Growing trembling aspen and white spruce intimate mixtures: Early results (13–17 years) and future projections

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Abstract

Controlled mixtures of trembling aspen (*Populus tremuloides* Michx.) and white spruce (*Picea glauca* [Moench] Voss) were established in 1989 at two locations in the Boreal White and Black Spruce (BWBS) biogeoclimatic zone in northeastern British Columbia. The initial study design of three aspen treatment densities of 0, 5000, and 10 000 stems per hectare was expanded by reducing existing densities of aspen on a subset of plots to 1000 and 2000 stems per hectare. A random-coefficients regression model was used to analyze height and diameter growth trends for aspen and spruce 13–17 years after establishment. White spruce grown without aspen had significantly greater rates of height and diameter growth. There were no significant differences in spruce growth between the 5000 and 10 000 aspen stems per hectare treatments. Differences in spruce height and diameter growth did not consistently display a pattern of declining growth as aspen density increased from 1000 to 10 000 stems per hectare. Aspen responded to aspen density reduction by increased diameter growth of the remaining stems.

The Mixedwood Growth Model was used to predict future growth of the experimental stands. Yield projections indicated that a total productivity gain of 21% may be achieved for mixtures compared to a pure spruce scenario. Over the range of conditions studied, spruce comprised approximately 40% of the total volume in mixed stands. These initial results will improve the assessments of the relative contributions that pure- and mixed-species management regimes may offer to achieving forest-level objectives.

KEYWORDS: *aspen, boreal mixedwoods,* Picea glauca*,* Populus tremuloides*, stand development, white spruce, yield projections.*

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Introduction

Significant portions of the boreal forests of northeastern British Columbia are mixed stands of conifer and broadleaf species, usually trembling aspen and white spruce, commonly known as "mixedwoods." When both spatial and temporal scales are considered, mixedwoods can occur in an almost infinite variety of combinations. In western Canada, both species are used commercially, but with highly disparate markets and values. These factors complicate decisions regarding their simultaneous management.

Aspen–white spruce mixtures have been observed and hypothesized to produce greater wood volumes than single-species stands (Man and Lieffers 1999). Temporal separation of the two species has been the most common approach to capturing the expected productivity gains, using tactics such as retaining white spruce advance regeneration (Brace and Bella 1988), or underplanting of aspen stands with white spruce (DeLong 2000). Rapid early growth rates of aspen compared to slower initial white spruce growth make it difficult to balance growing space requirements when both species are regenerated at the same time. In response to this challenge, operational personnel have often suggested decomposing the original mixed forest into spatially separate monocultures (e.g., Fort St. John Pilot Project Participants 2003). Regenerating "intimate" mixtures of trembling aspen and white spruce by design remains one of the most difficult challenges in boreal silviculture. The term "intimate mixture" is here defined as a mixture where the spatial separation of the species is on the scale of a few metres or less.

Quantitative comparisons of mixed- and pure-species stands under similar conditions are limited (Man and Lieffers 1999). Effective and cost-efficient mixedwood management practices require accurate simulations of forest dynamics at the stand level. Knowledge of the early successional dynamics of mixed-species stands is a particularly weak link in building prediction tools.

This study investigates the feasibility of growing trembling aspen and white spruce as an intimate mixture (Coopersmith and Hall 1999) where both species are established shortly after disturbance.

This paper addresses three questions:

1. Does the growth of white spruce vary with aspen density, and if so, are similar trends observed in different locations?

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2. Does the growth of aspen vary with aspen density, and if so, are similar trends observed at different locations?
3. What are the potential yield implications for development of pure and mixed stands?

Study Areas

Site Description

The study was conducted at Siphon Creek (120°19'W, 56°27'N) and Bear Mountain (120°20'W, 55°39'N) in northeastern British Columbia, 45 km northeast and 72 km southeast of Fort St. John, respectively. Both sites are within the Peace variant of the Boreal White and Black Spruce biogeoclimatic zone (BWBSmw1; DeLong *et al.* 1990). Elevations are 760 m for Siphon Creek and 880 m for Bear Mountain. The climate is generally continental with long, cold winters and short, warm summers that are accompanied by average precipitation of 250–350 mm during the growing season (Lord and Green 1986).

Soils on both sites were developed on loamy to clayey morainal material. They are classified as Luvisols, characterized by a loamy textured A horizon over a clay-enriched B horizon (Lord and Green 1986). Ecologically, the sites were very similar, comprising a fine mosaic of the "Aspen – Creamy peavine" (01) and the "Aspen – Oak fern" (05) site series. Their soil moisture regimes were mesic to subhygric, with medium to rich nutrient regimes (DeLong 2002).

Pre-Treatment History

The Siphon Creek site originally supported a mixed conifer–aspen stand that had a history of selective conifer logging in 1968 (Table 1). As part of a conifer reforestation program in the Fort St. John Forest District, the residual stand (mostly aspen) was brushbladed and windrowed in the early winter of 1984/85. The site was planted (before study establishment) with 3-year-old bareroot white spruce seedlings (PBR 2+1) at 1480 stems per hectare in May 1985. The Bear Mountain site was logged for aspen in the winter of 1987/88 and received no

TABLE 1. Pre-treatment and treatment history of the Siphon Creek and Bear Mountain sites

	Siphon Creek	Bear Mountain
Pre-treatment		
Conifer harvest (selective)	1968	(none)
Stand-initiating event	Brushblade and windrow Winter 1984/85	Aspen harvest Winter 1987/88
Aspen regeneration	1985	1988
Treatment		
Conifer planting date and stock type	May 1985 PBR 2+1 Summer 1989 1+0 PSB 313 (operational nursery)	Summer 1989-1991 1+0 PSB 313 (research nursery)
First aspen density treatment	1990	1990
Second aspen density treatment	2000	2000
Regeneration measurements	1993, 1996, 1998, 2002	1993, 1997, 1999, 2002

further treatment before study establishment. Installation of the research trial treatments began in 1989 at both locations (Table 1).

Study Design and Experimental Treatments

The experiment was initially laid out in 1989 as a (randomized block) factorial design with three aspen densities crossed with seven spruce planting densities. Because the spruce planting densities established for the research trial could not be maintained due to hare damage and mortality in the early years of the study (Table 2), spruce density was ignored in subsequent analyses.

