Growth responses of the balsam fir and black spruce spacing trials

M.B. Karsh, M.B. Lavigne and J.G. Donnelly

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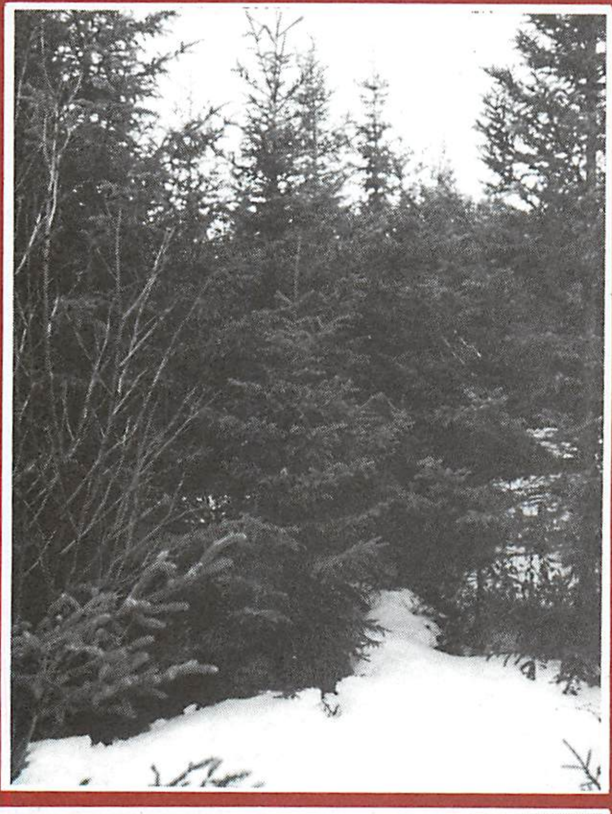

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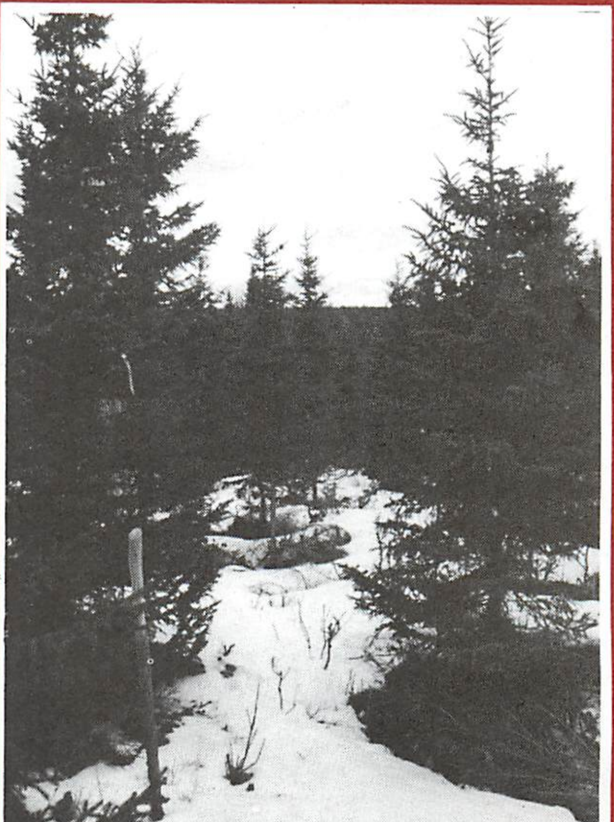

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Cover caption:

1. Black spruce spacing trial at North Pond (a) before and (b) after precommercial thinning. (Photos: Joe Donnelly)

2. Balsam fir spacing trial at Harpoon. (Aerial photo: Dave Stone)

GROWTH RESPONSES OF THE BALSAM FIR AND BLACK SPRUCE SPACING TRIALS

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ABSTRACT

Initial growth responses of plots thinned to a range of spacings in 3 balsam fir (*Abies balsamea* (L.) Mill) stands and 3 black spruce (*Picea mariana* (Mill.) B.S.P.) stands are reported. Periodic annual increments of total volume per hectare decreased with increasing spacing. Conversely, the growth per tree, as measured by diameter growth rates, increased with spacing. Plots thinned to closer spacings added more volume per hectare during the first 5 years to trees that will be merchantable than did plots thinned to wider spacings. Site quality, stand density prior to thinning and stand age at time of thinning appeared to affect initial conditions and hence growth rates during the first 5 years. Growth rates of a balsam fir trial on the Northern Peninsula, were lower than plots with similar initial basal area in western Newfoundland. Balsam fir plots in the same ecoregion however had similar growth - basal area relationships. For black spruce growing in the same ecoregion, growth rates were lower for plots with high initial densities (i.e., >20 000). All of the black spruce spacing trials responded to thinning. When black spruce occurs in dense stands, precommercial thinning appears necessary to obtain an operable stand at time of harvest. Growth responses after thinning black spruce are comparable to balsam fir when growing on equally productive sites.

RÉSUMÉ

Ce rapport fait état de la croissance initiale des arbres de 3 peuplements de sapins baumiers (*Abies balsamifera* (L.) Mill.) et de 3 peuplements d'épinettes noires (*Picea mariana* (Mill.) B.S.P.) à la suite de divers degrés d'éclaircie. Plus l'espacement était grand, plus l'accroissement périodique annuel du volume total à l'hectare diminuait. Par ailleurs, la croissance individuelle des arbres, telle que mesurée par l'accroissement du diamètre, augmentait avec l'espacement. Le volume des arbres d'avenir des parcelles moins espacées a augmenté davantage à l'hectare pendant les 5 premières années que celui des parcelles plus espacées. La qualité de la station, la densité préalable du peuplement et l'âge du peuplement au moment de l'éclaircie semblent avoir influé sur les conditions initiales et, par le fait même, sur les taux de croissance des 5 premières années. Les taux de croissance des arbres d'une parcelle de sapins baumiers de la péninsule Northern étaient plus faibles que ceux des parcelles présentant des surfaces terrières initiales similaires dans l'ouest de Terre-Neuve. Des parcelles de sapins baumiers de la même écorégion présentaient toutefois des rapports similaires entre leur taux de croissance et leur surface terrière. Dans le cas de l'épinette noire de la même écorégion, les taux de croissance étaient plus faibles dans les parcelles où les densités initiales étaient élevées (c'est-à-dire supérieure à 20 000). Toutes les parcelles expérimentales d'espacement de l'épinette noire ont bien réagi aux traitements d'éclaircie. Dans des peuplements denses d'épinettes noires, il semble nécessaire de pratiquer une éclaircie précommerciale pour obtenir un peuplement convenablement exploitable au moment de la récolte. Après un passage en éclaircie, la croissance de l'épinette noire est comparable à celle du sapin baumier dans des stations tout aussi productives.

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The authors thank the various agencies who contributed to this project. Trials at Pasadena and Cormack were spaced by Corner Brook Pulp and Paper, at Roddickton by the Roddickton Forest Management Unit, at Carmanville by the Department of Forestry, at Grand Falls by Abitibi-Price and at North Pond by the Canadian Forest Service. We are grateful to Dr. William Warren of the Department of Fisheries and Oceans for providing statistical advise.

GROWTH RESPONSES OF THE BALSAM FIR AND BLACK SPRUCE SPACING TRIALS

by

M.B. Karsh, M.B. Lavigne and J.G. Donnelly

INTRODUCTION

Precommercial thinning is usually prescribed to reduce the rotation length and increase total merchantable volume at rotation age. Thinning can also change the type of forest products yielded, i.e., from pulpwood to sawlogs. Depending upon forest level goals, the stand level objectives of thinning are not necessarily to maximize peak mean annual increment or present net worth of individually treated stands. For example, the objective might be to maximize merchantable volume when the stand reaches 50 years-old so that the stand can be used to alleviate a forest level wood shortage projected for some particular time in the future.

Spacing increases the growth of trees that will be merchantable (Smith 1986). One expects all trees in thinned stands to be merchantable at rotation age and none of the trees to have died from competition. Otherwise, the selected spacing has been too close and the growth of crop trees have been reduced by unnecessary competition. If selected spacings are too wide then more merchantable volume could have been produced while stands were young than was actually produced, without unduly reducing the growth of surviving trees. Since the rotation age and specification of merchantable size varies among stand level objectives, it is clear that forest managers need information about growth responses for a wide range of spacings. Moreover, growth after thinning depends on the crop species, site, unthinned density, stand age at time of thinning, regional climate and other biotic and abiotic influences. Consequently, forest managers must know how these factors affect growth responses over a range of spacings.

Spacing trials designed to answer the questions raised above have been established in 9 stands (Donnelly *et al.* 1986). These trials are established in balsam fir (*Abies balsamea* (L.) Mill), black spruce (*Picea mariana* (Mill.) B.S.P.), and jack pine (*Pinus banksiana* Lamb.) stands. Trials are located in different ecoregions, and in stands representing a range of site quality, age and initial density. Preliminary results from 1 trial in a black spruce stand at North Pond (Lavigne *et al.* 1987) and 1 trial in a balsam fir stand at Cormack (Lavigne and Donnelly 1989) have been previously reported. Early results of 6 trials are presented in this report. Three of the trials are in balsam fir stands and 3 of the trials are in black spruce stands. Our intent is to document early results to thinning and to make some preliminary comparisons of growth responses on different sites, ecoregions and crop species.

MATERIALS AND METHODS

Study Sites

Two of the balsam fir trials are in western Newfoundland within Rowe's (1972) Forest Region B28b. The Cormack trial is located near Sir Richard Squires Provincial Park (49°02'N, 57°08'W) and the Pasadena trial is located near Blue Gulch Pond (49°03'N, 57°32'E). Roddickton, the third balsam fir trial, is on the Northern Peninsula, Forest Region B29 (Rowe 1972), near Side Pond Road (50°59'N, 56°15'E).

The 3 black spruce trials are located in central and eastern Newfoundland within Forest Region B28a (Rowe 1972) as follows: (1) Carmanville (49°22'N, 54°18'E), (2) Grand Falls, near West Stony Brook, (48°52'N, 55°45'W) and (3) North Pond (48°41'N, 54°33'W). Table 1 shows some characteristics of the 6 spacing trials. The stands were selected to represent a range of ages, sites and initial conditions. Descriptions of the Damman Site Types are in Meades and Moores (1989).

Experimental Design

The spacing trials are laid out in a thrice replicated random block design. The model was specified as follows:

Table 1. Mensurational and ecological characteristics of 6 spacing trials (standard deviation in parentheses).

Location Name	Pasadena	Cormack	Roddickton	North Pond	Carmanville	Grand Falls
Main Crop Species	Balsam Fir	Balsam Fir	Balsam Fir	Black Spruce	Black Spruce	Black Spruce
Stand age at time of thinning	22	18	24	18	24	35
Stand age at time of initial plot measures	24	18	25	18	30	35
Year of Treatment	1981	1982	1983	1981	1979	1983
Initial volume (m^3/ha)	80.83 (7.84)	58.45 (14.46)	53.37 (9.27)	20.15 (3.16)	15.02 (9.05)	51.46 (17.75)
MAI (m^3/ha/yr)	3.67	3.25	2.22	1.12	0.63	1.47
Initial mean diameter (cm)	3.17 (0.24)	2.29 (0.20)	3.01 (0.33)	2.65 (0.27)	2.89 (0.86)	3.19 (0.73)
Initial mean height (m)	3.42 (0.22)	3.04 (0.32)	2.55 (0.11)	2.63 (0.15)	2.88 (0.54)	3.12 (0.51)
Initial total number of trees/ha	35523 (11086)	61964 (12166)	35353 (7475)	14090 (1829)	10101 (5821)	21730 (7409)
Damman Site Type	Fdh	Fr	Fc	SM/M	SM/R	SM/D
Elevation (m)	213	175	122	91	61	107
Terrain	upper slope	lower slope	upper slope	upper slope	upper slope	upper slope
Slope	flat, gentle	flat, gentle	moderate	moderate	moderate	moderate
Aspect	NE	NW	SE	N	SE	NW
Soil	Stony till	stony till	G. moraine till	stony till	till	till

$$Y_{ij} = \mu + \delta_j + \beta_i + \varepsilon_{ij}$$

where

Y_{ij} = plot measurement of a response variable
μ = mean for the spacing trial of the response variable
δ_j = treatment effect on the response variable ($j=1, k; k=5$)
β_i = block effect on the response variable ($i=1, n; n=3$)
ε_{ij} = amount that the observed response deviates from the predicted response

A permanent sample plot (PSP) was established within each larger 0.25 ha treatment plot. Sizes of the PSP's varied with spacing so as to include approximately 100 trees per plot. All trees in the PSP greater than 1.3 m height were tagged at plot establishment. Height, diameter at breast height (dbh), status (living or dead) and damage were recorded. Crown length, defined as distance from the ground to the height of first live whorl, was measured in the fifth year. Crews used tally sheets with records of previous measurements when doing re-measurements. The data was completely error checked by applying the editing techniques for permanent sample plots in Karsh and Lavigne (1993).

Five intertree spacings are being compared, the range of actual spacings (m) are shown in parentheses; unthinned (0.4-1.4), 1.2 m (1.1-1.6), 1.8 m (1.6-1.9), 2.4 m (1.9-2.5) and 3.0 m (2.4-3.2). There was no 1.2 m spacing in the black spruce spacing trial at North Pond, as unthinned plots were approximately the same as 1.2 m spacing.

Statistical Analysis

(a) Nominal Versus Actual Spacing

Nominal spacing refers to the experimental treatments being compared and is the intended distance between remaining trees after thinning. Actual spacing is the distance between trees that actually resulted from the thinning. In Carmanville, softwoods were spaced according to the experimental design but hardwoods were not spaced. Therefore unlike the other trials which had all trees spaced, actual spacing does not reflect the nominal spacing. This confounded the comparison between trials, therefore only data for softwoods are shown in the graphs and tables for Carmanville.

(b) Merchantable Trees at Rotation

A large number of trees in unthinned plots will die as stands mature or will not be merchantable at time of harvest. Therefore production estimates per hectare for all trees in unthinned plots overestimate the growth of trees that will be utilized. Therefore we have estimated the growth of trees in unthinned plots that would have been crop trees had the plots been spaced.

