Silvicultural Systems for Managing Deciduous and Mixedwood Stands with White Spruce Understorey

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Abstract

The white spruce understorey in deciduous and deciduous-conifer stands is a valuable conifer resource in the boreal forest. Numerous options are available for managing these stands and protecting the white spruce understorey. Selecting the most appropriate silvicultural and harvesting system requires clear definition of the management objectives and evaluation of the stand suitability, site conditions, and risk of wind damage. Expected gains in aspen regeneration, white spruce natural regeneration, growth response of released spruce, and aspen and spruce yield at the second harvest are discussed in this paper.

Background

On sites containing boreal mixedwoods that are difficult and expensive to reforest by conventional methods, it is economically and ecologically responsible to regenerate forests by extensive management of species adapted to specific sites (Benson 1988; Lieffers and Beck 1994). An essential requirement of extensive management is the adaptation of silvicultural systems to encourage and take advantage of natural regeneration.

Approximately 30% of fire-origin, deciduous and deciduous-coniferous stands in the Prairie provinces have a significant white spruce understorey resulting from natural regeneration. In these stands, white spruce naturally regenerates shortly after fire or gradually at later stages of stand development. The predominant deciduous species in the overstorey is aspen, with variable amounts of balsam poplar.

The forest industry, provincial managers, and research community have been challenged to develop the most appropriate methods for managing and utilizing these stands. Early research trials examined the effects of harvesting aspen overstorey on release of the white spruce understorey (Frohning 1980). Results of these trials demonstrated promising growth response of spruce in single-tree release treatments (Yang 1989), and led to the development of a two-stage harvesting and stand-tending model (Brace and Bella 1988) (Figure 1). Applying this model along with the proper silvicultural prescriptions for natural regeneration of white spruce could ensure the continuity of both white spruce and aspen on the same land base and avoid the risks and costs incurred by regenerating pure spruce stands on mixedwood sites (Navratil et al. 1989).

Harvesting techniques that protect the white spruce understorey, while harvesting the aspen overstorey, were evaluated in a set of the trials established in west-central Alberta in 1988–1989 (Brace 1991; Brace Forest Services 1992; Sauder 1992).

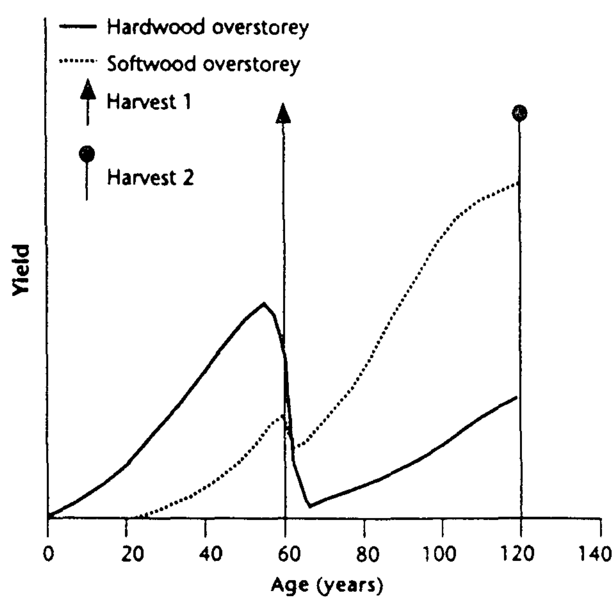

FIGURE 1 *Generalized two-stage harvesting and tending model (from Brace and Bella 1988).*

In the same trials other forest management objectives, such as the growth potential of released white spruce understorey, wind damage to released spruce, and quality of aspen and balsam poplar regeneration, have also been monitored and evaluated (Brace Forest Services 1992; Navratil et al. 1994). The results confirmed the feasibility and advantages of saving the white spruce understorey. However, windthrow damage to the released understorey spruce is a major concern, and operating strategies to minimize this damage are needed to manage this resource.

Consequently, methods for using conventional feller-buncher/grapple skidder technology were devised to minimize windthrow losses. A field trial that involved an array of silvicultural and harvesting systems and represented a range of harvesting difficulty was established in northern Alberta to test incremental wind protection levels (Navratil et al. 1994).

This paper addresses the steps required to design and select an appropriate silvicultural system specific to site and stand conditions, and to mixedwood and deciduous stands with white spruce understorey. The management objective involves protecting the white spruce understorey and managing the stand for white spruce and hardwood production using a two-stage silvicultural and harvesting model.

