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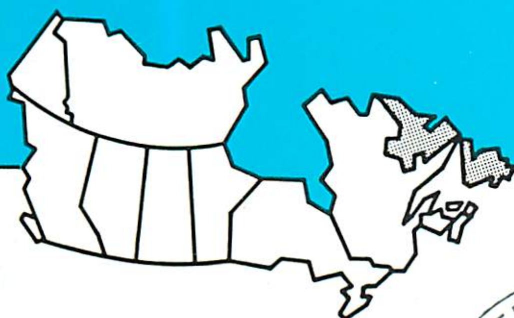
Early results of a spacing trial in a precommercially thinned balsam fir stand in western Newfoundland

M.B. Lavigne and J.G. Donnelly



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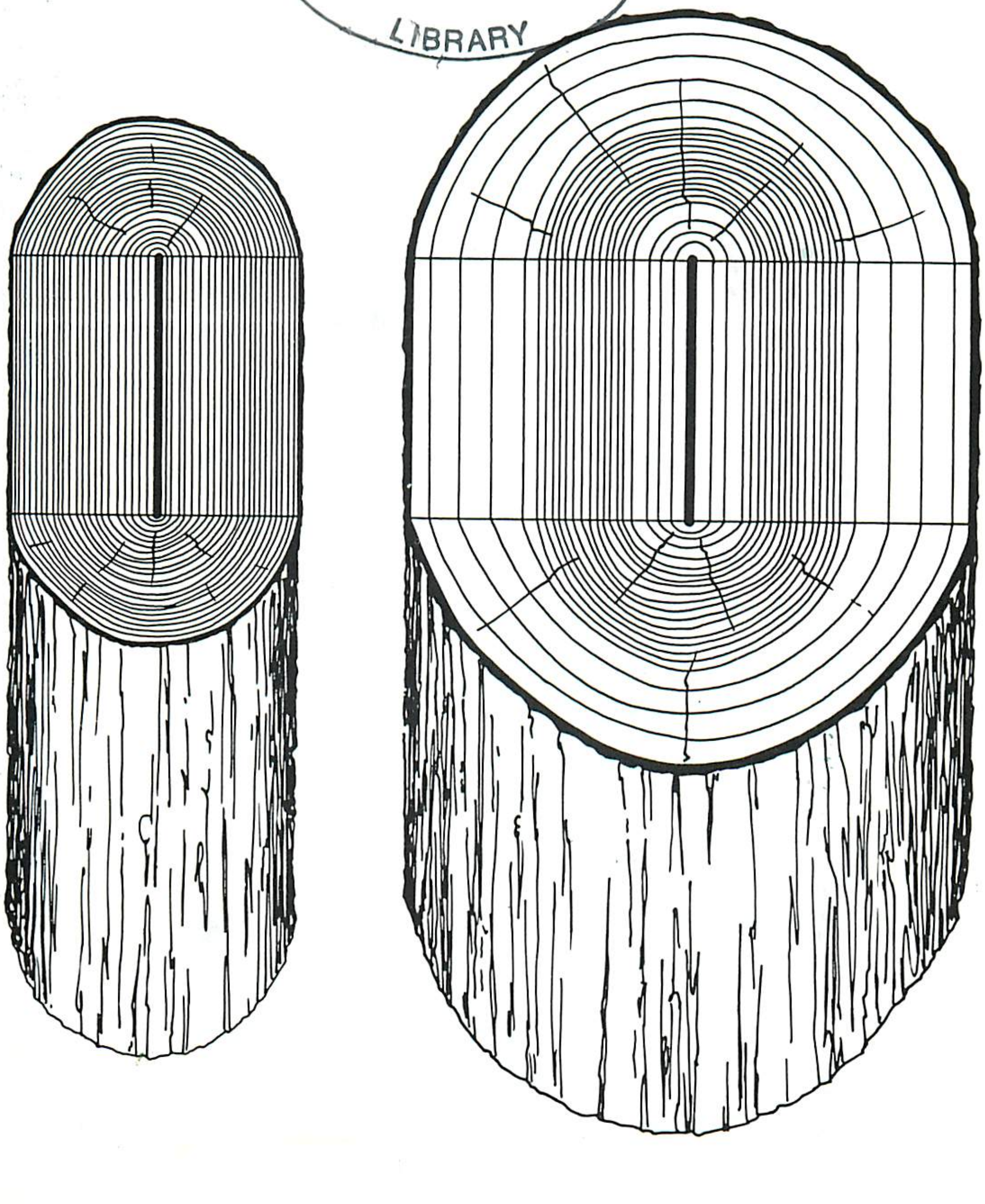

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by
M.B. Lavigne
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Abstract

Plots thinned to close spacing in a young balsam fir stand in western Newfoundland produced up to 3 times more total stemwood than did plots thinned to wide spacings during the first 5 years after treatments were applied. Growth per tree of large trees was up to 2 times greater at wide spacings than at close spacings. This difference between spacings is expected to continue after stands completely reoccupy the site. Thinning changed the competitive relationships within plots. Small trees responded more to thinning than did large trees. This effect of thinning is expected to continue until stands fully reoccupy sites; therefore, it will last longer in widely spaced plots than in closely spaced plots. Fertilization does not appear to have increased growth when applied in combination with thinning.

Résumé

Dan l'ouest de Terre-Neuve, des parcelles d'un jeune peuplement de sapin baumier éclaircies en espacements serrés ont produit trois fois plus de bois de fût que d'autres parcelles éclaircies de façon plus clairsemée au cours des cinq années suivent le traitement. Individuellement, les gros arbres des peuplements clairsemés ont poussé deux fois plus vite que ceux des peuplements serrés. Cet écart entre les types d'espacement devrait se maintenir aprés que les peuplements aient complètement réoccupé les parcelles. L'éclaircie a changé les rapports de compétition dans les parcelles. Les petits arbres ont mieux réagi que les grands à cette opération, dont les effets devraient se poursuivre jusqu'à ce que les peuplements réoccupent les parcelles complètement; par conséquent, ces effets seront plus durables dans les parcelles à peuplement clairsemé que dans celles à peuplement serré. Appliquée de concert avec l'éclaircie, la fertilisation ne paraît pas avoir accéléré la croissance des peuplements touchés.

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Early Results of a Spacing Trial in a Precommercially Thinned Balsam Fir Stand in Western Newfoundland

by

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Introduction

Precommercial thinning of young balsam fir (*Abies balsamea* (L.) Mill) stands is a common practice in eastern Canada, however, accurate predictions of the gains in yield have not been produced yet. Measurements of early responses, made by Piene (1981) and informally here in Newfoundland, have found that tree growth increases substantially, but data that describes later growth in thinned stands is not available. Thinning always involves trading off complete occupancy by the stand for increased growth per tree, but no data are available to show which spacing strikes the best balance in balsam fir stands. Spacing trials were established in precommercially thinned stands in Newfoundland to address these needs. Lavigne et al. (1987) reported on the first remeasurement of a spacing trial in a black spruce stand. The results of the fifth year remeasurement for the first trial in a balsam fir stand are presented in this report.

Effects of thinning on final yields and optimal spacing cannot be determined from the first remeasurement of a spacing trial. Nevertheless, something can be learned of the site and stand factors controlling tree growth by analyzing early remeasurements. This knowledge can be used to consider trends for the future. Growth rates during the first 5 years after thinning were used to examine the trade-off between site occupancy and growth per tree.

Materials and Methods

Study Site

The spacing trial is located near Sir Richard Squires Provincial Park, in western Newfoundland (49°02′ N, 57°08′ W), within Rowe's (1972) Forest Section B28b. The site was rated at capability class 5 by the Canada Land Inventory, and as a good site by the provincial forest management inventory.

The previous stand was harvested in 1962. A dense stand of balsam fir, white spruce and white birch developed after the clearcut. Prior to thinning the stand contained approximately 60 000 stems per hectare.

Experimental Design

Five spacings are being compared: unthinned, 1.2 m, 1.8 m, 2.4 m, and 3.0 m. In addition, fertilization with urea at a rate of 200 kg/ha of N, in combination with spacing to 2.4 m is being tested. The experiment is laid out as three adjacent randomized complete blocks. Each treatment plot and control plot is 0.25 ha. A permanent sample plot is located within each treatment plot. Sizes of permanent sample plots differ among the treatments so that there are approximately 100 trees per plot.

Employees of Corner Brook Pulp and Paper Ltd. spaced the treatment plots during the summer of 1982. Fertilizer was applied manually in the spring of 1984, prior to the growing season. The initial measurements of total height (H) and breast-height diameter (D) were made in August 1982. All trees were tagged when measured for the first time. The D and H of trees in permanent sample plots were remeasured in October and November 1987.

Stem Analysis

Thirty-five trees were cut from the treatment plots during the autumn of 1987 for measurements of biomass and for stem analysis. A total of ten trees were collected from the control plots, and a total of 5 trees were harvested from the treatment plots representing each spacing. The trees representing each treatment were chosen to cover the full range of diameters found in those plots. Fresh weights of stems were measured shortly after the trees were cut. Discs were cut from the middle of each internode for stem analysis, and additional discs were collected for determining oven-dried weights of stems. Equations for estimating the stem volume, stem weight and stem surface area from D and H were fitted to this data.

