

Will Minor Spruce Components of Boreal Broadleaf Stands Replace Themselves after Clearcut Harvesting?

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Ministry of Forests and Range
Forest Science Program

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Richard Kabzems and Craig DeLong



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ABSTRACT

We examined natural regeneration of white spruce (*Picea glauca*) in 13 broad-leaf stands in two areas of northeastern British Columbia, 14–25 years after harvest. Spruce natural regeneration was present in 11 of the 13 stands. Fort Nelson stands had more uniform spruce distribution and higher stocking than Dawson Creek stands. Regression analyses indicated that mineral soil seedbeds and seed source location relative to the harvested stand were able to predict Dawson Creek spruce regeneration, with a large component of unexplained variation. Distribution of spruce regeneration was more variable in harvest-origin stands than spruce found in mature aspen-dominated stands of wildfire origin. Model simulations indicated that rotation lengths of at least 80–100 years would be required for post-harvest spruce natural regeneration to contribute 10–20% of stand merchantable volume at the next rotation.

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1 INTRODUCTION

The boreal forests of northeastern British Columbia feature mixed stands of broadleaf and conifer species, usually trembling aspen (*Populus tremuloides* Michx.), balsam poplar (*Populus balsamifera* L.), and white spruce (*Picea glauca* [Moench] Voss) on upland mesic sites. Lodgepole pine (*Pinus contorta* Dougl. ex Loud.), black spruce (*Picea mariana* [Mill.] BSP), and paper birch (*Betula papyrifera* Marsh.) are usually minor components. The potential number of combinations of these species in terms of proportion, and spatial and temporal configuration, is very large, reflecting the original stand composition, disturbance history, time since disturbance, and influence of adjacent stands. Where a particular industry could use only one type of tree species, regulatory agencies often restricted harvesting to a portion of the mixedwood spectrum to optimize utilization of all species (e.g., an industrial user would harvest only those areas that were 80% or more broadleaf merchantable volume). The underlying assumption used in higher-level planning was that any “minor” species within these stands would naturally regenerate. Also, over large landscapes and longer time periods, stands with similar composition would exist at the next harvest rotation (B.C. Ministry of Forests 2002). Cumming et al. (2009) documented the prevalence of minor amounts of white spruce dominants within “pure” boreal broadleaf stands while noting that the origins and ecological importance of these spruce dominants are poorly understood.

In general, *Populus* species increase after wildfire or clearcutting (Strong 2004; Chen et al. 2009), rapidly dominating a given site through vegetative reproduction. Mechanical site preparation and planting of conifers do not hinder this development (Redburn and Strong 2008). In contrast, natural regeneration of white spruce in the boreal forest requires a favourable combination of seed source, seedbed, and appropriate microclimate (Coates et al. 1994). The strength of the white spruce seed source varies both spatially, according to its abundance and distribution on the landscape, and temporally, with large variation in seed production between years (Greene et al. 1999; Peters et al. 2005). The initial regeneration of white spruce generally occurs within 3 years of disturbance (Peters et al. 2005), until the available seedbed is occupied by other plants or covered with broadleaf litter. Post-wildfire mineral-soil seedbeds can vary from 5% within 50 m of the unburned edge to 35% within the interior of a large fire (Greene et al. 2005). After harvesting, exposed mineral soil may range up to 5% of the harvested area (LePage et al. 2000; Wurtz and Zasada 2001); disturbed forest floor, or well-decomposed wood, can provide other potential seedbeds (Greenway et al. 2002) for the regeneration of white spruce. Larger (3.6 m²) and more severely disturbed mineral soil seedbeds may remain receptive for up to 5 years (Lees 1963). With a particular combination of factors, white spruce natural regeneration may provide a minor white spruce component (Martin-DeMoor et al. 2010) over a range of mixedwood stand types (Solarik et al. 2010) after forest harvesting. A later recruitment of white spruce may occur at least 30 years after disturbance (Kabzems and Garcia 2004; Peters et al. 2005), reflecting development of seedbeds from decomposition of coarse woody debris (Lieffers et al. 1996; Simard et al. 1998) and increased light availability under the maturing aspen canopy (Lieffers et al. 2002).

Boreal mixedwood management objectives for species composition, stand structure, and timber production might be achieved more effectively by applying a range of silvicultural prescriptions. To implement such a mixedwood strategy, it is essential to predict how management activities affect the amount, type, and spatial distribution of stands across the landscape. In this study we examine one component of such a mixedwood strategy, specifically the natural regeneration of white spruce within stands managed for broadleaf, predominantly aspen, production.

This technical report addresses the following questions:

1. What is the occurrence and distribution of white spruce natural regeneration in broadleaf-dominated stands that are being managed for broadleaf production in northern British Columbia?
2. How does this distribution compare with the distribution of a minor white spruce component in wildfire-origin broadleaf-dominated stands?
3. Can a combination of inventory and site information provide reliable prediction of white spruce natural regeneration?
4. Will the post-harvest broadleaf-dominated stands develop into stands similar to those that occurred previously on site?

