REGENERATION IN THE MIXEDWOODS

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ABSTRACT

With increased aspen utilization, expansion of mixedwood harvesting and arrays of decisions in silviculture planning, regeneration in the mixedwood stands is becoming complex and exceedingly challenging. Diversity of management objective and the lack of biological solutions and resources for successful reforestation contributed to silviculture difficulties on spruce/mixedwood sites. The challenge is how to improve conifer regeneration and realize the productivity potential of mixedwood sites.

We examine silviculture alternatives and related stand development patterns in the scenarios of managing mixedwoods for softwoods, mixed woods for mixedwoods and mixedwoods for hardwoods and how these tender to potential improvements in regeneration strategies. We need to master a wide range of silviculture options. This demands that we learn more about the complexities and dynamics of mixedwood ecosystem and apply improved knowledge to both extensive and intensive management.

INTRODUCTION

The last 10 years has seen careful reappraisals of the regeneration status in Boreal forest and in mixedwoods (eg. Weetman 1982,1987,1989; Benson 1988; Yang and Fry 1981).

At the 1988 Mixedwood symposium (Samoil 1988) several speakers addressed the difficulties of regeneration and the need for more intensive establishment of conifer plantations on mixedwood sites (Day and Bell 1988; Drew 1988). There are two messages re-occurring in these reviews:

> "The wood growing potential of mixedwood sites is not currently being realized" and
> "There is a gradual shift to increasing hardwood component on mixedwood sites".

In a simplistic view it appears that foresters lag behind in maintaining productivity of the resource or it could even be suggested that regeneration specialists are to be blamed. On the other hand, many of us may feel that forest managers have clouded the issue of regeneration in mixedwoods by the conifer bias, emphasis on survival, overoptimistic expectations and viewing regeneration as an isolated process, when in reality it should be viewed as the critical first step in the silvicultural system.

There have been several issues suggested for the regeneration problems:

1. The prevailing attitude to regenerate extensively
2. Not enough money for the required work and
3. The lack of workable biological solutions for the establishment of regeneration that would maximize growth.

The first two issues are related to forest management strategies and policies, and have been reviewed superbly by Weetman (1987,1989), Benson (1988), and Baskerville (1982). The last issue, the lack of biological solutions, is broader and more contentious. We would like to challenge and examine regeneration problems in this context and offer some approaches to regeneration strategies.

REGENERATION STRATEGY MUST BE RESPONSIVE TO MANAGEMENT OBJECTIVES

Regeneration serves a purpose; it is a component of silvicultural systems and it must reflect management objectives.

Changes in utilization of the forest resource have been the driving force behind recent new approaches and improvements to traditional mixedwood regeneration. The key change and advantage of this new era is the acceptance of aspen as a commercially important and valuable species for regeneration. Thus mixedwood cover types can be regenerated under three management scenarios: mixedwoods to hardwoods, mixedwoods to softwoods, and mixedwoods to mixedwoods, and the regeneration strategies and silvicultural options vary accordingly.

ASPEN REGENERATION SILVICULTURE IN MIXEDWOODS FOR HARDWOOD PRODUCTION

With the acceptance of hardwood production on mixedwood sites, a silvicultural system of clearcutting and even-aged stand management can be readily used for aspen renewal and management. The reproductive and silvicultural characteristics of aspen have been reviewed by Davison et al. (1988), Debyle and Winokur (1985) and Doucet (1989).

Aspen content in the parent mixedwood stand is the major factor influencing aspen regeneration density. Aspen basal area in the parent stand as low as 2-5 m^2/ha (Perala 1977; Doucet 1989) and volume as low as 26 m^3/ha (Stoeckeler and Macon 1956) can produce adequate aspen stocking after clearcutting. Similarly, about 25-50 well-distributed trees/ha may produce over 10,000 suckers/ha.

On 15-year-old pine cutovers in the Grande Prairie region in Alberta we found that a single parent tree may restock a 400-500 m^2 area with suckers (Navratil and Bella 1988). This observation compares well to the above estimate of 25-50 aspen trees/ha to adequately regenerate the area.

The essential prerequisite of aspen regeneration systems is clearcutting. A partial cut with a residual canopy can severely reduce aspen regeneration density. The negative effects of such a canopy are threefold: a) maintenance of apical dominance, b) reduced soil temperature, and c) reduced light. A residual canopy allowing 50% sunlight has been found to reduce suckering density ten-fold, from 98,000 to 7,400 stem/ha (Baker 1925). As little as 1-1.5 m^2/ha basal area of residuals may slow sucker growth by 40% (Perala 1977). Thus, for example, in mixedwood stands with a considerable component of balsam poplar the residuals should be cut to optimize sucker growth and development.

Mixedwood stands as compared to pure, upland aspen stands, require more attention to aspen reproduction strategy. Low density sucker regeneration frequently develops after harvesting mixedwood stands for several reasons (Navratil et al. 1989; Peterson et al. 1989b).

Mixedwood cover types occur over a wide range of the moisture regimes, soil texture and thickness of organic layer, all of which affect density of aspen regeneration and aspen growth. Often on the most productive mixedwood sites, a thick duff layer, rise in the water table after harvest, low soil temperature and the invasion of alder and willow competition may hinder aspen regeneration. On such sites, the balsam poplar component in regeneration often increases compared to the original stand. Aspen roots have a low tolerance for high soil moisture content, and waterlogging after harvest can substantially reduce suckering (Yang and Fry 1981; Bates et al. 1989). Low soil temperature tends to reduce suckering capacity of aspen (Zasada and Grigal 1980; Peterson et al. 1989).

In this context, an ecologically based site classification that also incorporates soil moisture dynamics may be particularly useful in mixedwood management, because aspen productivity and stand response to logging, site preparation, and regeneration practices are all site related and predictable (Corns 1988).

Insufficient aspen stocking and patchy aspen regeneration in mixedwood cutovers, particularly on mesic sites, can frequently be ascribed to soil compaction and root disturbance from logging. Aspen roots producing suckers are in the very surface layers of the soil, 0-8 cm from the surface, and are vulnerable to mechanical damage. Scheduling of harvesting on sensitive sites and integrated one-entry harvesting of both species will be required to minimize damage and secure uniform regeneration.

