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Long-term response of planted conifers, natural regeneration, and vegetation to harvesting, scalping, and weeding on a boreal mixedwood site

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ABSTRACT

This study reports 14th-year response of a boreal mixedwood stand to different harvest intensities (uncut, 50% partial cut with and without removal of residuals after 3 years, and clearcut), spot site preparation treatments (none and scalped), and chemical weeding frequencies (none, single, and multiple) in northeastern Ontario. The response variables include the survival and growth of planted white spruce (*Picea glauca* [Moench] Voss) and jack pine (*Pinus banksiana* Lamb.), height and density of natural regeneration and shrubs, and cover of shrubs and non-woody vegetation. Harvesting and weeding generally improved survival and growth of planted trees, although white spruce survival did not significantly differ among the three weeding frequencies. Harvesting tended to increase heights of hardwood (mostly trembling aspen (*Populus tremuloides* Michx.)) and conifer (largely balsam fir (*Abies balsamea* (L.) Mill.).) natural regeneration, cover and density of shrubs, and cover of herbs, lichens, and ferns. Chemical weeding reduced height, density and cover of shrubs, height and density of hardwood regeneration, and fern cover, but increased moss and lichen cover. Spot scalping did not significantly affect planted seedling, natural regeneration, or the vegetation.

Maximum survival and growth of planted white spruce and jack pine were achieved using a combination of clearcutting and multiple weeding. However, partial cutting followed by a single weeding produced acceptable survival and reasonable growth of planted trees, particularly for white spruce. Partial canopy removal alone substantially reduced the amount of hardwood regeneration, relative to clearcutting, but did not adequately suppress understory shrubs. Significant improvement in seedling growth following multiple weedings was evident primarily in the complete canopy removal treatments: 50% partial cut with removal of residuals after 3 years and clearcut. While the effects of harvesting and weeding on planted crop trees found in the 5th-year assessments generally persisted at year 14, survival decreased, likely due to light competition from developing hardwood and shrubs.

1. Introduction

Partial harvesting is a silvicultural technique that has long been used in the boreal mixedwood forests to promote the natural regeneration of shade-tolerant conifers such as white spruce (*Picea glauca* [Moench] Voss) (Lees, 1963, 1964; Sutton, 1964; Waldron and Kolabinski, 1994; Ball and Walker, 1995; Prévost and Pothier, 2003), which can be difficult and costly to establish on clearcut sites due to rapid establishment of vegetative competition (Cater and Chapin, 2000; Lieffers et al., 1993) and extreme microclimate conditions (Grossnickle, 1988; Man and Lieffers, 1997, 1999a). Recent support for partial harvesting in boreal mixedwood stands is driven largely by interest in maintaining biodiversity and ecosystem processes at stand and landscape levels (Harvey et al., 2002; Thorpe and Thomas, 2007; Man et al., 2008). This includes patterning management after natural stand dynamics as would occur via succession (Harvey and Brais, 2007) and following non-stand replacing disturbances (Bergeron et al., 1999; Bergeron and Harvey, 1997) such as insect and disease outbreaks and wind (Chen and Popadiouk, 2002; Pham et al., 2004).

Regeneration of partially harvested stands, mainly conifers, can occur via advance regeneration that is well established prior to harvesting (Lieffers et al., 1996; Greene et al., 2002; MacDonald et al., 2004). The abundance of this advance regeneration is often sufficient for the next crop (Popadiouk et al., 2004) and protecting it during harvesting shortens rotation time and reduces cost associated with regeneration and stand tending (Lieffers et al., 1996; Greene et al., 2002; MacDonald et al., 2004).

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Where adequate advance regeneration does not exist under the uncut canopy, natural seeding from residual trees in combination with understory site preparation is frequently used to enhance natural regeneration (Lees, 1963; Waldron and Kolabinski, 1994; Ball and Walker, 1995). However, this approach requires coincidence of seed source availability with receptive seedbed conditions and is less reliable for securing adequate stocking and growth of desired conifer regeneration than underplanting (Greene et al., 2002). To minimize growth restrictions resulting from reduced understory light availability in partial cuts, the residual canopy is often removed within a few years of seedling establishment (Hannah, 1988; Waldron and Kolabinski, 1994). From the perspective of biodiversity and ecosystem process conservation, leaving the residual canopy on site provides continuous forest cover, old growth characteristics, and down woody material for increased habitat and nutrient cycling (Harvey et al., 2002; Bergeron et al., 2007) and thus is a desirable management option.

To compare the effectiveness of various levels of partial cutting in combination with scalping site preparation and chemical weeding on the survival and growth of planted conifers – white spruce and jack pine (*Pinus banksiana* Lamb.) – with contrasting shade tolerance and early growth rates, a study was established in northeastern Ontario in the winter of 1993–1994 (MacDonald, 2000). Fifth-year responses (1994–1998) of microclimate, understory shrubs, hardwood regeneration, and planted seedlings were reported by MacDonald and Thompson (2003). However, in boreal mixedwood stands, early dynamics of both the residual canopy and the developing understory after partial cutting are not necessarily reflective of longer-term responses (Man et al., 2008). As a result, longer-term monitoring of such studies is needed to reduce the uncertainty about the performance of planted seedlings relative to competing vegetation. In this paper, we report the longer-term (14th-year) responses of planted conifers, natural regeneration, and vegetation to different levels of canopy removal, scalping site preparation, and chemical weeding to determine differences between 5th-year and longer-term responses and to better understand the stand development trajectories following partial cutting in boreal mixedwoods.