Statistical Analyses

All statistical analyses were done by using SAS (SAS Institute Inc. 1985). The effects of treatment on stand structure and growth were assessed by analysis of variance. The data for individual trees were used when mean tree attributes were being assessed. For these analyses each tree was a sample, hence the number of samples per plot was large but not the same for all plots. The plot itself was a sample when per hectare values were compared. Consequently, it was possible to test for interactions between block and treatment when analyzing mean tree attributes, but not when analyzing plot attributes. Student-Newman-Keuls multiple comparison tests were used to compare the means of treatments.

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

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

where

N_i = number of trees in diameter class D_i

D_i = diameter class i

b, c = parameters

This form of the Weibull function requires that values of the minimum diameter class be subtracted from actual diameter classes to determine values of D_i. In these calculations the minimum diameter was 0 for all plots, so D_i equalled the actual diameter class. Bailey and Dell (1973) described the parameter b as the scale parameter, and showed that it equalled the diameter class of the trees of the sixty third percentile. The parameter c is referred to as the shape parameter since the value it takes describes whether the distribution is positively or negatively skewed (Bailey and Dell 1973).

Estimates of parameter values of the Weibull function for each plot and changes in these values during the growth interval were compared by analysis of variance. Treatment means were compared by using Student-Newman-Keuls multiple comparison tests.

Results

Stem Analysis

The equation for estimating stem volumes in permanent sample plots was

$$[1] \quad V = 0.035816 \times D^2H$$

where

V = stem volume, dm^3

This equation was suitable for all treatments (Figure 1). The parameter was estimated by ordinary least squares using the GLM procedure of SAS (SAS Institute Inc. 1985). Fit statistics were estimated by fitting an equation identical to Equation 1, except that it had an intercept term. The fit to the data was close ($r^2 \simeq 0.96$, $s^2 \simeq 14.89$).

Estimates of oven-dried stem weights in permanent sample plots were made with the following equation.

$$[2] \quad W = 0.0983 + 0.01705 \times D^2H - 0.0048839 \times MAX(D^2H-232.19,0)$$

where

W = oven-dried stem weight, kg

MAX = a Fortran function that chooses the largest value from a pair of arguments.

Equation 2 accurately estimated stem weights of all treatments (Figure 1). The parameters of Equation 2 were estimated by nonlinear regression using the NLIN procedure of SAS (SAS Institute Inc. 1985). Fit statistics can be calculated when estimating parameters by nonlinear regression but the values are approximate. Equation 2 fit the data closely ($r^2 \simeq 0.99$, $s^2 \simeq 0.72$).

Stem surface areas were estimated by using the following equation.

$$[3] \quad S = 5.0 + 0.3624 \times D^2H - 0.2455 \times MAX(D^2H-145.73,0)$$

where

S = stem surface area, dm^2

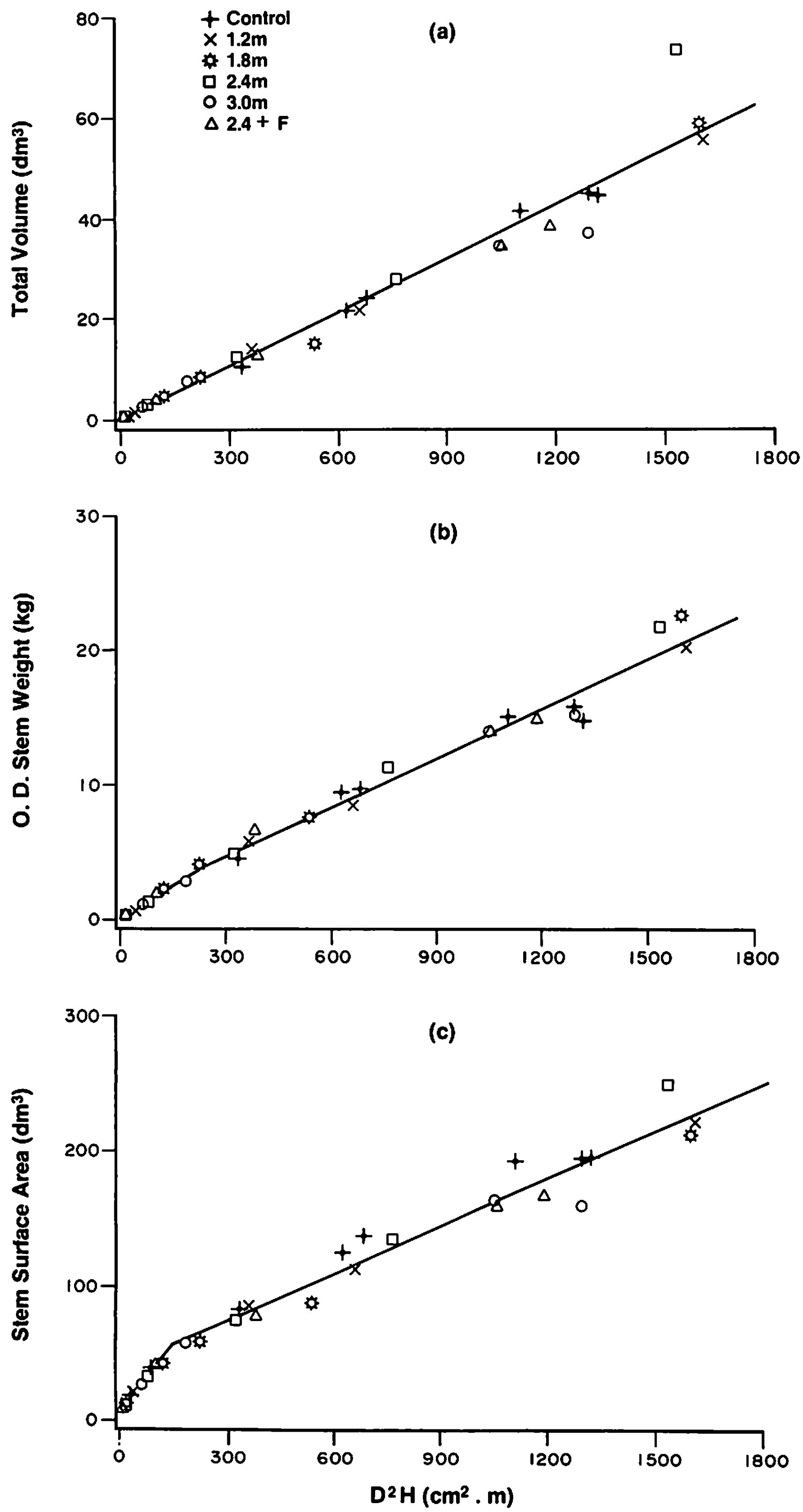

Figure 1. Tree volumes (a), oven-dried stem weights (b) and stem surface areas (c) of samples collected in spaced, fertilized and unthinned plots, of the spacing trial in a balsam fir stand near Cormack in western Newfoundland, and lines used for estimating these attributes for trees in permanent sample plots.

The parameters of Equation 3 were estimated by nonlinear regression using the NLIN procedure of SAS (SAS Institute Inc. 1985). The fit to data was close ($r^2 \approx 0.99$, $s^2 \approx 120.47$) as can be seen in Figure 1.

Stand Structure Immediately After Thinning

The means of D, H, V and W of thinned plots were greater than those of unthinned plots immediately after thinning (Table 1). The order of treatments according to these mean tree attributes was not what was expected because the values for the 3.0 m spacing were less than for the 2.4 m spacings. Thinning did not substantially reduce the ranges of D and H since minimum values in thinned plots were not much greater than those in unthinned plots. Some differences between plots were found in the ranges of D and H, which probably resulted from differences in stand density or species composition prior to thinning. The maximum D of plots thinned to 1.2 m and 1.8 m were substantially less than those of other plots.

In contrast to mean tree attributes, the volume/ha and stem weight/ha of thinned plots were significantly less than those of unthinned plots (Table 1). The position of the 2.4+F treatment in the ranking of treatments was higher than expected.

Thinning reduced the positive skew of the diameter class frequency distribution (Figure 2). The extent to which frequency distributions differed among treatments can be evaluated by comparing parameters of the Weibull distribution. The shape parameters (c for 1982 in Figure 2) of the unthinned plots were significantly ($P \geq 0.0009$) lower than those of thinned plots. A lower value of the shape parameter implies that the frequency distribution of D was more positively skewed. The values of the shape parameter were not statistically different among thinned plots but those of the 2.4+F and 1.8 m treatments were substantially higher than those of the 3.0 m spacing. This difference indicates that a greater proportion of trees were in larger diameter classes in the 2.4+F and 1.8 m treatments than the 3.0 m spacing. The differences between plots probably were the result of differences in stand density or hardwood content prior to thinning. The scale parameter (b for 1982 in Figure 2) differed significantly ($P \geq 0.0001$) among treatments. Moreover, the order of treatments, from largest to smallest, was widely spaced, closely spaced and unthinned, with the exception that the 3.0 m spacing was less than the 2.4 m spacings. This order was the same as the order of mean D (Table 1). Since the scale parameter estimates the diameter of the tree that is at the sixty-third percentile a correspondence between mean D and the scale parameter was logical.