The recent upsurge in logging mixedwood cover types coupled with aspen utilization has much improved the perception of aspen reproduction. Forest managers have come to realize that desirable aspen regeneration may not be free after all, and that aspen regeneration may need to be encouraged (Smith 1988, 1989) as is conifer regeneration.

Rehabilitation of high-graded and overmature mixedwood stands for hardwood production

A special aspen regeneration problem and the opportunity to substantially improve aspen productivity exists in high-graded mixedwood stands where conifers have been removed, and in overmature stands. Such stands are characterized by irregular, unevenly-aged regeneration and stand structure, and by heavy invasion of hazel and mountain maple on dry and well-drained sites and by willow and grasses on moist sites. For example, in Saskatchewan about 182 000 ha of mixedwood stands have reached such a decadent stage. Rehabilitation of these stands to full production is a challenging task that will require testing of stand rejuvenation methods (Jones 1987; Perala 1983) supported by appropriate management guidelines and incentives.

Trend toward short-rotation management

Aspen renewal and regeneration management under an even-aged silvicultural system will tend toward rotations of 40-50 years or shorter under special conditions (Fig.1). Techniques for producing aspen in short rotations has been developed (Perala 1979; Stiell and Berry 1986; Ek and Brodie 1975). At present there is a lack of experience with aspen rotations as low as 50-60 years and with intensive aspen management in the Boreal forest. The experience from Minnesota and elsewhere shows that aspen can be managed to maximize the benefits to wildlife by manipulating cut-block sizes, age-class distributions, edges, habitat and browse to support wildlife species. One factor that could encourage relatively short rotations is the culmination of mean annual increment (MAI) of 55 years on good sites and 65 years on poor sites (Plonski 1974). Views may differ about the age at which there is culmination of MAI in aspen. The B.C. Ministry of Forests currently assumes culmination of aspen MAI at age 100 (Peterson et al. 1989a).

REGENERATION OF CONIFERS ON MIXEDWOOD SITES

Several speakers at the 1988 Northern Mixedwood Symposium pointed out two main challenges of conifer regeneration on mixedwood sites:

- to recreate mixedwood stands with a minimum of spruce as a maintenance measure, and
- to create and maintain some pure conifer stands.

The same concerns have been identified as important stand-level mixedwood problems in the recent survey of forest managers (Peterson, et al. 1989b) in the Prairie Provinces.

There is a strong perception that conifer regeneration on mixedwood sites, primarily white spruce, is falling behind and as a result, declines in productivity of conifer species and in projected Annual Allowable Cut (AAC) are expected to occur in the future. On the other hand, Day and Bell (1988) suggest that coniferous species, particularly white spruce, may be far more productive than aspen when managed under intensive plantation regimes.

White spruce bias and fall-downs in conifer renewal

Historically, white spruce has been considered the most useful and desirable species in the mixedwood zone

Aspen regeneration/silviculture for hardwood production

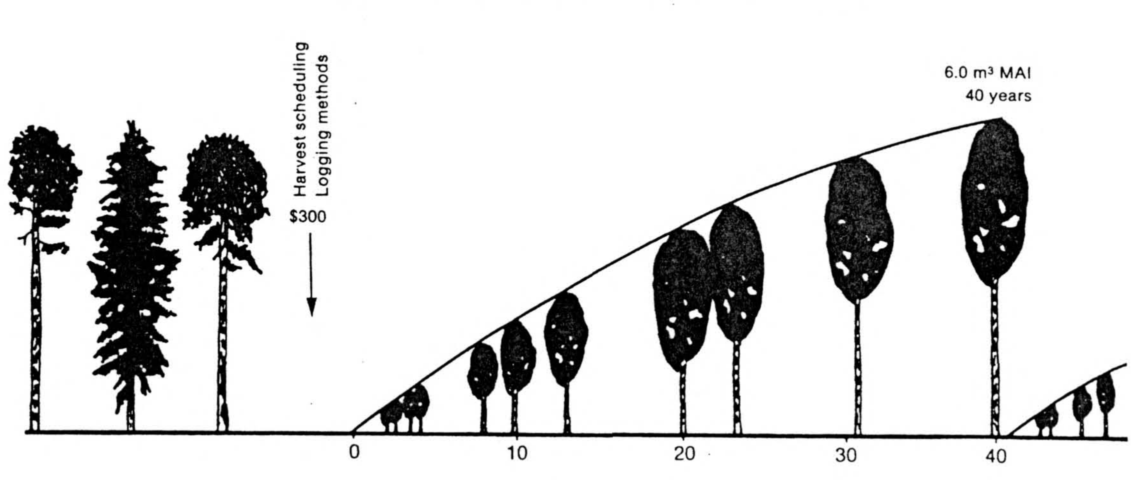

Figure 1

because of its impressive size, high yield and valuable wood.

There is obviously some bias in this. The fact is that white spruce has ranked high due to volume in the original stands, market value, and its contribution to wildlife and aesthetics. Opinion differs as to whether or not it will retain, or should retain, the same ranking in the future.

White spruce has been the primary regeneration species on mixedwood sites. In the period 1980 - 1985 the total area planted to white spruce in Canada amounted to 430,236 ha (Kuhnke 1989). In some areas and provinces the entire white spruce planting programs have been designated for mixedwood sites.

Yet, over the last several years provincial surveys have indicated serious fall downs in white spruce renewal and particularly in growth (Rannard 1988; Little 1988; Drew 1988). In Alberta up to 50% of the reforested areas on cutovers 10 years and older were found to be reverting to high density hardwoods, with another 14% developing as mixedwoods (Henderson 1988). Surveys also show that although density and survival may be adequate, the age and the height of crop trees is not consistent with cutblock age. Many crop trees suffer from heavy competition resulting in growth losses and there tends to be a continuing cycle of ingress and mortality.

The reasons commonly given for the fall-down in white spruce regeneration are repetitious across the mixedwood zone; biologically inappropriate site preparation, grass and shrub competition, aspen competition, impeded drainage, hare damage, and stock quality not matching site attributes. There is an underlying influence of site common to all of the listed impediments. It is evident that the prerequisites of successful white spruce regeneration are knowledge of the site and use of regeneration prescriptions reflecting the site attributes. The integration of the site classification systems into silviculture prescriptions has been done in the recently legislated Pre-Harvest Silviculture Prescriptions in B.C. (Wyeth 1989).

