Effect of precommercial thinning on the production of young fir stands on the Upper North Shore

Richard Zarnovican and Claude Laberge
CFS - Quebec ● Information Report LAU-X-118E

Natural Resources Canada
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Information Report LAU-X-118E
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Natural Resources Canada
Canadian Forest Service - Quebec

CANADIAN CATALOGUING IN PUBLICATION DATA

Zarnovican, Richard

Effect of precommercial thinning on the production of young fir stands on the Upper North Shore

(Information report; LAU-X-118E)
Includes an abstract in French.
Issued also in French under title : Effet de l'éclaircie précommerciale sur la production de jeunes sapinières de la Haute-Côte-Nord.
Issued by the Laurentian Forestry Centre.
Includes bibliographical references.
ISBN 0-662-24423-0
Cat. No. Fo46-18/118E

1. Balsam fir -- Quebec (Province) -- Growth.
2. Forest thinning -- Quebec (Province).
I. Laberge, Claude.
II. Canadian Forest Service
III. Laurentian Forestry Centre.
IV. Title.
V. Series: Information report (Laurentian Forestry Centre); LAU-X-118E.

SD397.B2Z37 1996 634.9'75453'09714 C96-980392-3

Catalog Number Fo46-18/118E
ISBN 0-662-24423-0
ISSN 0835-1570

Limited additional copies of this publication are available at no charge from:
Natural Resources Canada
Canadian Forest Service
Laurentian Forestry Centre
1055 du P.E.P.S.
P.O. Box 3800
Sainte-Foy, Quebec G1V 4C7

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Micromedia Ltd.
240 Catherine St.
Suite 305
Ottawa, Ontario K2P 2G8
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Toll free: 1-800-567-1914
Fax: (613) 237-4251

Cette publication est également offerte en français sous le titre «Effet de l'éclaircie précommerciale sur la production de jeunes sapinières de la Haute-Côte-Nord» (Numéro de catalogue Fo46-18/118).

PRINTED IN CANADA
IMPRIMÉ AU CANADA

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Zarnovican, R.; Laberge, C. 1996. Effect of precommercial thinning on the production of young fir stands on the Upper North Shore. Nat. Resour. Can., Can. For. Serv. - Quebec, Sainte-Foy, Qc. Inf. Rep. LAU-X-118E.

ABSTRACT

Analysis of balsam fir morphological and growth data from 16 plots in the Les Escoumins management unit on the Upper North Shore was made to assess the effects of precommercial thinning on sawlog quality, radial growth and volume production. The results indicate that precommercial thinning significantly stimulates radial growth of residual stems. However, this increase in radial growth was more significant on the stump than on the dbh. The effect of precommercial thinning on radial growth was maximal 4 years after the treatment and ceased after 7 years. Precommercial thinning had a significant impact on the qualitative parameters of the logs. In thinned stands, stem taper was greater than in control stands, principally because thinning promoted lower bole growth. Finally, precommercial thinning increased the number of live whorls as well as the knottiness on the first 8-foot section. Comparison of the yield indicates that heavy precommercial thinning, in addition to affecting the quality of the logs, can also affect the production level of fir stands. Finally, the report proposes a density model for fir stands based on dominant height and the spacing factor.

Zarnovican, R.; Laberge, C. 1996. Effet de l'éclaircie précommerciale sur la production de jeunes sapinières de la Haute-Côte-Nord. Ressour. nat. Can., Serv. can. for. - Québec, Sainte-Foy, Qc. Rapp. Inf. LAU-X-118.

RÉSUMÉ

À partir des données morphologiques et des données sur la croissance du sapin baumier, récoltées dans 16 parcelles de l'UG - Les Escoumins sur la Haute-Côte-Nord, le rapport analyse les effets de l'éclaircie précommerciale sur la qualité des billes pour le sciage, sur la croissance radiale et sur la production en volume. Les résultats obtenus indiquent que l'éclaircie précommerciale stimule de façon significative la croissance radiale des tiges résiduelles. Cependant, cette augmentation de la croissance radiale est plus importante à la souche qu'au dhp. L'effet d'éclaircie sur la croissance radiale est maximal 4 ans après le traitement et il s'estompe 7 ans après. Les résultats démontrent également que l'éclaircie précommerciale influence de façon significative les paramètres qualitatifs des billes. Les tiges éclaircies par rapport aux tiges témoins ont un empattement plus grand à cause de la répartition du bois sur la tige et, par conséquent, un défilement également plus grand. Finalement, l'éclaircie précommerciale augmente le nombre des verticilles vivants ainsi que la nodosité sur le premier tronçon de 8 pieds. La comparaison de la production en volume des parcelles éclaircies et des parcelles témoins avec la table de production du CAAF indique que l'éclaircie précommerciale intense, en plus d'affecter la qualité des billes, peut aussi affecter le niveau de production des sapinières. Enfin, le rapport propose un modèle de densité pour les sapinières, basé sur la hauteur dominante des peuplements et sur le facteur d'espacement.

INTRODUCTION

Since 1982, precommercial thinning has been carried out on more than 10,000 ha of young balsam fir (*Abies balsamea* [L.] Mill.) in the Les Escoumins Management Unit (MU). The Ministère des Ressources naturelles du Québec and its contractors under the forest development and supply program (CAAF) established this silvicultural regime to increase lumber yield and shorten the production cycle. Young stands have been thinned in an intensive procedure that reduces residual densities to 2,000 to 2,500 stems per hectare. Available documentation indicates that thinning was schematic, that is, aside from elimination of deciduous species, nothing was done about site quality or phase of stand development.

