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Planting White Spruce under Trembling Aspen

7-year Results of Seedling Condition and Performance

2000

British Columbia

Ministry of Forests Research Program

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ABSTRACT

I present the results on the performance of white spruce seedlings in relation to environmental conditions under 40- to 80-year-old aspen and in clearcuts within the boreal forest in northeastern British Columbia. This report outlines the feasibility of planting white spruce under aspen and gives advice for successfully implementing this alternative silvicultural system. Condition and growth of white spruce seedlings were assessed in the field over seven growing seasons. Incidence of frost damage and chlorosis was lower for seedlings planted under aspen than in clearcuts. Initially, seedlings planted under aspen grew faster than seedlings planted in the clearcut, while the reverse was true for the later growing seasons. Results indicate that 40- to 80-year-old aspen stands may offer less stressful early establishment conditions for white spruce relative to clearcuts. Once established, seedlings in the clearcut outperform underplanted seedlings, likely in response to higher light levels. High survival rates and adequate growth performance suggest that planting white spruce under aspen canopies represents a viable means of establishing mixed aspen–white spruce forests. A number of recommendations for successful establishment of white spruce under aspen are provided.

ACKNOWLEDGEMENTS

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1 INTRODUCTION

The boreal forest in Canada is under extreme pressure to provide wood for production of conifer and broadleaf products. Current forest management philosophy throughout most of the boreal forest promotes either deciduous or coniferous silviculture even where the original stand was mixed (Lieffers and Beck 1994). Management of the land base for other values, including biodiversity, has resulted in a demand for more ecologically based management systems. Mixedwood silvicultural systems aimed at producing both coniferous and deciduous volume on the same area are being promoted as one such management system (DeLong 1991; Rowe 1992; Lieffers and Beck 1994; Bergeron and Harvey 1997).

Mixed stands of aspen (*Populus tremuloides*) and white spruce (*Picea glauca*) are common throughout the boreal forest due to natural disturbance and the regeneration dynamics of the species involved (Rowe 1972; Kabzems et al. 1986). In certain areas, however, repeated cultural disturbance related to forestry, agriculture, or range has removed the source of spruce seed, resulting in large stands of pure aspen. The cumulative effect of removal of spruce seed source and the current forest management strategy was a gradual unmixing of the mixedwood forest. Public criticism of past forest practices and better understanding of natural systems have resulted in new ideas about forest management (Maser 1988; Franklin 1989; Hansen et al. 1991). One such idea was that managed forests should be patterned after natural forests. The underlying assumption is that the forest biota is adapted to the conditions created by natural disturbances and thus should cope more easily with the ecological changes associated with timber harvest if the patterns created resemble those of natural disturbances (Hunter 1993; Swanson et al. 1993; Bunnell 1995). Underplanting aspen stands with white spruce should generate stands similar to natural mixedwood stands and a two-pass multiple cropping system would allow continuous retention of forest cover, which may help meet visual management objectives.

Planting white spruce under a trembling aspen canopy could also offer certain silvicultural advantages. Less summer frost damage is likely, due to alteration of the radiation exchange surface to the forest canopy from the ground level (Stathers 1989). Cover and vigour of fireweed (*Epilobium angustifolium*) and bluejoint (*Calamagrostis canadensis*), common competitors during white spruce establishment in clearcuts, would be reduced under an aspen canopy (Lieffers and Stadt 1994). Maintenance of a major deciduous component over successive rotations should also be an effective management for reducing tomentosus root rot infection of white spruce (R. Reich, regional pathologist, B.C. Ministry of Forests, pers. comm., 1994).

To determine the feasibility of underplanting aspen stands, well-designed research projects that monitor the survival and growth of white spruce under aspen and compare them to the current clearcut management system are required. This report summarizes the 7-year results of a trial examining white spruce survival, condition, and performance in response to aspen understorey and clearcut environments. The report proposes an alternative silvicultural system based on the findings and discusses benefits and management considerations regarding this system.

2 METHODS

2.1 Site Selection

Six study sites were established within two stand types in the boreal forest about 80 km southwest of Dawson Creek, B.C. (55°35′ N, 120°50′ W; 850–950 m elevation). All sites are in the Peace variant of the moist warm Boreal White and Black Spruce subzone (BWBSmw1), which has a mean annual precipitation of 485 mm and a mean annual temperature of 1.1°C (DeLong et al. 1990). Three of the sites were 40- to 80-year-old aspen stands and three were recently harvested clearcuts (Table 1). Sites were chosen that limited the variability in site and soil conditions but represented the desired comparison between clearcut mixedwood and unharvested mid-aged aspen stands. All sites were circummesic (submesic to subhygric) in moisture regime and had relatively uniform slope, aspect, and soil texture over a 1-ha area. All sites faced south to southwest, with aspect ranging from 176° to 225°. Soil texture ranged from sandy loam to clay loam. Other ecological characteristics of selected sites are summarized in Table 1.

2.2 Experimental Layout and Treatments

The overall design of the experiment was a mixed model, randomized block split-plot design. The two main-plot treatments (M) were clearcut and aspen overstorey. Each treatment had three sites. In each of the clearcut sites two stock types (St) were planted: 1-year-old stock grown in full sun at a research greenhouse (full sun) and 1-year-old stock grown in a commercial nursery

TABLE 1 *Summary of selected ecological characteristics for study sites*

Site	Age[a] (yr)	Basal area[a] (m^2/ha)	Density[a] (stems/ha)	Moisture regime	Dominant vegetation[b]
A1	45	32.2	2400	submesic	*Leymus innovatus, Lathyrus ochroleucus, Rosa acicularis, Aster conspicuus*
A2	42	23.8	3100	mesic - subhygric	*Epilobium angustifolium, Lathyrus ochroleucus, Salix scouleriana, Rosa acicularis*
A3	78	28.1	1400	mesic	*Aralia nudicaulis, Aster conspicuus, Calamagrostis canadensis, Spiraea betulifolia, Smilacina racemosa*
C1	NA	NA	NA	mesic - subhygric	*Populus tremuloides, Calamagrostis canadensis, Epilobium angustifolium, Rosa acicularis, Leymus innovatus*
C2	NA	NA	NA	mesic	*Epilobium angustifolium, Rubus pubescens, Calamagrostis canadensis, Rubus idaeus*
C3	NA	NA	NA	mesic	*Epilobium angustifolium, Calamagrostis canadensis, Rosa acicularis*

a Age, basal area, and density of aspen stems.

b Includes species < 10 m in height and is listed in order of dominance.

