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Silviculture adapted for intolerant deciduous stands on mixedwood sites of the south-eastern boreal forest

by

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ABSTRACT

Recent boreal mixed-wood definitions are reviewed and refined. We review the attributes of natural disturbances which occur between large fire events in the boreal forest. The importance of these smaller scale disturbances is discussed for the south-eastern boreal forest region of Canada. Natural disturbance is a major factor shaping the boreal forest; in the south-east these disturbances vary greatly in size, from small inter-fire canopy gap formations, to large intense fires of 100 000's of hectares. Currently, disturbances induced by industrial forestry are quite uniform, favouring reproduction of certain tree species. A modified silvicultural system is proposed for mixed-wood stands with understrory conifers dominated by intolerant deciduous species such as aspen and white birch. This 3 stage partial cutting system incorporates a variety of disturbance intensities in order to emulate regional natural disturbance patterns in the region is proposed. Specifically this system attempts to mimic the gradual replacement of intolerant deciduous species with shade tolerant conifers that occurs in the absence of fire in our study area. An initial partial cut is followed by another cut a few years later, to harvest the remaining mature stems after advanced conifer regeneration has responded to the initial harvest. This step is repeated again as intolerant trees reach maturity to increase the conifer component. When this conifer dominated canopy reaches maturity, a final harvest using a variant of the traditional clearcut system is completed.

Key words: boreal, *Betula papyrifera*, disturbance, emulation, gap dynamics, mimic, mixed-wood, natural, partial cutting, *Populus tremuloides*, regeneration, trembling aspen, white birch

RÉSUMÉ

Nous examinons les caractéristiques des perturbations naturelles qui se produisent entre les grands feux dans la forêt boréale. L'importance de ces perturbations de plus petites envergures est discutée pour la forêt boréale du sud-est du Canada. Les définitions récentes de la forêt boréale mixte sont re-examinées et raffinées. Les perturbations naturelles constituent un facteur important qui façonne la forêt boréale; dans le sud-est ces perturbations sont de tailles très variables, allant des petites trouées entre les grands feux aux grands feux de plus de 100,000 hectares. Présentement, les perturbations anthropiques sont très uniformes, ce qui favorisent la régénération de seulement quelques espèces. Un nouveau système sylvicole est proposé pour la forêt boréale mixte du sud-est dominée par les espèces feuillues intolérantes comme le tremble et le bouleau blanc. Ce système de coupes partielles en trois étapes inclus une variété d'intensité de perturbation de facon à imiter le patron régional des perturbations naturelles. Ce système tente plus particulièrement d'imiter le remplacement graduel de tremble par les conifères qui se produit naturellement après les grands feux. Ce système en 3 étapes prévoit initialement une coupe partielle, suivit d'une coupe qui enlève tous les arbres matures, après que la régénération prétablie en résineux ait repondu à la coupe intiale. La coupe partielle suvit d'une coupe totale des arbres matures est répétée au moins une autre fois à la prochaine révolution de tremble pour augmenter le volume de résineux avant la coupe totale finale qui va permettre aux feuillus intolérants de se re-installer de nouveau.

Mots-cles: *Betula papyrifera*, boréale, bouleau blanc, coupe partielle, dynamiques des trouées, forêt mixte, imiter, naturel, perturbation, *Populus tremuloides*, régénération, tremble

SILVICULTURE AND DISTURBANCE

Global forest management goals have constantly evolved over recent decades (Rowe 1994, Kimmins 1995). One of the new, emerging paradigms in world forestry suggests that silvicultural prescriptions for any forest ecosystem should be inspired by natural succession and regional disturbance patterns (Attiwil 1994, Bergeron and Harvey 1997), primarily because it is the type, intensity, size and cycle of natural disturbances that tend to determine species composition and distribution (Runkle 1985, Attiwill 1994). This philosophy suggests that if resource management is to be sustainable and biodiversity maintained, natural disturbance dynamics at both stand and landscape levels must be understood, and harvest practices must be modeled using properties of these disturbances (Gauthier *et al.* 1995). In some provinces, forest management plans now include landscape level objectives for imitating disturbance patterns created by natural fire cycles. Mimicking natural disturbance regimes, with the implicit assumption that species have maximised fitness by evolving with natural disturbance patterns (Booth *et al.* 1993, Roberts and Gilliam 1995, Weetman 1995), has become a focus among many forest ecologists and managers. Consequently, to best manage these species we must attempt to mimic the natural disturbances within which they have evolved. Although exact replication of natural disturbance patterns is impossible, we can certainly increase the range of human- caused disturbances to more closely imitate natural disturbances. Runkle (1985) presents a comprehensive review of the relationship between community properties and disturbance regimes. Although many studies have examined disturbance regimes in detail (Sprugel and Bormann 1981, Palik and Pregitzer 1993, Attiwil 1994), few have looked at the unique conditions of the south-eastern boreal forest of Canada between incidence of fire.

