Abstract

A 44-year-old experiment was used to address the long-term effects of establishment methods and timing, scarification and overstory density on understory spruce growth. Height growth was highest for planted seedlings on scarified sites. Treatments effects varied between planted, seeded and naturally regenerated trees. The effect of overstory density differed depending on the life period. Early growth of trees was not affected by overstory density while 44 year-old trees were advantaged by a reduced overstory density. Scarification has a variable effect depending on site, but generally enhanced tree growth. Establishment season had no effect on seedling and sapling growth. In Northern British Columbia, stands that have been attacked by the Mountain Pine Beetle might provide excellent regeneration opportunities for interior spruce in the understory.

Key words: Interior spruce, overstory density, planting, scarification, Mountain Pine Beetle.
Introduction

The province of British Columbia is currently experiencing the largest recorded outbreak of a native insect, the Mountain Pine Beetle (*Dendroctonus ponderosae* (Hopkins)) (Drever et al. 2006). The epidemic led to a loss of pine timber volume totalling 530 cubic meters in 2007 (Ministry of Forests and Range, 2007). Because the outbreak caused extensive mortality in the canopy layer of Lodgepole pine (*Pinus contorta* Dougl. ex. Loud.) dominated stands, species of the understory (Interior spruce (*Picea glauca* x *Picea engelmannii*) and Subalpine fir (*Abies lasioscarpa* (Hook.) Nutt)) are currently experiencing a release, which will likely ensure a mid- and long-term timber supply (Burton, 2006). Hence, there is renewed interest for understanding short and long term growth and release patterns of interior spruce growing in pine stand understories. Moreover, there is a need to define desirable management strategies for stands with insufficient regeneration.

The extended areas of senescent lodgepole pine throughout British Columbia could provide an opportunity to effectively establish regeneration of Interior spruce, which is a native, late-successional species with commercial value. Regeneration initiatives in open sites for that species proved to be both difficult and expensive endeavours (Lieffers and Stadt 1994; Lepage et al. 2000; Stewart et al. 2000). Exposed sites generally show low survival and germination rates for planted or seeded seedlings while natural regeneration from existing seed-sources is very inconsistent (Youngblood and Zasada, 1991; Coates et al. 1994; Stewart et al. 2000). Establishment under an existing canopy (e.g. shelterwood) can prevent increased evapotranspiration, weather extremes (e.g. drought and frost heaving), reduce competition in the herbaceous layer, reduce browsing and pest infestation (e.g. sitka spruce weevil) and water table rising (Langvall and Löfvenius, 2002; Lieffers et al. 2003; CFS, 2008; Granhus et al. 2008; Paquette et al. 2006).
Previous studies have shown that establishment method and season of establishment, overstory density, site preparation (e.g. scarification) and site quality are all factors that can affect germination, survival and growth of interior spruce (or white spruce) seedlings underneath an existing canopy (Lieffers and Stadt, 1994; Stewart et al. 2001; Wurtz and Zasada, 2001). Furthermore, these factors often interact among themselves (Granhus et al. 2008; Langvall and Löfvenius, 2002). This could possibly explain the wide range of results observed in earlier studies.

Comparing establishment methods is very relevant for management purposes since the cost associated with planting seedlings has to be weighted against other options, such as natural regeneration. Generally, it is assumed that planted seedlings reach greater heights faster than seeded trees or natural regeneration (Coates et al. 1994). However, in some cases natural regeneration can become higher than planted seedlings (e.g. Scotch pine in Holgén and Hånell, 2000) and few studies compared establishment methods in shelterwoods (Holgén and Hånell, 2000).

Scarification usually enhances germination and survival (Stewart et al. 2001; Wang et al. 2000; Coates et al. 1994) by increasing mineralization rates. Previous studies have revealed that the positive effects of scarification on growth might weaken with time (Stewart et al. 2001; Wang et al. 2000; Wurtz and Zasada, 2001), and that in some cases, less site preparation promotes higher growth (Stewart et al. 2000; Wurtz and Zasada 2001).

