Site and stand constraints often limit the use of natural regeneration compared to that of artificial regeneration. Combinations of natural and artificial regeneration, known as blended regeneration, may be used under some conditions.

Natural Regeneration

Natural regeneration is the establishment of desired tree species by natural seeding, sprouting, suckering, or layering (NRC 1995, OMNR 1996). The success of natural regeneration depends upon the autecology of a species (includes seeding habits, potential for vegetative reproduction, seed germination and requirements for early seedling establishment, and tolerance of shade) and the seedbed (Groot *et al.* 2001).

Natural regeneration presents opportunities to maintain local gene pools. Higher initial establishment densities may result in better stem form and wood quality than that of planted stands (Janas and Brand 1988). However, naturally regenerated stands have more variable stocking, clumping, and species composition than do planted stands. In addition, natural regeneration often requires an extended regeneration period, contributing to an increase in the rotation age of the next stand. Groot *et al.* (2001) provides an excellent review on the use of planned natural regeneration for conifers in Ontario.

Advance Growth

Advance growth refers to young trees under existing stands capable of becoming the next crop (NRC 1995). Advance growth is usually composed of species that are mid-tolerant to tolerant of shade and are often a different species than that dominating the overstorey (Weetman and Vyse 1990). Balsam fir and black and white spruce may occur as advance growth in boreal mixedwood stands.

Protection of advance growth is an operational practice used in conjunction with any of the three silvicultural systems. The objective is to protect desirable, non-merchantable stems (usually less than 10 centimetres dbh) during the removal of the main canopy. Protection of advance growth involves restricting equipment to established and marked trails and spacing skid trails as far apart as possible. Harvesting in winter or with high floatation equipment in summer is preferable to minimize damage to advance growth (Groot 1987, Archibald and Arnup 1993). In boreal mixedwood silviculture, advance growth may be used to supplement other regeneration treatments such as planting or seeding.

Natural Seeding

Natural seeding is the dispersal by natural means of seeds from standing trees or from cone-bearing slash. Seeds may be dispersed by wind, birds, mammals, gravity or flowing water, or be released by fire from serotinous or semi-serotinous cones (NRC 1995).

Natural regeneration from seed requires the successful completion of a chain of events involving flowering, cone development, seed dispersal, germination, establishment, and early seedling growth. If this chain is broken (e.g. a drought limits seedling establishment), it can result in regeneration failure and a delay in renewing the site. Maximum success can be achieved when a good seed year is combined with a suitable seedbed and adequate moisture during the growing season.

Seed years in Ontario generally occur every four years for black and white spruce. Spruce seed years cannot be predicted more than one growing season in advance, although they tend to occur in the summer following a year when bud differentiation occurred during a period of hot, dry weather (MacLean 1959, Hughes 1967, Nienstadt and Zasada 1990, Greene *et al.* 2000). A seed year can be assessed in late June of the same year of planned harvest using binoculars to count the enlarging seed cones. It can also be evaluated during the year preceding harvest, by examining buds from the upper crowns of trees harvested in nearby areas, or by forcing buds on harvested branches after a post-chilling submersion in water.

Natural seeding is not a recommended technique for regenerating aspen stands. Most aspen seed is viable for only two to three weeks after dispersal (Navratil 1991) and seedbed conditions must be receptive during this period (Steneker 1976).

Vegetative Regeneration of Intolerant Hardwoods

Vegetative regeneration of intolerant hardwoods includes root suckers and stump sprouts. Root suckers are shoots that originate from adventitious buds on roots. Sprouts refer to shoots that arise from a cut stump. The term coppice is used to refer to both stump sprouts and root suckers.

Artificial Regeneration

Artificial regeneration is the establishment of desired tree species by either direct seeding or planting seedlings or cuttings (NRC 1995, OMNR 1996).

Direct Seeding

Direct seeding is the manual or mechanical sowing of seeds (NRC 1995). The biological requirements for direct seeding are more rigorous than for planting because both successful seed germination and seedling establishment are required. Successful direct seeding depends on proper site selection, adequate site preparation, and good seed distribution. Factors affecting success include harvest method, site selection, site preparation, timing, seeding rate, and quality of seed (Adams *et al*. 2001).

The time between harvesting, site preparation, and seeding should be minimal to avoid competition problems. Ideally, seeding of conifers should be done on snow in late winter, or in the spring shortly before snowmelt, so that soil moisture is optimal. Fall seeding is also an option, although there is increased risk of premature germination and seed loss due to predation, burial, or other causes.

The best results with conifer seeding are obtained on a combination of site types and seedbeds that provide plentiful but not excessive soil moisture and warm soil temperatures (Fleming *et al.* 2001). Seeding is most successful on sites where competition from other vegetation is minimal. Site preparation and vegetation management will likely be required on any boreal mixedwood site where direct seeding is the primary means of regeneration. Direct seeding is not advised on sites where Canada blue-joint grass is expected to compete with the germinants. This grass is a serious competitor of both white (Lieffers *et al.* 1993) and black (Bell *et al.* 2000) spruce.