In 1990, the plots on both sites were thinned to aspen densities of 0, 5000, and 10 000 stems per hectare. To expand the range of aspen densities found within the experimental treatments, two additional aspen treatments (1000 and 2000 stems per hectare) were created in the summer of 2000 by reducing existing densities in a randomly selected subset of plots initially designated as 5000 or 10 000 aspen stems per hectare. At both locations, aspen was manually thinned to the target densities. In addition, all balsam poplar (*Populus balsamifera* L.), willow (*Salix* spp.), green alder (*Alnus crispa* [Ait] Pursh), and paper birch (*Betula papyrifera* Marsh.) were removed then and during subsequent thinnings to maintain treatment densities.

TABLE 2. Numbers of plots in each aspen density treatment and survival of aspen and white spruce over the measurement period (1993–2002)

1990 aspen treatment (stems per hectare)	2002 aspen treatment (stems per hectare)	No. plots	Aspen survival (%)		Container spruce survival (%)		PBR spruce stock survival (%)
			Bear Mtn	Siphon Ck	Bear Mtn	Siphon Ck	Siphon Ck
0	0	6	—	—	78–100	80–100	96–99
5 000	1 000	1	96	100	85	Not planted	98
5 000	2 000	2	100	100	84–95	40	98–99
5 000	5 000	4	99–100	95–100	49–93	70–95	98–100
10 000	1 000	2	100	98–100	55	85	100
10 000	2 000	1	99	91	75	75	98
10 000	10 000	4	99–100	96–100	61-84	75–95	95–98

Within each treatment plot (0.3 ha), four subplots of 0.04 ha were established. At Bear Mountain, only one subplot in each plot was planted with 1-year-old containerized (CT) PSB 313 white spruce seedlings in 1989. During the summers of 1990 and 1991, all remaining subplots were planted with the same CT spruce stock type. A record of the planting year for individual white spruce was not available for the Bear Mountain site. All Bear Mountain CT spruce were planted using planting shovels into microsites that had been screefed using a Hawke power scarifier.

Since the Siphon Creek site had been operationally planted in 1985 with bareroot (PBR) stock, both the existing PBR stock type and the CT stock type planted as part of the research trial were tagged and measured during plot establishment. At Siphon Creek, the CT spruce were located in a single subplot, and planted using dibbles in the summer of 1989 (Table 1). The PBR spruce planted in 1985 were located in all four subplots. In 1993, two plots that had been designated as "0" stems per hectare of CT spruce were abandoned because of incomplete aspen regeneration. Two additional plots containing vigorous aspen were then added to the trial to retain the original number of plots in the study design.

Aspen and Spruce Height and Diameter Measurements

At the establishment of the experiment, 20 spruce trees and 20 aspen trees within each subplot were tagged and then used for repeated measurements. The sample trees were spatially distributed over the 0.04-ha subplot. The initial tree selection protocol was not documented; however, sampled aspen trees had a range in heights and diameters in 2002. Aspen and spruce height and diameter were measured in 1993, 1997, 1999, and 2002 at Bear Mountain, and in 1993, 1996, 1998, and 2002 at Siphon Creek (Table 1). Diameter at breast height (1.3 m), ground-level diameter (for spruce only), and tree height were measured. Type and cause of damage were assessed for each tree at the time of measurement.

Statistical Methods

To account for gaps in the data (Table 1), a random-coefficients (quadratic) regression model (see below) was used to analyze growth trends for selected subsets of the data. The effects of spruce density (both sites) and planting year (at the Bear Mountain site) were ignored. To facilitate interpretation of the results, only spruce trees that were alive and healthy at the last (2002) assessment were included in the analysis; damage and mortality among the spruce trees were assumed to have occurred independently of treatment (Table 2).

Trends in height and diameter were compared among sites (stock types) and treatments by fitting the following random-coefficients quadratic regression model:[1]

$$y_{ijklt} = (\alpha_{ij} + A_k + a_l) + (\beta_{ij} + B_k + b_l)t + (\gamma_{ij} + C_k + c_l)t^2 + \varepsilon_{ijklt}$$

where: i is either site (Siphon Creek or Bear Mountain) or spruce stock type (Plug Bareroot, PBR, or container, CT); j is the aspen thinning treatment;[2] k is the plot number; l is the subplot number; t is the number of years after the 1989 planting (i.e., calendar year – 1990); y_{ijklt} is the average (height, diameter, etc.) growth response for Subplot l (Site i, Treatment j, Plot k, Year t); $\alpha_{ij}, \beta_{ij}, \gamma_{ij}$ are coefficients that describe the (fixed) expected growth response for Site (Stock type) i and Treatment j; A_k, B_k, C_k and a_l, b_l, c_l are, respectively, independent (normally distributed with constant variances), random plot, and subplot effects; and ε_{ijklt} is the residual (unexplained) error, which is assumed to be independent and identically (normally) distributed for all subplots and years.

Before fitting the model, individual tree measurements were averaged by subplot and year (measurements were not averaged by plot because only one of four subplots was measured in 1993). To avoid bias in the estimated growth curves, only those trees that were measured in the same years were included in a subplot average (although measurement years for different

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1   This model assumes that the growth trends for individual subplots can be approximated by a quadratic function with a shape that is determined by the fixed effects of site (stock type) and treatment ($\alpha_{ij}, \beta_{ij}, \gamma_{ij}$), and random plot and subplot effects (A_k, B_k, C_k; a_l, b_l, c_l), with ε_{ijklt} representing all other sources of random variation.

2   There are a total of seven aspen thinning treatments: 0 (0/0), 5000/1000, 5000/2000, 5000/5000, 10 000/1000, 10 000/2000, and 10 000/10 000 where the first number is the aspen density (stems per hectare) after the first thinning and the second number is the density after the second thinning. For instance, 5000/1000 and 5000/2000 are considered different treatments, even though in both cases the initial density was 5000 stems per hectare; likewise, 5000/1000 and 10 000/1000, which resulted in the same final density (1000 stems per hectare), are considered different treatments. The number of aspen thinning treatments is respectively 7, 4, and 4 for Subsets 1–3.

subplots are not necessarily the same). Missing data (due to mortality, damage, etc.) were assumed to occur at random in all subplots. All models were fitted (using PROC MIXED in SAS statistical software; SAS 1996) by residual (restricted) maximum likelihood (REML) estimation with subplots weighted by the number of (live, healthy) trees. To answer the first two questions posed in the Introduction, separate models were fitted to three subsets of the data:

- **Subset 1** – PBR spruce from Siphon Creek, in plots with aspen densities 0, 5000/1000, 5000/2000, 5000/5000, 10 000/1000, 10 000/2000, and 10 000/10 000 stems per hectare (Question 1)
- **Subset 2** – CT spruce from both sites, in plots with aspen densities 0, 5000/2000, 5000/5000, and 10 000/10 000 stems per hectare (Question 1)
- **Subset 3** – Aspen from both sites, in plots with aspen densities 5000/2000, 5000/5000, 10 000/1000, and 10 000/10 000 stems per hectare (Question 2).