A Word of Caution

Forest management with emulation of natural disturbance as a guiding principal requires clear objectives. As Duinker (1998) cautions, it would be dangerous to assume that 1) we are actually capable of emulating natural disturbances; 2) we can in fact define «natural» and if so, find an appropriate «natural» benchmark and; 3) that application of emulation management practices that in fact do not replicate natural disturbance patterns will be less intrusive than current management techniques. These represent the major challenges of “natural forestry” for forest managers and researchers and is the focus of much research being conducted at present that is attempting to describe natural structure, composition and processes in forest ecosystems.

Emulation of natural disturbance may not be compatible with intensive forest management (Binkley 1997), although it does not necessarily preclude it completely if we designate certain sites for intensive management and others for natural forestry. A major question facing researchers and managers today is how can we fit, if possible, intensive management within a framework of emulating natural disturbance. Lands that are targeted for multiple-use may best fit this approach.

Disturbance in the South-eastern Boreal Forest

In the North American boreal forest, ecological processes are strongly controlled by large scale fires (Rowe 1961), consequently most research on disturbance in the boreal forest has been centred on this topic (Rowe and Scotter 1973, Heinselman 1981, Johnson 1992). However, Bergeron and Charron (1994) caution that while in much of the boreal forest arboreal succession is limited by large intense burns with short fire cycles; in the southern south-eastern part of the boreal forest longer fire cycles allow for changes in canopy composition. The prediction of forest composition for long fire cycles is complicated by interactions among site factors, post-fire composition and stand vulnerability to spruce budworm (*Choristoneura fumiferana* Clem.), which feeds selectively on spruce and fir (Bergeron and Dansereau 1993). Batzer and Popp (1985) confirmed that, following a spruce budworm epidemic in northern Minnesota, conifer dominated overstories changed to earlier successional stages in which trembling aspen (*Populus tremuloides* Michx.) and white birch (*Betula papyrifera* Marsh.) predominated.

Bergeron and Dansereau (1993) state that although the proportion of pure deciduous stands decreases with fire cycles exceeding 200 years, the proportion of mixed stands remains constant, suggesting that other disturbance factors (such as defoliating insects and stand break up at maturity) must be interrupting the regional successsional trend from intolerant deciduous species to tolerant coniferous species. Bergeron (unpub) observed that for the southern boreal forest of eastern Canada, directional succession is fairly complicated and is not simply a replacement of shade intolerant species with tolerant species. Trembling aspen can remain an important species in the canopy for over 180 years, possibly with successive cohorts, and white birch can maintain itself in stands for at least 230 years (Paré and Bergeron 1995). The shift to coniferous domination is gradual, and dependent on propagule sources, disturbance size, and disturbances intensity; presumably small and low intensity disturbances will favour shade tolerant species such as balsam fir (*Abies balsamea* Marsh.) and white spruce (*Picea glauca* (Moench.) A. Voss.). Kuuluvainen (1994) and Kneeshaw and Bergeron (1998a,b) show that small scale gap disturbances and gap regeneration can be common in boreal forests with long fire cycles. This evidence suggests that the nature of both large and small-scale disturbances is important in determining community structure in the south-eastern Canadian boreal forest. Thus, it becomes important to consider diversity of disturbance.

Clearly Defining the Boreal Mixed-Wood

Boreal Mixed-Wood Forest vs. Mixed-Wood Forest

The distinction needs to be made between boreal mixed-wood and mixed-wood forest. The mixed-wood forest in eastern Canada commonly refers to a geographic area, the transition zone between the boreal forest to the north, and the Great Lakes- St. Lawrence forest region to the south. Consequently tree species allied with the mixed-wood definition include the tolerant hardwoods, white pine (*Pinus strobus* L.), and red pine (*Pinus resinosa* L.). These are not characteristic boreal tree species as defined by MacDonald (1995) and regions which support merchantable stands of these species should be excluded from a boreal mixed-wood definition.