(operational). In each of the aspen overstorey sites the same two stock types plus 1-year-old stock grown under shade cloth at 66% full sun at a research greenhouse (shade acclimated) were planted. In addition, two types of planting spot preparation were applied to the shade-acclimated stock in the aspen overstorey: brushing and brushing plus screefing (Table 2). The main-plot and split-plot treatments were fixed; sites and trees were random.

TABLE 2 *Summary of treatments*

Main-plot treatments	Split-plot treatments
Clearcut	1 – 1+0 PSB research (full sunlight)
	2 – 1+0 PSB operationally grown
Aspen underplant	1 – 1+0 PSB research (full sunlight)
	2 – 1+0 PSB operationally grown
	3 – 1+0 PSB research (66% full sunlight)
	4 – 1+0 PSB research (66% full sunlight) + screefing

Plot dimensions in the aspen overstorey were 50 × 50 m and a minimum of 280 spruce seedlings were planted within the area for a stocking level of at least 1120 stems per hectare. Planting locations were selected as far from adjacent aspen stems as possible while still meeting the minimum stocking level for the plot. In the clearcut, the plot dimensions were approximately 25 × 50 m and the spruce seedlings were planted at 2.9 m spacing. This spacing represents a stocking level of about 1200 stems per hectare. For each stock type or stock type / site preparation combination, 70 trees were randomly assigned planting locations within the plots. Each seedling within a plot was assigned a letter code corresponding to site and treatment and a number from 1 to 70. The location and treatment for each seedling were mapped.

2.3 Site Preparation and Planting

Site preparation in the clearcuts was constrained by what already existed on the blocks operationally. Therefore, one block was disc-trenched, while the others were piled. In the aspen understorey, site preparation consisted of either removing shrub/herb vegetation from a 1-m-radius area surrounding each seedling location with a brush saw, or brushing plus screefing a 50 × 50 cm patch centred on the seedling location.

In addition to the treatment plots, two more plots were planted at all sites for all treatments using the same layout as described except that treatments were assigned to rows rather than randomly. These extra plots are being used for destructive sampling, demonstration, and for any additional research not included in the project. All the planting stock was thawed in storage for about 1 week. Just before planting, the seedlings were sorted to select the most uniform 1260 trees of the 1400 trees available of each stock type based on height and stem diameter. This was done to reduce some of the among-seedling variation.

Seedlings were randomly assigned to boxes identified clearly with the site and main-plot treatment to which they were planted. This process allowed for a completely random assignment to site as opposed to whole boxes in storage being moved to a site. Once packaged, seedlings were transported to the planting sites where planting spots had been pre-marked using flags of different colours.

2.4 Seedling Measurements

Seedling condition At the end of each growing season, seedling survival, damage, and chlorosis were assessed for 65 of 70 trees for each treatment per site (195 trees per treatment). Five of the 70 were randomly selected for destructive sampling. This destructive sampling was related to ecophysiology work not discussed in this paper. Damage was classified as follows: (1) undamaged; (2) damaged by grazing (e.g., nipped leaders); (3) damaged by frost; or (4) needle damage as indicated by incomplete needles or needle deformities.

Growth and yield Thirty trees per site for each treatment were randomly chosen for annual measurements. For these trees, height, stem diameter (at 1 cm), average crown diameter (average of two perpendicular measurements at base of crown), height from the ground to the base of live crown, and length of current year's laterals were recorded. All measurements were taken in the spring and fall of the first year, and in the fall of subsequent years, except for diameter, which was taken in the spring of the first year and at the end of the fifth growing season. At the end of each growing season, except the fourth and sixth, the number of buds on the current year's leader were counted and classified as whorl (clustered within about 2 cm of the terminal bud) and interwhorl (more than 2 cm below the terminal bud) according to the methods outlined in Tappeiner et al. (1987).

Foliar nutrients Spruce foliage was analyzed for nutrient concentrations in 1997. The foliage was collected between October 1 and November 30 at all sites for the 1+0 PSB (plug styroblock) full sunlight research stock only from the extra plots (see Section 2.3).

Samples of current year's foliage were collected from two laterals on the second whorl. Thirty trees were sampled from each site (three clearcut and three aspen understorey) and about 5 g per tree collected. Ten trees were randomly selected and this tree and its closest neighbours of that stock type were used to form a composite sample of about 15 g. This provided 60 samples for each of the two main treatment units, clearcut and aspen overstorey.

The samples were placed in labelled paper bags, kept cool with ice in coolers, and transported the same day to the Prince George Forest Region Lab. At the lab, the needles were separated from the twigs and frozen until drying occurred. The foliage was oven-dried in fully opened bags at 70°C until the mass remained constant (approx. 8–12 hours). After drying and before analysis, a subsample of 100 needles was taken from the composited samples and weighed to the nearest 0.1 g so that nutrient concentrations could be expressed as weight per 100 needles. The dry foliage was ground to an approximate maximum particle size of 1 mm. The ground samples were dried at 70°C for 12 hours and then stored in plastic bottles. The ground samples were analyzed for total N, P, K, S, Ca, Mg, Fe, Mn, Cu, Zn, B, and Al (Ballard and Carter 1986) by an independent lab.

3.1 Seedling Survival and Condition

Seedling survival after seven growing seasons was 94% and 88%, respectively, for white spruce seedlings planted under aspen and in clearcuts. The lowest survival was 79% for the clearcut site C2 that was disc-trenched before planting (Table 3).

Seedling damage varied significantly between aspen and clearcut treatments and between sites. Table 3 summarizes damage that affected more than 10% of the trees at any given site. Frost damage was highest for the clearcut treatment, especially at site C3 in the first two growing seasons. Hares caused considerable seedling damage at aspen site A1 and clearcut site C2. Hare damage was most severe at site A1, occurring in 3 separate years, with a high of 39% trees affected in 1999.

