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Direct Seeding Black Spruce on Peatlands: Tenth-year Results

Arthur Groot

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ABSTRACT

In four black spruce seeding experiments on forested peatlands, tenth-year stocking of seeded trees ranged from an average of 63 percent at a seeding rate of 50 000/ha to 74 percent at a seeding rate of 150 000/ha. Corresponding densities ranged from 4 340 seedlings/ha to 8 250 seedlings/ha. These values were similar to fifth-year observations of stocking and density.

For sites with similar amounts and distribution of seedbed, broadcast seeding at rates of 100 000 to 150 000 seeds/ha should yield acceptable stocking. In general, though, seeding rate prescriptions should be based on seedbed amounts and seedbed receptivity.

Mean tenth-year seedling heights showed a large variation, ranging from 24 cm to 67 cm, among the experimental locations. The average height of the tallest seedling per stocked quadrat was similarly variable, ranging from 32 cm to 90 cm. It is projected that the average height of the tallest seedling per quadrat will exceed 100 cm at ages ranging from 11 to 16 years.

Coefficients of variation for tenth-year seedling heights ranged from 0.50 to 0.65, and distributions were positively skewed. The height of the tallest seedling per quadrat increased as the number of seedlings per quadrat increased. Use of higher seeding rates can increase the mean height of dominant seedlings.

At one location, black spruce advance growth stocking alone was acceptable (80 percent), and at two other locations it was marginally acceptable (49 and 56 percent). Advance growth had a height and height growth advantage over seeded trees. Preserving advance growth during harvest is a regeneration option preferable to direct seeding. Seeding is appropriate when stocking of advance growth alone is insufficient.

RÉSUMÉ

Dans le cadre de 4 expériences d'ensemencement d'épinette noire en tourbière, la proportion moyenne de surface occupée après 10 ans allait de 63%, pour un taux d'ensemencement de 50000/ha, à 74%, pour un taux de 150000/ha. Ces minimum et maximum correspondaient respectivement à des densités de 4340 et 8250semis/ha. Ces résultats sont comparables à ceux obtenus après 5 ans.

Pour des stations présentant une quantité et une répartition analogues de surface préparée, l'ensemencement à la volée à raison de 100000 à 150000graines/ha devrait produire une proportion acceptable de surface occupée. Cependant, en général, il faudrait prescrire les taux d'ensemencement en fonction de la quantité de surface préparée et de la réceptivité du lit de germination.

Après 10 ans, la hauteur moyenne des semis variait beaucoup selon les stations, de 24 à 67cm. La hauteur moyenne du plus grand semis de chaque parcelle régénérée était tout aussi variable, allant de 32 à 90cm. On peut prédire que la hauteur moyenne du plus grand semis de chaque parcelle dépassera 100cm après 11 à 16ans.

Quant au coefficient de variation de la hauteur des semis après 10ans, il allait de 0,50 à 0,65, et les distributions étaient désaxées vers la droite. La hauteur du plus grand semis de chaque parcelle augmentait avec le nombre de semis par parcelle. L'utilisation de taux d'ensemencement élevés peut donc augmenter la hauteur moyenne des semis dominants.

Dans une des stations, la régénération préexistante d'épinette noire présentait à elle seule une proportion acceptable de surface occupée (80%); dans deux autres stations, cette proportion était tout juste acceptable (49 et 56%). La régénération préexistante présentait en outre une hauteur et un accroissement de la hauteur plus élevés par rapport aux semis. La conservation de la régénération préexistante au moment de la récolte est donc préférable à l'ensemencement direct. Cette dernière méthode s'impose cependant quand la régénération préexistante n'occupe pas à elle seule une proportion suffisante de la surface.

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INTRODUCTION

Direct seeding black spruce (*Picea mariana* [Mill.] B.S.P.) is a low-cost regeneration method that is often feasible for peatland forest sites. *Sphagnum* spp. moss is usually abundant on peatlands and can provide a good seedbed, particularly if the living portions of the moss have been scraped or sheared away (Johnston 1977, Groot and Adams 1994).

Some progress has been made in developing prescriptions for broadcast seeding black spruce on peatlands. For the Lake States, Johnston (1977) recommended a rate of about 250 000 seeds/ha, combined with the occurrence of *Sphagnum* seedbeds in at least 60 percent of 4-m^2 quadrats, to achieve stocking (4-m^2 basis) of 60 percent or more. In northeastern Ontario, fifth-year stocking of 70 percent or greater was achieved with seeding rates of 150 000/ha and a receptive seedbed cover averaging 18 percent. An effective seeding rate of 6 to 7 seeds per quadrat corresponded with an average stocking of 80 percent (Groot and Adams 1994).

Initial growth of black spruce seedlings on peatlands can be slow (Groot and Adams 1994), however, so it is important to carry out long-term assessments of seed-based regeneration methods.

This report summarizes the tenth-year results of black spruce direct seeding experiments carried out on peatlands in northeastern Ontario. The purpose of these experiments was to determine seeding rates and seedbed amounts required for successful regeneration. Fifth-year results have been reported previously by Groot and Adams (1994).

The objectives of this report are to summarize tenth-year stocking and density values; to examine the height development of seeded black spruce; and to discuss the implications for direct seeding prescriptions.

METHODS

Study Areas

Study areas have been described previously by Groot and Adams (1994). Seeding experiments were carried out at four locations in the Northern Clay Section of the Boreal Forest Region (Rowe 1972). These included Hanna Township, 25 km south of Cochrane; Williamson Township, 20 km west of Kapuskasing; Adanac Township, 40 km north of Smooth Rock Falls; and Sangster Township, 60 km north of Cochrane.

