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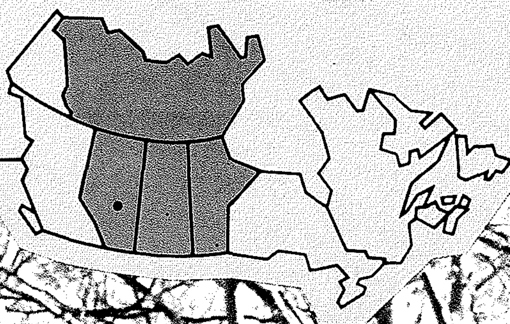
Growth response of white spruce to release from trembling aspen

R.C. Yang



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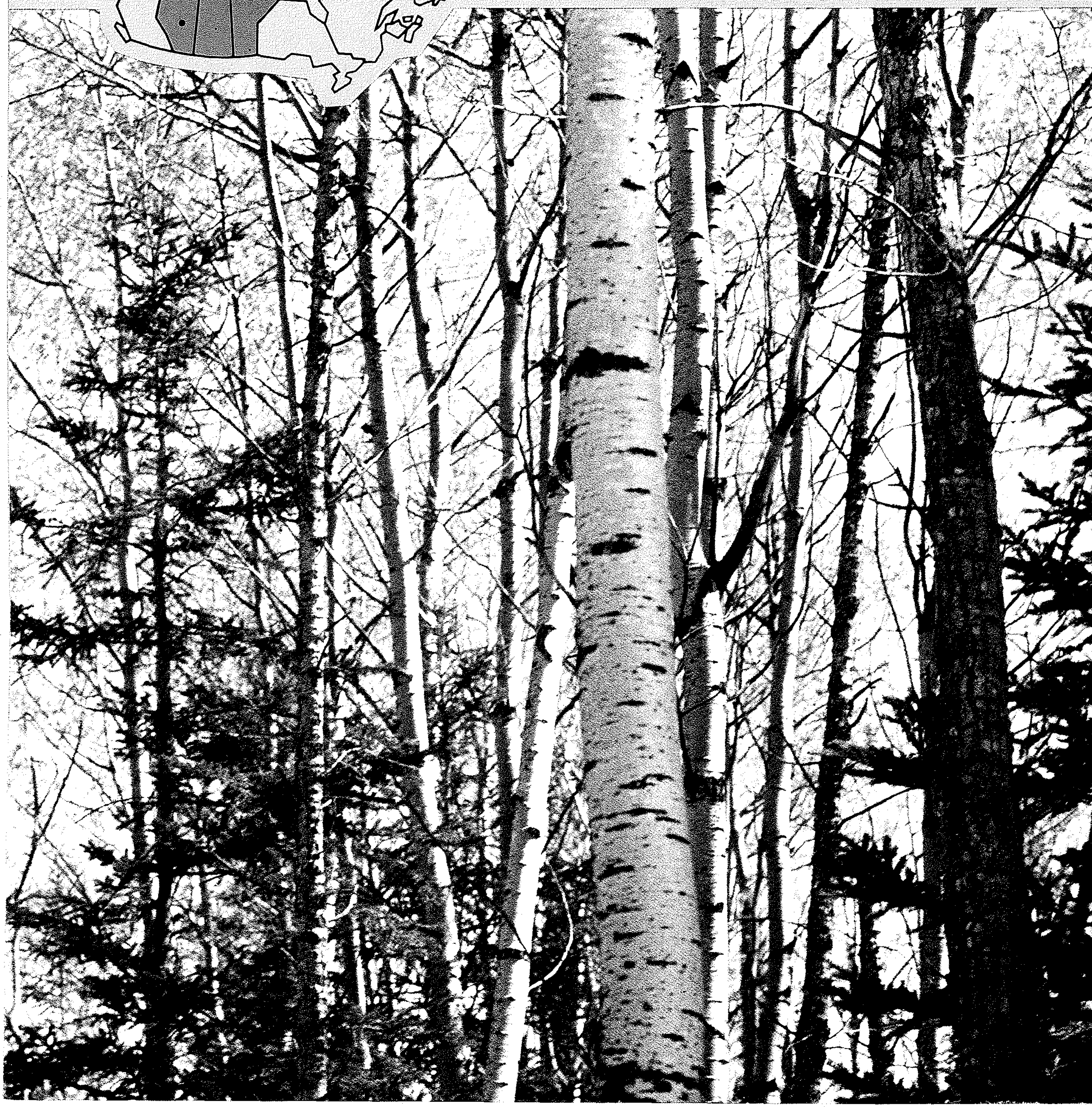

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GROWTH RESPONSE OF WHITE SPRUCE TO RELEASE FROM TREMBLING ASPEN

R.C. Yang

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ABSTRACT

Complete release of young to intermediate-age white spruce (*Picea glauca* (Moench) Voss) from trembling aspen (*Populus tremuloides* Michx.) competition in mixed stands in Manitoba and Saskatchewan increased diameter at breast height, height, basal area, total stand volume, and merchantable stand volume growth. Stand diameter at breast height growth was improved up to 177% in 30 years after treatment; the best growth occurred when the spruce was released at 15–40 years of age. Small trees (2–6) m) had greater height response than large trees. Spruce periodic annual total volume increment increased 93%, from 2.50 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ for the control stands to 4.83 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ for the released stands. Residual densities of 690–840 spruce per hectare released at 20–40 years of age are adequate for normal yield development. Mortality of small spruce was higher in the control stands, but mortality of large spruce was higher in the released stands due to windthrow.

RESUME

A la suite d'un dégagement total des épinettes blanches (*Picea glauca* [Moench] Voss) jeunes et d'âge intermédiaire de la concurrence du peuplier faux-tremble (*Populus tremuloides* Michx.) dans des peuplements mélangé au Manitoba et en Saskatchewan, on a observé des accroissements supérieurs du diamètre à hauteur de poitrine, de la hauteur, de la surface terrière, du volume total des peuplements et de leur volume marchand. Trente ans après le traitement, le gain obtenu pour l'accroissement du diamètre moyen des prédominants à hauteur de poitrine pouvait atteindre 177 %, le traitement étant le plus profitable lorsque les épinettes dégagées avaient de 15 à 40 ans. Le gain en hauteur a été plus élevé pour les petits arbres (de 2 à 6 m). Une différence de 93 % a été observée entre les peuplements dégagés et les peuplements-témoins en ce qui concerne l'accroissement périodique moyen du volume total pour les épinettes (4,83 $m^3 \cdot ha^{-1} \cdot an^{-1}$ par comparaison à 2,50 $m^3 \cdot ha^{-1} \cdot an^{-1}$ respectivement). Des densités résiduelles de 690 à 840 épinettes par hectare après un dégagement effectué à l'âge de 20 à 40 ans conviennent pour une production normale. Alors que pour les épinettes de petite taille la mortalité a été plus élevée dans les peuplements-témoins, pour les grosses épinettes elle a été supérieure dans les peuplements dégagés, à cause du déracinement par le vent.

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NOTE

INTRODUCTION

White spruce (*Picea glauca* (Moench) Voss) and trembling aspen (*Populus tremuloides* Michx.) mixed forests are widely distributed in western Canada east of the Rockies. In the spruce–aspen forests, aspen forms the upper canopy in young and intermediate–age stands, and spruce trees under the aspen canopy are often suppressed and whipped by the overtopping aspen (Kagis 1952; Kabzems 1952; Cayford 1957; Steneker 1963, 1967; Steneker and Jarvis 1963; Lees 1966). Studies show, with one exception (Steneker 1974), that white spruce responds to release in most ages and sizes. The amount of response depends on the intensity of the release cutting, with 30– to 60–year–old trees having the greatest ability to increase growth for a given degree of release (Jarvis et al. 1966; Steneker 1967).

Releasing the spruce understory from the aspen in mixed–wood forests might provide an expedient silvicultural alternative to planting spruce. A high proportion of the understory can be preserved by careful logging of hardwoods (Froning 1980). Increasing demand for aspen in recent years provides an added incentive for managing these forests and makes release cutting more economically feasible. Although it is commonly accepted that release cutting improves growth and yield of spruce, the response in growth and volume yield to release cuttings applied at different ages and stand conditions needs to be quantified before the management implications of release cutting can be fully assessed. This report presents 30– to 50–year effects of release cuttings at various levels of trembling aspen and white spruce stocking in terms of spruce diameter, height, basal area, and volume increments.

STUDY AREAS AND METHODS

Data analyzed in this report are from two similar but separate studies: one (MS–8) was established in 1936 in a 50–year–old stand in the Duck Mountain Forest Reserve in Manitoba; and the other (MS–153) was established in 1951–54 in 15– to 60–year–old stands at Candle Lake (two areas, referred to here as 1 and 2), Big River, Big River Nursery, Montreal Lake, Bertwell, and Reserve in Saskatchewan and at Riding Mountain in Manitoba (Fig. 1).

The Duck Mountain stand is situated on a southwest slope and is typical of the rolling uplands in the B.18a Mixedwood Forest Section (Rowe 1972). The parent material of the soils is a clay–loam till. Sites vary from moderately fresh to moist. White spruce and trembling aspen made up about 80% of the pretreatment stand, which originated from a fire in the late 1880s. Jack pine (*Pinus banksiana* Lamb.), black spruce (*Picea mariana* (Mill.) BSP.), and a few balsam poplar (*Populus balsamifera* L.) and white birch (*Betula papyrifera* Marsh.) were also present.

The MS–153 study comprises eight stands differing widely in age and stocking in seven locations (Table 1, Appendix 1), but the site conditions of these stands are similar. The topography is flat to gently rolling, and the soils vary from silty clay loams to clay loams. Soils at Montreal Lake have water–logged bands of silt and sand over the till. Grey wooded soils have developed in all areas except Bertwell, where degrading black or dark grey wooded soils predominate. This indicates that at one time grasses were the predominant vegetation.