TABLE 3 *Summary of percentage of trees damaged and year of damage for different agents by site. Only damage affecting > 10% of trees is noted.*

Site	Survival (%)	Percentage of damaged trees (year of damage)			
		Frost	Hare	Rust	Other
A1	1994		12 (1993), 17 (1998), 39 (1999)		13 (1993)
A2	1995				
A3	1993				
C1	1988	14 (1994)			15 (1994)
C2	1979		13 (1994)		
C3	1997	26 (1993), 11 (1994)		33 (1999)	

3.2 Seedling Performance

The height growth pattern was different for spruce grown under aspen versus in the clearcut. Height growth for spruce under aspen was fairly steady over the seven growing seasons. In contrast, height growth in the clearcut started slowly but increased exponentially in the final four growing seasons (Figure 1). Clearcut-grown spruce were significantly taller after seven growing seasons than the underplanted spruce: 105.7 cm (SD = 29.7) versus 78.0 cm (SD = 18.8; $p = 0.04$). Variability in height growth was generally greater for the clearcut sites than for the aspen sites even during years when growth was similar (Tables 4 and 5). Height growth of spruce at the best aspen site A3 is similar to that for the poorest clearcut site C2 (Figure 2).

Height growth for the three aspen sites differed slightly, with site A3 > A2 > A1, but the difference was minimal for A2 and A1 (Figure 3 and Table 4). All sites increased height increment in the fifth growing season (1997) (Table 4). This height increment was maintained for sites A2 and A3 but not A1 (Table 4). There was no consistent pattern of any establishment regime (i.e., nursery and site preparation treatment) outperforming the others (Table 4).

Height growth for the three clearcut sites differed, with C1 > C3 > C2 (Figure 4). The between-site difference in height growth started in the third growing season (1995) and was maintained until the sixth growing season (1998) (Table 5). However, in the seventh growing season (1999), height increment decreased for site C1 while increasing in sites C2 and C3 (Table 5).

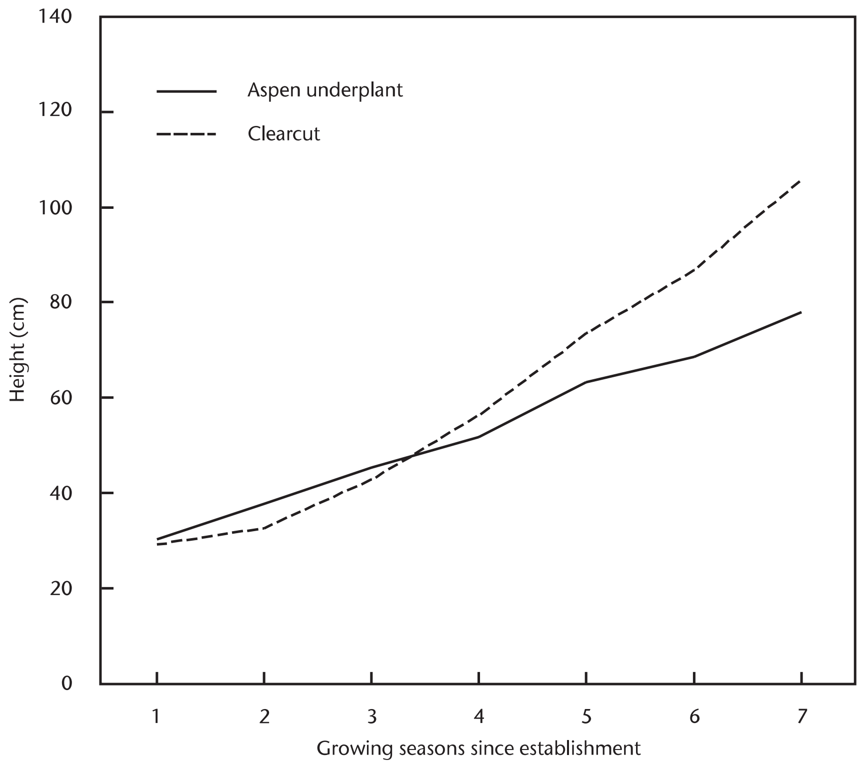

FIGURE 1 *Height growth over time of spruce planted under aspen versus in a clearcut environment.*

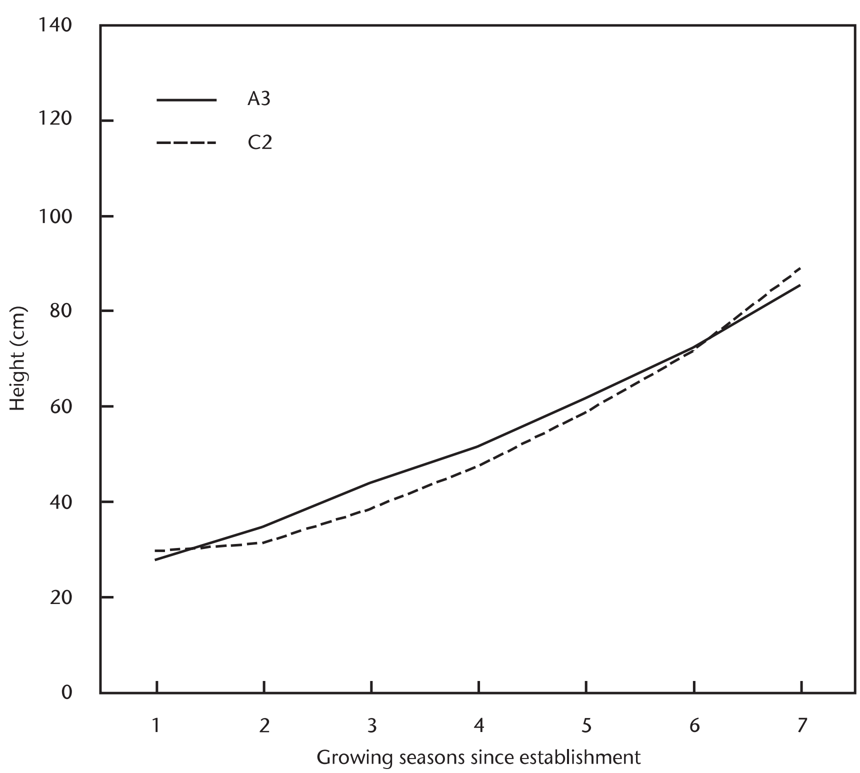

FIGURE 2 *Height growth over time for the best aspen site (A3) versus the worst clearcut site (C2).*

TABLE 4 *Mean and standard error of height and height increment for each measurement year by site, nursery treatment, and site preparation treatment for spruce planted under aspen*