Alnus–herb poor (OG12) and *Ledum* (OG11) Forest Ecosystem Classification (FEC) Operational Groups (OGs) (Jones et al. 1983) predominated at the experimental locations. *Alnus*–herb rich (OG13) and conifer–herb/moss rich (OG9) OGs were present at Williamson, and portions of Adanac graded into the *Chamaedaphne* (OG14) OG. Peat depths generally ranged from 50 cm to 200 cm, but some depths <40 cm also occurred. At all four locations the original stands were dominated by black spruce.

The stands at all locations were clear-cut. Tree-length harvesting was used at Hanna, Williamson, and Adanac, and full-tree harvesting was used at Sangster. Site preparation at all locations consisted of winter shearblading. This took place within 1 year of harvesting, except at Hanna, where the lag was 2 1/2 years. Seeding experiments were established in the spring following site preparation.

Aerial application of glyphosate herbicide was carried out at all four experimental locations as part of operational-scale treatments to control competing vegetation (mainly speckled alder [*Alnus rugosa* (Du Roi) Spreng]). Herbiciding was carried out 4 to 7 years after seeding (Table 1).

Table 1. Rate and timing of herbicide (glyphosate) applications.

Location	Year of seeding	Rate (kg a.i. ha^{-1})	Date of application
Williamson	1982	1.38	31 July 1985
Hanna	1982	2.13	30 August 1985
Adanac	1983	1.78	2 September 1989
Sangster	1984	2.20	24 July 1989

Experiments

Broadcast seeding experiments were established from 1982–1984 in the spring (late May or early June) following site preparation. Seeding at four rates (0, 50 000, 100 000, and 150 000 viable seeds/ha) was carried out on square plots of 400 m^2 (Williamson, Adanac, Sangster) or 900 m^2 (Hanna) using a hand-operated Cyclone seeder. Three (Williamson, Adanac) or four (Hanna, Sangster) replications of each seeding rate were established. Measurements of regeneration were carried out after the second, fifth, and tenth growing seasons on 4-m^2 quadrats (20 per plot at Williamson, Adanac, and Sangster and 25 per plot at Hanna). Stocking and density were recorded at each measurement date, and tree height and current annual height increment of all trees[1] on the measurement quadrats were recorded during the fifth- and tenth-year measurements. Measurements were made both on trees originating from seed after the harvest and on advance growth.

Analyses

The effect of seeding rate on stocking (percentage of 4-m^2 quadrats with at least one tree) and density (trees/ha) was examined using analysis of variance. Partitioning of the sources of variance is summarized in Table 2. The analysis of variance model used was:

$$y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij} \quad [1]$$

where: y_{ij} = observation for seeding rate i in replication j,

μ = the overall experimental mean,

α_i = the fixed effect associated with seeding rate (i = 1 to 4),

β_j = the random effect associated with replication (j = 1 to 3 or 4 depending on location), and

ε_{ij} = the sampling error associated with seeding rate i in replication j.

Table 2. Sources of variance in analyses of variance.

Source of variation	Degrees of freedom			
	Hanna	Williamson	Sangster	Adanac
Total	15	11	15	11
Seeding rate	3	3	3	3
Blocks	3	2	3	2
Error	9	6	9	6

Tenth-year height growth data for each experimental location were summarized by grouping seedlings into 10-cm total height classes (0 to 9.9 cm, etc.), and computing the average height growth for groups with more than five seedlings. A linear model was then used to relate tenth-year seedling height growth to height at the end of the ninth growing season, as a basis for making short-term forecasts of height growth. The linear model was used because little curvilinearity was evident in the data over the range of heights sampled. This model should not be extended beyond the range of the data (heights of about 200 cm), because it implies height developing in an exponential fashion. Coefficients of the linear model were determined using linear regression.

RESULTS

Stocking and Density

With one exception (Adanac Township at Year 10), seeding rate was a significant factor ($p < 0.05$) for both the stocking and density of seeded trees at all four locations and at each measurement date (Tables 3 to 6). Changes in stocking and density from the second-year assessment to the tenth-year assessment generally were not large.

Stocking and density of advance growth did not vary among seeding rates (Tables 3 to 6), although there were substantial differences among locations. Tenth-year stocking was low (4 percent) at Williamson, high at Sangster (80 percent), and intermediate at Hanna and Adanac (49 percent and 56 percent, respectively).

Seeding rate was consistently a significant factor ($p < 0.05$) in the stocking and density of all trees (seeded trees and advance growth) at Williamson Township, and in the stocking of all trees at Hanna Township (Tables 3 to 6). The influence of seeding rate at Hanna Township on the density of all trees was evident, but less pronounced in the fifth- and tenth-year assessments ($p < 0.10$).

As with seeded trees, stocking and density of all trees did not show large changes over time.

Tenth-year stocking of seeded trees, averaged for all four sites, increased with seeding rate in a curvilinear fashion (Fig. 1). The greatest average stocking, 74 percent, occurred at the highest seeding rate. For all trees, stocking was lowest (67 percent) for the 0 ha^{-1} seeding rate, but differed little (81 percent to 84 percent) among seeding rates from 50 000 to 150 000 ha^{-1}.

Tenth-year density of seeded trees increased with seeding rate in a linear fashion, with a slope of 0.044 seedlings per seed sown (Fig. 2). Tenth-year density of all trees also increased with seeding rate in a linear fashion, with a similar slope (0.035 seedlings per seed sown) but a larger y-intercept.

Stocking and density of postharvest origin trees in the control plots was substantial, with tenth-year values averaging 33 percent and 1 524 stems ha^{-1}, respectively. These values increased with time, implying a steady ingress of seedlings originating from natural seed sources. An estimate of the average natural seedfall for the four experimental locations is provided by the absolute value of the x-intercept of the line fitted to the density vs seeding rate data for seeded trees in Figure 2. This value is 40 393 seeds/ha.