Cover-Based vs. Site-Based Definitions for the Boreal Mixed-wood

Although the boreal forest is simple in terms of tree species composition, it possesses a very complex pattern at the landscape level (Weetman 1995, Zasada 1995). This paradox has created confusion in attempts to define the boreal mixed-wood. Most early definitions of boreal mixed-wood were entirely based on species composition at time of sampling. Most recent North American inventory systems classed species as either deciduous or coniferous; stands with less than 75% cover in one type were classed as mixed (Wedeles *et al.* 1995). While this approach may seem logical and easy to apply, it ignores other important components such as spatial and time scales which weaken the cover based definition. Depending on the mapping scale, the same forest could be classified as either mixed or monospecific (Frelich and Reich 1995). Sampling units smaller that are smaller (larger) than average stand size would be biased towards a monospecific (mixedwood) definition. In Quebec, minimum polygon size for stand mapping has doubled from 4 hectares in the 1980's to 8 hectares in the most recent 1:20 000 mapping exercise. The proportion of forest classified as mixed-wood using a cover based definition has therefore increased.

On southern boreal mixed-wood sites with a long interval between successive fires, canopy species composition can change with time. Forest managers (and hopefully the public) should consider successional change as a natural part of forest development (Kimmins 1992, 1995). Younger forests generally have fewer tree species (Stelfox 1995), and will be biased against a mixed-wood definition based only on cover.

Such problems can be avoided by considering a site's potential for tree growth, rather than current species growing on site (MacDonald 1995). Both MacDonald (1995) and Wedeles *et al.* (1995) require that to be classified as a boreal mixed-wood site, the soils must be capable of supporting commercial growth of all the characteristic boreal tree species. It then becomes necessary to define the soil type, usually in terms of nutrients and moisture content (Cartier *et al.* 1994, Sims *et al.* 1995). MacDonald (1995) also clearly differentiates between a site and a stand. A Boreal mixed-wood stand must be located on a boreal mixed-wood site, and have no single species that exceeds 80% of the total basal area. A Mixed-wood site refers to potential conditions whereas a mixed-wood stand refers to current conditions.

Regional Definition Of Mixed-Wood

Even with a clear site-based definition, the broadness is overwhelming. Indeed, Wedeles *et al.* (1995) suggest that mixed-wood sites are better defined by what they are not (extreme soil types: wet organic soils, shallow soils over bedrock etc.) Than what they are. In order for the mixed-wood site and stand to be useful concepts and management tools they must be classified into manageable units. We propose to do this along two axes: 1) the current deciduous component of the stand and 2) broad geo-climatic regions of the mixed-wood site type.

(1) To be classified a mixed-wood stand we feel there must be a significant deciduous component (>25% basal area) present. The insistence upon the presence of the deciduous species in the definition of the mixed-wood stand is threefold: a) succession following a large scale disturbance on mixed-wood sites often begins with white birch and/or trembling aspen, b) these

two species have been associated with higher nutrient availability compared with conifers (Paré et. al. 1996, Brais et. al. 1995), and c) both trembling aspen (Stelfox 1995, Constabel and Lieffers 1996 Degranpré at. al. 1993) and white birch dominated stands (Foster and King 1986) have well developed and highly diverse understories. The understory can play a key role in stand dynamics and is important to consider in management decisions (Lieffers 1995). It is useful to distinguish between aspen mixed-wood stands and white birch mixed-wood stands because such stands are likely to respond differently to disturbance due to differing regeneration strategies (reviewed briefly below). 2) Broad geo-climatic regions of the mixed-wood site type: Larsen (1980) divided the North American boreal forest into the following gross regions: Alaska, the Cordillera, south-western Mackenzie / Northern Alberta, and the Canadian Shield. Broad climatic and soil similarities in these regions provide a useful framework from which to classify boreal mixed-wood sites, since growth rates, germination, aspen sucker production, all vary significantly with climate and soil type. Effective silvicultural treatments should be able to be locally defined using this framework. Silvicultural treatments that are effective in one locality should have similar, predictable results if confined to another locality in the same regional classification, with the same deciduous component. We suggest that the deciduous component has primary importance due to the uniqueness of aspen regeneration strategies. However it is not clear if successful silvicultural prescriptions will be more closely related to the deciduous component or the broad geo-climatic zones listed above. For example, following the same silvicultural treatment, would a shield aspen mixed-wood stand respond more similarly to an Alaskan aspen mixed-wood stand, or to a birch mixed-wood stand within geo-climatic boundaries of the Canadian Shield?

