IMPACT OF A REGENERATION METHOD AND VERTICAL POSITION ON JUVENILE WOOD PROPERTIES OF JACK PINE IN NORTHWESTERN ONTARIO

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Abstract. The effects of regeneration methods and vertical positions on three juvenile wood properties of 25-yr-old jack pine grown in the Boreal forests of northwestern Ontario were studied. Modulus of elasticity and modulus of rupture in static bending and specific gravity were determined from clear wood specimens of three vertical positions of trees selected from four stands that were aerial-seeded, Bräcke-seeded, planted, and postfire naturally regenerated. Juvenile wood properties among the four regeneration methods were not significantly different, however, they were found to vary significantly among the vertical positions for three of the methods: aerial-seeded, Bräck-seeded, and postfire natural stands. The wood properties of juvenile jack pine were quite variable, irrespective of the regeneration method, but there is a substantial potential in separating jack pine logs along the stem for various uses based on the regeneration method.

Keywords: Mechanical wood properties, conifer species, silvicultural practices, regeneration methods, forest industry, boreal forests, northwestern Ontario.

INTRODUCTION

Jack pine is of great importance to the economy of Ontario, accounting for 33% of the total softwood volume harvested (OMNR 2008). Silvicultural practices are often applied to jack pine to control establishment, structure, and growth. These practices have primarily focused on increasing jack pine tree growth and thus volume within shorter harvest rotations. Researchers have investigated the effects of silvicultural practices such as initial spacing and stem growth and quality (Godman and Cooley 1970; Janas and Brand 1988; Bell et al 1990; Kang et al 2004; Tong et al 2005). Also, effects of precommercial thinning on stem quality and tree growth have been investigated (Bella and DeFranceschi 1974; Vassov and Baker 1988; Morris et al 1994; Tong et al 2005; Zhang et al 2006). In general, these studies have established that wide initial spacings and those formed from precommercial thinning cause unfavorable characteristics such as thicker branches, larger stem taper, decreased height, and delayed mature wood formation in the main stem. This trend, however, does not appear to occur beyond a stand density of 3000 stems/ha (Alteyrac et al 2005).

Stand density normally varies according to the regeneration method used. For example, in naturally regenerated stands, the stand density is

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initially high (about 25,000 stems/ha), reduced over time by self-thinning and pruning (Van Damme and McKee 1990). Plantations, on the other hand, are widely spaced compared with natural forests, particularly at the stand establishment phase. It is common to plant trees at a spacing that leads to a stand density of about 2000-2500 stems/ha (Van Damme and McKee 1990). Another method commonly used is aerial seeding, where large quantities of seeds (10,000-15,000 seeds/ha) are dispersed onto a site for regeneration of softwoods (Van Damme and McKee 1990). This method may lead to a higher initial stand density than that of a plantation, however, some areas may not receive any seeds and are regenerated naturally or through fill planting. An alternative regeneration method used in central Canada is Bräcke mounds with seed dispensers, which leads to a plantation-style system where several seeds are deposited in each mound by machine. This method more closely resembles the plantation method than does aerial regeneration, however, there remains an issue of wide spacing between the mounds with about 8000 seeds/ha (Van Damme and McKee 1990).

The use of different regeneration methods is important to the forest industry, however, little information exists on the effect of these methods on wood formation and properties. In particular, juvenile wood formation needs to be addressed for different regeneration methods to ensure that planted trees produce the best quality wood. Three important properties that can be used to compare dimension lumber from the four regeneration methods are modulus of elasticity (MOE), modulus of rupture (MOR), and specific gravity. Since regeneration methods have been found to influence tree form and growth, they are also expected to influence wood properties (Janas and Brand 1988; Van Damme and McKee 1990). Researchers have also demonstrated that wood property quality decreases with increasing height in the tree (Spurr and Hsiung 1954; Okkonen et al 1972; Markstrom et al 1983; Dechesne 2006).

