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Post-harvest regeneration of lowland black spruce forests in northeastern Ontario

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Key words: Careful logging around advanced growth (CLAAG), Group seed tree (GST), Group seed tree followed by shearblading site preparation (SHE), Harvest method, Regeneration density, Stocking

Abstract. Success of natural regeneration has been a concern since the introduction of heavy machinery in harvesting. The objective was to compare the effect of three operational harvest methods careful logging around advanced growth (CLAAG), group seed tree (GST), and group seed tree followed by shearblading site preparation (SHE) on natural regeneration in the Clay Belt region of Ontario. A total of 30 stands, 562 cluster sample plots, were surveyed. Total density of black spruce regeneration did not differ, but height structure of black spruce regeneration did among harvest methods. The CLAAG method resulted in highest total regeneration density of other conifers. Decreasing density of other conifers from the CLAAG to GST to SHE sites indicated that the CLAAG method protected advance regeneration as expected and the SHE method removed advance regeneration in the path of the shearing blade. Both black spruce and other conifer regeneration densities increased with increasing time since harvest. Stocking of black spruce, all conifers, or all tree species did not differ significantly among harvest methods, nor did it change with time since harvest. Stocking was nonlinearly related to regeneration density. Models developed in this study predict that full stocking (i.e., 60%) can be reached based on regeneration density of 5000 stems per ha regardless of crop species choice preference. However, the existing stocking criterion for assessing black spruce regeneration may be problematic.

Introduction

In Ontario, 17.7 million ha of forests, or about 41% of the province's total productive forest land, is dominated by black spruce [*Picea mariana* (Mill.) B.S.P.] (Ketcheson and Jeglum 1972; Ontario Ministry of Natural Resources 2002). In the Clay Belt region of northeastern Ontario, 81% of the productive forest land is black spruce-dominated. Successful regeneration of this ecologically and commercially important species, either by planting or relying on natural regeneration, is paramount to ensuring its sustainability in northern Ontario. Over 50% of the harvested areas in Ontario are left to regenerate naturally and this percentage is significantly higher for black spruce-dominated forests (Groot et al. 2001). Prior to the

1960s, black spruce regenerated successfully following selective horse logging in northern Ontario. With the advent of mechanized logging, the widespread use of heavy machines has had a great negative impact on advance growth, and thus presents a challenge to reliance on natural regeneration.

Over the last few decades, modified harvesting techniques have been developed to preserve advance regeneration, promote natural seeding, and create favourable seedbeds. Some examples are careful logging around advanced growth (CLAAG), group seed tree (GST), and GST followed by mechanical scarification, such as shearblading (SHE), to create suitable seedbeds (Groot and Horton 1994; Groot et al. 2001).With the CLAAG method, merchantable stems are cut and smaller individuals are protected to various degrees as future crop trees (Jeglum 1987; Groot et al. 2001). With the GST methods, patches of variable sizes are left uncut regardless of tree merchantability to provide a seed source for natural regeneration. With the SHE method, shearblading is used to remove *Sphagnum* and other moss mounds to create mineral exposure for regeneration.

The effect of CLAAG on natural regeneration has been well studied for black spruce-dominated forests where black spruce advance regeneration, predominantly of layer origin, is often abundant, particularly in older stands with low stand basal areas (Groot 1984; Pothier 2000; Harvey and Brais 2002). Moreover, height growth of black spruce advance growth following CLAAG has been shown to compare favourably with that of planted trees (Doucet and Boily 1986). Since advance growth usually has an initial size advantage over planted or seeded trees, it is possible that the rotation age may be reduced if advance regeneration is protected. Many studies and field trials have been conducted to evaluate natural regeneration in the Clay Belt of northern Ontario and Quebec (e.g., Jeglum 1987; Robinson 1987; Wood and Raper 1987; Groot 1995; Pothier 2000; Harvey and Brais 2002). However, few studies have evaluated the effects of different harvesting methods on natural regeneration in black spruce-dominated forests. Even fewer studies have monitored natural regeneration for more than 7 years after harvest (e.g., Tenhagen and Jeglum 1997a, b; Harvey and Brais 2002).

To evaluate the effects of different harvesting methods on natural regeneration density and stocking, including advance growth and regeneration established after harvest, this study sampled operationally harvested, black spruce-dominated forests in Ontario's Claybelt. Our main objective was to assess natural regeneration density and stocking of black spruce, other conifers, and hardwoods on sites harvested using CLAAG, GST, and SHE methods. We address the following questions: (1) do post-harvest regeneration density and stocking differ among harvest methods? (2) do regeneration density and stocking change with time since harvest? and (3) can stocking be predicted based on regeneration density?

