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# Enrichment of Natural Regeneration Through Direct Seeding and Fill Planting in Logging Trails of Black Spruce Stands

Martin-Michel Gauthier and Jean-Claude Ruel

*Graduate Student and Associate Professor, Faculté de Foresterie et de Géomatique, Université Laval, Québec, Canada*

## Abstract

Direct seeding and fill planting of black spruce [*Picea mariana* (Mill.) B.S.P.] were assessed in logging trails after irregular shelterwood cutting in the boreal forest of Québec, Canada. Two growing seasons after harvest, direct seeding increased seedling establishment when compared to control plots, but seeded seedling density represented only 17 percent of seeds initially deposited. Seedling establishment increased with increasing soil moisture. Planted container seedlings responded well with mean terminal shoot growth of 4.7 cm (1.9 in) yr$^{-1}$. Terminal shoot growth of planted seedlings decreased with increasing soil moisture. Results suggest potential for improvement of logging trail regeneration with fill planting.

## Introduction

In northeastern Canada, a form of irregular shelterwood cutting that protects seedlings, saplings, and small merchantable trees during harvest has been proposed to manage stands with irregular structures in the boreal forest zone (Jobidon and others 2002). This condition, often found in stands of black spruce [*Picea mariana* (Mill.) B.S.P.], is characterized by great variability in height and diameter (Paquin and Doucet 1992; Burton and others 2003). Subsequent development of treated stands has been linked to size and density of residual stems, percent area covered by logging trails, and regeneration of trails (Jobidon and others 2002).

Percent area covered by logging trails is critical because these areas tend to be less productive than residual forested strips (Grigal 2000). Soil compaction resulting from harvesting activities can reduce soil macroporosity and infiltration rates while increasing bulk density and resistance (Greacen and Sands 1980). When compaction is severe, tree root systems are negatively affected (Kozlowski 1999), reducing height (Corns 1988) and volume growth (Wert and Thomas 1981). Local effects on soil temperature and light conditions caused by slash deposits and residual trees can also influence regeneration (McInnis and Roberts 1995). Given that logging trails can often represent 20–25 percent of a harvested area with a cut-to-length system, effective regeneration of logging trails is essential to maintain stand productivity.

Artificial regeneration techniques, such as direct seeding and fill planting, could be used to supplement regeneration in logging trails. Direct seeding has been used in North America and Europe, particularly in the boreal forest (Nilson and Hjältén 2003). Seed predation, poor seedling survival, and strong competition from shrubs and herbs are disadvantages to the use of this method (Willoughby and others 2004). Direct seeding, however, is less expensive and easier to implement than planting (Wennström and others 1999).

Both regeneration techniques were investigated in this study to determine their usefulness as a complement to natural regeneration in logging trails. Two null hypotheses were tested: (1) direct seeding and fill planting are not effective in regenerating black spruce; (2) seeded seedling establishment, terminal shoot growth, and foliar nutrient concentrations of planted black spruce seedlings are not influenced by environmental conditions such as soil bulk density, soil moisture, and light availability.

## Methods

**Site Description.** Four sites at elevations of 520 to 600 m (1,705 to 1,968 ft) in northern Québec, Canada (50º 41'N, 72º 12'W), were used. Mean annual temperature, precipitation, and frost-free days at the Bonnard meteorological station, located 80 km (50 mi) east, are -1.8 °C (28 °F), 946 mm (37 in), and 135 d (Environment Canada 2004). Length of the growing season is approximately 2 to 3 mo. All sites were in the black spruce-moss bioclimatic domain of the boreal forest vegetation zone. Undifferentiated till was the main surface deposit, and humo-ferric podzols with a sandy loam texture were the predominant soil types. Drainage was imperfect. The mean humus layer depth was 16 cm (6.3 in), varying from 12 cm (4.7 in) to 20 cm (7.9 in) among study sites.

Sites were harvested in fall 2002 with a cut-to-length system. Irregular shelterwood cutting was applied in all study sites. Trees were felled and brought in front of the harvester for processing. Slash was deposited in the trails; bucked lengths were forwarded to the roadside along a preplanned trail system. Gross merchantable volume before harvest ranged from 75 to 125 $m^3$ $ha^{-1}$ (1,072 to 1,786 $ft^3$ $ac^{-1}$) among study sites, and volume removal varied from 88 to 92 percent. Site preparation was not applied after harvest. Logging trails represented 22 percent of the total area of each harvest block.

**Plant Material and Study Plots.** Planting and direct seeding were used to assess artificial regeneration success with regard to environmental conditions. Seed and seedlings were obtained from a provincial nursery (Sainte-Anne-de-Beaupré, Quebec, Canada). Seed germination rate was 89 percent. Seedlings were container-grown (340 $cm^3$, 21 $in^3$) black spruce (2+0). Mean height (± SE) before outplanting was 60.4 ± 0.4 cm (23.8 ± 0.2 in).