The purpose of this study was to evaluate the effects of four regeneration methods and three vertical positions of jack pine on MOE and MOR in static bending and specific gravity. The regeneration methods of interest were aerial seeding, direct seeding with a Bräcke scarifier (Bräcke seeding), planting, and postfire natural regeneration. This knowledge could assist forest managers in determining how to best manage and use jack pine timber for specific end products such as dimension lumber.

METHODS AND MATERIALS

Stand and Tree Selection

Four jack pine stands in northwestern Ontario, approximately 60 km east of Ignace, were selected. Each stand had been regenerated following a different method: aerial seeding, Bräcke seeding, planting, and postfire natural regeneration. The stands represented similar soil and climatic conditions because they were in close proximity. The aerial-seeded, Bräcke-seeded, and planted stands were regenerated in 1982, while the natural stand had been depleted by fire in 1980. Based on the forest resource inventory, the approximate age of trees in the stands at the time of study was 25 yr. From each stand, 12 trees were randomly selected for destructive sampling following a stratified random sampling procedure, each strata representing a regeneration method. Four circular 100-m^2 plots were randomly located in each stand. Within each plot, trees greater than or equal to 5-cm dia at breast height (dbh) were numbered and tallied. Trees greater than or equal to 10-cm dbh and free from visual defects were declared possible sample trees. Three of the possible sample trees were then randomly selected for destructive sampling, resulting in a total of 48 trees. For each sampled tree, the following attributes were measured: dbh, total height, height to live crown, length of live crown, and crown diameter. Table 1 presents sample tree attributes based on regeneration method. The Bräcke-seeded stand contained the most stems per plot (40) followed by the natural stand (32), aerial-seeded stand (26), and planted stand (23). Clear 60-cm-long bolts (stem

Table 1. Mean sample tree attributes for each regeneration method.

Variable[a]	Regeneration method			
	Aerial-seeded	Bräcke-seeded	Planted	Natural
Stems/plot[c]	26	40	23	32
DBH	12.2 ± 1.2[b]	11.8 ± 1.5	13.9 ± 1.2	12.1 ± 1.2
HT	9.88 ± 0.80	10.72 ± 0.54	12.07 ± 0.72	10.28 ± 0.58
HT to LC	4.45 ± 0.33	5.3 ± 0.68	5.75 ± 0.98	4.57 ± 0.87
LCL	5.44 ± 0.80	5.41 ± 1.18	6.33 ± 0.79	5.72 ± 0.73
LCD	2.44 ± 0.50	2.24 ± 0.53	2.53 ± 0.76	2.44 ± 0.53

[a] Stems/plot: all trees ≥5 cm dbh within a 5.64-m radius plot.
[b] Standard deviation.
[c] Stems/plot also represents the number of sample trees.
DBH, diameter at breast height of jack pine trees ≥5 cm dbh; HT, height; HT to LC, height to live crown; LCL, live crown length; LCD, live crown diameter.

sections) in the longitudinal direction were removed at approximately 1-, 2-, and 4-m heights starting from the tree base. All bolts were labeled with a metal tag indicating regeneration method, tree number, and bolt number. Bolts removed from the 1-, 2-, and 4-m heights were labeled Bolts 1, 2, and 3, respectively. These were then taken to the Lakehead University Wood Science and Testing Facility for further processing into samples for determining MOE, MOR, and specific gravity. The bolts were processed into 20 × 20 × 300-mm specimens for static bending tests. All specimens lying within a cruciform pattern, with the pith centered, were used for testing.

Testing Procedures

Static bending tests were performed on 20 × 20 × 300-mm specimens in 3-point flexure using a Tinius Olsen H10KT with a maximum load capacity of 4.9 kN and a load span of 240 mm with Test Navigator software. The loading head was applied at 8 mm/min until failure. Testing was in accordance with the methods outlined in ISO (1975a). A data acquisition computer using Test Navigator software recorded the load-deflection curve for each test sample and calculated MOE. After each test, a portion of the specimen (25 ± 5 mm) near the rupture was sampled to determine moisture content at the time of testing. The procedure was in accordance with ISO (1975b). Once the moisture content of each piece was determined, the corresponding MOE and MOR values were adjusted to 12% MC following the moisture adjustment procedures in ASTM (1998).

