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Trembling aspen (*Populus tremuloides* Michx.) volume growth in the boreal mixedwood: Effect of partial harvesting, tree social status, and neighborhood competition

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A B S T R A C T

Variable retention harvesting, with a focus on maintaining biological legacies on managed landscapes, has been practised in the trembling aspen (*Populus tremuloides* Michx.) dominated boreal mixedwood forests for about two decades. However, little attention has actually been given to the growth response of aspen to partial harvesting. This is the first study to report on tree-level volume growth response of aspen after partial or variable retention harvesting in the Canadian boreal forest. During the winter of 1998–1999, an uncut control, clearcut and two partial harvesting treatments – 1/3 partial cut (1/3PC, 33% BA removal using low thin); 2/3 partial cut (2/3PC, 61% BA removal using high thin) – were applied in 75 year old aspen-dominated mixedwood stands in a complete randomized block design. Twelve years after treatment application, 27 dominant and 27 co-dominant trees were collected from unharvested controls and the two partial cut treatments for stem analysis. Annual volume increment (AVI) of individual stems was analyzed as a function of treatment, tree social status, pre-treatment growth, time since treatment application (1–12 years) and neighborhood competition. The latter was estimated using a variety of neighborhood competition indices (NCI). There was no evidence of initial growth stagnation after partial harvesting applications. Only the most severe treatment of partial harvesting (2/3 PC) resulted in an increase in volume increment relative to trees in control stands. Annual increase in volume in the 2/3 partial cut was 25.6% higher than controls over 12 years. AVI of dominant trees was higher by 16.2 $dm^3\,yr^{-1}$ than that of co-dominants and was proportional to pre-treatment volume growth. No interaction between treatment and social status or pre-treatment growth was observed. The overall results indicate that competition for resources in these stands is essentially size symmetrical. These results should contribute to the development of silviculture prescriptions that aim to maintain both stand productivity and biological legacies.

1. Introduction

Variable retention harvesting, with a focus on maintaining biological legacies on managed landscapes, has been practised in the aspen-dominated boreal mixedwood forest for about two decades (Lieffers et al., 1996; Bose et al., 2014). Depending on the amount and configuration of tree retention, this system ostensibly emulates primary natural disturbances such as high intensity wildfires (less retention) or secondary disturbances such as insect outbreaks or individual or group mortality (more retention) (Thorpe and Thomas, 2007). In the boreal mixedwood, the southern-most swath of forest that extends across the boreal forest biome of Canada, partial harvesting has been proposed where intolerant hardwoods, especially trembling aspen (*Populus tremuloides* Michx.), reach maturity before more shade-tolerant softwood species (Lieffers et al., 1996; Bergeron and Harvey, 1997).While attractive from an ecosystem management viewpoint, from a timber supply and economic perspective, partial harvesting practices need to be evaluated over more than the short term (Ruel et al., 2013) and can be considered successful if residual trees respond well in terms of growth and survival (Coates, 1997; Thorpe et al., 2007).

In the last 15 years, a number of experiments have been set up across the boreal mixedwood forest to test the ecological feasibility of forest ecosystem management (FEM) (e.g., Brais et al., 2004; MacDonald et al., 2004; Solarik et al., 2010). While a number of studies have examined stand-level responses to partial harvesting

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(e.g., Man et al., 2008a; Gradowski et al., 2010; Brais et al., 2013), fewer have focused on how residual aspen trees respond individually to partial harvesting (Bladon et al., 2007; Solarik et al., 2012) and these have mainly focussed on aspen mortality in response to variable retention. Some other studies have evaluated tree-level growth responses in the continuous conifer boreal region, such as black spruce (*Picea mariana* (Mill.) responses to harvesting with advanced regeneration protection (Thorpe et al., 2007) and to commercial thinning (Goudiaby et al., 2012). We have found no studies quantifying the volume growth response of mature aspen trees to partial harvesting.

By removing trees from different canopy layers, partial harvesting affects light availability, and thereby competition among residual trees (Hartmann et al., 2009). Individual tree-level growth responses to partial harvesting have been shown to depend on tree age (Thorpe et al., 2007), size (Jones and Thomas, 2004), physiological traits (Jones et al., 2009; Anning and McCarthy, 2013b), and pre-harvest growth rate (Thorpe et al., 2007). Immediately following harvesting treatments, it is also expected that tree growth response will depend on acclimation to evolving growing conditions including availability of light and soil resources, post-harvest social status, and neighborhood competition (Thorpe et al., 2007; Hartmann et al., 2009; Anning and McCarthy, 2013a). Several studies have documented an initial (2–5 years) growth stagnation in residual trees immediately following harvesting (Jones and Thomas, 2004; Thorpe et al., 2007; Goudiaby et al., 2012) probably due to the sudden change in the stand's microclimatic condition (Bose et al., 2014). Kneeshaw et al. (2002) suggested, that larger trees may be more prone to initial growth stagnation due to the presence of higher non-photosynthetic biomass requiring higher maintenance costs and higher allocation to root growth for mechanical support.