All response variables (spruce height, spruce diameter, aspen height, and aspen diameter) were analyzed separately.

Site and aspen-density effects were assessed by testing whether the applicable groups or pairs of growth curves had:

1. equal β_{ij} and γ_{ij} coefficients (i.e., equal growth rates or parallel trends),
2. equal α_{ij} coefficients (i.e., equal intercepts).

In the case of parallel trends, equal intercepts imply that the growth curves are identical for the observation period. All tests were based on *F*-ratios with denominator degrees of freedom calculated by Satterthwaite's method (Satterthwaite 1941).

Methods for Predictions of Future Yield

Predictions of future growth were obtained by simulating standardized plots using the Mixedwood Growth Model (version MGM 2002a; Titus 2003). The MGM is an individual tree, distance-independent model developed at the University of Alberta for mixed-species stands. The model is driven largely by site vector, a derivative of site index that reflects observed rather than potential height growth to account for the effects of overtopping competition. Stands were simulated starting at age 15, with current compositions consisting of 10 000 stems per hectare aspen, 1200 stems per hectare spruce, and 1200 stems per hectare spruce in combination with each of 1000, 2000, 5000, and 10 000 aspen. Stands were simulated to age 80, beyond which age-related mortality

functions for aspen led to predicted successional patterns that deviated noticeably from regional observations for similar sites.

For each stand composition to be simulated, standardized tree lists were derived from Siphon Creek plots with similar characteristics, using a combination of plot sample trees (for diameters, heights, and site indices) and plot stem maps (for diameter distributions and stand basal areas). In all cases, the number of trees being simulated deviated from individual plot observations, and uniform adjustments were made to all diameters in a tree list to maintain stand-level basal areas of similar magnitude to those observed in the plots. Larger adjustments were required on the higher density plots, with only minor or no adjustments required at lower densities.

The results of these scenarios should be cautiously interpreted, given that the high site index of these stands is beyond the range of the calibration data for this model.

Actual site vectors used in the simulations were derived from Siphon Creek plot data, using height/age relationships provided by Huang (1997). A site vector of 25.6 m (breast height age 50) was used for aspen, while the spruce site vector varied with aspen density. At 10 000 stems per hectare of aspen, the spruce site vector was 24.0 m, at 5000 aspen it was 25.5 m, at 2000 aspen it was 26.4 m, at 1000 aspen it was 27.0 m, and with no aspen it was 27.4 m.

Results

Spruce Growth as Affected by Aspen Density

Significant differences in height growth trends were observed for PBR white spruce over the range of aspen densities at the Siphon Creek site (Figure 1; unpublished data available on request). Seventeen years after planting, PBR white spruce within the 0 aspen treatment had a predicted average height of 5.4 m (Figure 1; unpublished data available on request), which was 23–61% greater than any of the treatments that retained aspen (Figure 1; unpublished data available on request). The differences in spruce height did not display a clear pattern of declining height with increasing aspen density. Estimated average spruce heights of 3.7 m for the 5000/2000 treatment and 3.4 m for the 5000/1000 treatment were the lowest at year 17 (Figure 1). The remaining aspen density treatments contained spruce of intermediate height (Figure 1).

Ground-level diameter of the PBR white spruce had a growth pattern that was similar to the height growth responses at Siphon Creek (Figure 2; unpublished data
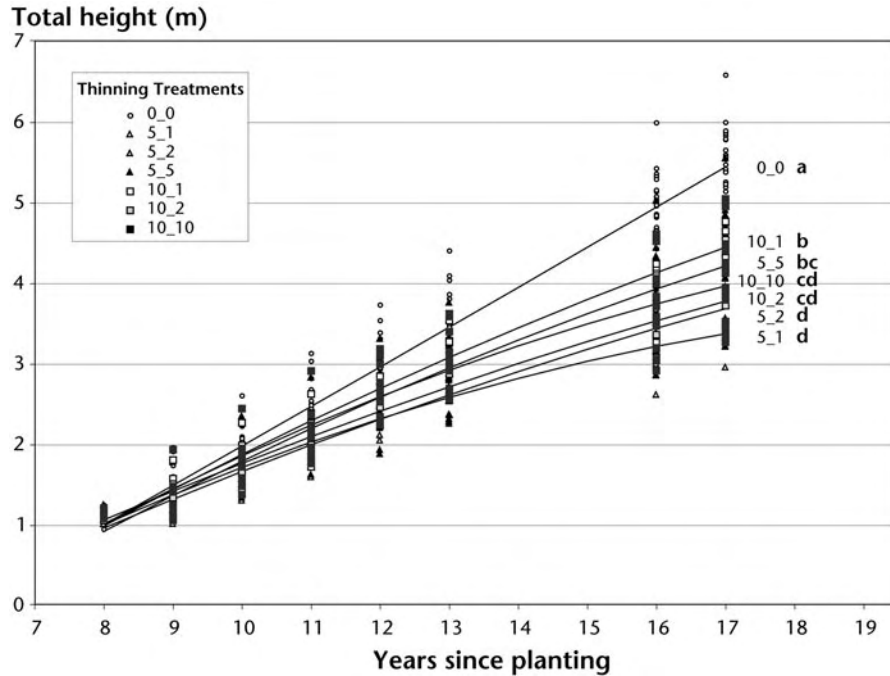
FIGURE 1. Height growth trends for PBR white spruce at Siphon Creek with the 0 (0_0), 5000 thinned to 1000 (5_1), 5000 thinned to 2000 (5_2), 5000 (5_5), 10 000 thinned to 1000 (10_1), 10 000 thinned to 2000 (10_2), and 10 000 (10_10) aspen stems per hectare treatments. (Coefficients of the fitted polynomial growth curve are not significantly different for treatments followed by the same letter.)
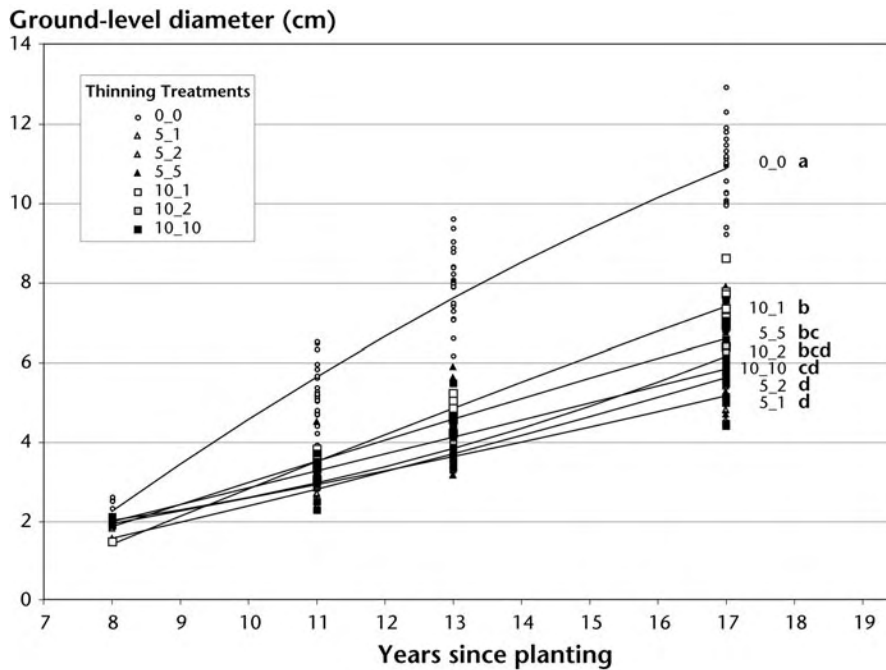