Stand Structure and Stand Development of Aspen Stands with White Spruce Understorey

By definition a stand with an aspen-dominated overstorey and lower stratum or strata of white spruce are two- or multistoreyed stands. The white spruce stratum may be in the regeneration stratum (consisting of seedlings and saplings of variable heights) or in the understorey stratum, having some trees forming intermediate or codominant crown classes.

White spruce in these stands originates during the stand or understorey initiation phase that follows a large-scale disturbance (Oliver and Larson 1990). Spruce regeneration can occur immediately after fire if seed is available (Zasada 1985), or may not occur until 20 or more years after the disturbance (Youngblood 1992), with the gradual ingress of white spruce occurring during the understorey initiation phase. The latter creates an understorey with varying heights and ages. Even greater variability in understorey heights and ages results from white spruce establishment after local disturbances such as endemic windthrows or aspen die-back at advanced age. Examples of the different patterns of spruce establishment are evident in the age class distribution of the white spruce understorey from deciduous and mixedwood stands in the Whitecourt area of Alberta (Figure 2).

Stands with an aspen overstorey and white spruce understorey can also be artificially produced. Underplanting aspen stands with white spruce can be successful and provides a viable alternative for enhancing the white spruce component on sites where seed sources are inadequate or have been removed.

In northeastern British Columbia, DeLong (1991) recommended underplanting of 30–40-year-old aspen stands. Waldron (1995) documented excellent results with underplanting and seeding of scalped strips prepared in 40–60-year-old aspen stands. The yield potential of underplanted white spruce was estimated to be 150 m^3/ha at 90 years.

Underplanting white spruce takes advantage of the natural dynamics of mixedwood ecosystems. Since the spatial distribution of planted spruce can be controlled, the white spruce understorey is protected when the aspen overstorey is harvested in 20–30 years after underplanting (DeLong 1991). The potential lack of natural regeneration due to insufficient seed or poor seedbed conditions is also addressed by underplanting.

Selecting a Silvicultural System

Selecting the most appropriate silvicultural system to manage a deciduous or mixedwood stand with white spruce understorey must be done on a site- and stand-specific basis. From a silvicultural perspective, stands with white spruce provide numerous stand management options. These options may vary from "doing nothing" to complex shelterwood systems (Table 1). By definition, the "do nothing" alternative falls into the category of natural shelterwood. Alternatives B, C, and D involve clearcutting systems or clearcutting with retained seed trees. Plantation technology (alternative B) has been attempted many times in the past, prevailing during the 1960–1980s in the Prairie Region. It involves clearcutting, site preparation, planting spruce, and variable levels of stand tending and competition control. Many cases