The small block of wood removed for the determination of the moisture content test was also used to determine specific gravity. The volume by measurement methodology outlined in ASTM (2002) was used to determine specific gravity based on oven-dry weight and volume. Digital calipers were used to measure the length, width, and depth of each piece to ±0.01 mm, while the weight was measured to ±0.01 g. The specific gravity of each specimen was then converted to a nominal (12% MC) basis following the procedure outlined in the Appendix of D 2395-02 (ASTM 2002).

Analysis of variance (ANOVA) tests were performed using the General Linear Model method in SPSS software to test the null hypotheses: 1) that regeneration method had no effect on MOE, MOR, or specific gravity; and 2) that vertical position of the bolt within each regeneration method had no effect on MOE, MOR, or specific gravity. When the null hypothesis was rejected, Tukey's honestly significant difference (HSD) test was performed to determine which means significantly differed. The significance level was 0.05 for all analyses.

RESULTS AND DISCUSSION

Influence of Regeneration Method on Wood Properties

Trees selected for analysis of wood properties were similar in diameter and crown characteristics (Table 1). A statistical summary of the mean MOE and MOR values for each regeneration

Table 2. Statistical summary of the wood properties for each regeneration method.

			Regeneration method			
Wood property	Bolt[a] no.	No. of bolts	Aerial-seeded	Bracke-seeded	Planted	Natural
MOE (GPa)	1	12	5.47 ± 0.93[b]-89[c]	5.31 ± 0.95-95	5.47 ± 1.03-127	6.19 ± 1.27-98
	2	12	5.17 ± 0.99-80	5.43 ± 0.99-80	5.41 ± 1.10-114	5.92 ± 1.18-82
	3	12	4.79 ± 1.10-62	5.45 ± 0.78-61	5.54 ± 1.19-88	5.45 ± 1.35-57
	Mean	36	5.14 ± 1.02-50	5.40 ± 0.89-79	5.47 ± 1.08-110	5.85 ± 1.27-79
MOR (MPa)	1	12	61.6 ± 5.2	60.9 ± 5.1	60.8 ± 6.2	67.3 ± 6.8
	2	12	58.7 ± 6.3	60.5 ± 4.5	59.3 ± 7.1	63.7 ± 7.9
	3	12	56.3 ± 6.1	59 ± 4.8	60.7 ± 6.8	59.5 ± 7.0
	Mean	36	58.9 ± 6.1	60.7 ± 4.7	60.2 ± 6.6	63.5 ± 7.7
SG	1	12	0.39 ± 0.02	0.4 ± 0.02	0.41 ± 0.03	0.41 ± 0.02
	2	12	0.38 ± 0.02	0.38 ± 0.02	0.39 ± 0.03	0.39 ± 0.03
	3	12	0.37 ± 0.02	0.36 ± 0.01	0.40 ± 0.03	0.38 ± 0.02
	Mean	36	0.38 ± 0.02	0.39 ± 0.02	0.40 ± 0.03	0.39 ± 0.03

[a] Center points of Bolts 1, 2, and 3 were located at 1, 2, and 4 m, respectively, from the base to the top of the tree.
[b] Standard deviation.
[c] Number of specimens cut from each bolt. Note: specimen number for MOR and SG are the same as for MOE.
MOE, modulus of elasticity; MOR, modulus of rupture; SG, specific gravity.