FIGURE 2. Diameter growth trends for PBR white spruce at Siphon Creek with the 0 (0_0), 5000 thinned to 1000 (5_1), 5000 thinned to 2000 (5_2), 5000 (5_5), 10 000 thinned to 1000 (10_1), 10 000 thinned to 2000 (10_2), and 10 000 (10_10) aspen stems per hectare treatments. (Coefficients of the fitted polynomial growth curve are not significantly different for treatments followed by the same letter.)

available on request), with significant divergence of several aspen density treatments occurring during the first 17 years after planting. The average ground-level diameter of 10.8 cm for PBR white spruce within the 0 aspen treatment was 47–112% greater than that of any of the treatments with aspen (Figure 2; unpublished data available on request). The 10 000/1000 treatment had the next largest diameter at 7.3 cm (Figure 2; unpublished data available on request). Diameter growth of conifers is more highly correlated with measures of competition than is height growth (MacDonald *et al.* 1990; Wagner and Radosevich 1991).

At both sites, height growth of CT white spruce was greatest in plots that were free of aspen (Figure 3; unpublished data available on request). Bear Mountain had a clear pattern of declining white spruce height growth with increasing aspen density. Eleven years after planting, predicted spruce heights were 2.6 m (0 aspen), 1.8 m (5000/2000 aspen), 1.2 m (5000/5000 aspen), and 1.2 m (10 000/10 000 aspen). Siphon Creek had a similar pattern of response except for the 5000/2000 aspen treatment. Heights of CT white spruce at Siphon Creek in the 5000/2000 aspen treatment were below all other treatments, well before differences between the other three treatments were expressed (Figure 3).

Height growth rates for CT white spruce height differed significantly between the two sites (unpublished data available on request). Eight years post-planting, heights of open-grown CT spruce averaged 1.5 m at Bear Mountain and only 0.9 m at Siphon Creek.

Aspen Growth as Affected by Aspen Density

Aspen diameters displayed a general trend of decreasing average diameter with increasing aspen density (Tables 3 and 4; unpublished data available on request) on both sites, although at Siphon Creek, the differences between treatments were not significant. Aspen stands younger than 30 years have often responded to density reduction by increased diameter growth of the remaining stems, but little change in height growth pattern (Perala 1991; Weingartner 1991). Within both sites there were no significant differences in aspen height growth trends over time for the aspen density treatments (unpublished data available on request). Disturbances that reduced aspen height growth, such as aspen leaf and twig blight (*Venturia macularis* [Fr.] E. Muller & Arx) outbreaks, have occurred several times at each of the study sites (Coopersmith and Hall 1999; Coopersmith *et al.* 2000). *Venturia* outbreaks in young aspen stands are most severe during wet growing seasons with high humidity (Allen *et al.* 1996).
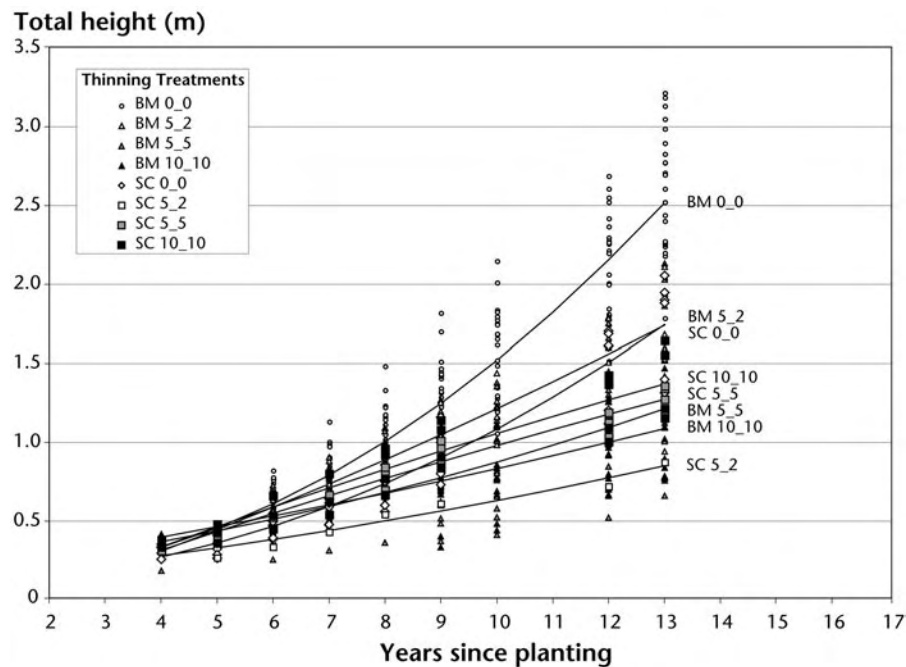

FIGURE 3. Predicted height of PSB container spruce stock at Siphon Creek (SC) and Bear Mountain (BM) with the 0 (0_0), 5000 thinned to 2000 (5_2), 5000 (5_5), and 10 000 (10_10) aspen stems per hectare treatments.

TABLE 3. Predicted diameter (cm) of aspen at Siphon Creek

Aspen (stems per hectare)		Years since site preparation disturbance					
First thinning	Second thinning	11	12	13	16	17	
5 000	2 000	6.23	6.98	7.63	9.07	9.38	a[a]
5 000	5 000	5.59	6.37	7.05	8.44	8.69	a
10 000	1 000	5.45	6.16	6.80	8.35	8.74	a
10 000	10 000	5.19	5.83	6.38	7.58	7.82	a

[a] Coefficients of the fitted polynomial growth curve are not significantly different for treatments followed by the same letter.

