Effects of initial density on the development of planted black spruce to age 17

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Abstract: The effects of initial density (inter-tree spacing ranging from 1.25 to 4.00 m) of planted black spruce (*Picea mariana* (Mill.) B.S.P.) on tree and stand growth to age 17 were examined in a study located on upland and transitional peatland sites in northeastern Ontario. As early as age 10, mean diameter and height decreased with increasing initial density, whereas basal area and total volume increased. The mean diameter of the largest 500 stems per hectare was not affected by initial density as late as age 17, but density effects will likely become apparent with further stand development. The effects of initial density on stand basal area and total volume will likely become more pronounced over the near term. Analyses that accounted for variation in site quality within the experiment allowed better detection and more precise estimation of initial density effects.

Introduction

The initial density of tree plantations affects the rapidity and completeness of site occupation and the division of growing resources among crop trees. Selection of initial density is an important management decision, since low densities can lead to loss of stand volume growth through delayed or incomplete site occupation, whereas high densities can reduce the growth and size of individual trees through diminished growing resources per tree.

Black spruce may require high initial densities for full site occupation, because it is a narrow-crowned species (Farrar 1998) and fully stocked natural stands carry high densities (Plonski 1974).

Two studies have examined the effect of initial density on tree and stand development in black spruce plantations. McClain et al. (1994) reported 37-year results for black spruce planted at 1.8, 2.7 and 3.6 m inter-tree spacings in Ontario. Matheson and Stewart (1986) reported 14-year results of black spruce planted in Nelder designs with effective spacing ranging from 1.08 m to 2.32 m in New Brunwick. Both these studies, which were located south of the Boreal Forest Region (Rowe 1972), indicated strong effects of initial density.

This note reports the results to age 17 of a third study, located within the Northern Clay Section of the Boreal Forest Region. The objective of the study was to examine the effect of initial density on black spruce tree and stand development.

Materials and Methods

Site Description and Experimental Layout

The experiment was established about 48 km southeast of Kapuskasing, Ontario (49º01'N, 82º09'E). Black spruce-dominated and mixedwood (trembling aspen (*Populus tremuloides* Michx.) , white birch (*Betula papyrifera* Marsh.), white spruce (*Picea glauca* (Moench) Voss) and balsam fir (*Abies balsamea* L.)) stands at this location were harvested in the summer and fall of 1981. A prescribed fire was carried out in August 1983, which reduced slash depth by 60%, and reduced the forest floor depth by an average of 3 cm.

The experiment was established on upland (clayey soil) and transitional peatland (15 to 40 cm of organic matter over clayey soil) site types. Post-burn forest ecosystem classsification of site was not possible, but based on the soil and nearby unburned stands, site types were likely ES9p (Black Spruce – Larch – Moist Soil – Species Poor) and ES8 (Black Spruce – Feathermoss – Sphagnum – Moist Soil) on the transitional sites and ES7f (Trembling Aspen – White Spruce – White Birch – Fine Soil) on the upland sites (Taylor et al. 2000).

In September 1983, 39 treatment plots (21 on the transitional site type and 18 on the upland type), each 0.64 ha in area, were established. Three replications of the following initial density treatments were randomly assigned to the plots: 1.25 m, 1.50 m, 1.75 m, 2.00 m, 2.50 m, 3.00 m and 4.00 m inter-tree spacing. The 4.00 m spacing was applied only on the transitional site type.

Bare-root 1½+2½ stock was planted at the prescribed spacings from late September to early October, 1983. The planted seedlings suffered high mortality (averaging 50%) by mid-summer 1984, possibly because of above-normal air temperatures during April 1984. In 1984, it was decided to abandon the two-thirds of the plots with the greatest mortality and carry out fill planting on one plot of each initial density on each site type. This planting was carried out with 1½+1½ stock May 27-28, 1985. A final fill plant was carried out June 10-14, 1986 with 1+2 and G-1½ stock. Control of competing vegetation was carried out periodically with manual (cutting or breaking aspen stems) and herbicide treatments.

Two measurement sub-plots were established within each treatment plot in fall 1993 and early spring 1994. The size of the sub-plot varied with the initial density treatment so that each sub-plot would contain about 100 trees. Each tree within each sub-plot was tagged and the diameter at breast height (dbh) and the height of each tree was measured in early spring 1994, early spring 1999 and in fall 2000 (at ages 10, 15 and 17).