For example, the periodic annual volume increment (PAVI) for all trees in an unthinned black spruce plot at North Pond was 8.38 m^3/ha/y whereas the estimated PAVI for trees in the unthinned plot that would have been crop trees had the plot been spaced to 3.0 m was 1.53 m^3/ha/y. In contrast, the observed PAVI for trees thinned to a nominal spacing of 3.0 m was 2.13 m^3/ha/y. The difference between 2.13 and 1.53 is 0.60 m^3/ha/y. This value provides a relative measure of the effectiveness of spacing, the larger the difference the greater the effect (i.e., more volume is added to trees that will be merchantable). Four of the graphs in this report compare the PAVI for a spaced plot (e.g., 2.13 m^3/ha/y) with these relative values (e.g., 0.60 m^3/ha/y). The graphs show annual volume (or diameter) increment in thinned plots relative to trees that were initially the same in unthinned plots. It is assumed that all trees in thinned plots will be merchantable when stands are mature. Details on obtaining the estimate of 1.53 m^3/ha/y are documented below.

To estimate the growth of trees in an unthinned plot that would have been merchantable had the plot been spaced to 3.0 m; first calculate the mean diameter and volume increments for each diameter class as illustrated in Table 2. For each diameter class multiply the mean increment value for the unthinned plot with the corresponding number of trees in the 3.0 m spaced plot. Sum these products across diameter classes and divide by the total number of trees in the 3.0 m spaced plot. The resulting values of 2.09 mm and 6.75 dm^3 is the average diameter and volume increment. Divide by the number of years in the measurement interval to obtain periodic annual increment (i.e., 0.42 mm and 1.35 dm^3, respectively). To convert the volume

Table 2. Values for estimating the growth of trees in unthinned plots that would have been crop trees had the plots been spaced.

A	B	C	D	E	F	G
Diameter Class (midpoints)	Mean diameter increment (cm) (unthinned plot)	Number of Trees (spaced plot)	Total Diameter Increment (cm) (Column B*C)	Mean Volume Increment (m^3) (unthinned plot)	Number of Trees (spaced plot)	Total Volume Increment (m_3) (Column E*F)
0	0.67	0	0.00	0.15	0	0.00
1	0.93	10	9.30	0.48	10	4.75
2	1.15	11	12.65	1.16	11	12.73
3	2.09	23	48.07	3.94	23	90.51
4	2.18	26	56.68	6.20	26	161.23
5	2.83	6	16.98	10.43	6	62.60
6	2.59	15	38.85	12.27	15	184.07
7	2.74	6	16.44	15.11	6	90.64
8	2.72	4	10.88	15.92	4	63.67
9	3.95	1	3.95	18.71	1	18.71
		102	2.10		102	6.75

increment to a per hectare basis use the following equation:

$$Y = ((X*10\,000/S)/1000)*N$$

where

Y = periodic annual volume increment ($m^3/ha/y$)
$X = ((\Sigma_i$ mean increments$)/N)/t$ ($dm^3/ha/y$)
i = diameter class midpoint (0-9)
t = number of years in measurement interval
N = total number of trees in the spaced plot
S = plot size (m^2)

For this example Y=1.53; X=6.75/5 or 1.35; N=102; S=900.46 for a nominal 3.0 m spaced plot.

The above calculations are obtained for each pair of an unthinned and a spaced plot. For example, an unthinned plot in block 1 would be paired with a 1.8 m spaced plot in block 1, or a control plot in block 3 would be paired with a 2.4 m spaced plot in block 3. Altogether 12 combinations are possible.

Sometimes a spaced plot will have a wider range of tree diameters than an unthinned plot. Mean diameter and volume increments for unrepresented diameter classes in unthinned plots may be estimated as follows:

$$Y_i = b_0 + b_1 D_i$$

where

Y_i = periodic annual increment for diameter class i
b_0, b_1 = regression coefficients
D_i = diameter class i

(c) Weibull Function

The Weibull function was fit to the diameter class frequency data. Values of the 2 parameter form of the Weibull function were fit with programs made available by Bailey (1974).

$$N_i = (c/b)*(D_i/b)^{c-1} * \exp[-(D_i/b)^c]$$

where

N_i = number of trees in diameter class D_i
D_i = diameter class i
b = scale parameter; approximates the 63rd percentile of the distribution
c = shape parameter; indicates direction and degree of skewness of the distribution

Further description of the use of the Weibull function in these spacing trials is found in Lavigne and Donnelly (1989). Specifically in a forest growth and yield modelling context, the Weibull distribution has been found useful for estimating the parameters of a distribution of tree diameters (Bailey and Dell 1973). These parameters can be used in growth modelling.

(d) Volume Equations

Estimates of stem volume were made with two equations.

$$[1]\ V_t = 0.00439*D^2(1-0.04365*b)^2/(c_1+0.3048*c_2/H))$$

where

V_t = total stem volume (m^3). Stem volume estimates were later converted to dm^3
D = diameter at breast height (cm) (outside bark)
H = total tree height (m)
b, c_1, c_2 = taper and volume coefficients for different tree species (Ker 1974)

$$[2]\ V_t = 0.035816 * D^2H$$

where

V_t = total stem volume (dm^3)
D = diameter at breast height (cm)
H = total tree height (m)

Equation [1] was used for black spruce, white spruce (*Picea glauca* (Moench) Voss), trembling aspen (*Populus tremuloides* Michx.), white birch (*Betula papyrifera* Marsh.) and other hardwoods. Equation [2] was used for balsam fir and was derived from stem analysis (Lavigne and Donnelly 1989).

To calculate merchantable stem volume we used the following equation from Warren and Meades (1986).

$$V_m = V_t(a + bX + cX^2)$$
$$X = (7.6/D)^2 * (1 + 0.1524/H)$$

where

V_m = total gross merchantable stem volume (dm^3)
V_t = total stem volume (dm^3)
D = diameter at breast height (cm) (outside bark)
H = total tree height (m)
a,b,c = volume coefficients for balsam fir and black spruce by Newfoundland forest management units

(e) Periodic Stemwood Production

Periodic stemwood production was estimated by subtracting estimated stem size based on the initial or previous measurements of diameter and height from stem size estimated at the next remeasurement period. The geometric mean was used throughout this report. The geometric mean is the nth root of the product of n values and it is more appropriate than the arithmetic mean when there is a high predominance of trees in the smaller diameter classes, i.e. positively skewed frequency distributions (Husch 1963).

RESULTS

Effects of Thinning on Initial Conditions

The number of trees per hectare of unthinned plots ranged between 10 000 and 62 000 (Table 1). Unthinned plots in black spruce stands contained much fewer stems than did the unthinned plots in balsam fir stands.

Initial total volumes of unthinned plots ranged between 15 and 80 m^3/ha (Table 1). Balsam fir stands had higher initial volumes than black spruce principally because the fir stands had more stems per hectare and were growing on more productive sites, not because they were older. Among the balsam fir stands, the mean annual increment (MAI) and height data suggest that the Pasadena trial was on the most productive site while the Roddickton trial was on the least productive site. Among the black spruce stands, the height and age measurements indicated that the North Pond trial was growing on the most productive site. The Grand Falls trial had produced more total volume than the other black spruce locations because of its very high number of stems per hectare and greater age, and despite the fact that it was growing on a site of relatively low productivity.

The initial total volumes of thinned plots were much less than those of unthinned plots for all trials (Figures 1 and 2). The decreases in volume for the more closely spaced plots as compared to unthinned plots were relatively larger at Cormack than at Roddickton and Pasadena (Figure 1). Except for plots at Grand Falls the initial volume per hectare appeared to decline linearly with increased spacing for the other black spruce trials (Figure 2).

The initial mean diameters of most thinned plots were greater than their respective unthinned plots (Figures 3 and 4) and appeared to show an increase with increasing spacing among thinned plots (Figures 3 and 4). They also appeared to not increase with increased spacing beyond the nominal 1.8 m spacing (Figures 3 and 4). Among the balsam fir stands, the differences between thinned and unthinned plots were much greater for the Pasadena trial. The initial diameters in thinned stands were similar, irrespective of species, for all 6 locations except Pasadena (Figures 3 and 4).

The initial values of the scale parameter (b) of the Weibull function differed between locations and spacings in a manner that was similar to those of initial mean diameter (Tables 3 and 4). The scale parameter values are greater than corresponding mean diameters because the scale value is the dbh of the tree at the 63rd percentile. Moreover, the percentage difference between thinned and unthinned plots were greater when comparing mean diameters than when comparing scale values.

With the exception of the 3.0 m spacing at the Carmanville trial, the initial values of the shape parameter (c) of the Weibull distribution were greater in thinned plots than unthinned plots (Tables 5 and 6). In contrast, there were no substantial differences between the thinned plots at each spacing trial (Tables 5 and 6). These values indicate that unthinned plots had positively skewed diameter distributions, meaning that there were relatively more small trees than large trees (i.e., $1 < c < 3.6$). This is the normal circumstance for stands with high levels of competition (Mohler *et al.* 1978). The initial values of the shape parameters of thinned plots indicated that these plots had normal or negatively skewed diameter distributions, with the exception of the Carmanville trial (i.e., $c = 3.6$ pseudo symmetric, $c > 3.6$ negatively skewed). Among the balsam fir stands, the differences in the initial shape parameter values between thinned and unthinned plots were greatest at the Pasadena trial (Table 5). Among the black spruce stands, the values of the initial shape parameters were greatest for the thinned plots at

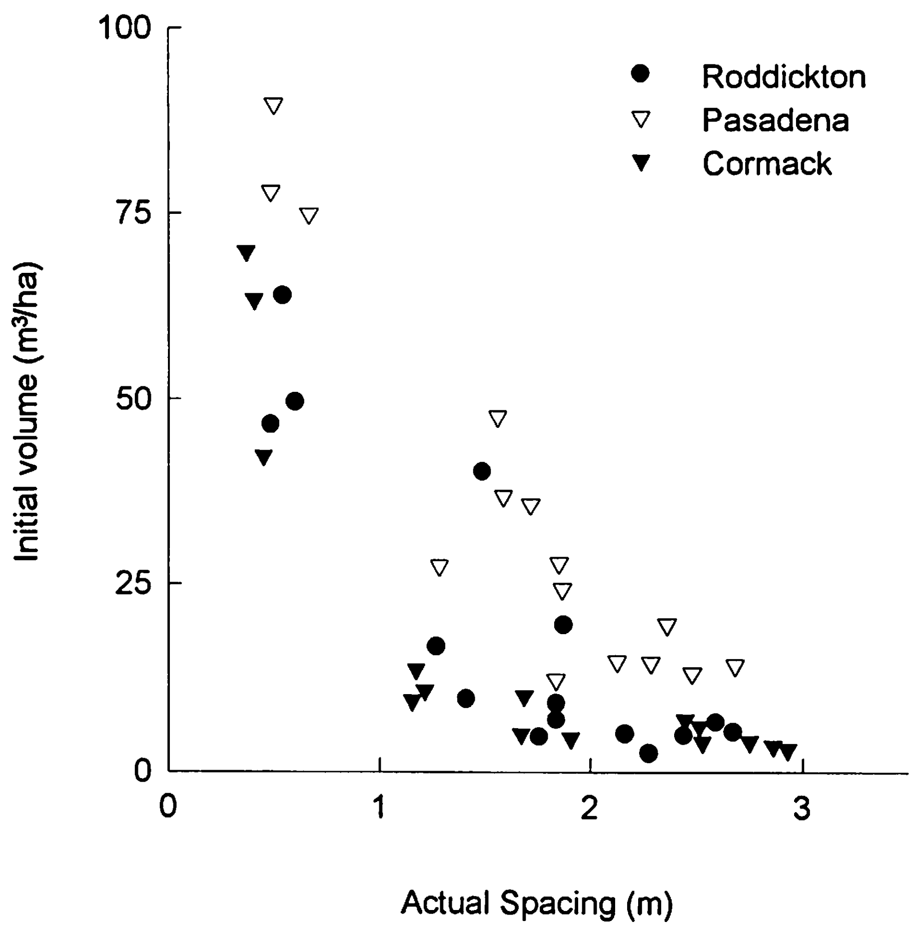


Fig. 1. Initial total volume per hectare versus actual spacing (average intertree distance) in thinned and unthinned plots of the balsam fir spacing trials. The unthinned plots have an average intertree distance of 0.5 m.

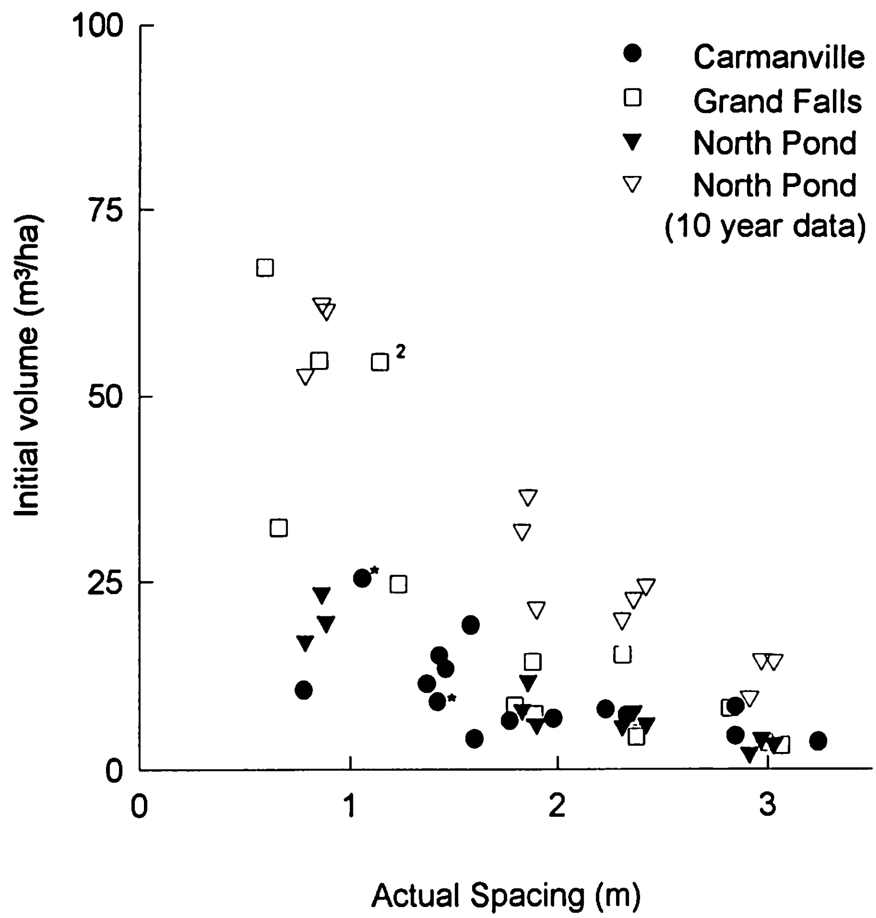


Fig 2. Initial total volume per hectare versus actual spacing in thinned and unthinned plots of the black spruce spacing trials. The unthinned plots have average intertree distances of < 1.0 m except for starred data points. The numbers indicate coincident values.