Overstory density is a feature of interest because it can be modified through management (Lieffers et al. 1999). Germination, survival and early growth (<3 years) of Interior spruce are superior in stands with a partial overstory providing protection (Coates et al. 1994; Wurtz and Zasada, 2001; Langvall and Löfvenius, 2002; Paquette et al 2006). Man and Lieffers (1999) suggest that a low overstory density creates an optimal environment for spruce regeneration, while Gradowski et al. (2008) recommend retention of residual of 50%. The optimal residual density in the overstory for the establishment of
interior spruce is still to be defined, and more research, particularly long term trials, are needed (Man and Lieffers, 1999; Paquette et al. 2006).

Relationships between successful regeneration of spruce, establishment method and timing, overstory density and site preparation need to be clarified. Because of the ongoing release of interior spruce following the Mountain Pine Beetle (MPB) epidemic in British Columbia, this information is crucial in understanding how these stands should be managed. We propose a long term (44-year) experiment to answer the following questions: 1) how overall performance of planted, seeded and naturally regenerated spruce seedlings vary under different overstory densities, establishment method, establishment season, and site preparation and 2) what are the determinant factors during early and mature growth stages.

Methods

Study sites

The experiment used in this study was established in 1962-1963 by the Ministry of Forest and Range of British Columbia (D. Armit) to study the regeneration of interior spruce (Picea glauca x engelmannii) under partially-cut lodgepole pine stand overstories. Blocks are located in Northwestern British Columbia in mesic or submesic stands in the Sub-Boreal spruce zone (SBSdk) (Pojar et al. 1984) between 53°11’, 54°61’ N. and 125°73’, 126°92’ W. All blocks are from fire-originated pine or pine-spruce stands that were partially logged before 1960. Initially, the experiment included 15 sites where pine densities varied from approximately 100 to 1100 stems/ha and where seedlings of interior spruce were either planted or seeded in scarified and unscarified microsites.

Each block was divided into two sub-blocks and 10 rows where a treatment was assigned. Rows were spaced between 1.8 to 3 meters. Treatments were randomly assigned to rows and consisted of: spring planted scarified (SPS), fall planted scarified (FPS), spring seeded scarified (SSS), fall seeded scarified (FSS), spring planted
unscarified (SPU), fall planted unscarified (FPU), spring seeded unscarified (SSU), fall seeded unscarified (FSU), scarified only (S) and unscarified only (U).

In each microsite of two square feet, two (2 years old) seedlings were planted, 25 to 35 viable seeds were seeded and rows assigned to natural regeneration were left untreated. Forest floor scarification was done manually with hand tools. After 5 years of establishment (in 1967), each microsite was thinned to two individuals. The experiment was abandoned from 1967 to 1993, when 8 remaining sites were re-measured. The next re-measurements were completed in 2003 and again in 2006, where most of the pine overstory had been attacked by the MPB.

The overstory density was measured in the first and last phase of the project. In 1963, two circular plots of 0.2 ha or 50 stems (whichever was smaller in size) were used to assess stand residuals in each site. In 2003 and 2006, two circular plots 0.4 ha were established within each of the experimental blocks. Densities of original overstory trees were recorded and averaged for each block.

**Tree measurements**

In the early phase of the project, height was measured for the tallest individual per microsite. In 1993, 2003 and 2006, height for experiment trees was measured using a hypsometer (Haglöf Vertex III), a height pole or a measuring tape depending on the individual’s size. Diameter at breast height (DBH) was taken in cm at a height of 1.3m using a diameter tape or callipers.

**Data analysis**

In order to determine if the establishment method and scarification had an impact on the regeneration of Interior spruce, a repeated measures ANOVA was performed using built-in commands in R (lm, anova.mlm). The response variable consisted of a matrix where height values were combined for the years 1993, 2003 and 2006 for each
experimental unit (at the tree level). Establishment method, scarification and block were between-subject factors and time was a within-subject factor. The sample size to consider for the between-subject effects is therefore the one corresponding to the number of trees sampled, while in the case of the within-subject effects, the sample size corresponds to the number of years where measurements took place (three times the number of trees sampled). Overall the sample size for the repeated measures analysis is reduced to tree-level data available for 1967 (mean height per row), 1993, 2003 and 2006.

Since there was a significant effect of the within-subject factor (time) and an interaction between time and one between-subject factor (establishment method), indicating that the effect of the establishment factor changed with time, we performed separate analysis for each year when data availability allowed (1967 and 2006). A General Linear Mixed Model (GLMM) procedure was conducted using the “nlme” package in R. This allowed to test simultaneously fixed effects (overstory density, scarification, season of establishment) and a random effect (block) on height and DBH (for the 2006 data only).