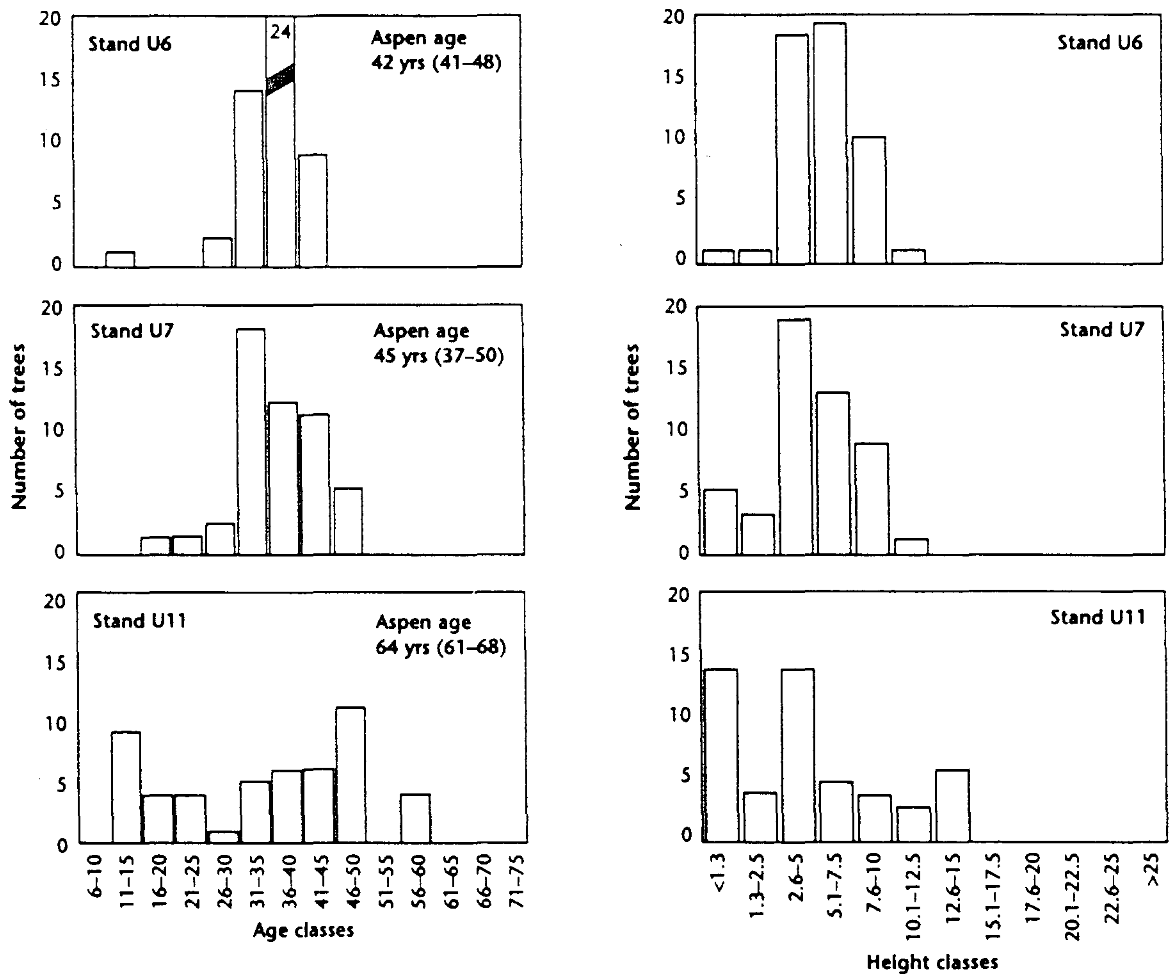

FIGURE 2 *Age class and height class distribution of white spruce understorey in three mixedwood stands, Whitecourt, Alberta (V. Lieffers and S. Navratil, unpublished data).*

TABLE 1 *Management and silviculture options for deciduous and mixedwood stands with white spruce understorey*

Management option	Silvicultural system
A. "Do nothing"	• extended rotation or use of other silvicultural systems at later stages of stand development • natural shelterwood systems
B. Plantation technology	• clearcutting, site preparation, planting, and tending
C. Deciduous production	• clearcutting and no treatments
D. Deciduous production with natural regeneration of white spruce	• clearcutting with retained white spruce seed trees
E. White spruce understorey protection, conifer and deciduous production	• two-stage harvesting model • array of systems with the incremental levels of harvesting protection of understorey, wind protection of released spruce, harvesting difficulty, and conifer yield

exist where these methods have resulted in poor coniferous stocking or high-cost plantation establishment (Samoil 1988; Shortreid 1991).

The last alternative (E) of white spruce understorey protection while harvesting aspen uses the two-stage harvesting model. This model can involve an array of silvicultural systems (see Navratil et al. [1994] and Navratil [1995] for details), ranging from clearcutting to several variants of shelterwood systems:

- Clearcutting with or without seed trees
- Clearcutting with or without windbreaks
- Alternate strip clearcutting
- Progressive strip clearcutting
- Patch clearcutting
- Uniform shelterwood
- Strip shelterwood
- Combined strip shelterwood
- Irregular shelterwood.

All of these systems can provide incremental levels of the understorey protection, wind protection of released spruce, harvesting difficulty, yield and value potential, biodiversity, and aesthetics. The overriding management objective applied here, and which we will also use in our discussion, is to enhance softwood production while sustaining mixedwoods on the site.

Two-stage Silvicultural and Harvesting Model

In this model (Figure 1), the first harvest takes place when aspen is 60–80 years old and understorey spruce is about 20–60 years old. All aspen forming the overstorey and all spruce over a dbh utilization limit is harvested, leaving a released spruce understorey. Following harvest, aspen resuckers in the available spaces, which results in a stand compromised of species clumps as well as broadleaf-conifer mixtures. Broadleaf regeneration may also contain suckers of balsam poplar and seedlings of both aspen and balsam poplar. If the objective of softwood production is to be maximized, conifers could be planted in areas inadequately stocked by the spruce understorey.