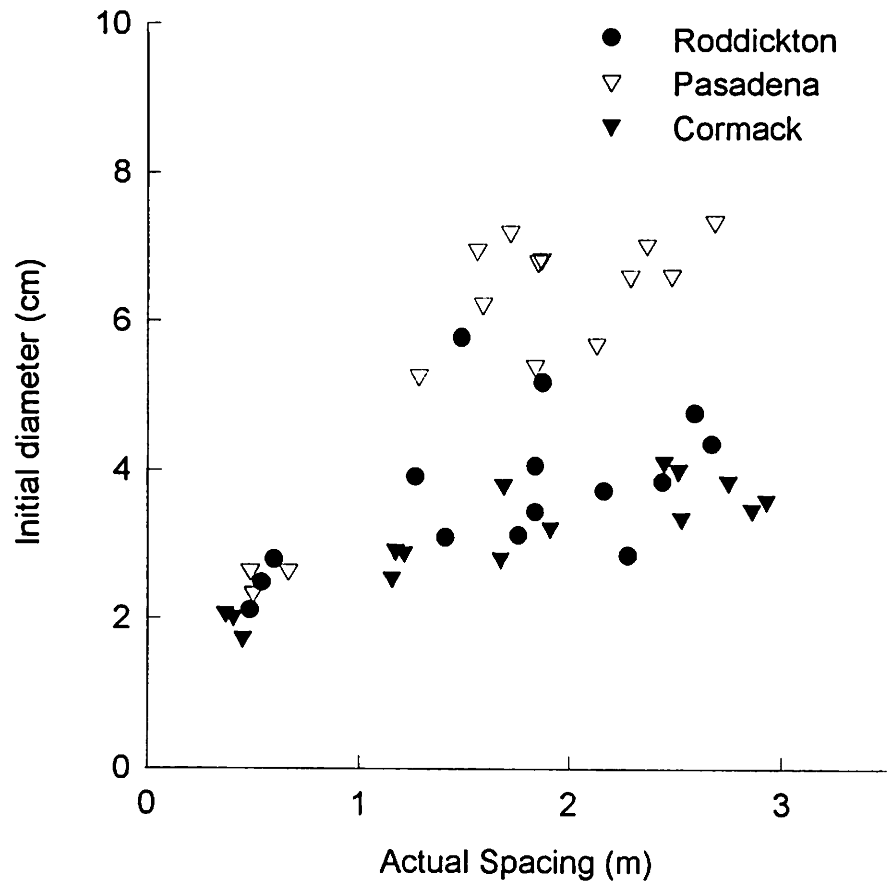


Fig. 3. Initial mean tree diameter versus actual spacing in thinned and unthinned plots of the balsam fir spacing trials. The unthinned plots have an average intertree distance of 0.5 m.

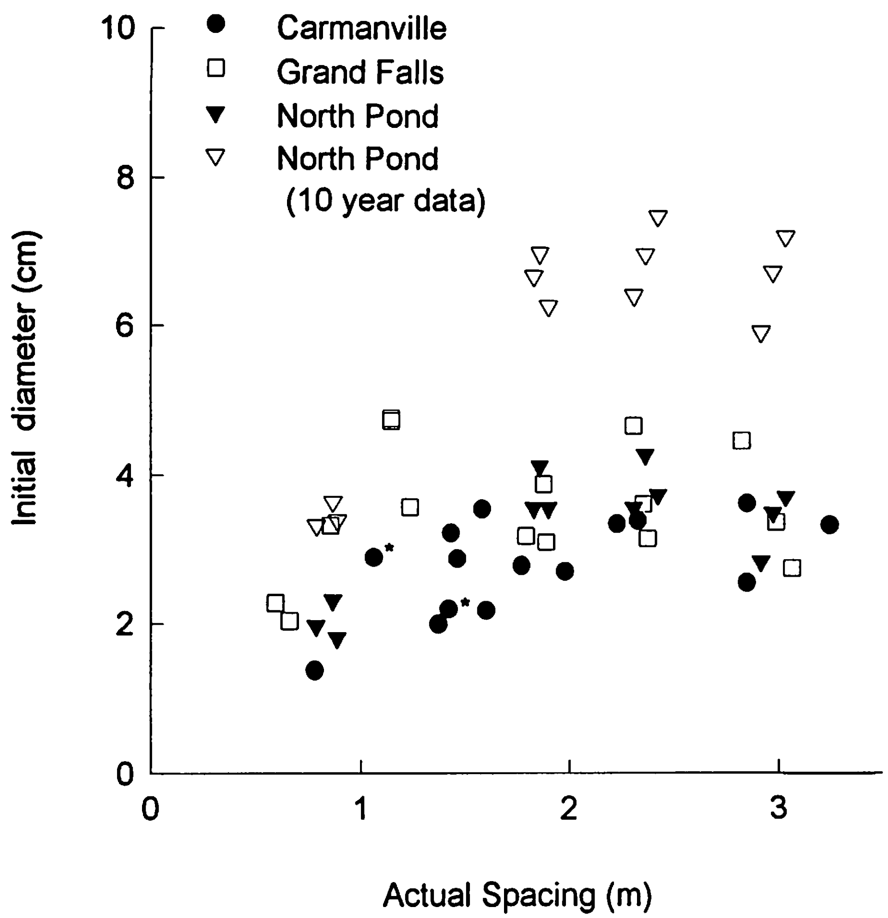


Fig. 4. Initial mean tree diameter versus actual spacing for thinned and unthinned plots of the black spruce spacing trials. The unthinned plots have average intertree distances of < 1.0 m except for starred data points.

Table 3. Values of the scale parameter of the Weibull function immediately after thinning and changes in the scale parameter during the measurement interval for the balsam fir spacing trials (standard deviation in parenthesis).

	Roddickton		Pasadena		Cormack	
Nominal spacing (m)	initial B	delta B	initial B	delta B	initial B	delta B
Unthinned	5.04 (0.37)	0.57 (0.07)	5.52 (0.38)	0.67 (0.63)	4.24 (0.21)	0.53 (0.03)
1.2	6.85 (1.61)	1.57 (0.30)	8.63 (1.14)	2.60 (0.31)	5.09 (0.21)	1.76 (0.37)
1.8	5.97 (0.60)	2.14 (0.08)	8.63 (1.04)	2.90 (0.29)	5.49 (0.56)	2.27 (0.34)
2.4	6.49 (1.49)	2.74 (1.06)	8.81 (0.44)	3.28 (0.15)	6.34 (0.38)	3.19 (0.12)
3.0	6.97 (0.50)	2.42 (0.21)	9.66 (0.31)	3.62 (0.20)	6.06 (0.16)	3.05 (0.12)

Table 4. Values of the scale parameter of the Weibull function immediately after thinning and changes in the scale parameter during the measurement interval for the black spruce spacing trials (standard deviation in parenthesis).

	Carmanville		Grand Falls		North Pond	
Nominal spacing (m)	initial B	delta B	initial B	delta B	initial B	delta B
Unthinned	4.89 (0.92)	1.40 (0.32)	5.24 (0.77)	0.64 (0.07)	4.63 (0.32)	1.73 (0.20)
1.2	5.61 (0.48)	1.94 (0.08)	6.91 (0.79)	1.14 (0.09)	N/A	N/A
1.8	5.22 (1.04)	1.80 (0.47)	5.92 (0.54)	1.70 (0.15)	6.00 (0.52)	3.01 (0.21)
2.4	5.70 (0.40)	1.56 (0.17)	6.41 (1.03)	1.91 (0.45)	6.20 (0.37)	3.23 (0.69)
3.0	5.91 (1.05)	1.72 (0.32)	6.25 (0.91)	2.32 (0.23)	5.75 (0.53)	2.44 (1.47)

Table 5. Values of the shape parameter of the Weibull function immediately after thinning and changes in the shape parameter during the measurement interval for the balsam fir spacing trials (standard deviation in parentheses).

	Roddickton		Pasadena		Cormack	
Nominal spacing (m)	initial C	delta C	initial C	delta C	initial C	delta C
Unthinned	2.59 (0.20)	-0.03 (0.07)	2.45 (0.31)	-0.12 (0.04)	2.78 (0.19)	-0.27 (0.10)
1.2	3.45 (0.55)	0.08 (0.15)	4.71 (1.07)	-0.01 (0.30)	3.38 (0.14)	-0.01 (0.07)
1.8	3.57 (0.30)	0.27 (0.07)	6.29 (0.27)	-0.01 (0.10)	3.90 (0.29)	0.17 (0.59)
2.4	3.17 (0.25)	0.69 (0.35)	5.22 (0.64)	-0.17 (0.30)	3.41 (0.03)	0.02 (0.24)
3.0	3.34 (0.17)	0.35 (0.03)	5.02 (1.08)	0.22 (0.19)	3.46 (0.31)	-0.15 (0.20)

Table 6. Values of the shape parameter of the Weibull function immediately after thinning and changes in the shape parameter during the measurement interval for the black spruce spacing trials (standard deviation in parenthesis).

	Carmanville		Grand Falls		North Pond	
Nominal spacing (m)	initial C	delta C	initial C	delta C	initial C	delta C
Unthinned	2.09 (0.26)	0.33 (0.18)	2.71 (0.09)	0.02 (0.01)	2.71 (0.52)	0.13 (0.07)
1.2	2.15 (0.43)	0.86 (0.52)	3.63 (0.14)	0.20 (0.08)	N/A	N/A
1.8	2.73 (0.31)	0.97 (0.34)	3.28 (0.32)	0.59 (0.14)	4.32 (0.17)	1.22 (0.33)
2.4	2.61 (0.28)	0.77 (0.12)	3.63 (0.39)	0.66 (0.38)	3.96 (0.39)	1.13 (0.19)
3.0	2.08 (0.34)	0.58 (0.41)	3.31 (0.46)	0.88 (0.27)	3.61 (0.49)	0.87 (0.09)

(Table 6). The Pasadena and North Pond spacing trials were growing on the most productive sites.

Effects of Thinning on Total Volume Growth

Periodic annual increments of total volume decreased as intertree distance increased (Figures 5 and 6). The relationship between annual volume growth and actual spacing was adequately described by a linear regression model ($p \leq 0.05$)(Figures 5 and 6). The unthinned plots had significantly more annual volume growth per hectare than thinned plots at all but Carmanville locations ($p \leq 0.05$) (Figures 5 and 6, Table 7).

Unthinned plots at Cormack and Pasadena had similar growth rates and grew at higher rates than at Roddickton ($p \leq 0.05$)(Figure 5). Thinned plots at Cormack and Roddickton had much lower growth rates than at Pasadena ($p \leq 0.05$)(Figure 5). Periodic annual volume growth in black spruce plots at North Pond are much greater than those at Grand Falls ($p \leq 0.05$)(Figure 6).

For each trial there appears to be a curvilinear trend between periodic annual volume growth and initial basal area (Figures 7 and 8). Large differences in growth are associated with small increases in basal area when initial basal areas are low; and small differences in growth are associated with large differences in basal area when initial basal areas are large (e.g., 15 to 20 m^2/ha, Figure 7). Grand Falls had less growth at any initial basal area than the other black spruce trials and North Pond appeared to have the most growth at any initial basal area (Figure 8).

Annual total volume growth was significantly affected by the location of the trials over and above that of initial basal area and spacing ($p \leq 0.01$) (Table 8). For example, growth rates at Roddickton were always much lower than plots with similar basal areas at the other balsam fir locations (Figure 7). Plots at Cormack appeared to have similar relationships between growth and basal area as plots at Pasadena (Figure 7). Growth rates at Grand Falls were consistently lower than other black spruce plots with similar basal areas (Figure 8).

Effects of Thinning on Merchantability

There were very few merchantable trees when each of these stands was thinned (Tables 9 and 10). Five years after thinning there were more merchantable trees per hectare in most spaced plots than in unthinned plots at all locations except for Roddickton and North Pond, however, most trees in thinned plots had not yet become merchantable (Tables 9 and 10). It is expected that all trees in thinned plots will be merchantable when stands are harvested but that many trees in unthinned plots will never reach merchantable size. Therefore, it is too early in stand development to use merchantable volume to assess responses to treatment. Therefore we have compared the growth of trees in thinned stands to trees in the unthinned stands that were similar initially as a means of assessing the gain in merchantability. See the Methods section for details.

(a) Diameter Growth Responses

Trees in unthinned plots of the balsam fir trials grew less than 2 mm per year in diameter on average (Figure 9). Annual average diameter growth rates of the 1.2 m spaced balsam fir plots was triple that of their unthinned plots and average diameter growth of the 3.0 m spaced plots was 5 times that of the unthinned plots (Figure 9). For the thinned plots, relationships between spacing and diameter growth were linear and statistically significant ($p \leq 0.01$)(Table 11). Diameter growth was greatest at Pasadena (Figure 9).

Relative to the growth of initially similar trees in unthinned plots the diameter growth responses were greatest at Roddickton, especially at closer spacings (Figure 10). The slopes of mean diameter growth versus spacing were positive (Figures 9 and 10), indicating that on an individual tree basis there is a continuously increasing response to thinning. Furthermore this relationship is expected to continue to increase with stand age. When comparing thinned plots with similar basal areas, diameter increments were greatest at Pasadena (Figure 11). At the lowest basal areas, the mean tree diameter increments of plots at Cormack equalled those of plots at Roddickton but at higher basal areas the diameter increments were greater at Roddickton.