Stemwood Production Rates per Hectare

Gross growth/ha (stem increment by surviving trees plus ingrowth) and net growth/ha (gross growth minus mortality) of unthinnned plots were significantly greater than those of thinned plots (Table 2). The greatest growth was made by the fertilized plots. Because variations of growth rates among plots with the same spacing were large (Figure 3), differences between spacings were not statistically significant (Table 2). Much of the variation within treatment was due to the comparatively low growth rates by the 1.2 m and 1.8 m spacings in blocks 2 and 3 (Figure 3).

Large mortality losses occurred in unthinned plots (Table 2, Figure 2). Much of the mortality in unthinned plots occurred among trees in the smallest size classes, hence it probably was caused by density stress. Some trees died in all treated plots, however, the losses were substantial only in 2 plots of the 1.2 m spacing. Density-dependent mortality was not expected in the thinned plots and trees dying in these plots were not predominantly from the smallest size classes.

Moose browsed a large proportion of the trees in thinned plots especially those thinned to wider spacings (Table 3). Physical damage caused by snow, wind or done during thinning was more common in plots thinned to closer spacings and in the unthinned plots than in plots thinned to wider spacing (Table 3). The total of mortality and damage varied greatly among plots, without any apparent relationship to spacing.

Mean Tree Growth

Thinning significantly increased mean tree growth rates (Table 4, Figure 4). Mean tree growth rate by

Table 1. Plot parameters immediately after thinning in 1982.

nominal spacing	block	stems/ ha	actual spacing	mean D	min D	max D	mean H	min H	max H	mean vol	min vol	max vol	mean wt	min wt	max wt	vol/ ha	stem wt/ha
m^2		x1000	m^2	cm			m			dm^3			kg				
cont	1	50.70	0.44	2.04	0.10	9.66	2.68	1.33	8.69	0.89	0.0005	29.04	0.50	0.10	11.10	45.19	25.56
cont	2	61.70	0.40	2.19	0.17	9.00	3.12	1.30	7.49	1.02	0.0014	17.26	0.58	0.10	7.10	62.82	35.46
cont	3	66.70	0.39	2.08	0.15	11.00	2.85	1.35	9.90	1.00	0.0011	42.90	0.54	0.10	15.81	66.66	36.19
1.2	1	6.74	1.22	3.16	0.63	6.80	3.14	1.50	4.97	1.58	0.0213	8.23	0.85	0.11	4.02	10.64	5.73
1.2	2	7.30	1.17	2.87	0.39	7.76	2.85	1.43	4.90	1.21	0.0078	9.17	0.67	0.10	4.35	8.86	4.93
1.2	3	7.23	1.18	3.30	0.84	7.71	3.04	1.57	7.72	1.84	0.0397	16.44	0.95	0.12	6.82	13.29	6.90
1.8	1	3.46	1.70	4.11	0.31	8.12	3.62	1.40	5.87	2.84	0.0048	12.75	1.44	0.10	5.56	9.83	4.98
1.8	2	2.69	1.93	3.43	1.20	6.69	2.99	1.26	5.14	1.64	0.0928	8.24	0.88	0.14	4.02	4.41	2.36
1.8	3	3.49	1.69	3.07	0.32	7.40	2.94	1.41	7.07	1.42	0.0052	13.06	0.76	0.10	5.67	4.95	2.66
2.4	1	1.68	2.44	4.50	1.08	10.57	4.16	1.68	7.59	4.29	0.0702	30.37	2.04	0.13	11.55	7.20	3.43
2.4	2	1.47	2.61	3.83	0.45	7.77	3.57	1.42	6.56	2.75	0.0103	12.18	1.39	0.10	5.37	4.04	2.04
2.4	3	1.57	2.52	4.37	0.38	11.16	4.09	1.31	6.65	3.78	0.0068	29.66	1.81	0.10	11.31	5.95	2.85
3.0	1	1.21	2.87	3.84	0.43	9.08	3.31	1.41	6.82	2.71	0.0093	19.92	1.35	0.10	7.99	3.29	1.64
3.0	2	1.21	2.87	4.12	0.79	10.00	3.74	1.56	7.09	3.19	0.0349	25.00	1.56	0.11	9.72	3.88	1.89
3.0	3	1.16	2.94	3.87	0.60	8.38	3.38	1.62	6.06	2.43	0.0224	14.06	1.24	0.11	6.01	2.82	1.44
2.4+F	1	1.73	2.40	5.42	0.90	11.99	5.21	1.78	8.71	7.16	0.0516	42.48	3.21	0.12	15.66	12.37	5.55
2.4+F	2	1.47	2.61	3.89	1.43	7.47	3.44	1.53	5.42	2.40	0.1370	9.33	1.24	0.16	4.40	3.52	1.82
2.4+F	3	1.55	2.54	4.62	0.78	9.61	4.15	1.52	8.19	4.75	0.0338	25.32	2.21	0.11	9.83	7.38	3.43

ANOVA (P values)

	mean D	mean H	mean vol	mean wt	vol/ ha	stem wt/ha
Block	0.02	.04	0.02	0.01	0.78	0.79
Treatment	0.00001	.00001	0.00001	0.00001	0.0001	0.0001
Treatment x Block	0.0001	.0001	0.0001	0.0001		

STUDENT-NEWMAN-KEULS MULTIPLE COMPARISON TESTS

mean D	mean H	mean vol	mean wt	vol/ ha	stem wt/ha
2.4+F a	2.4+F a	2.4+F a	2.4+F a	cont a	cont a
2.4 b	2.4 b	2.4 b	2.4 b	1.2 b	1.2 b
3.0 b	3.0 c	3.0 c	3.0 c	2.4+F b	2.4+F b
1.8 c	1.8 c	1.8 c	1.8 c	1.8 b	1.8 b
1.2 d	1.2 c	1.2 c d	1.2 c d	2.4 b	2.4 b
cont e	cont c	cont d	cont d	3.0 b	3.0 b

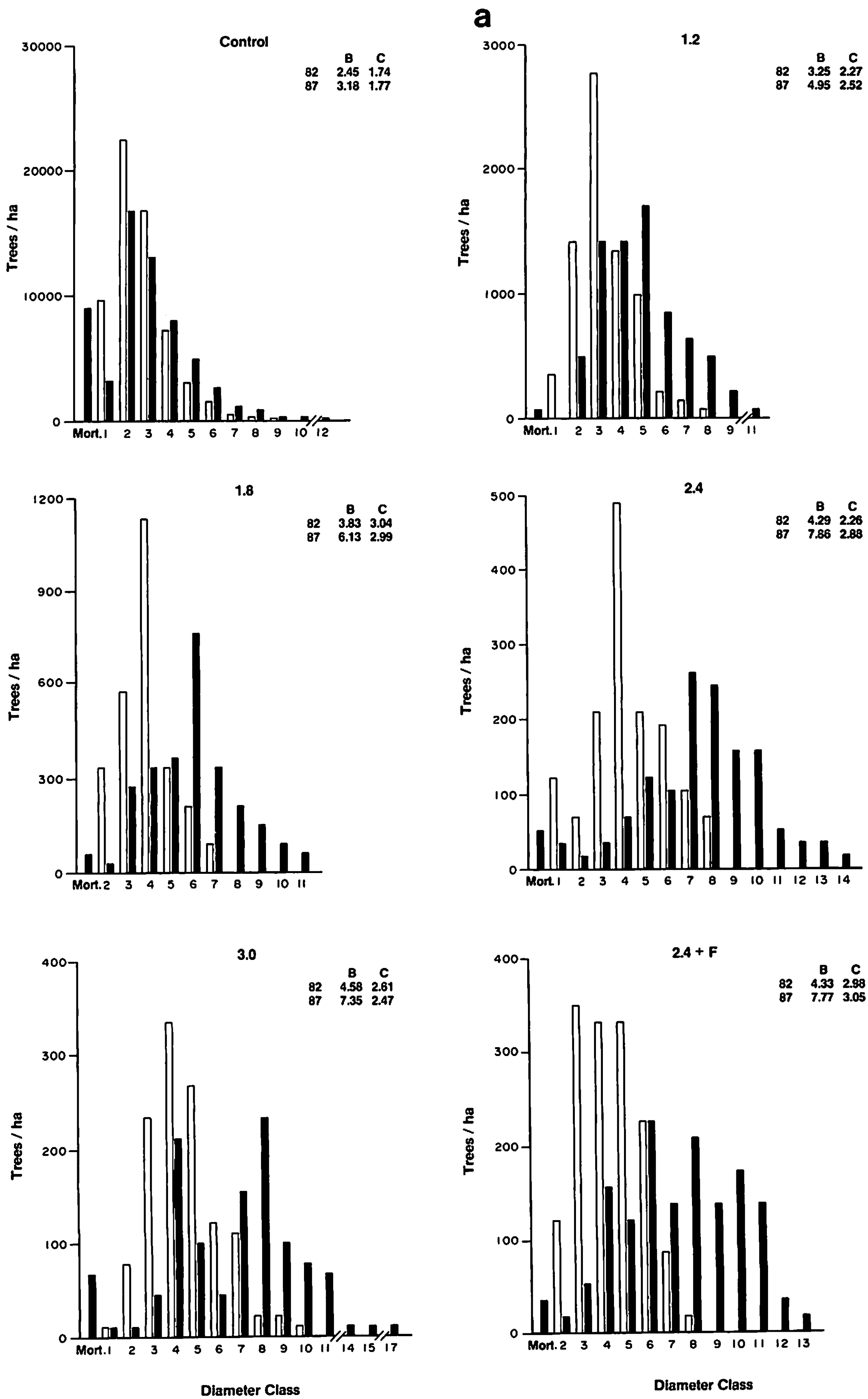

Figure 2. Histograms showing the frequency distribution of trees among diameter classes shortly after thinning (open bars) and 5 years after thinning (solid bars) of spaced, fertilized, and unthinned plots of the spacing trial in a balsam fir stand near Cormack in western Newfoundland. Block 1 (a), Block 2 (b) and Block 3 (c). Parameters of the Weibull distribution for the initial measurement and the remeasurement of the plot are reported with each histogram.