Site and treatment	Height (cm)							Height increment (cm)					
	1993	1994	1995	1996	1997	1998	1999	1994	1995	1996	1997	1998	1999
A1-FN[a]	27	33	40	45	57	64	72	6	6	5	12	8	8
	0.7	1.0	1.2	1.7	2.5	3.0	3.4	0.5	0.6	0.9	0.9	1.2	0.7
A1-ON	31	37	42	47	60	65	72	6	5	4	13	5	7
	1.4	1.5	1.7	2.0	2.7	3.2	3.5	0.7	0.6	0.7	1.1	1.6	0.6
A1-SN	27	33	39	43	54	57	64	6	6	4	11	6	7
	0.8	0.8	1.1	1.2	1.4	2.8	3.1	0.5	0.5	0.6	0.8	1.6	0.6
A1-SS	29	35	41	46	58	65	72	6	6	5	12	8	7
	0.7	0.9	1.0	1.3	1.9	2.8	3.0	0.5	0.6	0.7	1.0	1.6	0.6
A2-FN	26	34	43	49	58	63	71	9	8	6	10	10	7
	1.1	1.3	1.4	1.8	2.1	2.8	3.1	0.8	0.7	0.6	0.6	1.0	0.6
A2-ON	29	37	45	50	61	63	70	8	7	6	11	10	7.4
	1.1	1.2	1.5	1.9	2.4	3.6	3.9	0.7	0.7	0.7	0.7	1.2	0.5
A2-SN	32	38	44	49	59	65	73	7	5	5	10	11	8
	0.9	1.1	1.5	1.9	2.3	3.4	3.7	0.6	0.8	0.6	0.8	1.2	0.7
A2-SS	32	38	44	48	57	62	69	7	5	5	9	10	8
	1.6	1.6	1.6	1.9	2.3	3.1	3.4	0.7	0.6	0.7	0.9	1.1	0.6
A3-FN	24	30	39	46	55	65	78	6	9	7	9	12	13
	1.1	1.4	1.6	2.0	2.4	2.7	3.2	0.7	0.7	0.7	0.6	1.0	1.0
A3-ON	31	39	49	57	68	77	91	8	10	8	11	11	14
	1.5	1.7	2	2.3	2.8	3.5	4	0.6	0.6	0.6	0.7	1.1	1.2
A3-SN	30	36	45	53	64	71	85	6	9	8	11	12	13
	1.2	1.2	1.2	1.4	1.8	3.2	3.9	0.5	0.6	0.7	0.7	1.7	1.3
A3-SS	28	34	43	50	60	68	83	6	9	8	9	11	16
	0.9	1.1	1.4	1.7	2	2.5	3.3	0.5	0.7	0.8	0.9	1.2	1.1

a Two-letter code shows nursery and site preparation treatment where the first letter indicates nursery treatment: F = 1+0 PSB research (full sunlight); O = 1+0 PSB operationally grown; S = 1+0 PSB research (66% full sunlight). The second letter indicates site preparation treatment: N = no site preparation, S = screefing with Hawke power scarifier.

TABLE 5 *Mean and standard error of height and height increment for each measurement year by site and nursery treatment for spruce planted in clearcuts*

Site and treatment	Height (cm)							Height increment (cm)					
	1993	1994	1995	1996	1997	1998	1999	1994	1995	1996	1997	1998	1999
C1-F[a]	29	31	42	58	76	94	113	3	11	15	18	22	18
	0.8	0.8	1.5	2.2	2.9	5.4	6.9	0.5	1.1	1.2	1.7	1.8	2.1
C1-O	33	36	48	61	82	102	119	4	12	13	20	21	17
	2.1	2.2	2.6	4.1	4.9	6.5	8.2	0.5	1.3	2.2	2.5	3.0	2.6
C2-F	29	30	37	46	58	67	83	2	7	9	11	16	19
	0.8	0.9	1.7	2.9	4.5	6.5	8.6	0.5	1.0	1.7	2.8	2.5	2.7
C2-O	31	33	40	49	60	76	94	2	7	9	11	16	19
	1.5	1.3	1.5	2.9	5.1	6.6	9	0.5	1.0	1.7	2.8	2.5	2.7
C3-F	27	30	41	57	75	91	111	2	12	16	17	16	20
	1.1	1.2	1.7	2.6	3.6	4.2	5.4	0.4	1.3	1.3	1.2	1.7	1.8
C3-O	26	28	38	50	66	80	102	2	9	12	16	18	21
	1.2	1.3	2.0	3.3	4.8	6.8	8.5	0.5	1.4	1.7	1.8	2.3	2.3

a One-letter code indicating nursery treatment: F = 1+0 PSB research (full sunlight); O = 1+0 PSB operationally grown.