This is not, however, a simple task. In our view there is not sufficient information available on the establishment and growing requirements of white spruce to take into account site variations and appropriate site-specific treatments. Regeneration treatments are applied more often on the basis of experience and intuition than of detailed documented knowledge. Much site research will be required to provide the foresters with the knowledge base necessary to select the best regeneration treatments and prescriptions. It is also felt that separate guidelines may be required to meet the specific needs of regeneration planning on complex and diversified sites of the mixedwood zone (Peterson et al. 1989b).

A few experienced foresters who have taken the time and effort to appreciate local soil and environment conditions have been successful in establishing tracts of white spruce plantations (G. Marek Pers. Comm.). With the help of site classification guides (Corns and Annas 1986; Jones et al. 1983; DeLong 1988) available for large parts of the mixedwood zone there is now the opportunity to extrapolate local experience to similar sites and to consolidate fragmentary knowledge from numerous reforestation trials across the mixedwood zone.

Planting micro-sites and site-specific influences on regeneration may override the major site units as defined by site classification systems. Many good papers are available on interaction of site, micro-site, vegetation management and plantation performance of white spruce (Sutton 1975, 1984, 1985, 1988; McMinn 1982, 1985; Herring 1989). Work on consolidation of site classifications for silviculture prescriptions on mixedwood sites is needed urgently and such classifications should be tied into ratings of competition, frost damage and browsing.

Intensive management of conifer plantations

Realization that extensive regeneration systems will not give sufficient conifer survival and growth has lead the managers to see little option but to intensify silvicultural practice. The application of more-intensive regeneration systems for white spruce has been advocated for Alberta's reforestation strategy as described by Drew (1988) and is being considered in other provinces Rannard (1988). Weyerhaeuser Canada Ltd., Saskatchewan is currently addressing white spruce culture by intensive site preparation and multi-entry cleaning and tending of regeneration (R. Orynik Pers. Comm.).

A crop plan based on density models and prescriptions for white spruce plantations on mixedwood sites was discussed by Day and Bell (1988). Their plan includes pre-harvest hardwood poisoning, heavy site preparation planting large transplants, two weedings with herbicides, and successive multiple thinnings.

The potential of intensive plantations for securing and increasing conifer yield is high and as such it must be considered as one of the viable regeneration strategies on mixedwood sites (Drew 1988).

There are, however, several important prerequisites for high yeild white spruce plantations: improved knowledge of site selection and site productivity, high front-end investments, commitment to follow-up treatment, and improved knowledge of pest and physical damage management such as wind and snow.

There is little known about the ecological suitability and growth of white spruce in pure, even-aged plantations and there are uncertainties about pest and damage risk. We do not have many white spruce plantations where we can knowledgeably assess long-term productivity and risks.

White spruce has constraints that may limit its broad use in intensive plantations. It occupies a narrower range of sites than other species, eg. black spruce and is also more susceptible to frost. Black spruce has the ability for rapid juvenile growth and unlike white spruce is not considered a slow starting species.

Other species such as tamarack on hydric and subhydric sites, Siberian larch and lodgepole pine on mesic and submesic sites, may equally be considered for high production intensive plantations. Superior growth of larches as compared to white spruce found in the species testing program of the Alberta Forest Service (Table 1) demonstrates the potential of these species on mixedwood sites, though, as for white spruce, little is known about their long-term productivity and risks.

The role of pines in plantations on mixedwood sites should also be more vigorously explored. Lodgepole pine is easy to establish by planting, has rapid early growth, and competes well with aspen (Vyse and Navratil 1984). On average, planted lodgepole pine reaches a height of 1 m in 6 years, as compared to 11 years for white spruce on mixedwood sites in Alberta (Alberta Forest Service, unpublished data).

The choice and regeneration of conifer species may be influenced by climatic warming. Specialists stress sensitivity of the Boreal forest to warming and hypothesize that a warmer and drier climate would hinder conifer production and encourage the domination of hardwoods (J.P. Kimmins as quoted in Peterson et al. 1989a).

The potential effect of climatic warming on aspen productivity and regeneration was differentiated into three zones in the prairie provinces and British Columbia; negative effect on aspen productivity, positive effect on aspen productivity, and no effect (Navratil et al. 1989). For this reason alone the diversification of species composition including an increased component of lodgepole pine should be favoured in plantations on mixedwood sites.

Commitments to plantation management

A regeneration and silviculture system for intensively managed conifer plantations (Figure 2) requires intensive, "high cost" establishment and commitment to crop tending, thinning and protection regimes. The relevance of commitments is real and essential; the initial investments need to be secured by completing tending and thinning treatments. Furthermore, in managed, even-aged conifer stands many conditions are different from those of natural mixed stands and the stand's stability and resistance to environmental and biotic changes are affected.

Table 1. Performance of larch and white spruce on mixedwood sites. Footner La
Forest, Alberta[a]

	Siberian Larch			Tamarack			White Spruce		
	Total ht.	Ht. increment Mean ann.	Ht. increment Current	Total ht.	Ht. increment Mean ann.	Ht. increment Current	Total ht.	Ht. increment Mean ann.	Ht. increment Current
9 year-old Plantation	362	40	85		N/A		135	15	33
10 year-old Plantation	340	34	66	230	23	32		N/A	