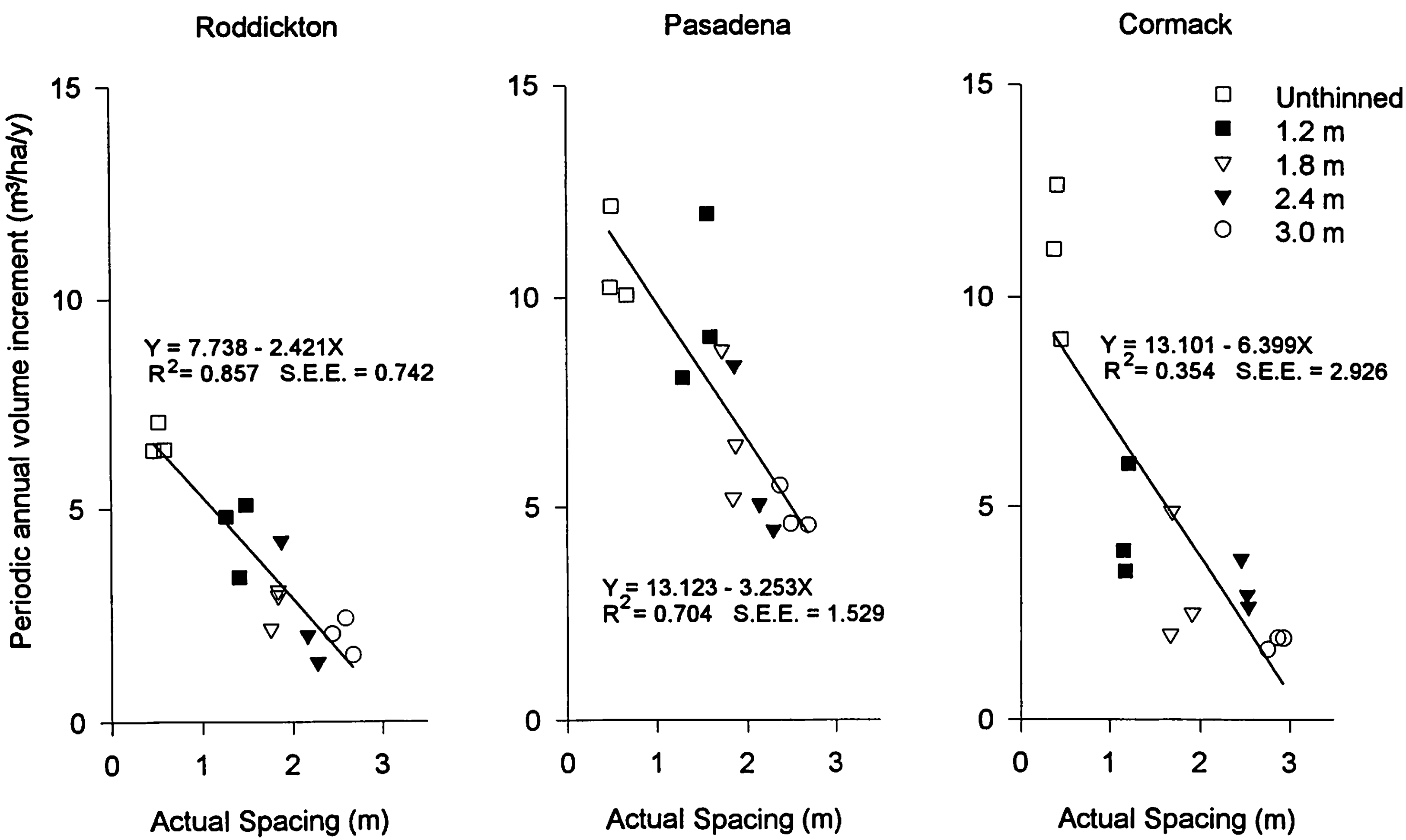


Fig 5. Periodic annual total volume growth in thinned and unthinned plots of the balsam fir spacing trials.

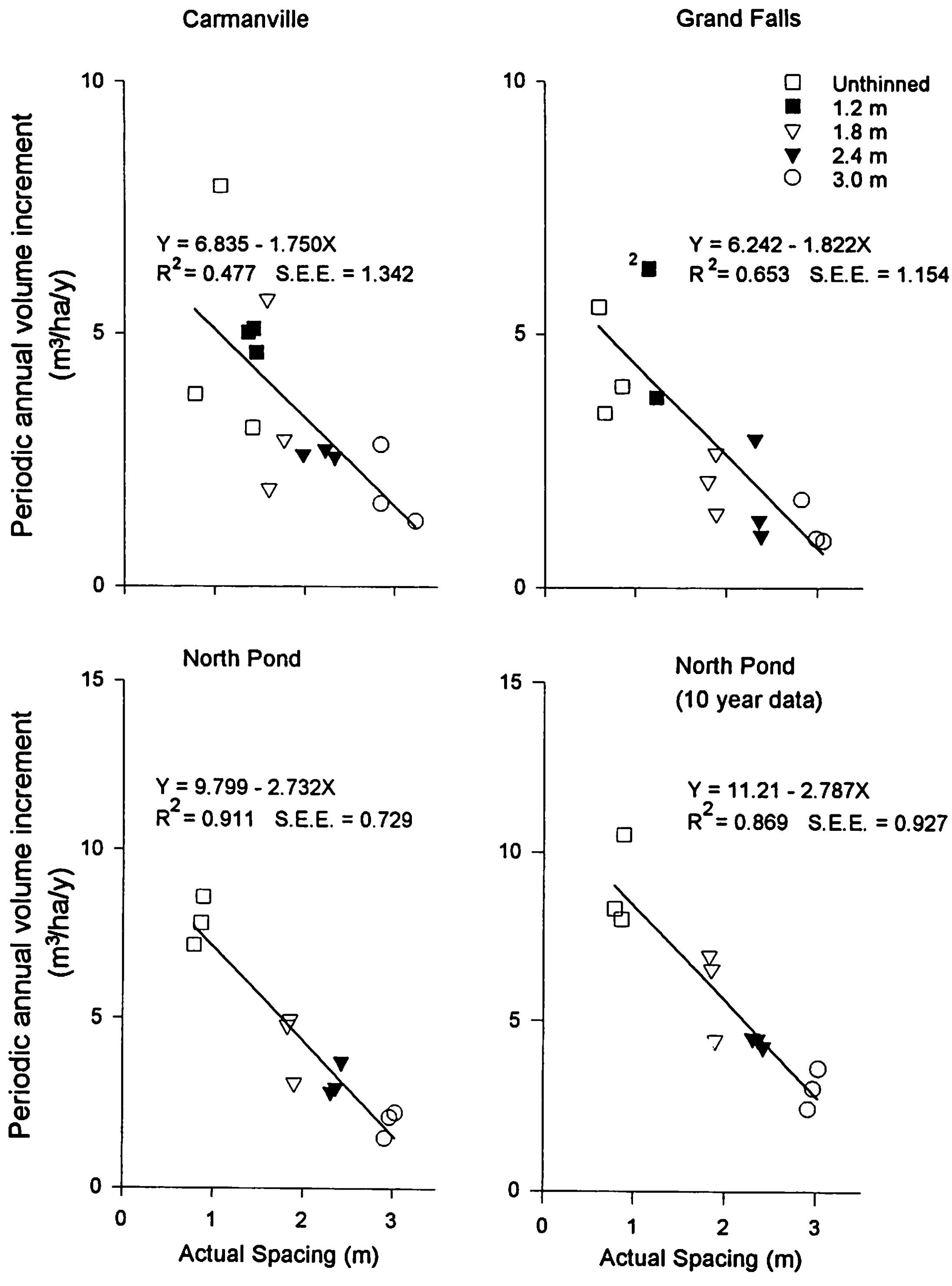


Fig. 6. Periodic annual total volume growth in thinned and unthinned plots of the black spruce spacing trials. The numbers indicate coincident values.

Table 7. Analysis of variance and linear contrasts of periodic annual volume increment and actual spacing for the 6 spacing trials.

Balsam Fir Spacing Trials

		Roddickton			Pasadena			Cormack		
Source of Variation	df	ms	F	P	ms	F	P	ms	F	p
Total	14									
Block	2	1.12	1.76	0.231	0.98	0.32	0.737	0.88	0.49	0.626
Treatment	4	10.64	16.84	0.001	19.02	6.14	0.015	39.06	21.99	0.000
Unthinned versus thinned	1	32.73	59.51	0.000	6.97	5.24	0.042	145.61	17.00	0.001
Linear	1	8.31	15.12	0.001	25.51	19.15	0.001	9.68	1.13	0.691
Quadratic	1	1.00	1.82	0.510	5.94	4.46	0.600	0.00	0.00	0.999
Cubic	1	0.52	0.94	0.747	1.66	1.25	0.663	1.01	0.12	0.972
Error	8	0.63			1.15			1.78		

Black Spruce Spacing Trials

		Carmanville			Grand Falls			North Pond			
Source of Variation	df	ms	F	P	ms	F	P	df	ms 5 Year 10 Year	F	p
Total	14							11			
Block	2	3.46	1.78	0.230	0.31	0.27	0.770	2	0.00 0.08	0.01 0.06	0.994 0.939
Treatment	4	5.57	2.86	0.096	10.02	8.75	0.005	3	18.78 19.14	31.77 14.69	0.000 0.004
Unthinned versus thinned	1	7.14	3.97	0.080	6.98	5.24	0.042	1	48.25 44.68	90.70 51.96	0.000 0.000
Linear	1	14.75	8.19	0.021	25.51	19.15	0.001	1	8.09 12.75	15.22 14.82	0.001 0.004
Quadratic	1	0.36	0.20	0.944	5.94	4.46	0.600	1	0.01 0.01	0.02 0.01	0.950 0.996
Cubic	1	0.02	0.01	0.991	1.66	1.25	0.663				
Error	8	1.95			1.15			6	0.59 1.30		

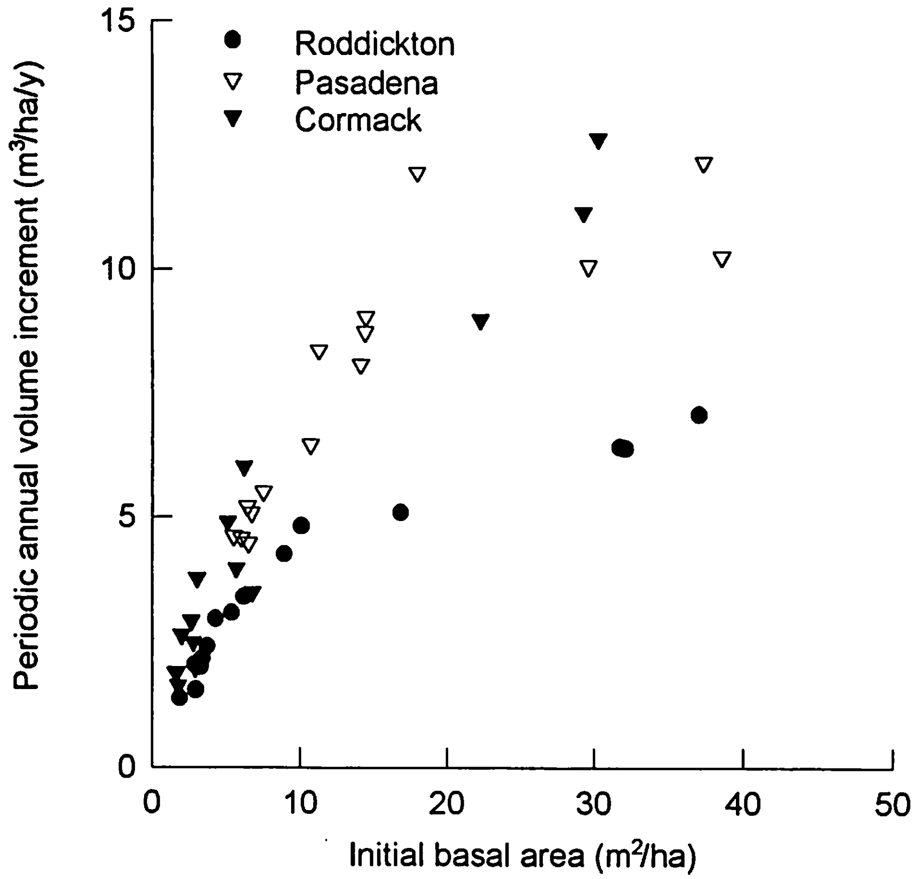


Fig. 7. Periodic annual total volume growth versus initial basal area per hectare of the balsam fir spacing trials.

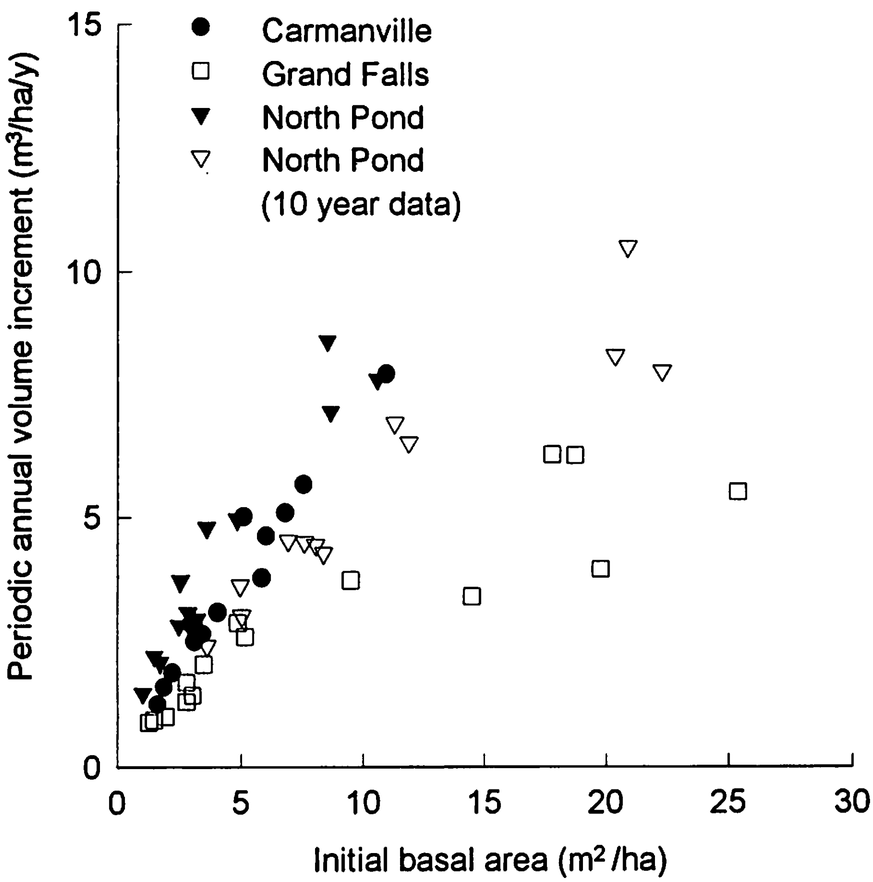


Fig 8. Periodic annual total volume growth versus initial basal area per hectare of the black spruce spacing trials.