Some of the advantages of seeding compared to planting include:

- well-proportioned seedlings with naturally-developed root systems are established (Fleming *et al.* 2001, Cayford 1974)
- the composition, densities, and distribution of species in direct-seeded stands may closely approximate those of natural stands (Fleming *et al.* 2001)
- less planning time is required (e.g. seedlings may need to be ordered up to 18 months in advance of planting)

Some of the limitations of seeding include:

- seed losses to small mammals and birds
- difficulty in achieving uniform seed distribution (Foreman and Riley 1979, Bell *et al.* 1992, Adams *et al.* 2001).
- high dependence on site conditions, leading to inconsistent results, especially with black spruce on upland sites (Richardson 1974)
- potential inefficient use of improved seed (i.e. many seeds fall on poor microsites)
- predisposition or loss of small germinants to competition or drought (Bell *et al.* 1992)

There may be operational impediments to the use of mechanized equipment for direct seeding where a full or partial canopy is to be retained.

Direct seeding includes broadcast seeding and precision seeding.

Broadcast Seeding

Broadcast seeding is the sowing of seeds more or less evenly over a whole area on which a forest stand is to be established (NRC 1995) and is typically applied following conventional clearcutting. It can be carried out with aerial or ground-based equipment, the cyclone hand seeder or a snowmobile-mounted seeder. Stocking levels are more directly related to the amount of receptive seedbed available than to the amount of seed applied (Riley 1980, Fleming and Mossa 1995).

Precision Seeding

Precision seeding is the systematic sowing of seeds by manual or mechanical means in an area on which a forest stand is to be grown (adapted NRC 1995). Precision seeding can be done either as spot seeding (sowing of seed within small prepared patches) with or without shelters, or as drill (row) seeding across an area (Haddon 1988, Davidson 1992, Sidders 1993, Adams *et al.* 2001). Precision seeding can be done either manually or with ground-based equipment.

Spot seeding using hand-held seeding devices provides the most reliable method of seed placement on receptive seedbeds. Stocking can be increased with seed shelters used in conjunction with hand precision seeding. The best results with seed shelters have been obtained on well drained upland sites with little competition.

Planting

Compared to other regeneration methods, planting provides the greatest control over stand density and structure to achieve management objectives. Planting is suitable for a wide range of sites and is often the regeneration option chosen for productive and competitive sites.

Ecosite, site preparation method, stock type, and the type of planting tool used can influence the number and distribution of planting spots (McLain and Willcocks 1988).

Planting provides (Bell *et al.* 1992):

- a choice of stock types
- a faster and often more successful method of re-establishing desired trees on a site
- an opportunity to match growing stock to the site
- planned control over species composition, spacing, and density (e.g. Smith 1986); uniformly spaced, planted stands may occupy the sites more fully than stands established by seeding or other natural methods (Stiell 1982); high-density stands from seeding (either natural or artificial) can stagnate and only grow slowly in diameter (Janas and Brand 1988)
- an opportunity to change species composition (e.g. balsam fir to black spruce dominated stands)
- an opportunity to introduce genetically improved stock (faster growth rates, disease resistance)

The following are considerations when selecting planting as a regeneration option:

- the availability of other less intensive regeneration options may be suitable (Bryson and van Damme 1994)
- the potential for ingress of naturals to cause overstocking may be a problem (Willcocks and Bell 1995)
- stock should be grown from seed from the appropriate seed zone
- the requirement for site preparation prior to planting
- potential for damage or mortality to planted seedlings from herbivory (e.g. nursery seedlings can be more desirable to snowshoe hares than naturally-regenerated seedlings) (Rodgers *et al.* 1993)

Stock Types and Seedling Quality

Container Stock

Container stock refers to seedlings grown in a package that retains the growing medium and separates individual root systems during the growing phase (Odlum *et al.* 2001). The seedlings are planted with the roots still in the growing medium (NRC 1995).

Bareroot Stock

Bareroot stock refers to seedlings that will be planted with their roots bare of soil (NRC 1995).

In selecting a type of planting stock, a number of factors should be considered, including;

- availability of seed
- length of planting season (planting window)
- site characteristics such as soil depth, texture, and amount of slash
- handling requirements
- type of site preparation and subsequent tending treatments
- degree of competition on the site
- lead time required to obtain stock

- health and vigour of seedlings
- field performance of the stock type on boreal mixedwood sites and under varying levels of canopy removal

Stock Quality

Seedling quality may be affected by nursery cultural practices and storage and handling techniques. Seedling quality can be determined by assessing morphological and physiological attributes as well as by visual inspection. Morphological attributes can be measured at the nursery prior to shipment or storage to determine if seedlings meet field specifications. These include measurement of height, diameter, and seedling balance (height: diameter ratio). Although seedlings may appear outwardly healthy, they may not perform well once outplanted if they have been stressed. Physiological attributes to determine performance after outplanting may be measured through standardized tests (Colombo *et al.* 1984, Colombo 1997). Seedlings may also be visually inspected regularly prior to planting and monitored for overheating, drying of roots, presence of pathogens, and physical damage (KBM Forestry Consulting 2002).

Cluster Planting

Cluster planting involves planting groups of trees in patches within the regenerating stand. Hardwoods (typically aspen) may regenerate vegetatively in the areas between the groups, with a hardwood-free zone being maintained around the clusters to maximize spruce growth (BCMoF 2000). The objective of this arrangement is to promote a hardwood-conifer mixedwood where the hardwood and conifer components are managed in pre-determined proportions. The number of clusters per hectare is controlled by varying the number of clusters and the inter-cluster distance (Figure 10). If conifer advance growth exists, it can also be protected to augment stocking. The hardwood component of the future stand will grow faster and, consequently, may be harvested earlier than the conifer component. A model based on light availability (LITE) has been developed in British Columbia to determine the optimum size of the hardwood-free zone to maximize spruce growth for aspen-white spruce mixtures (Comeau 2000).