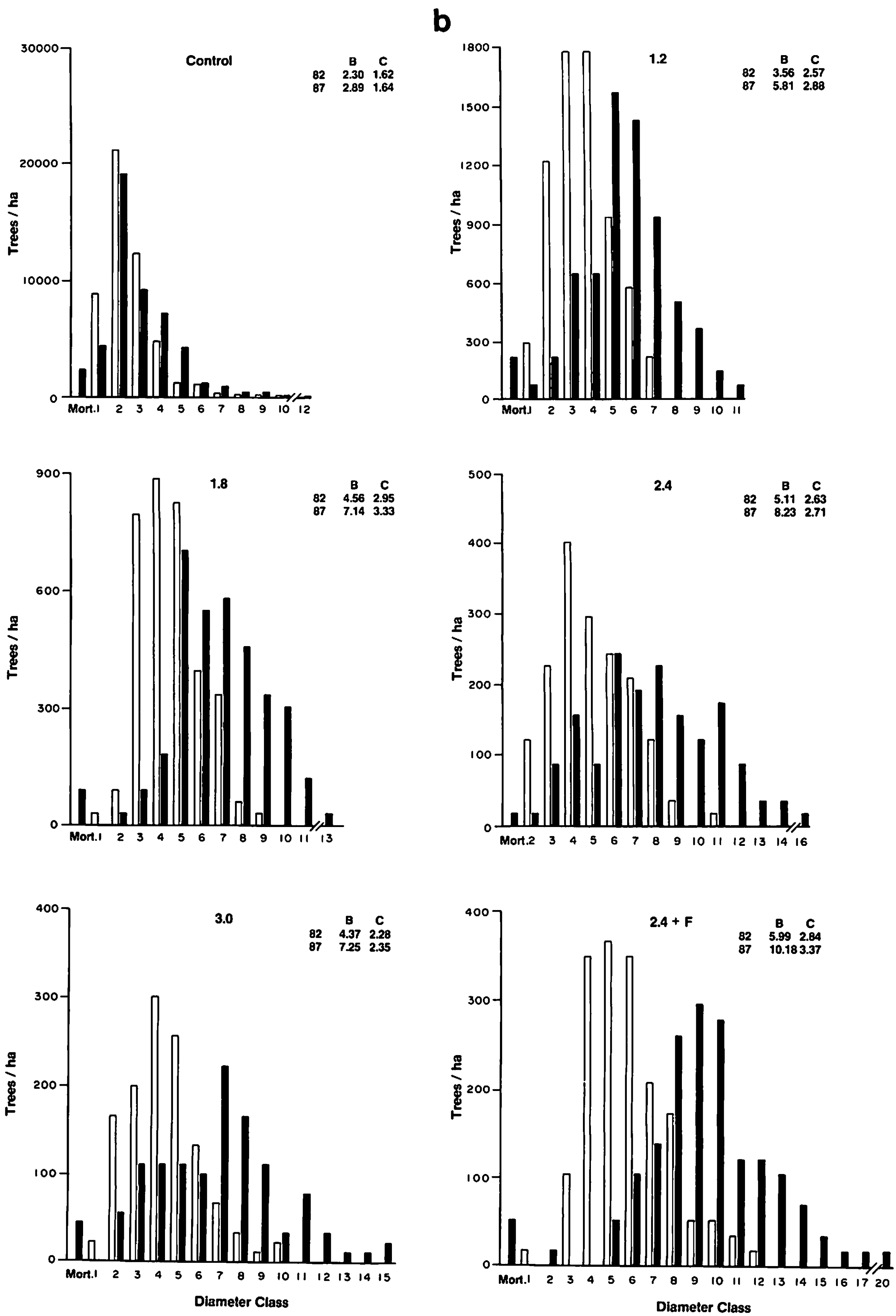

Figure 2. (cont'd)

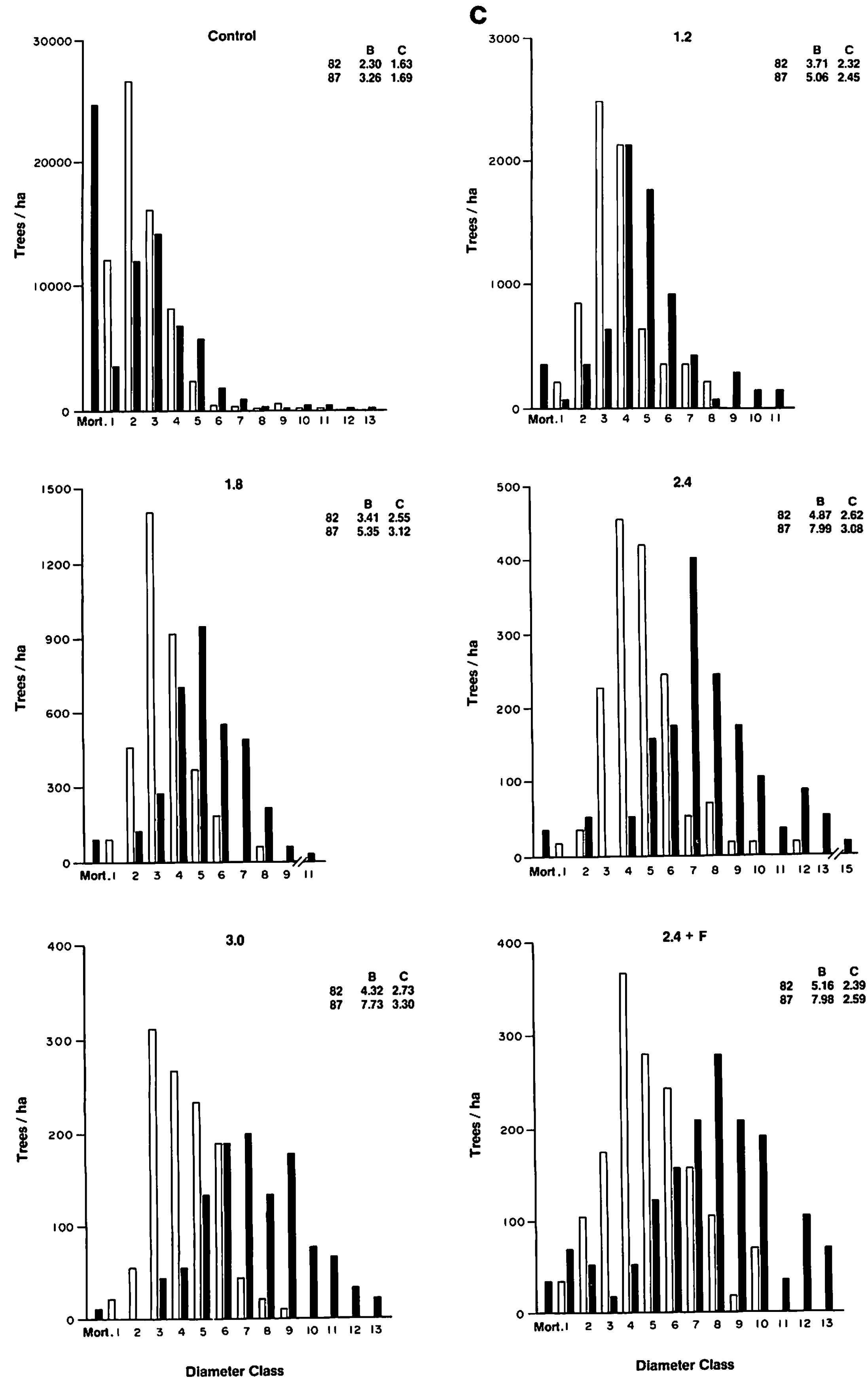

Figure 2. (concl'd)

Table 2. Periodic growth/ha of plots thinned to different spacings, fertilized or unthinned in precommercially thinned stand of balsam fir near Cormack in western Newfoundland.