The eight chosen stands, all of fire origin, were typical of mixed–wood conditions. The stands at Bertwell and Big River Nursery were young, whereas those at Candle Lake, Big River, and Reserve were somewhat older (Table 1). In all areas the hardwood overstory was generally older than the spruce understory. White spruce, ranging from 10 to 60 years of age, were irregularly dispersed among the aspen. Growing conditions of individual white spruces varied from completely suppressed to relatively free–growing (Steneker 1967).

Treatments

At the Duck Mountain stand (MS–8), two 0.10–ha (1/4–acre) plots were subjected to light and heavy release cuttings in 1936 in which trees competing with or overtopping the white spruce were removed. Most of the trees cut were aspen and jack pine, but a small number of white and black spruce in the lower diameter classes were also removed. Prerelease basal areas were 39.3, 40.9, and 42.0 $m^2 \cdot ha^{-1}$, respectively, for the control, light, and heavy release stands. The light release cutting removed 44% of the basal area, and the heavy removed 60% of the total basal area.

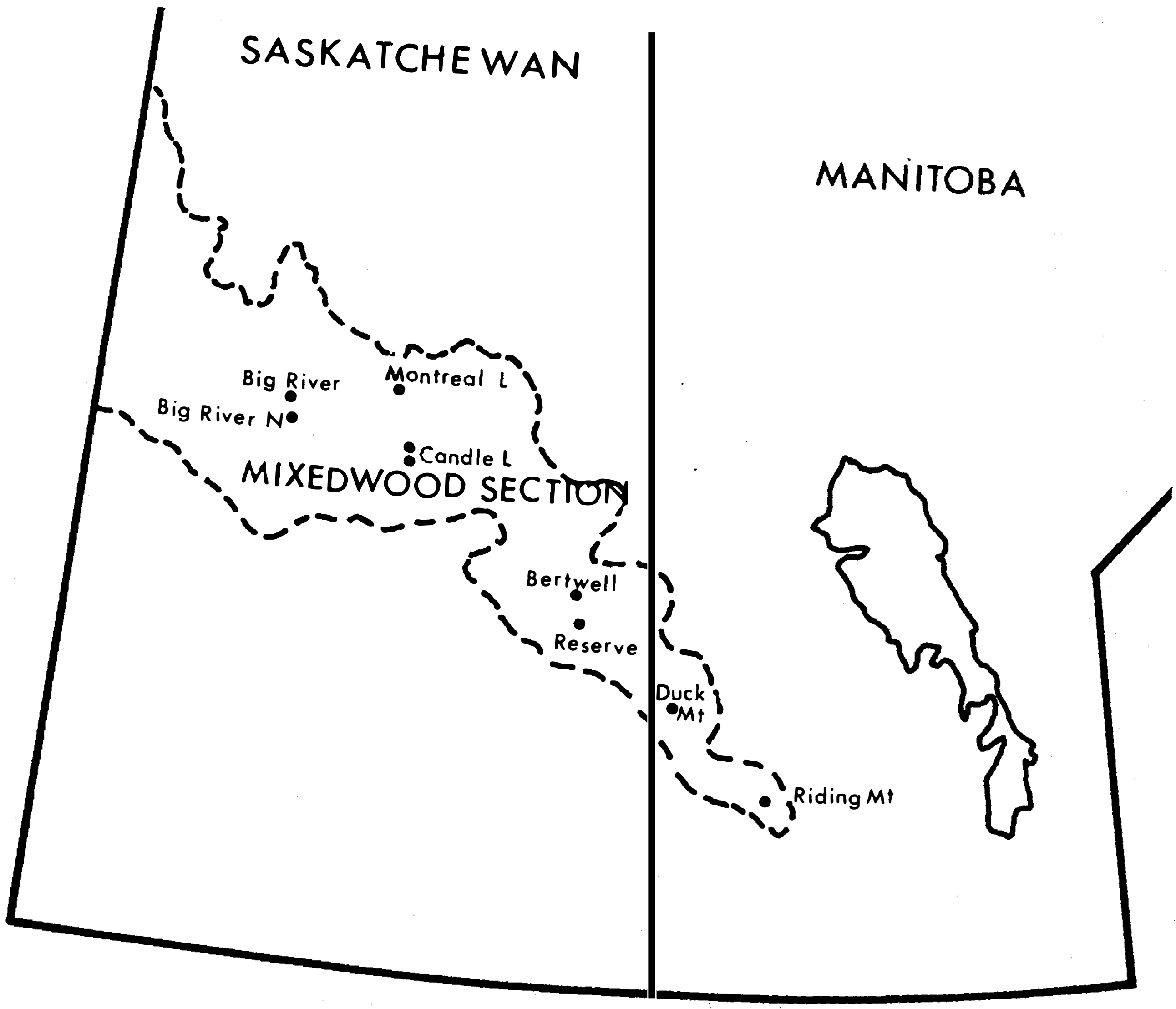

Figure 1. Location of the study area.

Table 1. Age and average diameter at breast height (dbh) and height of white spruce and trembling aspen when treated

Study area	Date of establishment	Age[a] (yr)		Avg. dbh (cm)		Avg. height (m)	
		Spruce	Aspen	Spruce	Aspen	Spruce	Aspen
Candle Lake 1	1953	15–40	45–60	5.1	14.0	4.6	16.8
Candle Lake 2	1953	15–50	50–60	5.8	16.0	5.2	16.5
Big River	1953	35–50	55–60	7.9	14.5	8.5	18.3
Big River Nursery	1953	15–25	20–40	5.6	8.4	4.6	12.5
Montreal Lake	1953	20–35	25–35	6.6	10.4	6.1	15.9
Riding Mountain	1954	20–35	25–40	3.0	10.7	3.3	13.7
Bertwell	1951	10–25	25–30	3.0	9.1	3.3	13.4
Reserve	1951	25–60	50–60	11.2	16.3	8.5	19.8
Duck Mountain	1936	50	—[b]	9.6	11.9	10.1	14.5

[a] Age at 0.3–m stump height.
[b] Aspen not aged.

For stands in other locations (MS–153), square 0.04–ha plots were installed in pairs within the selected stand and replicated once. One plot of each pair was for treatment and the other for control. On the treated plots all trees other than white spruce were removed, including a 9–m surround. Additionally, two partial release plots were established at both Bertwell and Reserve, where 50% of the aspen were removed by systematically cutting every other stem.

Aspen resuckered in all areas following release; suckers on treated plots at Bertwell and Reserve were re–treated 10 years after first treatment to prevent spruce crop trees from being overtopped.

Measurements

White spruce sample trees in all locations were tagged and mapped at establishment. Diameter at breast height (dbh) and total height were measured at establishment and 5 and 10 years (MS–153) or 20 years (MS–8) after release. Diameter at breast height was measured to the nearest one–tenth of an inch for trees on plots in all locations. For Duck Mountain plots, sufficient heights were measured to construct height–diameter (H–D) curves for each species within a plot. All measurements were initially taken in imperial units and were subsequently converted to metric (SI) units.

For MS–153 plots, the heights of tagged spruce and of several dominant and codominant aspen were taken at establishment and during remeasurements. A number of ring counts were made to establish the age of the aspen and spruce in each stand. Growing status (free–growing, whipped, or suppressed) in relation to surrounding trees was carefully noted for each spruce on the plots during tree tally in all areas.

Plot trees in all locations were re–examined and the dbh was tallied in the fall of 1985. Height was measured for all spruce in stands at Candle Lake, Montreal Lake, and Reserve. In other locations, sufficient white spruce heights were sampled on each plot for H–D curve construction. Growing status of living spruce was also recorded in all stands except those at Bertwell and Riding Mountain. Whipped and broken–top spruce in all locations were noted, and heights were measured. Approximately 10–20 aspen heights were also measured on each plot to construct aspen H–D curves.

Both control and release plots at Candle Lake 2 were spaced and fertilized in 1971. Increments of these plots were measured, but data from these plots were excluded from analyses for all data combined due to the variation in treatment.

Data Compilation and Analyses

Dbh and Height Increment

Both individual tree and stand dbh data were examined for release effect on dbh growth. Stand dbh is the average dbh of surviving crop trees in each plot, excluding ingrowth. Influences of residual spruce density (stems per hectare) and postrelease aspen basal area on stand dbh growth were analyzed for stands in all locations except Duck Mountain, where 30–year increments were not determined. Effects of treatment (complete and partial release) and stand age at release on spruce dbh growth were investigated by regression analysis on dbh data combined. The combined data were also used in the examination of postrelease dbh increment in relation to initial dbh.

Height growth after release was examined using combined data stratified by treatment and initial height classes; height increments of free–growing, suppressed, and whipped spruce trees were also examined. Distribution of dominant, codominant, intermediate, suppressed, and whipped spruces in released and control stands 30 years after treatment were analyzed for data from Candle Lake, Big River, Big River Nursery, Montreal Lake, and Reserve combined.

Basal Area and Stand Volume Increments

Periodic stand increments (basal area and total and merchantable volume) were obtained by calculating the difference between net values (including ingrowth but excluding mortality) of two measurements.

Individual tree total and merchantable (0.3–m stump and 10–cm top) volumes were estimated by Honer's (1967) equations using dbh and height. Actual height was used for whipped and broken–top trees and the sample trees that were measured; otherwise, height was estimated from an H–D curve developed for this area. The use of H–D curves might overestimate height, and thus volume, of suppressed spruce; however, regression analyses indicate that a combined H–D curve is statistically sufficient for both control and release stands. The impact of overtopping on spruce volume growth is mainly through its effect on diameter and height growth (Cayford 1957); suppression that inhibits spruce height growth also reduces dbh growth.

