International Conference "Wind Effects On Trees"
September 16-18, 2003, University of Karlsruhe, Germany

EFFECT OF PRECOMMERCIAL THINNING ON BALSAM FIR RESISTANCE TO WINDTHROW

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Abstract

Precommercial thinning is often used to control stand density in naturally regenerated balsam fir (*Abies balsamea*) stands. Early stand density control could have beneficial effects on longer term stand stability through a modification of stem shape and root development. To assess the effect of precommercial thinning, two thinned and two unthinned stands were studied. Detailed root measurements were taken on sample disks to assess treatment effect on root shape. Static tree pulling was used to measure treatment effect on tree resistance to uprooting. Growth response was more pronounced in the roots than in the stem. Trees allocated more to radial growth above the biological centre of the root, both in treated and control stands, but this trend was increased by thinning. Roots also tended to develop T-beam shapes over time, both in control and thinned stands. Trees allocated more to the root portions subjected to the greatest mechanical stresses. This enabled them to keep a balance with the better development of the above-ground part so that the relationship between critical turning moment and stem weight was not modified. However, the larger weight of thinned stems increase the critical wind speed at the moment where a commercial thinning could be applied.

Introduction

Balsam fir is a major species in the boreal forest of North America that can regenerate abundantly from an understory seedling bank (Morin and Laprise 1997). This regeneration often develops into over-dense sapling stands that require tending. Pre-commercial thinning has thus become a current practice for these stands.

The reduced number of trees left after thinning increases wind penetration into the stand and thus the transpiration rate (Pothier and Margolis 1990; Pothier and Margolis 1991). It also induces larger displacements of the tree stem, which translates into greater stresses acting on tree roots (Stokes et al. 1995). Increased tree sway would then lead to increased allocation to the parts of the trunk and the root system subjected to the highest stresses (Coutts et al. 1999; Mattheck 1991; Nicoll and Ray 1996). Modifications in root development in young stands would play a major role since they could have a long term impact on the stability of older stands (Coutts 1983; Coutts et al. 1999).

Most studies on adaptive growth have been conducted with Sitka spruce (Coutts et al. 1999; Nicoll and Ray 1996) in very windy conditions. We have very little information on root response to silviculture for other North American conifer species in less windy conditions.

The objectives of the present study are: 1) to describe root growth response over time after precommercial thinning; 2) to assess its impact on individual root morphology; and 3) to assess treatment effect on longer term stability.

Methods

The study was conducted at the Montmorency Forest, 75 km north of Québec city (47° 13' to 47° 22'N, 71° 05' to 71° 05'W). It is located in the boreal humid balsam fir-white birch climatic subdomain of central Québec. Our study sites were chosen in an area that regenerated naturally from advance regeneration left after clear fellings conducted in 1967. Four even-aged balsam fir stands were selected on deep mesic till. Two had been treated with precommercial thinning, and the two others had been left untended. The thinning operations were conducted respectively in 1984 and 1989 with circular brush saws.

Five dominant or co-dominant stems were randomly selected in each stand. Sample collection was done during July 1999. Root systems were carefully excavated by hand with the final removal of soil particles done with compressed air. For each subject tree, cross sections were cut at 25 cm from the biological centre of the stump on primary roots with a diameter greater than 2 cm. The top point of each root was marked so that growth could be differentiated between the upper and the lower part of the roots. A stem disk was also collected at breast height (1.40 m) to compare stem and root response.

Growth was analysed using WinDendro software (Guay et al. 1992). Radial increment was measured separately for two radii corresponding to the upper and lower part of the root and averaged for all the roots of a single tree. Root and stem growth after thinning was analysed as repeated measures series according to the approach suggested by Meredith and Stehman (1991). The time at which growth became significantly greater than pre- treatment values was determined by a t-test comparing mean growth for the three years before treatment with that for a single year after treatment. To compensate for multiple t-tests, a α level of 0.01 was used. To illustrate stem and root growth responses on a similar scale, a relative response was calculated:

$$response(\%) = 100 \times \frac{(growth_i - growth_0)}{growth_0}$$

where $growth_0$ represents growth before treatment and $growth_i$ corresponds to growth for year *i* after treatment.