[1] In the fifth-year measurements of advance growth at Sangster, height and height growth were measured only for the five tallest stems per quadrat.

Table 3a. Black spruce stocking (percent) in the Hanna Township seeding experiment.

	Seeding rate (viable seeds/ha)						
	0	50 000	100 000	150 000	MSE*	F**	p > F
Seeded trees (2nd year)	10.0	58.0	74.0	81.0	113.0	36.21	<0.0001
Seeded trees (5th year)	17.0	63.0	76.0	76.0	161.7	19.40	0.0003
Seeded trees (10th year)	15.0	65.0	80.0	80.0	170.7	22.27	0.0002
Advance growth (2nd year)	49.0	49.0	50.0	50.0	335.2	0.10	0.9589
Advance growth (5th year)	43.0	47.0	50.0	52.0	355.5	0.17	0.9123
Advance growth (10th year)	52.0	47.0	51.0	44.0	395.1	0.14	0.9346
All trees (2nd year)	56.0	74.0	85.0	90.0	162.7	5.58	0.0193
All trees (5th year)	61.0	76.0	86.0	87.0	167.5	3.48	0.0637
All trees (10th year)	62.0	76.0	88.0	88.0	203.1	3.01	0.0869

* MSE is the mean square error in the analysis of variance.
** F is the F-ratio in the analysis of variance.

Table 3b. Black spruce density (stems/ha) in the Hanna Township seeding experiment.

	Seeding rate (viable seeds/ha)						
	0	50 000	100 000	150 000	MSE*	F**	p > F
Seeded trees (2nd year)	275	3 550	7 100	9 325	3.4×10^6	18.40	0.0004
Seeded trees (5th year)	575	3 675	7 675	8 225	2.0×10^6	26.26	0.0001
Seeded trees (10th year)	525	3 850	8 175	8 325	2.4×10^6	23.76	0.0001
Advance growth (2nd year)	5 250	3 750	5 750	4 950	7.4×10^6	0.39	0.7630
Advance growth (5th year)	5 275	3 750	5 000	4 025	6.7×10^6	0.33	0.8059
Advance growth (10th year)	5 400	3 425	4 425	3 975	6.4×10^6	0.44	0.7316
All trees (2nd year)	5 525	7 300	12 850	14 275	4.6×10^6	15.40	0.0007
All trees (5th year)	5 850	7 425	12 700	12 250	5.1×10^6	9.20	0.0042
All trees (10th year)	5 925	7 275	12 600	12 300	5.4×10^6	8.77	0.0049

* MSE is the mean square error in the analysis of variance.
** F is the F-ratio in the analysis of variance.

Table 4a. Black spruce stocking (percent) in the Williamson Township seeding experiment.

	Seeding rate (viable seeds/ha)						
	0	50 000	100 000	150 000	MSE*	F**	p > F
Seeded trees (2nd year)	26.7	78.3	70.0	90.0	78.5	29.19	0.0006
Seeded trees (5th year)	36.7	66.7	53.3	70.0	86.8	7.94	0.0164
Seeded trees (10th year)	48.3	75.0	61.7	73.3	49.3	9.28	0.0113
Advance growth (2nd year)	0.0	5.0	5.0	5.0	27.1	0.69	0.5894
Advance growth (5th year)	0.0	6.7	3.3	3.3	22.2	1.00	0.4547
Advance growth (10th year)	0.0	11.7	3.3	1.7	7.6	10.55	0.0083
All trees (2nd year)	26.7	78.3	70.0	90.0	78.5	29.29	0.0006
All trees (5th year)	36.7	70.0	55.0	70.0	110.4	6.81	0.0233
All trees (10th year)	48.3	78.3	63.3	73.3	81.3	6.46	0.0262

* MSE is the mean square error in the analysis of variance.
** F is the F-ratio in the analysis of variance.

Table 4b. Black spruce density (stems/ha) in the Williamson Township seeding experiment.

	Seeding rate (viable seeds/ha)						
	0	50 000	100 000	150 000	MSE*	F**	p > F
Seeded trees (2nd year)	1 000	6 458	5 458	13 375	3.4×10^6	23.45	0.0010
Seeded trees (5th year)	1 500	5 833	4 208	9 250	2.2×10^6	14.59	0.0037
Seeded trees (10th year)	2 542	6 333	4 750	9 708	9.1×10^5	30.02	0.0005
Advance growth (2nd year)	0	333	250	625	3.6×10^5	0.56	0.6605
Advance growth (5th year)	0	333	208	458	2.2×10^5	0.51	0.6889
Advance growth (10th year)	0	458	125	458	1.9×10^5	0.86	0.5095
All trees (2nd year)	1 000	6 792	5 708	14 000	3.9×10^6	22.18	0.0012
All trees (5th year)	1 500	6 167	4 417	9 708	2.9×10^6	12.07	0.0059
All trees (10th year)	2 542	6 793	4 875	10 167	1.5×10^6	21.00	0.0014

* MSE is the mean square error in the analysis of variance.
** F is the F-ratio in the analysis of variance.

Table 5a. Black spruce stocking (percent) in the Adanac Township seeding experiment.