The second harvest is taken approximately 60 years later, when both aspen and spruce are harvested. During the time between the first harvest at age 60 and the second harvest at age 120, natural regeneration of spruce could occur (Navratil et al. 1989).

Successful application of the two-stage harvesting system requires decision-making steps that involve the evaluation of stand suitability, site factors, and wind risk.

Stand Suitability

Density and Spatial Distribution of White Spruce Understorey Results of pre-harvest and post-harvest assessments of white spruce densities in the Alberta harvesting trials show that 40–80% of white spruce understorey is destroyed or damaged during harvesting of the aspen overstorey when intermediate and high levels of protection are employed. The amount of immature spruce protected is influenced by its pre-harvest density, the harvesting equipment used, the operating techniques, and the levels of planning and supervision (Brace Forest Services 1992; Sauder 1992). Conventional roadside harvesting equipment protected more understorey than cut-to-length Scandinavian equipment. The differences were directly related to felling and skidding methods. Roadside harvesting equipment left well-defined skid trails with islands of relatively undamaged understorey between the trails. Cut-to-length equipment left skid trails that were less visible, but more of the understorey between the trails was damaged (Brace Forest Services 1992; Sauder 1992).

The density of white spruce clumps may also influence the degree of understorey protection. High protection levels were observed in stands with dense clumps that restricted equipment entry for aspen removal. The operator may also leave marginally merchantable spruce standing if these are surrounded by dense immature spruce (Navratil et al. 1994).

Based on these estimates, the pre-harvest understorey density should be about double the targeted post-harvest densities. Targeted post-harvest densities will greatly depend on management objectives and wind-risk level. Management objectives could specify the highest level of spruce protection during harvest to achieve the maximum spruce yield or thermal cover for wildlife. Maximum spruce yield (expressed as total volume at the second harvest) may be achieved when post-harvest densities exceed 850 spruce trees per hectare. If the management objective is to sustain production of both hardwoods and spruce on the same site and to harvest aspen and spruce at the second harvest, lower spruce densities may be desired to enhance vigorous aspen regeneration.

Tree Morphology of Understorey Spruce Resistance of a tree to windthrow results from a combination of several tree characteristics. Height is important because wind speed, and therefore windload on a tree, increases exponentially with distance from the ground. In the pooled data from the Alberta harvesting trials, cumulative windthrow damage 5 years after release for spruce trees with heights up to 7 m was less than 5%. However, trees taller than 10 m had the most windthrow damage during the first 3 years after release. The lack of damage in the 4–5 years after release indicates an improvement in tree stability resulting from crown, stem, and root system growth after release, which is a function of increased light and wind stimulus (Navratil et al. 1994).

Crown morphology, shape, and size affects the centre of gravity and windload on a tree. Crown morphology is influenced by the intensity and quality of light in the understorey. Shade-tolerant spruce may be more affected by side shade than by high shade cast by the upper canopy. We found that higher spruce density and volume in the stands with understorey was associated with higher slenderness coefficient of understorey spruce, presumably because of greater side shade cast by neighbouring spruce (Navratil et al. 1994.) (Figure 3).

The slenderness coefficient, expressed as a height per dbh ratio, is correlated with the crown size and particularly crown length, which often serves as an indication of wind damage resistance. The slenderness coefficient has been intensively studied in Europe where the importance of maintaining well-tapered trees for protection against wind and snow damage is emphasized. The desirable height per dbh ratios vary with species and site. In central Europe, a ratio of 80 to 90 (or less) is acceptable for Norway spruce (Navratil 1995).

At present, in the absence of more specific local data for white spruce, we consider white spruce understorey trees with the values equal or greater than 100 and taller than 7 m as a high-risk category.

Site Evaluation Site, primarily soil characteristics, directly affects windthrow hazard of released spruce. Susceptibility to windthrow is related to the

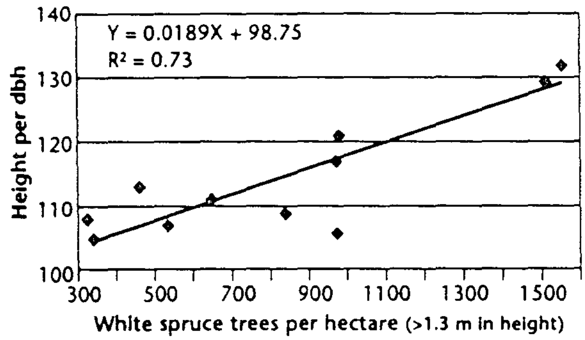

FIGURE 3 *Linear regression of slenderness coefficient of white spruce understorey trees and number of white spruce per hectare (from Navratil et al 1994).*

effectiveness of root anchorage, which in turn is mainly governed by the depth and size of structural roots. Depth of roots (shallowness of root system) and biological depth of soil is often used to rate wind risk (Stathers et al. 1994).