method is presented in Table 2. The natural stand had the highest mean MOE and MOR (5.85 GPa and 63.5 MPa, respectively), while the aerial-seeded stand had the lowest (5.14 GPa and 58.9 MPa, respectively). Although differences in mean MOE and MOR were observed among the four regeneration methods, the ANOVA revealed that they were not different at the 5% significance level. The lack of significant difference for both mechanical properties may have been because of similar sample tree characteristics and juvenile wood content. Because the stands were established about 1980, trees sampled within this study, greater than or equal to 10-cm dbh, were representative of the largest trees within each established plot. Also, from visual observations, the trees tended to have more growing space and were classified codominant or dominant. Codominant and dominant trees generally possess large, vigorous crowns with relatively wide bands of earlywood produced along the bole of the tree (Larson 1962). Overall mechanical property differences may not have been identified because all the sample trees were in a similar stage of development and dominance. For example, Amarasekara and Denne (2002) observed that crown class influenced MOR and MOE for Corsican pine (*Pinus nigra* var. maritime). They found that MOR and MOE from small clear specimens of Corsican pine decreased as crown class went from dominant to suppressed.

In addition to similar tree attributes, the presence of juvenile wood most likely contributed to a lack of significant difference of MOE and MOR among the four regeneration methods. Jack pine juvenile wood reportedly extends over 12-18 yr (Bodie 1988) or up to 20 yr (Hatton and Hunt 1993). Juvenile wood in widely spaced plantations has also been found to extend this phase of growth to beyond 20 yr (Eriksson et al 2006). Therefore, the wood specimens tested in the present study were mostly comprised of only juvenile wood. Within the juvenile zone, wood properties such as tracheid length (Seth 1981) and microfibril angle (Barnett and Bonham 2004) rapidly change from pith to bark. The jack pine wood specimens used for determining MOE and MOR would have contained rapidly changing cell characteristics. Consequently, similar MOE and MOR values were observed across all regeneration methods. Differences in MOE and MOR may have been found if the trees were older and contained a greater portion of mature wood (Eriksson et al 2006).

Both MOE and MOR values from all four regeneration methods were low compared with published values for jack pine (Porter 1981). MOE and MOR values from Porter (1981) were based on mature naturally grown trees, whereas trees sampled for the present study were primarily composed of juvenile wood, which has been demonstrated to have lower strength properties compared with mature wood (Bendtsen 1978; Bendtsen and Senft 1986; Zhou and Smith 1991; Kretschmann and Bendtsen 1992; Bao et al 2001; Passialis and Kiriazakos 2004). For example, Bendtsen and Senft (1986) demonstrated an approximate 5-fold increase in MOE and 3-fold increase in MOR for loblolly pine from early juvenile wood to mature wood. In both plantation and naturally grown trees, Bao et al (2001) found that juvenile wood was weaker than mature wood in five coniferous and five deciduous species. Differences in strength between juvenile and mature wood was attributed to the differing cell characteristics (Bao et al 2001). In addition to juvenile wood content, compression wood may also have been a contributing factor resulting in lower strength values. The stem in young trees is quite flexible and the presence of wind induces the production of compression wood to maintain a fixed vertical position of the trees (Brazier 1977). Juvenile wood tends to contain compression wood, which is weaker than normal wood (Panshin and de Zeeuw 1980; Dhubhain et al 1988).

Table 2 also presents the mean specific gravity for all four regeneration methods. The values were similar for all four regeneration methods ranging from 0.38 for the aerial-seeded stand to 0.40 for the planted stand. ANOVA confirmed that specific gravity values did not differ at the 5% significance level among the four regeneration methods. The lack of a significant difference may be from the strong heritability of specific gravity in jack pine (Okwuagwu and Guries 1980; Villeneuve et al 1987). Moreover, a significant difference may not have been observed since the trees were in a juvenile stage of development. Larocque and Marshall (1995) studied the influence of seven initial stand densities on wood-specific gravity in red pine plantations. They found that although stand density strongly affects specific gravity, it did not differ much among initial stand densities at young ages. As the stands grew older, specific gravity increased and closer initial stand densities resulted in higher relative wood-specific gravity at maturity. The specific gravity values found in our study were lower than the nominal specific gravity of 0.44 for jack pine mature wood reported by Porter (1981). The specific gravity has also been found to increase from pith to bark for most conifer species (Spurr and Hsiung 1954; Megraw 1985; Zobel and van Buijtenen 1989).