Materials and methods

Study area

Study sites were selected within 150 km of Hearst, Ontario (49°25′ N; 82°28′ W), in the western part of the Clay Belt, a large physiographic zone that straddles the Quebec-Ontario border. The climate is continental with mean annual temperature of 0.7 °C and annual precipitation of 831 mm (Environment Canada, Canadian Climate Normals website 2001). The dominant soil types in the study area range from the Organic order in peatland sites to Brunisolic, Luvisolic, and Gleysolic orders on upland sites (Soil Classification Working Group 1998).

While black spruce is the dominant tree species in the study area, associated coniferous species include white spruce [*Picea glauca* (Moench) Voss], balsam fir [*Abies balsamea* (L.) Mill.], eastern white cedar (*Thuja occidentalis* L.), and tamarack [*Larix laricina* (Du Roi) K. Koch]. Hardwood tree species occur occasionally and include trembling aspen (*Populus tremuloides* Michx.), balsam poplar (*Populus balsamifera* L.), and white birch (*Betula papyrifera* Marsh.). Mature stands are mostly of fire origin although some were horse logged prior to 1960.

Sampling design

All study sites supported organic horizons ≥20 cm (Soil Classification Working Group 1998) and were dominated by black spruce before harvesting (Table 1). Full-tree logging methods were applied in all harvest

Table 1. Site characteristics and pre-harvest stand condition in relation to harvest method (CLAAG – careful logging around advance regeneration; GST – group seed tree, and SHE -group seed tree followed by shearblading). TSH is time since harvest (years).

Harvest method		TSH (years)	Pre-harvest stand age, volume, and species composition by basal area (%)*							
			Age (years)	Volume (m^3/ha)	Sb	Sw	Bf	Ce	La	Po
CLAAG (*n* = 13)	Mean	11.5	123	152	79.5	4.6	6.7	4.8	1.4	1.8
	Range	5–16	70–150	79–204	40–100	0–20	0–20	0–18	0–10	0–10
GST (*n* = 12)	Mean	11.9	116	151	84.8	0.9	6.4	1.5	1.0	5.0
	Range	9–17	70–168	107–204	60–100	0–6	0–20	0–10	0–9	0–20
SHE (*n* = 5)	Mean	16.6	123	172	93.3	0.2	1.3	3.8	0.0	1.1
	Range	15–17	90–158	141–195	84–96	0–1	0–5	0–11	0–0	0–4

*Species codes are: Sb – black spruce, Sw – white spruce, Bf – balsam fir, Ce – eastern white cedar, La – tamarack, Po – trembling aspen or balsam poplar, and Bw – white birch.

operations. To evaluate the effect of harvest methods on natural regeneration, the three most commonly used operational harvest and stand establishment methods were examined: careful logging around advance growth (CLAAG), group seed tree (GST), and group seed tree followed by shearblading (SHE). With the CLAAG method, all stems greater than 10 cm DBH were cut and smaller individuals were protected to various degrees as future crop trees in strips between skid trails (Jeglum 1987; Groot et al. 2001). Skid trails and between-trail strip widths varied from 4 to 6 m and 6 to 10 m, respectively. In the group seed tree (GST) harvest, 5–10% of the area was left uncut as small, randomly located patches of various shapes and sizes (0.01–0.1 ha) to provide a seed source for natural regeneration. In the SHE approach, shearblading was used to remove *Sphagnum* and other moss mounds, align harvesting slash, and reduce competition from shrubs and herbaceous plants. Shearblading typically resulted in 15–30% mineral seedbed exposure, depending on the intensity of the operation. Between the shearing trails, the advance regeneration was left on original substrates, but the debris from the shearing is pushed into non-sheared area and thus on some of advanced regeneration.

Thirty stands, each varying from 10 to 150 ha, were sampled. Pre-harvest stand condition was determined using forest resource inventory maps. The latest photographs before harvest were used to ensure the accuracy of the inventory maps. Pre-harvest stand age, volume, and composition did not differ significantly among the treatments ($p > 0.05$) as large variability in pre-harvest stand characteristics occurred among stands within each treatment type (Table 1). Time since harvest varied from 5 to 17 years (Table 1). Sites treated using the SHE method were older since this method is no longer commonly used.

Within each stand, a series of sampling plots were established: a cluster of 8 quadrats (2 × 2 m) on sites harvested with GST and SHE methods or a cluster of 25 quadrats (2 × 2 m) on sites harvested with CLAAG were established. The larger cluster on CLAAG sites was intended to capture the variation between skid trails and leave strips (Harvey and Brais 2002). The first plot was established at a random point with remaining plots established 150–200 m apart, resulting in approximately 1 plot per 3 ha of stand area. A total of 562 plots were sampled. Within each plot, all trees, regardless of vegetative or sexual origin, were counted by species and height class: small (≤ 30 cm), medium (31–130 cm), and large (> 130 cm).