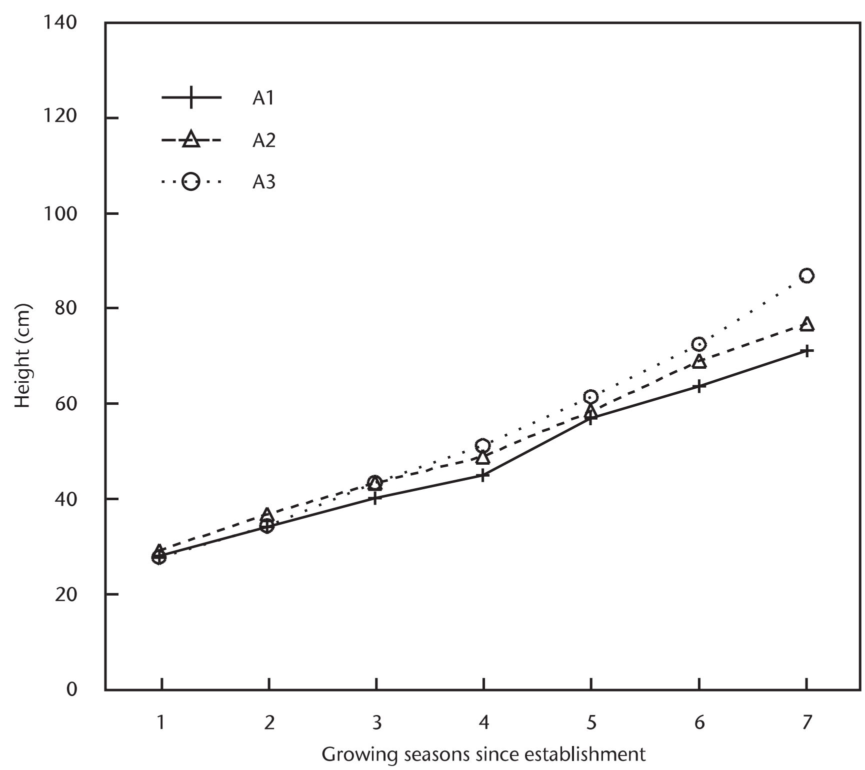

FIGURE 3 *Height growth of spruce over time planted under aspen at three sites.*

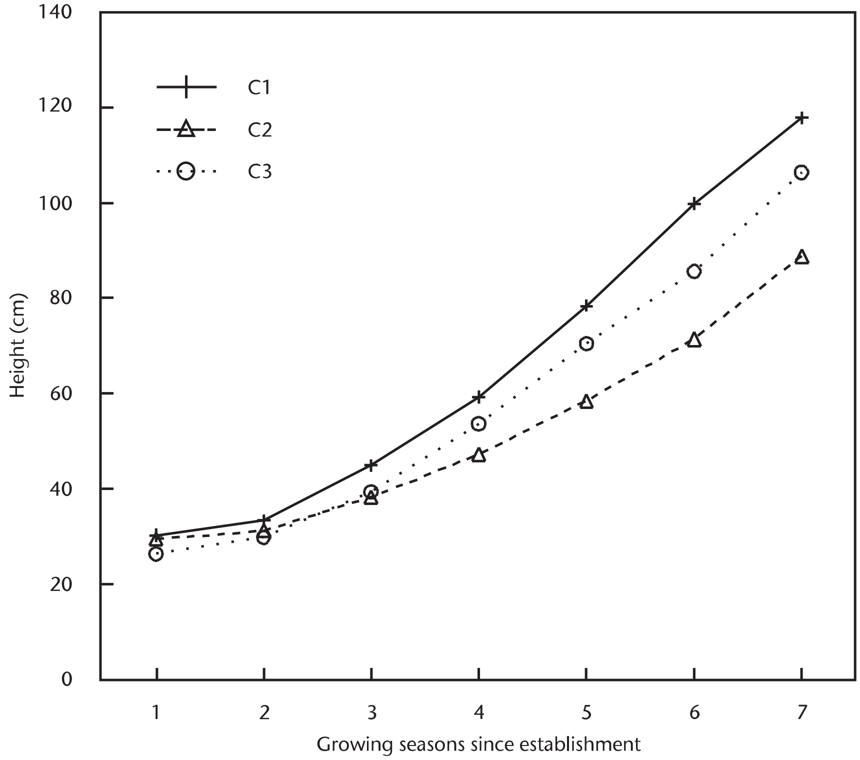

FIGURE 4 *Height growth over time for clearcut sites.*

Diameter after five growing seasons was significantly greater for the clearcut sites compared with the aspen sites ($p = 0.01$) (Figure 5). Height-to-diameter ratio (HDR) after five growing seasons was higher for the aspen sites than for two of the clearcut sites but similar to the other clearcut site C1 (Figure 6).

Number of interwhorl buds in the fifth growing season was consistently higher for trees grown in the clearcuts (Figure 7). In the seventh growing season, the number of interwhorl buds was still generally higher for clearcut sites, except for aspen site A3 and clearcut site C1, which were similar (Figure 8).

3.3 Foliar Nutrients

Foliar needle mass was generally higher for the clearcut sites than for the aspen sites, especially for clearcut site C1 (Table 6). Foliar nutrient concentrations were generally slightly higher or the same for the aspen sites compared with the clearcut sites, except for Zn and Mn, which were higher for the clearcut sites (Table 6). In general, nutrient content expressed as weight per 100 needles was higher for the clearcut sites (Table 6). This result reflected the higher mass of the needles for the clearcut sites, especially for site C1.