[a]source: N. Dhir, Alberta Forest Service
N/A = Not Available

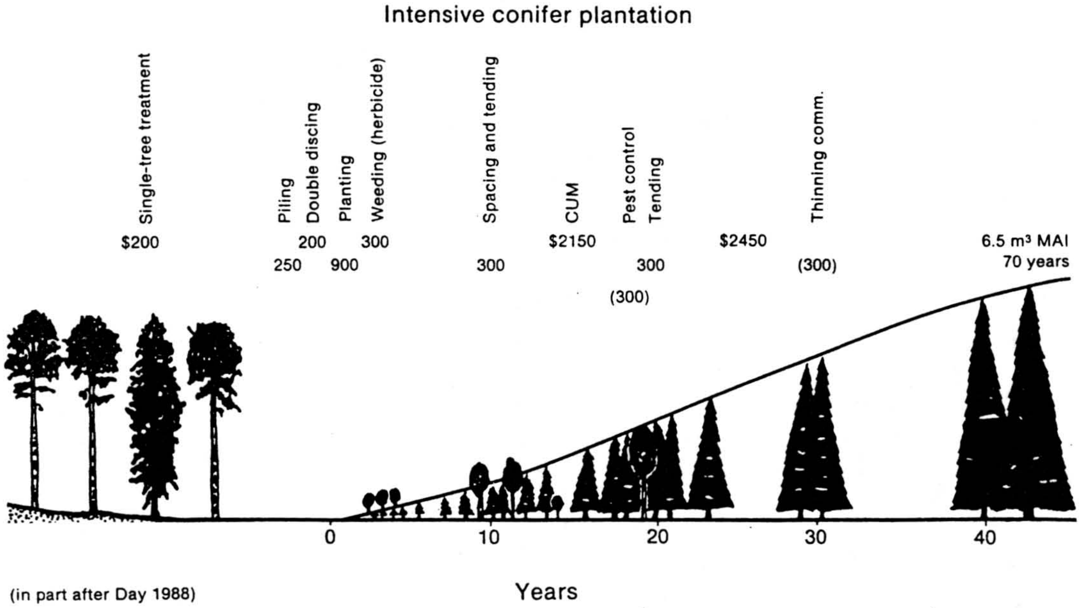

Figure 2

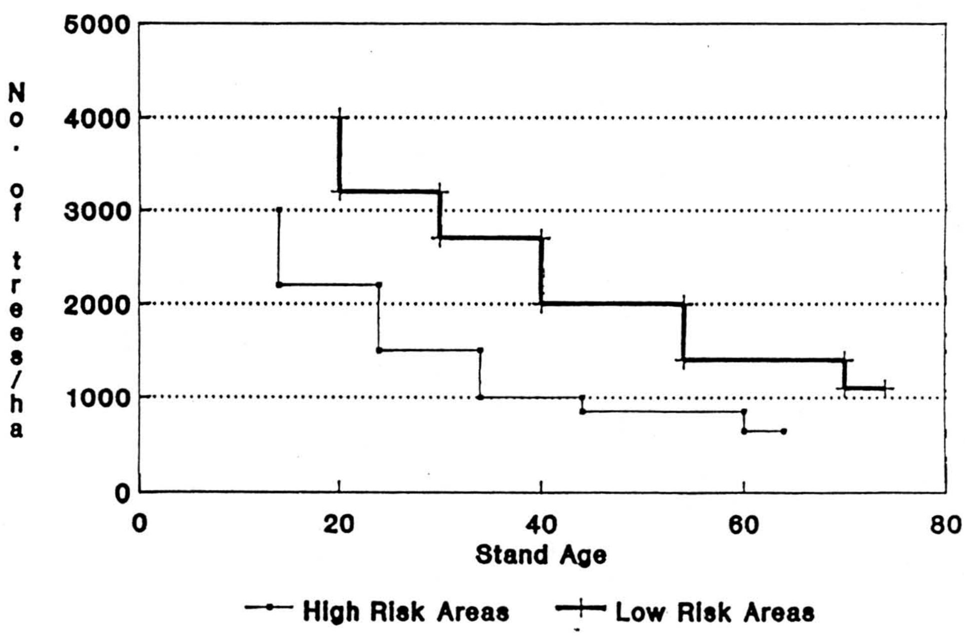

Figure 3. Thinning regimes to minimize wind and snow damage in Norway spruce stands on high productivity sites (adapted from Parez and Chroust 1988)

Wind and snow damage hazard increase significantly in managed stands. In many countries with large areas of even-aged managed stands of conifers, wind is a constant risk. In Sweden, 75% of the annual mortality, which amounts to 11% of the total annual increment of the country, is attributed to damage by wind and snow.

In central Europe, for example in Czechoslovakia in the period 1976-1985, salvage cuts in conifer plantations due to damaging agents amounted to 62% of the total AAC from which wind and snow damage accounted for 46% and 18% respectively (Perina 1987). It is not surprising that in the countries with intensively managed conifer stands stand treatment regimes and risk rating schemes to minimize wind and snow damage are given high priority in renewal and silviculture systems.

When considering intensive conifer plantations designed for maximum production, it is essential to remember that tending and thinning regimes and wind and snow damage are directly linked. In other words, crop plans designed for maximum yield production without giving attention to stand stability could jeopardize the outcome. Timing of the first thinning and of its relation to tree height and site conditions and subsequent thinning regimes is critical. Figure 3 demonstrates thinning regimes designed to minimize wind and snow damage in Norway spruce stands under conditions of high and low risk on high productivity sites.

EXTENSIVE REGENERATION SYSTEMS FOR WHITE SPRUCE RENEWAL

In Boreal mixedwood cutovers, left untreated following harvesting, the proportion of spruce often declines, and succession is to all-aged stands dominated by aspen in western provinces or by balsam fir and aspen in eastern provinces (Yang and Fry 1981).

Extensive regeneration systems which rely on seed, either natural or artificially supplied, can increase levels of spruce regeneration, provided that they adhere to critical elements in planning and execution of the regeneration systems.

Critical elements of extensive regeneration systems

Natural regeneration of white spruce can produce excellent results on some sites. But adequate spruce regeneration is often accompanied by good hardwood regeneration (Lees 1964; Zasada and Grigal 1980) and in order to assure stands with a high spruce content from natural regeneration, weed control is necessary. The most probable use of natural regeneration systems would be in the regeneration of mixedwood stands through creation of small clearcuts or 2-cut silviculture systems as discussed later.

Planning must occur prior to harvesting in order to assure that adequate seed sources are reserved and that logging plans protect the seed source. In those situations where site preparation is not prescribed, careful consideration must be given to type of harvesting equipment to be used, in terms of its effect on surface disturbance, slash volume and distribution, and site conditions by season (eg. winter vs. summer).