Tree stocking was determined for each 2 × 2 m quadrat since tree planting typically establishes 2500 trees ha^{-1} at a spacing that is equivalent to one tree per 2 × 2 m quadrat. If at least one tree, regardless of size, occurred in the 2 × 2 m quadrat, it was considered to be stocked. Black spruce stocking refers to the proportion of the 2 × 2 m quadrats with at least one black spruce. Conifer stocking refers to the proportion of the 2 × 2 m quadrats with at least one coniferous tree, and tree stocking refers to the presence of any tree species.

Statistical analysis

Prior to analysis, all plot data were averaged and scaled up to stand-level (per ha) values. Analysis of covariance was performed using harvest method as a fixed factor and time since harvest as a covariant:

$$Y_{ijk} = \mu + HM_i + TSH_j + \varepsilon_{k(ij)} \quad (1)$$

where Y_{ijk} is a regeneration variable; μ is the overall mean for the regeneration variable; HM_i is the effect of harvest method; TSH_j is the effect of time since harvest; $\varepsilon_{k(ij)}$ is the sampling error. The interaction between harvest method and time since harvest was also tested, but was not significant for any regeneration variable. Residual analysis was conducted to assess normality and homogeneity of variances following Neter et al. (1996). No transformations were necessary. Pairwise contrasts were conducted if harvest method significantly affected a regeneration variable.

Regression analysis was used to examine the relationship between regeneration stocking and density. We used the modified Poisson function (Greene et al. 2002) as follows:

$$T = 1 - e^{-a(D)^b} \quad (2)$$

where T is stocking; e is the exponential base; D is regeneration density (stems/ha); and a and b are coefficients to be estimated to account for clumping. Regression selection and diagnosis followed the procedures described by Neter et al. (1996). Only the best-fit regression models are presented. Statistical significance was considered at $\alpha = 0.05$. All analyses were performed using SYSTAT 10 (SPSS Inc., Chicago, IL).

Results

Total black spruce regeneration density did not differ significantly among harvest methods, but increased significantly with time since harvest for CLAAG and GST harvest methods (Table 2, Figure 1a). The effect of time since harvest on the SHE sites could not be determined because only older sites existed for sampling. Density of other conifers varied significantly among harvest methods and increased with time since harvest for CLAAG and GST methods Table 2, Figure 1b). Density of other conifer was significantly lower on SHE sites compared to CLAAG and GST treatments. Density of hardwoods was low on these black spruce-dominated lowland sites and did not differ significantly among harvest methods, nor did it vary with time since harvest Table 2, Figure 1c).

Black spruce height structure differed significantly among harvest methods and was also related to time since harvest Table 3, Figure 2a). Density of black spruce stems ≤ 30 cm was significantly higher on the sites harvested using