REGENERATION OF WHITE BIRCH AND ASPEN IN GAPS

White Birch

Although traditionally thought of as highly shade intolerant, white birch has been shown to be able to tolerate up to 90% shade for a few years, and grow extremely well in 50% shade (Perala and Alm 1989, 1990). White birch is considered a pioneer species, and establishment is associated with large scale disturbances such as fire (Foster and King 1986), or clear-cutting (Ruel 1992). However, white birch can maintain and even increase prevalence with time, and has been shown to be associated with late successional and climax communities (Frelich and Reich 1995, Bergeron and Dubuc 1989), usually in mixtures with other species (Buell and Niering 1957, Ohmann and Ream 1971, Grigal and Ohmann 1975, Bélanger et. al. 1993). White birch can maintain itself by sprouting (Buell and Niering 1957) although regeneration from seed generally becomes the predominant method of reproduction when stands reach maturity since sprouting ability declines with age (Peterson and Peterson 1995).

In the temperate deciduous forests of New Hampshire (Marquis 1965), white birch regenerated well following partial cutting. Mineral soil exposure from harvesting may favour seedling establishment, although growth was best in undisturbed soil. Competition from weed species, coppice shoots, and aspen suckers seriously limited seedling growth, especially in second growth forests. Jeglum and Kennington (1993) reported similar success for birch regeneration in strip cuts in upland black spruce. The regenerating strips are a mix of black spruce, white birch, and trembling aspen, and the proportion of hardwood to conifer is about 50:50. White birch seed can be very abundant and may explain success in these small disturbed patches (Archibold 1980).

Trembling Aspen

Carbohydrate reserves and growth hormones vary among clones, thus the degree of overstory disturbance required to promote suckering may vary (Shepperd 1986). All-aged stands, although rare, do exist and may be the result of clones that are easily stimulated to produce suckers even by small disturbances. Horton (1956) found aspen suckers in most of his study area regardless of stand age, density, or prevalence of conifers. For the closely related European aspen, *Populus tremula* (Bärring 1988) and our native trembling aspen (Peterson and Peterson 1992, Schier *et al.* 1985) inconspicuous shade suckers that can be morphologically different from suckers growing in the sun have been noted growing in the understory. Microclimate variability and root position in the soil can also influence suckering capacity within a single clone (Schier 1978), as can changes in carbohydrate and growth promoter levels during a season. Messier *et al.* (1998) provide further discussion of aspen regeneration in the understory.

Aspen root suckering is affected by the depth and possibly the diameter of parent roots (Kemperman 1978, Schier and Campbell 1978, Schier *et al.* 1985). The majority of suckers on clear-cut stands develop from small roots within the top 6 cm of the ground surface, generally within the combined litter and humus layers. Relatively few suckers develop from the mineral soil layers. It is not clear, however, whether roots with larger diameters are poor sucker producers, or are simply less abundant than the smaller roots in the surface layer (Perala 1978). When surface roots have been damaged by severe burns suckers can originate from deeper, undamaged parent roots. Schier (1978) indicated that neither distance from the parent tree, nor root age regulate suckering within lateral roots. Provided that the parent root system is intact and healthy, stand age does not appear to affect suckering capacity, although increased humus depth associated with older stands may decrease suckering (Lavertu *et al.* 1994). Stands breaking up due to decay may have reduced suckering ability (Shepperd 1986).

The extent of vegetative reproduction limits sexual reproduction by seed. Areas with a few widespread clones have limited participants for sexual reproduction, and even where genotypes are abundant, the difficulties of sexual reproduction limit the selection of new genotypes. Consequently, local populations of aspen genotypes are virtually fixed on many aspen sites. Except during periods of widespread seedling establishment, there may be essentially no competition between aspen genotypes, except along clonal boundaries. Most of the literature is primarily concerned with sucker reproduction, which is predominant, but recent studies in the prairie provinces and elsewhere have indicated that reproduction by seedlings may be more common and significant than previously realised (McDonough 1979, Peterson and Peterson 1992).