Although it might also be possible to use black spruce for cluster planting, this approach has not yet been attempted with this species.

Timing of Regeneration Treatments

Many silvicultural treatments should be timed to coincide with certain periods or seasons throughout the year. In addition, the timing of silvicultural treatments in relation to final harvest should be considered, since many treatments may be conducted either pre-harvest, post-harvest, or, to a lesser extent, during harvest. For example, tending may be implemented to treat advance growth prior to harvest, to remove undesirable stems during harvest, or to release regeneration that has established after harvest.

With respect to pre-harvest treatments, understorey scarification in a seed year and underplanting have particular application in boreal mixedwood management.

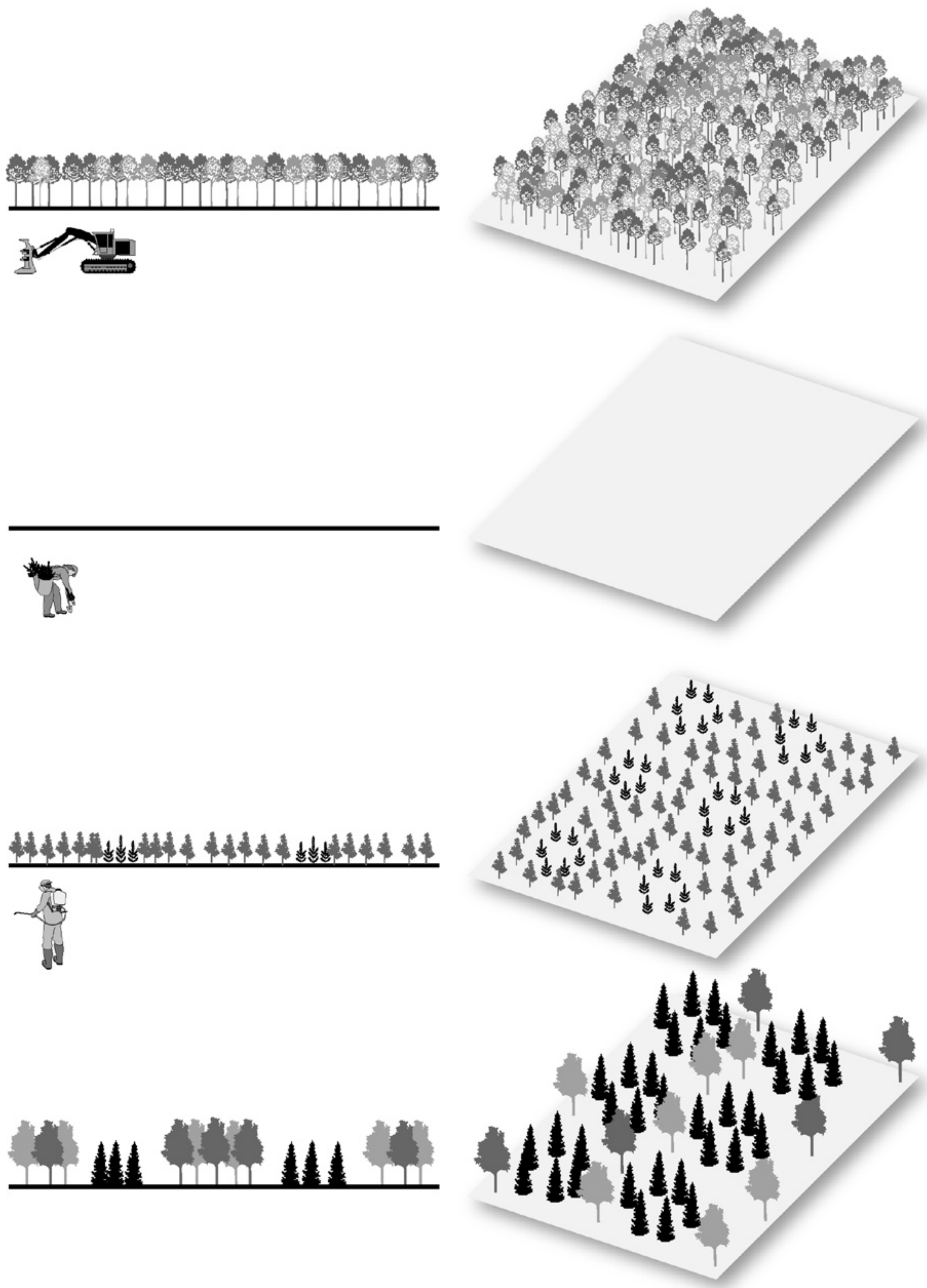
Understorey Scarification in a Seed Year

Timing pre-harvest understorey scarification with a seed year and delaying clearcut harvest until after seed release increases the chance of securing successful natural regeneration of spruce, particularly white spruce. Root raking has been suggested as a method of understorey scarification to promote natural spruce regeneration on boreal mixedwood sites prior to harvesting in a seed year (Greene *et al.* 2000).

