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Influences of gap position, vegetation management and herbivore control on survival and growth of white spruce (*Picea glauca* (Moench) Voss) seedlings

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ABSTRACT

The boreal mixedwood forest type of the Canadian interior boreal is largely comprised of two dominant tree species: white spruce and trembling aspen (*Picea glauca* and *Populus tremuloides*). This forest type is expansive, providing important ecosystem services and economic production, yet such mixtures are difficult to establish after harvests. While aspen resprouts and grows vigorously following disturbance, spruce growth is relatively slow and is often limited by intense competition from associated vegetation, including aspen. To improve management, it is important to understand how environmental and vegetative conditions vary in relation to the competitive–facilitative relationship of spruce–aspen mixtures. In this study white spruce was planted across large canopy openings to determine whether survival and height growth is influenced by position within gap and by differing levels of competing vegetation control of aspen and understory plants. In addition, we addressed the issue of herbivory, which can pose a significant threat to planted spruce seedlings. Within each of four sites, linear gaps were created and five gap positions were recognized spanning the southern and northern forest understories, and southern, center and northern positions within each opening. Three different levels of vegetation management were implemented: a brush saw treatment in which all vegetation was cut to ground level, a mixing treatment in which all vegetation and rootstock was ground up, and a control with no vegetation management. The three herbivory treatments excluded large ungulates, small herbivores (rabbits, hares) or had no herbivore exclusion. Growth and survival of white spruce seedlings were measured for four years (1997–2000). Understory survival was significantly lower than within the gap, with the sheltered southern edge position providing the best initial environmental conditions and or ameliorative cover for spruce establishment. However, after four years the shelter effect starts to be inhibitive relative to center and northern gap positions, suggesting the removal of the canopy is necessary before spruce productivity declines. The optimal vegetation management treatment also changed over the study period. The most intensive treatment (mixing) initially showed a negative influence on survival and growth, but by year four, survival converged to approximately 75% for all treatments, and the mixing treatment produced the best height growth. The growth advantage became most evident in the center gap positions, which initially lagged the brushsaw and control treatments. Lastly, some growth losses from herbivory must be expected in boreal mixedwoods, although not enough to merit control. Results have implications for the timing and intensity of silvicultural treatments for harvesting and planting.

1. Introduction

Boreal mixedwood forests of white spruce (*Picea glauca* (Moench) Voss) and trembling aspen (*Populus tremuloides* Michx.) dominate the sub-boreal forest regions of central and western Canada (Lieffers and Beck, 1994; MacDonald, 1995). The natural regime of catastrophic fire facilitates the development of stratified mixtures, in which aspen initially forms the upper stratum over spruce (Purdy et al., 2002). However, such mixtures are difficult to establish after harvests. Aspen regenerates vigorously by root suckering following stand-replacing disturbance (Frey et al., 2003a), but spruce growth is relatively slow and generally limited by intense competition from associated vegetation, better adapted to these high resource conditions (Hogg and Lieffers, 1991; Lieffers and Beck, 1994). Under these circumstances, spruce generally experiences several decades of suppression, only dominating the canopy when the overstory aspen begin to decline. Given the status of *P. glauca* as a major commercial species in Canada, forest managers have great interest in using silviculture to generate greater spruce volume on a shorter time scale. A common approach has been the

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use of herbicide to reduce or eliminate aspen competition, with the goal of producing pure spruce stands. However, there is considerable public resistance to herbicide use in addition to increasing interest in mixedwood management for improved forest productivity and biodiversity values (Wang et al., 1995; Simard, 1996). Thus, it is necessary to develop silvicultural methods that maintain a productive spruce component in mixedwood stands.

In order to ensure the competitive status of *P. glauca*, it is especially critical to provide appropriate growing conditions at the establishment phase. Mid-tolerant white spruce seedlings can attain maximum height growth at 40% of full light, a level that is limiting to most competing species, while diameter growth will continue to increase up to full light levels (Lieffers and Stadt, 1994). Height growth is sensitive to soil temperature (Brand and Janas, 1988), with cold soils inhibiting growth (Stiell, 1976; Brand, 1990). Growing season soil temperatures of 19–20 °C are optimal, and 7–8 °C is seen as a lower threshold for growth (Coates et al., 1994). Both insufficient light levels (Comeau et al., 1993; Lautenschlager, 1995) and inhibitively low soil temperatures (Jobidon, 2000) have been associated with competing herbaceous and woody vegetation cover, including *P. tremuloides*. Intensive site preparation (e.g. mixing) that mechanically destroys or removes competing vegetation and reduces resprouting competitors can improve white spruce seedling growth (Groot, 1999; Jobidon, 2000; Frey et al., 2003b; Macadam and Kabzems, 2006).