Table 8. Parameters of the analysis of covariance for periodic annual volume and diameter growth for each spacing trial.

Dependent Variable		Periodic annual volume increment			Periodic annual diameter increment				
Source of Variation	df	ms	F	P	Source of variation	df	ms	F	p
Species	1	2.32	1.77	0.187	Species	1	11.30	18.27	0.000
Location (species)	5	27.88	21.24	0.000	Location (species)	5	10.48	16.94	0.000
Block	2	0.48	0.36	0.697	Block	2	0.05	0.07	0.930
Initial Basal Area per ha.	1	44.30	33.74	0.000	Initial Basal Area per ha.	1	171.61	277.42	0.000
Spacing	1	38.21	29.11	0.000					
Error	88	1.31			Error	89	0.62		

Table 9. Number of merchantable trees per hectare immediately after thinning and 5 years after thinning for the balsam fir spacing trials (standard deviation in parentheses).

	Roddickton		Pasadena		Cormack	
Nominal spacing (m)	initial (no. * 1000)	second	initial (no. * 1000)	second	initial (no. * 1000)	second
Unthinned	253 (125)	593 (323)	257 (338)	1273 (463)	0	0
1.2	283 (491)	543 (577)	473 (391)	2007 (832)	0	70 (70)
1.8	0	267 (200)	237 (290)	1570 (680)	0	153 (172)
2.4	120 (207)	353 (452)	197 (148)	1403 (471)	7 (12)	313 (143)
3.0	40 (26)	310 (130)	287 (103)	1090 (144)	7 (6)	103 (29)

Table 10. Number of merchantable trees per hectare immediately after thinning and 5 years after thinning for the black spruce spacing trials (standard deviation in parentheses).

	Carmanville		Grand Falls		North Pond	
Nominal spacing (m)	initial (no. * 1000)	second	initial (no. * 1000)	second	initial (no. * 1000)	second
Unthinned	0	87 (75)	83 (144)	170 (193)	0	380 (459)
1.2	23 (40)	353 (145)	93 (40)	567 (395)	N/A	N/A
1.8	30 (52)	310 (537)	10 (17)	123 (164)	0	327 (210)
2.4	13 (12)	213 (46)	40 (69)	180 (270)	0	282 (137)
3.0	40 (61)	387 (341)	10 (17)	127 (91)	0	173 (81)

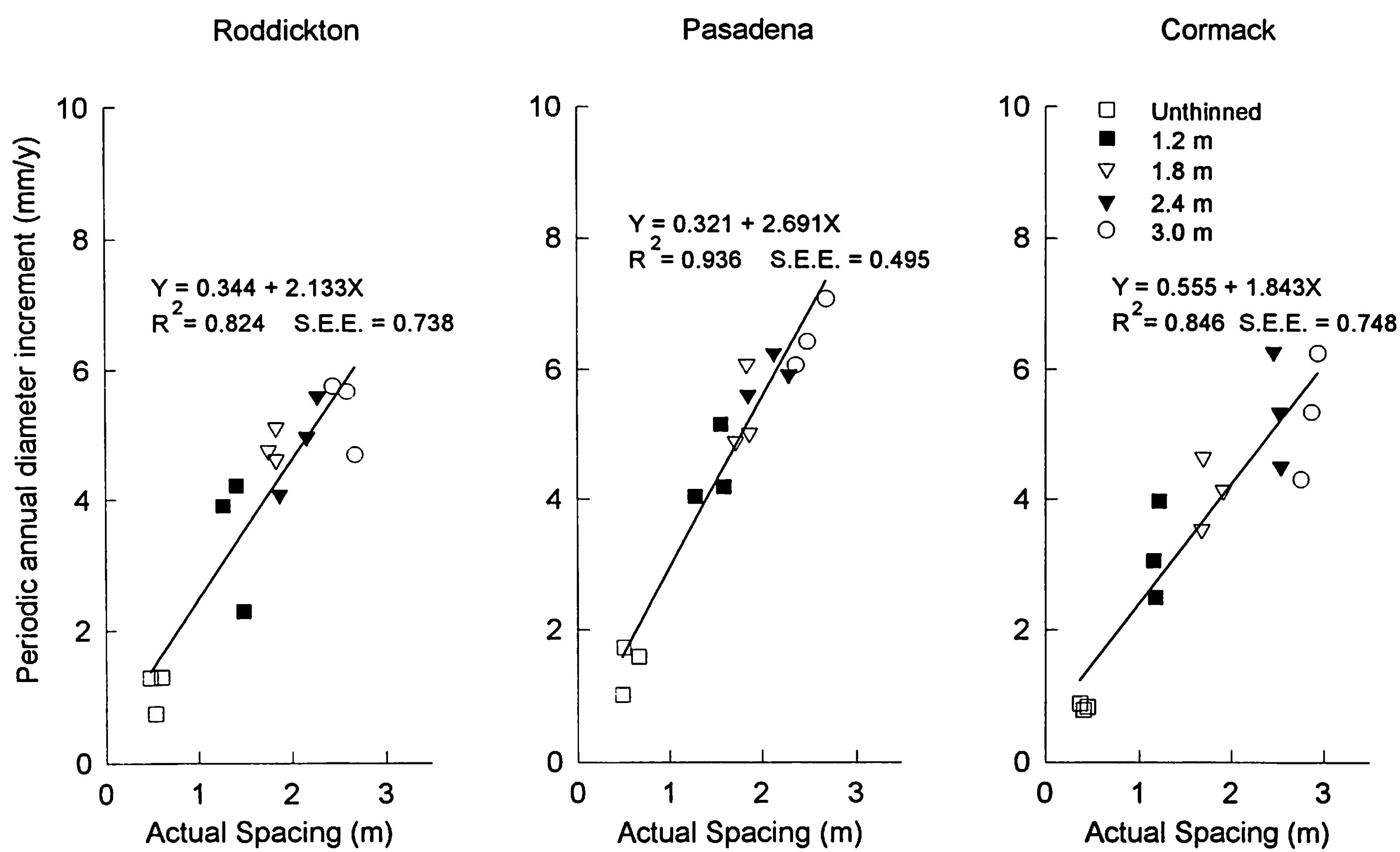


Fig. 9. Periodic annual mean tree diameter growth in thinned and unthinned plots of the balsam fir spacing trials.

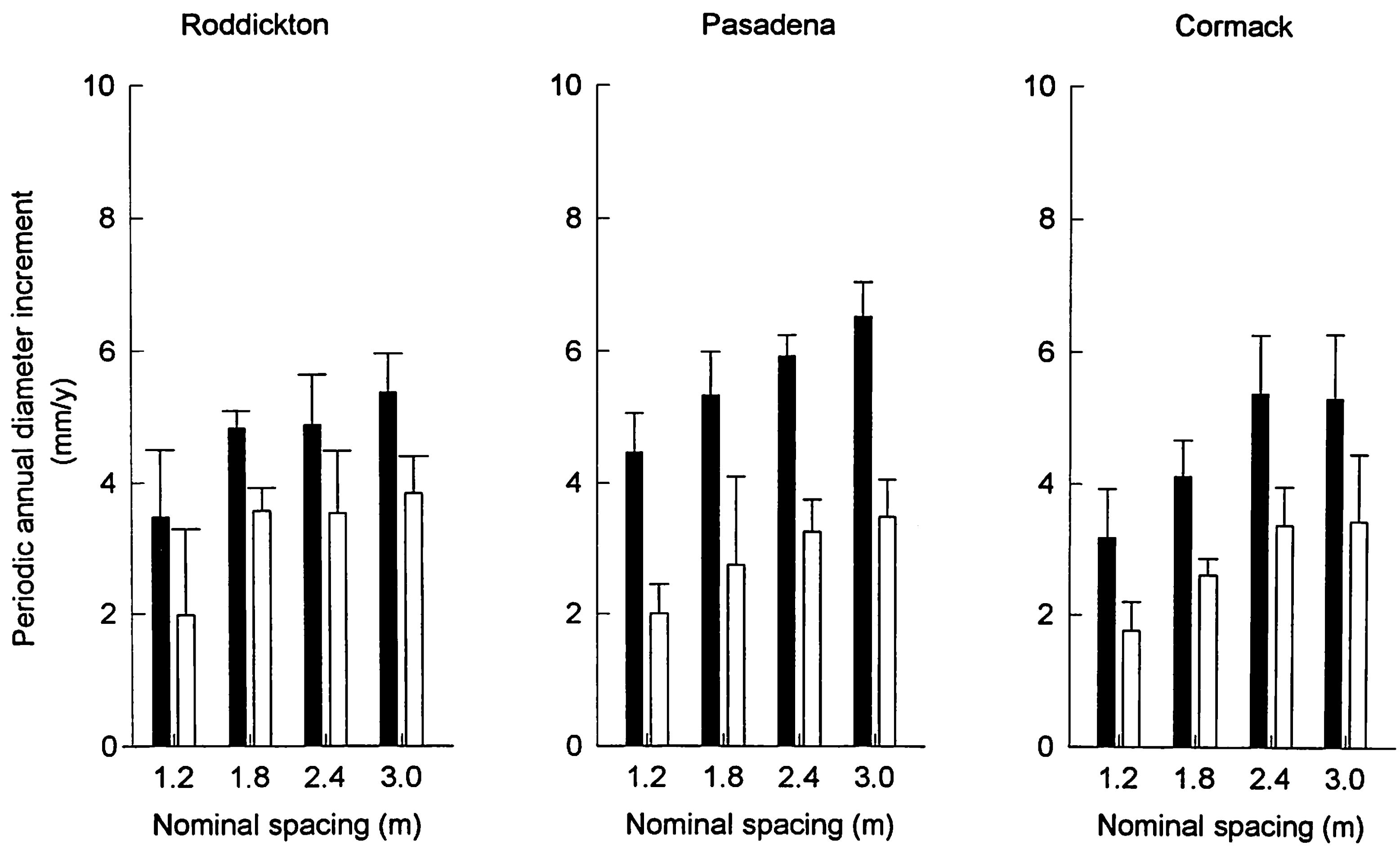
Table 11. Analysis of variance and linear contrasts of periodic annual diameter increment and actual spacing for the 6 spacing trials.

Balsam Fir Spacing Trials

		Roddickton			Pasadena			Cormack		
Source of Variation	df	ms	F	P	ms	F	P	ms	F	p
Total	14									
Block	2	0.85	5.60	0.135	0.423	1.93	0.207	0.92	2.21	0.173
Treatment	4	8.98	27.42	0.000	11.88	54.27	0.000	10.50	25.16	0.000
Unthinned versus thinned	1	29.99	55.11	0.000	40.60	165.72	0.000	32.04	57.32	0.000
Linear	1	5.05	9.29	0.015	6.84	27.93	0.000	8.77	15.69	0.001
Quadratic	1	0.55	1.01	0.720	0.05	0.22	0.944	0.76	1.36	0.634
Cubic	1	0.47	0.86	0.763	0.01	0.05	0.986	0.42	0.74	0.805
Error	8	0.33			0.22			0.42		

Black Spruce Spacing Trials

		Carmanville			Grand Falls			North Pond			
Source of Variation	df	ms	F	P	ms	F	P	df	ms 5 Year 10 Year	F	p
Total	14							11			
Block	2	0.00	0.15	0.895	0.11	1.15	0.364	2	0.28 0.08	0.59 1.04	0.583 0.410
Treatment	4	0.03	10.69	0.003	5.27	55.99	0.000	3	8.70 19.14	18.34 185.60	0.002 0.000
Unthinned versus thinned	1	0.10	25.30	0.000	11.39	91.09	0.000	1	25.19 44.68	42.55 100.86	0.000 0.000
Linear	1	0.03	6.78	0.028	9.40	75.21	0.000	1	0.90 12.75	1.53 6.51	0.608 0.020
Quadratic	1	0.00	0.15	0.605	0.18	1.43	0.606	1	0.00 0.01	0.00 0.19	0.999 0.560
Cubic	1	0.00	0.69	0.815	0.12	0.95	0.746				
Error	8	0.00			0.09			6	0.47 1.30		



Y = 0.430 + 1.422X
R^2= 0.378 S.E.E. = 0.889

Y = -0.022 + 1.469X
R^2= 0.468 S.E.E. = 0.693

Y = 0.542 + 1.599X
R^2= 0.231 S.E.E. = 0.825

Fig. 10. Periodic mean tree diameter growth of thinned plots relative to periodic annual mean tree diameter growth of similar trees in the unthinned plots (white) and total diameter increment (black) for the balsam fir spacing trials. Regression equations are given for the growth of similar trees in unthinned plots. Error bars are determined by the standard error.