Pre-harvest understorey scarification may also be implemented in a non-seed year. However, the harvest should be delayed for four years. Generally, a seed year will occur during this period and seedbeds will still be receptive (Greene *et al.* 2000). Harvest of the seed trees is then scheduled after seed release has occurred.

Refer to the information on use of natural seeding and techniques for forecasting seed crops (see Natural Seeding [page 28], Site Preparation techniques [page 22], and Section VII).

Figure 10. An example of cluster planting using systematic location of white spruce clusters.



Underplanting

Pre-harvest underplanting creates a distinct two-tiered stand structure which is compatible with two-stage harvesting or shelterwood harvest.

Advantages of underplanting include:

- moderated understorey microclimate favourable to white spruce establishment (Groot and Carlson 1996, Tanner *et al.* 1996, Groot *et al.* 1997, Man and Lieffers 1999, Delong *et al.* 2000)
- protection from some insects and disease (MacLean 1996, Su *et al.* 1996, Taylor *et al.* 1996, Man and Lieffers 1999)
- maximum potential yield and site occupancy (underplanting conifers in hardwoods) (Man and Lieffers 1999, Lieffers *et al.* 1999)

Supplemental Regeneration

Supplemental regeneration refers to the application of one or more silvicultural treatments to establish trees in areas of inadequate stocking to meet compositional objectives.

The appropriate portions of Sections III and VI should be referenced for information on supplemental regeneration.

Reinitiation

Reinitiation refers to the application of any combination of appropriate silvicultural treatments throughout a stand at the initiation stage when the composition or condition of the stand is deemed to be not acceptable.

The appropriate portions of Sections III and VI should be referenced for information on reinitiation.

Genetic Resource Management

Genetic resource management is *"the incorporation of genetic principles into forest practices in order to conserve genetic diversity in trees while promoting economic development through the maintenance and enhancement of productivity"* (Joyce *et al.* 2001). Because silvicultural practices may have an effect on genetic diversity by changing the population structure (i.e. the distribution and abundance of trees) (Mullin and Bertrand 1999), the impact of specific silvicultural practices must be considered in genetic resource management.

Boreal mixedwood management can involve both natural and artificial regeneration. The different impacts of natural and artificial regeneration on genetic viability must be considered. The genetic resource management principle for natural regeneration is the maintenance of a broad genetic base to reduce the risk of inbreeding and genetic drift that may otherwise occur in small, isolated populations. This goal can be achieved by ensuring that a large number of trees contribute to regeneration and that high-grading does not cause genetic degradation.

Genetic resource management principles for artificial regeneration involve seed source control of seed and planting stock and maintenance of a broad genetic base in tree breeding programs. Generic seed zones for all Ontario species have been derived using elevation and climate models to reduce the risk of using maladapted seed and stock in artificial regeneration programs (OMNR 1997b). Seed and planting stock must be used in the seed zone in which it originated, unless there is an indication that transfers are acceptable (OMNR 1997b) since seedlings may be poorly adapted to other climatic conditions when moved some distance from their geographic origin.

The five defining boreal mixedwood species can be classified as common species since they are well-represented throughout the landscape and gene flow among populations is usually relatively high. Because these species are common, they are not normally at any great risk for loss of genetic diversity across the majority of their range. However, genetic degradation can occur even within such common species if high-grading or overharvesting occurs at their range limit. These practices must be avoided to ensure the conservation of genetic diversity.

Associated boreal mixedwood species such as red and white pine and balsam poplar are likely classified as minor species (Joyce 2002). Minor species have low-density local populations and fragmented populations at the landscape scale. These minor species are the most vulnerable to genetic erosion and extirpation. Landscape-level silvicultural guidelines must be applied to ensure that these susceptible species do not gradually disappear.

Elements of management guidelines at various scales to conserve genetic diversity are covered in detail by Joyce *et al.* (2001). The major goal is to maintain genetically viable populations in which the genetic forces are in a dynamic balance.

Tree improvement programs are directed at improving the quality of commercial forest tree species. Tree improvement strategies vary depending on differences in species biology, breeding objectives, and economic and political considerations. However, all tree breeding programs utilize the breeding cycle concept which consists of the following four elements: selection, breeding, testing, and operational seed production.

The primary conifer species of interest for artificial regeneration in boreal mixedwood management are white and black spruce. Genetics research has indicated that adaptive variation in traits such as height, diameter, wood quality, and phenology exist for both black spruce (Morgenstern 1978, Boyle 1985, Parker *et al.* 1994, 1996, Parker and van Niejenhuis 1996) and white spruce (Nienstaedt and Teich 1972, Teich and Holst 1974, Teich *et al.* 1975, Pollard and Ying 1979a, b, Radsliff *et al.* 1983, Murray and Skeates 1984, Khalil 1985, Corriveau *et al.* 1991, Peng *et al.* 1997).

In boreal mixedwood management, aspen and birch are often desired as component species at certain stages of stand development. Both of these species can be managed by natural vegetative reproduction, although birch also regenerates well from seed if suitable seedbeds are available.

For aspen, vegetative reproduction by root suckering causes aspen stands to develop as mosaics of clones. Genetic variation among aspen clones has been demonstrated for characteristics such as tree form, frost resistance, patterns of height growth, suckering and rooting ability, susceptibility to Hypoxylon canker (*Entoleuca mammata*), wood specific gravity, and fibre length (Davidson *et al.* 1988). This variation should be considered for any type of thinning since genetic differences have been shown to be responsible for much of the thinning response (Penner *et al.* 2001). Genetic improvement of aspen is currently a low priority in Ontario since excellent natural regeneration of aspen occurs by suckering and there has historically been no demand for planting stock.

