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Current trends in the management of aspen and mixed aspen forests for sustainable production[1]

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Quaking aspen (*Populus tremuloides* Michx.) is a remarkable species that performs several significant ecological roles throughout its range while at the same time is facing ever-increasing harvesting pressure. Although its full product potential remains untapped, aspen utilization has increased noticeably in the past 15 years as it has become a desired species for engineered wood products such as oriented strand board, and a preferred hardwood in the production of high quality pulp and paper products. Concurrent with this increase in aspen utilization has been an increase in the importance of ecological concepts in forest management. Any new silvicultural concepts in aspen management designed to address these ecological concepts must be grounded in the silvics and life history traits of the species. Here we present three trends in aspen management; aspen retention, a renewed interest in aspen thinning, and the advent of cut-to-length (CTL) harvesters that allow forest managers to address these considerations by capitalizing on aspen's unique characteristics. Finally, we discuss traditional harvesting methods and these trends in the context of their genetic implications.

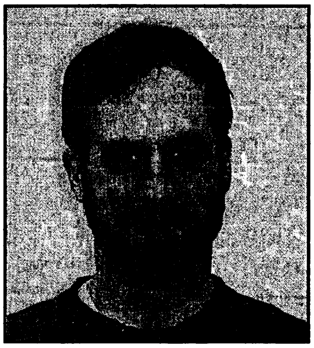
Key words: aspen management, retention, thinning, cut-to-length harvesting, genetic variation, genetic diversity

Le peuplier faux-tremble (*Populus tremuloides* Michx.) est une espèce remarquable qui joue plusieurs rôles écologiques importants partout dans son aire de distribution tout en faisant face au même moment à pression de récolte sans cesse croissante. Même si le potentiel complet en tant que produit n'a pas encore été atteint, l'utilisation du tremble s'est accrue de façon appréciable au cours des 15 dernières années alors qu'il est devenu une espèce recherchée dans le cadre des produits de bois d'ingénierie tel le panneau de lamelles orientées, et en tant que feuillu préféré dans la production de produits de pâte et de papier de grande qualité. En parallèle à cette utilisation accrue du tremble, il s'est établi une augmentation de l'importance des concepts écologiques en aménagement forestier. Tout nouveau concept sylvicole en aménagement du tremble conçu pour faire face à ces concepts écologiques doit reposer sur la sylviculture et caractéristiques historiques de cette espèce. Nous présentons dans cet article trois tendances en matière d'aménagement du tremble : la conservation du tremble, un intérêt renouvelé dans l'éclaircie du tremble, et l'utilisation des abatteuses-façonneuses qui permettent aux aménagistes forestiers de répondre à ces considérations en capitalisant sur les caractéristiques uniques du tremble. Finallement, nous discutons des méthodes traditionnelles de récolte et de ces tendances dans le contexte de leurs implications génétiques.

Mots-clés : aménagement du tremble, conservation, éclaircie, bois court, génétique

Introduction

Quaking aspen, or more commonly aspen, has a transcontinental range and is the most widely distributed tree in North America. Throughout its range aspen plays an important, sometimes critical, ecological role providing habitat and food for wildlife, insects and pathogens, reducing erosion and providing enormous aesthetic value to forests and woodlots. Economically, the history of aspen utilization is quite varied. Prior to the late 1970s industrial use of aspen was relegated to a few niche markets despite the fact that its potential uses had been well documented in a series of publications from the 1940s (e.g., Zasada 1947). This thorough analysis of the properties and potential uses of aspen that describes products such as house logs, veneer, lumber, chemicals, and furniture core stock was written by foresters and wood products specialists at a time when the forests were recovering from severe over-exploitation.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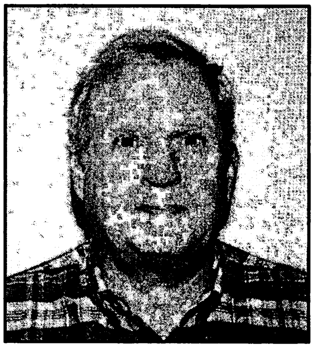
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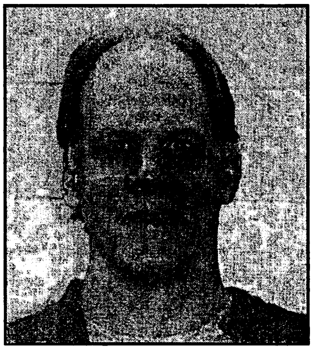
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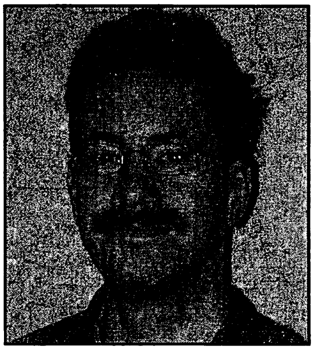
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Their aim was simply to identify the highest and best use of this plentiful, but largely unused, resource.