Analyses

The mean dbh and height of all trees, the mean dbh and height of the 500 largest trees ha^{-1} (dbh_{500} and $height_{500}$, respectively), the stand basal area, and the total stand volume, using Honer's volume equation for black spruce (Honer et al. 1983), were determined for each subplot. The subplot values were averaged to provide mean values for each combination of initial density and site type. Increments of all tree and stand characteristics were determined for the periods 11 to 15 and 16 to 17.

Two-tailed t-tests, with the assumption of unequal variance, were used to compare the mortality rate and mean height of upland and (n = 6) transitional site types (n = 7).

Simple linear regressions were used to examine the relationship of dbh, dbh_{500}, height, $height_{500}$, basal area and total volume age 17 to age 10 density. It was evident, however, that some of these dependent variables were affected not only by density, but also by variation in site quality. The t-test showed that age 17 mean height was greater ($p = 0.01$) on the upland site type (4.56 m) than on the transitional type (3.94 m). Furthermore, there was substantial variation in mean height (range of about 1 m) among treatment plots within each site type (Table 1). This variation in site quality between and within site types to some extent obscured the effects of initial density. For example, the age 17 mean height for the 1.25 m spacing on the upland type was substantially less than for the 1.5 m spacing, and correspondingly, the basal area and volume were less (Table 1). To account for the effect of site variability, further analysis was carried out using multiple linear regression with two independent variables representing initial density and site quality: (i) age 10 density and (ii) the residuals from the linear regression of age 17 height on age 10 density. Residuals were used for the latter variable to remove the non-significant trend of decreasing height with increasing density. The residuals ranged from –0.60 m to +0.70 m with a mean of 0. Because this variable accounted for site quality variation, the multiple regression analysis was carried out with both site types pooled ($n = 13$).

Results

Mortality

T-tests indicated that the average annual mortality was greater on the transitional peatland plots than on the upland plots from age 11 to 15 (0.41% yr^{-1} vs 0.07% yr^{-1}, $p = 0.002$) and from age 16 to 17 (0.34% yr^{-1} vs 0.13% yr^{-1}, $p = 0.06$). Mortality was uncorrelated with initial density for either site separately or both site types combined.

Diameter

Mean dbh decreased with increasing initial density for both site types at age 17 (Table 1) in the simple linear regression analysis, and at all ages in the multiple linear regression analysis (Table 2). Mean dbh and dbh_{500} increased with higher site quality at all ages (Table 2).

A significant relationship between dbh_{500} and initial density was detected only for the upland site at age 17 in the simple linear regression analysis (Table 1), although there was also evidence of a relationship ($p = 0.067$) at age 17 in the multiple linear regression analysis.

Height

Mean height and $height_{500}$ were not related to initial density in the simple linear regression (Table 1). In contrast, mean height decreased and $height_{500}$ increased with increasing initial density at all ages in the multiple regression (Table 2). Both mean height and $height_{500}$ increased with increasing site quality at all ages (Table 2).

Basal area

Basal area increased as initial density increased on the transitional site type and on the upland site type ($p = 0.061$) in the simple linear regression analysis (Table 1), and at all ages in the multiple regression (Table 2). Basal area also increased with site quality at all ages (Table 2).

Total volume

A significant increase in total volume at age 17 was detected with the simple linear regression analysis on the transitional site type, but not on the upland type (Table 1). In the multiple regression analysis, total volume increased with increasing initial density and with site quality at all ages (Table 2).

Increments

The mean diameter increment decreased with initial density for both the age 11-15 and the 16-17 periods, but the dbh_{500} increment decreased only for the latter period (Table 3). A significant effect of site quality on mean diameter and on dbh_{500} was detected only for the age 11-15 period.

Mean height increment showed a significant decrease with increasing initial density for the age 11-15 period, but not for the subsequent period. No significant relationship between $height_{500}$ increment and initial density was detected, although there was some evidence ($p = 0.076$) of an increase in $height_{500}$ increment with initial density for the age 11-15 period. Both mean height increment and $height_{500}$ increment increased with greater site quality during both periods (Table 3).