No information is presently available on genetic variation of birch in Ontario and genetic improvement of birch is currently not a priority.

Tending Treatments

Tending is any operation that is carried out to improve the survival, growth, or quality of forest stands. Tending in boreal mixedwood management may involve cleaning, compositional treatment, juvenile spacing, liberation treatment, pre-commercial and commercial thinning, and pruning.

Selecting a Tending Treatment

The following factors should be considered when developing a prescription for a tending treatment (Jaciw 1969):

- management objectives
- accessibility and topography
- size and extent of competing vegetation
- desired species
- environmental considerations
- value of end product
- equipment and labour availability

Tending may have an impact on wood production (yield, quality, and value), species and genetic diversity (richness and evenness), soil conservation, and risk of loss to fire, insects, disease, and severe weather (Bell 2001).

Cleaning

Cleaning is a treatment conducted to release a regenerated stand from competing vegetation, including undesired tree species. Cleaning allows crop trees to establish dominance of the site. Removal or suppression of competing non-crop vegetation speeds stand development toward a future forest of the desired composition, structure, and growth rate (Wagner *et al.* 2001).

Major competitors of spruce on boreal mixedwood sites include aspen, alder, mountain maple, beaked hazel, willow, raspberry, sedges, and grasses (Buse and Baker 1991, Lautenschlager 1995). The type and timing of disturbance, pre-harvest stand condition, site characteristics, and autecology of competitor species all interact to influence post-harvest abundance of competing vegetation. For example, harvest methods on mixedwood sites that maintain a partial canopy can reduce the level of shade intolerant competitors, such as Canada blue-joint grass, relative to total canopy removal (Landhäusser and Lieffers 1998).

Vegetation does not always have a level of impact on crop tree survival or growth that warrants an investment in cleaning (Oliver and Larson 1990). Some vegetative cover may be desirable to protect conifers, particularly white spruce, during establishment. Cleaning treatments must consider the tolerance of crop trees relative to the presence and abundance of vegetation, its impact on crop tree survival and growth, and the optimum timing for release.

Every tree species has a competition threshold. This threshold can be defined as the level of vegetation abundance where there is an abrupt increase or decrease in the rate-of-change in tree growth or survival (Wagner *et al.* 1989). In addition, there is a critical period during which cleaning must occur to prevent yield loss (Wagner 2000).

A variety of methods are available to remove or suppress non-crop vegetation (Wagner *et al.* 2001). Common methods include manual, motor-manual, and mechanical methods, and herbicide application. Others include animal grazing, mulching, cover crops, and biological control. Combinations of these methods may be prescribed to secure the desired future stand condition.

Manual and Motor-manual Cleaning

Manual cleaning involves manual cutting with motorized or non-motorized tools (e.g. motorized brushsaws, chainsaws, and axes), girdling, clearing or scalping with hoes, and hand pulling, trampling, or binding of unwanted vegetation. Manual and motor-manual cleaning are especially suited to harvest methods that leave an overstorey canopy, although these types of cleaning are costly, labour intensive, and can involve greater risks to operator safety than most other cleaning methods.

Clearing or scalping with hoes can be used to remove herbaceous or low-growing woody vegetation around crop trees, although it is generally only effective for one growing season (Wagner *et al.* 2001). Hand pulling of non-crop vegetation is of limited value in boreal mixedwood stands since the removal of the entire plant is usually only possible on coarse-textured soils, and the vegetation must not have extensive or brittle root systems or the ability to resprout (Wagner *et al.* 2001).

Manual and motor-manual cutting are effective methods for controlling the density of conifer stems (e.g. unwanted balsam fir) and temporarily reducing woody tree and shrub vegetation. Substantial resprouting of woody vegetation generally diminishes treatment effectiveness on boreal mixedwood sites (Bell *et al.* 1997 a, b, Reynolds *et al.* 1997). Consequently, multiple cleaning treatments over several years are usually required for successful control of unwanted hardwoods and woody shrubs. For greater control of resprouting, manual cutting can be combined with either herbicide application or a biological control agent (see Chemical Cleaning and Biological Control). Survival can be reduced in aspen by controlling cut height and season of cutting (Bell *et al.* 1999). Harvey *et al.* (1998) describes tools available for manual and motor-manual cutting.

Girdling involves removal of the bark and cambial layer (phloem) around the total circumference of larger stems (usually > 15 centimetres dbh) using motorized or non-motorized hand tools (Otchere-Boateng and Ackerman 1990). The wound must be wide enough to ensure that the cambium will not regrow and connect. Girdling is an effective technique to minimize resprouting when conducted in mid- to late-spring to coincide with reduced carbohydrate root reserves. Full control is not achieved until several years after treatment.

Mechanical Cleaning

Mechanical cleaning involves the use of self-propelled, wheeled, or tracked prime movers with motorized cutting attachments to remove woody vegetation. The Silvana Selective has a vertical-shaft cutting head that allows removal of individual stems of vegetation around crop trees. In contrast, the Seppi horizontal-shaft brush cutter is a non-selective, broadcast mower. Bell *et al.* (1996) suggests that non-selective cutting could be useful in boreal mixedwood management to remove all vegetation above the height of a uniformly-sized conifer crop. Mechanical cutting, like manual cutting, is most effective in mid-summer to reduce resprouting.