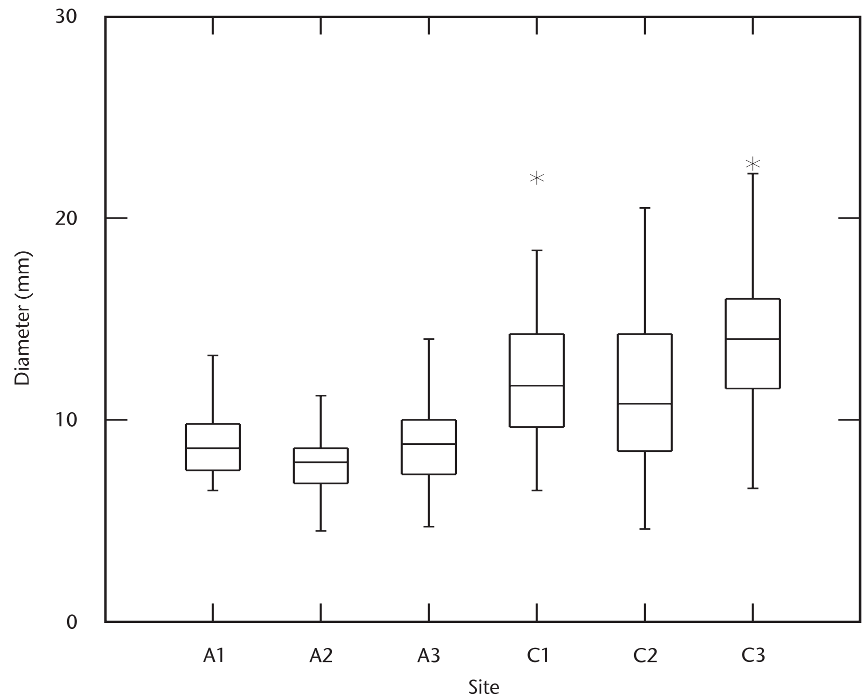

FIGURE 5 *Box plot of diameter after five growing seasons for all sites.*

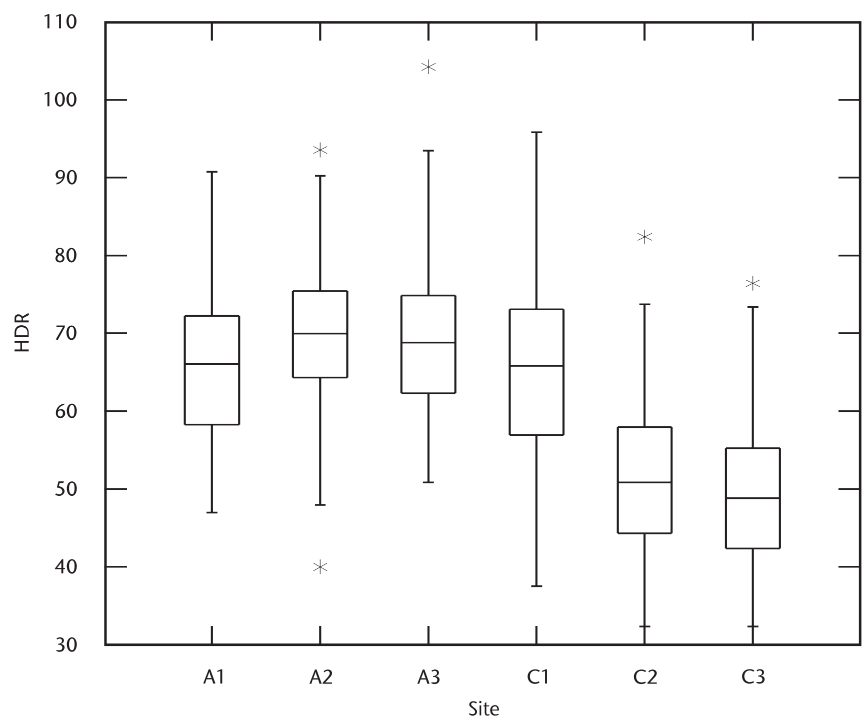

FIGURE 6 *Box plot of height-to-diameter ratio (HDR) after five growing seasons for all sites.*

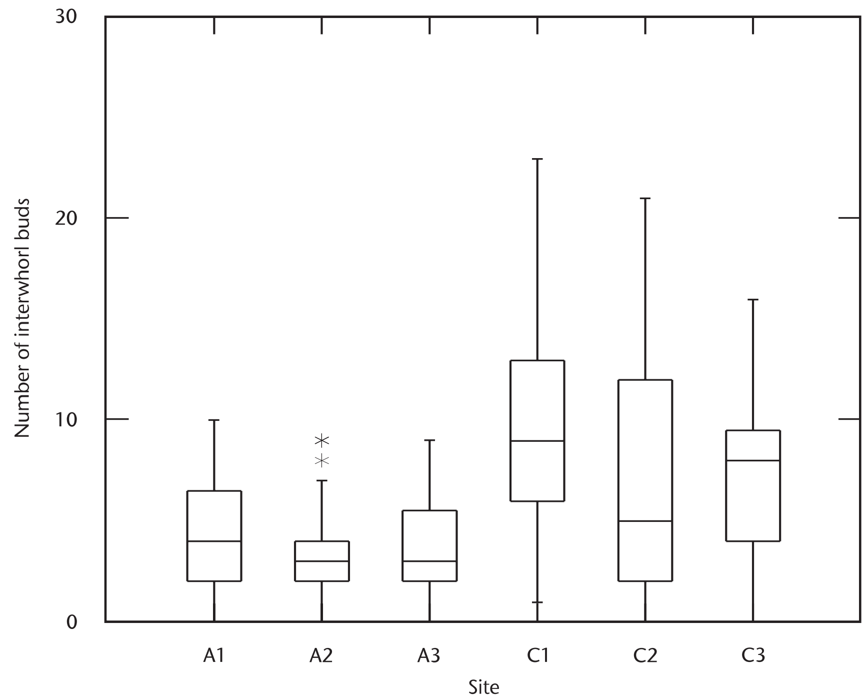

FIGURE 7 *Box plot of number of interwhorl buds for the fifth growing season by site.*

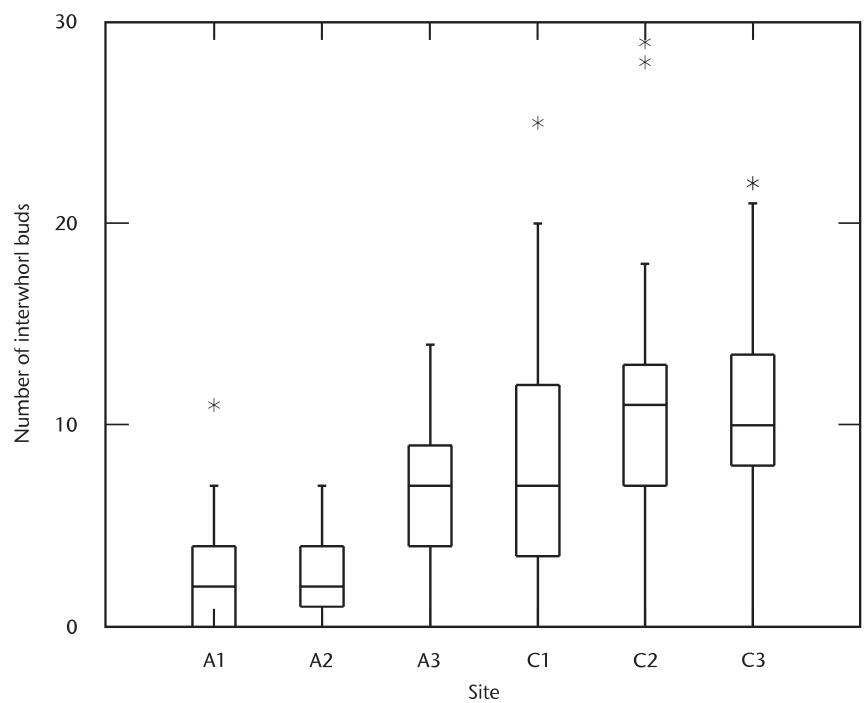

FIGURE 8 *Box plot of number of interwhorl buds for the seventh growing season by site.*

TABLE 6 *Foliar needle mass, nutrient concentration, and nutrient content by site*