But other aspects of white spruce seedling ecology challenge a management strategy based on providing open, warm, high-light conditions with minimal vegetative cover. *P. glauca* seedlings are sensitive to high vapor pressure deficits (VPDs) between leaf and air, and VPD is higher in clearcuts than under partial aspen cover (Marsden et al., 1996). Open-grown seedlings of the closely related species Engelmann spruce (*Picea engelmanii* Perry ex Engelmann) experience significantly greater chlorosis damage and mortality than partially shaded seedlings (Ronco, 1970). Growing-season frost damage can also occur to seedlings planted in exposed conditions, which can be reduced by adjacent aspen cover (Voicu and Comeau, 2006; DeLong, 2007) and even overtopping shrub cover (Posner and Jordan, 2002).

These characteristics indicate that woody and herbaceous vegetation exert a complex mixture of facilitation and inhibition on establishing spruce seedlings. The relative benefit or harm from such cover likely depends on density levels, site conditions and stand age (Filipescu and Comeau, 2007). It may be possible to identify optimal vegetation cover that can provide protection while having limited effect on tree seedling growth (Coates et al., 1994).

One approach to meeting these complex requirements has been to plant *P. glauca* seedlings within linear gaps in mixedwood stands. The theory behind this practice is that sufficient light levels (40% of full light) and soil temperatures (19–20 °C) will be attained within the gap, while adjacent forest cover will ameliorate light extremes that can lead to problems such as chlorosis, and temperature extremes that can lead to VPD-driven moisture stress and frost damage (Groot, 1999). In order to understand how (and whether) this might work, it is important to examine how environmental and vegetative conditions vary across linear gaps in a boreal mixedwood. In boreal forests the south edge of an opening receives diffuse light from the northern hemisphere of the sky, as well as some light transmitted through the stand, while the northern edge of an opening (of sufficient size) will receive both diffuse and direct radiation (Canham et al., 1990). The greater availability of light at the north end and center of gaps may result in enhanced seedling growth (Coates, 2000). But higher irradiation in these positions may also increase stress through reduced soil moisture and higher VPD, and the development of competitors such as aspen, which are better adapted to these high light conditions (Groot et al., 1997). At the south end of gaps light intensity is lower, soil moisture is generally higher (likely due to increased shading and perhaps to extended persistence of snow in the spring) and leaf area index of aspen and herbs is lower (Voicu and Comeau, 2006).

This study was thus initiated to determine whether *P. glauca* height growth is influenced by position within experimental linear gaps and by differing levels of competing vegetation control. In addition, we addressed the issue of herbivory, which can pose a significant threat to planted spruce seedlings (Krefting and Stoeckeler, 1953). The use of exclosures allowed us to protect some seedlings from varying levels of herbivory, thus demonstrating its influence on height growth. The following hypotheses were developed: (1) herbivore exclusion will increase spruce growth, particularly by reducing small mammal (hare) browse, (2) vegetation management will result in increased growth, and (3) spruce growth and seedling survival will be greatest at the south end of harvest gaps, where moderated light conditions are sufficient for optimal spruce growth but limiting to the development of competitor vegetation.

2. Methods and materials

2.1. Study area

This study was carried out on lands owned by the Cree First Nation and managed by Mistik Management Ltd. in west-central Saskatchewan, Canada, near the community of Meadow Lake (54°13′N, 108°42′W). The study area is within the Boreal Plain Ecozone, a transition zone between prairie and the Boreal Shield in the north of the province. Mixed forests of aspen and white spruce predominate, with balsam poplar (*Populus balsamifera* L.), black spruce (*Picea mariana* (Mill) B.S.P.) and jack pine (*Pinus banskiana* Lamb.) as minor components. Soils in the region are classified as gray luvisols on sandy loam subsoil (Agriculture Canada, 1992). The climate is continental with a mean annual precipitation of 406 mm. Temperatures range from a daily mean high of −13.7 °C in January to 24.2 °C in July (Environment Canada, 1993).

2.2. Field methods

The study site comprised a mixed aspen–spruce stand of about 500 ha on the Cree land base. Eight experimental linear gap (ELG) harvests were created, within which all trees greater than 2 m in height were removed by a feller-buncher. The ELGs measured 340 m (E-W axis) by 80 m (N-S axis) and were arranged north-south, separated by 100 m buffers of uncut forest. Four of the eight ELG's were chosen for this study.

Five 4 m wide (N-S) gap positions were recognized: northern understory (NU: 20 m inward from the northern edge of the ELG beneath the forest canopy in uncut adjacent forest), northern edge (NE: the first 4 m of the northern edge of the opening), center (C: centered 40 m from S and N edges), southern edge (SE: the first 4 m of the southern edge of the opening) and southern understory (SU: 20 m inward from the southern edge of the ELG beneath the forest canopy).

Nine treatments were laid out in each of the four selected ELG's, extending 120 m N-S as 20 m E-W wide strips across all gap positions (Fig. 1). Each N-S treatment strip was separated by 10 m of untreated area, and 50 m untreated buffers were left extending in from the east and west boundaries of the ELG's. A combination of vegetation management and herbivory control treatments were imposed in each strip. Three different levels of vegetation management were implemented: a brush saw (BS) treatment in which all vegetation remaining after the harvest was cut to ground level, a full treatment with a Meri Crusher (MC) site preparation in which all vegetation and rootstock was ground up, and a control (C) with no vegetation management. The three herbivory control treatments