2. Methods

The site conditions, experimental design, and harvest treatments were described in detail by MacDonald and Thompson (2003) and are summarized briefly here. The study site is in an upland mid-successional boreal mixedwood stand north of Chapleau, Ontario (47°59′N, 83°25′W). Prior to harvesting, the overstory was dominated by 70-year-old trembling aspen (*Populus tremuloides* Michx.) and white birch (*Betula papyrifera* Marsh.), with a 20% component of codominant conifers, including black spruce (*Picea mariana* [Mill.] B.S.P.), white spruce, jack pine, and balsam fir (*Abies balsamea* (L.) Mill.). Understory trees were mainly balsam fir and white spruce and shrub species were predominantly mountain maple (*Acer spicatum* Lam.) and beaked hazel (*Corylus cornuta* Marsh.). The area has fresh to moist, non-calcareous, coarse loamy soils.

A split-plot design was used with four levels of harvesting intensity in the main plot (112 m × 56 m) and a factorial arrangement of three frequencies of weeding by ground spraying of glyphosate (none, 2nd-year, and 1st- through 5th-year after harvesting) and two site preparation levels (none and manually scalped) in the subplots (14 m × 14 m). Harvesting treatments included uncut, 50% partial cut without (PC50) and with (PC100) removal of residuals after 3 years, and clearcut. In the winter of 1993–1994, full tree logging was conducted, preferentially removing dominant aspen and balsam fir. Careful logging practices were applied to minimize damage to residual trees. In the spring of 1994, seedlings were planted in a 6 × 7 grid at 2 m spacing, with white spruce planted in half the subplots in each main plot and jack pine in the other half. All treatment combinations were replicated six times (blocks). Due to substantial windthrow in one replication in the winter of l995–1996, the 14th-year re-assessment focused on the remaining five replications.

All overstory trees (≥10.0 cm DBH, diameter at breast height) in the subplots were measured for survival, DBH, dominance class, and damage condition. All planted seedlings, except a single buffer row surrounding each subplot, were recorded for survival, height, root collar diameter (RCD), and DBH (when available). Understory vegetation and hardwood and conifer regeneration were assessed in four vegetation plots (2 m × 2 m) within each subplot. Recorded were (1) the height and density of natural hardwood and conifer under 4.0 m tall in 1994 and post-harvest natural ingress, (2) height and density of understory shrubs, and (3) percent cover of shrubs, herbs, grasses, ferns, mosses, and lichens.

Analysis of variance on 14th-year data followed the approach used by MacDonald and Thompson (2003) for the 5th-year data and were separated by the species of planted tree subplots. The percent tree survival and vegetation cover data were arcsine-square root transformed (Little and Hills, 1978) prior to analysis using the Proc Mixed procedure available in SAS 9.1 (SAS Institute Inc., 2003). The exception was grass cover where logarithm transformation was applied. Normality was checked with graphical display and Shapiro–Wilk test on residuals. Multiple contrasts were conducted after significant effects of treatments or harvest by weeding interaction were suggested.

3. Results

3.1. Residual overstory

The percent mortality of residual trees between years 5 (1998) and 14 (2007) was highest in the PC100 (20%) and lowest in the clearcut (about 10%) treatments, but similar between the PC50 and uncut treatments, ranging from 14% to 17% (Table 1). The growth of residual trees still alive in 2007 increased with harvest intensity, with the percent basal area increment (BAI) less than 50% in the uncut and PC50 treatments, and over 100% in the PC100 and clearcut treatments. As a result, in 2007 the overall BA in the uncut

Table 1
Changes in basal area (BA, $m^2\ ha^{-1}$) and stems per hectare (SPH) of residual trees (DBH ≥ 10 cm in 1998) in a partial cutting study in northeastern Ontario between 1998 and 2007. Basal area increment (BAI) was calculated for living trees only; percent changes are in parentheses.

Harvest intensity	Year 5 (1998)		Year 14 (2007)		Mortality (between years 5 and 14)		BAI (%) (between years 5 and 14)
	BA	SPH	BA	SPH	BA (%)	SPH (%)	
Uncut	37.3	988	37.4	826	5.2 (14)	162 (16)	5.3 (16)
PC50	16.2	436	18.1	364	2.5 (16)	72 (17)	4.4 (32)
PC100	0.6	52	1.4	43	0.1 (20)	11 (20)	0.9 (156)
Clearcut	1.3	71	2.7	65	0.1 (9)	7 (10)	1.5 (133)

Note: Numbers may not add up due to rounding.