In total, 15 study plots were established per site in the spring of 2003. A study plot was composed of three separate quadrats of similar substrate located within a radius of 5 m (16 ft) (figure 1). Quadrats were 1 × 1 m (3.3 × 3.3 ft). All quadrats were established on areas free of competing vegetation such as Labrador tea (*Ledum groenlandicum* Oeder) and sheep laurel (*Kalmia angustifolia* L.). One quadrat served as a control to determine natural seedling establishment. A second quadrat was used to evaluate seedbed quality by dispersing 50 black spruce seeds within the quadrat. Seeds were not mixed with the organic matter because advance regeneration was abundant on each site and severe mortality would have resulted. Environmental conditions were evaluated in a third quadrat by planting four seedlings.

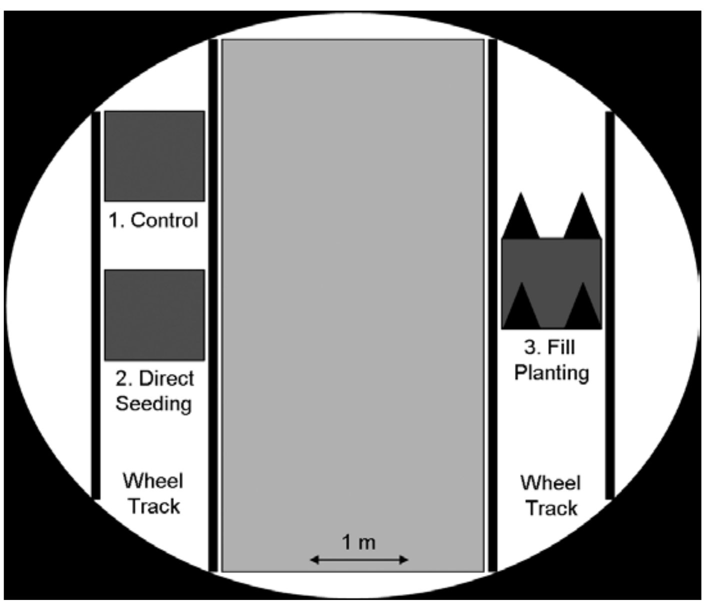


**Figure 1.** Schematic map of one study plot with (1) control quadrat, (2) seeded quadrat, and (3) planted quadrat located inside wheel tracks of the logging trail.

A seedling tally was carried out in the seeded and control quadrats after two growing seasons (15 mo, ~150 growing d). Total height was measured before planting, and terminal shoot growth was measured after 15 mo. In each planted quadrat, average terminal shoot growth of the four seedlings was used for statistical analysis.

At the end of the second growing season (23–24 September 2004), the terminal shoot of each planted seedling was collected and refrigerated until processed and analysed. One hundred current-year needles were selected per sample for each study plot. Samples were dried at 65 °C (150 °F) for 48 h to determine average weight of single needles (Thiffault and others 2004). Foliar nutrient samples were processed following the methods of Parkinson and Allen (1975). Total N was determined by flow injection analysis with the Quickem method (Zellweger Analytic Inc., Milwaukee, WI). P and K were determined by inductively coupled plasma analysis (ICAP-9000, Thermo Instruments, Franklin, MA).

**Environmental Conditions.** Light availability, soil bulk density, and soil moisture were measured in each study plot. Photosynthetic photon flux (PPF) was measured with calibrated ceptometers (AccuPAR and Sunfleck, Decagon Devices Inc., Pullman, WA). Measurements were taken on clear days between 10:00 and 14:00 on 12 and 14 August 2003, based on methods from Jobidon (1992). One ceptometer was located in the trail, just above the planted stock, and the other was placed in the center of the access road. Measurements were taken simultaneously at fixed time intervals. The ratio of light in the trails to light on the access road was used as a percentage of available light to the planted stock.

Bulk density was measured in each study plot to assess whether severe soil compaction occurred as a result of harvesting. Samples were collected in the upper 10 cm (4 in) of mineral soil with a polyvinyl chloride slip cap

10 cm in diameter and 460 cm$^3$ (28 in$^3$) in volume. Samples were taken within the 5-m radius, but not directly inside one of the quadrats. Samples were oven-dried at 105 °C (220 °F) for 48 h before weighing (Brais and Camiré 1998).

Soil moisture was measured using time domain reflectometry (Field Scout TDR 100 Soil Moisture Meter, Spectrum Technologies Inc., Plainfield, IL). Measurements were made monthly from June to August during the second growing season. Four readings were taken and averaged within each planted quadrat. The mean of all 3 mo was used as the mean soil moisture throughout the growing season.

