

Early development of tended mixtures of aspen and spruce in western Canadian boreal forests

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Abstract

In 1992, the Western Boreal Growth and Yield Association (WESBOGY) began a long-term study to evaluate the dynamics of regenerated aspen (*Populus tremuloides* Michx.)—white spruce (*Picea glauca* (Moench) Voss) mixedwood stands following manipulation of aspen to a range of densities. In this study six levels of aspen (0, 200, 500, 1500, 4000 stems ha⁻¹ and natural) and three levels of spruce (0, 500 and 1000 stems ha⁻¹) densities have been created.

Data from four locations demonstrate substantial variation in initial aspen densities following clearcutting of aspen dominated stands. After 9 years densities begin to converge with the highest rates of mortality associated with high starting densities. A model was developed that shows a significant relationship between the proportion of trees surviving to the end of a year and the density at the beginning of the year. Size-density relationships based on quadratic mean root collar diameter, mean tree volume and mean tree height are presented.

Three to four years following spacing of aspen to densities ranging from 200 to 4000 stems ha⁻¹ there were no significant effects of density on aspen size. In addition, spacing of the aspen had no significant effect on spruce height at year 9 (3–4 years after spacing), but spruce root collar diameter (RCD) was significantly smaller in the unspaced compared to the spaced plots. The ratio of height to root collar diameter (HDR) for white spruce showed a significant and clear response to aspen density and increased with increasing aspen density.

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1. Introduction

Mixedwood forests are widespread in western Canada and represent some of the most productive forest lands within the boreal forest (Kabzems et al., 1986; Drew, 1988). The most important commercial species in western boreal mixedwood forests are white spruce (*Picea glauca* (Moench) Voss) and aspen (*Populus tremuloides* Michx.). Past management of these forests has tended to focus on growing only spruce or aspen by themselves. Current forest practices are now attempting to take advantage of these mixtures and are therefore searching for efficient and effective ways of creating and managing these mixedwood stands.

Following harvesting of upland mixedwood stands, aspen generally regenerates vigorously from root sprouts and dominates during early stages of development of the subsequent stand. When conditions are ideal, aspen can regenerate to very high densities, sometimes exceeding 100,000 stems per hectare at age 2 (Steneker, 1976; Bella, 1986). However, self-thinning generally occurs rapidly due to the shade intolerance of this species and its susceptibility to drought and disease (Peterson and Peterson, 1992). Although there have been numerous studies dealing with aspen self-thinning, few are based on annual re-measurements beginning immediately after harvest and others are limited by the number of re-measurements. More commonly juvenile aspen mortality is represented using chronosequence data or partial datasets using periodic re-measurements (Pollard, 1971; Ek and Brodie, 1975; Bella, 1986). Although insight into the self-thinning of juvenile aspen has been obtained from these studies, we currently lack juvenile aspen mortality functions for growth modeling. The lack of these functions is a major limitation in modeling the dynamics of young aspen and mixedwood stands.

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Mortality can be modeled at a stand level or at an individual tree level. At a stand level, future stand density can be predicted as a function of present stand density along with other site and stand characteristics. At an individual tree level, survival probability can be calculated based on tree size, social position, competitive status, site, and stand conditions. Because modeling mortality is so difficult, modelers often use a representation of the average rate of mortality (Flewelling and Monserud, 2002). These functions commonly underestimate mortality in very dense stands. Consequently, most models also use size-density relationships (maximum average tree size that can be achieved at a given density) to constrain stocking levels (Yang and Titus, 2002).