Windthrow risk is expected to be higher on moist and wet sites. Wet soils in general have lower shear strength and lower cohesion. Clay is very cohesive when dry, but its cohesion becomes increasingly weaker as moisture content increases.

White spruce is a shallow-rooted species and forms flat root plates on moist soils. On sites with a high water table, the root systems often have a flat table-like appearance on the bottom. When the water table fluctuates, spruce roots may be killed during temporary wet periods. The presence of endemic windthrows with flat root systems and signs of gleying in upper soil horizons may help to diagnose these sensitive sites (Navratil 1995).

On sites with wet soils, the extent of uprooting is more affected by the duration of wind storms than on drier sites. When a tree sways, movement is transferred to the root plate, which rises and sinks. In the process, water is mixed with soil particles and washes soil particles from and below the root plate. As a result, the roots are pressed deeper into the soil, swaying is greater, and finally the tree is uprooted.

Understorey protection trials in Alberta were established mainly on mesic sites, where wind damage to residual spruce may be a less critical issue because of deeper spruce rooting than on moist to wet sites. On sites with higher soil moisture, root anchoring strength is reduced. Root expansion and growth may be inhibited by anaerobic soils (Navratil et al. 1994; Urban et al. 1994).

Wind Risk Assessment Wind gusts produce most of windthrow. Expected return periods for maximum gusts (the average length of time between gusts of a given wind speed) can be calculated from long-term meteorological records and are useful for identifying the areas that will require special attention in wind protection planning (Flesch and Wilson 1993). In complex terrain and topography, particularly in mountain regions that modify the wind direction and speed, the occurrence of high-speed winds is less predictable and probability calculations may have less applicability and reliability.

Directional analysis of maximum gusts (Figure 4) is also essential in planning for sheltering effects and cutblock layouts. The sheltering effect of stands that are located upwind from the stands requiring protection have long been recognized. However, little quantitative information is available on the speed change of winds leaving forest stands and entering open cutblocks (McNaughton 1989).

Figure 5 provides a simplified illustration of wind behaviour where a sheltering stand is on the windward side of the open area. The open area may represent a cutblock with released white spruce understorey. Wind speed changes depicted in the figure show that when a wind leaves the stand it accelerates to about 30%; at 50 m into the clearing it reaches 80%; and at about 100 m it reaches 100% of the original speed.

Different wind speeds and the roughness of the forest stand can affect the extent of turbulence and the width of the protection zone. Therefore, the above values cannot and should not be broadly applied.

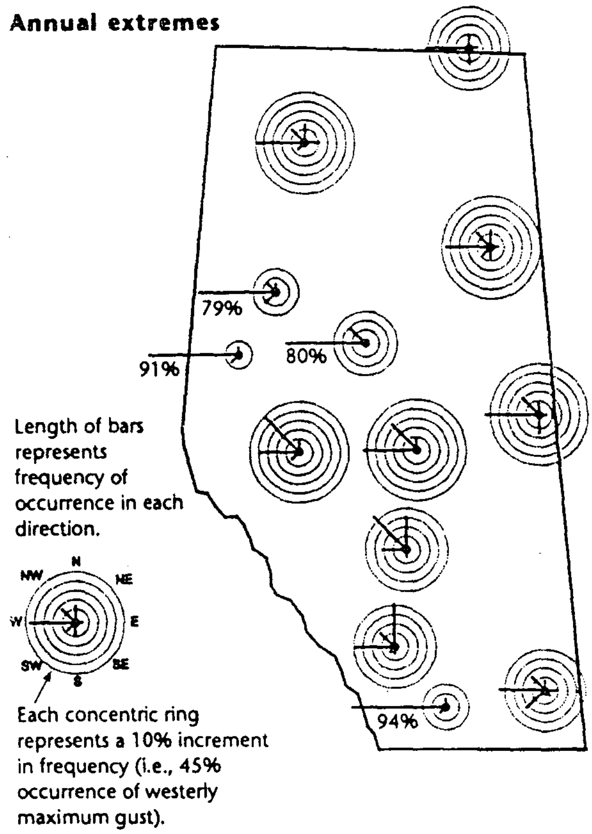

FIGURE 4 *Directional frequencies for the annual extreme wind gusts in Alberta (from Flesch and Wilson 1993).*