Alternative Boreal Mixed-Wood Silviculture

Alternative silviculture in the boreal mixed-wood began as methods to release suppressed conifers (usually white spruce) from an aspen overstory. These programs started as early as 1924 in Saskatchewan (Waldron 1959) and continue today (Lees 1970, Yang 1989, Kolabinski 1994, Palik and Pregitzer 1995). Such «two pass» systems are possible because of the stratification that normally occurs on mixed-wood sites. In the first pass the aspen overstory is removed, the second pass harvests the released understory decades later when it matures. Harvesting systems that protect advanced regeneration follow a similar logic. The first pass (a modified clear cut) is designed to protect and release conifer regeneration already on site.

Lieffers et. al. (1996), expanding on ideas by Lieffers and Beck (1994), describe some silvicultural options based on desired outcomes for various boreal mixed-wood (aspen - white spruce mixtures) forest types of the boreal plain. Options are constrained by the current state of the stand and the desired composition of the new stand. Generally, if the objective is to increase conifer component following harvest, management options become more intensive. We present a management approach for a particular type of forest structure, specifically an aspen overstory with a softwood understory. We consider the mixed-wood from a successional viewpoint by proposing a silvicultural system that attempts to mimic natural succession in the south-eastern boreal forest of Canada as presented in Bergeron and Harvey (1997). A silvicultural trial using this philosophy is currently underway in the Lake Duparquet Teaching and Research Forest.

Diversity of Disturbance

Natural disturbance occurs within a great range of patch size, severity, and type, from the death of a single tree to fires of thousands of hectares. Such diversity favours the establishment of a variety of species, each adapted to a gradient of type and size of disturbance. Figure 1. illustrates how traditional clear-cut harvesting or even modified clear cutting has very limited diversity of disturbance (illustrated as a function of size and intensity), and thus favours one or two species at the expense of others. Between large-scale catastrophic fires (high intensity and patch size), smaller scale disturbances occur through succession. These include individual tree mortality due to competition, or small groups of trees due to pathogens, windthrow and beaver, or gradual species specific mortality as a result of insect infestations. Kneeshaw and Bergeron (1998a), provide an interesting portrait of gap formation in early successional aspen stands and late successional fir dominated stands, characteristic of south-eastern boreal mixedwood sites. We present a silvicultural system that utilises a wider range of disturbance intensity and thus more closely emulates what would happen on these sites without human intervention. While it is impossible to replicate natural disturbance patterns fully, variance may be increased by implementing a number of discrete disturbance size classes ranging from light partial cuts to large clear-cuts.