Both basal area increment and volume increment increased with increasing initial density and with greater site quality during both periods (Table 3).

Discussion

The incorporation of a site quality measure in the multiple regression analysis provided better detection and more precise estimation of the effects of initial density on tree and stand growth than did the simple linear regression analysis. For example, because of variability in site quality, the simple linear regression analysis for the upland site type failed to detect the effect of initial density on total volume, and may have detected a spurious effect of initial density on dbh_{500}.

The decreases in mean height, mean dbh, and their increments with increasing initial density indicates that density-related growth reduction was occurring as early as age 10. Such early (age 14) effects were also observed by Matheson and Stewart (1986). In the current study, the growth reduction was mainly concentrated among the smaller trees within the size distributions, because dbh_{500} was unaffected by and $height_{500}$ increased with increasing initial density.

It appears, however, that by about age 15, initial density was beginning to affect the diameter of the largest 500 trees as well as the diameter of all trees. This is indicated by the negative coefficient of age 10 density in the multiple regression analysis of dbh_{500} increment, and by change with time from positive to increasingly negative, and nearly significant, values of the coefficient of age 10 density in the analysis of dbh_{500}. As a consequence, it seems likely that with further stand development, both mean dbh and dbh_{500} will decrease with initial density.

The increase in $height_{500}$ with increasing initial density probably occurred because this variable increasingly represents the uppermost portion of the height distribution as density increases.

Full site occupation has not yet occurred for most initial densities, because both basal area increment and total volume increment during the age 16-17 period increased with increasing initial density. As a consequence, the effects of initial density on basal area and total volume will become more pronounced, at least in the short term.

The multiple linear regression model coefficients in Tables 2 and 3 can be used to estimate tree and stand characteristics and their increments for various combinations of density and site quality. The values of the density and site quality variables used should not go beyond those observed in this study (i.e, age 10 density ranging from 0.6 to 6.3 thousand stems ha^{-1}, and residuals from age 17 height vs age 10 density ranging from –0.6 to +0.7 m).

Acknowledgements

Kent Virgo, Spruce Falls Power and Paper Inc., provided valuable assistance in establishing this study. Mike Adams, provided skilled technical assistance in field measurements and in data management. The 17th year remeasurement was funded by the Ontario Living Legacy Trust.

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Table 1. Stand characteristics for upland and transitional site types at age 17.

	Nominal spacing (m)							R^2
	1.25	1.5	1.75	2.0	2.5	3.0	4.0	
Age 10 Density (ha^{-1}), upland	5760	4133	3184	2400	1544	1083	**-**	
Age 10 Density (ha^{-1}), transitional	6272	4689	2890	2350	1512	1379	619	
DBH (cm), upland	4.6	6.2	5.8	6.7	6.5	7.9	**-**	**0.82**[a]
DBH (cm), transitional	4.5	4.1	5.0	4.7	6.6	5.7	6.1	**0.64**
DBH_{500} (cm), upland	7.4	8.6	8.4	8.7	8.4	9.5	**-**	**0.71**
DBH_{500} (cm), transitional	7.6	7.0	7.8	7.2	8.5	8.1	6.9	0.03
Height (m), upland	3.88	4.80	4.36	4.96	4.43	4.83	-	0.42
Height (m), transitional	3.88	3.58	3.99	3.67	4.55	3.88	4.05	0.19
$Height_{500}$ (m), upland	5.43	5.83	5.72	5.91	5.40	5.52	-	0.00
$Height_{500}$ (m), transitional	5.54	5.21	5.34	4.76	5.40	5.00	4.38	0.44
Basal area (m^2 ha^{-1}), upland	10.5	13.3	9.3	8.8	5.5	5.6	-	0.62
Basal area (m^2 ha^{-1}), transitional	11.6	7.3	6.4	4.6	5.4	4.1	2.1	**0.90**
Total volume (m^3 ha^{-1}), upland	23.4	34.3	22.9	23.2	13.4	14.4	-	0.43
Total volume (m^3 ha^{-1}), transitional	27.2	15.9	14.7	10.0	13.4	9.5	4.8	**0.85**

[a]R^2 values are for simple linear regressions on age 10 density; bold values indicate $p < 0.05$ for the regression F-ratio.