2 METHODS

We used the B.C. Ministry of Forests Results Based Code Silviculture and Land Status Tracking System (RESULTS) to identify populations of regenerated, managed aspen stands at least 14 years old in the boreal forests of northeastern British Columbia (Figure 1). All of the candidate aspen stands in the Dawson Creek area had met their legal reforestation obligation. In the Fort Nelson area, the reforestation obligations had not been completed but the candidate stands were expected to have had sufficient regeneration to have met the reforestation obligation, based on RESULTS and available survey information. We used the B.C. Ministry of Forests and Range Seed Planning and Registry System (SPARS) to identify white spruce mast years (widespread and synchronous seed production) based on seed collection years near Dawson Creek and Fort Nelson similar to those used by Peters et al. (2005).

Before fieldwork, white spruce seed sources were examined using inventory cover maps and air photos. For each harvested stand the percentage of shared perimeter with an inventory polygon containing white spruce was calculated. Field sampling used GPS and prism sweeps to determine location, basal area, and areal extent of white spruce seed sources near the harvested aspen stands (Greene et al. 1999; Albani et al. 2005).

From the potential area of 412 ha of managed aspen in the Fort Nelson area, we sampled approximately 182 ha within five stands. In the Dawson Creek area, the population of managed aspen was stratified into two groups based on the amount of white spruce in forest inventory map polygons adjacent to the managed stand boundary. The percentage of aspen post-harvest stand perimeter shared with map polygons with > 30% white spruce composition, or ≤ 30 but $\geq 10\%$ white spruce composition, was calculated using ArcGIS software (www.esri.com).

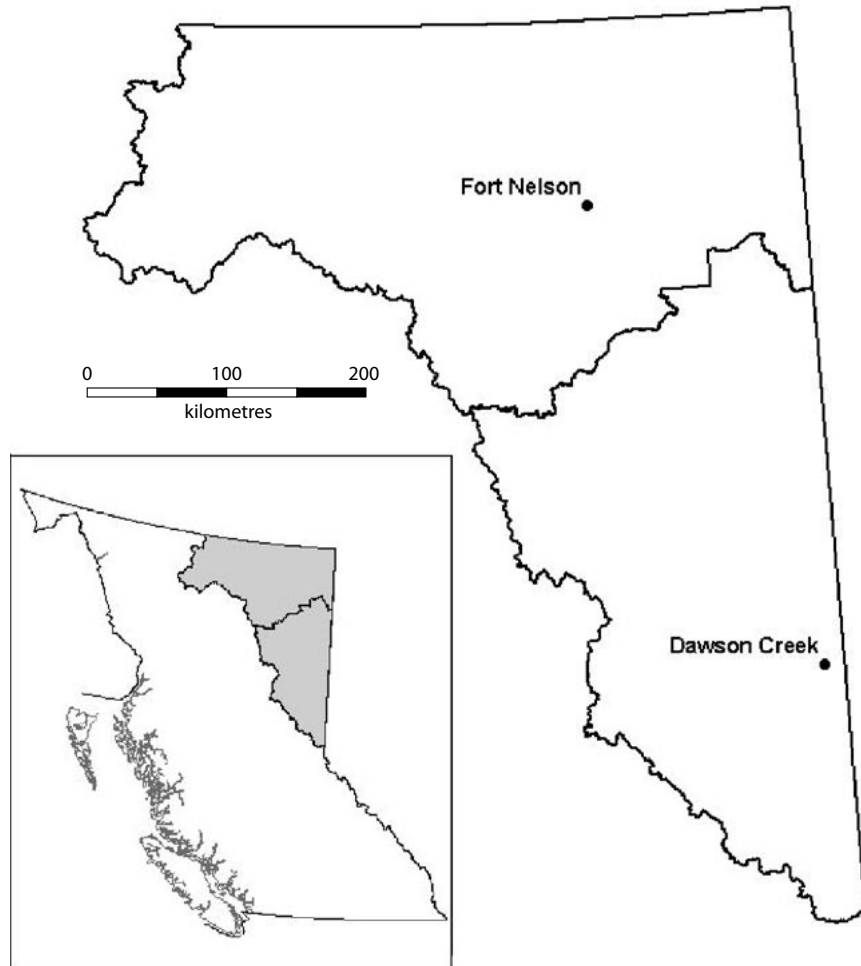


FIGURE 1 *Locations of the Dawson Creek and Fort Nelson study areas.*

For managed aspen polygons that had less than 15% shared boundary with inventory polygons containing $\geq 10\%$ white spruce (weak seed source), 214 ha (within four stands) out of 310 ha were sampled. Where white spruce was at least 10% composition of adjacent forest inventory polygons on more than 15% of the boundary of the managed aspen polygon (strong seed source), we sampled 204 ha (within four stands) from a potential population of 333 ha. None of the sample stands shared perimeter with both $< 30\%$ and $> 30\%$ spruce categories of map polygons.