Fast forward to the mid-1990s and the utilization of aspen is almost staggering. Measured as volume or biomass, the use of aspen as a raw material for forest industry is dominated by its harvest for pulp and paper and engineered wood products in the northern Great Lakes region (Minnesota, Wisconsin, and Michigan) and the boreal mixedwood region of Canada. The volume of aspen harvested in the Lake States alone in 1996 was approximately 10.4 million m^3 and accounted for 44% of the pulpwood harvest (Piva 1998). The volume of aspen harvested in Alberta in 1997 was 10.0 million m^3 and accounted for 43% of the total harvest. For British Columbia, 2.9 million m^3 were harvested in 1998 accounting for 4.3% of the total harvest for the province. Trends in utilization between these two areas have been generally similar but differ in magnitude. Both have experienced increases, but in Alberta, for example, over the last 15 years utilization has increased by 800% (National Resources Canada 2000). In all areas, there is concern that there is little room for additional industrial expansion that depends primarily on the availability of aspen. Accurate estimates of area harvested are difficult to derive but have numbered well into the tens of thousands of hectares annually for the last few years.

As utilization has increased there has been an increased interest in the biology, ecology, silviculture, and management of aspen throughout Canada and the United States and in the past two decades a number of excellent reviews have addressed these topics (DeByle and Winokur 1985, Burns and Honkala 1990, Peterson and Peterson 1995, Rauscher *et al.* 1995). However, during the 1990s concepts that had previously received relatively little attention, e.g., ecosystem management, management of mixed species forests and gene conservation, have created new management objectives and an opportunity to rethink the traditional clearcut silvicultural system for aspen. With increasing interest in aspen as a valuable resource and the evolution of new management objectives, the question becomes one of balance. How do we manage for economic and ecological concerns? Ultimately, forest managers will implement silvicultural systems that allow for the simultaneous management of timber and non-timber values and capitalize on specific aspen characteristics; its regeneration ability, clonal nature and high level of genetic diversity. This paper will touch upon what we believe are important basic concepts for developing new aspen silvicultural systems and discuss several trends that are bringing change to the practice of silviculture in aspen and mixed aspen forests. We conclude with a discussion of the genetic implications of different silvicultural systems on both seedling-derived and clonally derived aspen stands.

Regeneration Ecology

Aspen is capable of both sexual and asexual reproduction. Sexual reproduction is thought to be infrequent because aspen seed has a very short life expectancy and the range of suitable seedbed conditions for germination is quite narrow and uncommon in areas where mineral soil exposure is not prevalent. Asexual or vegetative reproduction via root suckers is common after a stand disturbance event like fire or harvest and from a silvicultural point it is aspen's most important trait.

Root suckers develop from adventitious primordia (meristematic cells) in the cork cambium laid down during secondary growth of the roots. The formation of these primordia may be present before a stand replacement disturbance or develop after the disturbance. Suckering from the clonal root system is thought to be internally driven by the hormonal balance between auxins produced in the shoots and cytokinins produced in the roots. External factors such as increased soil temperatures after canopy removal and/or removal of the insulating organic soil layers are also thought to significantly affect suckering. Suckering is normally completed after two years at which time hormone levels are thought to have stabilized and the closing canopy leads to cooler soil temperatures.