	Seeding rate (viable seeds/ha)						
	0	50 000	100 000	150 000	MSE*	F**	p > F
Seeded trees (2nd year)	16.7	55.0	70.0	80.0	318.8	7.27	0.0201
Seeded trees (5th year)	21.7	58.3	71.7	75.0	213.8	8.36	0.0145
Seeded trees (10th year)	41.7	58.3	66.7	73.3	229.9	2.44	0.1622
Advance growth (2nd year)	48.3	65.0	46.7	61.7	513.8	0.50	0.6951
Advance growth (5th year)	56.7	58.3	45.0	58.3	615.9	0.20	0.8915
Advance growth (10th year)	55.0	61.7	48.3	58.3	516.0	0.19	0.9005
All trees (2nd year)	53.3	83.3	83.3	86.7	123.4	1.49	0.3106
All trees (5th year)	65.0	85.0	83.3	85.0	217.3	1.24	0.3750
All trees (10th year)	73.3	85.0	83.3	81.7	199.3	0.40	0.7556

* MSE is the mean square error in the analysis of variance.
** F is the F-ratio in the analysis of variance.

Table 5b. Black spruce density (stems/ha) in the Adanac Township seeding experiment.

	Seeding rate (viable seeds/ha)						
	0	50 000	100 000	150 000	MSE*	F**	p > F
Seeded trees (2nd year)	542	2 917	4 833	7 083	$3.0x10^6$	7.67	0.0178
Seeded trees (5th year)	708	3 375	6 458	8 167	$6.1x10^6$	5.42	0.0383
Seeded trees (10th year)	2 083	3 458	6 875	7 542	$4.9x10^6$	4.29	0.0612
Advance growth (2nd year)	7 583	10 500	4 625	10 750	$5.7x10^7$	0.44	0.7334
Advance growth (5th year)	7 667	9 208	4 208	9 375	$3.9x10^7$	0.44	0.7318
Advance growth (10th year)	6583	9167	4208	9 333	$3.2x10^7$	0.55	0.6640
All trees (2nd year)	8125	13417	9458	17833	$7.8x10^7$	0.74	0.5673
All trees (5th year)	8417	13250	10667	17708	$7.6x10^7$	0.63	0.6212
All trees (10th year)	8667	12625	11083	16875	$5.6x10^7$	0.64	0.6181

* MSE is the mean square error in the analysis of variance.
** F is the F-ratio in the analysis of variance.

Table 6a. Black spruce stocking (percent) in the Sangster Township seeding experiment.

	Seeding rate (viable seeds/ha)						
	0	50 000	100 000	150 000	MSE*	F**	p > F
Seeded trees (2nd year)	10.0	56.3	63.8	68.8	387.6	7.50	0.0081
Seeded trees (5th year)	22.5	56.3	70.0	73.8	377.0	5.77	0.0175
Seeded trees (10th year)	28.8	53.8	70.0	70.0	368.8	4.12	0.0428
Advance growth (2nd year)	81.3	88.8	77.5	81.2	119.6	0.74	0.5521
Advance growth (5th year)	78.8	87.5	76.3	77.5	194.4	1.09	0.4009
Advance growth (10th year)	77.5	92.5	73.8	76.3	158.3	1.82	0.2144
All trees (2nd year)	82.5	96.3	91.3	90.0	88.9	1.45	0.2913
All trees (5th year)	83.8	96.3	93.8	92.5	100.1	1.18	0.3706
All trees (10th year)	82.5	96.3	93.8	88.8	93.2	1.58	0.2610

* MSE is the mean square error in the analysis of variance.
** F is the F-ratio in the analysis of variance.

Table 6b. Black spruce density (stems/ha) in the Sangster Township seeding experiment.

	Seeding rate (viable seeds/ha)						
	0	50 000	100 000	150 000	MSE*	F**	p > F
Seeded trees (2nd year)	406	3 438	6 156	6 938	4.7×10^6	7.43	0.0083
Seeded trees (5th year)	1 063	3 969	7 000	7 844	5.3×10^6	7.18	0.0092
Seeded trees (10th year)	1 469	3 719	5 469	7 375	5.2×10^6	4.92	0.0272
Advance growth (2nd year)	19 719	23 281	16 875	16 813	5.9×10^7	0.63	0.6125
Advance growth (5th year)	21 188	22 875	18 500	16 938	5.7×10^7	0.50	0.6918
Advance growth (10th year)	19 688	20 531	14 688	15 563	4.0×10^7	0.85	0.5015
All trees (2nd year)	20 125	26 719	23 031	23 750	6.9×10^7	0.42	0.7405
All trees (5th year)	22 250	26 938	25 563	24 781	7.2×10^7	0.22	0.8833
All trees (10th year)	21 156	24 250	20 156	22 938	5.3×10^7	0.25	0.8600

* MSE is the mean square error in the analysis of variance.
** F is the F-ratio in the analysis of variance.

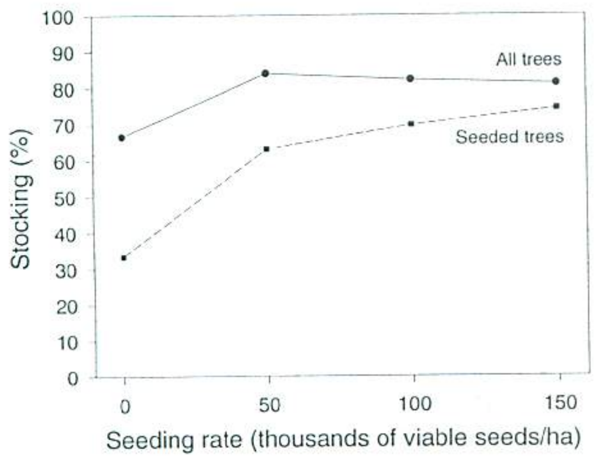

Figure 1. Average (four locations) tenth-year stocking to black spruce seedlings versus seeding rate.