For all tests, homoscedasticity of the data was confirmed by plotting the residuals against the predicted values, while skewness and kurtosis of residuals were calculated to identify cases where a departure from normality would be present. In order to meet the sphericity assumption of the covariance matrix, the baseline values (mean height per row for the year 1967) were subtracted from the height values of each year (sensu Maindonald and Braun, 2003). The sphericity assumption was considered to be met when the Greenhouse-Geisser and Huynh-Feldt epsilon values were higher than 0.5. All analyses were performed using R (v. 2.7).
Results and Discussion

The repeated measures analysis (Table 2) confirms that height increases with time and the interaction between time and the establishment method indicated that growth patterns might differ overtime between planted, seeded or naturally established trees (Figure 1). Discrepancies between planted, seeded or naturally established trees reveal that planted trees attain greater heights (and DBH, results not shown) than others after 5 years of growth (33.91 cm (±12.68), compare to 6.82 cm (± 3.69) for seeded and 8.22 cm (± 5.75) for naturally regenerated trees). Establishment method is an important factor for overall growth, the difference increases with time and by the age of 44 years old, planted trees averages 8.16 m (± 4.6), seeded 4.80 (± 3.03) and natural regeneration averages 2.77 m (± 1.97). These values are generally low when compared to those of earlier studies (Comeau et al, 2004; Coates et al. 1994), but growth could have been enhanced by thinning. Even though results vary considerably between studies, natural regeneration is usually growing slower and rotations can be as much as 3 times longer than when seedlings are planted (Holgén and Hånell, 2000).

The repeated measures analysis suggests that scarification, combined with other predicators, is not an important factor for the overall growth of spruce in this study. Previous studies have shown that the impact of scarification can decrease with time (Wurtz and Zasada, 1991; Wang et al. 2000; Stewart et al. 2001). There is an interaction between scarification and both establishment method and block (Table 2), suggesting that the treatment might have a different impact on seeded and planted trees (see below for GLMM results). Interaction between site (block) and scarification has been observed in a study on Norway spruce (Granhus et al. 2002). This study demonstrated that scarification can interact with soil properties (fine particles) and allow frost heaving, which in turn can cause mortality and reduce growth of spruce seedlings.

The General Linear Mixed Model analysis, conducted separately for planted, seeded and natural trees, reveals trends for the early (1967) and mature (2006) growth phases (Table 3). During the first phase, height of planted, seeded and naturally
regenerated trees was analysed in regards to season of establishment, overstory density and scarification. Planted seedlings are not affected by any factor while the growth of seeded and naturally established trees is enhanced by scarification. Seeded and natural regeneration exhibit greater heights when established in scarified micro-sites (Table 3). Scarification improves growth of natural regeneration and seeded seedlings (Miina and Saksa, 2008; Stewart et al. 2001; Wang et al. 2000; Wurtz and Zasada, 1991) and the magnitude of the effect is greater compare to planted trees (Miina and Saksa, 2008). It has been observed that planted white spruce seedlings growing under an existing canopy and on scarified sites have increased net photosynthesis (Man and Lieffers, 1999). Also, mycorrhizae of such planted seedlings might be more persistent in scarified sites (Lazaruk et al. 2008) and promote higher growth. Our results are opposed to these tendencies, but in agreement with Man and Lieffers (1999), who only observed a weak correlation between white spruce planted seedling height and canopy density and also with the findings of Wang et al. (2000), who observed no effect of scarification on 10 year old white spruce planted seedlings. It is hypothesized that larger planted seedlings might be less affected by their environment than smaller seedlings (Johansson et al. 2006).

Results from the analysis of the mature growth (44 years) suggest that scarification has an effect for the planted individuals long after their establishment (Table 3, Figure 2), although the difference is not large (planted with scarified seedbeds average 8.43m. (±4.33) versus unscarified seedbeds 7.85 (±4.84)). Most studies show that the effect of scarification decreases in importance with time (Stewart et al. 2001; Wang et al. 2000; Wurtz and Zasada, 1991) but Orlander et al. (2008) observed that after a period of 70 years, scarification could still promote higher tree growth for Scots pine (Pinus sylvestris) with superior soil C and N contents. It could be hypothesized that the accelerated mineralization rate and increased amount of mycorrhizae that occurs for seedlings on scarified sites optimize the overall performance of the individual.