TABLE 4. Predicted diameter (cm) of aspen at Bear Mountain

Aspen (stems per hectare)		Years since site preparation disturbance					
First thinning	Second thinning	10	11	12	14	15	
5 000	2 000	4.94	5.78	6.56	7.92	8.51	b[a]
5 000	5 000	5.46	6.52	7.38	8.46	8.68	a
10 000	1 000	4.90	5.55	6.13	7.11	7.50	b
10 000	10 000	5.38	5.85	6.28	7.02	7.33	c

[a] Coefficients of the fitted polynomial growth curve are not significantly different for treatments followed by the same letter.

Future Potential Yields for Aspen and White Spruce Mixtures Using MGM Predictions

Simulated growth rates by scenario are listed in Table 5 and illustrated in Figures 4 and 5. Merchantable volume production (10 cm top, 30 cm stump, and 12.5 cm minimum DBH, for both species) is excellent in all cases, as would be expected given the relatively high site indices measured for the trial. Volume growth rates are lowest for pure aspen stands (at least for the establishment densities tested), highest for mixed stands, with pure spruce stands in the middle (Table 5).

TABLE 5. Rates of volume production for six MGM simulated stand management scenarios, with mean annual increment (MAI) (m³/ha per year) values reported at age 50

Scenario	MAI spruce	MAI aspen
Spruce 1200	7.6	—
Aspen 10 000	—	5.4
Aspen 10 000, spruce 1200	2.7	3.8
Aspen 5000, spruce 1200	3.0	4.9
Aspen 2000, spruce 1200	3.9	5.2
Aspen 1000, spruce 1200	4.7	4.5

In general, the modelled rate of volume production at culmination appears higher in the mixed stands compared with pure stands of either species. While mixed stands with the highest densities of aspen produce slightly less combined volume than does the pure spruce stand, admixtures with moderate densities are predicted to produce considerably more combined volume (up to 21% more for the stand with 1000 stems per hectare of aspen).

For mixed stands, the simulated percentage of volume by species at age 50 varies little over the range of conditions tested, with the spruce volume consistently comprising approximately 40% of the total (Figure 4). Simulations suggest that spruce volume production increases with decreasing aspen stocking as expected, but at a slow rate. Spruce production appears relatively insensitive to a wide range of aspen densities greater than 1000 stems per hectare. This is unlikely to be an artefact of the model as the height growth trajectory of the overtopped spruce within these mixed stands was determined using the observed growth rates to date in the experiment. The large difference in mean annual increment (MAI) between spruce in the mixed stands and in the pure stands (2.7–4.7 m³/ha per year vs. 7.6 m³/ha per year), however, suggests that the presence of relatively small amounts of aspen (below the range of densities tested) has a large effect on spruce production.
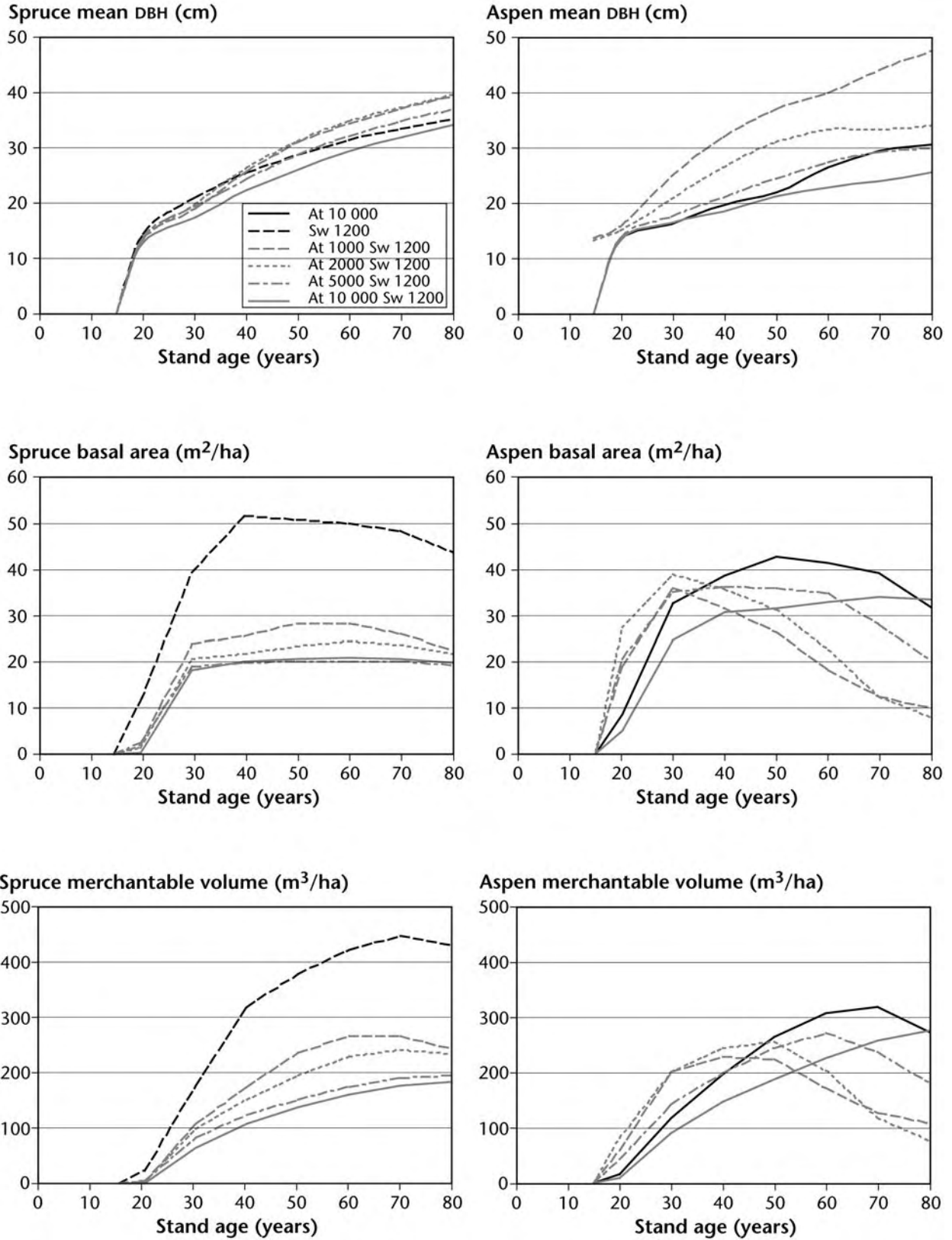
FIGURE 4. Simulated mean diameter, basal area, and merchantable volume by species (At = aspen; Sw = white spruce).