Some level of flexibility for implementation and timing of operations needs to be built into a regeneration plan. For example, where seedbed preparation is prescribed to best utilize natural seed-fall, chances of more efficient use of the available seed and regeneration success are greater if the scarification is done in a year when seed will be readily available as opposed to having to do it immediately after harvest regardless of the seed crop. This option may be limited where site preparation is restricted to the winter season due to ground conditions, or when site preparation has to be carried out after the production of the seed crop and before seed fall.

Knowledge of reproductive characteristics of the species

The use of regeneration methods which depend on natural seedfall and artificial seeding requires a thorough knowledge of the reproductive characteristics of the crop species and their competitors. Without this information, most attempts to apply these systems will result in less than optimum results or in failure. For white spruce, these characteristics have been reviewed by Dobbs (1972), Fowells (1965), Zasada (1986), Burns (1983), and Haeussler and Coates (1986).

Prompt regeneration requires that a number of important factors occur simultaneously; adequate seed supply, receptive seedbed conditions and low levels of competition, particularly from herbs and grass during the establishment period. Although adequate seed crops may occur as frequently as every 2 to 3 years, intervals between good to excellent seed crops are more commonly 4 to 6 or more years. Seed dispersal distance also limits regeneration. Even though spruce seed has been found in fair quantities 100 m or more from a seed source (Dobbs 1976; Zasada 1985), it would appear that placing a seed source more than 40 to 50 m from the area to be regenerated greatly reduces the probability of obtaining natural regeneration even with the best possible seedbed conditions.

If moderate to good seed crops are to be of value for natural regeneration, distances of 30 to 40 m or less may be more desirable. Although seed crops from several years may contribute to the regeneration of an area (Gardner 1986), the efficiency of reproduction (i.e., the number of seeds required to produce an established seedling) decreases quickly as the seedbed becomes less receptive due to the development of competing (vascular and nonvascular) plants on receptive surfaces and the physical effects of annual litter fall. Although germinants are commonly found on a variety of seedbeds, mineral soil provides the best conditions for germination and survival, and regeneration from seed is generally more efficient on these surfaces. Rapid regrowth of competing vegetation, particularly grass, causes high levels of seedling mortality and often causes regeneration failure. Seedling growth is generally slow and is affected by competition and residual overstory conditions. Under the best conditions, seedlings will grow to breast height (1.34 m) in 8 to 10 years.

Harvest with no additional treatment

White spruce regeneration using this method has usually been poor throughout the Boreal mixedwood region (Lees 1964; Dobbs 1972; Jarvis et al. 1966; Fox et al. 1984; Gardner 1986). This poor success has usually been attributed to inadequate seedbed conditions and rapid development of competing vegetation following harvesting, however, inadequate seed supply is also important. There are some notable exceptions to the poor regeneration associated with organic seedbeds following harvest (Wurtz and Zasada 1988), indicating that more information is needed on the site-specific factors controlling germination and establishment on organic seedbeds. At this time, it is not possible to recommend the use of this extensive method of regeneration if prompt establishment of new seedlings (stocking goals of 50 to 60 % or greater within 5 to 10 years) is required. This appears to be true even when an adequate seed supply is maintained as in the case of the shelterwood system (Jarvis et al. 1966; Lees 1964, 1970; Zasada and Grigal 1980; Wurtz and Zasada 1988).

Assisted natural regeneration: Harvest with additional site preparation

Harvesting with additional site preparation has evolved as the method that will produce the best natural regeneration from seed following harvesting (Waldron 1966; Jarvis et al. 1966; Lees 1964, 1970; Fowells 1965; Burns 1983; Zasada and Grigal 1980; Wurtz and Zasada 1988). Stocking levels on exposed mineral soil seedbeds are frequently above 60 percent and can approach 100 percent, while stocking on adjacent untreated areas is usually 25 percent or less. Seed to seedling ratios are lower on mineral soil by an order of magnitude or more.

Site preparation can be either by burning or mechanical treatment. The general experience with burning in the case of white spruce is that only the most severe fires will result in adequate mineral soil exposure and in many cases mechanical treatment is also needed. Mechanical methods have evolved significantly during the past two decades and specialized equipment has been developed for forest sites. An important point to stress is that the use of this specialized equipment should be considered on a site by site basis. The degree of site disturbance is related to the equipment used (e.g., patch scarification, continuous strips, mounding) and this in turn affects the availability of microsites for invasion by different species.

The location of the seed source and microsite conditions are also affected by overstory treatment. Although clearcutting has become the predominant, if not exclusive method, of overstory removal, shelterwood and seed tree systems have been shown to be equally good on some sites when accompanied with site preparation (Jarvis et al. 1966; Lees 1964, 1970; Zasada and Grigal 1980; Wurtz and Zasada 1988). The application of these systems which remove the overstory in two or more cuts is often visualized as a treatment uniformly applied to the whole stand. However, in order to reduce damage to residual trees and utilize modern harvesting systems (feller-bunchers) clearcut strips of various width, with partial cutting in adjacent strips can be used as well as other combinations and cutover configurations to achieve the desired conditions (Zasada and Benzie 1970). Renewal systems which retain a portion of the mature stand are often criticized because of the loss of the residual stand to a combination of factors, such as wind, related to sudden release and damage during harvesting. Experience in interior Alaska on upland and floodplain sites has indicated that this is not a serious problem. Residual trees should be the best in the stand and not selected from the subordinate crown classes which usually have a high level of mortality following harvesting (Lees 1964). Damage to trees during harvesting should be kept at a minimum to prevent a loss of vigour and consequent increased chances of infection by disease or insect attack.

Assisted natural regeneration: site preparation and artificial seeding

This option differs from the above in that an adequate supply of seed is applied to the recently exposed mineral soil seedbed and dependence on natural seed fall is eliminated. Artificial seeding has never been widely accepted in the western boreal forest. The primary reasons have been inefficient utilization of seeds, predation of seeds by mammals, and generally poor experience when it has been attempted. New methods of seeding and protecting seeds developed in Finland and Sweden provide promise and may make seeding a more viable option under some site conditions (see for example Dominy and Wood 1986; Putman and Zasada 1986; Youngblood in press). These methods provide a means of using seeds more efficiently and creating an environment that may improve germination and early seedling growth. A further improvement in the use of artificial seeding may be achieved if we examine and more closely mimic the natural process of seed dispersal.