Sampling intensity averaged one 50-m² circular plot per 10 ha of harvested area for aspen. Sample plot locations within a harvested area were randomly located using Hawth's Tools utility in ArcGIS (www.esri.com). To reduce errors due to mistyping or edge effects, sample plots were established at least 20 m from the mapped polygon boundary. Within each plot we recorded spe-

cies, stem diameter at 1.3 m, height, and height to live crown for each tree above 1.3 m in height. For trees less than 1.3 m in height, we recorded species and total height. White spruce natural regeneration was assessed at an average intensity of one 50-m² circular plot for every 5 ha. If there were one or more spruce seedlings within a 50-m² plot, the plot was considered to be stocked. To determine if white spruce had regenerated on exposed mineral soil post-harvest, the combination of very shallow (< 2 cm depth) forest floor and evidence of microtopography created by machine disturbance was used to assign the plot to a category of post-harvest mineral soil exposure—“Present” or “Absent.”

Sample discs were taken to determine breast height age and total age for each tree species. Sample discs for total age determination were cut at ground level and at 1.3 m for breast height age. Discs were sanded in the laboratory and growth rings counted along two radii using WINDENDRO™ (Regent Instruments Inc.).

We compared white spruce distribution in mature aspen stands of wildfire origin to that of harvested stands by analyzing inventory maps to locate mature aspen stands (> 100 years) with “minor” spruce components within 5 km of the harvested stands described above. Three of these mature stands, which were considered comparable to the pre-harvest conditions of the managed aspen stands, were selected for field sampling. Sample plot locations within the inventory polygon were randomly located using the Hawth's Tools utility in ArcGIS (www.esri.com). A nested plot design was used to sample different sizes of white spruce. All white spruce were counted within the 50-m² circular plot, and a 1000-m² (17.84-m radius) plot was used to assess for white spruce greater than 1.3 m in height.

Future growth predictions were obtained by using plot data as inputs for the Mixedwood Growth Model (version MGM2009b) (Bokalo et al. 2009). MGM is an individual-tree, distance-independent model developed at the University of Alberta for mixed-species stands. To run the model, tree lists for plots within sample stands were used. Aspen site index for each plot was determined from results of destructive sampling and by using height/age relationships provided by Nigh et al. (2002). Aspen site index ranged from 16 to 22 m (breast height age 50). White spruce site index ranged from 14 to 18 m (breast height age 50) based on sample tree data, and ecological classification estimates (B.C. Ministry of Forests and Range 2008). Stands were simulated to age 130 years.

To project stand level yields, MGM runs were done for each plot within a stand, and the average of all the plot simulations was used to provide a stand-level value. Merchantable volume (10 cm diameter top, and 30 cm stump height for both species, minimum diameter at breast height [dbh] 12.5 cm for aspen and 17.5 cm for white spruce), canopy gaps (20%), and breakage and decay factors (20%) were based on assumptions used in a recent Timber Supply Analysis for the Dawson Creek area (B.C. Ministry of Forests 2002).

2.1 Data Analysis Within-cutblock distribution patterns for white spruce natural regeneration were assessed using the Morisita Index of dispersion. The Morisita Index (MI) provides an assessment of the mean degree of spatial dispersion (Morisita 1962; Hurlbert 1990):

$$MI = n \times \frac{\sum d^2 - \sum d}{(\sum d)^2 - \sum d}$$

where n is the number of plots, d is the number of trees in a plot, and the summations are across all plots in the stand or cutblock. An MI value of 1 indicates a random pattern; > 1 indicates clumping; and < 1 , a regular dispersion. A highly regular pattern with no more than one tree per plot has an MI near zero, while the most clumped pattern, where all trees are in a single plot, has an $MI = n$ (Feng et al. 2006).

Prediction of white spruce natural regeneration was modelled statistically by general linear models (GLMs), and logistic regression models as appropriate using SYSTAT 10 (SPSS Inc. 2000). The parameters used in regression analysis were distance from spruce seed source (m), direction to spruce seed source (degrees), and presence or absence of post-harvest mineral soil exposure. Where appropriate, data were transformed to improve assumptions of normality and equality of variances.