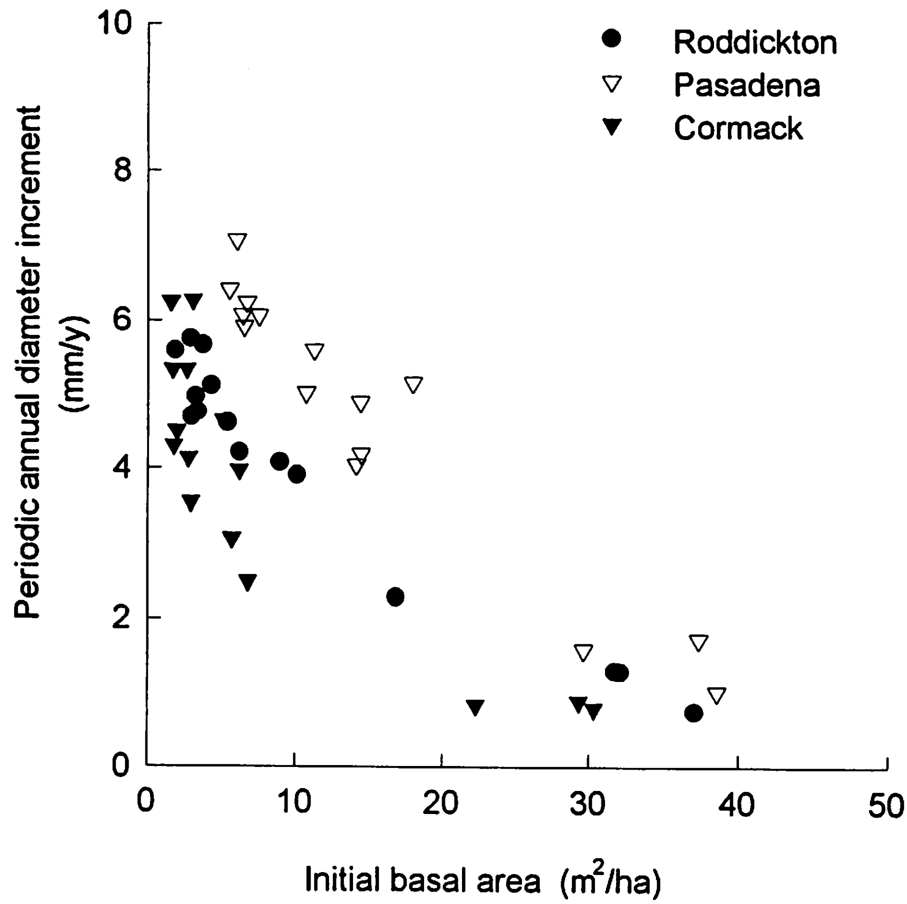


Fig. 11. Mean tree diameter growth versus initial basal area per hectare for thinned and unthinned plots of the balsam fir spacing trials. The unthinned plots have initial basal area's of > 20 m^2/ha.

Unthinned black spruce plots grew in diameter by 1 and 3 mm/yr (Figure 12). Thinned plots increased in mean tree diameter by 1 to 4 mm/yr more than did their adjacent unthinned plots (Figure 12) and these differences were statistically significant ($p \leq 0.01$)(Table 11). Diameter increment in thinned plots relative to trees that were initially the same in unthinned plots also increased with spacing (Figure 13). The thinned plots at Grand Falls added smaller diameter increments than thinned plots of comparable basal area at the other locations (Figure 14). Both species and location had a significant effect on annual diameter growth over and above that of initial basal area per hectare (Table 8). Hence, differences between stands explained a portion of the variability in diameter growth.

Values of the shape parameter (c) in the black spruce trials did not decline during the measurement interval, for thinned and unthinned plots (Table 6). Specifically, values for thinned plots at Grand Falls and North Pond increased, thus becoming more negatively skewed, whereas values for unthinned plots did not change substantially. Values for thinned plots at Carmanville also increased but the distributions remained positively skewed (Table 6).

(b) Volume Growth Responses

Total volume production in thinned plots were greater than those of initially similar trees in the unthinned plots at all spacings (Figures 15 and 16). Plots thinned to closer spacings added more volume per hectare to trees that will be merchantable than did plots thinned to wider spacings (Figures 15 and 16).

10 Year Growth Responses at North Pond

North Pond is the only trial to be remeasured twice. All plots gained more volume during the second measurement period than during the first 5 years after thinning (Figure 17). Their level of occupancy in unthinned plots apparently increased during the past 10 years because volume growth per hectare was greater during the second measurement interval than during the first 5-year interval (Figure 17). The more widely spaced plots have performed slightly better than more closely spaced plots when comparing diameter growth (Figure 18). Thinning has not significantly increased the number of merchantable trees or the merchantable volume in the first 10 years after thinning (Figure 19).

DISCUSSION

Effects of Spacing

With early results of silvicultural trials it is important to reflect on how responses might change over time before drawing any conclusions. A stand characteristic of thinned plots that will change considerably during the next several years will be the extent to which the trees fully occupy the site. Thinning reduces occupancy, but the crowns and root systems of the remaining trees will expand to reoccupy the site. For the years that thinned stands do not fully occupy sites, their growth is limited in part by their inability to acquire all the light, water and nutrients that the site makes available. However, the crop trees grow faster than they would have without thinning because of the reduction in competition. Plots thinned to wider spacings have more free space than do plots thinned to narrower spacings, but trees in widely spaced plots grow to reoccupy the site at a faster rate. These differences between spacings in the reduction of occupancy and return to full occupancy will cause the temporal response in volume growth per hectare and growth rates of the individual trees to differ.

The potential for stand volume growth is less for stands that do not fully occupy the site than for those that acquire the maximal resources available from the site. During the first 5 years after thinning, plots thinned to wider spacing occupy the site less than unthinned plots and those thinned to closer spacings, resulting in less stand volume growth (Figures 5 and 6). This effect of thinning on production processes is temporary. Eventually trees in thinned plots will expand to fully reoccupy the site, and from that point stand growth will not be limited by the ability of the stand to acquire the light, water and nutrients available from the site. Plots thinned to closer spacings continue to access more of the resources available from the site until the more widely spaced plots fully reoccupy the sites. Therefore plots thinned to closer spacings

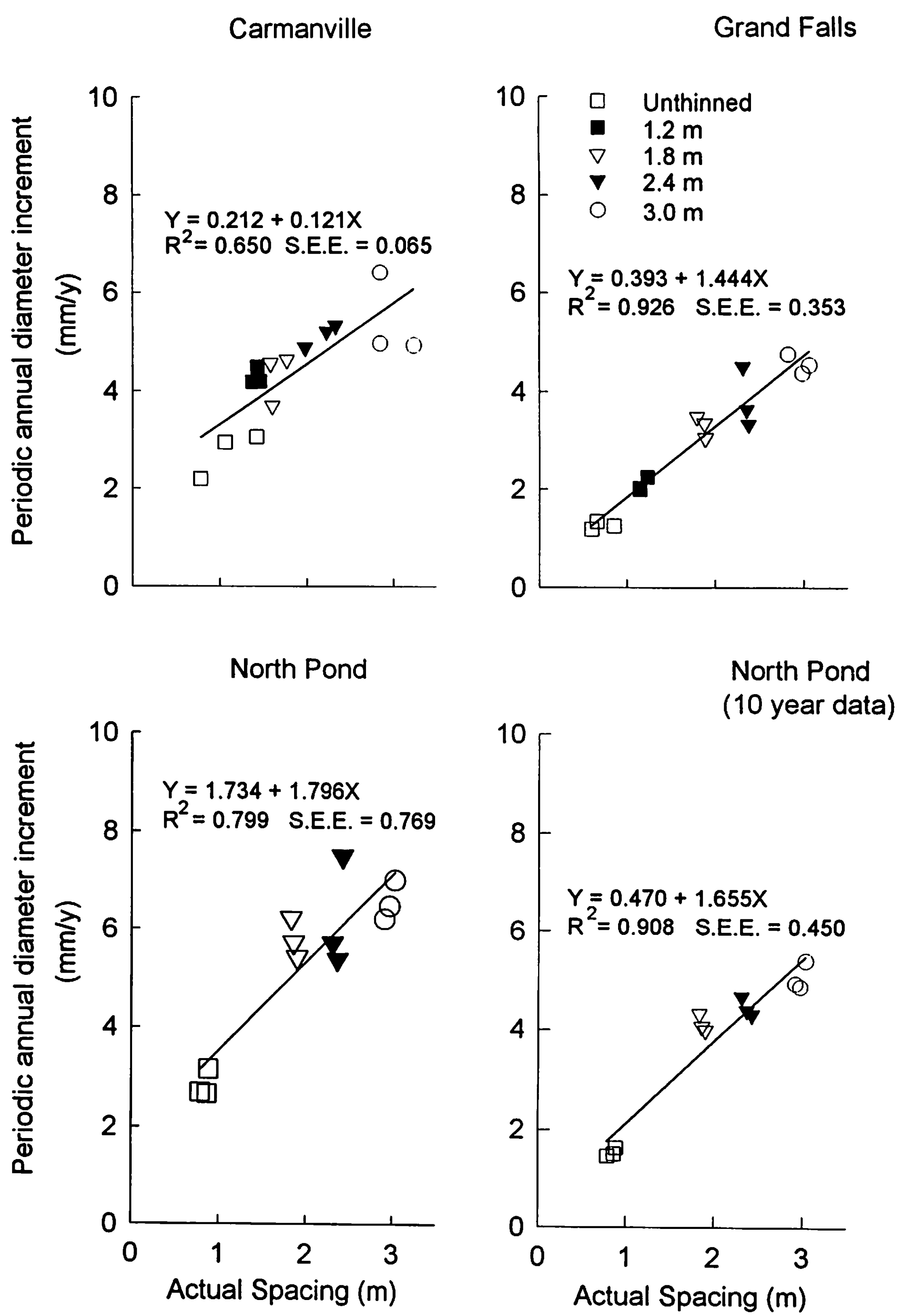


Fig. 12. Periodic annual mean tree diameter growth for thinned and unthinned plots of the black spruce spacing trials.

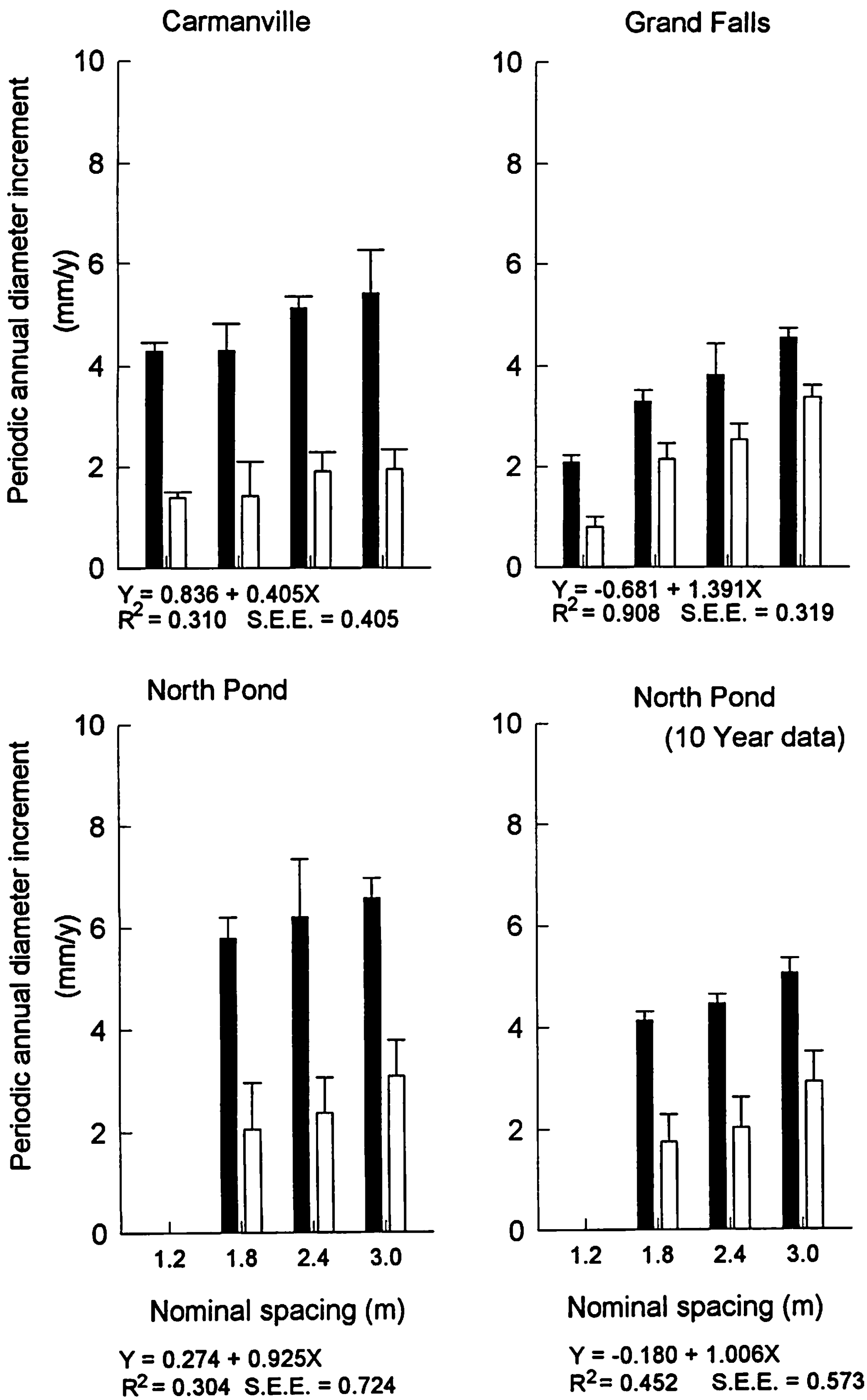


Fig. 13. Periodic mean tree diameter growth of thinned plots relative to periodic annual mean tree diameter growth of similar trees in the unthinned plots (white) and total diameter increment (black) for the black spruce spacing trials. Regression equations are given for the growth of similar trees in unthinned plots. Error bars are determined by the standard error.