REGENERATION OF MIXED STANDS FOR HARDWOOD AND SOFTWOOD PRODUCTION

There is a considerable reluctance among managers to accept mixed regeneration as an objective of regeneration strategy. Yet, despite efforts to manage for a conifer species, the end result is nearly always a mixed regeneration because of ingress of hardwood components. It is also argued that even if government policies do not encourage extensive management, the level of funding will force us to apply it to sites of average productivity (Benson 1988). Furthermore, extensive silviculture systems encourage integration of fibre and non-fibre uses and biological diversity, and for this reason alone may gain increasing support. As a result, the use of extensive regeneration methods on mixedwood sites will undoubtedly increase the amount of mixed regeneration.

The major objections to the acceptance of mixed regeneration commonly quoted by forest managers are:

- management of mixed stands is more difficult than managing pure stands,
- the serious gap in our understanding of juvenile mixed stand development and difficulties in projecting growth and yield,
- the lack of knowledge of silviculture of mixedwood stands, and
- the lack of clear guidelines for handling integrated AAC for mixed stands.

These objections have been reiterated by leading ecologists, silviculturists and managers alike. How much has our knowledge of mixed regeneration, juvenile mixed stand development and yield, and silviculture of mixed stands improved?

Concerns about yield performance of regeneration on mixedwood sites have moved attention from survival and stocking in provincial surveys to growth and competition. Free-to-grow, free of competition, defined and implemented to various degrees, has become an important addition to current and anticipated performance standards.

In designing performance standards and in defining free-to-grow status many questions go unanswered as we have little information on mixed regeneration dynamics, competition dynamics and interactive growth of competitors and crop trees. Similarly, available data and our ability to forecast juvenile stand development are very poor. In most inventory sampling systems PSP's are rarely located in stands younger than 30 years. In that sense even the definition "Juvenile stand" is not adequately understood. What is the age range of a juvenile stand, 1-20 years? 15-30 years? Yet the need for wood supply projections and concerns about the reliability of computer simulations of juvenile and future growth have created a powerful mandate for monitoring and stand development modelling of juvenile mixed stands (Weetman 1987).

To fill the gap D. Brand, Forestry Canada (Brand and Weetman 1986; Brand 1988), has developed a biologically meaningful definition of the free-growing tree and a model for calculating and projecting free-to-grow status. Brand's free-to-grow model is based on the relative growth of the crop trees and competitors and is portable to any region of Canada where this type of definition is required. Brand (1988) also developed the system for assessment of regeneration and the software programs that provide summaries of free-growing projections, and application of GIS for mapping the total and free-growing stocking.

Forestry Canada, Northern Forestry Centre, has initiated a study aimed at defining the levels of aspen competition that affect lodgepole pine growth and at quantifying growth losses due to competition. The primary use for such information is in planning of tending treatments and forecasting growth and yield.

Less obvious but equally important are the other questions related to the role of aspen in the mixture, as a potential asset in the renewal process. Can aspen admixture be beneficial and function as a nurse crop? Aspen provides frost protection and shade not only in pine but also in aspen-spruce mixtures. Fast-released spruce is known to suffer from late frost and winter drying damage. Examples from fire-origin stands show that two intolerant species - pine and aspen - can grow together to rotation in mixed stands, but we do not know the composition of such initial mixed regeneration, or at what stage aspen admixtures become inhibitive to the growth of crop trees.

Silviculture of mixed stands

In Scandinavia and Central Europe the concept of a beneficial effect of species mixture on growth and stand conditions has received much attention (Hagglund and Peterson 1985). The existence of positive effect on yield results from species mixture has been accepted, but the effect is not believed to exceed five percent of total yield (Frivold 1985).

It is recognized, however, that mixed stands have greater stability, greater resistance to the spread of root rots attacking conifers, and permanency of site productivity. Mixture of broadleaf species has positive effect on the nutrient cycling. On mixedwood sites in the boreal forest the number of years required for nutrient replacement of N, P, and K, following full-tree harvesting decreases with increasing hardwood component in the harvested stand (Table 2)(Gordon 1981). Pure spruce stands may increase soil acidification as shown for Norway spruce (eg. Kantor 1981) or white spruce in Canada (Brand et al. 1986).

Development of silviculture systems for regeneration purposes in the mixedwood zone of the Boreal forest has had more than a 60 year tradition. A 1966 publication on silviculture research by the Canada Department of Forestry, described a number of regeneration trials in aspen-spruce cover types spanning a period of 40 years. The studies investigated the value of various silviculture systems, ranging from clearcutting with hardwood residuals, clearcutting with residual spruce seed trees and uniform shelterwood cutting,for managing white spruce and aspen (Jarvis et al. 1966).

These studies provide a valuable source of information for current and future mixedwood silviculture treatments, such as the guidelines for release of white spruce from competition (Johnson 1986; Yang 1989) and white spruce understory release (Brace and Bella 1988).

The urgency of improved silvicultural knowledge for mixedwood management is great. As Armson (1988) writes "well tried silvicultural practices for the treatment of mixedwood stands are not available yet". The point is further argued by Rowe (1989) and Baskerville (1982) who suggest that the absence of understanding of biological dynamics in boreal forest ecosystems is a serious constraint to its management.

Two-stage silvicultural system for management of uneven-aged, mixed stands

Several silvicultural systems responsive to forest management objectives and site and stand conditions of mixedwood types will need to be developed. The two-stage silvicultural system consists of two harvesting and regeneration cycles (Figure 4) aimed at hardwood and softwood production from the same land base. The prerequisite of the system is controlled and prompt spruce regeneration after harvest of the parent mixedwood stand. This is achieved by applying the above discussed principles of white spruce natural regeneration. Seed tree retention, or other secured seed source, is mandatory in the first renewal cycle and may be extended into the second renewal cycle to enhance seed production from the now maturing released spruce trees. In the subsequent third cycle new seed trees would be selected from the trees of the maturing understory.