3 RESULTS

3.1 Composition of Pre- and Post-harvest Broadleaf-dominated Stands

The pre-harvest species compositions for each of the broadleaf-dominated stands are summarized in Table 1. All 13 sample stands were classified as broadleaf dominant with greater than 80% of the stand being aspen and balsam poplar. The post-harvest stand composition was dominated by broadleaf regeneration (Table 1). The Dawson Creek (DC) stands were logged between June 1988 and December 1990, except for 30 ha of DCS 3 logged in 1982. Logging of Fort Nelson (FN) stands occurred between February 1990 and December 1991. White spruce mast years were 1990 in Fort Nelson and 1982, 1983, and 1993 in Dawson Creek (B.C. Ministry of Forests and Range, SPARS). All of the Dawson Creek stands, and four of the five Fort Nelson stands, had a summer logging history. Only FN 2 was logged during the 1990 Fort Nelson mast period. Only FN 1 was entirely logged during winter conditions (December 1990 to March 1991).

White spruce natural regeneration was found in 11 of the 13 post-harvest sampled stands (Table 2). Mean value for the Morisita Index for the distribution of spruce regeneration for Fort Nelson was 2.1 compared to 4.3 for the Dawson Creek stands that had a “strong” white spruce seed source (i.e., DCS stands). The mean spruce density, and percentage of spruce stocked plots tended to be greater for Fort Nelson than Dawson Creek stands (Table 2).

The mean distance between spruce seed sources and sample plots was 252.5 m for Dawson Creek strong seed source stands (range 1–856 m) and 133.8 m for Fort Nelson samples (range 13–579 m). For Dawson Creek weak seed source stands (DCW), the distance between spruce seed sources and sample plots ranged up to 1900 m (DCW 4). The DCW stands were not used in the regression analyses described below.

TABLE 1 Pre- and post-harvest species composition for sampled aspen stands

Sample opening ^a	Area sampled (ha)	Pre-harvest information source	Pre-harvest species ^b composition (%)	Post-harvest species composition basal area (%)	Post-harvest species composition stem count (%)
FN 1	90	Timber cruise	At > 80 Ac < 20	At 93 Ep 5 Ac 2	At 88 Ep 7 Ac 3 Sw 2
FN 2	61	Not on file	At > 80	At 72 Ac 27 Ep 1	At 71 Ac 25 Ep 3 Sw 1
FN 3	15	Timber cruise	At & Ac > 80 Sw < 20	At 94 Ep 6	At 77 Sw 13 Ep 10
FN 4	36	Timber cruise	At > 80 Sw < 20	At 90 Ep 10	Ep 51 At 45 Sw 4
FN 5	35	Timber cruise	At > 80 Sw < 20	At 79 Ac 13 Ep 8	At 63 Ep 28 Ac 9
DCS 1	51	Scale volume	At 95 Sw 5	At 80 Ac 20	At 86 Ac 12 Sw 2
DCS 2	50	Inventory label	At > 80 Pl < 20	At 65 Ac 35	At 75 Ac 22 Sw 2
DCS 3	101	Scale volume	At 88 Sw 12	At 87 Ac 13	At 78 Ac 19 Ep 2 Sw 1
DCS 4	25	Inventory class	At & Ac 82 Sw & Pl 18	At 69 Ac 31	At 57 Ac 35 Sw 8
DCW 1	61	Scale volume	At & Ac 100	At 84 Ac 16	At 83 Ac 17
DCW 2	73	Inventory class	At & Ac > 80 Sw < 20	At 100	At 98 Ac 1 Sw 1
DCW 3	57	Scale volume	At & Ac 92 Sw 8	At 99 Ac 1	At 99 Ac 3
DCW 4	23	Inventory class	At & Ac > 80	At 92 Ac 8	At 90 Ac 10

^a FN = Fort Nelson, DCS = Dawson Creek “strong spruce seed source”; DCW = Dawson Creek “weak spruce seed source.”

^b Species codes: At = *Populus tremuloides*; Ac = *Populus balsamifera*; Sw = *Picea glauca*; Pl = *Pinus contorta*; Ep = *Betula papyrifera*.

TABLE 2 Selected characteristics of spruce natural regeneration for sampled stands

Sample stand ^a	Morisita Index	Range of spruce density (stems/ha)	Spruce density (stems/ha)	Mean spruce stocked plots (%)	Shared perimeter where spruce cover > 30% (%)	Shared perimeter where spruce cover > 10, < 30% (%)
FN 3	1	1400–2800	2067	100	4.4	0
FN 1	1.3	0–1000	450	75	0	28.6
FN 5	2.3	0–400	86	28.6	11.9	0
FN 2	2.8	0–1800	375	75	18.3	0
FN 4	3	0–9000	2233	66.7	25.7	0
DCS 4	2.3	0–5200	1138	61.5	0	27.9
DCS 1	3.9	0–1800	291	36.4	13	0
DCS 2	4.6	0–2600	422	33.3	22.8	0
DCS 3	6.2	0–5000	571	35.7	0	17.8
DCW 1	4	0–400	50	16.7	0	6.7
DCW 3	12	0–600	50	8.3	0	12.7
DCW 2	na	0	0	0	0	12.3
DCW 4	na	0	0	0	0	0

^a FN = Fort Nelson, DCS = Dawson Creek “strong spruce seed source,” DCW = Dawson Creek “weak spruce seed source.”

na – not applicable, no spruce present.