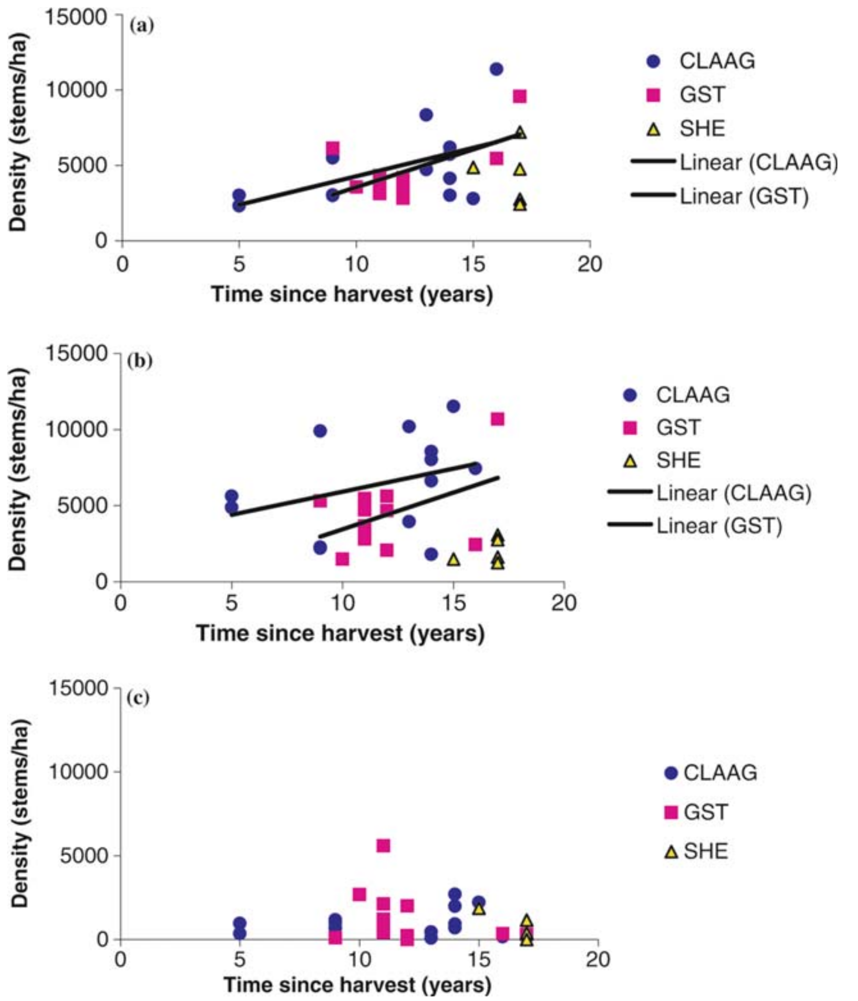

Figure 1. The effects of harvest method and time since harvest on density of (a) black spruce, (b) other conifers, and (c) hardwoods. Statistical results are shown in Table 2. Regression slopes did not differ significantly between CLAAG and GST in Figure 1a and b ($p > 0.05$).

CLAAG, followed by those harvested using GST and SHE. Density of the stems in this size class also increased with time since harvest. Medium-size black spruce (31–130 cm) density did not differ significantly between CLAAG and GST sites, but was significantly lower on SHE sites; it increased significantly with time since harvest. Large-size black spruce (>130 cm) density was significantly higher on SHE sites than that on CLAAG and GST sites, but was not affected by time since harvest Table 3, Figure 2a).

Height structure of other conifers also differed significantly among harvest methods Table 3, Figure 2b). Compared with black spruce, density of other

Table 2. Effect of harvest method (HM) and time since harvest (TSH, years) on total regeneration density of black spruce, other conifers, and hardwoods.

Source	df	Black spruce		Other conifers		Hardwoods	
		F-ratio	*p*	*F*-ratio	*p*	*F*-ratio	*p*
HM	2	2.076	0.146	7.90	0.002	0.25	0.784
CLAAG vs. GST	1				0.133		
GST vs. SHE	1				0.049		
TSH	1	9.580	0.005	4.38	0.046	0.06	0.805
Error	26						

conifer stems ≤ 30 cm was low and did not change with time since harvest, but was significantly higher on GST sites than on CLAAG and SHE sites. Density of other conifers in the medium size class differed significantly among harvest methods and increased with time since harvest. Density decreased significantly from CLAAG to GST to SHE sites. Density of other conifers in the large size class averaged < 450 stems/ha and was not significantly related to time since harvest, nor did it differ significantly among harvest methods. Similar to the density of other conifers in the large size class, hardwood density was low and did not vary among harvest methods, nor was it related to time since harvest Table 3, Figure 2c).

Black spruce stocking (all height classes combined) varied from 38% to 83% (Figure 3), but did not differ significantly among harvest methods, nor did it change with time since harvest Table 4). Stocking of all conifers and that of all tree species varied from 44% to 90% and 44% to 91%, respectively (Figure 3). Similar to black spruce stocking, stocking of all conifer species did not differ significantly among harvest methods, nor did it change with time since harvest (Table 4).

Black spruce stocking was correlated with its density, regardless of harvest methods and time since harvest (Figure 4). Increasing density resulted in large increases in stocking when density was < 5000 stems/ha, but further increases in density led to lower stocking increases as stocking approached to its maximum (Figure 4). Based on the regression model, black spruce stocking reached 60% at densities of 5000 stems/ha. Similar to the relationship between black spruce stocking and density, stocking of all conifers and all tree species were significantly related to density (Figure 4), suggesting that stocking could be predicted based on regeneration density.

Discussion

Post-harvest density of natural regeneration varied from 3000 to 12,000 stems/ha for black spruce, and from 1200 to 12,000 stems/ha for other conifers including balsam fir, white spruce, tamarack, and eastern white cedar. Groot (1995) reported similar densities of black spruce regeneration 6 years after