Although aspen stands normally regenerate well after clearcutting, suckering can be negatively affected by a combination of factors relating to timing of harvest, type of harvest, soil temperature, soil compaction, stand age, root carbohydrate reserves, clonal variability, herbivory and plant competition. There have been numerous examples of aspen clearcuts that have resulted in sparse and sporadic sucker initiation, especially in the northern extension of the boreal mixedwood region. However, the importance of initial sucker density on future growth performance is not quite clear. It can be speculated that if initial sucker density is too low there could be effects on root system maintenance and competition with other vegetation, especially grasses. Competition can lead to a number of other problems, such as lower soil temperature and decreased resource availability, that collectively impact aspen sucker density and growth. Low soil temperature, which is a major limiting factor in the boreal forest, especially in soils with thick organic layers or high slash loads, has a strong effect on suckering and growth. Results from growth chamber studies suggest that new fine root growth, essential for water and nutrient uptake, is lacking at soil temperatures below 6°C (Landhäusser and Lieffers 1998). To generalize, a thick grass mat results in a slow decomposing litter layer, which results in additional insulation, cooler soil temperatures, and therefore lower sucker densities and slower growth rates.

Stand Development

Regardless of parent stand origin (i.e., clonal or seedling) there are large variations in plant density after stand disturbance events such as fire or harvesting. Initial sucker densities can range from 10 000 to over 100 000 stems per hectare but within eight to ten years after harvest aspen will have self thinned using density-dependent mortality to 5 000 to 10 000 stems per hectare. Mortality tends to be much greater on more productive sites during this period, and at maturity tree density ranges from 500 to 700 stems per hectare. During the first 30 years of stand development, mortality occurs in waves rather than through a gradual loss of individual stems but there is no stagnation in the growth of individual stems during this self-thinning. If allowed to grow indefinitely, aspen stands will deteriorate and succeed to more tolerant species. If however, a stand is disturbed by either fire or harvesting it will become a clonal stand of sucker origin which then follows the previously described successional trajectory through self-thinning to another mature stand.

The clonal habit of aspen has many important implications for site quality assessment and growth and yield. In almost all cases, assessment of productivity in natural stands is based on measurement of one or more clones comprised of varying

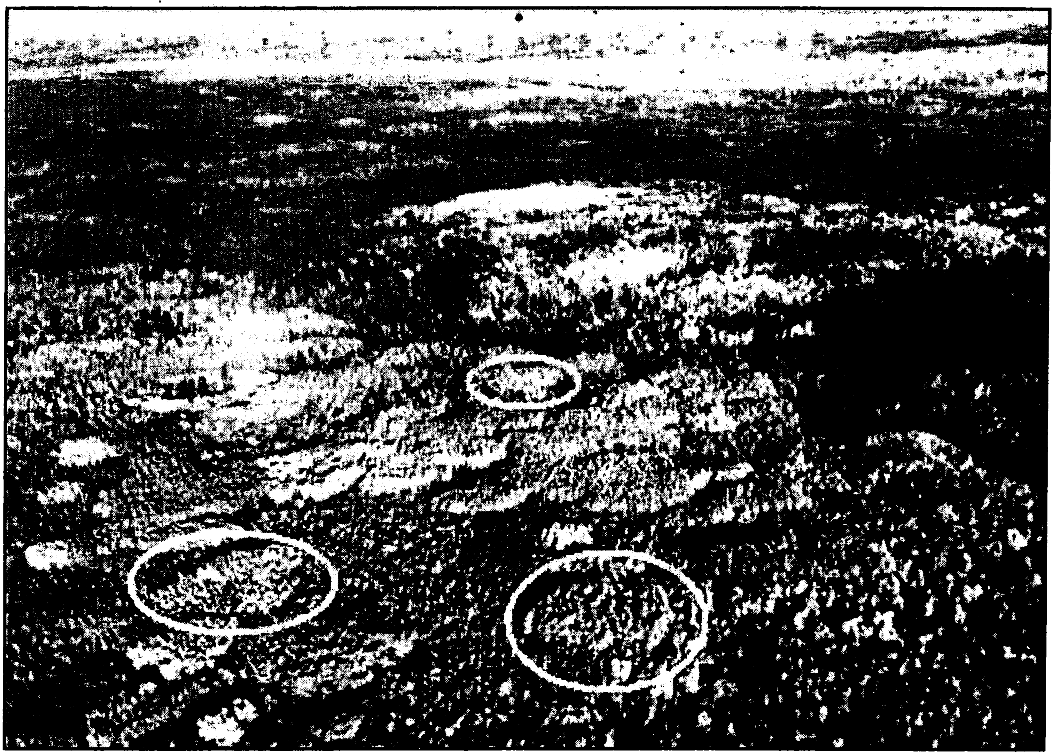

Fig. 1. The high capacity for suckering results in the development of clones that cover variable sized areas. Three easily identified clones are circled, but there are at least seven or eight other clones in the aspen stands shown in this scene. The other broadleaved species occupying areas around the aspen is paper birch. This photograph shows an upland area in interior Alaska.

numbers of individual, but possibly connected, trees in a clone. Although clones from all areas originated from seed at some time in the past, most commercially harvested stands are likely several generations removed from the original establishment event. Consequently, once established on a site an aspen clone, or group of clones, have the potential to propagate themselves indefinitely. The size of a clone is roughly correlated with its age—the larger it is the older it is (Fig. 1).