There were distinct differences between the Fort Nelson and Dawson Creek managed aspen stands for predicting the presence and density of white spruce natural regeneration. A logistic regression equation for presence of white spruce natural regeneration, which combined the Fort Nelson and Dawson Creek samples, was statistically significant, though with a very low predictive ability (McFadden’s $Rho^2 = 0.104$, chi-square $p < 0.014$). When the

two areas were analyzed separately, the relationship was not significant (at $p < 0.05$) for Fort Nelson (chi-square $p < 0.080$).

For Dawson Creek, there was increased presence of white spruce natural regeneration with more mineral soil seedbeds in the post-harvest stand, and when the stand was east of a spruce seed source. For the Dawson Creek sites, the presence of mineral soil exposure from harvest disturbance and being downwind (east) of spruce seed sources were the best predictors in a logistic regression equation for presence of white spruce natural regeneration, although with a low predictive ability (McFadden's $Rho^2 = 0.217$, chi-square $p < 0.001$). The best combined model for density of white spruce natural regeneration in Dawson Creek stands was a multiple regression equation that included mineral soil exposure from harvest disturbance (+), direction to seed source (northwest to west +, median 307° , average 267°), and distance to seed source (-) ($r^2 = 0.241$, $p < 0.002$). The interaction of direction and distance to white spruce seed source was not statistically significant ($p < 0.837$). A regression equation with only mineral soil exposure from harvest disturbance and direction to seed source was only slightly reduced in predictive ability ($r^2 = 0.223$, $p < 0.002$).

3.2 Age-class Structure

All broadleaf species regenerated within 3 years of the harvest disturbance (Table 3). This relationship was present for both vegetative reproduction (aspen, balsam poplar) and seed reproduction (paper birch) strategies. None of the sampled balsam poplar had evidence of originating from seed, nor did any of the sampled paper birch regenerate as a coppice. Balsam poplar that could have been of seed origin was observed on roads, landings, and other bladed surfaces within the study sites. The harvest records for DCS 3 indicated harvest entries in 1982 and 1989, giving rise to two distinct cohorts of regeneration. This variation in age structure was confirmed by the stem analysis (Table 3).

TABLE 3 Age structure for sampled stands

Stand ^a	Mean total age by species				Years to 1.3 m
	<i>Populus tremuloides</i>	<i>Populus balsamifera</i>	<i>Picea glauca</i>	<i>Betula papyrifera</i>	<i>Populus tremuloides</i>
FN 1	16		20		1-2
FN 2	16	15	10		2-3
FN 3	15		10	12	2
FN 4	15		14	13	1-2
FN 5	14	14		13	1-3
DCS 1	16	16	10		2-4
DCS 2	17	17	17		1-3
DCS 3	25,* 18	16			1-5
DCS 4	15	15	14		1-3
DCW 1	18	17			1
DCW 2	17				5-7
DCW 3	16				2-3
DCW 4	18				5

^a FN = Fort Nelson, DCS = Dawson Creek "strong spruce seed source," DCW = Dawson Creek "weak spruce seed source."

* Two harvest entries within this stand in 1982 and 1989.

White spruce regenerated within 1 year of disturbance in three of the seven stands (FN 4, DCS 2, and DCS 4) where white spruce was sampled for age (Table 3). White spruce ages were 5–6 years younger than aspen regeneration in three of the seven stands (FN 2, FN 3, and DCS 1; Table 3). In one stand (FN 1), the sampled white spruce was 4 years older than the aspen regeneration.

Most sampled aspen reached 1.3 m in height within 3 years (Table 3). Some of the within-stand variation was likely due to canopy position of the sampled individuals. Lower canopy and suppressed broadleaf stems required more years to achieve 1.3 m in height.

3.3 White Spruce Distribution in Mature Broadleaf Stands

The three mature broadleaf stands with a minor spruce component had white spruce present both in the upper canopy and as advance regeneration (Table 4). Spruce tall enough to be among the broadleaf canopy was present in 9–22% of the sample plots. White spruce natural regeneration was present in the three sampled mature stands (Table 4). The Morisita Index ranged from 1.7 to 2.8, indicating a clumped distribution. The percentage of plots stocked with spruce in the sampled mature stands ranged from 43 to 78%, and average spruce density ranging from 171 to 927 stems/ha (Table 4).