**Statistical Analysis.** All analyses were conducted with SAS (Version 8.2, SAS Institute, Inc., Cary, NC). Because data for control quadrats could not be normalized, type III contrast analyses (likelihood ratio statistics) of the Generalized Models procedure (GENMOD) were used to test for significant differences ($p<0.05$) between seeded and control quadrats. A Poisson distribution, logarithmic function, and Pearson scale parameter options were specified in the model statement to account for the nature of the variables, as well as for overdispersed data. Overdispersion occurs when the data show more variability than is predicted by the sampling model chosen (Fitzmaurice 1997).

To test for the influence of environmental factors on artificial regeneration techniques, the Generalized Linear Models (GLM) procedure was initially used to detect potential site differences. This factor proved insignificant for all analyses, and linear regression was subsequently used. Seedling establishment from direct seeding, terminal shoot growth, and foliar nutrient concentrations (N, P, K) of planted seedlings were tested as a linear function of soil bulk density, soil moisture, light availability, and all interactions. The stepwise selection was used to determine the best model. Correlations, studentized residuals, and variance inflation factors were used to detect possible correlations between independent variables, test for potential outliers, and evaluate parameter estimates. Homogeneity of variance was assessed visually, and the Shapiro-Wilk test was used for normality. Logarithmic transformation was applied to seedling establishment to correct for normality.

## Results

**Direct Seeding.** Direct seeding resulted in significantly higher density than in control plots ($p=0.0001$). The number of seedlings established after 15 mo represented 18 percent of the initial amount of seed deposited. Under natural conditions, seedling establishment was measured at 1.6 seedlings m$^{-2}$ (10.8 ft$^{-2}$). With direct seeding, seedling establishment increased to 8.6 seedlings m$^{-2}$. After two growing seasons, however, seedlings were not much taller than 5 cm (2 in). Seedling establishment increased with increasing soil moisture ($r^2 = 0.28$, figure 2).

**Planting.** Survival rate of planted seedlings across all study sites after two growing seasons was 96 percent. Average terminal shoot growth of planted seedlings was 4.7 ± 0.2 cm (1.9 ± 0.1 in). Mean light availability to planted seedlings for all study sites was 84 percent, varying from 77 percent to 90 percent among sites. Terminal shoot growth decreased with increasing soil moisture ($r^2=0.20$, figure 3). Compared with averages from Swan (1970), foliar nutrient concentrations (mean ± SE, n=60)

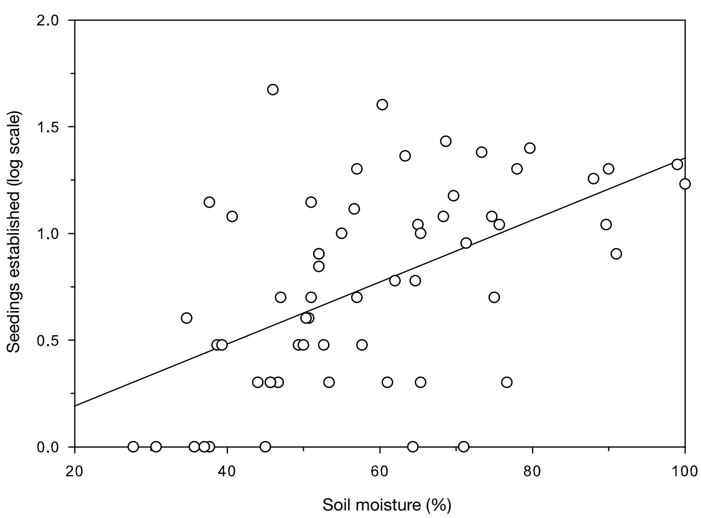


**Figure 2.** Number of seedlings established from direct seeding with increasing soil moisture for all study sites ($r^2=0.28$, $p<0.0001$).

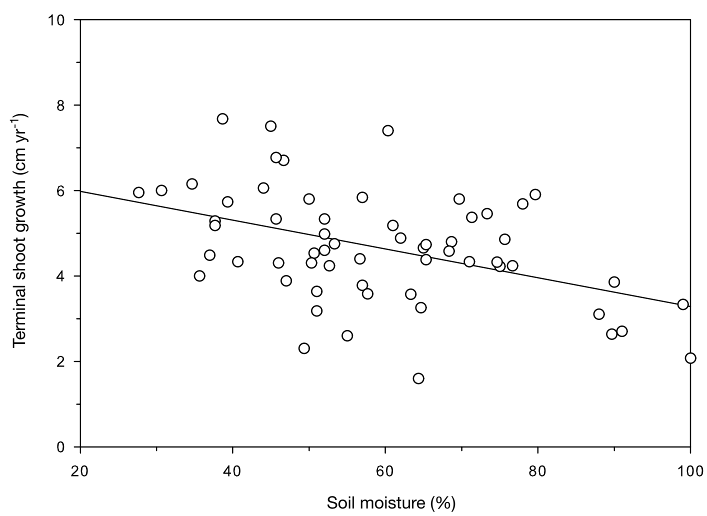


**Figure 3.** Terminal shoot growth of planted black spruce seedlings with increasing soil moisture for all study sites ($r^2=0.20$, $p=0.0004$).