Targeted and Expected Gains

Aspen Regeneration The density, stocking, and growth of aspen and balsam poplar established after the first harvest is of importance in sustaining a mixedwood stand and ensuring expected hardwood yield at the second harvest.

The prerequisites for successful aspen regeneration are largely met by harvesting the aspen overstorey in aspen-dominated stands where a good supply of viable root suckers exists. It is estimated that approximately 50–60 aspen trees per hectare with uniform distribution are needed to fulfil aspen regeneration targets (Doucet 1989; Navratil 1996).

Deterrents to adequate aspen regeneration could come from two sources: a lack of soil warming because of shading by retained spruce, and soil disturbance on skid trails and landings. Soil warming is essential for root suckering, particularly on mixedwood sites with thick insulating forest floor layers. For stands of retained spruce with gaps of irregular size and shape, the effect of shading on soil temperatures, as well as on the light levels available for vigorous growth of emergent suckers has not yet been determined.

Observations of the effects of harvesting on aspen regeneration in hardwood cutblocks (Kabzems 1993; Navratil 1996; Shepperd 1993) can likely be extended to aspen harvesting with

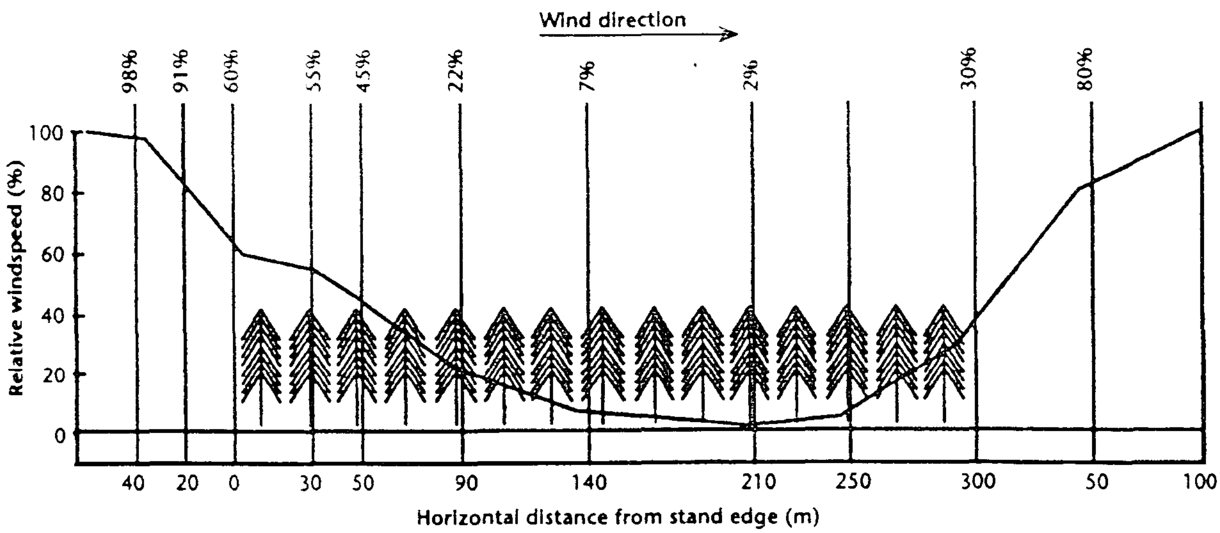

FIGURE 5 *Relative wind speed in a forest stand and adjacent open areas (after Vicena et al. 1979, from Navratil 1995).*

understorey protection. On the harvested blocks with protected white spruce understorey in the trials in west-central Alberta, overall aspen stocking and densities had attained acceptable levels 4–5 years after harvesting. The overall aspen stocking was greater than 80%, and aspen densities varied from 8600 to 21 600 trees per hectare (Navratil et al. 1994). Shading by retained spruce and its effect on soil temperature (if any) did not significantly affect the thresholds vital for suckering. Height growth of aspen regeneration, however, was less than the expected growth rate for the same general area (Navratil et al. 1994). This could be attributed to the reduced light caused by spruce shading. Whether or not the observed initial slow growth will be expressed in long-term stand development and yield is not clear. Balsam poplar regeneration showed a consistent increase in stocking during the first 4–5 years after harvesting, particularly on exposed mineral soil. This confirms the affinity of this species to colonize areas with heavy ground disturbance. The same was not observed for aspen. Balsam poplar is more versatile than aspen in both vegetative and seed-origin reproduction (Zasada and Phips 1990).