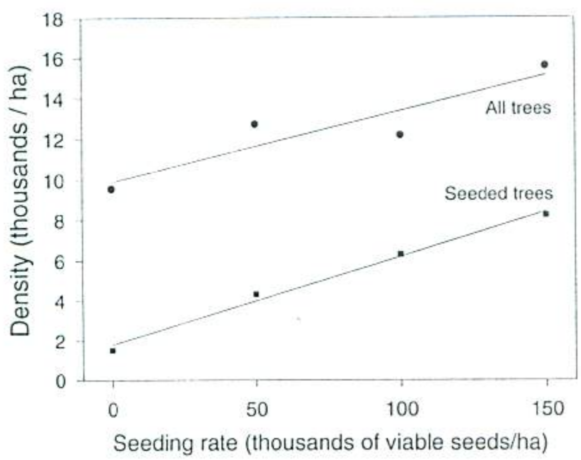

Figure 2. Average (four locations) tenth-year density of black spruce seedlings versus seeding rate (density of seeded trees = 1787 + 0.044 x seeding rate, density of all trees = 9899 + 0.035 x seeding rate).

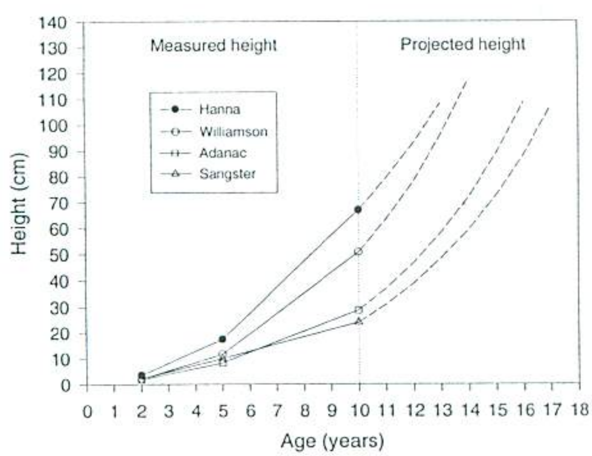

Figure 3. Black spruce seedling height development at four experimental locations. Broken lines indicate projected development.

Height and Height Growth

The average tenth-year height of seedlings varied considerably among experimental locations, from 24 cm at Sangster to 67 cm at Hanna (Table 7). Differences in seedling heights among locations had increased since the fifth year (Fig. 3). Average annual tenth-year height growth also varied among locations, from 5 cm/yr to 11 cm/yr.

Seedling height distributions were positively skewed at each location (Fig. 4). Coefficients of variation for seedling height ranged from 0.50 to 0.65.

The height of the tallest seedling on a quadrat generally increased with the number of seedlings on a quadrat (Fig. 5), and the height of the tallest seeded tree on a quadrat was from 34 percent to 44 percent greater than the average height (Table 7).

Advance growth showed greater height and height growth than did seeded trees at all four locations (Table 7), with tenth-year height ranging from about 80 cm to 125 cm, and tenth-year height growth ranging from 11 cm/yr to 18 cm/yr.

For both seeded trees and advance growth, height growth increased with increasing height in a relationship that was similar among all sites (Fig. 6). Coefficients for the relationships between tenth-year height growth and ninth-year height of seedlings are presented in Table 8.

Table 7. Tenth-year height and height growth (cm) of black spruce seedlings and advance growth in four broadcast seeding experiments.

	Hanna	Williamson	Adanac	Sangster
Seeded trees				
Average height	66.9	50.6	28.7	24.0
Average height growth	10.6	10.3	7.2	5.4
Maximum height per quadrat	90.3	72.7	39.5	32.2
Maximum height growth per quadrat	14.7	14.8	9.9	8.0
Advance growth				
Average height	125.6	100.9	80.9	81.5
Average height growth	15.7	17.6	12.9	11.3
Maximum height per quadrat	165.5	139.5	126.6	131.8
Maximum height growth per quadrat	23.0	28.4	21.3	21.2