nominal spacing	block	stems/ha			volume/ha (m^3)					stem weight/ha (Mg)				
		total	mort-ality	ingrow	total	mort-ality	ingrow	gross growth	net growth	total	mort-ality	ingrow	gross growth	net growth
cont	1	48.02	2420	127	81.11	0.574	0.627	37.02	36.45	40.91	0.511	0.311	16.15	15.64
cont	2	51.46	9044	0	112.52	1.190	0.0	51.18	49.99	55.41	1.456	0.0	21.65	20.19
cont	3	46.37	24584	637	115.02	3.061	4.925	51.67	48.61	54.34	3.875	1.922	21.80	17.93
1.2	1	6.52	213	0	34.84	0.202	0.0	24.40	24.20	16.31	0.117	0.0	10.70	10.58
1.2	2	7.30	71	71	24.14	0.028	0.016	15.31	15.28	11.85	0.020	0.015	6.94	6.92
1.2	3	6.95	355	71	26.61	1.279	0.001	14.60	13.32	12.46	0.644	0.007	6.20	5.56
1.8	1	3.40	92	31	29.21	0.140	0.058	19.52	19.38	12.89	0.076	0.031	7.99	7.91
1.8	2	2.63	61	0	14.17	0.047	0.0	9.81	9.76	6.59	0.029	0.0	4.26	4.23
1.8	3	3.40	92	61	12.68	0.154	0.011	7.93	7.78	6.20	0.083	0.011	3.65	3.57
2.4	1	1.64	17	0	22.91	0.026	0.0	15.76	15.73	9.32	0.014	0.0	5.92	5.91
2.4	2	1.34	52	17	14.98	0.059	0.0001	11.01	10.95	6.37	0.033	0.002	4.37	4.34
2.4	3	1.55	35	17	17.96	0.036	0.004	12.05	12.01	7.61	0.021	0.004	4.78	4.76
3.0	1	1.18	45	11	10.96	0.041	0.003	7.71	7.67	4.67	0.024	0.002	3.06	3.04
3.0	2	1.09	67	22	10.58	0.066	0.002	7.16	7.09	4.50	0.038	0.003	2.83	2.79
3.0	3	1.14	11	0	10.58	0.004	0.0	7.77	7.77	4.61	0.003	0.0	3.18	3.18
2.4+F	1	1.66	52	0	37.66	0.219	0.0	25.53	25.31	14.71	0.107	0.0	9.28	9.17
2.4+F	2	1.43	35	35	14.15	0.027	0.014	10.78	10.75	6.08	0.016	0.010	4.34	4.32
2.4+F	3	1.57	35	52	19.35	0.011	0.0007	11.98	11.97	8.06	0.009	0.005	4.64	4.63

ANOVA (P values)

Block	0.80	0.21	0.41	0.43	0.35	0.88	0.30	0.40	0.46	0.19
Treatment	0.0001	0.04	0.30	0.0001	0.0001	0.0001	0.04	0.26	0.0001	0.0001

STUDENT-NEWMAN-KEULS MULTIPLE COMPARISON TESTS

cont a	cont a	cont a	cont a	cont a	cont a	cont a	cont a	cont a	cont a
1.2 b	1.2 a	1.8 a	1.2 b	1.2 b	1.2 b	1.2 a	1.8 a	1.2 b	1.2 b
2.4+F b	1.8 a	1.2 a	2.4+F b	2.4+F b	2.4+F b	1.8 a	1.2 a	2.4+F b	2.4+F b
1.8 b	2.4+F a	2.4+F a	2.4 b	2.4 b	1.8 b	2.4+F a	2.4+F a	1.8 b	1.8 b
2.4 b	2.4 a	3.0 a	1.8 b	1.8 b	2.4 b	2.4 a	2.4 a	2.4 b	2.4 b
3.0 b	3.0 a	2.4 a	3.0 b	3.0 b	3.0 b	3.0 a	3.0 a	3.0 b	3.0 b

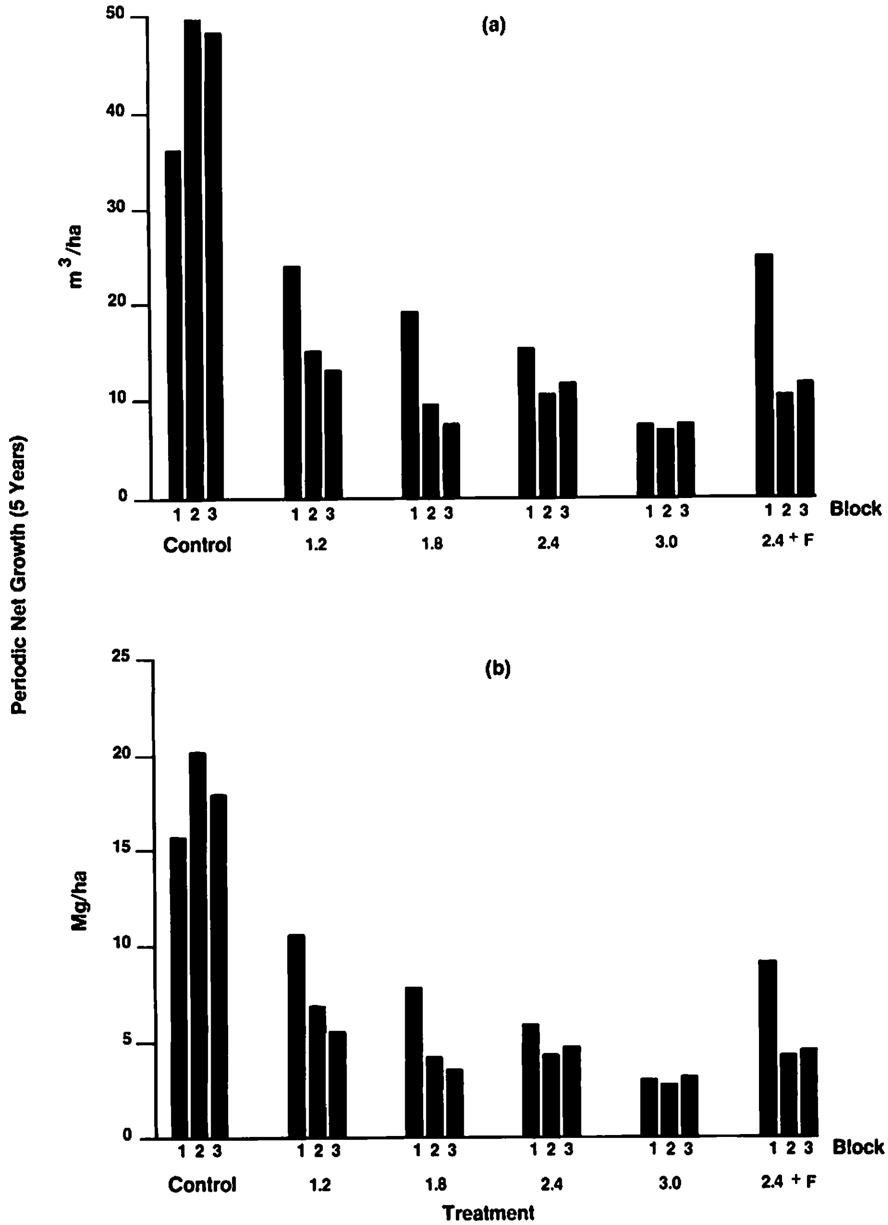

Figure 3. Net stemwood production (growth of surviving trees minus the initial values of trees that died plus ingrowth) during the first 5 years after thinning in terms of total volume (a) and oven-dried weight (b) of spaced, fertilized and unthinned plots of a spacing trial in a balsam fir stand near Cormack in western Newfoundland.

Table 3. Moose damage, physical damage and mortality not caused by competition in plots thinned to different spacings, fertilized and unthinned plots in a precommercially thinned stand of young balsam fir near Cormack in western Newfoundland.

nominal spacing	block	total stems	browsed		damaged		dead	
cont	1	398	2	(0.5)	70	(17.6)	0	(0.0)
cont	2	484	1	(0.2)	75	(15.5)	4	(0.8)
cont	3	524	5	(1.0)	123	(23.5)	6	(1.1)
1.2	1	95	7	(7.4)	9	(9.5)	3	(3.2)
1.2	2	103	1	(1.0)	26	(25.2)	1	(1.0)
1.2	3	102	23	(22.5)	26	(25.5)	5	(4.9)
1.8	1	113	3	(2.7)	4	(3.5)	3	(2.7)
1.8	2	88	54	(61.4)	4	(4.5)	1	(1.1)
1.8	3	114	14	(12.3)	17	(14.9)	5	(4.4)
2.4	1	96	25	(26.0)	9	(9.4)	1	(1.0)
2.4	2	84	11	(13.1)	6	(7.1)	3	(3.6)
2.4	3	90	14	(15.6)	12	(13.3)	2	(2.2)
3.0	1	109	42	(38.5)	6	(5.5)	4	(3.7)
3.0	2	109	31	(28.4)	13	(11.9)	5	(4.6)
3.0	3	104	37	(35.6)	22	(21.2)	2	(1.9)
2.4+F	1	99	1	(1.0)	5	(5.1)	3	(3.0)
2.4+F	2	84	46	(54.8)	5	(6.0)	2	(2.4)
2.4+F	3	89	12	(13.5)	17	(19.1)	1	(1.1)

the fertilization treatment was greater than that of the 2.4 m spacing. Plots thinned to wider spacing produced significantly more growth by the mean tree than plots thinned to closer spacing, except that on average trees in the 3.0 m spacing grew less than those in plots spaced to 2.4 m. Five years after thinning the mean D, V and W of plots spaced at 3.0 m were significantly less than those of plots spaced at 2.4 m (Table 4) as they were immediately after thinning.