In an attempt to improve management of white spruce understory in fire origin hardwood and HS and SH stands, Brace and Bella (1988) developed a tending and harvesting scenario that realizes the growth and yield potential of existing white spruce understory. Harvest technology that provides adequate protection for white spruce understory during removal of aspen at the end of the first cycle is being vigorously tested (see L. Brace in this volume).

The two-stage silviculture system is well suited for adopting the management objective of a sustained yield policy for white spruce on the land base concerned. If needed for changing AAC goals, the system allows for

Table 2. Number of years for nutrient replacement following full-tree harvesting on mixedwood sites in the boreal forest (from Gordon 1981)

Mixedwood stand	N	P	K
25%S - 75%H	19	15	17
50%S - 50%H	20	16	19
75%S - 25%H	21	19	22

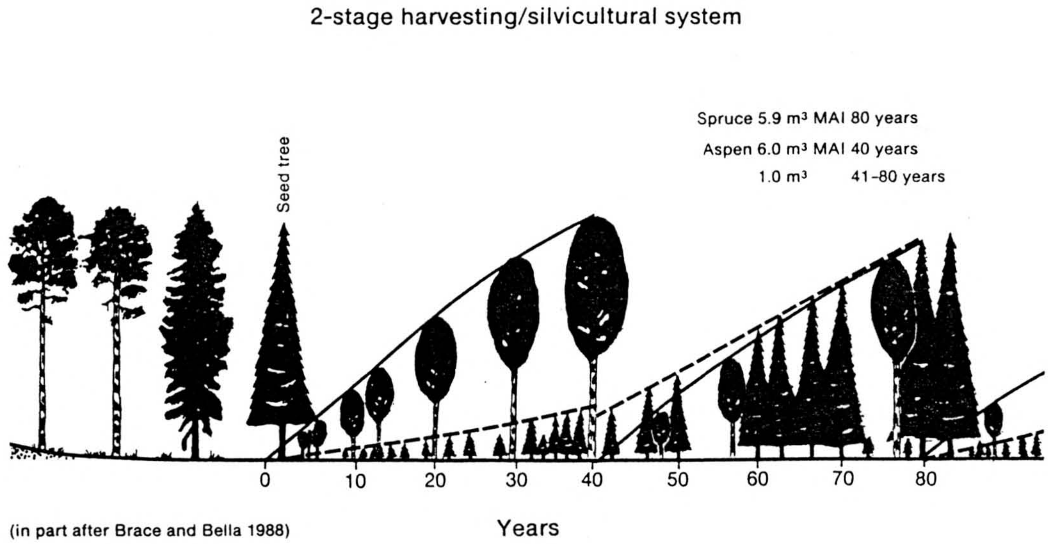

Figure 4

adjustment of the ratio of hardwoods and softwood production in the next rotation by promoting aspen establishment or by lowering protection of white spruce understory during harvest.

REGENERATION IN THE MIXEDWOODS IN THE FUTURE

Parabolic reminders

"Chunk the problems and blitz their solutions" (Management consultants)

Chunking means breaking things up into bits and pieces, fragmenting the problems. Though it works for industrial companies it may be counterproductive in forest management. The essential feature of forest management is that all steps and stages are interlinked in a long-term framework. In the past we have treated many solutions in isolation. We have put too much emphasis on survival and did not foresee competition problems and tending commitments. We were prepared to blitz competition problems with herbicides and now are poorly prepared for alternatives to herbicide use.

"Nature must be ridden not driven" (MacInnis & Rowland 1989, The Polar Passage)

It is not surprising that there is some disillusionment about the quality of regeneration on mixedwood sites. Perhaps we felt that we are powerful and that the forest ecosystem can be subdued.

Perhaps we expected too much for too little money and investment, and we overestimated our knowledge. We assigned renewal expenditures without knowing biological consequences. We must learn more about improving regeneration by adding to and enhancing the biological and silvical principles of the natural ecosystem.

Discipline the knowledge and investment loop

Regardless of the level of investment, regeneration success may fall short of objectives if it is not based on thorough knowledge of species silvics, responses to treatments, relationship to site and so on. Improved knowledge in all these areas can increase the cost-effectiveness of regeneration systems.

Securing appropriate conifer regeneration on mixedwood sites will require high initial levels of investment and continuous high levels of investment are unavoidable in ensuring that the conifer component in regenerated stands and softwood fibre yield will be brought to rotation age.

Figure 5 shows a generalized trend for the proportion of conifers in regeneration on mixedwood sites as a function of investment. At lower investment levels under more extensive regeneration practices we feel that the application of better knowledge can increase the conifer component. There is much information available on natural regeneration of white spruce that can be utilized. Knowledgeable modification of harvesting and site preparation practices and particularly integration of harvesting and silviculture operations can, at a minor additional cost, improve white spruce regeneration.

Better decision-making - Decision Support system for regeneration strategies on mixedwood sites

Selection of the most appropriate and best regeneration system requires substantial informational and technological input. Mixedwood issues are many, complex and interlinked. In many cases it is not possible for one individual to have all of the knowledge necessary to select the best system. This can be overcome by assembling a team of experts to organize, synthesize and access the information.

Rapidly emerging computer-assisted technologies (Decision Support Systems, Advisory Systems, Knowledge Based Systems, Expert Systems) have been used for strategic decision-making as well as for day-to-day tactical decisions in the manufacturing industry and are finding their way into forest management (Schmoldt and Martin 1986; Rauscher and Cooney 1986; Perala and Rauscher 1989; Pearce et al. 1990). These systems offer forest managers advantages in handling and compiling large amounts of fragmented knowledge and information, in integrating growth and other simulation models and in facilitating custom solutions to complex problems.

Silviculturists have tended to lag behind in the use of decision support technology, though some systems are being developed (Pearce et al. 1990). The complexity of decision-making in the renewal options for mixedwood stands offers a unique opportunity to benefit from "hands-on" support system tools.

In view of approaching FRDA renewals, Reed (1989) points out the need for a ranking system which assigns priorities objectively among a variety of regeneration and silvicultural options. Such a system requires syntheses of information on site productivity and growth predictions in regenerated stands that are unfortunately not at present readily available, but it emphasizes one of the roles to be filled by Decision Support Systems which incorporate rotation-length growth and yield prediction models.