Influence of Vertical Position on Wood Properties

The mean MOE and MOR values for three vertical positions in each regeneration method are presented in Table 2. Both the aerial-seeded and natural stands exhibited mean MOE values that decreased with increasing height. In contrast, the Bräcke-seeded stand exhibited the opposite pattern. The planted stand did not follow either of these vertical patterns, where Bolt 3 had the highest mean MOE value followed by Bolts 1 and then 2. Although vertical variation in MOE was observed within each regeneration method, MOE values were not found to be significantly different at the 5% level using ANOVA analysis (Fig 1). Earlier studies observed decreasing MOE values with increasing height in planted slash pine (MacPeak et al 1990), planted jack

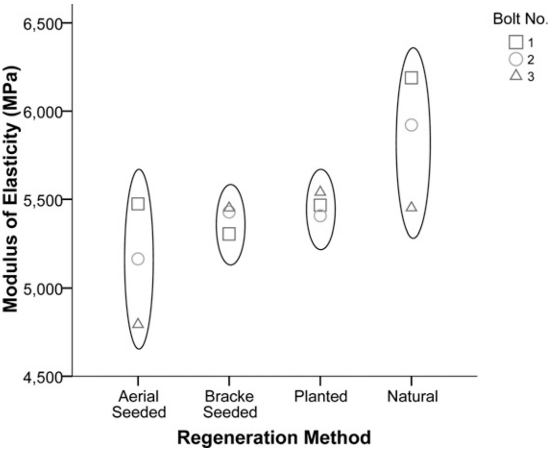

Figure 1. Variation of modulus of elasticity (MOE) with regeneration method and vertical position. Bolts within the same ellipses do not have significantly different MOE at the 5% level.

pine (Zhang et al 2005), and seeded Scots pine subjected to thinning (Eriksson et al 2006). Higher stiffness in the planted Bolt 3 compared with Bolts 1 and 2 was possibly because of proximity to the crown and increased resin content. This pattern has been observed in 35-yr-old planted loblolly pine (Biblis et al 1995), however, the authors did not provide reasons for the difference. In the Bracke-seeded stand, the average lower stiffness value near the base may have been from compression wood, which is a common occurrence at and below breast height.

The mean MOR values of the aerial-seeded, Bräcke-seeded, and natural stands follow the pattern of decreasing MOR with increasing height (Table 2). In contrast, while Bolt 1 had the greatest MOR for the planted stand, Bolt 3 was slightly greater than Bolt 2. Vertical variation in MOR within each regeneration method was observed to be different at the 5% significance level using ANOVA analysis. Tukey's HSD post hoc tests revealed that MOR values were significantly different between Bolts 1 and 3 only for the aerial-seeded and natural stands (Fig 2). The lack of significant difference in MOR values with height for the Bräcke-seeded and planted stands may be attributed to their crown attributes. On average, the heights to live crown for the aerial-seeded and natural stands were approximately 4.5 m (Table 1); thus, top bolts within these stands came from just below the live crown. In contrast, the height to the live crown for Bräcke-seeded and planted stands was higher by approximately 1 m (Table 1), and therefore, the top bolt came from much below the live crown. Cell characteristics are influenced by proximity to live crown and cambial age (Hillis 1984; Savidge 1993; Larson 1994). A greater percentage of cells within each growth ring exhibit latewood characteristics such as thicker cell walls away from the live crown because of the presence of older cambium and greater distance from the growth centers. Latewood cells are stronger than earlywood, which are found in greater proportions closer to and within the crown; therefore, wood produced higher within the tree tends to be weaker than wood produced basipetally along the bole. Also, the aerial-seeded and natural stands might have begun production of transition wood at the base of the stem. This would create differences in earlywood and latewood proportions, microfibril angle, specific gravity, and cell length, which would contribute to the differences in MOR between Bolts 1 and 3.