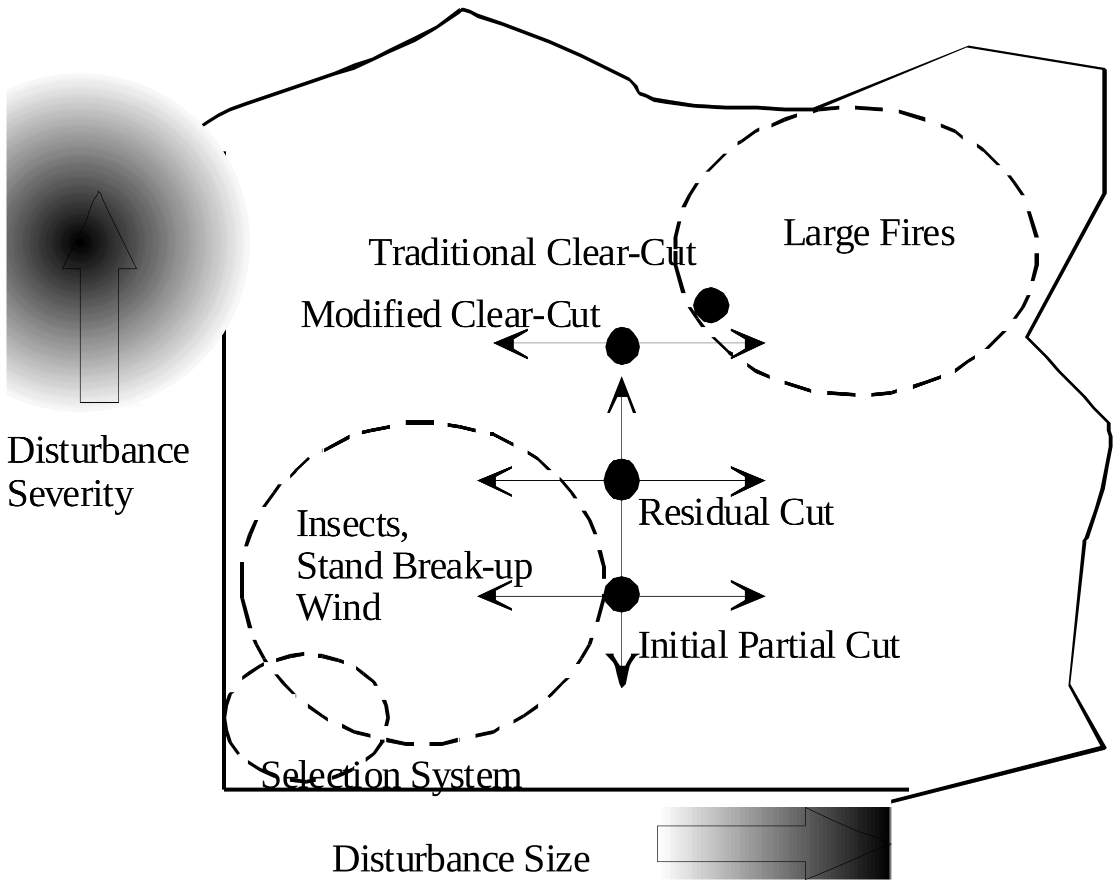

Figure 1. The Range of Disturbance Intensity and Size. There is a great range in natural disturbance patch size, intensity, and type. Disturbance varies from individual tree death to fires of thousands of hectares. Such diversity favours the establishment of a variety of species, each adapted to a particular type(s) and size(s) of disturbance. Traditional clear-cut harvesting has very limited diversity of disturbance, and thus favours one or two species at the expense of others. If emulation of natural disturbance is an objective, clear-cutting alone does not provide the necessary diversity. We present a silvicultural system that utilises a wider range of disturbance intensity and thus more closely emulates what would happen on these sites without human intervention. While it is impossible to replicate natural disturbance patterns fully, diversity may be increased by implementing a number of discrete disturbance size classes ranging from light partial cuts to clear-cuts. The arrows represent a possible range for size and intensity. Traditionally, clear-cuts have had a very limited range (represented by the absence of arrows on both the size and intensity axes) and thus a low diversity of disturbance. Modified clearcuts can have variance in size but we assume variance in intensity will be limited (represented by no arrows on the intensity axis) since usually the whole canopy is removed. The 3 stage partial cutting system will increase the range of disturbance size and intensity. Partial cuts will emulate insect attack and stand break-up, clear-cuts will emulate a large fire.

Proposed Aspen Mixed-Wood Silviculture - 3 Stage Partial Cutting

Dominance of trembling aspen regeneration following clear-cutting on sites containing aspen is a result of several factors: high light levels, damage to conifer advanced regeneration, competitive exclusion due to the extensive root system of trembling aspen, and high initial growth rates due to suckering (Palik and Pregitzer 1993). Clear-cutting would seem to afford aspen an unnatural advantage in regeneration (Weber 1991) and and as a result foresters trying to increase conifer yields are forced to deal with vigorous aspen regrowth following clear-cutting. On mixedwood sites, without strong post-harvest tending actions, clear-cutting will perpetuate trembling aspen as a canopy dominant which does not seem an economic or ecological solution to maintaining conifer components in disturbed ecosystems.

Between incidences of fire, small scale gap disturbances (insects, stand break-up, windthrow) will provide for shade tolerant conifer recruitment as individuals are recruited from advance growth. However, at the same time, these small scale disturbances may increase light levels enough in the understory for some successful aspen recruitment. Consequently, in the absence of fire, aspen may persist for several generations in the canopy. This «persistent aspen» can serve to regenerate the site to aspen following the next large fire or clear-cut. Partial cutting techniques combined with clear-cutting are more suited to mimic these diverse disturbances than are traditional clear-cutting techniques alone.