Variable	Site					
	A1	A2	A3	C1	C2	C3
Needle mass (g/100 needles)	0.292	0.295	0.221	0.694	0.377	0.371
N concentration (%)	1.27	1.37	1.22	1.24	1.18	1.08
P concentration (%)	0.22	0.27	0.24	0.22	0.21	0.19
Ca concentration (%)	0.44	0.36	0.39	0.41	0.45	0.38
Mg concentration (%)	0.09	0.08	0.08	0.08	0.07	0.09
K concentration(%)	0.67	0.78	0.73	0.61	0.58	0.54
S concentration (%)	0.12	0.12	0.12	0.11	0.10	0.10
Cu concentration (ppm)	5.13	6.91	5.10	5.61	5.82	4.60
Zn concentration (ppm)	62.46	65.53	57.65	72.95	70.50	69.38
Fe concentration (ppm)	71.20	63.87	38.03	46.66	28.80	28.60
Mn concentration (ppm)	59.87	117.57	87.70	58.71	400.17	656.70
B concentration (ppm)	9.74	8.57	9.93	7.71	7.16	9.37
Al concentration (ppm)	58.90	57.64	33.59	51.11	33.78	38.89
N content (mg/100 needles)	3.72	4.05	2.70	8.58	4.44	3.99
P content (mg/100 needles)	0.66	0.79	0.54	1.54	0.78	0.71
Ca content (mg/100 needles)	1.28	1.05	0.86	2.83	1.70	1.41
Mg content (mg/100 needles)	0.25	0.23	0.19	0.54	0.26	0.32
K content (mg/100 needles)	1.97	2.30	1.61	4.22	2.18	1.99
S content (mg/100 needles)	0.35	0.36	0.25	0.77	0.40	0.36
Cu content (µg/100 needles)	1.50	2.04	1.13	3.90	2.19	1.71
Zn content (µg/100 needles)	18.27	19.33	12.74	50.63	26.58	25.74
Fe content (µg/100 needles)	20.83	18.84	8.40	32.38	10.86	10.61
Mn content (µg/100 needles)	17.5	34.69	19.38	40.74	150.87	243.63
B content (µg/100 needles)	2.85	2.53	2.19	5.35	2.70	3.48
Al content (µg/100 needles)	17.23	17.00	7.42	35.47	12.74	14.43

The high survival rate of white spruce planted under aspen is a promising indication of the feasibility of establishing spruce under aspen canopies. Data from plantations in Alberta established by P.J.B. Duffy and Z. Nemeth on similar sites indicate 20-year survival rates from 28 to 83% (unpublished data, 1983, Forestry Canada Project A.83). However, because the Alberta plantations were established in 1963, the lower survival rates may be attributed to poorer seedling quality, stock handling, and planting. Data summarized by Dyck (1994) for 21 planting trials established in the early 1960s in Manitoba indicate that 5-year survival of trees planted on scarified strips under aspen averaged 73% and was as high as 90%.

Finding lower frost damage of seedlings for the aspen overstorey treatment supports previous findings of reduced frost events beneath aspen canopies (Groot and Carlson 1996; Man and Lieffers 1997). It is also corroborated by the reduced number of frost events recorded in this trial (DeLong et al. in prep.).

Hares can cause major damage to young boreal plantations (Radvanyi 1987). The relatively low level of hare damage of seedlings at two of the aspen sites could be in part due to the age of the stands (i.e., 40–80 years). In stands of this age, available preferred browse such as willow and aspen is low, since hares cannot reach most of the more succulent buds and twigs of these species. The much higher damage recorded for the one aspen stand may relate to its slope position. Site A1 is on a relatively steep, warm aspect, which would become snow-free earlier than many other sites. At this site, early-season browse on the previous year's leader of the established spruce would be available. The average seedling heights of 60–70 cm in the years of heaviest damage indicate low or no snowpack at the time of damage. Throughout most of the winter, seedlings would have been covered by the average 1 m of settled snowpack (R. Kabzems, research silviculturist, B.C. Ministry of Forests, Fort St. John, B.C., pers. comm.). The poorer height growth performance of aspen site A1 appears to be partly related to hare damage. Often, most of the previous year's leader had been bitten off, resulting in height decreases of up to 10 cm.

The rapid initial growth but slower longer-term growth of seedlings in the aspen understorey appears to be related to micro-environmental differences between the aspen and clearcut environments. Superior establishment conditions such as reduced frost events (Groot and Carlson 1996; Man and Lieffers 1997; DeLong et al. in prep.) and reduced stress from the combination of low humidity and high temperature (Marsden et al. 1996) could explain faster initial growth for seedlings established under aspen, while the superior light regime of the clearcuts (DeLong et al. in prep.) would explain the more rapid post-establishment growth of seedlings in the clearcuts.

The average height at 5 years of 59 cm for the stock planted under aspen is superior to that of 52 cm reported in a summary of 21 planting trials established in the early 1960s in Manitoba (Dyck 1994). Average height increment of seedlings grown under the aspen should increase once they get above the shrub/herb canopy that was observed to be 80–100 cm tall. For the data summarized by Dyck (1994), average annual height increment was 7.5 cm for the first 5 years (compared with 15 cm overall after 17–23 years) and average annual height increment in the last 3 years was 31 cm. A study by Lieffers et al. (1996) of naturally established white spruce under aspen indicated substantial increases in height increment when tree height exceeded 130 cm. Even assuming the current average height increment of about 10 cm, most of the trees in our study would attain the minimum height of 100 cm by year 15 required for spruce on these sites by current establishment to free growing regulations in British Columbia (B.C. Ministry of Forests 1995).

Lack of increased performance of stock pre-conditioned for a lower light regime indicates that needle acclimation is rapid, and therefore pre-conditioning has no effect on performance. Man and Lieffers (1997) showed that white spruce physiological parameters such as light compensation and saturation point could change throughout the growing season in response to varying microclimatic conditions.

Site preparation treatments such as power screefing are intended to decrease competing vegetation and increase soil temperature by decreasing the insulating humus layer. The effect of power screefing on competing vegetation and soil temperature was not tested. However, the lack of growth difference for spruce in screefed versus non-screefed spots planted under aspen indicates that either the treatment was ineffective in altering shrub/herb vegetation competition and/or soil temperature, or these factors are not growth limiting on these sites. Lack of a requirement for site preparation to establish white spruce under aspen, apart from brushing planting trails, could offer a significant cost advantage over establishing white spruce in clearcuts—some form of mechanical site preparation and/or chemical brushing and weeding is generally required within the first 5 years in clearcuts.