Individual tree volumes were summed for each plot to obtain per–hectare stand values. Adjustments on yields were made using tree maps for plots at Reserve (Plots 2 and 3) and Big River Nursery (Plot 13) that were partially destroyed by road construction.

Stand increments were subjected to an analysis of covariance using the value following establishment as a covariate. The effects of covariates, however, showed no statistical significance in all analyses. Consequently, increments due to treatment were not adjusted for initial values.

Merchantable volumes of released stands were extrapolated to a rotation age of 100 years using Kabzem's (1971) yield table for medium sites as a guiding curve. The projected volumes, estimated by moving current volume parallel to the curve, make it possible to approximate the effects of age and stand stocking at release on merchantable volume production. Although the actual stands after release may depart from the normal pattern of development suggested by the yield table, the projected values should provide a valid basis for comparison in view of the relatively short projection periods.

Mortality

Mortality, excluding recent windfall at Montreal Lake and Reserve, was computed on total volume loss in 30 years and expressed in actual volume and percentages. Dead trees in the MS–153 plots were also analyzed to determine the effect of initial spruce size on mortality.

For convenience of discussion, the response periods are referred to as 50 and 30 years for Duck Mountain and other locations, respectively. The actual periods are 49 years for the former and 30–34 years for the latter.

RESULTS AND DISCUSSION

Dbh Increment

Complete release from aspen competition improved spruce stand dbh growth in all areas. Thirty–year stand dbh increments ranged from 6.90 to 24.93 cm in complete release stands compared with increments of 4.63 to 15.83 cm in untreated stands, up to a 177% increase. At Duck Mountain, the increment over 50 years was 15.15 cm for the heavy release plot and 10.1 cm for the control plot, a 50% increase (Table 2).

Stand dbh growth response varied considerably among locations (Table 2) owing to the wide differences in stand age, density, and prerelease dbh. In complete release stands, spruce dbh generally decreased with an increase in residual spruce density (Fig. 2). At a similar density and initial dbh, the increments in partially released and untreated stands were smaller than in complete release stands, probably due to the combined effects of crowding and suppression (Fig. 2). Regression analysis (not presented here) indicates that residual spruce density and prerelease dbh accounted for 86% of the variation in dbh growth 30 years after release; residual density and prereleased dbh accounted for 75 and 35%, separately.

Age of white spruce at release affected the postrelease dbh gain (Table 2). In general, dbh improvement was larger in young stands (Montreal Lake, Big River Nursery, and Candle Lake 1) and smaller in intermediate–age stands (Reserve, Big River, and Candle Lake 2). The greatest dbh growth responses were in stands released at between 15 and 40 years of age.

A direct comparison of prerelease versus 30–year postrelease dbh curves for stands released at various ages would have revealed the effects of stand age at release on dbh growth, but large variations (particularly in young stands) in dbh increments 30 years after release prohibit making such a comparison. Regression analysis of 10–year postrelease dbh development nevertheless confirms larger dbh growth in young than in intermediate–age stands (Fig. 3). The 10–year dbh growth response to release was significantly higher in the Big River Nursery than in the Big River and Duck Mountain stands.

On an individual tree basis, release improved all spruce dbh growth (Fig. 4). Average dbh in released stands was similar to that in control stands for all classes 5 years after treatment but surpassed the control 30 years after release, with an average improvement of 31% over the control.

Although complete removal of aspen resulted in a substantial increase in dbh growth, the response to partial release was somewhat inconsistent. The partial release improved dbh growth of spruce at Duck Mountain and Bertwell (Figs. 5a, b) but not at Reserve (Fig. 5c) 10 years following release. This suggests that some spruce do not respond to systematic removal of aspen.

Height Increment

Spruce showed no significant improvement in height growth 5 years after release, but an improvement became apparent in all classes during the second 5–year period. Release increased spruce height increment in all classes by an average of 42% after 30 years (Table 3).

The improvement in height growth varied with initial height. The 30–year height increments generally increased from 9.54 m in the 2–m height class to 11.88 m in the 6–m height class and then leveled off (Table 3). Apparently, release cutting done before a stand reaches 6 m is most beneficial.

Thirty–year average height increments for all initial height classes combined were 9.16, 6.90, and 7.43 m for free–growing, suppressed, and whipped spruce, respectively (Table 4). This suggests that through suppression and whipping, overtopping aspen might reduce spruce height growth by 19 to 25% in 30 years.

Release improved the crown status of residual spruces. The proportion of dominant and codominant spruce increased from 34.1% in untreated stands to 63.9% in stands 30 years after release (Table 5). The treatment also reduced the proportion of suppressed spruce to 15.2% in released stands from 34.5% in control stands; however, the percentage of intermediate spruce remained similar in both released and control stands.

Basal Area Increment

Thirty–year basal area increments ranged from 0.6 to 19.4 $m^2 \cdot ha^{-1}$ for the control compared to

Table 2. Average white spruce stand diameter at breast height (dbh) 30 years after treatment for all areas except Duck Mountain, which is 50 years after treatment

Study area	Treatment	Avg. dbh (cm)		Avg. gain over control	
		Initial[a]	Increment	cm	%
Candle Lake 1	Control	5.23	15.83		
	Complete release	4.62	24.93	9.10	57
Candle Lake 2	Control	5.03	13.21		
	Complete release	5.62	16.67	3.46	26
Big River	Control	6.99	7.21		
	Complete release	7.26	8.75	1.54	21
Big River Nursery	Control	4.65	6.48		
	Complete release	5.55	16.11	9.63	149
Montreal Lake	Control	6.26	5.50		
	Complete release	5.76	15.39	9.89	177
Riding Mountain	Control	2.85	4.63		
	Complete release	3.07	6.90	1.54	49
Bertwell	Control	3.28	5.33		
	Partial release	2.40	5.11		
	Complete release	2.35	10.01	4.68	28
Reserve	Control	7.59	13.64		
	Partial release	13.53	10.92		
	Complete release	14.08	15.62	1.98	15
Duck Mountain	Control	9.02	10.09		
	Light release	9.40	12.93	2.84	28
	Heavy release	9.73	15.15	5.06	50

[a] Of surviving trees.

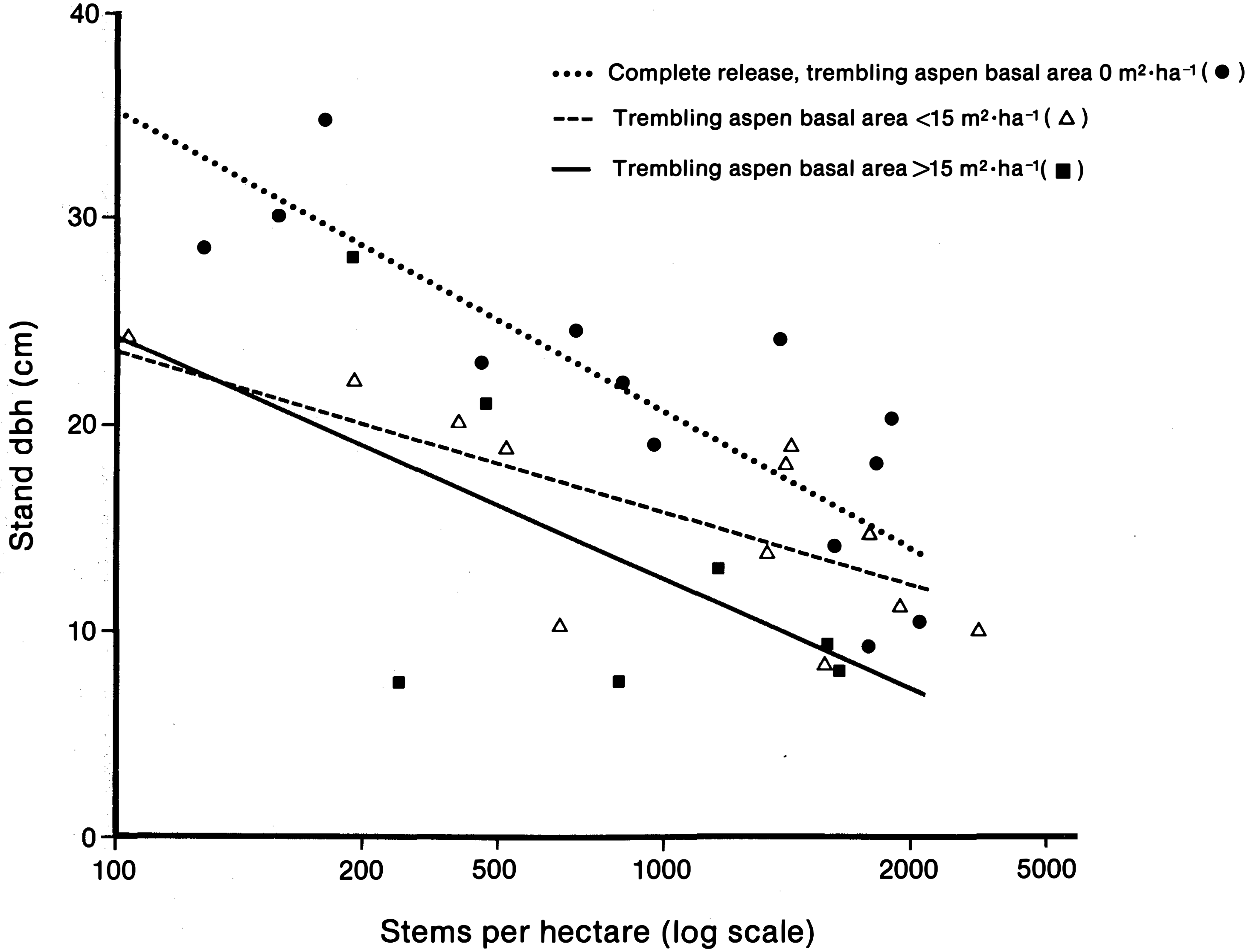

Figure 2. Relationship between density of white spruce residuals and stand diameter at breast height (dbh) 30 years after release for three trembling aspen density levels.