Asymmetry was analysed according to Nicoll and Ray (1996). The *Va/Vb ratio* compares thickening in a vertical plane between the upper and the lower part of the root. The *T-angle* describes the tendency to develop a T beam shape by increasing the lateral widening of the upper part of the root relative to the lower part. The *I-angle* measures the tendency to develop an I-beam shape by allocating more biomass to the widening of both the upper and the lower sections in comparison with the biological centre.

The *Va/Vb* ratio was calculated for each year following treatment and analyzed as repeated measures following Meredith and Stehman (1991). *I-* and *T-angle* values were calculated for each tree at the time of treatment and ten years later and those values were compared with a t-test to detect significant changes in root form at the tree level. Mean differences in angle were then compiled for each tree. A t-test was performed with these differences to detect changes at the treatment level followed by an ANOVA to compare treatment effect.

Ten stems were selected in each stand for tree pulling studies according to Meunier et al. (2000) and Silva et al. (1998). A load was applied with a winch and the load was recorded with a load cell. A video camera, placed at a 90-degree angle from the tree-winch axis, recorded each tree pulling trial in order to know stem position at the time of maximum load. The trees were cut into sections. Sections were weighed and detailed crown measurements were taken. Covariance analysis using stem weight as a covariate was used to test the stand effect on critical turning moments. The critical wind speed required to damage the stands 25 years after treatment was calculated by adjusting ForestGales model parameters (Gardiner et al. 2000) and using published data (Ker 1987) for precommercially thinned balsam fir stands.

Results

Stem growth after thinning was greater on the average than in control stands (p=0.0001). An interaction between the effect of treatment and the cubic effect of time was also detected, suggesting that radial growth evolved differently between treatments (p=0.0036). Significant increases in growth were noted in treated stands 2 and 3 years after thinning (Figure 1). Afterwards, radial growth dropped back to values similar to before treatment. In control stands, a significant decrease was noted 10 years after treatment.

Thinning induced a strong response in root growth which was, on the average greater in treated stands (p=0.0003). A significant interaction also occurred between the effect of treatment and the quadratic effect of time (p=0.0003). In control stands, growth remained relatively stable (no response coefficient was significant) while a significant quadratic effect was detected in thinned stands. Growth in thinned stands was significantly different from pre-treatment for all years, except year 9 (Figure 1).

The growth response in roots did not occur in a uniform fashion. There was a significant interaction between the effect of treatment on *Va/Vb* ratio and the linear effect of time (p=0.0103). A significant increase in the *Va/Vb* ratio with time was noted in the thinned stands but not in the control stands. *Va/Vb* values started to differ from pre-thinning values at year 3 after treatment (Figure 2). In control stands, even though there was a tendency for an increase in ratio over time, the linear trend was not significant and the values did not differ from initial values. Even in the absence of treatment, trees allocated more to the upper part of the root.