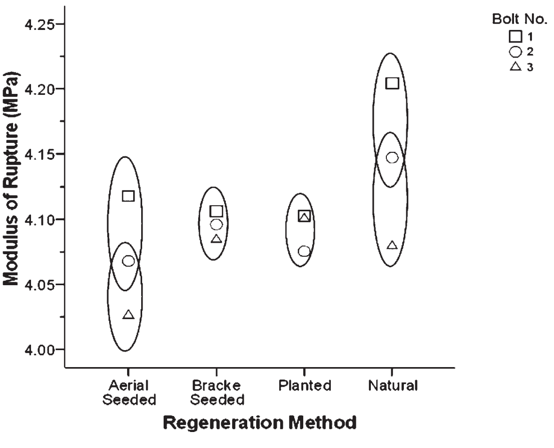

Figure 2. Variation of modulus of rupture (MOR) with regeneration method and vertical position. Bolts within the same ellipses do not have significantly different MOR at the 5% level.

The aerial-seeded, Bräcke-seeded, and natural stands had a decrease in specific gravity with height (Table 2). Similar differences have been observed for loblolly pine (Megraw 1985), ponderosa pine (Mackes et al 2005), and jack pine (Dechesne 2006). However, the planted stand did not show the same pattern for specific gravity with vertical position since Bolt 3 was greater than Bolt 2. Results of ANOVA analysis and Tukey's HSD post hoc tests revealed that bolt positions 1 and 3 were significantly different at the 5% level for specific gravity in three stands: aerial-seeded, Bräcke-seeded, and natural (Fig 3). The presence of knots and branches along vertical positions can also affect the specific gravity of wood in the proximity of knots. Larson (1962) attributed an increase in specific gravity within the upper crown to the presence of knots and branches, however, our study did not account for these. An increase in resin

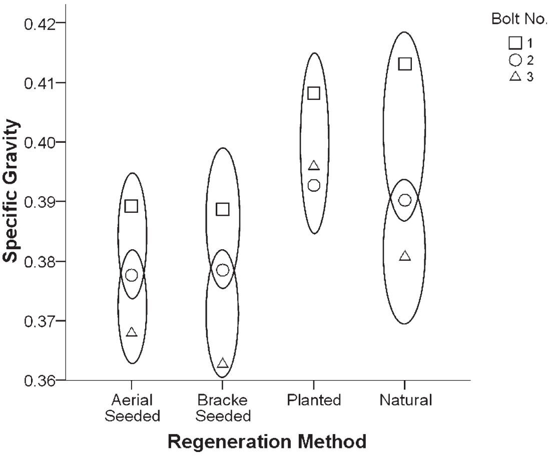

Figure 3. Variation of specific gravity with regeneration method and vertical position. Bolts within the same ellipses do not have significantly different specific gravity at the 5% level.

content and grain deviations caused by compression wood produced near branches may have led to an increase in specific gravity within Bolt 3 in the planted stand.

CONCLUSIONS

The objective of the study was to test the effects on static bending properties and specific gravity of juvenile jack pine growing under four different regeneration methods in boreal forests of northwestern Ontario: aerial-seeding, Bräcke-seeding, planted, and postfire natural growth. It was expected that different regeneration methods would produce different wood properties because of differences in initial stand density. No significant differences were found among regeneration methods with respect to MOE and MOR in static bending and specific gravity. However, significant variability of these properties was observed within each regeneration method. This indicates that wood properties of jack pine in the juvenile stage of development are quite variable, regardless of the regeneration method.

The aerial-seeded, Bräcke-seeded, and postfire natural regeneration methods exhibited a significant difference in wood properties between the lower and upper bolts. These results indicate that there is potential in sorting jack pine logs along the stem for various uses based on the regeneration method. For example, the top portions of logs from the aerial-seeded, Bräcke-seeded, and natural stands may be more suitable for pulp production while the bottom log could be used for lumber. This sort would add value to the utilization of jack pine. However, the results of this study are not conclusive because it was limited to investigating the properties of only juvenile wood. Because of the observed variability of juvenile wood properties, it is recommended that future studies should reinvestigate the properties within these jack pine stands when a majority of the stem is mature wood.

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