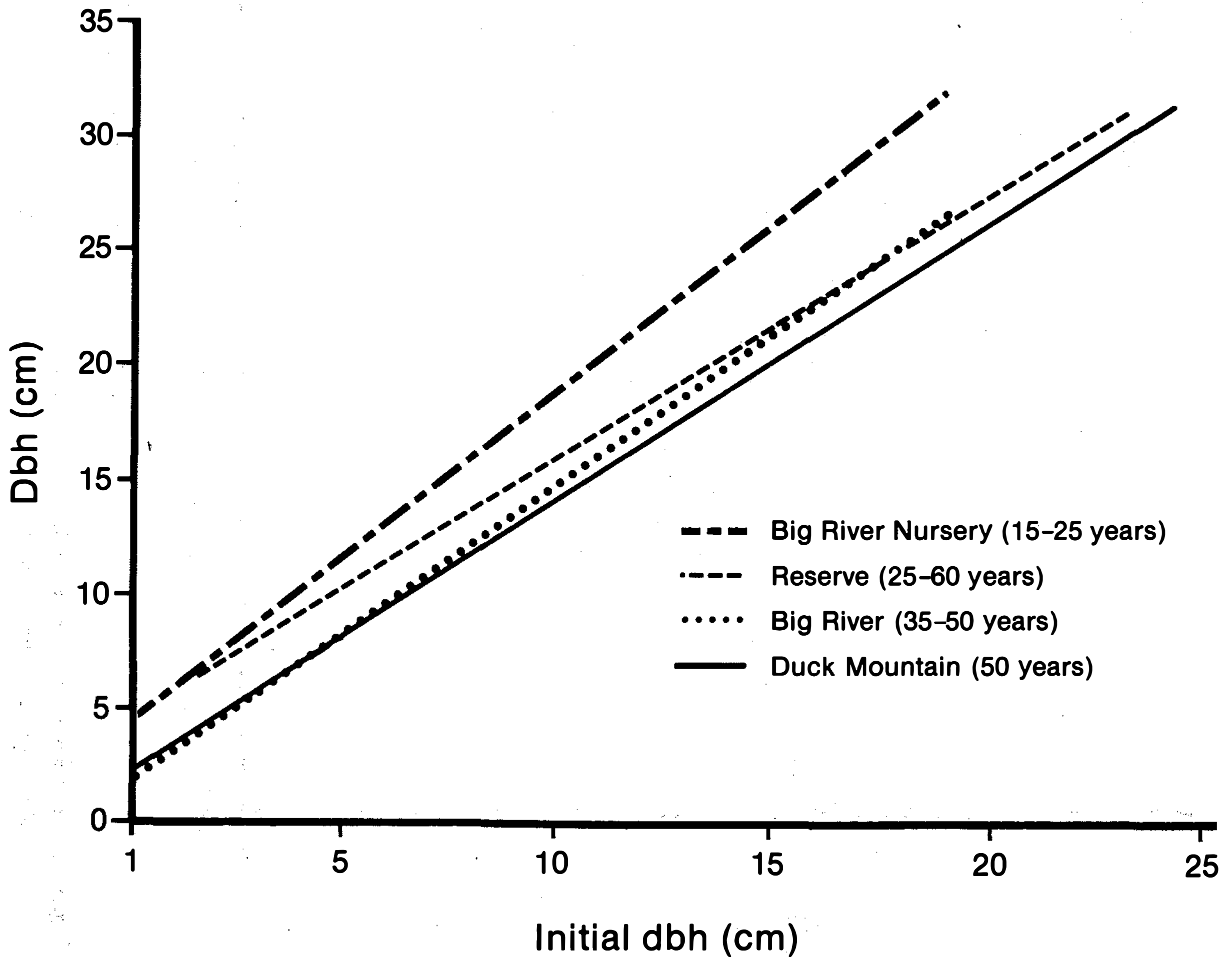

Figure 3. Relationship between white spruce initial diameter at breast height (dbh) and dbh 10 years after complete release in stands of various ages at release.

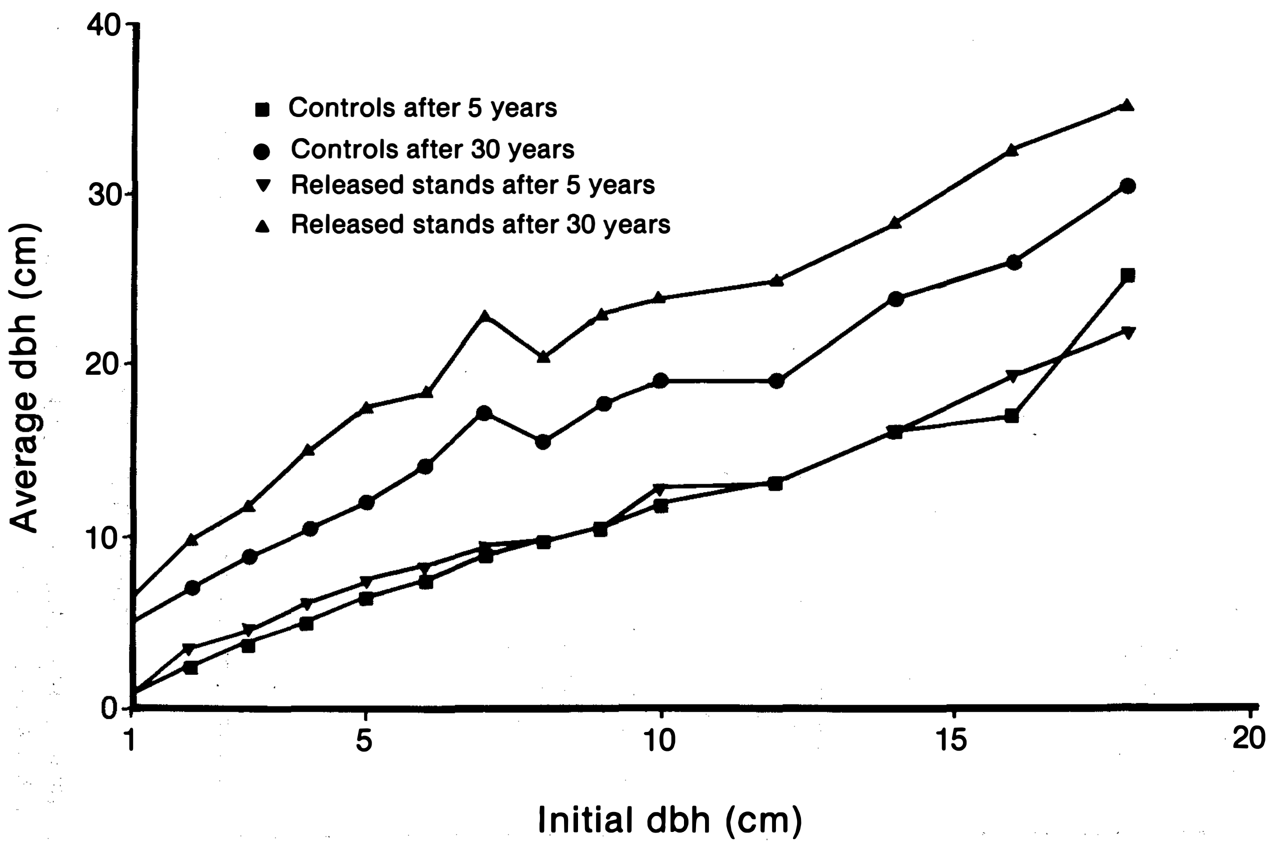

Figure 4. Relationship between white spruce initial diameter at breast height (dbh) and average dbh for released and control stands 5 and 30 years after release.