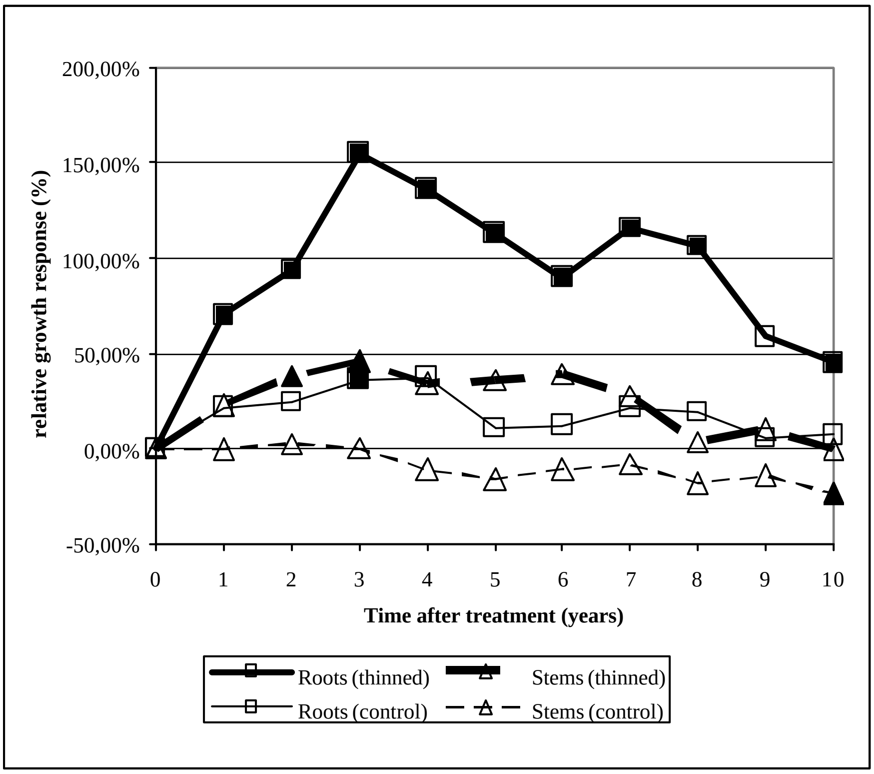

Fig. 1. Relative growth response to thinning in stem and roots. Filled symbols denote significant differences with initial values (α=0.01).

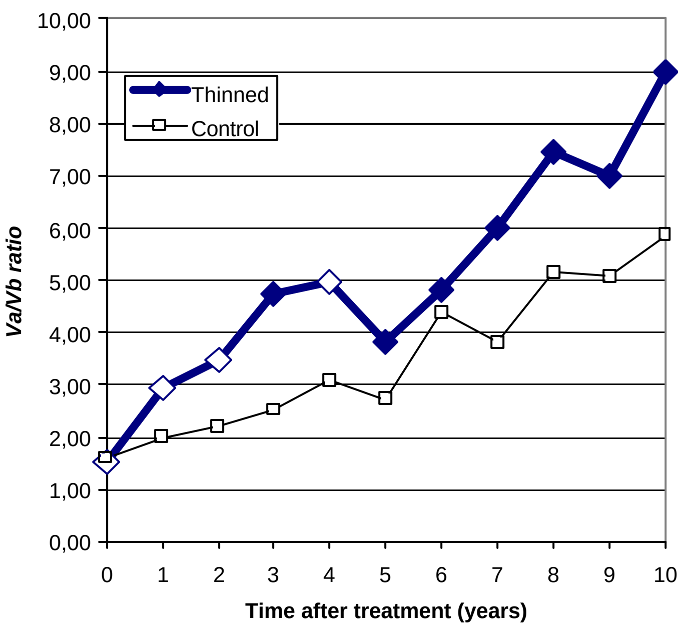

Fig. 2. Evolution of the Va/Vb ratio. Filled symbols denote significant different differences with initial values (α=0.01).

Root shape at the time of thinning varied but some of them already showed T-beam shapes (angles greater than 90^o). There was a general increase in *T-angle* over time for both the control (p=0.0106) and the thinned (p=0.0001) stands. However the evolution in *T-angle* was not affected by treatment (p=0.4053). At the end of the study most roots had angles greater than 90^o. Most roots initially did not possess an I-beam shape (*I-angle* greater than 180^o) and did not develop one during the course of the study. However, an increase in *I-angle* occurred in thinned stands (p=0.0257) and the trend was almost significant in the control stands (p=0.0692). Treatment effect on the evolution of *I-angle* was not significant (p=0.9012).

