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Effect of natural root grafting on growth response of jack pine (*Pinus banksiana*) after commercial thinning

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ABSTRACT

Commercial thinning is a silvicultural treatment used to increase the merchantable yield of residual trees. Growth response to thinning, however, is highly variable and discrepancies between studies remain largely unexplained. The objective of this study was to demonstrate the effect of natural root grafting on growth response after thinning. We excavated root systems of jack pine (*Pinus banksiana*) in five naturally regenerated stands, in which three had been commercially thinned 6 and 9 years earlier. Radial growth before and after thinning was examined using dendrochronological techniques. Thinning increased radial growth of trees, however growth increments were significantly less for trees that had root grafts with removed trees, while growth of grafted trees was better in unthinned stands. Furthermore, radial growth response of trees grafted to removed trees was smaller than that of non-grafted trees 4 years and more post-thinning. On average, non-grafted stumps survived less than 1 year (0.4 year), while grafted stumps lived 2.0 years after the stem was removed. Differences in growth response to thinning between grafted and non-grafted trees thus appear to be linked to the support of roots and stumps of removed trees by live residual trees.

1. Introduction

Commercial thinning is often prescribed to increase merchantable yield and profitability of forest stands by increasing the diameter growth of residual trees, salvaging potential mortality, increasing product quality, releasing suppressed individuals, and removing undesirable species (Karsh et al., 1994; Pothier and Margolis, 1991; Schneider et al., 2008; Smith et al., 1997). Thinning affects tree growth by reducing the number of stems and concentrating resources (light and nutrients) on remaining crop trees (DeBell et al., 2002; Smith and Oerlemans, 1988). However, this silvicultural treatment does not always give expected results; in some cases, tree growth stagnates or decreases, and stands often show high mortality rates following treatment (Cayford et al., 1967; Day and Rudolph, 1972; DeBell et al., 2002; Gingras and Favreau, 1998; Harrington and Reukema, 1983; Staebler, 1956; Vincent et al., 2009). Mäkinen and Isomäki (2004a,b) compared different thinning intensities with unthinned stands and did not find differences between stem volume increments in Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris* L.). Growth delays after thinning were also observed in tropical species such as *Eucalyptus grandis* (Smith and Brennan, 2006). These negative responses, which are referred to as "thinning shock" (DeBell et al., 2002; Harrington and Reukema, 1983), have generally been observed immediately following treatment and usually lasted less than 15 years (Harrington and Reukema, 1983).

Different explanations have been given to describe "thinning shock," but there is no general consensus in terms of explaining differences in response to thinning. Some authors have shown that residual trees responded to new growing conditions after thinning by increasing root biomass allocation (Liu et al., 2003; Nicoll and Dunn, 2000; Nicoll and Ray, 1996; Ruel et al., 2003; Urban et al., 1994; Vincent et al., 2009). Wind penetrates more easily into forest stands after thinning or partial cutting, which translates into greater mechanical stress acting on roots (Man and Lieffers, 1999; Nicoll and Dunn, 2000; Pothier and Margolis, 1991; Rizzo and Harrington, 1988; Ruel et al., 2003; Vincent et al., 2009). As woody root systems provide anchorage and structural support, trees need to immediately allocate more biomass to parts of the trunk and roots that are subject to higher stresses, while growth of aerial parts may be delayed (Coutts et al., 1999; Rizzo and Harrington, 1988; Ruel et al., 2003).

Thinning shock could also be explained by increased water stress following thinning (Bladon et al., 2007; Man and Lieffers, 1999; Proe et al., 2001); Although reduced tree density may increase soil moisture availability, greater wind and sunlight pen-

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Table 1
Characteristics of the five excavated plots.

	Site 1	Site 2	Site 3	Site 4	Site 5
Total size of excavated area (m^2)	40	50	50	40	40
Stand age (years)	1953–1956	1948–1952	1943–1948	1944–1947	1942–1947
Density prior to/after thinning (trees ha^{-1})	3700/2000	3600/1600	5000/3200	4400	4000
Thinning date	1998	1998	1998	Unthinned	Unthinned
Mean DBH (cm)	12.27	15.61	12.80	17.22	13.17
Mean height (m)	14.38	18.40	12.65	15.40	15.89
Number of excavated trees	13	18	25	17	16
Number of grafts	12	12	18	15	11
Number of grafted trees	9	8	15	12	9
Number of grafted trees thinned	5	5	8	Unthinned	Unthinned
Number of grafted trees uncut	4	3	7	Unthinned	Unthinned
Mean number of grafts per tree	0.92	0.67	0.72	0.88	0.69
Mean number of grafts per hectare	3000	2400	3600	3750	2750
Percentage of grafted trees (%)	69	44	60	71	56

etration into the stand increases evapotranspiration rates (Pothier and Margolis, 1991). Furthermore, machinery used for removing trees can cause wounds on residual tree boles and their root systems, which may weaken them or create entry points for diseases (Boddy, 2001; Hennon and DeMars, 1997). As thinning shock is reduced with nitrogen fertilization (Brix, 1993; Crown et al., 1977; DeBell et al., 2002; Devine and Harrington, 2009; Winston, 1977), it has also been suggested that site quality contributes to differences in stand response to thinning (DeBell et al., 2002; Harrington and Reukema, 1983; Mäkinen and Isomäki, 2004a, 2004b). In poor sites, thinning may not increase growth of residual trees if nutrients are limiting (Devine and Harrington, 2009). Other studies have suggested that thinning shock results from deterioration of leaf photosystems following increased light exposure of the shade-tolerant species that remain after thinning (Krause, 1988; Leverenz et al., 1990; Marshall et al., 2000; Öquist et al., 1992).