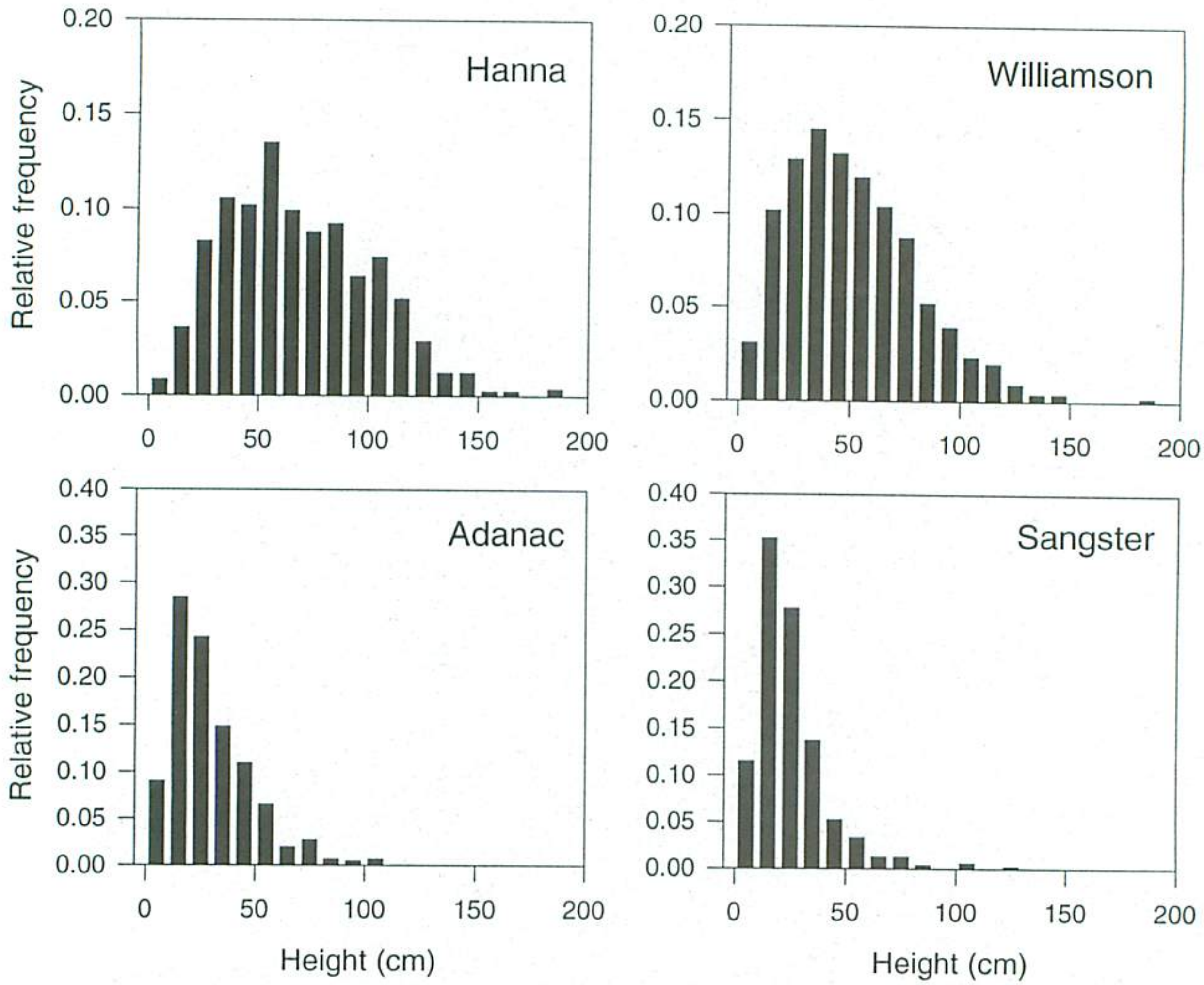

Figure 4. Black spruce seedling height frequency distributions at four experimental locations.

Table 8. Height growth–height relationships for seeded trees. Tenth year height growth = $a_0 + a_1$ x ninth-year height. All values are in cm.

Location	a_0	a_1	R^2
Adanac	2.93	0.200	0.97
Hanna	3.07	0.134	0.99
Williamson	2.49	0.197	0.92
Sangster	2.30	0.184	0.61

Based on these relationships, the projected age at which the average height of the tallest seedling per quadrat would exceed 100 cm ranged from 11 to 16 years, and the age at which the average height of all seedlings would exceed 100 cm ranged from 13 to 17 years (Fig. 3).

DISCUSSION

Broadcast Seeding Prescriptions

On peatland sites with seedbed amounts similar to those in this study, broadcast seeding should produce similar stocking and density results. The initial area of receptive seedbed (poorly decomposed *Sphagnum* peat and compact living *Sphagnum* moss), averaged for all four locations, was 18.4 percent. However, areas varied considerably from quadrat to quadrat (Groot and Adams 1994). With this amount of seedbed, a seeding rate of 100 000 seeds/ha produced an average tenth-year stocking of 70 percent. A seeding rate of 150 000 seeds/ha was required for stocking to equal or exceed 70 percent at all four sites, however.

The results of this study should not be considered as a blanket prescription, because peatland sites vary in seedbed amounts. The amount and distribution of seedbed, along with seedbed receptivity and the seeding rate, are