Chemical Cleaning

Chemical cleaning involves the use of herbicides to control non-crop vegetation. Herbicides are the most effective and least expensive means of providing longer term control of non-crop vegetation (Wagner *et al.* 2001).

The following factors should be considered in developing a chemical cleaning prescription:

- conifer seedlings can be damaged if sprayed before buds have hardened off and set (Walstad and Kuch 1987, Carruthers and Towill 1988, McLaughlan *et al.* 1996)
- the height and distribution of crop trees may limit use of some vehicle-mounted equipment because of potential physical damage to the seedlings
- combining chemical and manual treatments can be effective in cleaning operations to control coppice growth; for example, brushsaws with an attached herbicide applicator can be used to apply a systemic herbicide while cutting stems (Mallik *et al.* 1997)

Herbicides can be applied through aerial spraying or through on-ground treatments using vehicle-mounted equipment, backpack sprayers, or other hand application tools (refer to Site Preparation, pages 24 and 25, for description of appropriate herbicides and equipment).

Vegetation Management Alternatives

Animal Grazing

Research into the use of sheep grazing for forest vegetation control in Ontario began in the early 1990s (Foster 1998) and draft guidelines have been developed for this technique (Lautenschlager *et al.* 1993). Although sheep grazing appeared to be successful in releasing black and white spruce plantations in northeastern Ontario (Pickering and Richard 1993), it was subsequently determined that only a temporary reduction in non-crop vegetation abundance and a limited boost in tree growth occurred in the season following grazing (Luke and Vasiliauskas 1998). Wagner *et al.* (2001) suggests that although sheep grazing has not been tested on partially cut sites, it is not likely to be feasible in such conditions and is probably best suited to clearcuts. Bell *et al.* (1996) suggest that with effective flock management, sheep grazing can encourage spruce-aspen mixedwoods since herbs, grasses, and low shrubs can be removed and aspen and spruce taller than 1.5 metres will remain unharmed.

Mulching

Mulching is the placement of material on the ground around crop trees to smother and prevent the invasion of competing vegetation. Mulching is the only currently effective alternative method to herbicides to control herbaceous and low-growing woody vegetation (Wagner *et al.* 2001). Suggestions for the proper application of mulches are given by Strobl (1994). The high cost of mulches has limited their use to special, high-value plantations (Strobl 1993).

Cover Cropping

Cover cropping involves the regeneration of non-woody species that are beneficial or more competitive than existing competing vegetation but less competitive than the desired tree species. The intention is that the cover crop will outcompete the native competitors to either eliminate or at least suppress them but not outcompete the desired species. Experimental use of cover crops in northern Ontario has indicated that they are more difficult to establish in boreal than southern Ontario forests

(Wagner *et al.* 2001). However, cover crops have shown potential for controlling competing vegetation in spruce plantations in northeastern British Columbia (Negrave and Kabzems 1996).

Biological Control

Biological control involves the introduction of naturally-occurring fungi, bacteria, viruses, or herbivorous insects, or phytotoxins (naturally-occurring compounds produced by micro-organisms) to suppress or reduce plant populations (Wagner *et al.* 2001). Several native fungal pathogens and rhisosphere bacteria are showing potential as biological control agents of Canada blue-joint grass (Winder and Macey 1998, Winder 1999, Macey and Winder 2001). The indigenous fungal pathogen *Chondrostereum purpureum* has been shown to reduce the vigorous regeneration of speckled alder, red maple, aspen, and birch (Wall 1990, Dumas *et al.* 1997, Jobidon 1998, Harper *et al.* 1999, Pitt *et al.* 1999). Differences in susceptibility between aspen and birch could be useful in boreal mixedwood management when the objective is to promote an aspen dominated mixedwood. *Chondrostereum purpureum* is applied as a paste to cut stumps and is now registered for use in Ontario. However the high cost of this product may limit its use to special high-value situations.

Compositional Treatment

Compositional treatment alters the proportion of species in the overstorey to meet compositional and/or structural objectives (Figures 11 and 12). Trees can be removed by cutting, girdling, or herbicide application. Stems that are removed may be merchantable or non-merchantable. One or more boreal mixedwood species may be targeted for removal in order to shift from one composition type to another. However, compositional treatments must ensure that site occupancy is recovered.

Juvenile Spacing

Juvenile spacing is the spacing of crop trees during the stand initiation stage. It is similar to pre-commercial thinning, except that it is carried out before canopy closure has occurred. At this stage of stand development, it may not be possible to select for dominance if it has not yet been expressed. Juvenile spacing does not alter the species composition of the stand.

Liberation Treatment

Liberation treatment is the release of young trees not past the sapling stage from the competition of distinctly older, overtopping trees (Smith *et al.* 1997). The overtopping trees can be removed by cutting, girdling, or herbicide application. Stems that are removed during this treatment may be merchantable or non-merchantable.

Thinning

Thinning is a form of partial canopy removal in an established stand that concentrates potential wood production of a stand on selected trees (Smith *et al.* 1997). Thinning does not include an objective to create space for regeneration and does not alter species composition. Two types of thinning, pre-commercial and commercial thinning, are applicable to boreal mixedwood management.