TABLE 4 Selected characteristics of spruce regeneration in mature aspen-dominated stands comparable to DCS 1, 2, and 4

Adjacent opening	Number of sample plots	Canopy spruce stocking 0.1-ha plot (%)	Spruce regeneration Morisita Index	Mean spruce regeneration stocking (stems/ha)	Spruce regeneration stocked plots (%)
DCS 1	11	9	2.8	927	64
DCS 2	9	22	1.7	422	78
DCS 4	14	21	1.9	171	43

MGM simulations for DCS 1 and DCS 4 are found in Figure 2. Simulations for DCS 2 were very similar to DCS 1 and are not presented here. The MGM simulations illustrate the rapid dominance of each site by aspen and the gradual increase in spruce presence over time. In both simulations, aspen merchantable volume is greater than 250 m³/ha by 80 years after disturbance. White spruce do not reach merchantable size (17.5 cm dbh) until 85 (DCS 1) or 75 (DCS 4) years after disturbance (Figure 2).

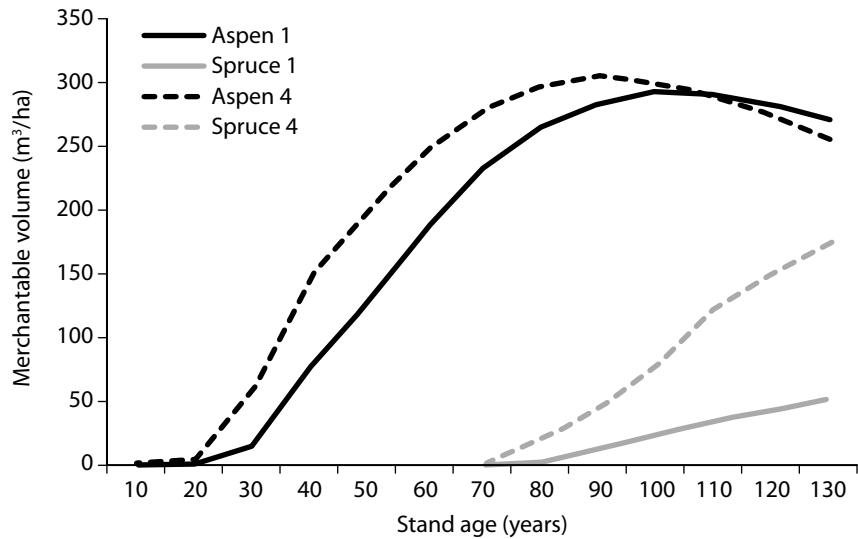


FIGURE 2 Stand-level summary of net merchantable volume development for aspen and white spruce regeneration found in Dawson Creek strong spruce seed source stands (DCS) 1 and 4, as forecast by the Mixedwood Growth Model.

4 DISCUSSION

The stocking and density of spruce in the Fort Nelson stands (28.6–100% stocking; Table 2) and the Dawson Creek strong seed source stands (33.3–61.5% stocking; Table 2) were similar to or greater than those found on comparable western boreal sites. The natural regeneration on 8-year-old harvested alluvial sites in northern Alberta averaged 500 stems/ha and 30% stocking (Timoney and Peterson 1996). In northern Alberta, 81 sampled stands had a 6.8% mean stocking rate for transects 8–15 years after harvest (Martin-DeMoor et al. 2010). Clearcut areas at the northern Alberta EMEND site had 53.7% stocking 10 years after summer harvest (Solarik et al. 2010).

Alberta cutblocks, which had been planted to white spruce, had average MI values of 2.02 at 12 or 13 years (Feng et al. 2006). All of the stands in this study were naturally regenerated with MI values ranging from 1 to 12 (Table 2), where clumped distribution patterns (high MI value) likely reflect the clumped distribution of favourable seedbeds (Greene et al. 2002; Purdy et al. 2002).

The proportion of mature white spruce in adjacent stands, and the percentage of shared perimeter between cutblocks and spruce component stands were important variables for assessing the amount of white spruce natural regeneration in the Dawson Creek area. The shared perimeter is GIS information that acted as a surrogate for the strength of the white spruce seed source. On a landscape level, this could be used to identify areas where a minor white spruce component could be expected to establish within a broadleaf-dominant stand after harvest disturbance.

There is a high degree of unexplained variation when attempting to describe spatial relationships of natural regeneration years after the original disturbance (Asselin et al. 2001). A wide variety of factors could have changed between the time of regeneration and later assessments, such as

environmental conditions and plant community composition. Successfully established individual spruce seedlings are the product of dispersal patterns combined with recruitment success (Nathan and Muller-Landau 2000).