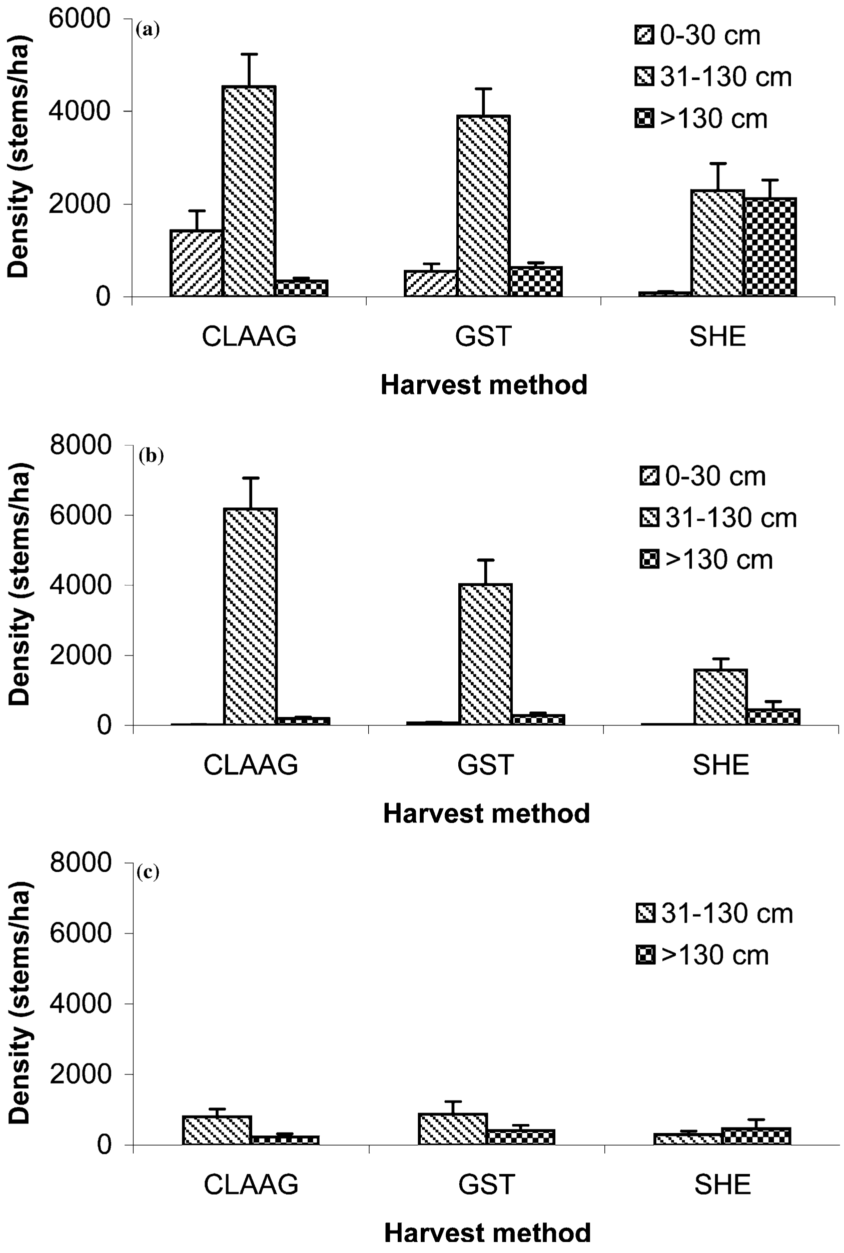

Figure 2. The effect of harvest method on the height structure (mean and 1 SE) of natural regeneration of (a) black spruce, (b) other conifers, and (c) hardwoods. Statistical results are shown in Table 3.

Table 3. Effect of harvest method (HM) and time since harvest (TSH, years) on regeneration density of black spruce, other conifers, and hardwoods by three height classes.

Source	df	< 30 cm		31–130 cm		> 130 cm	
		F-ratio	*p*	*F*-ratio	*p*	*F*-ratio	*p*
Black spruce							
HM	2	10.01	0.001	6.35	0.006	19.15	< 0.001
CLAAG vs. GST	1		0.043		0.949		0.376
GST vs. SHE	1		0.041		0.020		< 0.001
TSH	1	12.89	0.001	9.76	0.004	0.02	0.881
Error	26						
Other conifers							
HM	2	5.86	0.008	9.38	0.001	2.08	0.145
CLAAG vs. GST	1		0.007		0.083		
GST vs. SHE	1		0.488		0.031		
TSH	1	1.32	0.261	5.17	0.031	0.89	0.354
Error	26						
Hardwoods							
HM	2			0.589	0.562	1.23	0.308
TSH	1			0.04	0.845	1.24	0.275
Error	26						

CLAAG in black spruce-dominated forests. Harvey and Brais (2002) monitored post-harvest regeneration density for 7 years following CLAAG in Quebec. They found that black spruce density varied from less than 2,000 stems/ha on skid trails to over 25,000 stems/ha on between-trail strips, with an average density of less than 10,000 stems/ha. On the same sites, they reported that balsam fir density varied from less than 1000–27,000 stems/ha. Natural regeneration density in this study was lower, but within the range of those reported by Harvey and Brais (2002). Although both studies took place in a similar climatic region, site condition and time since harvest differ. Harvey and Brais (2002) studied regeneration dynamics on upland black spruce forests up to 7 years after harvest and this study reported natural regeneration on lowland black spruce forests from 5 to 17 years after harvest. Further, harvest techniques have improved since adoption of the CLAAG method with more versatile machinery and better operator training (Groot et al. 2001).