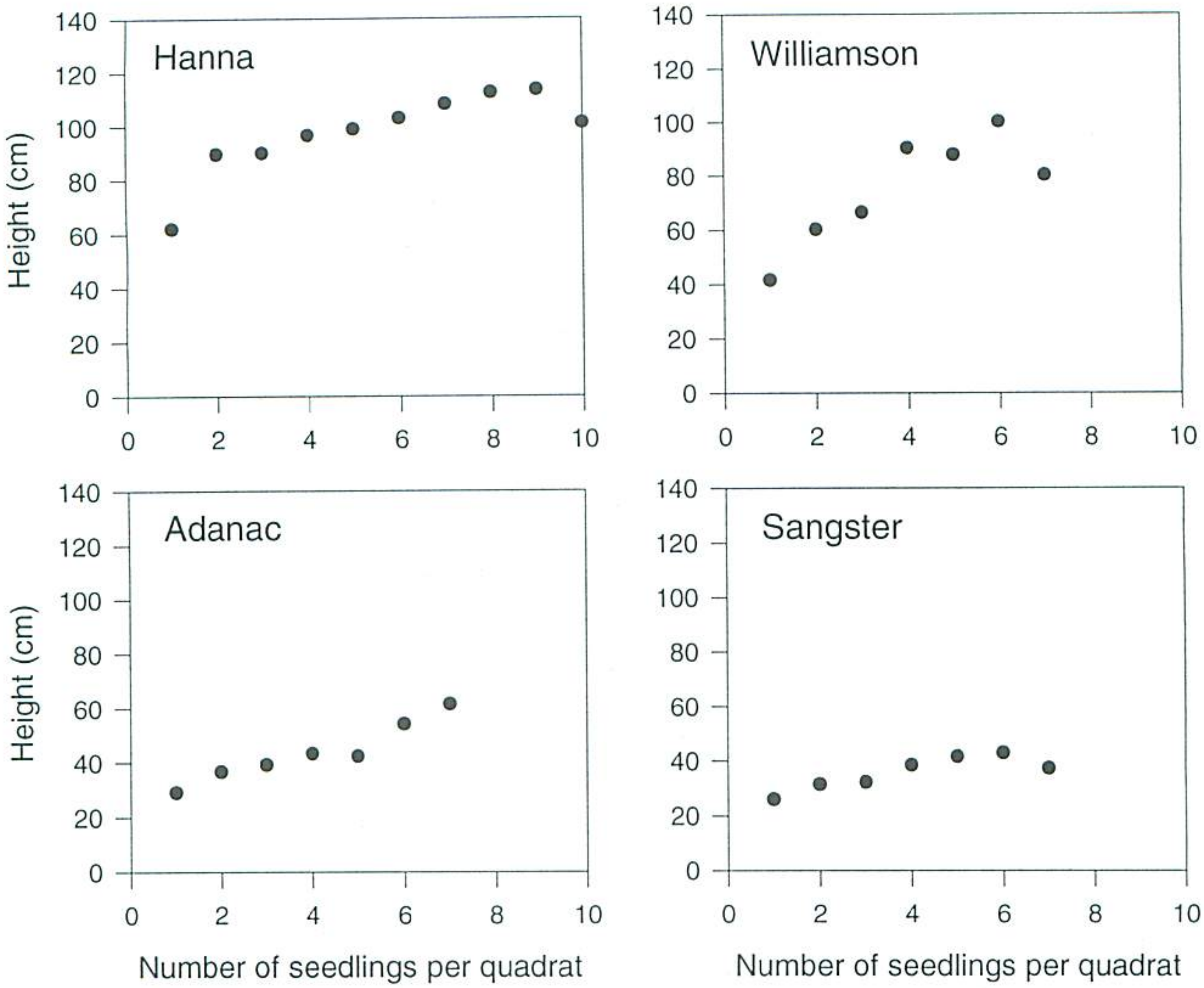

Figure 5. Average height of tallest seedling per quadrat versus number of seedlings per quadrat at four experimental locations.

key determinants of stocking and density in broadcast seeding (Groot 1995). The results from Williamson Township illustrate the importance of seedbed amount. The area of receptive seedbed of plots seeded at a rate of 100 000 seeds/ha was low, and consequently the stocking and density of these plots were lower than in plots seeded with 50 000 seeds/ha.

Statistical relationships between effective seeding rate (Groot and Adams 1994) and stocking and density provide a starting point for prescription development. The effective seeding rate is the number of seeds that land on receptive seedbed (on peatlands, predominantly poorly decomposed *Sphagnum* peat and compact living *Sphagnum* moss). The effective seeding rate is determined by multiplying the actual seeding rate by the area of receptive seedbed. Fifth-year results from these experiments indicated that an effective seeding rate of 6 to 7 seeds per quadrat is required to achieve stocking of 80 percent. All of the following combinations yield an effective seeding rate of 6 seeds per quadrat: 150 000 seeds/ha and 10 percent receptive seedbed; 100 000 seeds/ha and 15 percent receptive seedbed; and 50 000 seeds/ha and 30 percent receptive seedbed.

The effective seeding rate provides some general guidance in developing prescriptions, but it also has shortcomings. The relationship between stocking and effective seeding rate is nonlinear, and when seedbed area (and thus effective seeding rate) varies from quadrat to quadrat stocking calculated from an average effective seeding rate will be inaccurate. Correct results can be obtained only by first computing the likelihood of each quadrat being stocked, and then averaging. Also, the relationship between stocking and effective seeding rate likely differs between regions and site types due to differences in seedbed receptivities and the proportions of receptive seedbeds.