Aspen 2000, White spruce 1200

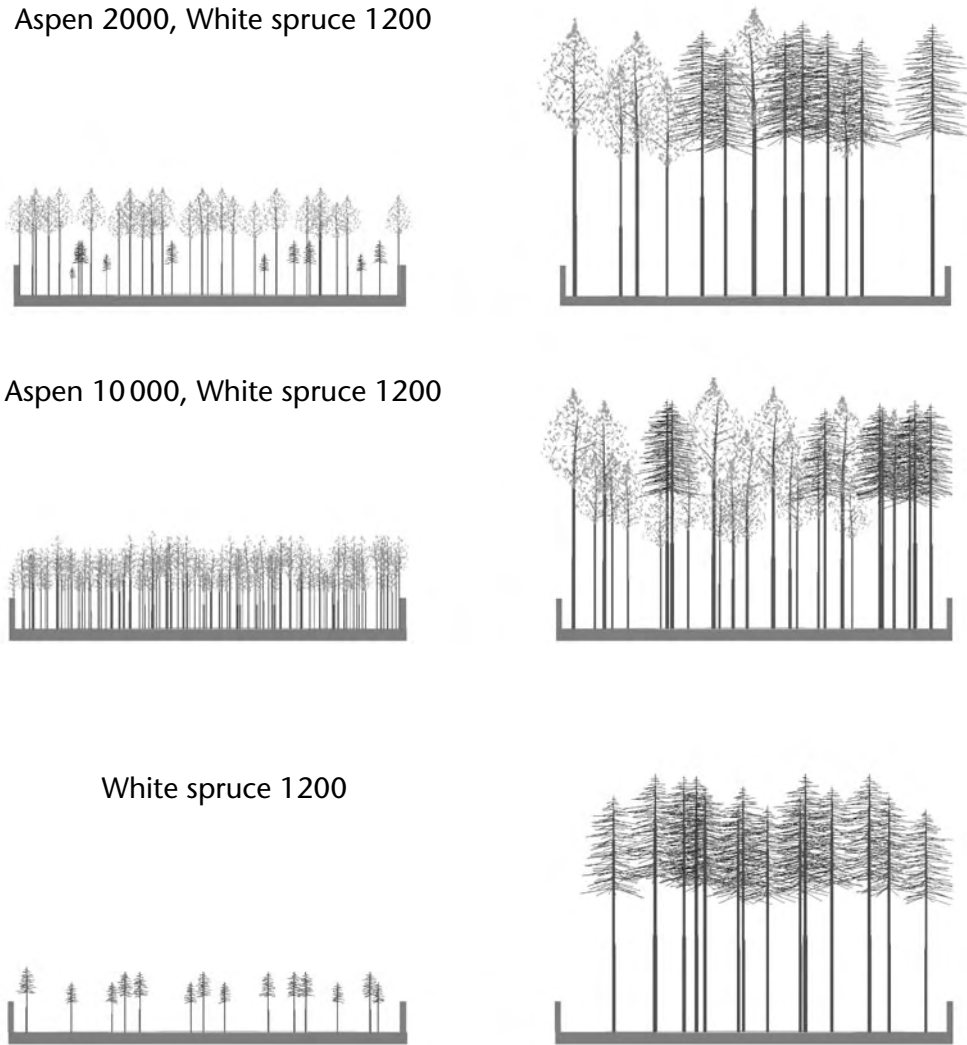Aspen 10 000, White spruce 1200

White spruce 1200

FIGURE 5. Stand profiles created from MGM model output using the Stand Visualization System (SVS). Images on the left represent current stand conditions (age 15); images on the right represent the same stands projected to age 60. Note that corner posts are 3 m tall.

In mixed stands, simulated diameter, basal area, and volume growth for the spruce component appear to vary less than for the aspen component, although spruce growth for all three attributes increases with decreasing aspen densities. Aspen mean diameter in particular appears to be dramatically affected by varying stocking levels (Figure 4), a relationship that is also reflected in the merchantable volume (higher aspen densities result in lower rates of merchantable volume increment early in the rotation). The considerable delay in simulated merchantable volume accumulation at high establishment densities has resulted in the low MAI values listed for stands established with 10 000 stems per hectare aspen.

The MGM simulations predict a definite pattern of convergence in mixedwood stand conditions as development progresses. Self-thinning in the aspen component leads to a lessening degree of plot-to-plot diversity towards age 80 (Figure 5), although stands starting with more aspen will continue to carry more aspen and less spruce. Such trends will have important implications in silvicultural strategies where the spruce component is carried through to a longer rotation than the aspen. Early spruce mortality was greater in the simulations under more dense aspen canopies, resulting in lower spruce stocking levels to be carried through following aspen removal or death.

Aspen volumes in these simulations tend to decline beyond 50–60 years, with large decreases by age 80 (Figure 4); however, such predicted declines are not consistent with observations in northeastern British Columbia. Vigorous aspen stands not undergoing patterns of break-up are common in this region beyond stand ages of 100 years or more. The MGM model uses a height threshold to initiate stand break-up, and the thresholds used are not likely realistic for stands such as these with very high site indices.

Discussion

At the end of the observation period (up to 17 years after planting), open-grown white spruce had significantly greater height and basal diameter growth than treatments that retained aspen. This difference was present on both sites, and with both immediate and delayed planting of white spruce. Future yields of white spruce were predicted to be greatest for the open-grown spruce regime. Where conifer timber production is the primary management objective, brushing to control broadleaf competition has been an effective tool to maximize conifer growth (Harper *et al*. 1997; Biring *et al*. 1999; Comeau *et al*. 1999; Boateng *et al*. 2000; Cole *et al*. 2003; Pitt *et al*. 2004).

Where 5000 or 10 000 aspen stems per hectare were retained, there were no statistically significant differences in spruce height and diameter 13–17 years after establishment. The effects of the second aspen density manipulation did not display a clear trend of declining spruce growth with increasing aspen density. Even before the second aspen treatment was carried out, PBR spruce in the 10 000/1000 treatment had better height and diameter growth than spruce in the 5000/1000 and 5000/2000 aspen stems per hectare treatments. The 2 years between the second aspen manipulation and measurement may not have been sufficient to allow spruce growth patterns to change. Differences in PBR spruce height by aspen density treatment at Siphon Creek did not begin to appear until 5 years after the initial aspen density manipulations, which were 10 years after planting.