As a result of aspen's ability to vegetatively propagate after harvest the current silvicultural prescription is relatively uncomplicated; clearcut harvest and allow the stand to develop naturally to rotation age with no intermediate treatments between final harvest cuts. Because the removal step is absolutely crucial to regenerate the stand via suckering all aspen silvicultural systems are based on a final harvest prior to stand deterioration and break-up. In the interim, a manager may invoke a thinning regime or leave residual trees or residual patches in a harvest area but the key to regenerating aspen stands is a final harvest prior to stand break-up.

As with all aspects of forestry, the past 10 to 15 years have signalled changes in diverse areas of aspen silviculture. Concerns about ecosystem management and maintenance of species and genetic diversity have been the primary forces behind the development of different harvesting and thinning regimes, in particular the use of retention trees in harvesting operations and the increased occurrence of commercial thinning operations in aspen-dominated stands. Moreover, the advent of new harvesting technology in the form of cut-to-length (CTL) harvesters and their associated forwarders provide harvesting capabilities that allow forest managers to better address these ecological concerns.

Aspen Retention

The traditional harvesting method for aspen is to clearcut and to allow the stand to regenerate naturally via root suckers. But in harvest units where enhancing biodiversity is an objective individual trees can be left unharvested (Fig. 2). This retention of aspen stems increases stand structure after harvest and increases species richness because retained trees provide habitat for wildlife, insects and pathogens.

The potential retention of trees on a harvest unit can be thought of as a continuum from uniformly distributed to highly aggregated. In the uniformly distributed example trees are left standing at an equidistant spacing after harvesting while the density of the retained trees can vary depending on the goals and objectives for the site. In the aggregated option, patches of aspen are retained after harvest or a single large patch may be retained. The distribution of these patches may be equidistant, random or planned based on landform or other site characteristic.

The consequences of aspen retention associated with harvesting will vary depending on whether individual trees are dispersed equally throughout the harvest site or aggregated in one or a few sections of the site. While both provide species retention and an increase in structural diversity on the site, there are concerns that cannot be overlooked.

First, retention of trees will reduce aspen suckering and may negatively impact early sucker growth, however the effect has not been adequately quantified over a range of sites and tree densities. This inhibition of root sucker production may be pervasive when leave trees are equally distributed in a tract, or localized within the harvested unit when aspen are retained in patches or aggregated in one spot. Perala (1977) indicated that 2.4 to 3.6 m^2/ha of residual overstory would reduce sucker growth