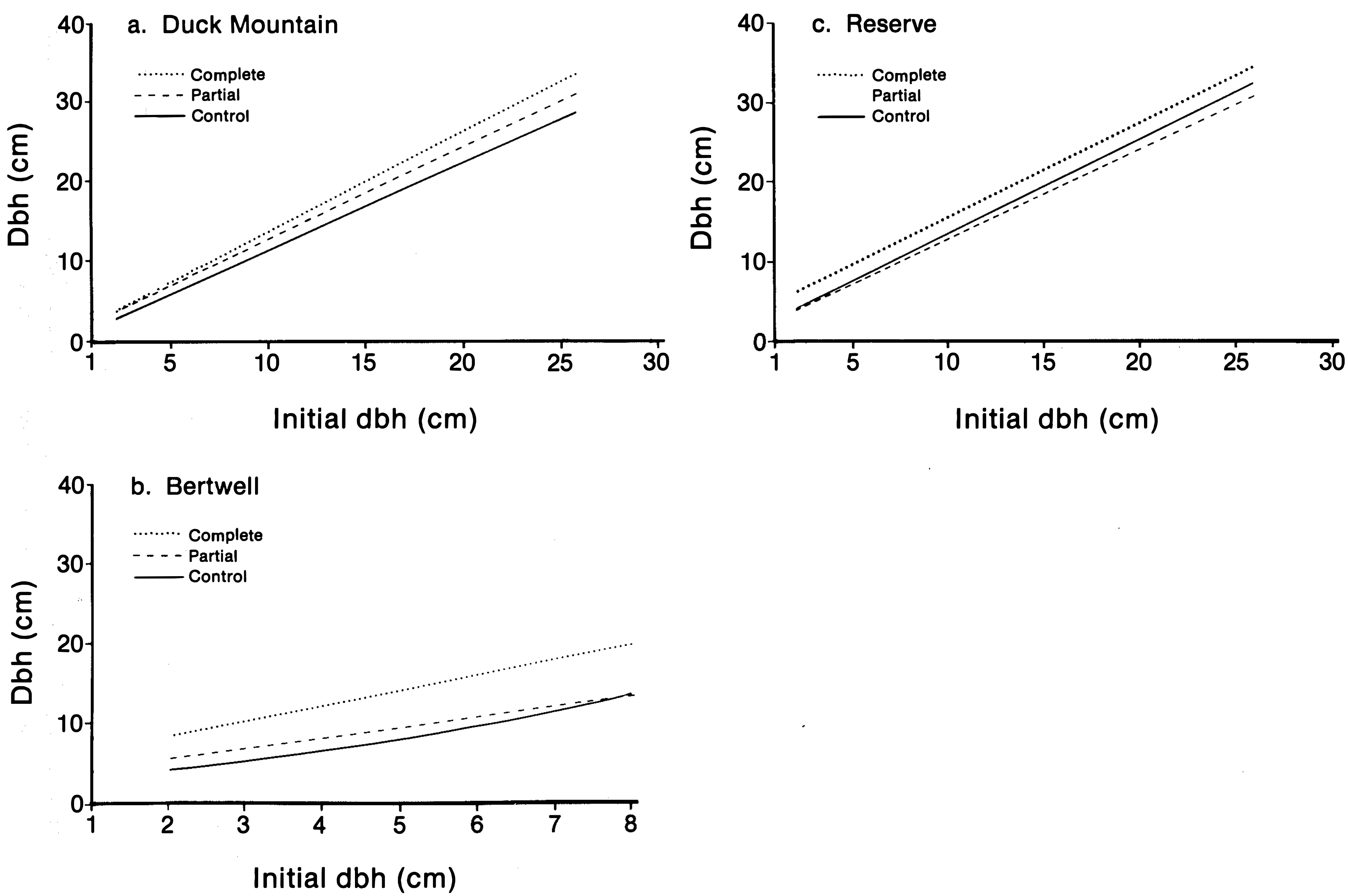

Figure 5. Relationship between white spruce initial diameter at breast height (dbh) and stand dbh 10 years after complete and partial release at a) Duck Mountain, b) Bertwell, and c) Reserve.

Table 3. Average white spruce height increment 5 and 30 years after treatment by initial height class for all areas except Duck Mountain (incompatible measurement periods)

Initial height class (m)	Avg. increment of control stands (m)		Avg. increment of release stands (m)		% increase at 30 years
	5 years	30 years	5 years	30 years	
2	0.89 (124)[a]	7.23 (7)	1.19 (93)	9.54 (13)*[b]	32
3	0.89 (169)	7.45 (27)	0.97 (137)	10.33 (21)*	39
4	0.88 (129)	6.63 (21)	1.17 (97)	10.61 (26)*	60
5	1.35 (95)	7.15 (27)	1.22 (70)	11.05 (22)*	55
6	1.77 (80)	8.02 (34)	1.58 (39)	11.88 (17)*	48
7	1.34 (44)	7.19 (9)	1.45 (37)	10.62 (22)*	48
8	1.38 (32)	6.72 (13)	1.18 (20)	8.73 (10)*	30
9	1.26 (23)	6.97 (7)	1.36 (24)	9.83 (9)*	41
10	1.48 (22)	6.66 (15)	1.42 (25)	8.53 (5)	28
11	1.67 (19)	5.76 (5)	1.99 (26)	8.51 (11)*	48
12	3.09 (4)	6.95 (2)	2.60 (3)	8.88 (2)	28
13	3.57 (4)	7.26 (2)	—[c]	—	—

[a] Number in parentheses is sample size.
[b] Difference between control and release increments significant at the 5% level.
[c] No trees in this height class.

Table 4. Thirty-year height increments of free-growing, suppressed, and whipped white spruce by initial height for all areas except Duck Mountain, where growing status was not identified

Initial height class (m)	Height increment (m)		
	Free-growing	Suppressed	Whipped
1	8.38	6.24	—[a]
2	9.06	7.95	7.30
3	8.81	9.32	7.91
4	9.87	5.60	7.91
5	10.77	9.33	7.92
6	9.39	—	—
7	10.60	8.04	—
8	8.61	5.87	6.94
9	9.39	—	8.68
10	7.68	—	6.15
11	8.05	4.39	8.81
12	9.25	5.37	5.22
Average	9.16	6.90	7.43

[a] No trees in this height class.

Table 5. Distribution of surviving spruce by crown class and treatment for plot trees at Candle Lake, Big River, Big River Nursery, Montreal Lake, and Reserve

Crown class	Control stands		Release stands	
	Frequency	%	Frequency	%
Dominant	36	12.3	73	29.9
Codominant	64	21.8	83	34.0
Intermediate	75	25.6	51	20.9
Suppressed	101	34.5	37	15.2
Whipped	17	5.8	0	0
Total	293	100.0	244	100.0

13.0 to 28.3 $m^2 \cdot ha^{-1}$ for complete release stands (Table 6). Improvement in basal area varied from 18% in Candle Lake 1 to 246% in Riding Mountain. Several large spruce (initial dbh 20–42 cm) at Montreal Lake were uprooted by a 1960 hurricane, and this resulted in a decline in basal area growth on control plots.

Total spruce basal area increments in complete release stands increased with the number of residual spruce (Fig. 6). The residuals explain the relatively poor basal area improvement (18%) at Candle Lake 1 (173 stems/ha) and the marked improvement (246%) at Riding Mountain (2706 stems/ha) (Tables 6 and 7). Heavy release at Duck Mountain improved total basal area by 357% over the control stand in 50 years because the control stand had become decadent by the 1985 remeasurement.

Like dbh growth, the response in stand basal area growth to partial release varied. Light release at Duck Mountain improved basal area increment by 88% over control in 50 years, but partial release at both Bertwell and Reserve resulted in no improvement in basal area increment 30 years after treatment.

Total Stand Volume Increment

Release treatment substantially improved spruce total stand volume in all locations (Table 6). Increments over 30 years ranged from 106.0 to 237.3 $m^3 \cdot ha^{-1}$ for complete release stands and –1.5 to 144.8 $m^3 \cdot ha^{-1}$ for the controls (Table 6). Periodic annual increment (PAI) of spruce total volume averaged 4.83 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ for the released stands and 2.50 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ for the control stands, an increase of 93%.

The poor PAI (1.06 $m^3 \cdot ha^{-1} \cdot yr^{-1}$) in Riding Mountain control stands indicates the need for stand tending to improve spruce productivity in mixed–wood forests. The dense spruce (3965 stems ha) under an overstocked aspen (4089 stems ha) overstory yielded only 1 $m^3 \cdot ha^{-1} \cdot yr^{-1}$. In contrast, removal of aspen competition increased PAI by three times.

Improvement in spruce total stand volume after release is clearly illustrated in the Duck Mountain Forest Reserve (Fig. 7). Total volumes of spruce (white and black) in control and light– and heavy–release stands were approximately equal after treatment in 1936. Heavy and light release increased spruce total volume in 10 years by 124% and 73%, respectively. This favorable effect continued during the second 10 years, when total volume increments were 64.4 and 42.4 $m^3 \cdot ha^{-1}$ for heavy and light release compared to 36.9 $m^3 \cdot ha^{-1}$ for the control. After 50 years, the volume increments were 164.3 and 82.7 $m^3 \cdot ha^{-1}$ for heavy and light release compared to 45.64 $m^3 \cdot ha^{-1}$ for the control. Heavy release increased spruce total volume by 260%

Table 6. Thirty-year basal area, total volume, and merchantable volume increments of white spruce for all areas. Percentage increase only refers to the complete release treatment.

			Basal area			Total volume			Merchantable volume		
			Increment			Increment			Increment		
Study area	Treatment	No. of plots	$m^2 \cdot ha^{-1}$	% gain over control	PAI[a] $(m^2 \cdot ha^{-1} \cdot yr^{-1})$	$m^3 \cdot ha^{-1}$	% gain over control	PAI $m^3 \cdot ha^{-1} \cdot yr^{-1})$	$m^3 \cdot ha^{-1}$	% gain over control	PAI $(m^3 \cdot ha^{-1} \cdot yr^{-1})$
Candle Lake 1	Control	2	11.0		0.34	85.5		2.67	76.3		2.38
	Complete release	2	13.0	18	0.41	106.0	24	3.31	98.5	29	3.08
Candle Lake 2	Control	2	9.9		0.31	87.3		2.73	71.9		2.25
	Complete release	2	17.0	72	0.53	163.2	87	5.10	142.0	97	4.44
Big River	Control	2	13.7		0.43	144.8		4.53	141.3		4.42
	Complete release	2	23.4	71	0.73	198.7	37	5.27	202.1	43	6.32
Big River Nursery	Control	1	19.4		0.61	112.4		3.51	77.6		2.43
	Complete release	1	26.7	38	0.83	237.3	111	7.42	196.0	153	6.13
Montreal Lake	Control	2	–0.6		–0.02	–1.5		–0.05	–0.3		–0.01
	Complete release	2	16.5	—[b]	0.52	126.9	—	3.97	111.7	—	3.49
Riding Mountain	Control	2	7.7		0.25	33.0		1.06	10.5		0.34
	Complete release	2	26.6	246	0.86	133.3	304	4.30	90.8	765	2.93
Bertwell	Control	2	17.8		0.52	107.5		3.16	48.6		1.43
	Partial release	2	15.3		0.45	78.5		2.31	29.6		0.87
	Complete release	2	28.3	59	0.83	160.2	49	4.71	111.8	130	3.29
Reserve	Control	2	7.3		0.21	54.6		1.61	52.3		1.54
	Partial release	2	6.4		0.19	58.3		1.71	57.0		1.68
	Complete release	2	17.3	137	0.51	214.5	293	6.31	177.1	239	5.21
Duck Mountain	Control	1	4.2		0.09	45.6		0.93	51.6		1.05
	Light release	1	7.9		0.16	82.7		1.69	89.8		1.83
	Heavy release	1	19.2	357	0.39	164.2	260	3.35	173.7	237	3.54

[a] Periodic annual increment.