The GLMM results suggest that season of establishment has no influence on height and DBH of trees in this study. While it is suggested that it is desirable to plant
seedlings before mid-June in most of British Columbia (Coates et al. 1994), experiment results on the growth of seedlings regarding season of planting have been contradictory (Dong and Coates, 1993). Previous studies on the timing of spruce seeding have shown that season of establishment is generally not a good predictor of seeded tree growth (Coates et al. 1994) or that other factors might be confounding the results.

Overstory density is a determinant factor affecting height and DBH of seeded and planted trees (Table 3) during the mature growth stage. Height of mature trees is inversely correlated with overstory density (Figure 3), the highest trees being in stands with low residual densities, around 200 st/ha. Previous studies have observed the advantage of an existing canopy, and a minimum density of 200 stems per hectare (st/ha) has been suggested by Holgén and Hånell (2000). In aspen and spruce mixed-stands, Man and Lieffers (1999) recommended a residual basal area of 12 to 20 m²/ha, compared to 25 m²/ha in Comeau et al. (2008).

Stands that have been attacked by the Mountain Pine Beetle will naturally experience an overstory density reduction that will allow a considerable release of the interior spruce seedlings and saplings. This study shows that these stands could harbour productive regeneration of interior spruce, since they might provide excellent conditions for the establishment of that species. Furthermore, once the canopy opens as a result of the pine mortality, a natural thinning will take place and more light in the understory will allow a substantial growth release of the interior spruce.

**Conclusion**

Based on the study results; differences in growth between planted, seeded and naturally regenerated trees persist with time and overall higher stand growth can be achieved when regeneration is planted in scarified microsites. Some stands that have been attacked by the Mountain Pine Beetle will likely provide very good regeneration possibilities for interior spruce by offering the shelter of a partial canopy during the early growth phase, and by ensuring a natural release that will allow spruce individuals to reach to overstory.
References


Dong, H. Coates, K. D. 1993. Effects of residual density, forest floor scarification and planting season on early development of white spruce in northern interior British Columbia. Unpublished manuscript, Ministry of Forest and Range, Smithers, BC.


Table 1: Site characteristics for all blocks of the initial experiment

<table>
<thead>
<tr>
<th>Slope Aspect</th>
<th>Block 1 Babine rd.*</th>
<th>Block 2 Eli rd.*</th>
<th>Block 3</th>
<th>Block 4</th>
<th>Block 5 Family forest*</th>
<th>Block 6 Tchesinkut*</th>
<th>Block 7</th>
<th>Block 8 Tchesinkut*</th>
<th>Block 9</th>
<th>Block 10 North rd.*</th>
<th>Block 11 Broman*</th>
<th>Block 12</th>
<th>Block 13</th>
<th>Block 14 McKilligan*</th>
<th>Block 15 Lawson rd.*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Slope</strong></td>
<td>5% West</td>
<td>0%</td>
<td>0%</td>
<td>2.5%</td>
<td>5% West</td>
<td>0%</td>
<td>3.7%</td>
<td>4.8%</td>
<td>7%</td>
<td>0-2% North-east</td>
<td>3%</td>
<td>1.5%</td>
<td>2%</td>
<td>4%</td>
<td>3.5% North</td>
</tr>
<tr>
<td><strong>Aspect</strong></td>
<td>West</td>
<td>South-east</td>
<td>South-east</td>
<td>West</td>
<td>West</td>
<td>South</td>
<td>West</td>
<td>South</td>
<td>South</td>
<td>South-east</td>
<td>West</td>
<td>West</td>
<td>West</td>
<td>North-west</td>
<td>North-west</td>
</tr>
<tr>
<td><strong>Elevation</strong></td>
<td>884</td>
<td>777</td>
<td>777</td>
<td>792</td>
<td>914</td>
<td>945</td>
<td>914</td>
<td>823</td>
<td>732</td>
<td>762</td>
<td>792</td>
<td>732</td>
<td>732</td>
<td>853</td>
<td>549</td>
</tr>
<tr>
<td><strong>Soil Texture drainage</strong></td>
<td>Silty-sand.</td>
<td>Sandy loam</td>
<td>Clay-sand loam</td>
<td>Gravel-sand</td>
<td>Good to high</td>
<td>Almost complete moss cover</td>
<td>Moderate</td>
<td>Almost complete moss cover</td>
<td>Good to poor</td>
<td>Almost complete moss cover</td>
<td>Good to high Light</td>
<td>Good to poor Moderate-dense</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Understory Vegetation</strong></td>
<td>Moderate</td>
<td>Light to moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td><strong>Site index at 80 y. Stemha</strong></td>
<td>23</td>
<td>23.5</td>
<td>23.5</td>
<td>20.5</td>
<td>20.5</td>
<td>20.5</td>
<td>21</td>
<td>21</td>
<td>23.5</td>
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<td>24</td>
<td>23.5</td>
<td>25</td>
<td>24</td>
<td></td>
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<tr>
<td><strong>Stemha</strong></td>
<td>350</td>
<td>800</td>
<td>160</td>
<td>620</td>
<td>845</td>
<td>1126</td>
<td>650</td>
<td>500</td>
<td>10</td>
<td>637</td>
<td>700</td>
<td>346</td>
<td>13</td>
<td>87</td>
<td>570</td>
</tr>
</tbody>
</table>