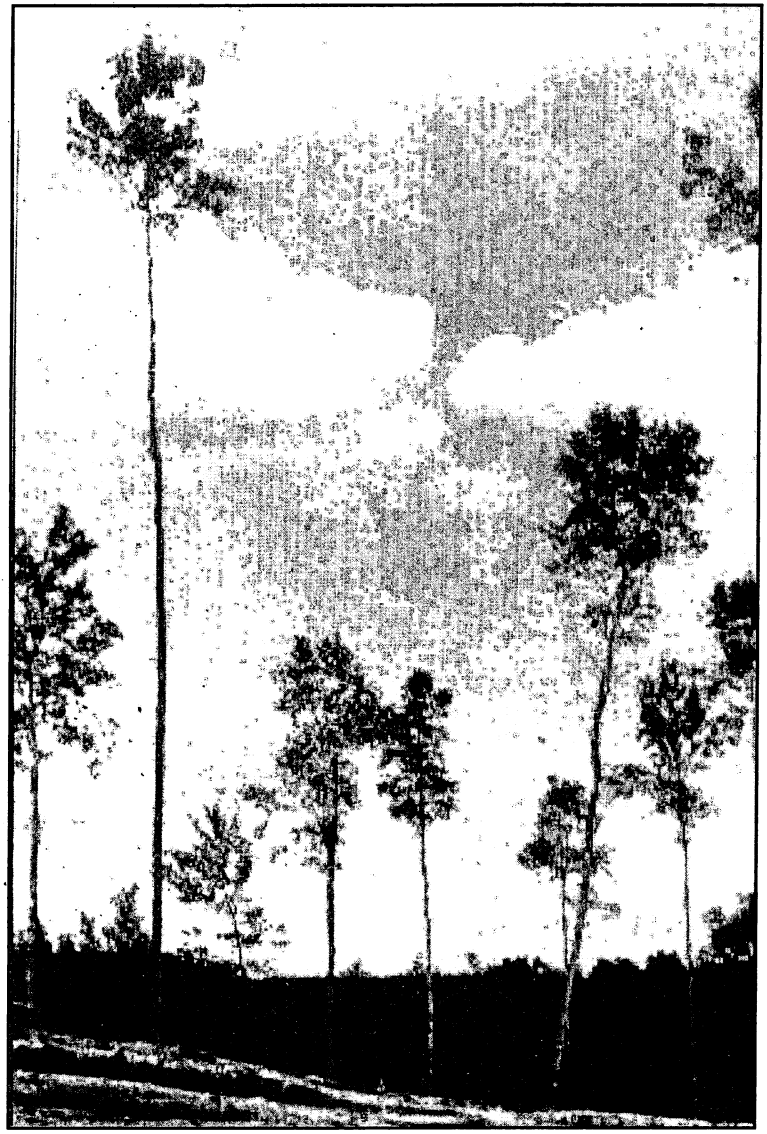

Fig. 2. One method used to meet ecosystem management objectives is to retain reserve trees in areas that are other wise clearcut. The purposes of the reserve trees are to suppress suckering, maintain large trees for animal habitat, and provide large woody debris for the future. (Photo provided by Dr. Doug Stone, USDA Forest Service, Grand Rapids, MN.)

by 35–40%. Doucet (1989), however, cited examples of adequate stocking with residual basal areas as high as 14 m^2/ha. In a case study conducted on the Superior National Forest in Minnesota, Stone *et al.* (2000), reported that leaving 75 uniformly dispersed reserve trees/ha on a harvest unit reduced aspen sucker density 33–41%, but sucker growth was not affected. A minimum sucker number of 15 000 per hectare has been determined to be adequate for successful regeneration of clearcut aspen sites and 30 000 per hectare as optimal (Graham *et al.* 1963) and this can serve as a target for baseline number of suckers required for stand regeneration in the case of aspen retention. These minimum numbers are for suckers equally spaced and uniformly distributed across the site. Patches of sucker regeneration will result in patches of aspen regeneration. In areas where aspen retention remains a major management objective, forest managers need to know the relationship between the basal area, or number of retained stems, and the amount of sucker regeneration to expect. This would allow them to retain the maximum number of stems on a site while having the least impact on aspen regeneration and growth.

Secondly, the decision to equally disperse or aggregate the retained stems will have an impact on the risk of blowdown and windshear. Aggregating the trees would provide some additional protection against strong winds and present opportunities for patch design to mitigate the impact of strong winds.

Regardless of how aspen are retained on site there is the obvious loss of volume and fibre. Although in an economic sense this may be regarded as a lost opportunity, aspen retention does address some of the aforementioned ecological concerns and provides an opportunity for initiating mixed species stands. These mixed species stands may be created through recruitment of existing advanced regeneration, natural regeneration from other species via seed rain from outside the stand, or by underplanting desired species within the matrix of regenerating aspen.

Harvesting Technology

The development of CTL whole tree processors and their associated forwarding machines is creating new opportunities for harvest and thinning operations. The maneuvrability of this equip-