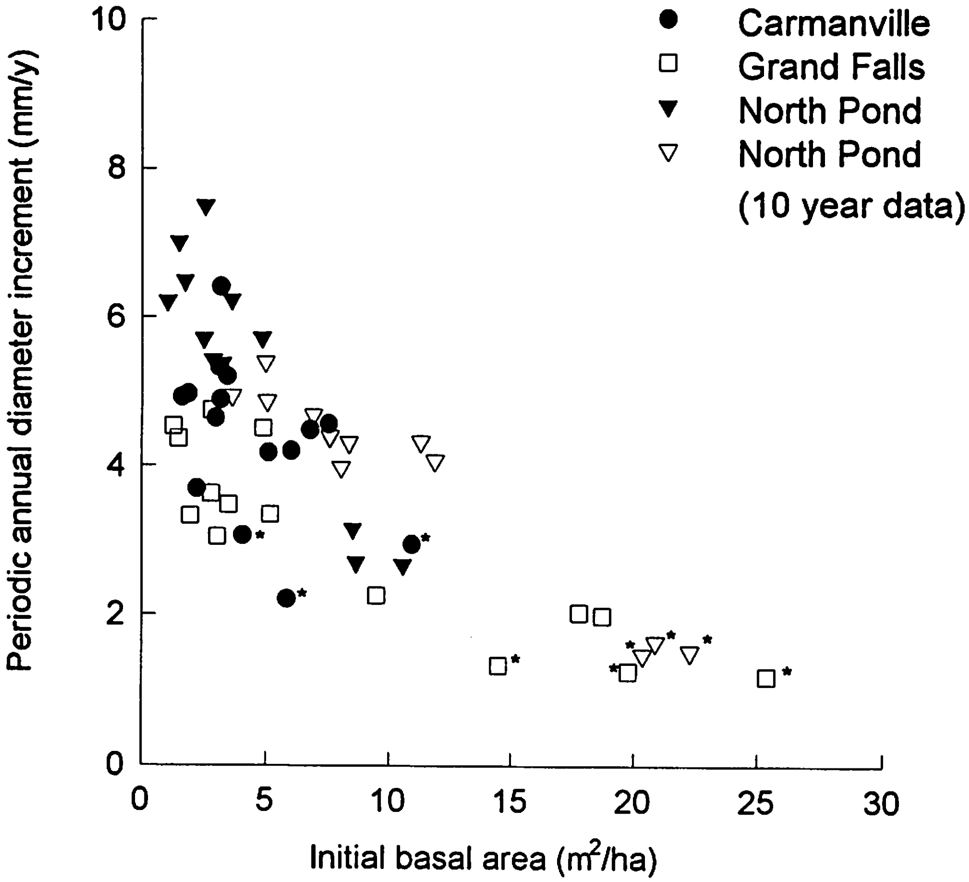


Fig. 14. Mean tree diameter growth versus initial basal area per hectare for thinned and unthinned plots of the black spruce spacing trials. The unthinned plots are denoted by asterisks.

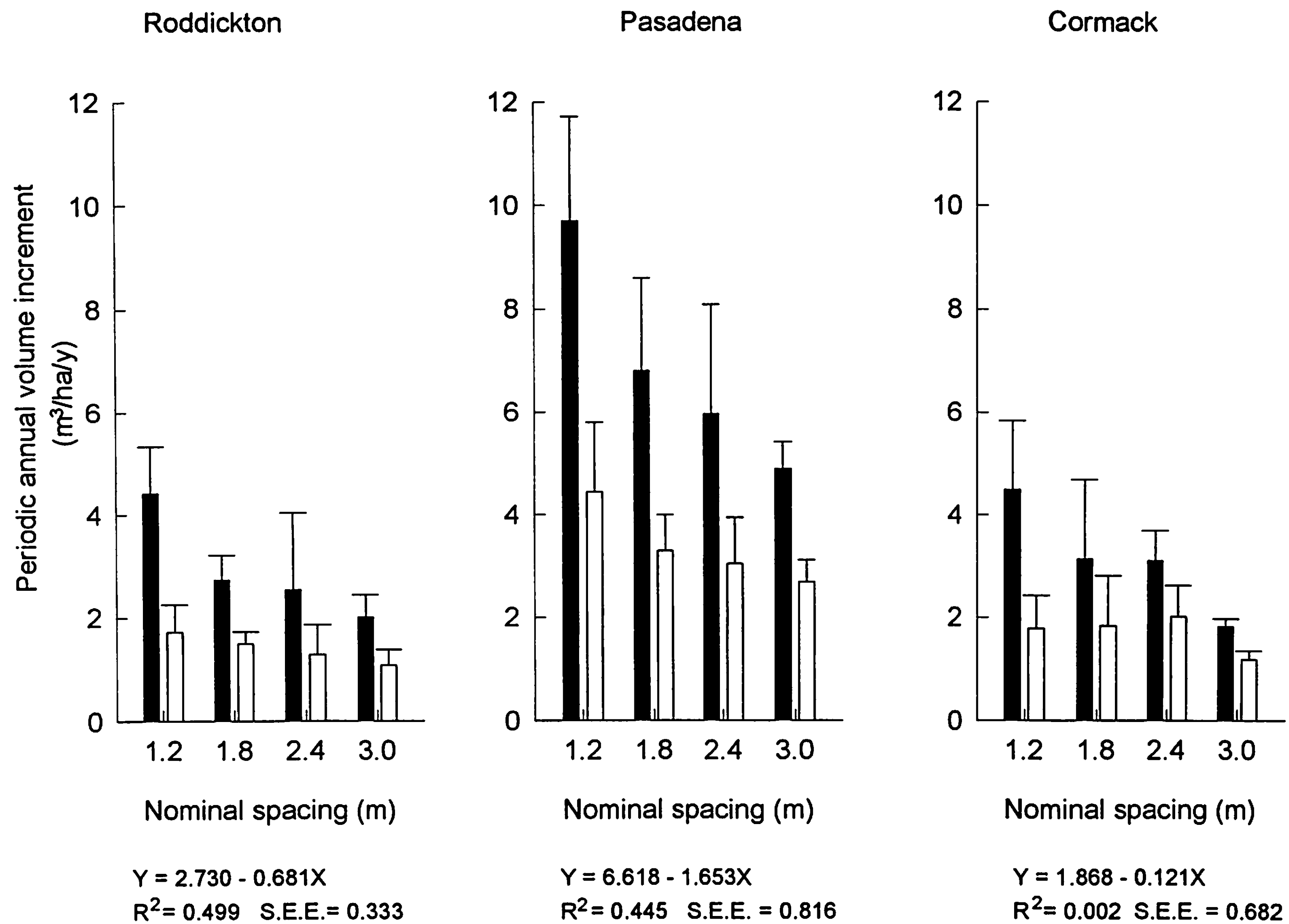


Fig. 15. Periodic annual total volume growth of thinned plots relative to periodic annual total volume growth of similar trees in unthinned plots (white) and total annual volume growth (black) for the balsam fir spacing trials. Regression equations are given for the growth of similar trees in unthinned plots. Error bars are determined by the standard error.

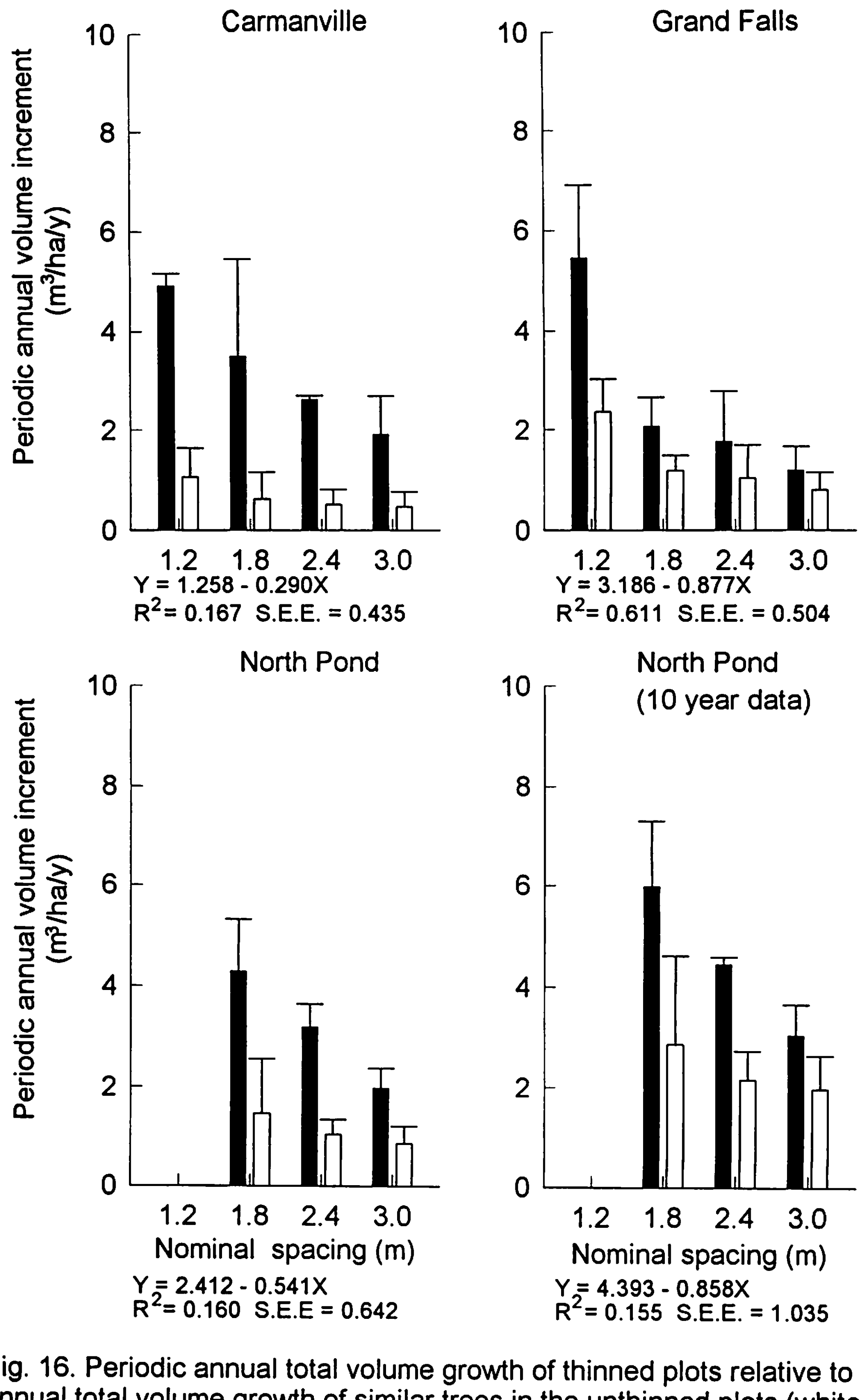


Fig. 16. Periodic annual total volume growth of thinned plots relative to periodic annual total volume growth of similar trees in the unthinned plots (white) and total annual volume growth (black) for the black spruce spacing trials. Regression equations are given for the growth of similar trees in unthinned plots. Error bars are determined by the standard error.

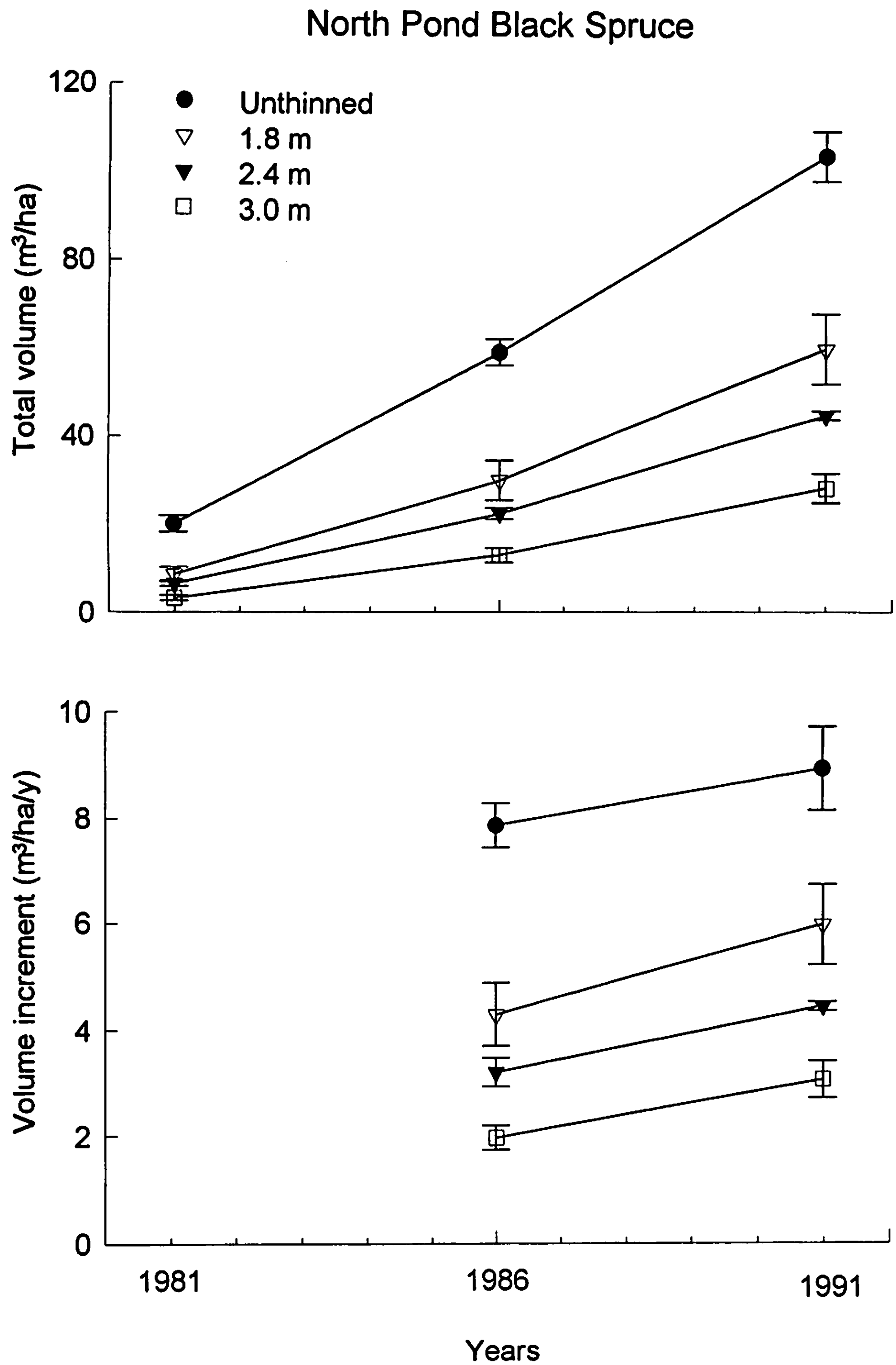


Fig. 17. Changes in (a) total volume per hectare and (b) periodic annual total volume growth in thinned and unthinned plots of the North Pond black spruce spacing trial. Data points for growth increments are shown at the end of each 5-year growth period. Error bars are determined by the standard error.