Partial cutting will reduce vigorous aspen suckering that often follows clear-cutting, but still provide for some trembling aspen recruitment in the resultant gaps. Concurrently, some advanced conifer regeneration that develops naturally under the aspen canopies will be recruited into these same gaps and surrounding areas. Partial cuttings should mimic stand break-up and tree mortality that occurs naturally as deciduous dominated stands shift towards coniferous domination.

Assume we have a young aspen mixed-wood site with mature aspen ready for harvest, with the characteristic understory of conifer advanced regeneration. Consideration of the understory is a key component in this silvicultural system. If density of conifer regeneration is low, and/or a dense mountain maple (*Acer spicatum*) or beaked hazel (*Corylus cornuta*), understory is present, release of the conifer understory would be problematic. In the presence of a suitable understory, we propose a 3 stage partial cutting system composed of two partial cutting pairs, each comprised of 1 initial and 1 residual cut, and a final traditional clear-cut with protection of regeneration and soil (Figure 2).

The initial partial cut («A» in Figure 2) removes only a portion of the canopy. The residual canopy basal area remaining following the partial cut will increase aspen sucker mortality (compared to total canopy removal) via:

a) a reduction in light reaching the forest floor, lowering soil temperature and reducing sucker initiation (Doucet 1989);
b) canopy reclosure of remaining deciduous component reducing light levels further;
c) height growth of suckers prior to canopy reclosure will mean that these suckers will need more light precisely when light levels are falling (Givnish 1988; Messier *et al.* 1998).

All these factors should result in the release of advanced conifer regeneration with reduced competition from aspen. Once the understory conifers have shown a response to the partial canopy removal, the remaining mature aspen can be removed in the residual cut («a» in Figure 2). This process will lead to an increased conifer component at the time of the next harvest.

Because of its rapid suckering and competitive ability, trembling aspen will still make up a significant portion of new canopy. When the second rotation of aspen has reached maturity, presumably with a significant proportion of conifer stems, a second partial cut is initiated in the same manner as the first. An initial partial cut to suppress aspen regeneration («B» in Figure 2), followed by a return for the residual mature aspen stems once conifer advance growth has responded to the partial cutting («b» in Figure 2). This second partial cut should favour even more conifer recruitment leading to a conifer dominated mixed stand. Once this coniferous mixed stand is harvested with a final clear-cut, the cycle starts again with a new aspen dominated stand. The delay between the the partial cut and the residual cut attempts to simulate gap dynamics that favour conifer regeneration over aspen, but yet still maintains some aspen component in the canopy. We believe we can mimic the gradual break up of mature aspen stands, even though most merchantable timber will be removed from the site relatively quickly. The clear-cut at the end simulates a large scale disturbance such as fire that renews the forest into an early successional aspen stand («C» in Figure 2).