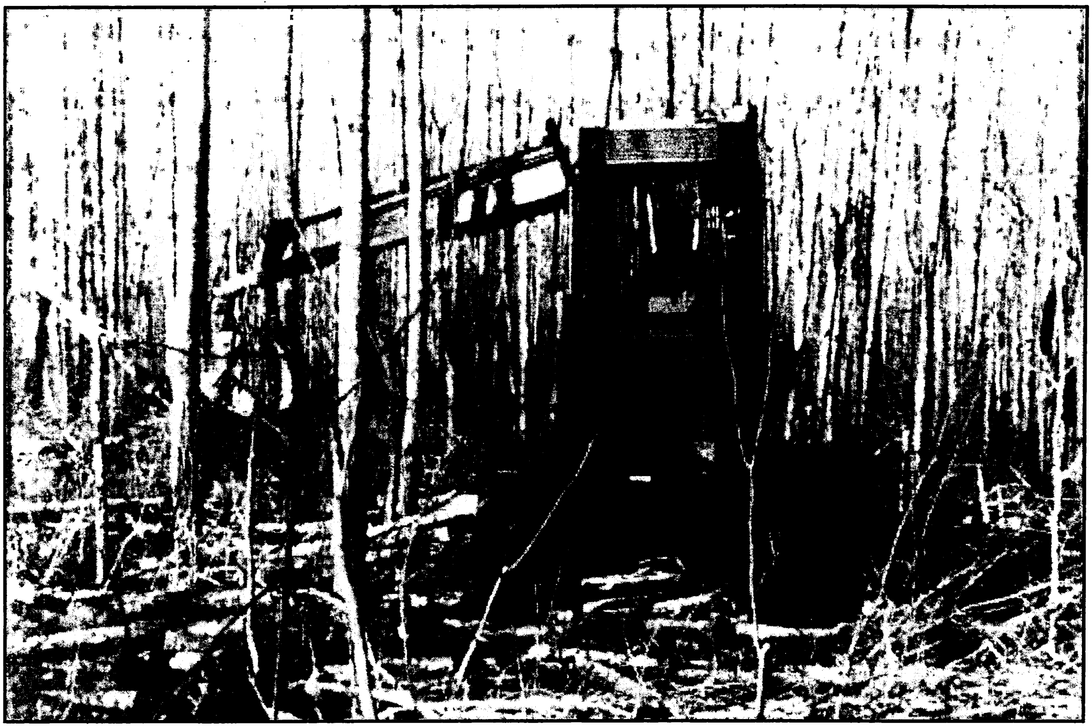

Fig. 3. Cut-to-length processor harvesting small diameter aspen from partially cut strip; processor is in strip from which all trees are harvested. Merchantable logs piled to left side for removal by forwarder. Unmerchantable material is placed in the total removal strip to provide protection to soil surface and reduce compaction. (Photo provided by Jim Marshall, Blandin-UPM Paper Company, Grand Rapids, MN.)

ment and the skill of the machine operator provides the lowest impact machine harvesting that has ever been available and is appropriate for both clearcutting and partial cutting. Protection of an established understory of desirable trees during clearcutting of crop trees in a thinning operation is a common practice with these machines. In addition to protecting desirable trees, the branch and unmerchantable stem wood can be distributed such that machine travel occurs over this material reducing the amount of direct contact with the forest floor and mineral soil (Fig. 3). The harvesting pattern in stands to be partially harvested, or where protection of regeneration is necessary, usually consists of alternating narrow clearcut strips where the machine travels and uncut or partially cut strips with no machine travel. Depending on the machine and application, the clearcut travel corridors are 2.5 to 4.5 m wide. The boom on the processor can reach 6 to 7 m on either side of the strip, making it possible to have the partially cut strips 12 to 14 m wide when travel corridors are on each side. An extremely important aspect in the use of these machines is the skill and training of the machine operator. In many cases, the operator is given a density or basal area guide to follow and no trees are marked prior to harvest. The machine operator applies the silvicultural treatment checking as the operation progresses with prism plots to assure harvesting is within the recommended guides.

In Alberta, partial cutting is sometimes prescribed in stands with varying mixtures of aspen and conifers. In these mixed stands, aspen is removed in the first entry leaving the conifers to occupy the site, but the goal is to maintain a mixed species stand with both aspen and conifer outputs over the long-term (Fig. 4). In the northern Great Lakes states, there is a tendency on all ownerships, but particularly on lands managed by the federal government, to retain both aspen and other species. The objectives of these practices include type conversion to longer-lived species (retained trees provide seed sources and suppress suckering), protection and restoration of riparian habitat, and wildlife habitat with particular emphasis on providing conditions for species that require later successional forests.

Commercial and Precommercial Thinning

The introduction of CTL harvesting technology has been responsible for a renewed interest in commercial thinning. Commercial thinning is recommended in Minnesota for aspen stands growing on good sites (site index 24.5+ m at 50 years) that are 25–30 years old and which have basal areas of 25–30 m^2/ha. The maneuvrability of these CTL machines greatly reduces damage to the residual stand compared to older mechanical harvesting. In addition, their ability to distribute the unmerchantable materials for use as a travel surface reduces impact to the forest floor and has the potential for reducing compaction and root damage.