Harvest method significantly affected natural regeneration. Although total regeneration density of black spruce did not differ, but height structure of regeneration did significantly among harvest methods. Black spruce density of stems ≤ 30 cm was highest on CLAAG sites and lowest on SHE sites, indicating better continuous recruitment on CLAAG and GST sites. The lower density of small regeneration on GST and the lowest on SHE sites probably reflects the reduced availability of *Sphagnum* moss seedbeds, which is an ideal regeneration substrate but a nutrient-poor growth substrate (Viereck and Johnston 1990), as magnitude of site disturbance increases from CLAAG to GST to SHE method (Groot 1995). The high density of large size stems and

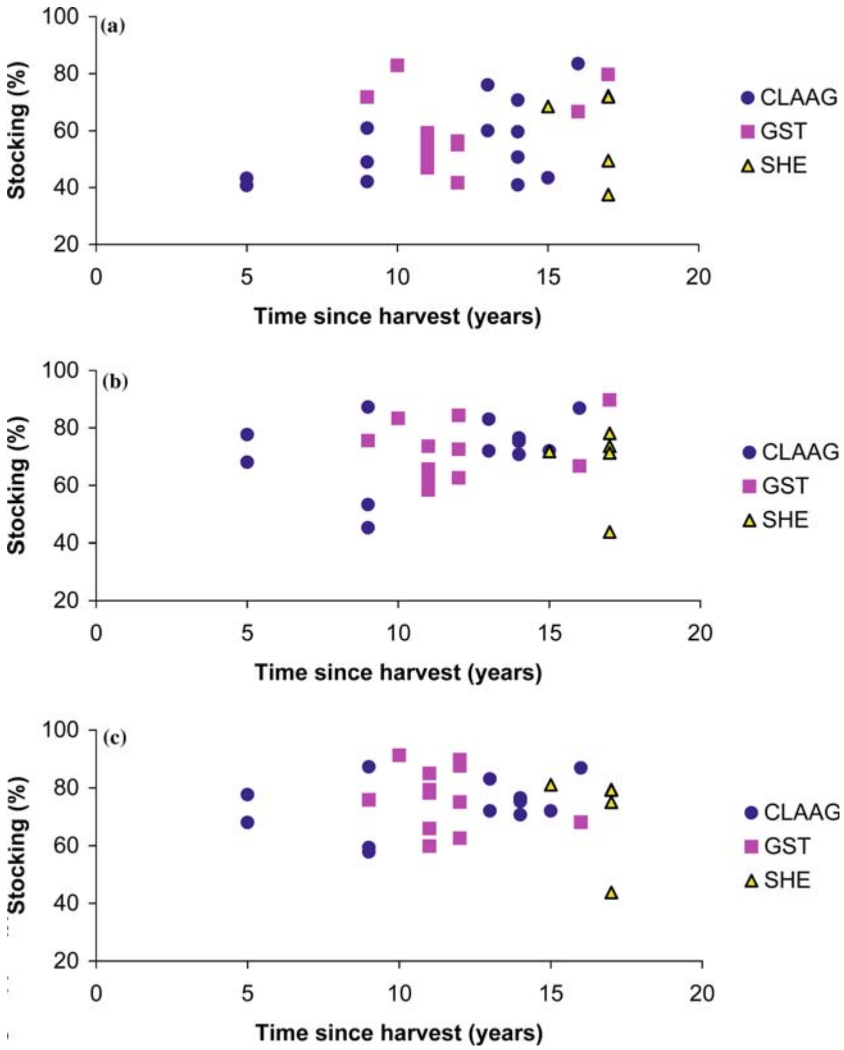

Figure 3. The effect of harvest method and time since harvest on stocking of (a) black spruce, (b) all conifers, and (c) all tree species. Associated statistics are shown in Table 4.

Table 4. Effect of harvest method (HM) and time since harvest (TSH, years) on stocking of black spruce, all conifers, and all tree species.