Figure 3 shows the relationship between the critical turning moment and stem weight for all pulled trees ($M_{crit} = 147.8 \times SW - 3110$; r^2=0.81). The covariance analysis performed on this data showed that both the single effect of the stand and its interaction with stem weight were far from being significant. This means that the thinning treatments had no impact on the critical turning moment required to uproot or break a tree of a given weight. However, since stem size is increased by the treatment, the simulated critical wind speed was increased by 10 and 19% respectively for overturning and stem breakage, 25 years after treatment.

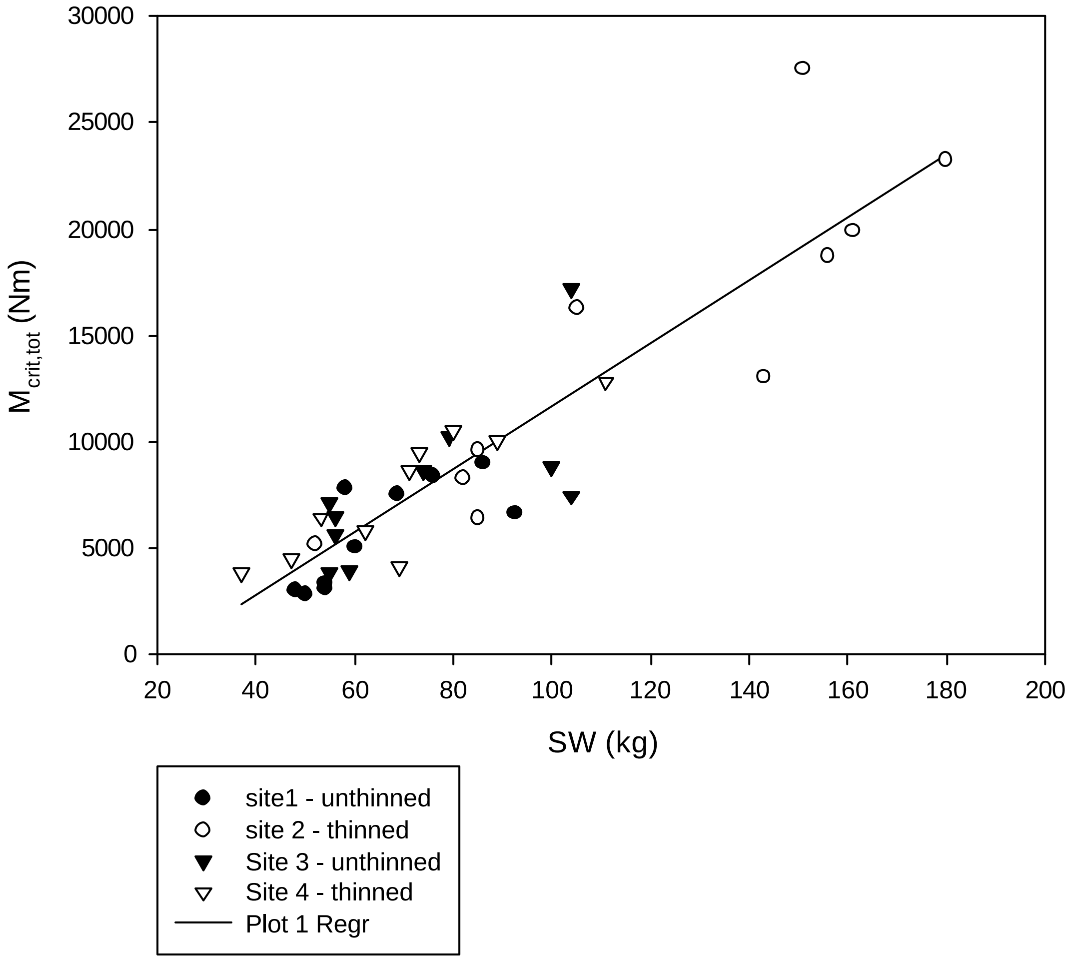

Fig. 3. Relationship between stem weight (SW) and critical turning moment (Mcrit) for thinned and unthinned balsam fir stands.