*These blocks have been found and measured in 1993, 2003 and 2006.*
### Table 2: Summary of Repeated Measures ANOVA for tree height

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>Df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Between subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Establishment method</td>
<td>223.12</td>
<td>2</td>
<td>111.56</td>
<td>4.78</td>
<td>0.009</td>
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<tr>
<td>Scarification</td>
<td>17.02</td>
<td>1</td>
<td>17.02</td>
<td>0.73</td>
<td>0.393</td>
</tr>
<tr>
<td>Block</td>
<td>23893.05</td>
<td>7</td>
<td>3413.29</td>
<td>146.29</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Establishment method X Scarification</td>
<td>461.76</td>
<td>2</td>
<td>230.88</td>
<td>9.89</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Block X Scarification</td>
<td>1653.57</td>
<td>7</td>
<td>236.22</td>
<td>10.12</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>error</td>
<td>38966.03</td>
<td>1670</td>
<td>23.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Within subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>5116.73</td>
<td>2</td>
<td>2558.36</td>
<td>2412.59</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Time X Establishment method</td>
<td>22.08</td>
<td>4</td>
<td>5.52</td>
<td>5.21</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Time X Scarification</td>
<td>0.036</td>
<td>2</td>
<td>0.01</td>
<td>0.01</td>
<td>0.983</td>
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<tr>
<td>Time X Block</td>
<td>1117.15</td>
<td>14</td>
<td>79.79</td>
<td>75.24</td>
<td>&lt;0.0001</td>
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<tr>
<td>error</td>
<td>3558.77</td>
<td>3356</td>
<td>1.06</td>
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</tr>
</tbody>
</table>

G-G. epsilon: 0.64
H-F. epsilon: 0.64
Table 3: Result summary ($P$-values) for the Generalized Linear Mixed Models, dependent variables are tree height for 1967 and 2006 and DBH for 2006, scarification, establishment season and overstory density are fixed-effects and block is a random effect (not shown).

<table>
<thead>
<tr>
<th>Source</th>
<th>Height in 1967</th>
<th>Height in 2006</th>
<th>DBH in 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>planted</td>
<td>seeded</td>
<td>naturals</td>
</tr>
<tr>
<td>Scarification</td>
<td>0.1721</td>
<td>0.0003</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Establishment season</td>
<td>0.3076</td>
<td>0.4158</td>
<td>-</td>
</tr>
<tr>
<td>Overstory density</td>
<td>0.2977</td>
<td>0.34</td>
<td>0.1253</td>
</tr>
</tbody>
</table>
Legends for Figures

1-Height of planted (A), seeded (B) and naturally regenerated trees (C) for all years.

2- Height of planted trees on scarified (downward triangle) and unscarified sites (diamond), seeded on scarified (x) and unscarified sites (plus sign) and natural regeneration on scarified (triangle) and unscarified sites (circle).

3-Tree height vs overstory density for all trees in 2006. Intercept is 10.41 and slope is -0.0095.
Figure 1
Figure 2
Figure 3

Height vs overstory density, year 06

$r^2 = 0.32$