Source	df	Black spruce		All conifers		All tree species	
		F-ratio	*p*	*F*-ratio	*p*	*F*-ratio	*p*
HM	2	0.61	0.550	1.04	0.369	0.62	0.545
TSH	1	3.90	0.059	1.89	0.181	0.59	0.450
Error	26						

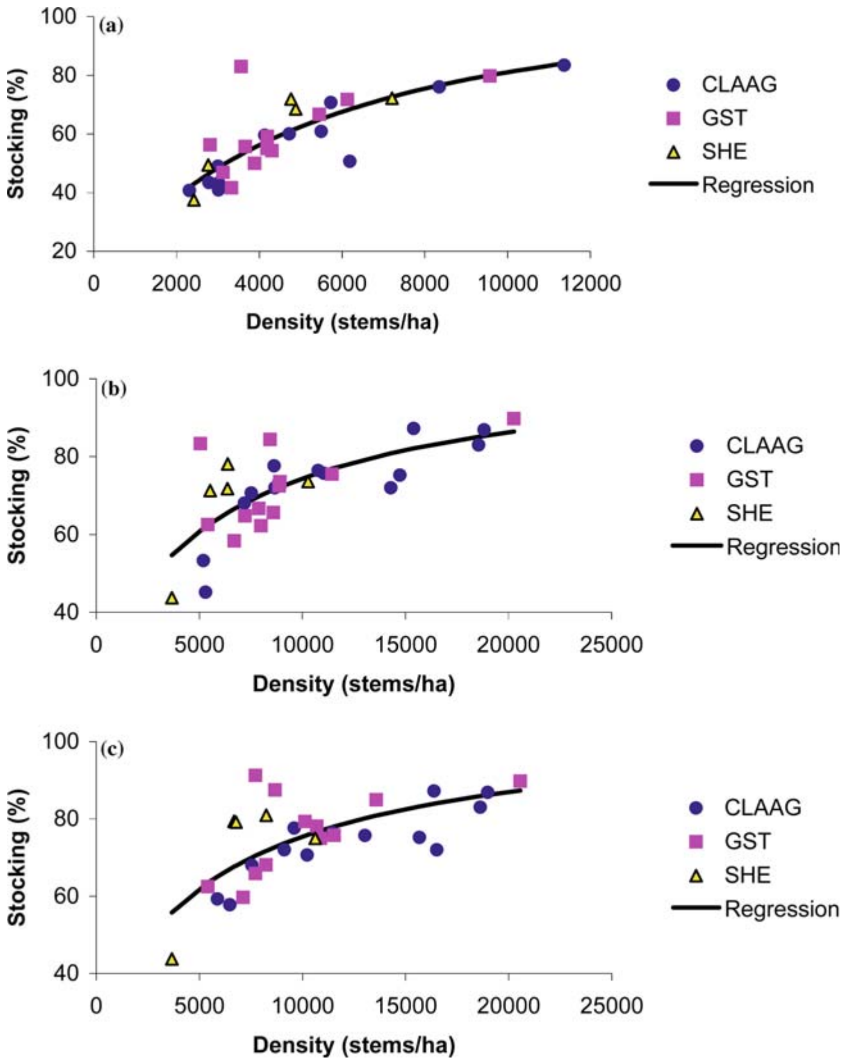

Figure 4. Relationship between stocking (y) and density (x) for (a) black spruce ($y = 1 - e^{-0.0014x^{0.77}}$, $n = 30$, $R^2 = 0.66$, $p < 0.001$), (b) all conifers ($y = 1 - e^{-0.0092x^{0.54}}$, $n = 30$, $R^2 = 0.51$, $p < 0.001$), and (c) all tree species ($y = 1 - e^{-0.0097x^{0.54}}$, $n = 30$, $R^2 = 0.48$, $p < 0.001$).

low density of small size stems on SHE sites may suggest a tradeoff between reduced recruitment and better growth as black spruce grows faster on non-*Sphagnum* moss substrates (Viereck and Johnston 1990; Vasiliauskas and Chen 2002).Other than removing *Sphagnum* moss, shearblading also reduces herb and shrub competition and creates mounds between-trail strips, which may improve soil drainage and allow better height growth on these lowland sites. However, because of the lack of continuously repeated measurements and the fact that the SHE sites were older, the difference in large size regeneration may be the result of the difference in time since harvest among treatments.

As expected, density of other conifers, primarily stems > 30 cm, was highest on the CLAAG sites since this method was developed to protect advance growth. On the SHE sites, density of other conifers was lowest, suggesting that shearblading had removed more advance regeneration than GST without shearblading. Besides black spruce, tamarack was the only conifer species represented in the ≤ 30 cm height class, and its densities were less than 100 stems/ha. Differences in density of stems ≤ 30 cm among harvest methods could be confounded with minor differences in pre-harvest stand species composition. Compared with conifers, hardwood density was significantly lower and their density did not differ among harvest methods. Regeneration of trembling aspen, balsam poplar, and white birch is related more to pre-harvest species composition (Perala 1990; Safford et al. 1990; Zasada and Phipps 1990), which was not considered in this study.