Aspen and balsam poplar regeneration will likely fill the openings. Aspen and balsam poplar growth and yield at the second harvest should be affected more by the density, stand development patterns, and spatial distribution of retained spruce understorey than by the initial regeneration potential of aspen and balsam poplar at the first harvest.

Natural Regeneration of Spruce after the First Harvest When shelterwood systems are applied in aspen-dominated mixedwoods, 60–100% stocking levels of white spruce regeneration are commonly produced by the partial removal of the overstorey and site preparation. Adequate surface soil exposure directly affects the establishment of white spruce seedlings (Waldron 1966; Wurtz and Zasada 1986; Zasada 1990).

In white spruce understorey stands after aspen overstorey has been harvested, stand and forest floor conditions are variable and favour white spruce natural regeneration. The removal of aspen always generates some degree of surface disturbance and mineral soil exposure. In Alberta's harvesting trials with understorey protection, ground disturbances with mineral soil exposure averaged about 19–23% (Navratil et al. 1994). Spatial distribution of retained spruce on harvested blocks is highly irregular, varying from very open to very dense conditions. The resulting variability in soil moisture and light is also high. A seed source is available from cone-producing released trees or adjacent stands and could be further enhanced by intentionally retaining white spruce seed trees in the first harvest. Preliminary observations show that in the existing understorey protection trials white spruce regeneration is common on disturbed soil surfaces such as skid trails and landings.

Spruce regeneration established between the first and second harvest has substantial benefits for the ecosystem, but primarily for sustaining conifer production in the second cycle, which is after the second harvest of the two-stage harvesting model. After the second harvest, the existing advanced spruce regeneration will develop into the next stand concurrently with newly regenerated aspen and form a merchantable spruce component in the first harvest of the second cycle.

Growth Response of Spruce after Release The two-stage harvesting model is based on the unobstructed growth of retained understorey spruce after the first harvest.

The tree's condition at the time of release governs how rapidly and how great the growth response will be after release. The crown size and condition are the most critical factors in this process (Oliver and Larson 1990). White spruce has a remarkable ability to respond to release at all ages. For white spruce saplings, there is no evidence of reduced photosynthetic capacity following the removal of overtopping hardwoods (Lieffers et al. 1993). The potential for white spruce growth response is greatest in the range of 30–70 years (Jarvis et al. 1966; Johnson 1986). Yang (1989) found the best growth response in the age range of 15–40 years for released individual understorey trees in aspen stands. Substantial increases in diameter growth also occurred in 174-year-old spruce after the seed-cut of a shelterwood system (Youngblood 1991).

Remeasurement of the spruce understorey 5 years after the removal of aspen canopy in west-central Alberta's trials showed positive and uniform diameter growth response across a range of densities. A 20–30% increase in diameter occurred 4–5 years after release (Navratil et al. 1994).

Growth response, and particularly the response in diameter growth, are equally important for volume gains as well as for improvement of tree stability. The slenderness coefficient for the released spruce was consistently reduced. This reduction indicated gradual improvement in tree stability and coincided with the observed lack of significant windthrow in 4 or more years after release (Navratil et al. 1994). Decreasing wind damage with time since release is a similar trend to those reported for other conifers and thinning treatments (Navratil 1995). For example, Lohmander and Helles (1987) found a rapid decline in windthrow probability of Norway spruce in years 1 to 3, a slight decline between years 4 and 5, and a very slight decline or no change between years 5 and 10 after thinning.

Improvement of tree stability does not come from the changes in taper (slenderness coefficient) alone but is probably related to strengthening and expansion of the root system after wind exposure. An increase in the growth of structural roots is believed to counterbalance sway and prevent blowdown (Coutts 1983).

Yield of Aspen and Spruce At First Harvest and Second Harvest The volume removed in the first harvest depends on the volume of overstorey aspen, volume of spruce in the canopy, volume of merchantable understorey spruce, and the type of silvicultural system prescribed.