Relative Growth Rates

Thinning significantly increased relative growth rates (Table 5). The relative growth rates of plots thinned to wide spacings were significantly greater than those of plots thinned to close spacings except that plots spaced at 3.0 m did not have significantly different relative growth rates from plots spaced at 2.4 m. Fertilized plots did not have relative growth rates that were significantly greater than those of plots thinned to the same spacing.

Stem Growth Rates per Unit of Stem Surface Area

Thinning significantly increased stem growth rates per unit of stem surface area (Figure 5, Table 6), whether growth was described by volume or by stem weight. The growth rates/stem surface area of plots thinned to close spacing were significantly less than those of plots thinned to wide spacing, except for plots spaced at 3.0 m. The mean growth/stem surface area of the fertilized plots was significantly greater than that of the plots thinned to the same spacing.

Changes in Diameter Distribution

Shape parameters, c, of the Weibull function increased significantly ($P \approx 0.0001$) during the remeasurement period (Figure 2). Shape parameters for the unthinned plots continued to be significantly ($P \approx 0.003$) lower than those of thinned plots (Figure 2). The scale parameters, b, also increased significantly ($P \approx 0.0001$) during the remeasurement

Table 4. Mean tree increments and dimensions in plots thinned to different spacing, fertilized and unthinned in a precommercially thinned young stand of balsam fir near Cormack in western Newfoundland.

nominal spacing	block	mean D	D inc	mean H	H inc	mean vol	vol inc	mean st wt	st wt inc	merch trees
		cm		m		dm^3		kg/ha		
cont	1	2.57	0.51	3.08	0.39	1.69	0.77	0.85	0.33	127
cont	2	2.82	0.42	3.81	0.50	2.19	1.00	1.08	0.42	255
cont	3	2.92	0.51	3.72	0.57	2.48	1.11	1.17	0.47	637
1.2	1	5.21	2.03	4.16	1.01	5.34	3.74	2.50	1.64	71
1.2	2	4.36	1.51	3.39	0.56	3.30	2.09	1.62	0.95	71
1.2	3	4.51	1.30	3.47	0.49	3.83	2.10	1.79	0.89	142
1.8	1	6.43	2.33	4.59	1.00	8.60	5.74	3.80	2.36	184
1.8	2	5.47	2.02	3.72	0.73	5.39	3.73	2.51	1.62	61
1.8	3	4.81	1.80	3.46	0.56	3.76	2.36	1.83	1.08	31
2.4	1	7.32	2.79	5.09	0.91	13.96	9.60	5.68	3.61	349
2.4	2	7.11	3.09	4.57	0.92	11.14	8.19	4.74	3.26	140
2.4	3	7.17	2.81	4.83	0.77	11.56	7.76	4.90	3.08	192
3.0	1	6.46	2.60	4.07	0.75	9.28	6.53	3.96	2.60	156
3.0	2	6.46	2.42	4.27	0.58	9.69	6.55	4.13	2.60	100
3.0	3	6.93	3.01	4.26	0.85	9.31	6.84	4.06	2.80	123
2.4+F	1	9.17	3.69	6.11	0.88	22.70	15.39	8.87	5.60	506
2.4+F	2	6.95	3.14	4.33	0.98	9.89	7.54	4.25	3.04	192
2.4+F	3	7.15	2.62	4.77	0.69	12.32	7.63	5.13	2.95	227

ANOVA (P values)

	mean D	D inc	mean H	H inc	mean vol	vol inc	mean st wt	st wt inc
Block	0.001	0.0001	0.38	0.10	0.0001	0.0001	0.0001	0.0001
Treatment	0.0	0.0	0.0	0.0001	0.0	0.0	0.0	0.0
TxB	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

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mean D	D inc	mean H	H inc	mean vol	vol inc	mean st wt	st wt inc
2.4F a	2.4F a	2.4F a	2.4 a	2.4F a	2.4F a	2.4F a	2.4F a
2.4 b	2.4 b	2.4 b	2.4F ab	2.4 b	2.4 b	2.4 b	2.4 b
3.0 c	3.0 c	3.0 c	1.8 abc	3.0 c	3.0 c	3.0 c	3.0 c
1.8 d	1.8 d	1.8 d	3.0 abc	1.8 d	1.8 d	1.8 d	1.8 d
1.2 e	1.2 e	1.2 e	1.2 c	1.2 e	1.2 e	1.2 e	1.2 e
cont f	cont f	cont f	cont d	cont f	cont f	cont f	cont f

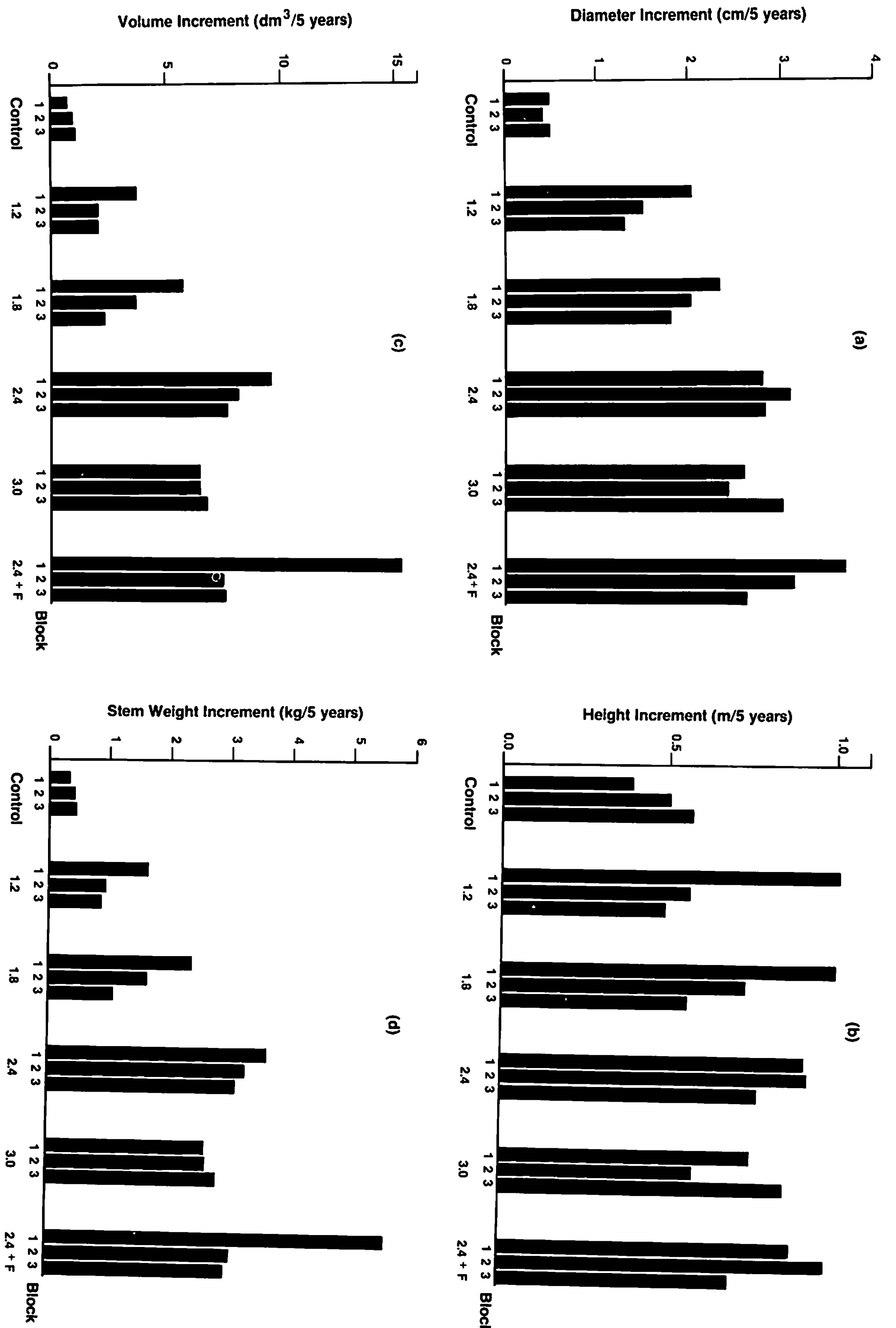


Figure 4. Mean tree increments of surviving trees (and excluding ingrowth) during the first 5 years after thinning for spaced, fertilized and unthinned plots of a spacing trial in a balsam fir stand near Cormack in western Newfoundland. (a) Average diameter increment per tree; (b) Average height increment per tree; (c) Average volume increment per tree; (d) Average stem weight increment per tree.

Table 5. Relative growth rates of plots thinned to different spacing, fertilized and unthinned in a precommercially thinned young balsam fir stand near Cormack in western Newfoundland.