Pre-commercial Thinning

Pre-commercial thinning is thinning that does not yield trees of commercial value and is also referred to as "thinning to waste" or "early stocking control" (Oliver and Larson 1990). The primary objective of pre-commercial thinning is to improve crop spacing, growth, and stem form, without altering the species composition of the future stand. In boreal mixedwood management, pre-commercial thinning can be applied at the stem exclusion stage of stand development for any of the following purposes:

- to increase individual tree volume and regulate stand density (Bell *et al.* 1990)
- to improve stand quality through the removal of diseased trees or those with poor form
- to modify wildlife habitat
- to improve future wood quality (Willcocks and Bell 1995)

Figure 11. Compositional treatment at stand initiation in an aspen leading mixture. The removal of much of the aspen promotes a softwood dominated mixture.

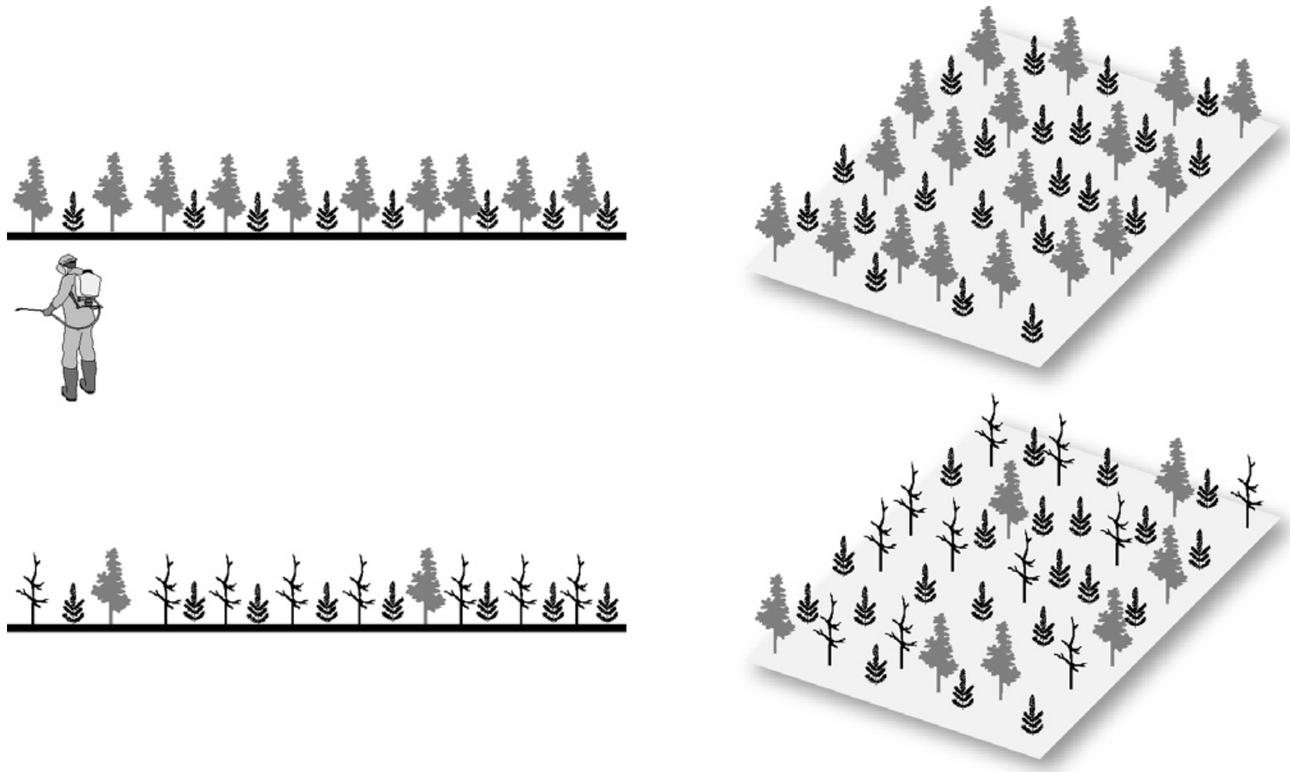
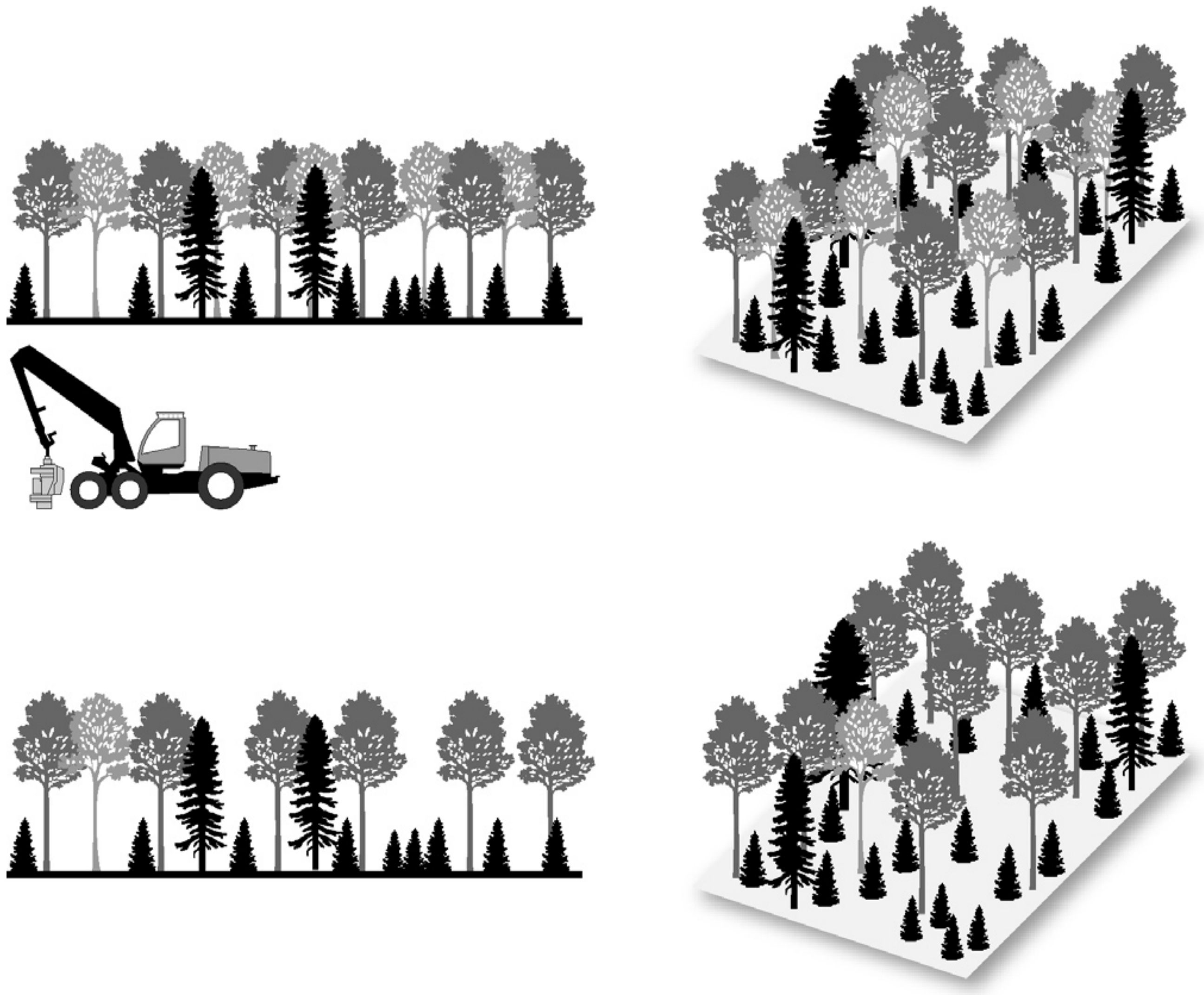