After the removal of aspen in the first harvest, the released understorey spruce is expected to develop along with aspen regenerating from the root systems of harvested aspen. The second harvest is expected 60 years later. Since aspen can only develop into the spaces unoccupied by spruce, aspen yield would be lower in proportion to the spruce density increase.

Brace Forest Services (1992) estimated the proportion of aspen yield 60 years after the understorey release compared to the white spruce post-harvest densities (assuming trees are uniformly distributed across the site), as follows:

	White spruce post-harvest density (trees per hectare)				
	0	1–200	201–400	401–600	601–800
% aspen yield of total yield	100	80	40	20	0

According to these estimates, aspen yields in stands with post-harvest white spruce densities greater than 600 trees per hectare would be insignificant because the site would be fully occupied by spruce 60 years after first harvest.

Crown closure at the rotation age of 100 years predicted from simulations using the Tree and Stand Simulator (TASS) model compares well to the above estimates. In the TASS simulations, the canopy closure (or, in reverse, unoccupied canopy space) varied with the number of spruce trees and also with the spatial distribution of trees expressed in three levels of clumpiness: random, low, and high (Table 2). Stands that started with initial white spruce densities of 600 trees per hectare had (white spruce age = 100 years) an unoccupied canopy space of 13, 21, and 44% for random distribution, low clumpiness, and high clumpiness, respectively, at second harvest.

Since aspen is expected to regenerate after the first harvest into gaps in retained understorey spruce, it is unlikely that all available space would be filled fully with aspen. In addition, Johnson (1986) calculated that if spruce is taller than 2.4 m at the time of release, newly regenerated aspen will not grow fast enough to overgrow the spruce. For the levels of unoccupied canopy space in the range of 0–20%, very few aspen will form dominant or codominant crown classes of the canopy.

TABLE 2 *Percentage of unoccupied canopy space at 100 years in simulations[a] of a white spruce stand with different densities (trees per hectare) and spatial distribution at age 40*

Density	Clumpiness		
	Random	Low	High
250	26	51	64
600	13	21	44
900	7	12	31

[a] TASS simulation by Forest Productivity Section, Research Branch, B.C. Ministry of Forests.

Therefore, insignificant aspen volume will be produced at the second harvest.

Stands with spruce densities lower than 600 trees per hectare or stands with a high clumpiness of retained spruce will have a higher yield of aspen though, at present, we lack the tools to forecast these proportions. Higher yields of aspen can also be expected in harvested stands with larger open areas such as landings, if soil disturbance in these areas can be minimized. This, for example, may be done by winter harvesting.

Examples of the expected white spruce yield at the second harvest compared to understorey density (in stands harvested by conventional clearcutting with white spruce protection) are presented in Table 3. The simulations also show that spruce yields are significantly influenced by the level of clumpiness of white spruce. Higher levels of understorey clumpiness produce lower spruce yield at the second harvest.

TABLE 3 *White spruce yield (in m^3/ha) at second harvest in relation to understorey density*

	White spruce per hectare after first harvest		
	250	580	850
TASS simulations[a]	230	369	452
Spruce age = 100 years			
Trials in Drayton Valley[b]	162	346	468
Whitecourt	142	310	428
Hinton	132	294	411
estimated spruce age = 110 years			

[a] TASS simulations by Forest Productivity Section, Research Branch, B.C. Ministry of Forests. TASS simulations based on random distribution of white spruce and densities at age 40.

[b] Projections based on calculations of 5-year PAI (the first 5 years after release) and compounded mortality (1% per year) as reported in Navratil et al. (1994). Densities of 246, 577, and 851 trees per hectare were used, which are identical to those used in the TASS simulations.

Conclusions

My introductory remarks placed the silviculture of stands with understoreys within the context of extensive and ecosystem management. A well-designed and properly implemented silvicultural system that protects spruce understorey does provide an extensive management option that is affordable, ecologically sound, and can provide high yields.

Managing stands with understorey is more complex than the clearcutting approach practised in the past. Successful management of these stands requires new knowledge and a change in attitudes. However, the rewards and long-term gains, in addition to conifer yield, are also higher. The use of these systems as a management strategy is important for ensuring long-term ecosystem resiliency, wildlife habitat, biodiversity and landscape aesthetics, thereby addressing the shortcomings of clearcutting.

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