Table 2. Statistics for multiple linear regressions of tree and stand characteristics on density and site quality variables. The density variable is age 10 density (thousand stems ha^{-1}) and the site quality variable is the residual (m) from the simple linear regression of age 17 mean height on age 10 density.

	Age (years)	Intercept	Density variable coefficient	Site quality variable coefficient	R^2
Dbh (cm)	10	[a]**1.71**	[a]**-0.111**	[a]**0.61**	[b]**0.82**
Dbh (cm)	15	**5.26**	**-0.289**	**1.38**	**0.93**
Dbh (cm)	17	**6.97**	**-0.432**	**1.66**	**0.93**
Dbh_{500} (cm)	10	**2.42**	0.047	**0.72**	**0.56**
Dbh_{500} (cm)	15	**6.48**	-0.010	**1.36**	**0.74**
Dbh_{500} (cm)	17	**8.41**	-0.140	**1.43**	**0.75**
Height (m)	10	**1.98**	**-0.040**	**0.37**	**0.87**
Height (m)	15	**3.78**	**-0.078**	**0.71**	**0.98**
Height (m)	17	**4.48**	**-0.091**	**1.00**	**1.00**
$Height_{500}$ (m)	10	**2.32**	**0.060**	**0.36**	**0.64**
$Height_{500}$ (m)	15	**4.25**	**0.080**	**0.58**	**0.78**
$Height_{500}$ (m)	17	**5.07**	**0.092**	**0.81**	**0.83**
Basal area (m^2 ha^{-1})	10	**0.26**	**0.106**	**0.34**	**0.85**
Basal area (m^2 ha^{-1})	15	**1.72**	**0.981**	**2.70**	**0.90**
Basal area (m^2 ha^{-1})	17	**3.08**	**1.445**	**4.07**	**0.94**
Total volume (m^3 ha^{-1})	10	**0.35**	**0.115**	**0.47**	**0.82**
Total volume (m^3 ha^{-1})	15	**3.90**	**1.901**	**6.67**	**0.88**
Total volume (m^3 ha^{-1})	17	**8.11**	**3.224**	**12.28**	**0.92**

[a]bold values are significantly different from 0, $p < 0.05$.
[b]bold values indicate $p < 0.05$ for the regression F-ratio.

Table 3. Statistics for multiple linear regressions of increments of tree and stand characteristics on density and site quality variables. The density variable is age 10 density (thousand stems ha^{-1}) and the site quality variable is the residual (m) from the simple linear regression of age 17 mean height on age 10 density.

	Age	Intercept	Density variable coefficient	Site quality variable coefficient	R^2
Dbh (cm yr^{-1})	11-15	[a]**0.711**	[a]**-0.036**	[a]**0.158**	[b]**0.86**
Dbh (cm yr^{-1})	16-17	**0.856**	**-0.071**	0.140	**0.66**
Dbh_{500} (cm yr^{-1})	11-15	**0.811**	-0.011	**0.129**	**0.68**
Dbh_{500} (cm yr^{-1})	16-17	**0.965**	**-0.064**	0.036	**0.53**
Height (m yr^{-1})	11-15	**0.360**	**-0.008**	**0.067**	**0.90**
Height (m yr^{-1})	16-17	**0.352**	-0.006	**0.146**	**0.90**
$Height_{500}$ (m yr^{-1})	11-15	**0.386**	0.004	**0.044**	**0.75**
$Height_{500}$ (m yr^{-1})	16-17	**0.410**	0.006	**0.113**	**0.69**
Basal area (m^2 ha^{-1} yr^{-1})	11-15	**0.293**	**0.175**	**0.472**	**0.89**
Basal area (m^2 ha^{-1} yr^{-1})	16-17	**0.677**	**0.232**	**0.686**	**0.85**
Volume (m^3 ha^{-1} yr^{-1})	11-15	**0.711**	**0.359**	**1.241**	**0.87**
Volume (m^3 ha^{-1} yr^{-1})	16-17	**2.104**	**0.662**	**2.806**	**0.91**

[a]bold values are significantly different from 0, $p < 0.05$.
[b]bold values indicate $p < 0.05$ for the regression F-ratio.