Tree recruitment in boreal upland forests is usually completed within several years after a stand-replacing disturbance because herbaceous vegetation, accumulated litter, and mosses quickly cover all available mineral seedbeds (Greene et al. 1999; Chen and Popadiouk 2002; Harvey and Brais 2002). However, coniferous regeneration density, particularly that of black spruce, was found to increase from 5 to 17 years after harvest on lowland sites in this study. The slow height growth of black spruce, thus slow crown expansion, in comparison to other pioneer species such as jack pine, trembling aspen, and white birch may have allowed growing space to remain available for continuous recruitment for a long period of time (Chen et al. 1996; Greene et al. 1999; Chen and Popadiouk 2002; Vasiliauskas and Chen 2002). Further, the continuous increase of *Sphagnum* moss cover after harvest may explain the increase in black spruce density with time since harvest. Harvey and Brais (2002) also reported that black spruce density increased continuously from 1 to 7 years after harvest on skid trails and there was no evidence that the increase had reached an asymptote. The effect of time since harvest on regeneration density found in this study could be even stronger if the improvement had not occurred in harvest techniques and operator training through time that positively contributes to regeneration density on the sites of recent harvests (Groot et al. 2001).

Stocking of black spruce, all conifers, and all tree species did not differ among harvest methods, nor did it change with time since harvest. The different responses of regeneration density and stocking may suggest that horizontal distribution of regeneration differed among harvest methods (Clark and Evans 1952). Although it was not measured, regeneration on CLAAG sites appeared to be clumped whereas that on GST and SHE sites appeared to be random. Greene et al. (2002) also attributed the different regeneration density and stocking relationships between western and eastern Canada to the difference in horizontal distribution of regeneration stems. The limited variation in stocking may also partially explain the non-significant effects of harvest methods and time since harvest on stocking.

Black spruce stocking for all except one SHE stand reached the minimum 40% requirement set by the Ontario Ministry of Natural Resources (1997). Using the stocking criteria developed by Greene et al. (2002), all stands reached moderate or full stocking (i.e., 60%) even if only black spruce was considered as the crop tree species. When all tree species are considered, only 2 of 30 sites did not reach full stocking within 5–17 years since harvest. Significant correlations between stocking and regeneration density indicate that stocking is predictable from regeneration density. The model relating black spruce stocking to black spruce density indicates that full stocking can be achieved when black spruce density reaches 5000 stems/ha. Similarly, when all conifers or all tree species are considered as crop species, full stocking can be achieved when density reaches 5000 stems/ha. However, if desirable stocking is 80%, it takes ~15,000 stems/ha to achieve.

Stocking is a common criterion in measuring success of forest regeneration (Greene et al. 2002), using existing stocking criterion alone may be problematic for assessment of black spruce regeneration. Stocking assumes that a perfectly systematic distribution of a hypothetic number of stems per ha is ideal for a tree species. First, while most populations are randomly distributed naturally (Clark and Evans 1952), even if only for fiber production, the underlying assumption that a perfectly even distribution is ideal is not necessarily validated. Second, one stem for each 2×2 m^2 (i.e., 2500 stems/ha) is arbitrarily determined as the same number is applied for all tree species in Ontario regardless of the potential crown size of mature trees. Third, it is questionable that 60% is considered full stocking for the reasons described above. Lastly, assessment of stocking without considering height of tree regeneration and its competitors does not warrant stands productive at their maturity as growth and mortality of individual stems in a stand are highly associated with their existing size and neighboring individuals. Therefore, in absence of an improved stocking guide for natural regeneration of these black spruce forests, regeneration density and its height structure shall be important criteria for assessment of regeneration success.

Conclusions

In black spruce dominated forests in northeastern Ontario, post-harvest regeneration density was affected by harvest method and site preparation, and increased with time since harvest. Total black spruce regeneration density did not differ, but height structure of black spruce regeneration did significantly among harvest methods. The CLAAG method resulted in the highest regeneration density of other conifers including balsam fir, eastern white cedar, white spruce, and tamarack. The finding suggests that the CLAAG is the best approach to ensure sufficient regeneration density of mixed conifers as it is designed to protect advance regeneration. The lowest regeneration density on SHE sites may explain why it is no longer a popular harvest method for promoting conifer regeneration in the region. Continuous recruitments of black spruce up to 17 years since harvest indicates that post-harvest regeneration process is significantly longer than that of pioneer species after wildfires.

All but one SHE study stand reached minimum stocking requirement, i.e., 40%. Stocking of black spruce, all conifers, or all tree species did not differ significantly among harvest methods, nor did it change with time since harvest. The different responses of regeneration density and stocking indicate different horizontal distributions among harvest methods. Stocking was highly related to regeneration density. Models developed in this study predict that given a regeneration density of 5000 stems/ha full stocking (60%) will be achieved regardless of chosen crop species. However, the existing stocking criterion for assessing black spruce regeneration may be problematic.

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