The results from this study may represent a conservative estimate of the growth of white spruce under aspen. The density of the selected stands, especially A1 and A2, are at the high end of those examined by Tanner et al. (1996). This study showed a strong negative relationship between light available for photosynthesis and increasing stand density. The site that had the best height growth in the present study was the least dense of the stands. However, factors such as the high level of hare damage to trees at site A1 confound this relationship. In addition, potential increased competition from bluejoint (*Calamagrostis canadensis*) and fireweed (*Epilobium angustifolium*) under more open aspen stands, as reported by Lieffers and Stadt (1994), may offset increased growth due to less light interception by the aspen canopy.

5 MANAGEMENT IMPLICATIONS

5.1 Proposed System

The high survival rates and acceptable growth of white spruce grown under maturing aspen canopies demonstrated by this study indicate that underplanting of 40- to 60-year-old aspen stands may be an attractive, alternative mixedwood silvicultural system. The proposed alternative silvicultural system as outlined in DeLong (1991, 1997) would be to (1) harvest the aspen approximately 20 years after spruce establishment, and then (2) re-enter the stand when the spruce was about 100 years old to remove the spruce and any aspen that had regenerated since the first entry. Options after the second entry would include managing as a pure broadleaf stand, a mixedwood stand, or a pure white spruce stand. Final choice would depend on factors such as the vigour of the broadleaf component at time of harvest, proximity of adjacent mature spruce, and current demand for wood products.

5.2 Benefits

Using this alternative silvicultural system has the potential to:

- reduce overwinter injury to spruce trees by maintaining snow cover (Krasowski 1996);
- manage frost-prone sites by improving influence of the aspen canopy on nighttime minimum temperatures (Groot and Carlson 1996; Man and Lieffers 1997; DeLong et al. in prep.);
- reduce damage to young spruce trees by white pine weevil by having overhead shading (Taylor et al. 1996);
- decrease root rot infestation of spruce by having a fallow of resistant broadleaf species (R. Reich, regional pathologist, B.C. Ministry of Forests, Prince George, B.C., pers. comm.);
- reduce intense competition for resources, and reduce vegetation press by bluejoint (Lieffers and Stadt 1994);
- provide thermal cover for ungulates as the spruce become larger;
- improve visual quality by continual maintenance of tree cover;
- reduce establishment costs associated with establishing spruce in clearcuts or in even-aged mixtures with aspen;
- reintroduce spruce into areas dominated by aspen where it previously existed before cultural influence;
- help to maintain site productivity by always maintaining a mix of spruce and aspen (Bergeron and Harvey 1997);
- emulate natural disturbance patterns and processes that will help maintain biodiversity (Hunter 1993; Haila et al. 1994; Bergeron and Harvey 1997); and
- increase yield compared with single-species–management silvicultural systems (Man and Lieffers 1999).

Making the best use of this alternative silvicultural system will require some changes in policy. For instance, it would make economic sense to allow the conversion of some leading aspen mixedwood stands to a higher component of aspen by leaving the stand to regenerate naturally. Underplanting aspen stands somewhere else on the landscape could offset the loss of spruce volume. Shifting obligation to a different area of the landscape than where the timber was harvested will take some adjustments but appears to be ecologically and economically justified (Grover and Greenway 1999).

5.3 Management Considerations

To successfully implement the alternative silvicultural system outlined in this report, a few important management concerns should be considered, some of which have been previously outlined in DeLong (1997).

Suitability of the site for removal of the broadleaf overstorey while protecting the understorey will be an important consideration when choosing a site for underplanting. For example, available harvesting technology may limit the success of overstorey removal on steeper slopes. Previous studies have indicated that sites where windthrow hazard is high, such as sites with shallow or poorly drained soils, will increase damage to the understorey spruce (Brace Forest Services 1992). Consequently, these sites should receive a lower priority for underplanting. Ideally, the best aspen stands for underplanting are those with densities < 1200 stems per hectare and basal areas < 35 m^2/ha (DeLong 1997). In stands with higher density or basal area, some removal of poorer-quality suppressed aspen through falling or girdling may be beneficial.

Although maturing aspen stands are not preferred habitat for snowshoe hares, these animals cause extensive damage to underplanted spruce. Reducing damage by hares would appear to be a combination of site selection and timing of planting. It is advisable to:

- avoid underplanting stands that are close to recently disturbed areas, since they are prime hare feeding habitat,
- avoid areas such as steep south-facing slopes where snowmelt occurs early, and
- plant the year after the 10-year peak in the hare cycle to provide enough time for the new tissue of the leader to be out of reach of the hares, whose reported reach is 60 cm (Keith et al. 1984).

Other suggestions for reducing hare damage include reducing understorey vegetation, planting larger seedlings, using chemical or physical barriers, and controlling population (Radvanyi 1987).

On most sites, brushing of planting trails where shrub competition is high appears to be all that is required for spruce establishment under mid-rotation aspen. Vegetation competition from species such as bluejoint has been observed to be high on wetter than average sites (C. DeLong, pers. observation). These sites may need brushing and weeding during spruce establishment. Chemical treatment using a backpack sprayer effectively controlled understorey vegetation under broadleaf stands (P. Lepage, research silviculturist, B.C. Ministry of Forests, Prince Rupert, B.C., pers. comm.). Mechanical brushing may also be effective under a broadleaf overstorey due to the lack of resources (e.g., light) for rapid recovery of the competing species (C. DeLong, unpublished data).

Planting density should be 1400–1800 stems per hectare to ensure adequate stocking after harvesting of the broadleaf overstorey. This density should ensure a fully stocked spruce stand despite anticipated losses due to pests, environmental extremes, physical damage suffered during harvesting, and windthrow.

Seedlings should be planted as soon as possible in early spring to take advantage of early-season moisture from snowmelt and higher light levels before full leaf emergence of deciduous species. After full leaf emergence of the aspen canopy, moisture levels will drop significantly due to the relatively high moisture demand of this canopy. Thus, planting should be avoided after abnormally dry winters or during abnormally dry spring conditions to reduce the potential for drought-induced seedling losses. Planters should be instructed to avoid planting close (< 1 m) to live dominant broadleaf stems to reduce the potential damage to the established spruce during broadleaf overstorey removal. In addition, laying out all hauling and skidding roads before planting should reduce unnecessary loss of spruce stock during overstorey harvesting. Also, pre-located roads, which would remain unplanted, would be easy to relocate without the spruce stocking along them.

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