[b] Percentage gain over control not computed due to the negative increment of control plots.

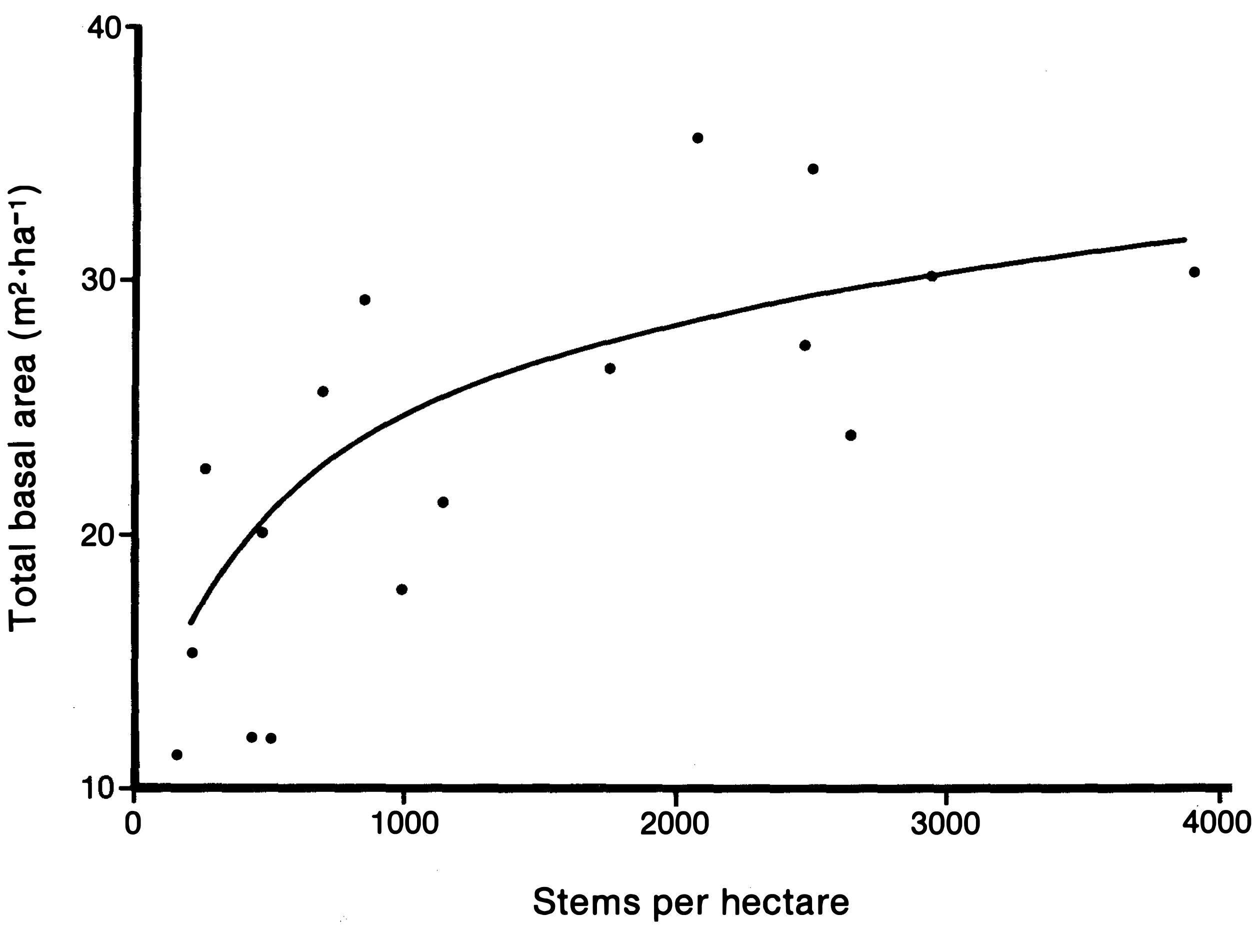

Figure 6. Relationship between white spruce residual density and total basal area 30 years after release.

Table 7. Yield of white spruce 30 years after complete release and projected to age 100 for all areas except Duck Mountain (stand age over 100 years)

Study area	Plot no.	Initial: Age (yr)	Initial: Density (stems/ha)	30 years after release: Density (stems/ha)	30 years after release: Merchantable volume ($m^3 \cdot ha^{-1}$)	Projected merchantable volume to age 100 ($m^3 \cdot ha^{-1}$)
Candle Lake 1	2	15–40	148	173 [a]	84.47	122.9
	4	15–40	197	197	112.55	198.1
Candle Lake 2	6	15–50	2643	717 [b]	148.92	198.3
	8	15–50	1136	445 [b]	138.03	183.8
Big River	10	35–50	2495	1161	210.62	230.5
	12	35–50	2075	1013	216.40	236.8
Big River Nursery	13	15–25	840	618 [c]	196.52	320.4
Montreal Lake	15	20–35	969	519	122.55	163.2
	18	20–35	988	544	104.27	138.9
Riding Mountain	20	20–35	2940	1483	99.89	145.3
	22	20–35	2471	1458	81.68	108.8
Bertwell	3	10–25	1754	1137	104.98	152.8
	6	10–25	3914	1433	118.59	219.9
Reserve	3	25–60	691	371 [c]	230.68	283.2
	5	25–60	247	222	173.65	184.5

[a] Included ingrowth.
[b] Crop trees were removed in 1971.
[c] Adjusted for loss to highway and road construction.

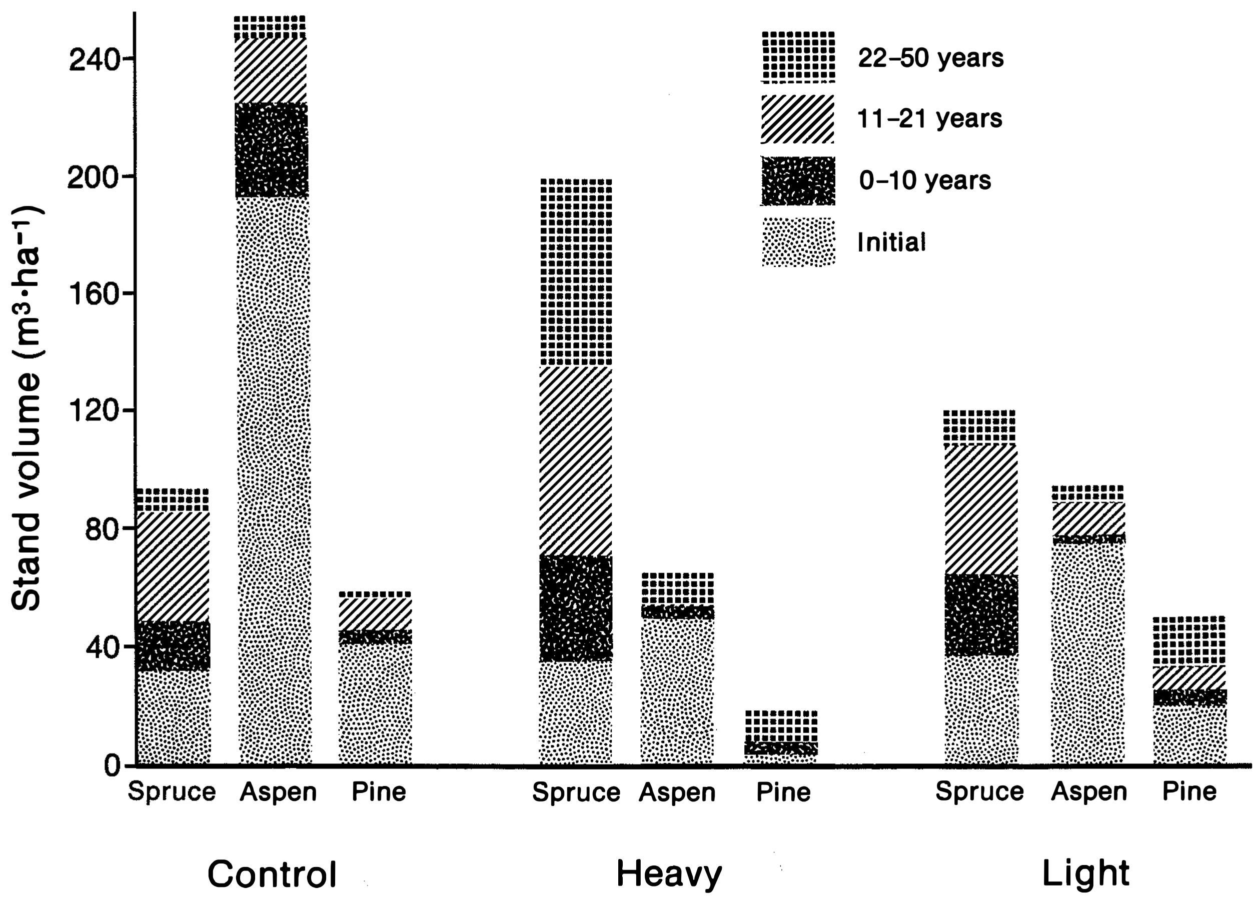

Figure 7. Total stand volume increments of white and black spruce, trembling aspen, and jack pine at Duck Mountain 0–10, 11–21, and 22–50 years after release.