A typical commercial thinning site has corridors that resemble row thinning with some selection from the strips between the clearcut travel corridors to bring the stand to the desired basal area or tree density level. Although currently recommended for better than average aspen stands only, commercial thinning may find increasing favour if the desire to maintain longer rotations, especially on public lands, dictates delayed harvesting schedules. In this case, commercial thinning offers access to high quality fibre before the advanced age of the stand results in increased rot and decay. Additionally, the corridors created in commercial thinning operations create openings in the canopy allowing gap phase dynamics and the regeneration of mid-tolerant tree species in the understory. Manipulation of corridor size and thinning levels may allow for mixed species management that utilizes a two-aged, multi-species system of aspen and other tree species depending on available seed rain.

Several questions related to the use of commercial thinning in aspen stands remain to be answered. One in particular is a determination of the minimum basal area required to maintain

Fig. 4. The area in the photo was harvested using cut-to-length processors. In this stand, an aspen overstory was removed leaving the white spruce understory. The pattern of strips with all trees removed for access alternating with uncut or partially cut strips is the standard pattern for all cut-to-length harvesting and use of forwarders to move product to the landing. Photo credit Mr. Robert Wynes, Peace River, Alberta.

the site in aspen once the unthinned trees are finally harvested. Other questions are related to the impacts and applicability of commercial thinning on stands that do not meet the current minimum recommendations, or exactly how to maintain long-term outputs from mixed species stands. Regardless of how commercial thinning of aspen is applied, it results in an increase in structural diversity, a potential increase in species richness and the opportunity for an additional harvest at a later date.

Precommercial thinning in aspen has been a topic of research for nearly 60 years. Although there has been research in other parts of aspen's range, the majority of the information has come from studies in Minnesota where precommercial thinning has been conducted on a relatively large-scale basis. For example, Blandin Paper Company in Grand Rapids, Minnesota has mechanically thinned about 6500 ha in the past decade. Renewal of interest in precommercial thinning has occurred because of the predicted wood shortages in the Lake States due to an imbalance in age classes and the need to obtain high quality fibre from younger stands.

The standard practice consists of alternating strips (2–2.5 m wide) of flattened, but not severed, eight to 10 year old aspen saplings and 2–3-m untreated strips. The goal is to move a cohort of stems to rotational age faster by reducing competition between remaining stems and early results suggest significant growth responses in the residual trees, perhaps due to the increased availability of resources (B. Berguson, unpublished data).

But little is known about the biological ramifications of this version of precommercial thinning. Of primary concern is the ability to promote and sustain crop tree growth, the implications for insect and disease incidence with the resulting effect on fibre quality and the establishment potential of other species in the thinned rows. From a modelling perspective, thinning is assumed to remove the smaller diameter trees, i.e., thinning from below. This current row thinning method departs from the traditional thinning methods used in past research so models need to be tested and likely modified to accommodate this new method.

Genetic Considerations

Another ecological concern that has come to the forefront in the past decade or so is the impact of harvesting practices on genetic variation in a species. This is a genetic diversity issue that is concerned with maintaining similar gene frequencies in the pre- and post harvest populations. Because gene frequencies in a population are a function of a species' life history traits (mating system, method of pollination, etc.) and evolutionary history, each species needs to be evaluated separately in the context of the particular silvicultural system being employed.

We will discuss genetic impacts of harvesting for several silvicultural treatments in both clonally derived and seedling-derived aspen stands. The occurrence of seedling-derived aspen stands is thought to be rare owing to the establishment difficulties that aspen seedlings face. These stands are included in this discussion because initially all aspen stands were seeding stands and it serves to highlight the genetic differences between clonal and seedling-derived stands.

When discussing the impacts of specific silvicultural systems on gene frequencies one must be careful to realize that there is a fundamental difference between the loss of a genotype, the loss of a gene, and a change in gene frequency. A genotype is the individual seedling, tree or clone that is composed of many different genes. Although each genotype is unique, the loss of any one genotype has virtually no impact on the loss of genes or the frequency of particular genes in the population. This is possible because each genotype is a unique combination of genes that are common to the population as a whole and the removal of a single copy of a gene has little bearing on the frequency of that gene in the population. Likewise, several genotypes (trees) can be removed from a stand without losing genes or changing the gene frequencies in the population as long as the genotypes are removed at random. The possible exception is the so called private gene, that occurs only once in a population.