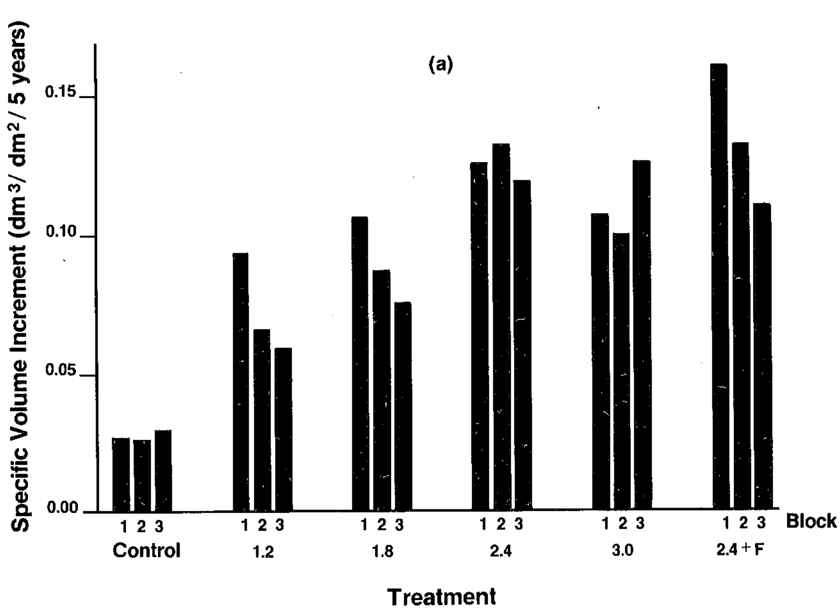
nominal spacing	block	relative growth rates		
		diameter	volume	stem weight
		$cm \cdot cm^{-1}y^{-1}$	$dm^3 \cdot dm^{-3}y^{-1}$	$kg \cdot kg^{-1}y^{-1}$
cont	1	0.0415	0.1043	0.0645
cont	2	0.0294	0.0807	0.0581
cont	3	0.0335	0.0929	0.0649
1.2	1	0.1035	0.2613	0.2139
1.2	2	0.0896	0.2122	0.2138
1.2	3	0.0717	0.1723	0.1359
1.8	1	0.0919	0.2306	0.1987
1.8	2	0.0908	0.2213	0.1889
1.8	3	0.0983	0.2323	0.1868
2.4	1	0.0967	0.2312	0.1985
2.4	2	0.1177	0.2800	0.2401
2.4	3	0.1018	0.2378	0.2067
3.0	1	0.1039	0.2451	0.2028
3.0	2	0.0920	0.2086	0.1810
3.0	3	0.1168	0.2764	0.2398
2.4+F	1	0.1055	0.2426	0.2119
2.4+F	2	0.1181	0.2834	0.2453
2.4+F	3	0.0941	0.2188	0.1878

ANOVA (P values)

	diameter	volume	stem weight
Block	0.0001	0.0001	0.0001
Treatment	0.0	0.0	0.0

STUDENT-NEWMAN-KEULS MULTIPLE COMPARISON TESTS

diameter	volume	stem weight
2.4+F a	2.4 a	2.4+F a
2.4 a	2.4+F a	2.4 a
3.0 a	3.0 a	3.0 a
1.8 b	1.8 b	1.8 b
1.2 c	1.2 c	1.2 c
cont d	cont d	cont d



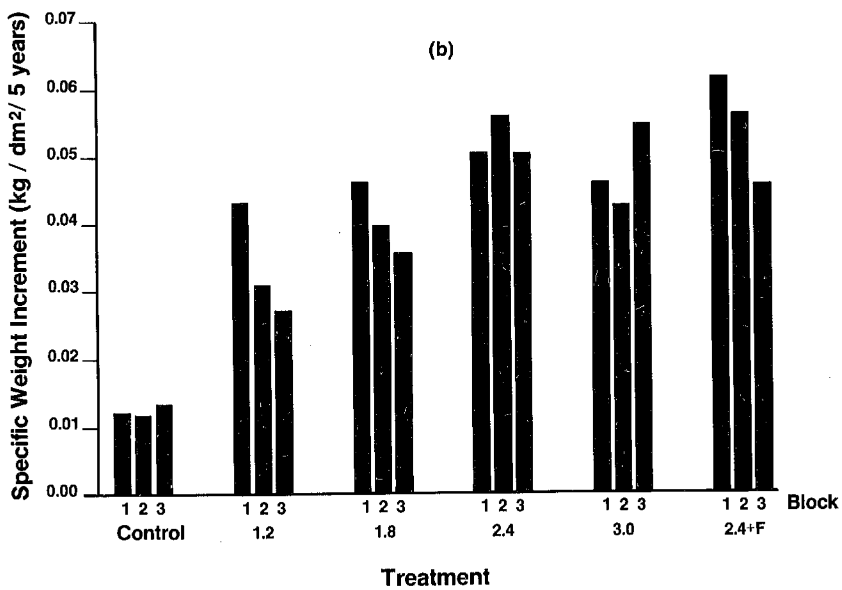


Figure 5. Periodic stem growth per unit of stem surface area during the first 5 years after thinning for spaced, fertilized and unthinned plots of a spacing trial in a balsam fir stand near Cormack in western Newfoundland. (a) Periodic stem volume growth per unit of stem surface area; (b) Periodic oven-dried stem weight growth per unit of stem surface area.

Table 6. Stem surface areas and stem growth per unit of stem surface area of plots thinned to different spacing, fertilized and unthinned in a precommercially thinned young balsam fir stand near Cormack in western Newfoundland.

nominal spacing	block	surface area	growth/surface area	
			volume	weight
		m^2/ha	dm^3/dm^2/5 yrs	kg/dm^2/5 yrs
cont	1	8852	0.0266	0.0123
cont	2	11562	0.0261	0.0119
cont	3	10828	0.0294	0.0134
1.2	1	3028	0.0943	0.0430
1.2	2	2396	0.0664	0.0309
1.2	3	2393	0.0593	0.0270
1.8	1	2098	0.1069	0.0462
1.8	2	1207	0.0879	0.0397
1.8	3	1244	0.0761	0.0357
2.4	1	1307	0.1259	0.0505
2.4	2	960	0.1323	0.0558
2.4	3	1150	0.1196	0.0504
3.0	1	726	0.1078	0.0460
3.0	2	685	0.1008	0.0426
3.0	3	736	0.1265	0.0545
2.4+F	1	1886	0.1611	0.0615
2.4+F	2	942	0.1325	0.0560
2.4+F	3	1167	0.1112	0.0457

ANOVA (P values)

	surface area	volume	weight
Block	0.9885	0.0001	0.0001
Treatment	0.0001	0.0	0.0
TxB		0.0001	0.0001

STUDENT-NEWMAN-KEULS MULTIPLE COMPARISON TESTS

surface area		volume		weight	
cont	a	2.4+F	a	2.4+F	a
1.2	b	2.4	b	2.4	a
1.8	b	3.0	c	3.0	b
2.4+F	b	1.8	d	1.8	c
2.4	b	1.2	e	1.2	d
3.0	b	cont	f	cont	e

period (Figure 2). Moreover, the increases in b differed significantly ($P \approx 0.0001$) among treatments. Increases of b were least for unthinned plots, and greatest for plots thinned to wide spacings. The changes in b were similar to changes in mean tree dimensions, which is logical since b estimates the D of the tree at the sixty-third percentile.

The stem growth of large diameter trees was greater than that of small diameter trees in all plots (Figure 6). However, changes in relative growth rate with increasing initial tree size differed between thinned and unthinned plots. Relative growth rates of D, V and W by small trees were greater than those of larger trees in thinned plots but in unthinned plots the relative growth rates by small trees were less than those by larger trees (Figure 6).

Rates of stem growth/stem surface area by small trees were less than those by large trees in all plots (Figure 7). Within each plot those trees with diameters greater than 6 cm had approximately equal rates of stem weight growth per unit of stem surface area. No trend for equal rates of stem volume growth per unit of stem surface area among larger trees was observed.

Discussion

Effects of Thinning on Stand Structure

Some small trees must be left when thinning to obtain regular spacing, with the result that the sizes of the smallest trees in thinned and unthinned plots were not substantially different (Table 1). In addition, many large trees are cut when thinning to reduce the number of trees/ha to the desired level and have the trees regularly spaced, as can be seen by comparing the number of trees having larger diameters in thinned and unthinned plots (Figure 2). Since large trees are preferred to small trees when thinning the treatment does reduce the abundance of small trees in comparison to large trees, thereby changing the shape of the frequency distribution of trees among diameter classes (Figure 2). The small trees left after thinning are expected to become merchantable, whereas small trees are not expected to become merchantable in unthinned stands. Moreover, removing some large trees probably benefits the remaining trees more than removing the small trees.

Growth Responses

In general, the responses to spacing were as expected: growth per tree was greater, on average, at wider spacing than at closer spacing, and growth per hectare was greater for plots spaced at closer spacing than those thinned to wider spacing. Exceptions to these generalizations were lower growth per tree than expected in plots spaced at 3.0 m, and higher stem growth/ha than expected by plots spaced at 2.4 m. Relative growth rates and specific increments indicated that growth per tree increased with increasing spacing without exceptions. These parameters discount initial differences in tree sizes when comparing treatments; therefore, the confounding influences of differences among plots in stand density and hardwood content prior to thinning are minimized when comparing responses to treatments.

