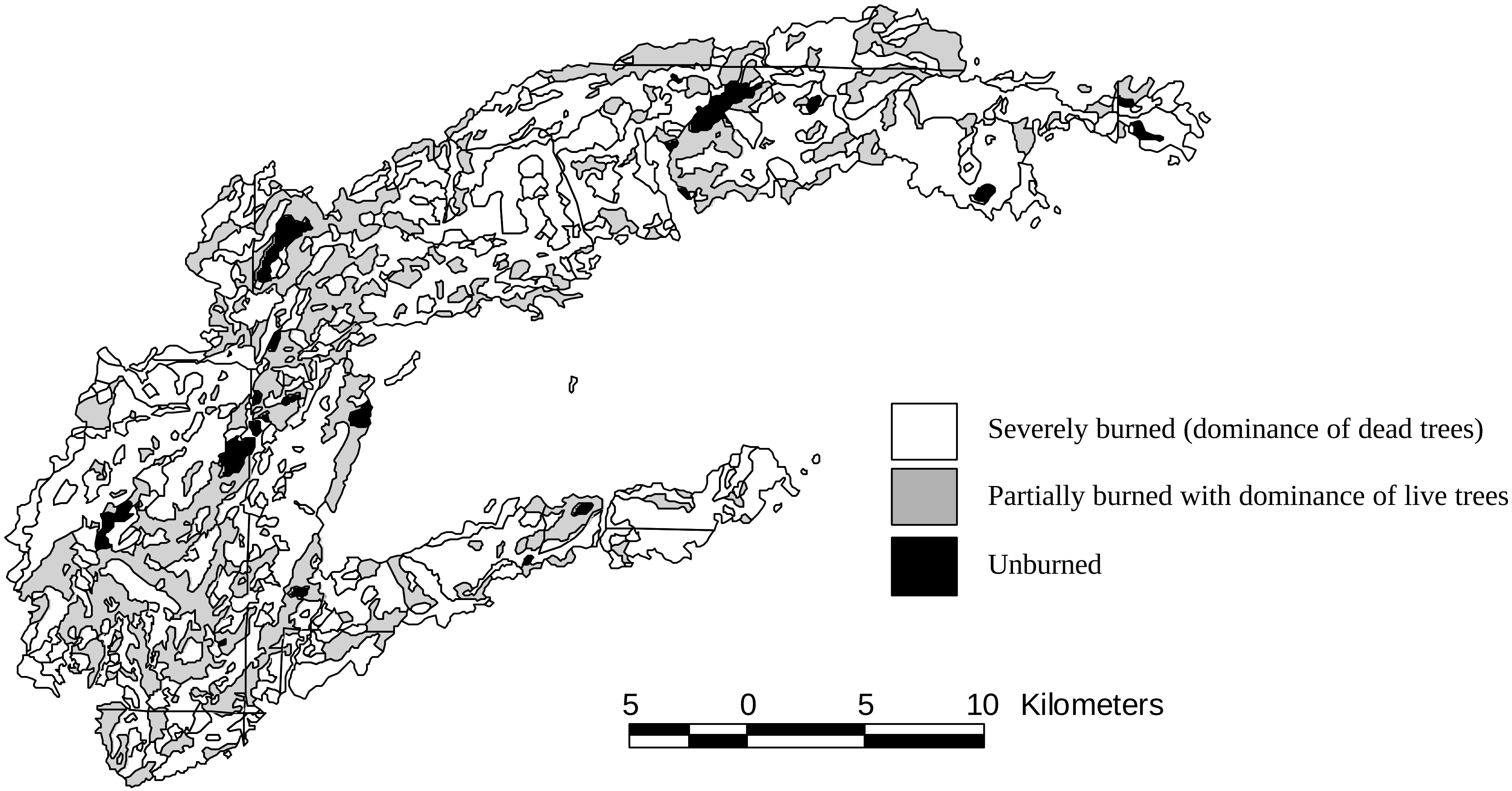

100
90
80
70
60
50
40
30
20
10
0
1995
1996
Partially
Unburn
Proportion of burned area
59 74
78 55
23 43 6
29 41 8
40 69 6
49 07 4
66 65 5
25 67
45 09
46 50
93 72
12 19 1
14 05 9
14 50 4
16 22 5
25 07 4
Fire size (ha)

Figure 8.


Severely burned (dominance of dead trees)
Partially burned with dominance of live trees
Unburned
5 0 5 10 Kilometers