Merchantable Stand Volume Increment

Merchantable volume increments of spruce ranged from 90.8 to 202.1 $m^3 \cdot ha^{-1}$ for complete release stands and 10.5 to 141.3 $m^3 \cdot ha^{-1}$ for the control after 30 years (Table 6). At Duck Mountain, heavy release improved spruce merchantable volume by 122 $m^3 \cdot ha^{-1}$, or 237%, over the control in 50 years. The periodic annual increment of merchantable volume averaged 4.25 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ for release stands compared to 1.94 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ for the control, an improvement of 114%. Projected spruce volumes at age 100 range from 108.8 to 320.4 $m^3 \cdot ha^{-1}$ (Table 7); two released stands have merchantable stand volumes higher than the yield table values for fully stocked spruce on medium sites (Kabzems 1971).

Spruce density at release determines the yield following treatment. The data limitations preclude prediction of merchantable volume at rotation age based on prerelease spruce density; nevertheless, 840 stems/ha of spruce residuals released at age 20 or 690 stems/ha at age 40 appear to be adequate for normal yield development (Table 7). These density values (690–840 stems/ha) are similar to those reported by Bella and De Franceschi (1978), who estimated that at least 610 trees/ha of well-distributed white spruce are required for full site utilization at 50 years on medium or better sites in Alberta.

Stands with 250 stems/ha released at age 40 would yield 185 $m^3 \cdot ha^{-1}$ merchantable volume at age 100, two–thirds of the normal yield of 276 $m^2 \cdot ha^{-1}$ projected for medium sites by Kabzems (1971). It appears that 250 stems/ha of spruce residuals at age 40 are inadequately stocked for release treatment. On the other hand, excessively dense spruce stands (over 2500 stems/ha at age 30) also have low merchantable volumes (Table 7). Johnson[1] suggests that white spruce residual stands over 2270 trees/ha (1000 trees/acre) at age 0–10 require thinning in addition to a release treatment.

Mortality

Spruce mortality ranged from 0.35 to 25.63 $m^3 \cdot ha^{-1}$ (12.30 to 76.05%) in the control and 0 to 18.75 $m^3 \cdot ha^{-1}$ (0–35.30%) in complete release stands over the 30–year period (Table 8). In general, mortality was significantly lower in complete release stands than in the controls, except at Big River, where trees were killed due to porcupine girdling shortly after release (Steneker 1967). A hurricane in 1960 was also responsible for the high mortality in Montreal Lake and Big River.

Spruce mortality varied with treatment and tree size (Fig. 8). Mortality of young spruce (dbh $\leq$ 3 cm) was higher in control than in released stands, indicating vulnerability of small spruce due to suppression by overstory aspen. In addition to suppression, small trees (dbh $\leq$ 2 cm) were also susceptible to animal browsing and seldom survived repeated leader damage. Mortality rates in 4– to 8–cm dbh classes were similar for release and control. Above 8 cm, higher mortality was observed in released than in untreated stands (Fig. 8) due to windthrow following release.

Although white spruce is a wind–firm species (Sutton 1968), thinning on wet soils may render the stand susceptible to wind damage. Scattered windthrows of large white spruce observed in Montreal Lake, Reserve, and Duck Mountain confirmed their shallow rooting.

White spruce at Riding Mountain also had excessive mortality during the 30–year period; percentage mortality was higher in the control (51%) than in the release stands (16%). This was mainly due to the excessive density of both spruce and aspen in these stands (Appendix 1). Partial–release stands at Bertwell and Reserve showed mortality similar to that in unreleased stands (Table 8).

Silvicultural Implications

In white spruce–trembling aspen stands, spruce current annual increment starts to drop sharply at about 30 years, when the top of the spruce gets into the crown of the trembling aspen (Kagis 1952). The drop in current increment probably marks the intensification of suppression and whipping on spruce by the overstory canopy. For best spruce growth, release cutting should be done before this occurs.

Because spruce may become suppressed at an early age, release of the spruce understory as soon

[1] Johnson, H.J. 1986. The release of white spruce from trembling aspen overstoreys: a review of available information and silvicultural guidelines. Report prepared for the Manitoba Department of Natural Resources, Forestry Branch, Winnipeg, Manitoba, under the Canada–Manitoba Forest Renewal Agreement.

Table 8. Thirty-year total volume loss and percentage mortality of white spruce for all areas except Duck Mountain

Study area	Treatment	No. of plots	Total volume loss $m^3 \cdot ha^{-1}$	Total volume loss S.D.[a]	Mortality %	Mortality S.D.
Candle Lake 1	Control	2	0.35	0.49	12.30	17.39
	Complete release	2	0.00	0.00	0.00	0.00
Candle Lake 2	Control	2	7.72	1.23	—[b]	—
	Complete release	2	11.05	8.49	—	—
Big River	Control	2	7.72	2.33	20.75	14.50
	Complete release	2	18.75	1.10	35.30	9.62
Big River Nursery	Control	1	0.67	—	4.00	—
	Complete release	1	0.08	—	1.00	—
Montreal Lake[c]	Control	2	25.63	17.20	76.05	0.64
	Complete release	2	2.82	3.33	26.70	22.77
Riding Mountain	Control	2	2.16	0.88	50.95	10.11
	Complete release	2	0.75	0.23	15.75	0.78
Bertwell	Control	2	0.58	0.24	11.50	3.39
	Partial release	2	0.06	0.02	13.95	14.35
	Complete release	2	0.01	0.01	2.15	3.04
Reserve	Control	2	3.99	5.49	14.80	13.86
	Partial release	2	4.18	5.49	13.85	17.04
	Complete release	2	0.69	0.97	1.95	2.76

[a] Standard deviation.
[b] Not estimated; crop trees were spaced in 1971.
[c] Plots severely damaged by 1960 hurricane.

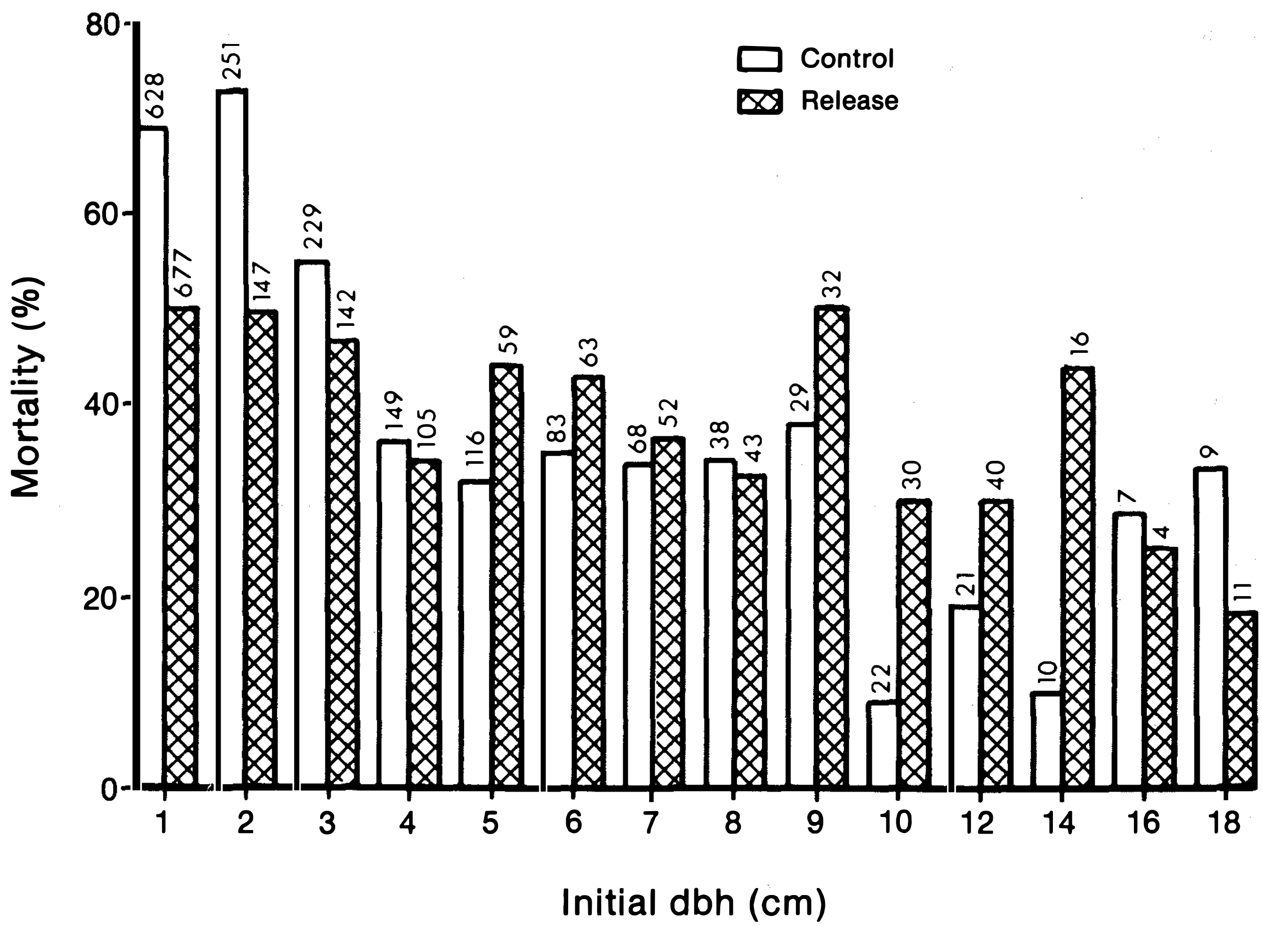

Figure 8. Relationship between white spruce initial diameter at breast height (dbh) and mortality 30 years after treatment. (Number above each bar is number of initial stems at that diameter.)

as it is well established should produce the maximum silvicultural benefits. Release at early age, however, also involves the risk of aspen suckers outgrowing and overtopping the spruce. This ocurred at Bertwell, and the resuckered aspen were removed 10 years after initial treatment.