Reductions in occupancy caused by thinning were greater at wider spacings and were responsible for lower rates of stem growth/ha. Plots with lower occupancy had less capacity to acquire all of the available resources necessary for growth than did more closely spaced plots. Competition between trees was reduced by decreasing the occupancy, thereby increasing the growth per tree. Higher relative growth rates in widely spaced plots than closely spaced plots showed that increased growth per tree was caused by less competition not because the remaining trees were larger.

The specific weight increment measures the rate by which tree crowns and roots provide the materials necessary for stem growth (primarily carbohydrate) to each unit of cambium. Hence, values of this parameter depend on the balance between heterotrophic and autotrophic tissues, and on the rate of acquiring resources (Brix 1983). Specific weight increments of widely spaced plots were greater than those of closely spaced plots because they acquired more resources per unit of foliage and roots, and the trees have developed to have more foliage per unit of stem surface area. Higher rates of resource acquisition per unit of foliar weight will continue until stands fully reoccupy the site, hence it will last longer in widely spaced plots. In contrast, the differences between spacings of the amount of heterotrophic tissue per unit of autotrophic tissue will continue to widen until stands reoccupy the site, and persist for the life of the stand. Therefore,

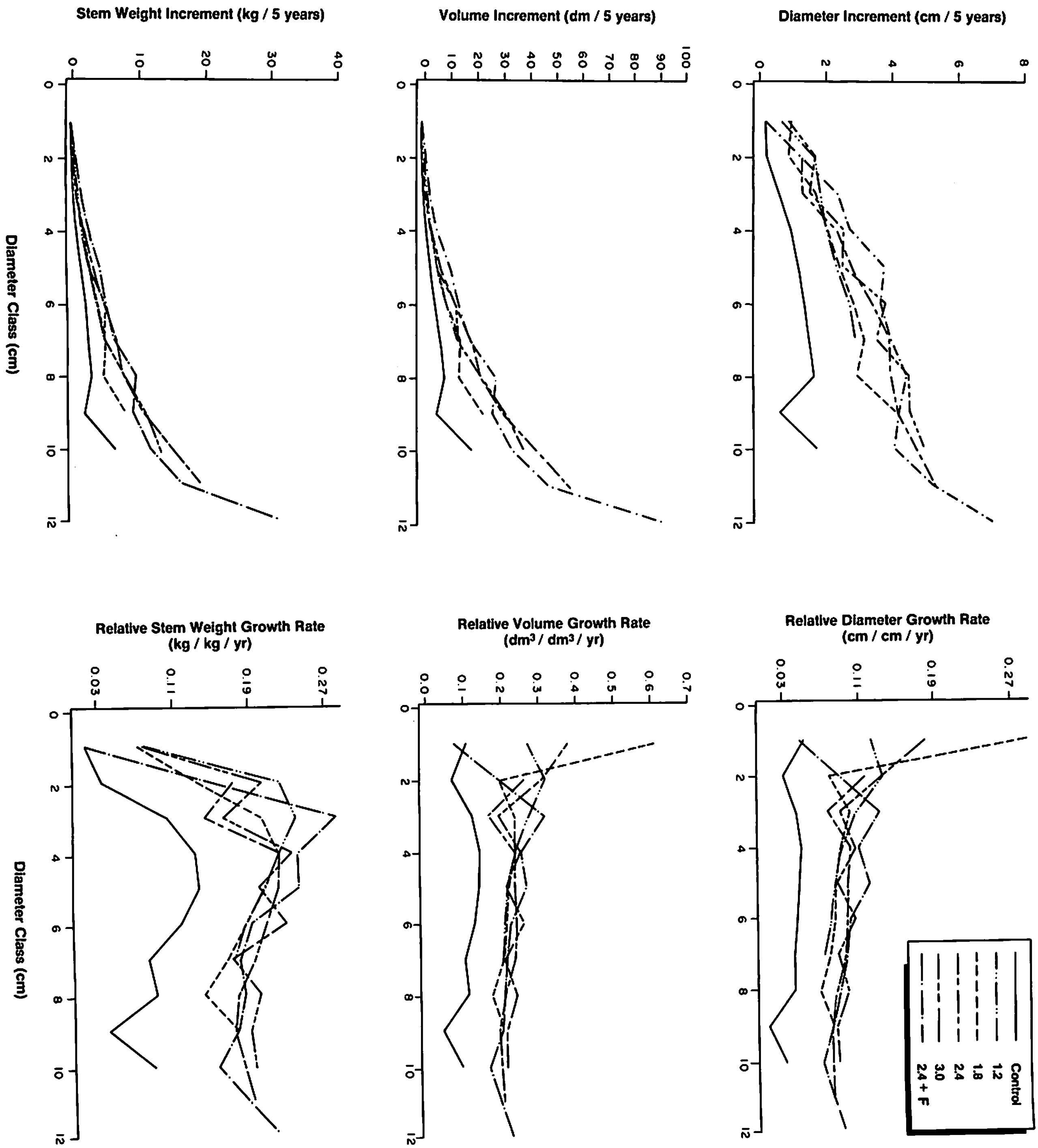


Figure 6. Periodic diameter, total volume and oven-dried stem weight growth and relative growth rates during the first 5 years after thinning by initial diameter class of trees in spaced, fertilized and unthinned plots of a spacing trial in a balsam fir stand near Cormack in western Newfoundland. (a) Block 1; (b) Block 2; (c) Block 3.

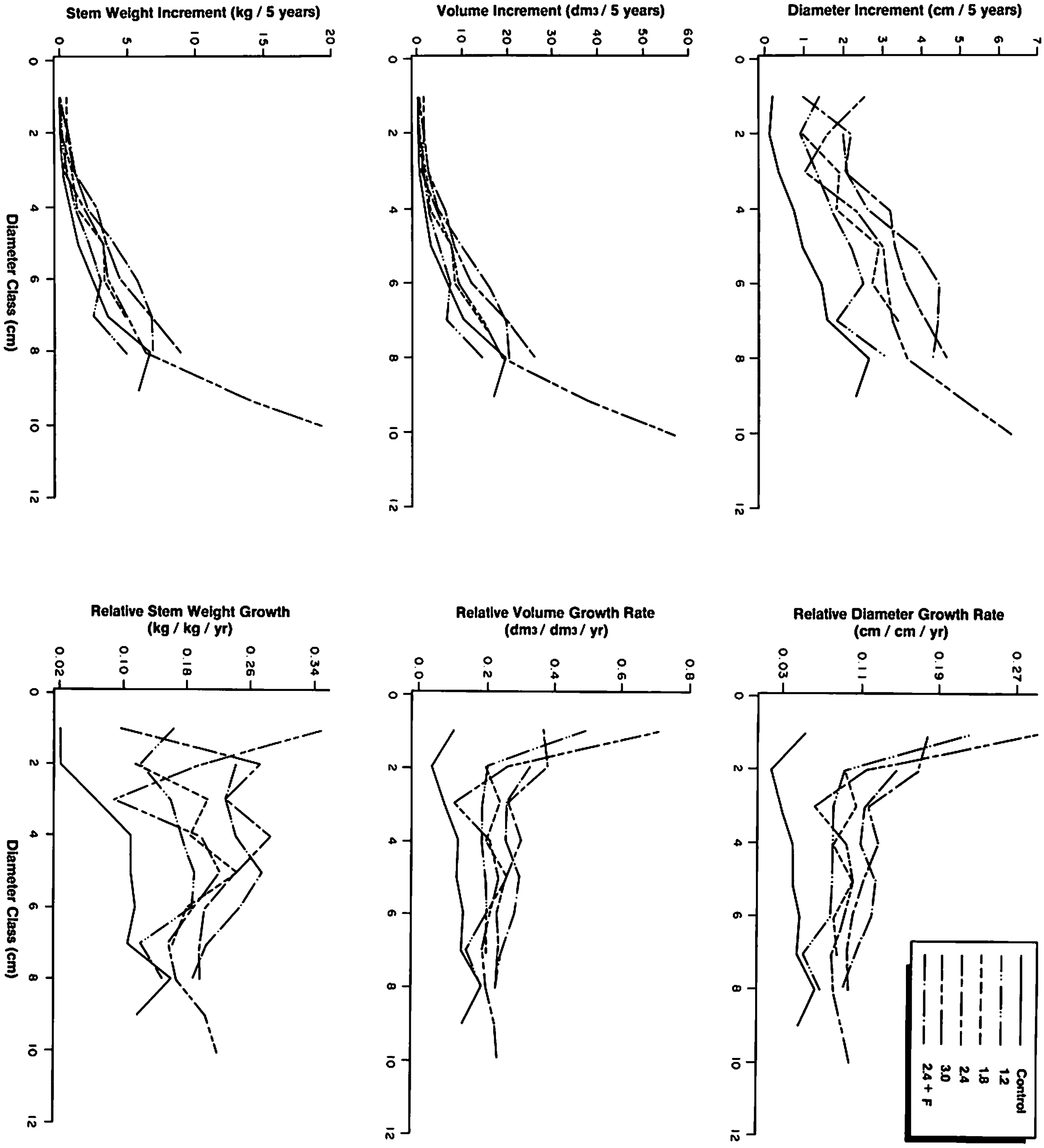


Figure 6. (cont'd)