For Dawson Creek stands, direction to the nearest white spruce seed source was also a significant predictor of spruce regeneration, while distance made only a small contribution to improved prediction. Direction of the seed source was independent from distance (i.e., the interaction was not statistically significant). White spruce seeds have been documented to disperse up to 400 m on open sites (Zasada 1972) but most seedfall occurs within 50–150 m of the source (Stewart et al. 1998; Greene et al. 1999). The density of seed trees within 60 m of spruce regeneration was a better predictor than using density of seed trees within 100 and 200 m of the regeneration for northern Alberta stands (Martin-DeMoor et al. 2010). The significance of direction as a predictor indicates that long-distance transport (over 250 m from the seed source; Stewart et al. 1998) of white spruce seeds on prevailing winds is an important mechanism, in contrast to the results of Asselin et al. (2001). Strong wind events (> 50 km/h) occur more than once per year in both our study areas (Flesch and Wilson 1993; Jull¹), which would contribute to wider dispersion of white spruce seed. For the Dawson Creek area, 88% of the July to October extreme wind gusts come from the west (Flesch and Wilson 1993). Turbulence and uplift can result in long-distance transport of 1–5% of a tree seed crop (Nathan et al. 2002), which could enable establishment much farther from the seed source than distances determined by wind tower studies. All the study stands were clearcuts, which would contribute to long distance dispersal of seed due to the greater wind speeds at ground level (Greene et al. 1999). The relative proximity of white spruce seed sources may partially explain the lack of significant predictive equations for the Fort Nelson stands. Even at 300 m away from the source, the dispersed white spruce seed density can be greater than 3% of that recorded in the source stand (Dobbs 1976; Nathan et al. 2002). With an average distance of 133.8 m to the nearest spruce seed source in the Fort Nelson stands, proximity of seed source would not be a limiting factor.

Regional climate may also contribute to the more consistent presence of white spruce natural regeneration in Fort Nelson. The average May to September precipitation is 332 mm in Fort Nelson compared to 315 mm for the Dawson Creek area. The Cumulative Moisture Deficit for the May to September period is 121 mm for Fort Nelson compared to 166 mm for Dawson Creek (using 1971–2000 climate normals from ClimateBC; Wang et al. 2006). The better moisture conditions during the growing season would reduce mortality of spruce germinants when they are most vulnerable to moisture stress. Reduced drought stress would also improve spruce survival on less favourable substrates, which would be reflected in higher stocking rates.

The importance of mast years (Peters et al. 2005; Martin-DeMoor et al. 2010) in white spruce reproduction was not obvious for stands sampled in this study. The 30-ha portion of DCS 3 logged in 1982 would have had receptive seedbeds during the 1983 Dawson Creek mast year. The Morisita Index of 6.2 and spruce stocking of 35.7% for DCS 3 (Table 2) did not indicate that this mast event made a noticeable difference in DCS 3. Similarly, even though FN 2 had a 1990 summer logging history and had receptive seedbeds during the

¹ Jull, M. 2001. Wind damage incidence following group shelterwood and understory retention harvesting in boreal mixedwood stands. Aleza Lake Research Forest, University of Northern British Columbia. Report on file.

1990 Fort Nelson mast year, the Morisita Index and spruce stocking percentage were similar to the other Fort Nelson stands (Table 2). Spruce natural regeneration was present in 12 of the 13 stands where a spruce seed source existed (Table 2). Thus there was a sufficient level of seed production, transport, and survival to result in some degree of white spruce presence in over 90% of the broadleaf harvest stands, similar to the “background” level of spruce regeneration described by Stewart et al. (1998).

Sampling 15–22 years after harvest, only mineral soil seedbeds could be identified in the field. The presence of this type of seedbed was a useful predictor of white spruce natural regeneration in this study. This is consistent with the literature in which dense spruce seedling establishment occurs on exposed mineral soil and thin forest floor seedbeds (Greenway et al. 2002; Wang and Kembell 2005). Three growing seasons after winter harvest of mixedwood sites in Fort Nelson, white spruce natural regeneration stocking was only 1.9% (Kabzems 2001), well below what was found in most of the stands we examined in this study. The harvested stands were surrounded by potential seed trees, and opening sizes were less than 80 m from the forest edge. Winter harvesting had resulted in relatively little forest floor disturbance or exposure of mineral soil. On experimental plots near Dawson Creek (Kabzems and Haeussler 2005) where forest floor was removed 15 years previously, there was 100% stocking, and spruce densities averaged 6533 stems/ha (R. Kabzems, pers. data). On the Dawson Creek experimental plots where the forest floor was left intact, white spruce stocking was only 16%, with an average of 78 stems/ha (R. Kabzems, pers. data). The receptive mineral soil seedbeds created in the machine traffic corridors had six times greater white spruce regeneration than adjacent areas in retention strips at the EMEND site in northern Alberta (Solarik et al. 2010).

All of the openings in the Dawson Creek area had a summer (June to October) harvest history. This harvest timing is most likely to create a variety of potential seedbeds (exposed mineral soil, reduced or disturbed forest floor). The degree and distribution of other types of potential seedbed that may have existed immediately post-harvest could not be quantified. The possible contribution of these other types of seedbed to distribution and density of white spruce natural regeneration could not be examined in this study.