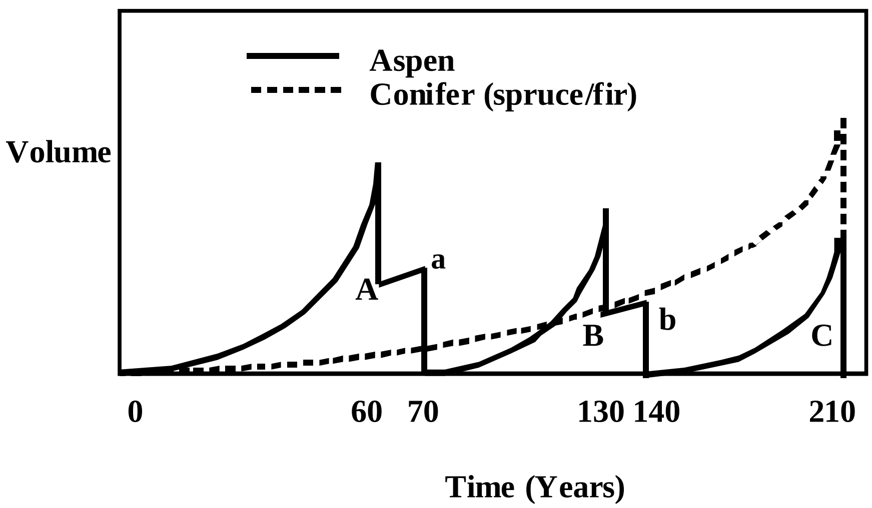

Figure 2. Three stage partial cutting system. Solid line represents aspen volume, dashed line represents conifer (spruce/fir) volume. A = first partial cut, a = removal of residuals, B = second partial cut, b = removal of residuals, C = final clear-cut harvest. After the final harvest the cycle begins again with an aspen dominated stand. The amount of time between aspen rotations and partial cuts is for illustration purposes only. Conifer stems have not been harvested until the clearcut at the end of the system, but could conceivably be a part of the harvest at B and/or b. Conifer volume has been exaggerated to separate curves.

This harvest system has several discreet disturbance intensity classes that rotate across the landscape, consequently a variety of disturbance intensity impacts the same patch of forest. First a moderate disturbance with the initial partial cut, followed by a more intense disturbance when the residual canopy is removed. However, the residual partial cut is not equivalent to a clear-cut (even though the entire canopy has now been removed) since the understory has had time to respond between the initial partial cut and the residual cut. These “moderate” disturbances are repeated again to increase the conifer component further. Finally comes the greatest disturbance intensity with the clear-cut at the end of the system. Since this system attempts to mimic succession, it is important to consider a stand’s successional state. If one is considering harvesting an early succession, pure aspen stand then one would start at «A» in Figure 2. If it was a late succession conifer dominated stand one would start with «C» (clear-cut) thereby resetting the successional process to an early phase. Note that with any partial cutting system windthrow is a major concern. Navratil (1995) outlines the dangers of windthrow and how to avoid them.

There will be increased short term costs with this system, the most serious being costs of protection of advanced regeneration (Navratil *et al.* 1994) as well as increased road costs, and the delay required to harvest the residual timber after the initial partial cut (Ketcheson 1980). However, after these initial expenses this system could actually reduce overall long-term costs by reducing regeneration expenses and increasing yield of the more valuable conifer species. There are also the potential benefits associated with mixed species stands of increased productivity, insect, disease, and fire resistance, although these have yet to be proven conclusively. Although we use the term partial cutting it is important to note that this is not an true uneven aged silvicultural system. The partial cut and the residual cut are only a few years apart, and the system terminates with a clear-cut. Functionally, this proposed silviculture is closer to an even aged system. We hope it will fit well with current harvesting techniques and equipment used in the boreal forest. We do identify two major weaknesses: 1) this system is designed for an aspen stand with a well developed conifer understory, and 2) lack of equipment / experience to harvest large aspen stems in a partial cut environment without harming the conifer understory.

SUMMARY

The existence of boreal mixed-wood stands is somewhat of a contradiction to classical succession theory. Canopy positions are held by both shade tolerant (spruce and balsam fir) and intolerant (trembling aspen and white birch) species at the same time. In uniformly shaded understories, typical "shade" attributes (morphological plasticity, low respiration and transpiration rates) will provide for shade tolerant seedling survivorship and recruitment. In the boreal mixed-wood, however, aspen and white birch can persist in the canopy long after individual longevity. Gap dynamics must allow the recruitment of aspen and birch into the canopy between incidence of large fires. These species must possess the capability of exploiting canopy openings that increase light availability at the forest floor. The 3 stage partial cutting system is suited to forest types with high disturbance variability. Such systems mimic natural processes by promoting the gradual change from hardwood dominance to softwood dominance naturally seen on mixed-wood sites in the south-eastern boreal forest of Canada.

The key points are:

1) Disturbance is an important factor shaping the boreal forest.
2) In the south-eastern Canadian boreal forest these naturally caused disturbances vary greatly in size and intensity, from small inter-fire events (individual and group tree mortality), to large intense fires of 100 000's of hectares.
3) Species respond differently to different types and sizes of disturbance;
4) Disturbance caused by industrial forestry has quite low variation which favours reproduction of some species over others;
5) By incorporating a greater range of disturbance classes in our silvicultural systems, (such as the 3 stage partial cutting system) we can mimic natural processes and manage for growth of all boreal mixed-wood species on the same site.
6) The partial cutting system discussed here will maintain an even-aged character and so should fit in well with current harvesting technology for the boreal forest.

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