The white spruce basal diameter results from Siphon Creek suggest that the 0 aspen treatment has the least amount of competition, while differences between other treatments are less apparent. Possible explanations for the lack of separation between treatments include:

1. the short time (2 years) between the second aspen density reduction and assessment;

2. the aspen stem counts may not accurately describe the level of competition (i.e., basal area of aspen

may better predict light availability under the aspen canopy; see Comeau 2001); or

3. the type of stem selection used to establish the 1990 aspen density treatments (systematic pattern with lower priority given to size of aspen stem compared to location) may have accentuated the variability in aspen diameters existing at the 2002 assessment.

Mixedwood Growth Model projections suggested that the range of aspen densities found in this experiment might not result in substantial differences in the merchantable volume of the spruce component at the end of the rotation. The threshold for aspen density to have an effect on white spruce growth may be below 1000 stems per hectare. Model projections indicated that retaining 1000–10 000 stems per hectare of aspen could increase total production, but spruce merchantable volume in these mixedwood regimes would be about half the production from pure spruce regimes. Results from this study, which used merchantable volumes, would initially appear to contrast with those of Pitt *et al*. (2004), where MGM projections of gross total volumes were compared for various mixedwood management scenarios. In that study, Pitt *et al*. (2004) stated that while proportions of aspen and white spruce varied with management actions, total volume production was relatively fixed.

One of the commonly described benefits of growing white spruce in mixed-species stands is a reduced incidence of growing season frost damage (Groot and Carlson 1996; Cole *et al*. 2003; Pritchard and Comeau 2004). The aspen canopy manipulations in this experiment occurred in the fifth growing season, and the aspen may have provided frost protection before creation of the open-grown conditions. There may also be differences in the regional climate of northeastern British Columbia compared to the Alberta site described by Man and Lieffers (1997), where white spruce planted in open conditions showed reduced growth and needle discolouration, in contrast to spruce grown under a shelterwood. Reductions in white spruce height growth, which could be attributed to growing season frost damage, were not observed in this study.

Reduction of white pine weevil (*Pissodes strobi*) attack has also been cited as a benefit for white spruce growing under broadleaf canopies (Taylor *et al*. 1996). To date, there has been no evidence of white pine weevil attack at the Siphon Creek or Bear Mountain sites.

Shading by a broadleaf canopy can reduce cover of understorey plants. In boreal ecosystems, bluejoint (*Calamagrostis canadensis* [Michx] Beauv.) and fireweed (*Epilobium angustifolium* L.) can be important

competitors with spruce (Lieffers and Stadt 1994). On productive boreal mixedwood sites such as these, which have little or no moisture deficit (Coopersmith *et al.* 2000), light is the resource most limiting to growth and survival of juvenile spruce (e.g., Lieffers *et al.* 2002; Comeau *et al.* 2005). Manual brushings were carried out several times to reduce tree and shrub cover in this experiment. Competition for light from grasses and herbaceous plants would have occurred until the spruce began overtopping this layer of vegetation. Some of the between- and within-site variation in spruce growth may have been due to this type of competition, which was not quantitatively assessed.

Careful site assessments and knowledge are required to determine the potential extent and severity of factors such as growing season frosts, pest incidence, and vegetation competition. Where these factors occur rarely, or have been mitigated by silvicultural practices, inter- and intra-species competition become the dominant factor in mixed-species early stand dynamics. Other authors (see Pitt *et al.* 2004) have modelled a wider variety of potential scenarios for boreal mixed stands, including harvesting aspen in the first stage of a two-pass harvest. We chose to limit our modelling and discussion to the management of an intimate mixture with a single harvest entry. This is the dominant current practice in British Columbia's boreal forests and follows a common natural disturbance pattern.

Conclusions

This study directly compares early growth rates for controlled-density plantations of mixed and pure boreal forest species on productive sites. The 13- to 17-year results of this research trial demonstrate a clear separation of spruce growth patterns between pure spruce and mixed aspen–spruce management regimes. Yield projections indicate that a total productivity gain of about 21% may be achievable for aspen–white spruce mixtures compared to a pure spruce scenario. Spruce merchantable volume in these mixedwood regimes was predicted to be approximately half the production from pure spruce regimes. These initial results improve the assessments for the contributions of pure- and mixed-species management regimes to forest-level objectives. The implications for wood quality, timber volume production, and sustainability of various boreal forest values from manipulations of mixed-species stands will become more obvious with continued monitoring of stands established under controlled conditions and improvement in modelling tools.

The results of this research trial demonstrate a clear separation of spruce growth patterns between pure spruce and mixed aspen–spruce management regimes. A total productivity gain of about 21% may be achievable for aspen–white spruce mixtures compared to a pure spruce scenario.

References

Allen, E.A., D.J. Morrison, and G.W. Wallis. 1996. Common tree diseases of British Columbia. Natural Resources Canada, Canadian Forest Service, Victoria, B.C.

Biring, B.S., W.J. Hays-Byl, and S.E. Hoyles. 1999. Twelve-year conifer and vegetation responses to discing and glyphosate treatments on a BWBSmw backlog site. B.C. Ministry of Forests, Research Branch, Victoria, B.C. Working Paper No. 43.

Boateng, J.O., S. Haeussler, and L. Bedford. 2000. Boreal plant community diversity 10 years after glyphosate treatment. Western Journal of Applied Forestry 15(1):15–26.

Brace, L.G. and I.E. Bella. 1988. Understanding the understory: Dilemma and opportunity. *In* Management and utilization of northern mixedwoods. Proceedings symposium, April 11–14, 1988, Edmonton, Alta. J.K. Samoil (editor). Canadian Forest Service, Northern Forestry Centre, Edmonton, Alta. Information Report NOR-X-296. pp. 69–86.

Cole, E., A. Youngblood, and M. Newton. 2003. Effects of competing vegetation on juvenile white spruce (*Picea*

glauca [Moench] Voss) growth in Alaska. Annals of Forest Science 60:573–583.

Coopersmith, D. and E. Hall. 1999. Experimental project 1077, The Siphon Creek mixedwood trial: The use of a simple height-to-diameter ratio to predict the growth success of planted white spruce seedlings beneath aspen canopies. B.C. Ministry of Forests, Prince George, B.C. Prince George Forest Region Forest Research Note No. PG-17.

Coopersmith, D., B. Sagar, and D. Thompson. 2000. Ten-year results of the Bear Mountain Mixedwood Trial (EP 1077): The effect of overtopping aspen canopies on white spruce seedling growth and seedling microclimate. B.C. Ministry of Forests, Prince George, B.C. Prince George Forest Region Forest Research Note No. PG-23.