Longer planning horizons need to be encouraged

There has been a tendency to focus on the results of individual regeneration treatments, rather than the entire renewal, silvicultural and management cycle. Regeneration is the cornerstone of forestry and the ripple, domino effect of deficient regeneration can be avoided by improving the quality of decisions on long-term effects of regeneration options.

Federal-Provincial agreements, which are a significant source of support for silvicultural activities in Canada, tend to constrain planning within the 5-year funding-renewal horizon. Regulatory requirements for renewal and corresponding silvicultural activities focus on survival and competition problems in the first 5-8 years of stand establishment. The acceptance of stand renewal as one phase of a silviculture and management system, and its integration with long-term growth and yield and economic projections will gradually force forest planning horizons to 40 or more years.

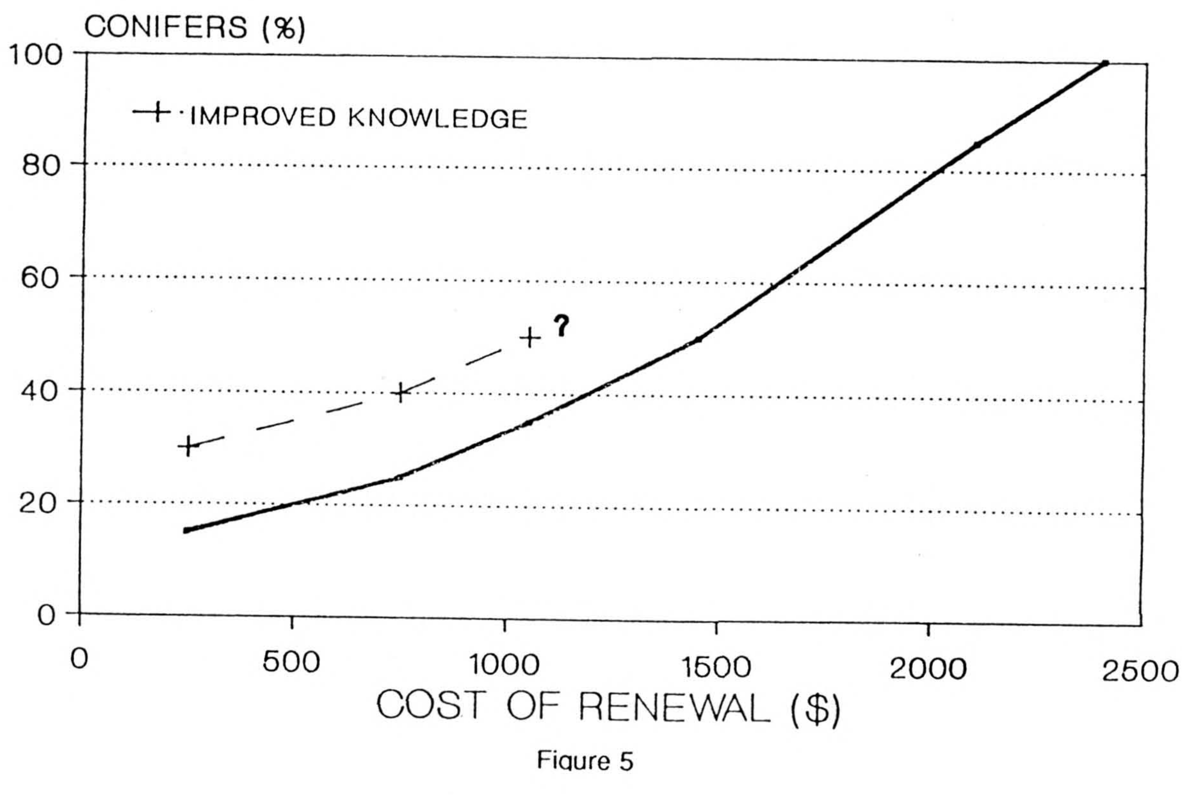

Figure 5

Regeneration options for extensive and intensive management in the mixedwoods

At the beginning of the paper we reflected on the performance of conifer regeneration established 15-20 years ago. Since that time knowledge of regeneration in the mixedwoods has improved; many things have been done well and worked well. We have learned from the work of Sutton, McMinn, and Revel. Older research on extensive silviculture systems in the mixedwoods initiated by Steneker, Lees and Waldron is now producing dividends and valuable inputs into silviculture options for the mixedwoods. Good examples of the returns possible from intensive management of white spruce on mixedwood sites are described by Willcocks (1980) and Arnup et al.(1988).

We expect that the following regeneration scenarios will be used in the mixedwoods:

Regeneration for hardwood production: aspen regeneration with a trend to short rotations

Regeneration for softwood production: coniferous plantations, monocultures with transition to mixed regeneration

Regeneration for hardwood and softwood production: mixed regeneration managed as even-aged, mixed stands at longer rotations, and in two-stage harvesting and silviculture systems.

We must develop and use the widest variety of regeneration options available for balancing extensive and intensive regeneration and silviculture systems, and for maintaining renewal capacity and species diversity in mixedwood ecosystems.

Wise use and selection of the best alternative can only occur when the forest manager can predict the consequences of various alternatives. This is only possible with a site classification framework upon which we can evaluate success or failure of regeneration, tree growth and successional changes.

Computer technology for planning and modelling regeneration and ecosystem response provides us with exceptional opportunities and tools for examining the consequences of decisions. However, we must remember that this technology is only of use when data from good field research or observations are available. Regeneration decisions must remain a strongly field oriented task.

Ecosystems, not short-term economics, should determine the correct regeneration and silviculture option. We must learn more about the complexities and dynamics of ecosystems, integrate regeneration objectives with ecological principles, and minimize the adverse consequences of our practices. The chain of understanding must start with the linkage of harvesting and silviculture and simultaneous design of harvesting, regeneration and silviculture plans.

The forests which we renew are the source of products other than wood. They also have potential to influence world-wide CO^2 and climate change. As a result, the actions of forest managers are becoming more complex and increasingly in the eyes of the public. We need to master a wide range of silviculture options and inform the public about the economic and ecological consequences of forest management alternatives. In mixedwoods ecosystems this demands that we bridge current information gaps and apply improved knoledge and understanding to both extensive and intensive management.

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