were sufficient in K (5.1 ± 0.1 mg $g^{-1}$ or 5,100 ± 100 ppm), but acutely deficient in P (1.0 ± 0.1 mg $g^{-1}$ or 1,000 ± 100 ppm) and moderately deficient in N (0.9 ± 0.3 percent). Statistically significant relationships were found between soil moisture and foliar nutrients (data not shown), but the small amount of variation explained by soil moisture did not warrant further investigation.

## Discussion

**Direct Seeding.** Direct seeding increased seedling establishment, but the percent survival remained low (18 percent). Also, seedlings were not much taller than 5 cm (2 in) after two growing seasons. Brais and others (1996) found an establishment rate of only 6 percent after direct seeding on coarse-textured sites after careful logging around advanced regeneration. The substrate type in our sites was mostly undisturbed peat moss (*Sphagnum* spp.) and feather moss (*Pleurozium schreberi* (Brid.) Mitt.), which Prévost (1997) has shown to be a receptive seedbed for black spruce. Black spruce establishment is generally favored by an organic-mineral mix or exposed mineral soil (Prévost 1996). This suggests direct seeding may be more beneficial in logging trails after moderate soil disturbance in areas where advance regeneration is poor.

**Fill Planting.** After two growing seasons, mortality of planted black spruce seedlings was limited to 4 percent. Terminal shoot growth was similar to values reported by Prévost and Dumais (2003) in similar sites of the boreal forest zone. Foliar nutrient analysis showed 82 percent and 90 percent of the planted stock were moderately deficient in N and P, respectively. The N levels observed in our study are comparable to those observed by Prévost and Dumais (2003) for black spruce planted without site preparation, whereas P levels are much lower. This likely will limit seedling development over a longer time because P is a major factor in energy transfer, root system development, drought tolerance, and disease resistance (Camiré and others 1996). Still, the survival rate tends to indicate that such concentrations, although quite low in some cases, may not necessarily be critical.

Planting large stock seedlings up to 50 cm (20 in) in height is usually successful on a variety of sites (Thiffault and others 2003). Fill planting could be considered as a viable option in areas of poor seed supply and insufficient regeneration on undisturbed substrate such as peat moss.

**Environmental Conditions.** Soil moisture was the only environmental variable that influenced seedling establishment and terminal shoot growth of black spruce. The moisture-holding capacity of substrate types such as peat moss may account for part of the positive relationship found with seedling establishment. The negative relationship with terminal shoot growth may be related to imperfect drainage of the sites. Water stress is usually caused by low moisture levels (Hébert and others 2006), but high moisture levels, such as those found in our study, can also damage black spruce seedlings by limiting root hydraulic conductance (Islam and others 2003).

In terms of light availability, a 9-yr study by Logan (1969) showed height growth of black spruce seedlings was adequate when full light was ≥45 percent. Among our study sites, lowest mean available light was measured at 77 percent. Hence, light availability inside logging trails was sufficient.

Mineral soil bulk density values reported in this study are unlikely to hinder seedling root growth. Only 10 percent of the samples were compacted to a level that could restrain root growth (≥1.25 g $cm^{-3}$ or 78 lbs $ft^{-3}$), based on a study of black spruce by Prévost and Bolghari (1990).

## Conclusion

Results from this study suggest direct seeding was unsuccessful in regenerating black spruce 15 mo after establishment. Fill planting was effective, and this treatment could be employed in areas of insufficient natural regeneration, seed supply, and poor seedbed receptivity. Results showed that increasing soil moisture improved early establishment of black spruce, but decreased terminal shoot growth of the planted stock. Monitoring over a longer time frame (10–15 yr) will be necessary to further evaluate the regeneration techniques in logging trails.

**Address correspondence to:** Jean-Claude Ruel, Département des sciences du bois et de la forêt, Faculté de foresterie et de géomatique, Pavillon Abitibi-Price, Université Laval, Québec (Québec, Canada) G1K 7P4; e-mail: Jean-Claude.Ruel@sbf.ulaval.ca; phone: 418–656–2131, extension 7665.

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