Reineke's (1933) stand density index (SDI) and the $-3/2$ power law of self-thinning¹ (Yoda et al., 1963) are two of the most commonly applied size-density relationships. Reineke's SDI relates density to quadratic mean diameter. By plotting the number of trees per unit area over the quadratic mean diameter on double log scale graph paper, a line fit through the upper points has a slope of approximately -1.605 . The $-3/2$ power law represents an empirical relationship between the maximum achievable average plant weight that can be reached at a particular density for a particular species (Yoda et al., 1963; Drew and Flewelling, 1977). By plotting the average plant weight over the number of trees per unit area over on double log scale graph paper the line fit through the upper data points has a slope of $-3/2$ and is referred to as the maximum size-density line. Although biomass was the original variable used with the $-3/2$ power law, any measure of mean plant size can be used, but the slope of the relationship may deviate from $-3/2$. For both SDI and the $-3/2$ power law, the relationship was initially believed to be linear and apply to all species, although this has been challenged (Weller, 1987; Zeide, 1987; Cao et al., 2000). Lieffers and Campbell (1984) found that the slope of the relationship between tree biomass and stand density was -0.96 for 23–57 year-old aspen stands. Since the $-3/2$ power law was introduced, subsequent papers have focused on verifying the intercept and constancy of the slope for different species (Puettmann et al., 1993; Begin et al., 2001), the placement of the self-thinning line (Smith and Hann, 1984; Weller, 1990; Sackville Hamilton et al., 1995), the appropriateness of the fitting methods used (Puettmann et al., 1993; Begin et al., 2001) and whether the functions are linear or curvilinear in the log form (Zeide, 1987; Cao et al., 2000).

For the boreal forest Yang and Titus (2002) developed maximum size-density functions for aspen, white spruce and lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.). However, several difficulties arise when attempting to apply these functions in juvenile stands. Due to the lack of data for young and very old stands, these functions do not provide reliable predictions in these age classes. In addition, models based upon diameter at breast height (DBH) cannot be used when some or all of the trees in the stand are smaller than 1.3 m in height.

Although results from past studies are sometimes contradictory (Peterson and Peterson, 1992), in some stands early juvenile spacing of aspen can accelerate the growth of residual trees (Bickerstaff, 1946; Steneker, 1976; Perala, 1978), accelerating achievement of merchantable diameter and improving the quality of the stand. However, thinning of aspen (as with most other species) typically results in reduced total standing volumes at harvest (Bella and Yang, 1991). Rice et al. (2001) found that, while thinning of young aspen (5–15 years old) resulted in reduced gross stand volume, it did not significantly change merchantable volumes 15 years after treatment. They also found that thinning resulted in significant increases in diameter growth of the remaining trees. Height and height growth were increased by thinning in 3 of the 7 stands that they studied. In contrast, a study by Penner et al. (2001) found no benefit to thinning a stand with 4000–5000 stems per hectare at age 20, due to the fact that unspaced plots had self-thinned to densities (1000–2000 stems ha^{-1}) similar to those of treated plots by age 36. During the 16 years following thinning to 1100 stems ha^{-1} very little mortality was observed. In their study, frequency distributions of tree diameters 16 years after thinning showed substantial reductions in the number of trees in smaller size classes and only some increases in the numbers of trees in larger size classes on the good site.

Treatments which reduce competition from aspen and other broadleaved trees can provide substantial increases in growth of white spruce (e.g. Lees, 1966; Biring et al., 1999; Biring and Hays-Byl, 2000; Jobidon, 2000; Pitt et al., 2004). Reducing aspen densities by selective removal of aspen by manual, mechanical, or chemical spacing treatments or removal of aspen around crop conifers, is widely used to improve growing conditions for white spruce. Studies in northern B.C. and Alberta indicate that light levels underneath aspen canopies are related to the basal area of aspen (Comeau, 2001; Lieffers et al., 2002). Comeau (2001) suggests that maintaining total aspen basal area below $8 \text{ m}^2 \text{ ha}^{-1}$ may provide near optimal conditions for growth of white spruce.

Competition has an immediate effect on diameter growth of conifers, while impacts upon height growth do not generally appear until severe competition levels are reached or competition remains at sufficient intensity for a period of time. As a result, the ratio of height to root collar diameter (HDR) increases in response to increases in level of competition (Tesch et al., 1993; Wagner et al., 1999; Coopersmith and Hall, 1999; Coopersmith et al., 2000; Opio et al., 2000). For white spruce, HDR values exceeding 55–60 are considered to indicate stress. In addition to competition, HDR is influenced by a range of environmental factors, including variations in spring, summer and fall growing conditions, soil resource availability, and stem sway and bending (Opio et al., 2000).

This paper presents results from analysis of 9 years of measurement of natural self-thinning of regenerated aspen and the early dynamics and growth of tended mixtures. The objectives of this manuscript are to: (a) quantify self-thinning of naturally regenerated aspen and develop survival and size-density functions; (b) evaluate the effects of thinning of aspen

¹ From this point onward the $-3/2$ power law of self-thinning will be referred to as the $-3/2$ power law.

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