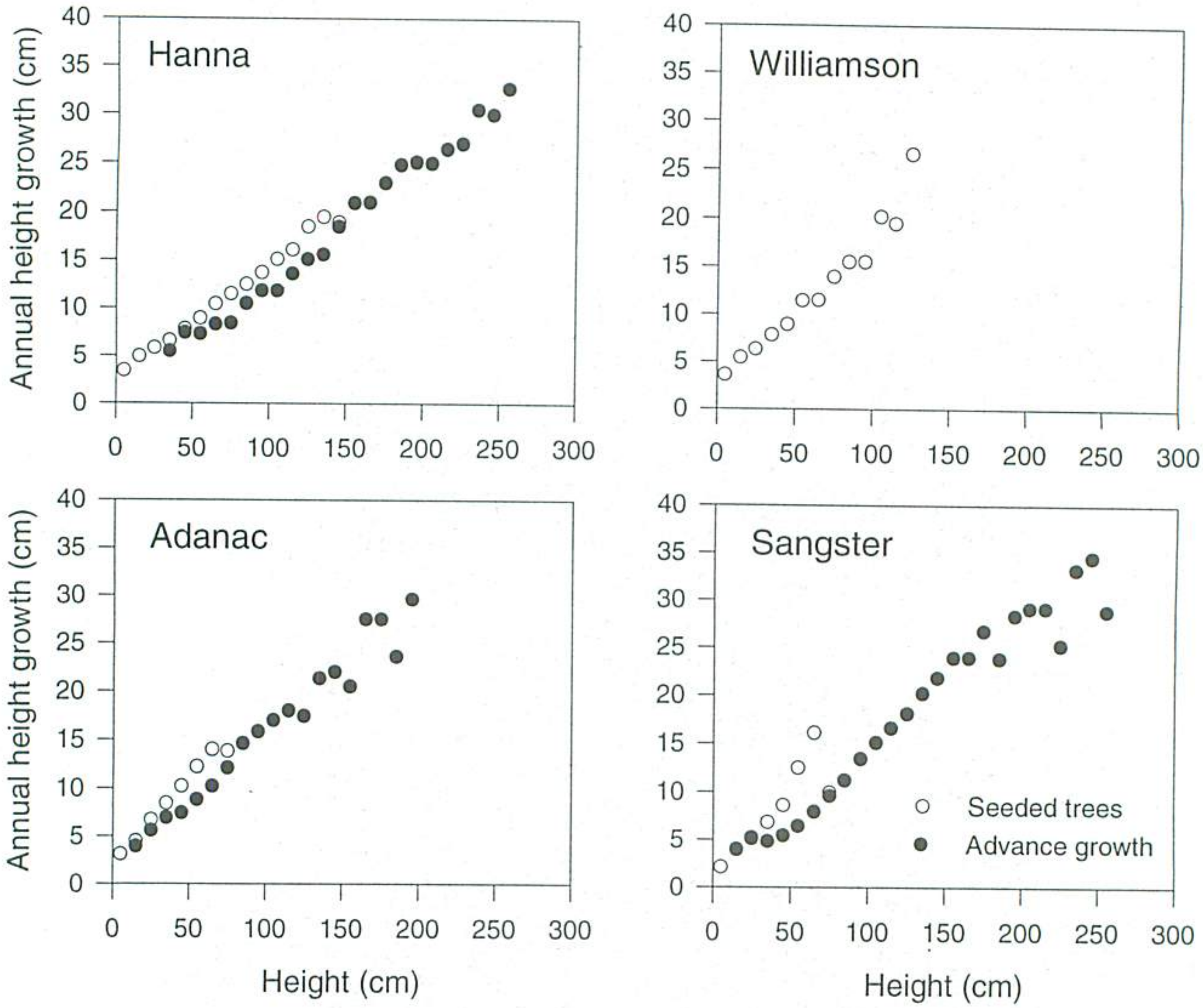

Figure 6. Tenth-year height growth versus tenth-year height for black spruce seedlings and advance growth at four experimental locations.

More detailed prescriptions can be developed using probabilistic models developed by Régnière (1982) and Groot (1988). These models use information on seedbed receptivity, seedbed area, and seeding rate to determine stocking and density. Software that simplifies use of these models is being prepared as part of a direct seeding guide.[2,3]

Stocking and density of both seeded and advance growth black spruce are relatively stable; tenth-year values changed little from fifth-year values (*cf.* Groot and Adams 1994). Thus, fifth-year information likely provides a suitable basis for prescriptions.

Height Development

The height development of trees established from seed on peatlands is slow, and foresters should expect lengthy regeneration periods. Average tenth-year seedling heights observed in this study (24–67 cm) are generally less than have been reported elsewhere (Table 9). Slow height growth may be related in part to site type. For example, seedlings planted on *Ledum* (OG11) substrates grow less rapidly than seedlings planted on *Alnus*–herb poor (OG12) substrates (Munson and Timmer 1989). The *Ledum* site type dominated at Sangster, which had the poorest height growth. It was also prevalent at Adanac, where growth was nearly as poor as at Sangster. On peatlands, growth of

[2] Groot, A. User's guide to PC-SEED. Nat. Resour. Can., Canadian Forest Service–Sault Ste. Marie, Sault Ste. Marie, ON. (In prep.)

[3] Adams, M.J.; Groot, A.; Crook, G.W.; Fleming, R.L.; Foreman, F.F. Direct seeding guide. Nat. Resour. Can., Canadian Forest Service–Sault Ste. Marie, Sault Ste. Marie, ON. (In prep.)

Table 9. Tenth-year heights of black spruce seedlings reported in the literature.

Source	Height at Age 10	Conditions
Ahlgren (1974)	Approximately 45 cm	Upland, post-fire
Fleming and Mossa (1995)	70 cm to 85 cm	Upland, some suppression
Millar (1939)	72 cm to 80 cm	Upland and peatland
MacArthur (1964)	110 cm	Upland, post-fire

Sphagnum moss is another factor that reduces the height of seedlings relative to the soil surface (Roe 1949). Seedling growth may also have been reduced by damaging agents. A high incidence of needle rust (*Chrysomyxa* spp.) was observed at the Sangster site, and damage by frost during the growing season was observed on a number of occasions.

The linear relationship between height growth and height suggests that height development will accelerate with time, and that it can be used to make short-term predictions of height development. The mean height of the tallest seedling per quadrat should exceed 100 cm in the eleventh year in Hanna, but not until about the sixteenth year in Sangster, where height development has been slowest.

One strategy to increase the stocking of taller seedlings is to take advantage of the fact that the seedling height distribution includes individuals that are considerably taller than average. Prescriptions that achieve high overall seedling densities will also result in more of these taller seedlings.

The gain in height development obtained with higher densities is demonstrated by the increase in maximum seedling heights per quadrat with increasing numbers of seedlings per quadrat. Applying the height development equations to these data indicates that the maximum seedling height with one seedling per quadrat is 3 to 5 years behind the maximum seedling height with six seedlings per quadrat. But because broadcast seeding typically produces some quadrats with more than one seedling, the 3- to 5-year period probably represents the upper limit on the gain in height development that can be achieved by establishing high densities.

Establishing high seedling densities does carry a risk of an eventual reduction in individual tree growth because of competition. However, this risk is mitigated by the uneven size distribution of seedlings. The smaller seedlings will probably become increasingly suppressed and will have little impact on the growth of larger trees.

Role of Advance Growth

At two of the locations in this study the effect of seeding rate on total black spruce stocking and density could not be detected against a background of abundant advance growth. If sufficient black spruce advance growth remains after harvesting, seeding is unnecessary. Advance growth has a substantial height and height growth advantage over seedlings established after the harvest, thereby allowing a considerably reduced regeneration period following harvesting.

Seeding can be used as a regeneration supplement when advance growth stocking alone is insufficient. For example, careful logging methods often result in well traveled equipment trails where little advance growth survives. Direct seeding may be an effective method to regenerate these trails.

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