Discussion

Precommercial thinning had a significant effect on radial stem growth relative to the control. However, the effect was more to prevent a decrease rather than to generate a marked increase. Growth reaction was stronger and significant increases occurred earlier in root than in stem growth. Such a difference has been cited by various authors after release or thinning treatments (Fayle 1983; Kneeshaw et al. 2002; Urban et al. 1994).

The fact that root growth is enhanced before stem growth could be explained by the need for the tree to increase its water absorbing capacity in order to meet the increased evaporation of the existing and newly produced foliage (Kneeshaw et al. 2002). An increase in root growth can also be beneficial in terms of tree stability (Crook 1996). Diameter growth is especially important since the stiffness of the root is function of its diameter raised to the fourth power (Coutts 1983). In a flexing study, Stokes et al. (1997) observed an increase in the biomass of the main roots and in the root/stem biomass ratio under their low nutrient treatment. This would help to increase the tree resistance to uprooting so that the tree remains stable in the new wind conditions.

If the increase in root growth did occur only to meet the respiration needs of the foliage, root growth would probably be distributed rather evenly. Clearly, this was not the case; some heterogeneity occurred but not for all the variables measured. An asymmetry occurred in the allocation between the upper and the lower parts of roots. Even if control trees allocated more to the upper part, their *Va/Vb ratio* did not increase significantly during the course of the study, contrary to what occurred after thinning. Near the base of the trees, the stress transmitted to the root would be maximum at the top of the root (Mattheck 1991). Thus, the increase in *Va/Vb ratio* would be consistent with the assumption that trees allocate more to regions submitted to higher stresses (Mattheck 1991; Mattheck and Kubler 1997). It is interesting to note that this response was observed in an environment where wind conditions are far from extreme. Mean annual wind speed at the local weather station is only 7 km/h which is much lower than Great Britain conditions where many studies on asymmetry were conducted. For instance, Hannah et al. (1995) reported mean wind speed values of 22 to 24 km/h for Edinburgh, respectively for 1989 and 1990.

There was a natural tendency for roots in both stand types to develop T-beam shapes and this trend was not influenced by treatment. An increase in *T angle* could have the same explanation as the increase in *Va/Vb ratio.* There was a general tendency for an increase in *I-angle* but the trend was not affected by treatment and most roots did not develop an I-beam shape during the study. The I-beam shape would maximise the resistance in flexion for a given amount of biomass allocated (Mattheck and Kubler 1997). According to Mattheck (1991) and Nicoll and Dunn (2000), such a shape would occur farther away from the stem where only bending forces occur. The fact that our samples were cut close to the stem could explain why this shape was not seen more often.

Even though a strong response in root growth suggesting an adaptative growth was noted, the relationship between critical turning moment and stem weight was not affected. This suggest that the root response was only sufficient to keep in balance with the larger above-ground part favoured by thinning. Even then, stability at the time on commercial thinning could be enhanced by the larger stem weight at a specific age.

Conclusion

Our study has shown a strong and quick response of root growth to thinning. However, the added diameter growth was not distributed evenly inside a root. The top part of the root incorporated more new material than the bottom part. This differential allocation suggests that factors other than water transport are implicated and that mechanical adjustments are involved. Some asymmetry was also detected in control stands. It seems that the treatment effect was to enhance patterns of allocation that were also occurring in control stands. Root response appeared only sufficient to keep a balance with the larger above-ground part. However, even though the drag area of the trees and wind penetration into the stand can be increased by precommercial thinning, the greater stem weight would make the trees more resistant at the time of commercial thinning.

Acknowledgements

This study was funded by the Natural Sciences and Engineering Research Council of Canada and Hydro-Québec

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