The SAFE project ("Sylviculture et Aménagement Forestier Ecosystémique") (Brais et al., 2004; Brais et al., 2013) is a series of experiments undertaken in Northwestern Quebec, Canada to assess the feasibility of FEM silvicultural practices for this region. The first phase of the SAFE project was established in post-fire, naturally regenerated aspen-dominated stands (Brais et al., 2004; Harvey and Brais, 2007) that were submitted to four levels of harvesting, including two intensities of partial harvesting, in 1998.

The objective of the study is to evaluate the effects of partial harvesting on the annual volume increment of residual trees of trembling aspen over a 12-year period following harvesting. We specifically investigated the effects of partial harvesting treatment and tree social status on volume increment of residual trees. Because stand conditions evolve in response to harvesting (Harvey and Brais, 2007; Bose et al., accepted for publication), we also considered pre-treatment volume growth and neighborhood competition as possible explanatory factors for volume increment during last 3 year period (10–12 years following treatments). Accordingly, we tested the following hypotheses: (i) tree volume increment would increase with increasing intensities of partial harvesting (Thorpe et al., 2007), but decrease with increasing neighborhood competition in the longer term (Hartmann et al., 2009; Anning and McCarthy, 2013a); (ii) size-dependent competition indices are expected to better explain the annual volume increment of aspen residual trees over distance-dependent indices (Canham et al., 2006); and (iii) a growth lag is expected immediately after treatment applications followed by a linear increase in annual volume increment (Jones and Thomas, 2004; Thorpe et al., 2007). We also anticipated that the size of residual trees could affect their response in two different ways: (iv) dominant stems or stems with the highest pre-treatment volume increment would experience the strongest volume growth response following harvesting (Berntson and Wayne, 2000; Jones and Thomas, 2004) or, inversely, light-limited co-dominant trees (relative to dominants) could benefit the most from canopy opening (Walter and Maguire, 2004).

2. Methods

2.1. Study area

The study area is located in the Lake Duparquet Research and Teaching Forest (48°86′N–48°32′N, 79°19′W–79°30′W) in the Abitibi region of Northwestern Quebec. The region is part of the balsam fir-white birch bioclimatic domain (Saucier et al., 1998), and is characterized by the presence of extensive clay deposits left by proglacial Lake Ojibway (Vincent and Hardy, 1977). Soils are gray Luvisols and soil texture is that of heavy clay (>75% clay). The forest floor is a thin mor of 2–7 cm (Canada Soil Survey Committee, 1987).The climate is continental with mean annual precipitation (1991–2010) of 847 mm, of which 583 mm falls as rain from April to September. Mean annual temperature is 1.95 °C with an average daily temperature of 11.9 °C from April to September (BioSIM, 2012).

The stands are even-aged (75 years old at time of treatment) and originated from a wildfire in 1923 (Dansereau and Bergeron, 1993). Before treatment application, average stand basal area was 42.1 m^2 ha^{-1} of which 92.6% was trembling aspen and 3.3% conifer species. The shrub layer was dominated by mountain maple (*Acer spicatum* Lamb.) with an average density of 1327 stems ha^{-1} (Bourgeois et al., 2004). Four harvesting treatments, including a no harvest control, two intensities of partial harvesting and a clearcut, were applied during the 1998–1999 winter. The two partial harvesting treatments were designed to remove 33% (1/3 partial cut) and 61% (2/3 partial cut) of the stand's merchantable basal area. Stands in the 1/3 removal were low thinned with primarily smaller, low-vigor aspen stems removed (1/3 partial-cut). This treatment was intended to emulate density dependent mortality (self-thinning) in stand development. Stands in the 2/3 removal were crown thinned with more vigorous co-dominant and dominant aspen stems preferentially selected (2/3 partial-cut), thus presenting a mortality analogue of stand senescence (Brais et al., 2004). Harvesting treatments were applied according to a complete randomized block design with three replications (blocks) of each treatment. Experimental units ranged from 1 to 2.5 ha. In 2001, the stands were affected by a forest tent caterpillar (FTC, *Malacosoma disstrium* Hübner) outbreak.

2.2. Data collection

Trees selected for stem analyses were harvested in the fall and winter of 2011 and summer of 2012 in control and partially harvested experimental plots. Both dominant and co-dominant residual trees were selected based on their diameter, crown size and crown's relative exposure among neighbors. Average diameter at breast height (DBH, 1.3 m) was first compiled from the most recent tree inventory (2010) in permanent sample plots for each of the three experimental blocks in order to determine size ranges for each social status. DBH size was used as a first step because of its strong correlation with tree height ($r = 0.77$). Trees were considered dominant if their DBH was $\geqslant 2$ standard deviations (SD) of the experimental block average, and co-dominants if their DBH was $\geqslant 1$ SD. In addition to diameter size, visual inspection of relative crown size and exposure among neighbors was also used to select sample trees. Specifically, trees in the dominant social class (according to DBH) had to clearly have large crowns compared to others in the canopy and crowns of "DBH co-dominants" situated close to dominants had to be smaller than those of dominants. Harvested trees were located at least 20 m from roads to minimize edge effects, from permanent sample plots and from other sampled trees. All sampled trees were free of any visible damage, decay or infection.