In this study we propose an alternative hypothesis to thinning shock: natural root grafting. Natural root grafts have been found in many tree species (Graham, 1959), including natural stands and plantations of jack pine (*Pinus banksiana* Lamb.), where we found a high frequency of natural root grafting (up to 70% or more of the trees; Tarroux and Desrochers, 2010). It has been found that the roots and stumps of dead or cut trees could be kept alive through root grafts with living residual trees (DesRochers and Lieffers, 2001; Fraser et al., 2007; Tarroux and Desrochers, 2010). This indicates that carbohydrates are transferred from living trees to the roots and stumps of removed or dead trees (Fraser et al., 2006). Consequently, if stands are heavily thinned, grafted residual trees might not benefit from decreased competition for resources that results from stand thinning (Bormann, 1966), because the roots and stumps of the removed trees would constitute a sink for carbohydrates, thereby limiting aboveground growth of the residual trees (Bormann, 1966; Eis, 1972; Graham and Bormann, 1966). No previous study has demonstrated that tree response to thinning could be hindered by the presence of root grafts. The objective was to determine if the presence of root grafts affected diameter stem growth response to commercial thinning. We hypothesized that growth of residual trees grafted to removed trees would be less than growth of non-grafted trees after thinning.

2. Materials and methods

2.1. Study sites

Root systems in five mature (age ≥50 years) jack pine stands were excavated. Three of the sites had been commercially thinned (i.e., stems removed had diameter at breast height (DBH) > 10 cm) in 1998 (stands T) while the two other sites were control unthinned stands (stands C; Sites N1 and N2 in Tarroux and Desrochers, 2010). The stands were located between 48°20′N and 48°41′N, and between 77°16′O and 78°8′O in the western balsam fir-paper birch (*Abies balsamea–Betula papyrifera*) bioclimatic domain of the boreal forest of eastern Canada (Grondin, 1996). Precipitation averages 918 mm annually (rainfall 671 mm, snowfall 248 mm) and average (±standard deviation, SD) annual temperature is 1.2 ± 2.2 °C (Environment Canada, 2004). Soils were sandy sediments associated with glaciofluvial deposits (eskers) originating from the retreat of the Laurentide ice sheet (8000–10,100 years bp) during the last glacial cycle and the submergence of the region by proglacial Lake Barlow-Ojibway (Veillette, 1994). Stands were even aged and of post-fire origin, with trees fairly uniform dimensions (mean ± standard error (SE): DBH, 14.21 ± 0.85 cm; height, 15.34 ± 0.84 m; Table 1). The stands were constituted of more than 90% jack pine and were located near a water source (pond, lake or river) to allow hydraulic excavation. Prior to thinning, tree density ranged from 3800 to 5000 stems ha^{-1}, which was reduced to 2000, 2200 and 3200 stems ha^{-1} after thinning for sites 1, 2 and 3, respectively (Table 1). In control stands, tree density was 4400 and 4000 stems ha^{-1} for sites 4 and 5, respectively (Table 1). On all thinned sites, basal diameter of the trees removed in the thinning treatment was similar to that of the residual trees (Table 2). This treatment could be labelled as ‘crown thinning’ (MRNFQ, 2003).

2.2. Field work

Sampling was done in June 2005 for sites 1, 2, 4 and 5 and in October 2007 for site 3. Trees were felled with a chain saw, and cross-sectional disks were taken at ground level (0 m) and at breast height (1.30 m) for age determination. Root systems were excavated using a high pressure water spray from a forestry water pump (Mark III, Wajax, Lachine, QC). Excavated areas ranged from 40 to 50 m^2 in size, depending on the spatial distribution of the trees, so that at least 10 individuals were included per site (Table 1). Roots of trees extending outside the excavated area were followed up to a diameter of 2 cm to ensure that no root grafts were missed. Maps depicting all trees, stumps, roots, and grafts were carefully drawn by hand. To assess the condition of stumps from thinned trees (dead/alive), we examined the state of decomposition of the wood

Table 2
Student’s *t*-test results on diameter at stem base of cut and uncut trees at thinning date (1998) for each thinned stands.

	Site 1	Site 2	Site 3
Mean diameter of uncut trees (cm)	8.800	9.419	10.512
Mean diameter of cut trees (cm)	10.230	11.423	9.269
P-Value	0.598	0.399	0.112