The age distribution of sampled spruce reflects the dominance of regeneration within the first few years of disturbance, while a portion of regeneration occurred up to 6 years post-disturbance, and a few small spruce are actually advance regeneration, similar to the age distribution found by Solarik et al. (2010). Very few white spruce that were tall enough to be advance regeneration at the time of harvest were observed in the post-harvest sample stands. The mature stand surveys identified advance spruce regeneration that could be retained in the post-harvest stand by appropriate harvest practices or within reserves. Retention of spruce advance regeneration during harvest is the most effective mechanism to retain a conifer component in future mixedwood forests (Greene et al. 2002; Lieffers et al. 2003). White spruce seedbed availability has been observed to decline rapidly in the first few years after fire or logging disturbance (Purdy et al. 2002; Coates et al. 1994; Peters et al. 2005). The 6-year period between disturbance and spruce establishment indicates that certain microsites created by harvest disturbance remained as receptive seedbeds longer than those usually found following wildfire. Large

(3.6 m²) mineral soil seedbeds remained receptive to white spruce establishment up to 5 years after scarification in northern Alberta mixedwood sites (Lees 1963).

Distribution of white spruce in the mature stands sampled was moderately clumped with a Morisita Index (MI) of 1.7–2.8. Alberta permanent inventory plots in mature stands with more than 50% white spruce basal area had average MI values of 1.12 (Feng et al. 2006). Post-harvest white spruce regeneration in the Dawson Creek stands had a more irregular distribution pattern (MI values 2.3–12; Table 2) than that found in natural stands. Canopy white spruce within forest dominated by western boreal broadleaf has a clumped distribution (Cumming et al. 2009).

At these early stages of succession, the stands that had been aspen dominant had a very minor presence of white spruce. Broadleaf cover reaches its maximum approximately 15 years after disturbance (Lieffers et al. 2002; Redburn and Strong 2008). At later stages of succession, the combination of aspen mortality and white spruce growth would increase the proportion of white spruce in these stands (Youngblood 1995; Chen and Popadiuk 2002), as illustrated in the MGM simulations (Figure 2).

5 MANAGEMENT IMPLICATIONS AND CONCLUSIONS

White spruce natural regeneration was present in most managed broadleaf stands older than 14 years in the Dawson Creek and Fort Nelson areas. Most of the spruce became established within the first few years after harvesting. The spruce natural regeneration had an irregular distribution, and highly variable density, even where a strong spruce seed source was available. Distribution of spruce within Fort Nelson broadleaf stands was less variable than within Dawson Creek stands.

The proportion of white spruce natural regeneration after harvesting was similar to its presence in mature aspen-dominated stands, but the distribution of spruce regeneration was more irregular after harvest. At the microsite level, mineral soil exposure was an important predictor for the presence of spruce natural regeneration. Summer harvest, where more mineral soil is likely to be exposed, would be preferred over winter harvest, if spruce natural regeneration was an objective for the regenerated stand.

Inventory and site information can be used to predict the presence of spruce regeneration, but a large component of the variation was not accounted for. The combination of more favourable microclimate for germination and a more ubiquitous seed source may have contributed to the weak predictive relationships for spruce natural regeneration in Fort Nelson. Important regional differences in climate must be recognized when analyzing the potential for achieving white spruce natural regeneration. Better growing-season moisture availability likely contributed to increased spruce stocking in Fort Nelson. The location of seed sources and direction of prevailing winds relative to planned harvest areas would be important predictive tools at the landscape level for Dawson Creek. Strong wind events appeared to contribute to spruce regeneration occurring more than 200 m away from identifiable seed sources near Dawson Creek.

Current economic rotation lengths of less than 90 years for broadleaf stands would be too short for spruce natural regeneration to become canopy dominants in managed broadleaf stands. In the 2002 Dawson Creek Timber Supply Analysis (B.C. Ministry of Forests 2002), 120 m³/ha was used as a minimum level for merchantability of aspen stands, and average aspen yields for harvested stands were 240 m³/ha. Using either 120 or 240 m³ as harvesting thresholds, both DCS 1 (60–80 years) and DCS 4 (40–60 years) would be harvested before the white spruce component produced merchantable volume. A minor (< 20%) white spruce merchantable volume objective would mean rotation lengths of 100–130 years for DCS 1 and 80–100 years for DCS 4 (Figure 2). The MGM simulations also indicate that the tallest white spruce trees would not become canopy dominants until at least 100 years after harvest. Harvest of merchantable aspen stands older than 100 years is consistent with current harvest practice and with future forecasts for Dawson Creek (B.C. Ministry of Forests 2002). As alternatives to longer harvest rotation periods, provision for a component of white spruce dominants in post-harvest broadleaf-dominated stands can be accomplished by retaining advance regeneration during harvest, or by ensuring that reserves contain white spruce in the tree canopy or as advance regeneration.

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