Comeau, P.G. 2001. Relationships between stand parameters and understorey light in boreal aspen stands. BC Journal of Ecosystems and Management 1(2):103–110.

Comeau, P.G., B.S. Biring, and G.J. Harper. 1999. Conifer response to brushing treatments, a summary of B.C. data. B.C. Ministry of Forests, Victoria, B.C. Extension Note No. 41.

Comeau, P.G., R. Kabzems, J. McClarnon, and J.L. Heineman. 2005. Implications of selected approaches for regenerating and managing western boreal mixedwoods. Forestry Chronicle 81:559–574.

DeLong, C. 2000. Planting white spruce under trembling aspen: 7-year results of seedling condition and performance. B.C. Ministry of Forests, Victoria, B.C. Working Paper No. 54. URL: *http://www.for.gov.bc.ca/hfd/pubs/ Docs/Wp/Wp54.htm*

_____. 2002. Draft field guide insert for site identification of seral *Populus* units of the northeast portion of the Prince George Forest Region. B.C. Ministry of Forests, Victoria, B.C.

DeLong, C., A. MacKinnon, and L. Jang. 1990. A field guide for identification and interpretation of ecosystems of the northeast portion of the Prince George Forest Region. B.C. Ministry of Forests, Victoria, B.C. Land Management Handbook No. 22.

Fort St. John Pilot Project Participants. 2003. Sustainable Forest Management Plan. Canadian Forest Products, Ltd., Fort St. John, B.C. URL: *http://www.fsjpilotproject. com/sfmp.html*

Groot, A. and D.W. Carlson. 1996. Influence of shelter on night temperatures, frost damage and bud break of white spruce seedlings. Canadian Journal of Forest Research 26:1531–1538.

Harper, G.J., L.J. Herring, and W.J. Hays-Byl. 1997. Conifer and vegetation response in the BWBSmw 12 years after mechanical and herbicide site preparation. B.C. Ministry of Forests, Victoria, B.C. Working Paper No. 29.

Huang, S. 1997. Subregion-based compatible height and site index models for young and mature stands in Alberta: Revisions and summaries (Part II). Forest management. Alberta Environmental Protection, Land and Forest Service, Edmonton, Alta. Research Note No. 10.

Lieffers, V.J. and K.J. Stadt. 1994. Growth of understory *Picea glauca*, *Calamagrostis canadensis*, and *Epilobium angustifolium* in relation to overstory light transmission. Canadian Journal of Forest Research 24:1193–1198.

Lieffers, V.J., B.D. Pinno, and K.J. Stadt. 2002. Light dynamics and free-to-grow standards in aspen-dominated mixedwood forests. Forestry Chronicle 78:137–145.

Lord, T.M. and A.J. Green. 1986. Soils of the Fort St. John–Dawson Creek area, British Columbia. B.C. Soil Survey, Research Branch, Agriculture Canada, Vancouver, B.C. Report No. 42.

MacDonald, B., D.M. Morris, and P.L. Marshall. 1990. Assessing components of competition indices for young boreal plantations. Canadian Journal of Forest Research 20:1060–1068.

Man, R. and V.J. Lieffers. 1997. Seasonal photosynthetic responses to light and temperature in white spruce (*Picea glauca*) seedlings planted under an aspen (*Populus tremuloides*) canopy and in the open. Tree Physiology 15:437–444.

_____. 1999. Are mixtures of aspen and white spruce more productive than single species stands? Forestry Chronicle 75:505–513.

Perala, D.A. 1991. Déjà vu: "Does it pay to thin young aspen?" *In* Space to grow: Spacing and thinning in northern Ontario. Proceedings of a symposium sponsored by Forestry Canada, Ontario Region, and Ontario Ministry of Natural Resources. June 18–20, 1990, Sault Ste. Marie, Ont. V.F. Haavisto, C.R. Smith, and C. Mason (editors). Forestry Canada, Ontario Region, and Ontario Ministry of Natural Resources, Joint Report No. 15. pp. 139–144.

Pitt, D.G., M. Mihajlovich, and L.M. Proudfoot. 2004. Juvenile stand responses and potential outcomes of conifer release efforts on Alberta's spruce-aspen mixedwood sites. Forestry Chronicle 80:583–597.

Pritchard, J.M. and P.G. Comeau. 2004. Effects of opening size and stand characteristics on light transmittance

and temperature under young trembling aspen stands. Forest Ecology and Management 200:119–128.

SAS Institute, Inc. 1996. SAS/STAT software: Changes and enhancements through release 6.11. Cary, N.C.

Satterthwaite, F.F. 1941. Synthesis of variance. Psychometrika 6:309–316.

Taylor, S.P., R.I. Alfaro, C. DeLong, and L. Rankin. 1996. The effects of overstory shading on white pine weevil damage to white spruce and its effect on spruce growth rates. Canadian Journal of Forest Research 26:306–312.

Titus, S.J. 2003. Mixedwood Growth Model (MGM). University of Alberta, Edmonton, Alta. URL: *http://www. rr2.ualberta.ca/Research/MGM/mgm.htm*

Wagner, R.G. and S.R. Radosevich. 1991. Neighbourhood predictors of interspecific competition in young Douglas-fir plantations. Canadian Journal of Forest Research 21:821–828.

Weingartner, D.H. 1991. Spacing and thinning in aspen and mixedwood: Some thoughts, theories and observations? *In* Space to grow: Spacing and thinning in northern Ontario. Proceedings of a symposium sponsored by Forestry Canada, Ontario Region, and Ontario Ministry of Natural Resources. June 18–20, 1990, Sault Ste. Marie, Ont. V.F. Haavisto, C.R. Smith, and C. Mason (editors). Forestry Canada, Ontario Region, and Ontario Ministry of Natural Resources, Joint Report No. 15. pp. 145–149.

Test Your Knowledge . . .

Growing trembling aspen and white spruce intimate mixtures: Early results (13–17 years) and future projections

How well can you recall some of the main messages in the preceding Research Report?
Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. Compared to a pure spruce scenario, what was the greatest projected productivity gain
    for the spruce aspen mixtures?
    A) 12%
    B) 21%
    C) 40%

2. Which spruce growth variable had the greatest percentage difference between open grown spruce
    and spruce which were growing under aspen?
    A) ground-level diameter
    B) breast height diameter
    C) total height

3. Which agent was observed to result in reduced aspen height growth on these sites?
    A) frost damage
    B) ice storms
    C) tent caterpillar
    D) leaf and twig blight