Based on height–age development curves for spruce and aspen in this region, Johnson[2] suggests that spruce must be at least 10 years old, or 2.4–3.0 m in height, to escape overtopping by future suckers after a single release treatment. The need for a second release in the Bertwell stands, released at age 10–25 and having a 3.4-m average spruce height (Table 1), suggests that release should not be attempted before 3.4-m height or 20 years of age to prevent residuals from being overtopped by aspen sprouts. The growth response at Big River Nursery, which was released at 4.6 m average height and 15–25 years old for the spruce (Table 1), substantiates the timing of release.

It is generally realized that a release treatment might cause losses and damage in the white spruce understory because of the changed environment and competition from aspen sprouts and other underbrush (Cayford 1957). Release operations on taller spruce will doubtless reduce these side effects.

Although release at age 25–30 benefits spruce residuals the most, current changes in the economic position of aspen probably will make release cuttings in 40– to 50–year–old stands more economically feasible. In spruce–aspen mixed stands, the aspen component is 10–15 years older than the spruce (Kabzems 1971). By the time the spruce reaches 40–50 years old, the aspen component becomes harvestable, and revenues from aspen harvest could defray release costs. By combining volumes from intermediate cuttings and the final spruce crop trees, the productivity of mixed–wood stands can be substantially increased.

CONCLUSIONS

1. Complete release of white spruce from aspen competition in mixed–wood forests stimulated dbh growth up to 177% in 30 years; the largest dbh improvements were when the released spruce was between 15 and 40 years of age.

2. The 30–year height increment of released stands was 42% greater than that of untreated stands. Response was greater in small trees (2–6 m in height) than in large ones. To maximize height increment, release cuttings should be done before spruce reaches 6 m in height.

3. Complete release improved spruce total basal area and total and merchantable volumes. Improvements in basal area were 18 to 246% over the control in 30 years. The periodic annual increment of spruce total volume averaged 4.83 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ after release and 2.50 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ for the control, a 93% increase. Released stands have merchantable volumes higher than yield table values for fully stocked spruce on medium sites.

4. Although release markedly improved spruce merchantable volume in all areas, the density of spruce residuals following treatment dictated stand yield. Residuals of 690–840 stems/ha released at 20–40 years of age are adequate for yield development. Release cuttings are not justified in stands having under 250 spruce stems/ha; stands with over 2500 stems/ha after release require thinning to improve spruce merchantable volume.

5. Generally, releasing spruce from aspen reduced spruce mortality, but mortality depended on tree size. For trees under 3 cm in diameter, release reduced mortality because small trees are vulnerable to suppression and browsing. Mortality of larger spruce was higher in release stands due to windthrows.

6. Release stimulates spruce dbh and height growth more in young than in intermediate–age stands, but spruce released at a very young age runs the risk of being outgrown and overtopped by new aspen suckers. Release is recommended for stands at least 3.5 m in height or 25–30 years of age to prevent aspen sprouts and other underbrush competition. Increased demands for aspen make release cutting in 40– to 50–year–old spruce more economically feasible.

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[2] Johnson, H.J. 1986. The release of white spruce from trembling aspen overstoreys: a review of available information and silvicultural guidelines. Report prepared for the Manitoba Department of Natural Resources, Forestry Branch, Winnipeg, Manitoba, under the Canada–Manitoba Forest Renewal Agreement.

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APPENDIX I

PRE- AND POSTTREATMENT PLOT STATISTICS

Study area	Plot no.	Treatment	At establishment: White spruce Density (stems/ha)	Dbh[a] (cm)	Basal area ($m^2 \cdot ha^{-1}$)	At establishment: Trembling aspen Density (stems/ha)	Basal area ($m^2 \cdot ha^{-1}$)	1985 measurement: White spruce Density (stems/ha)	Dbh (cm)	Basal area ($m^2 \cdot ha^{-1}$)	Total volume ($m^3 \cdot ha^{-1}$)	Merchantable volume ($m^3 \cdot ha^{-1}$)	Trembling aspen total volume ($m^3 \cdot ha^{-1}$)
Candle Lake 1	1	Control	271	6.24	0.93	1457	19.2	222	22.18	8.80	66.17	58.25	144.54
	3	Control	420	4.23	0.71	1729	19.2	395	19.95	14.90	109.48	94.29	54.37
	2	Complete release	148	4.95	0.35	0	0	173	28.91	11.28	92.26	84.47	5.07
	4	Complete release	197	4.29	0.31	0	0	198	30.19	15.32	121.47	112.55	0
Candle Lake 2	5	Control	1705	5.09	4.30	1161	23.6	445	18.56	12.46	75.36	62.28	2.31
	7	Control	1705	4.97	4.01	1136	21.1	568	17.92	15.78	101.28	82.09	0
	6	Complete release	2643	5.43	7.65	0	0	717	20.27	23.94	174.05	148.92	0
	8	Complete release	1136	5.80	3.59	0	0	445	24.30	21.38	153.51	138.03	0
Big River	9	Control	2446	6.96	11.96	1334	18.3	1038	14.67	28.71	206.33	167.05	58.90
	11	Control	1581	7.02	7.34	1260	18.8	741	13.73	17.86	171.19	134.83	93.40
	10	Complete release	2495	7.49	13.80	0	0	11611	8.27	34.39	253.14	210.62	6.05
	12	Complete release	2075	7.02	9.46	0	0	1013	13.73	35.58	255.38	216.40	2.44
Big River Nursery	14	Control	2742	4.65	5.57	3681	24.5	1310	11.13	25.02	128.96	77.65	259.27
	13	Complete release	840	5.55	2.51	0	0	618	21.66	29.22	245.06	196.52	0
Montreal Lake	16	Control	1284	6.72	8.84	1853	11.4	297	13.38	6.85	44.94	33.24	197.23
	17	Control	642	5.80	3.35	2520	16.5	173	10.14	4.19	19.66	12.17	253.07
	15	Complete release	469	5.64	1.47	0	0	519	22.81	20.11	146.09	122.55	17.20
	18	Complete release	988	5.88	3.46	0	0	544	19.49	17.83	124.11	104.27	15.39

Continued on next page

Appendix 1. Continued

			At establishment					1985 measurement					
			White spruce			Trembling aspen		White spruce					
Study area	Plot no.	Treatment	Density (stems/ha)	Dbh[a] (cm)	Basal area ($m^2 \cdot ha^{-1}$)	Density (stems/ha)	Basal area ($m^2 \cdot ha^{-1}$)	Density (stems ha)	Dbh (cm)	Basal area ($m^2 \cdot ha^{-1}$)	Total volume ($m^3 \cdot ha^{-1}$)	Merchantable volume ($m^3 \cdot ha^{-1}$)	Trembling aspen total volume ($m^3 \cdot ha^{-1}$)
Riding Mountain	19	Control	2075	3.00	1.38	4694	27.5	568	7.92	8.87	34.96	12.10	249.55
	21	Control	5856	2.69	3.50	3484	22.9	741	7.04	11.30	40.08	8.92	196.61
	20	Complete release	2940	3.25	2.67	0	0	1483	10.48	30.21	145.68	99.89	1.78
	22	Complete release	2471	2.88	1.83	0	0	1458	9.45	27.46	130.58	81.68	0
Bertwell	1	Control	2001	3.44	2.26	1779	13.7	1260	9.14	19.50	107.80	46.04	141.74
	4	Control	2940	3.12	2.91	2050	11.4	1186	8.08	21.38	121.47	51.16	176.44
	2	Partial release	7240	2.58	0.58	1927	11.9	964	7.58	17.04	84.90	27.89	182.80
	5	Partial release	4522	2.22	0.16	2223	12.1	791	7.43	14.32	73.28	31.39	103.80
	3	Complete release	1754	2.75	0.22	0	0	1137	11.72	26.56	149.88	104.98	0
	6	Complete release	3914	1.95	0.09	0	0	1433	13.00	30.39	171.20	118.59	0
Reserve	2	Control	518	9.23	6.14	1013	24.1	297	18.65	14.19	95.82	86.05	94.76
	4	Control	99	5.94	0.56	988	25.4	148	23.79	7.14	47.65	43.94	218.22
	1	Partial release	469	11.66	4.09	518	10.1	469	21.03	13.58	94.33	80.94	260.05
	6	Partial release	271	15.40	5.76	568	9.8	148	27.86	9.13	69.71	64.97	102.16
	3	Complete release	691	10.67	7.08	0	0	371	24.42	25.59	315.64	230.68	0
	5	Complete release	247	17.48	5.76	0	0	222	34.97	22.62	183.37	173.65	12.87
Duck Mountain	4	Control	1202	9.02	6.20	3741	27.8	610	19.11	10.04	77.80	64.50	211.04
	3	Partial release	1658	9.73	7.10	1665	11.3	732	22.33	15.00	119.50	102.50	83.02
	5	Complete release	1150	9.40	5.50	645	8.0	784	24.88	24.70	198.80	184.50	51.40

[a] Diameter at breast height.