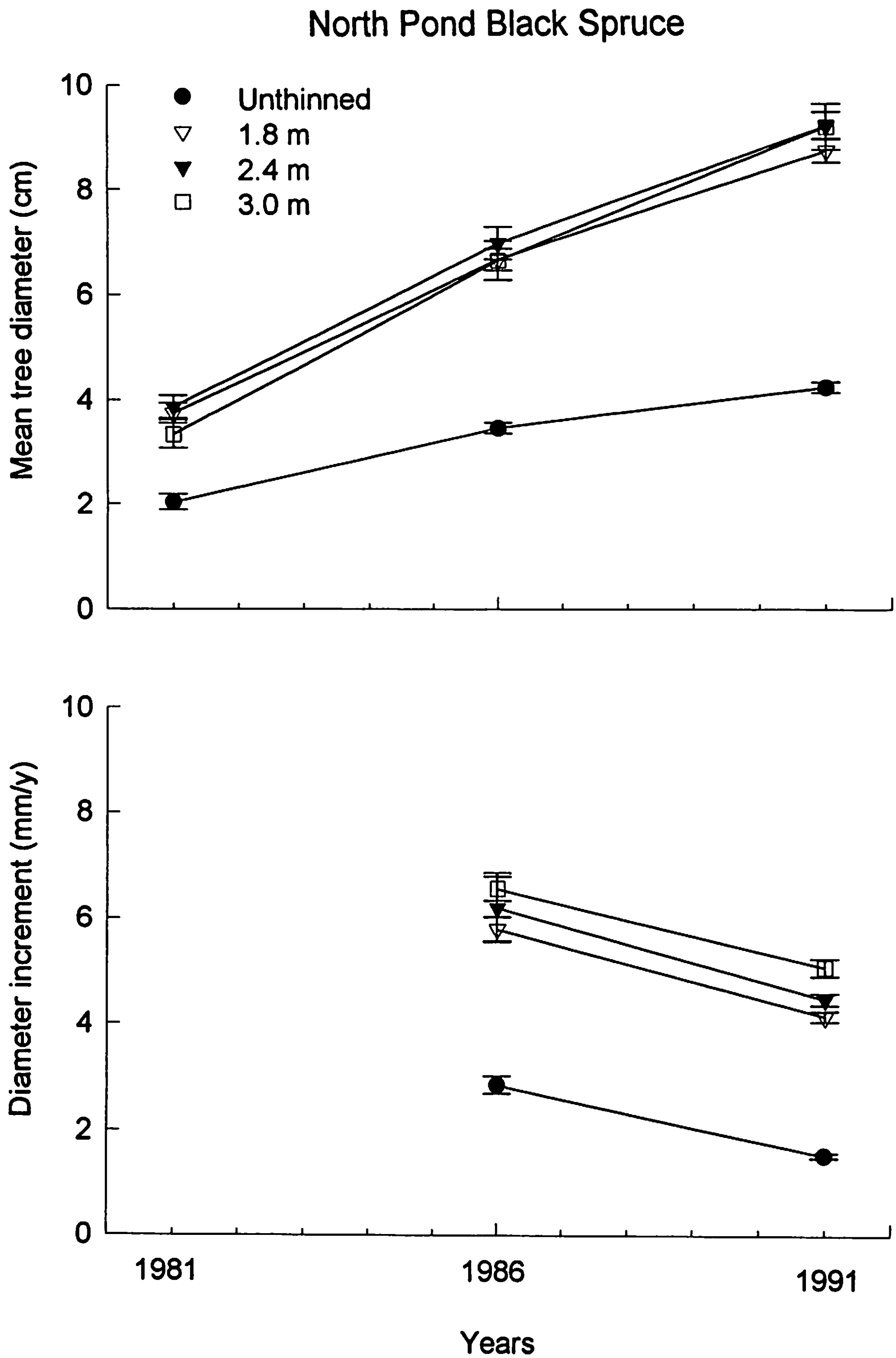


Fig. 18. Changes in (a) mean tree diameter and (b) periodic annual mean diameter growth in thinned and unthinned plots of the North Pond black spruce spacing trial. Data points for growth increments are shown at the end of each 5-year growth period. Error bars are determined by the standard error.

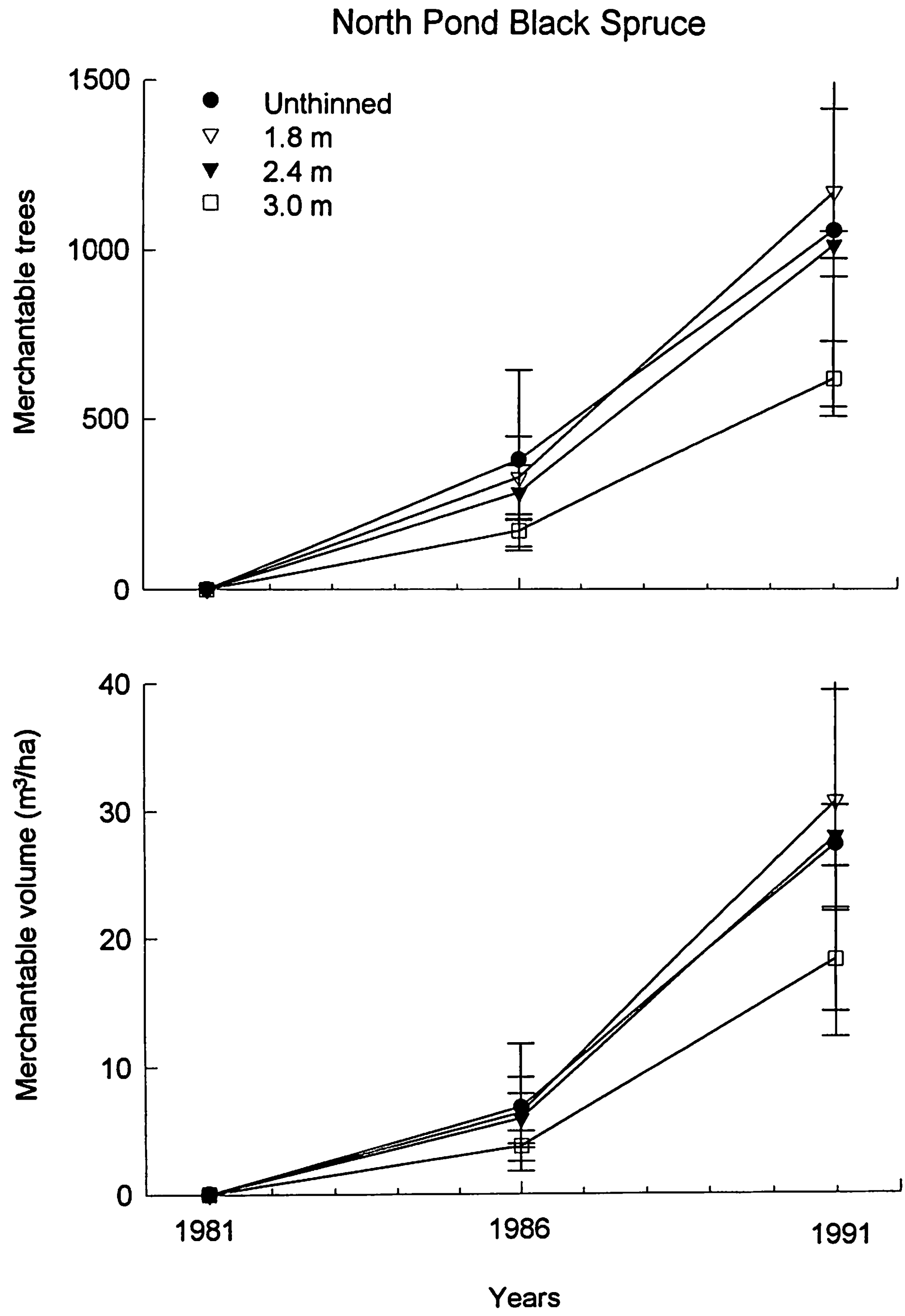


Fig. 19. Changes in (a) number of merchantable trees per hectare and (b) total merchantable volume per hectare in thinned and unthinned plots of the North Pond black spruce spacing trial. Error bars are determined by the standard error.

will probably maintain higher growth rates than plots thinned to wider spacings for some additional time.

An important question is the length of time that differences in potential growth will persist between plots thinned to close spacings and those thinned to wider spacings. Our results showed that doubling the spacing reduced per hectare growth by less than 50 % (Figure 5) and increased tree growth rates by more than 25% (Figure 9), indicating that initial rates of reoccupancy were greatest in the more widely spaced plots. Therefore, we expect widely spaced plots to lag the closely spaced plots in terms of occupancy by approximately 5 years rather than taking twice as long.

As expected, in plots with lower levels of occupancy we observed higher growth rates by individual trees (Figures 9 and 12), because lower levels of occupancy implies less competition from neighbours. This effect of thinning will continue even after stands have regained full occupancy. When the widely spaced plots return to full occupancy, they will acquire approximately the same amount of light, water and nutrients as will be acquired by the more closely spaced plots, but these resources will be shared by fewer trees. Therefore, the same potential for growth will be shared by fewer trees in the wider spaced plots.

Some acquired resources are used to replace shed foliage and fine roots that have died, or are used to maintain the life of existing, living biomass. The total of these drains on potential growth become greater with increasing tree size and total standing biomass. Therefore, even as thinned plots regain full occupancy not all of the increased potential growth is converted into actual growth. Moreover, after full occupancy is achieved actual growth declines because an increasing proportion of potential growth is used to maintain the existing biomass. One example of this aspect of production can be seen by comparing growth of unthinned plots having different basal areas. Unthinned plots fully occupy the site, and therefore those growing on the same site type have equal potential growth. Those plots having greater basal area do not grow as much as those having less basal area (Figures 11 and 14) because those having more basal area use more potential growth to maintain the existing stand volume. Widely spaced plots will use less of their potential growth for maintenance than do closely spaced plots for the remainder of stand development because their standing total biomass will be less than that of the closely spaced plots.

When a tree passes the merchantability threshold some of the volume produced in previous years gains value. As the tree continues to grow, additional amounts of volume produced in earlier years become merchantable, and a smaller proportion of total tree volume is found in stumps and unmerchantable tops. Therefore, the proportion of total volume that is merchantable depends on the fraction of trees exceeding the merchantability threshold, and the size of merchantable trees. These determinants of the merchantability factor are affected by intertree spacing. Trees in widely spaced plots become merchantable earlier than trees in closely spaced plots. Therefore, merchantable volume should have appeared somewhat earlier in the widely spaced plots. However, it is probable that merchantable volume will accumulate most rapidly in the more closely spaced plots because at these spacings so many more trees will become merchantable at an early age as to more than compensate for their smaller size. Subsequently, some more widely spaced treatments may increase in merchantable volume beyond the levels of the more closely spaced plots because total volume will be tending to converge on the same asymptotic value, and the more widely spaced plots will have higher merchantability factors.

Comparison of Trials

Growth rates at Roddickton were much lower than plots with similar initial basal areas at other balsam fir locations, possibly because of its less productive climate. Climatic conditions on the Northern Peninsular are rigorous, and exposure to fog and wind may be factors serving to limit growth of trees (Rowe 1972). For example, the estimated site index at 50 years given in Meades and Moores (1989) is 7.9 m compared to 15.2 m in the Roddickton and Pasadena regions, respectively. Soil and climate conditions are more favourable in southwestern Newfoundland where the Cormack and Pasadena trials are located. Soil fertility is lower in the Roddickton region and crop trees on that site have an estimated volume of 168.2 m^3/ha compared to 209.0 m^3/ha for the Pasadena region (Meades and Moores 1989). Cormack and Pasadena are in the same ecoregion and had similar growth - basal area relationships (Figure 7). Therefore, it would appear that the current growth of plots of similar initial basal area is dominated by site effects.

Unthinned plots at Cormack had similar growth rates as Pasadena but thinned plots at Cormack were similar to Roddickton. Cormack is on a poorer site than Pasadena (Meades and Moores 1989). Also, unthinned trials at Cormack had almost twice the initial density of the other balsam fir sites (e.g. 61 964 versus 35 438 trees/ha, respectively). The relatively large difference in volume growth between the unthinned plots and the 1.2 m spaced plots at Cormack (Figure 5) reflects these large differences in initial densities. Hence, the effects of stand structural attributes on growth can mask effects of site quality on growth.

Volume growth rates were much greater at North Pond than at Grand Falls and Grand Falls had less growth at any initial basal area and North Pond had the most. The North Pond site is more fertile and moister than the Grand Falls site (Meades and Moores 1989). Grand Falls had higher residual densities than the other spruce sites and this also contributed to observed lower growth rates. Grand Falls had greater initial basal area and more total volume than the other spruce sites because of its greater initial density and age and in spite of growing on a poorer site. This illustrates, once again, that stand structural attributes can mask effects of site quality on growth rates.

The most productive site of each species, Pasadena and North Pond, showed the greatest changes in diameter frequency distributions. Prior to thinning, the distributions were positively skewed because of the large numbers of small trees. After thinning, diameter distributions became negatively skewed and numbers of trees appeared in larger diameter classes not previously represented.

Carmanville was unusual because the initial values of its shape parameter at the widest spacing was less than at the unthinned plots. This is presumably because of inadequate spacing at Carmanville. For example, there were 30 to 50% more crop trees in the smallest diameter class at the 3.0 m spacing than in plots thinned to closer spacings, resulting in lower shape parameter values for the 3.0 m spaced plots. Also, there was an average of 4 trees in the smallest diameter class at the other black spruce trials compared to an average of 15 trees at Carmanville. Thinning did not substantially reduce the annual volume growth per hectare at Carmanville possibly because of the large number of small trees that remained after thinning.

Black Spruce Responses to Thinning

All of the black spruce trials responded to thinning. When black spruce is growing on sites of comparable productivity to the balsam fir trials, as at North Pond, the growth responses to thinning are comparable. When black spruce is growing on poor sites, growth of thinned plots is less than that of thinned balsam fir plots. When unthinned densities are extremely high, such as those found at Grand Falls, thinning of black spruce on poor sites appears necessary to obtain a merchantable stand at all (Table 10).

CONCLUSIONS

Growth responses during the first 5 to 10 years after thinning have been described. No attempt was made to draw conclusions about optimal spacing or to forecast final yields. Linear trends were observed between actual spacing and most growth response variables, indicating that an optimal spacing was not apparent from early growth responses. However, tradeoffs between lost occupancy and increased growth per tree for the production of merchantable wood should manifest themselves in the near future at these spacing trials.

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