Figure 12. Compositional treatment at stem exclusion in an aspen leading mixture. The removal of much of the birch promotes an aspen dominated mixture.



Mechanical strip thinning and motor-manual thinning using brushsaws are the two most common pre-commercial thinning techniques used in Ontario. Stem injection and basal bark herbicide treatments can also be used to selectively thin hardwoods (Miller 1988, 1990). Removal of individual stems by motor-manual or chemical thinning targets the smallest, most inferior trees in the stand. This is not possible with mechanical strip thinning as individual trees cannot be preferentially selected (David *et al.* 2001).

Commercial Thinning

Commercial thinning is the partial removal of overstorey trees in well stocked stands where some portion of the trees removed have reached a merchantable size and where the sale of the timber harvested will potentially earn a positive financial return. The primary purpose of commercial thinning is to enhance the growth response (and perhaps form and quality) of the remaining overstorey stems. As opposed to compositional treatments, commercial thinning retains the original species composition of the overstorey. With commercial thinning, there is no regeneration objective.

Note: Although commercial thinning is usually considered a tending treatment (as it is in this guide), the *Forest Management Planning Manual for Ontario's Crown Forests* (OMNR 1996) classifies it as a harvesting method because merchantable volume is being removed from the stand.

Considerations for commercial thinning include:

- species or species mixture
- stand age
- thinning intensity
- thinning type: specifying which crown classes (canopy position) will be treated (e.g. thinning from below)
- spatial distribution of the remaining overstorey stems
- genetic variation: e.g. genetic differences among aspen clones are responsible for much of the thinning response (Penner *et al.* 2001)
- windthrow risk: residual trees should have a slenderness coefficient (SC) ratio less than 100 (see Wind Damage, Section IV) and a live crown ratio of at least 30 percent to reduce windthrow risk

Pruning

Pruning is the removal of lower branches from standing live trees by natural or artificial means (NRC 1995). It is generally done when the desired end product is of high value (e.g. veneer logs). Pruning can also be done to improve aesthetics and interior access to a stand.

Amelioration

Amelioration is any operation carried out on the physical site to change one or more abiotic factors in order to improve the growth or quality of a stand. It usually involves fertilization and/or drainage improvements. Neither of these operations would typically be required on boreal mixedwood sites which tend to be fertile and well-drained. Nutrient cycling studies in boreal mixedwoods have shown that after clearcutting, sufficient nutrient stores remain on site to sustain future growth (Morris 2002). Forest fertilization is not currently permitted on Crown land in boreal Ontario (OMOEE 1994).