As a wind-pollinated species with separate male and female trees (dioecy), aspen maintains large levels of genetic diversity at the population level which means that the majority of genes that can be found in the species can be found in each population (Hyun *et al.* 1987, Yeh *et al.* 1995). The greatest loss of genotypes in the life cycle of a seedling-derived aspen stand would occur during the waves of density-dependant mortality. But this loss of genotypes appears to be random, as mature aspen stands do not differ from Hardy-Weinberg expectations (Lund *et al.* 1992).

Recruitment of new genes from other populations would have to occur via pollen flow or seed migration in conjunction with seedling establishment. Because aspen is intolerant, the logical time for seedling establishment to occur is immediately after harvest when light levels and seedbed requirements are optimized for seed germination. However, the potential for establishing new seedlings after harvest is low because seedlings grow slower than aspen suckers and the competition for resources, especially light, is severe.

Whether aspen stands are seedling derived or clonally derived their ability to sucker after a clearcut harvest means that the genotypes of the individual trees (and therefore the genes that comprise them) are conserved on site. However, a change in gene frequencies may occur if genotypes with decreased suckering ability or slower sucker growth produce fewer stems or occupy a smaller than average area in a post-harvest clonal sucker stand. This suggests a potential loss of genotypes on a particular site over the course of several generations but the actual extent of this loss, if any, is unknown. Genetic evidence from coppicing studies in other species may provide some insight into the dynamics of long-term coppicing in aspen-dominated stands.

When aspen retention in clonal stands is practised without a final harvest of retained trees it will not cause a loss of genotypes or genes as long as there is sufficient light and soil disturbance to promote vigorous suckering and the retained aspen were individual stems and not an entire clone. As the density of retained stems increases, the chance of genotype loss increases because of reduced light levels and therefore reduced suckering. A loss of genotypes will occur in seedling-origin stands, or in extremely aggregated examples where aspen patches greater than the size of the average clone are retained without a final harvest of retained trees. Theoretically, the loss of genotypes is random and the frequency of genes in the population will not change as long as the retained aspen stems are randomly selected.

The impacts of commercial and precommercial thinning on genotypes and gene frequencies are analogous to a high-density aspen retention harvest. Therefore, if the stand is of clonal origin the loss of an entire clone (genotype) is very unlikely. This is true because the size of the average clone in the Lake States (where average clone sizes are smallest) is 200–800 m^2 (Barnes 1966), and this easily exceeds the maximum clearcut corridor width of a CTL harvester (4.5 m) or a bulldozer (3 m) used in precommercial thinning. In the case of seedling-origin stands, there will be a loss of genotypes anytime stems are harvested and there is insufficient light to recruit suckers into the overstory. Again, if these selections are random, there will be no change in gene frequencies in the stand even though genotypes were lost.

Summary

Aspen is the most widely distributed tree species in North America with a true transcontinental range. It may originate from seed or propagate vegetatively via root suckers after a stand disturbance event such as harvest or fire. In either case, aspen possesses large levels of genetic variation in each population. Throughout its range, aspen fulfils a number of ecological roles from providing habitat and food for wildlife and other organisms, to soil stabilization and aesthetics to name a few. Although it is suitable for many industrial uses, its current uses are primarily for the production of engineered wood products such as oriented strand board and high quality pulp and paper. During the past 15 years, as harvest levels for aspen were increasing in the Lake States and the boreal mixedwood region of Canada, concern over ecological issues related to ecosystem management, maintenance of genetic biodiversity and mixed species management has caused a rethinking of the traditional clearcut harvest system. Current trends in aspen management such as aspen retention and an increased interest in commercial thinning reflect these concerns and attempt to balance the ecological issues with the economic demand for the species. Each of these silvicultural options provides increased structural diversity for maintaining species biodiversity after harvest and an opportunity to manage for mixed species stands without sacrificing genetic diversity. The advent of cut-to-length harvesters with their ability to travel over unmerchantable material and harvest individual stems without damage to residuals provides the best low impact harvesting methods available and the harvesting technology to make these new management options commonplace.

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