Fir stand production on the Upper North Shore is currently estimated for CAAF purposes using Table PL275. According to the Quebec forest management manual (Ministère de l'Énergie et des Ressources du Québec 1989), this table applies to plantations in the mixed ecological region and is adapted from tables by Bolghari and Bertrand (1984) and Vézina and Linteau (1968). Although the management manual does not refer to site indices, it may reasonably be assumed that the table is based on the site index model of Vézina and Linteau (1968). In addition, the Vézina-Linteau tables assume natural thinning from below, whereas Table PL275 assumes intensive thinning.

Consequently, the MU requested that the authors examine the effect of precommercial thinning on lumber yield and determine the appropriateness of Table PL275 for modeling yield from thinned fir stands.

OBJECTIVES

The objectives of this work were to:

1) study the effect of precommercial thinning on stem quality;

2) evaluate the effect of precommercial thinning on radial increment;

3) verify whether the Vézina and Linteau (1968) site index applies to fir stands considered in the study;

4) establish a predictive model for estimating volume yield;

5) determine whether Table PL275 applies to thinned young fir stands.

MATERIALS AND METHODS

Forest inventory

During the summer of 1994, MU managers prepared a simple random sampling plan in preparation for an inventory of thinned and control stands on well drained, shallow till. In this plan, 0.04 ha circular plots within fir stands were sited on 1/20,000 forest maps: five plots in mature stands, eight plots (four thinned and four control) in stands thinned in 1984 and eight plots (four thinned and four control) in stands thinned in 1988.

A further inventory in autumn 1994 enumerated all living trees 1.5 cm and over in DBH in 2-cm categories. Proportional selection (according to DBH category) of 13 trees (5 cm and over in DBH) was carried out within a range of ± one standard deviation from mean DBH for the plot. In addition, to measure site quality, two trees were randomly selected from among the largest 10% of the trees in the plot without apparent defects in the crown and on the stem. These 15 trees were then harvested and their morphology measured (see Fig. 1). Finally, stem cross sections were cut for analysis. Stem analysis (Zarnovican *et al.* 1988) was conducted to establish growth as measured by DBH, basal area, height and volume in the last five years. Time series of radial increment along four radii were established on the disks taken at breast height and ground level.

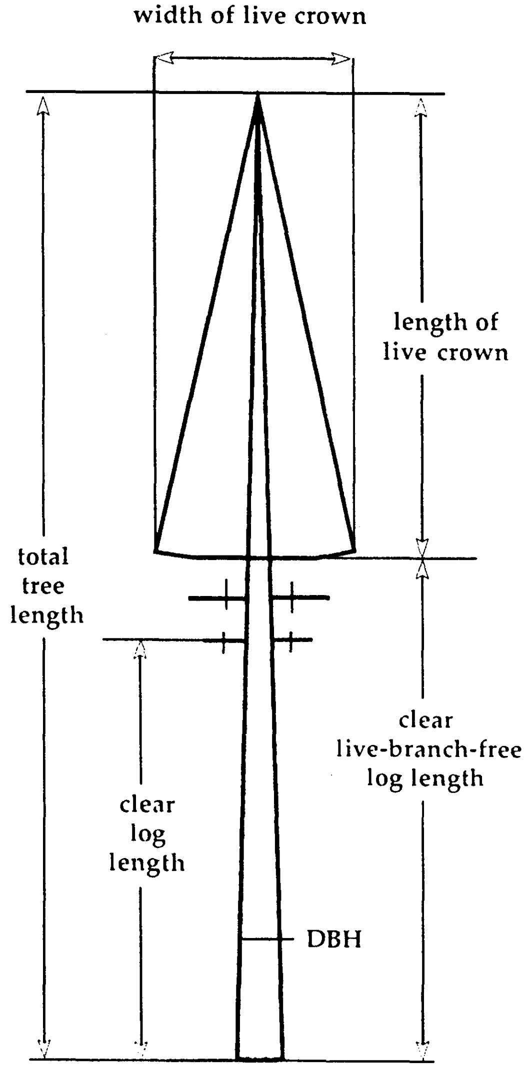

Figure 1. Tree morphology measurements.

Description of stands and environment

Tables 1 and 2 describe the main characteristics of the 21 plots, all of which were sampled from fir stands in MU 91 - Les Escoumins. All mature plots as well as plots 1, 2, 3 and 4 lie within the balsam fir - white birch forest domain, while plots 8, 9, 11, 12 and 14 lie within the balsam fir - yellow birch forest domain. The silvicultural regime (release harvesting of softwood) was applied between July and October 1984 using mechanical saws in plots 1, 2, 3 and 4; a similar regime was implemented in plots 9, 11, 12 and 14 in November 1988. Available data on treatment intensity indicate that 82% of basal area was removed from plot 9, 71% from plot 11, 76% from plot 12, and 86% from plot 14. The purpose of thinning was to release softwood species by removing selected hardwood species. Stem counts taken following thinning and in 1994 (Table 2) indicate that stands were in the constitution phase at the time, as the number of stems increased between the two inventories in plots 9, 11, 12 and 14.

Data analysis

Effect of thinning on log quality

Although plots 1, 2, 3 and 4 (control and thinned in 1984) are located in the same stand, thinned and control plots were not directly paired. Therefore, these plots are compared in groups, i.e., control plots (1 to 4) with thinned plots (1 to 4). Because plots control-8 and thinned-9 were adjacent, they were paired in statistical analyses. The same was done for control vs. thinned pairs in plots 11, 12 and 14.

The analysis of variance consists in comparing a number of tree morphology variables between thinned and control plots. These variables are studied for all trees in the eight control plots and eight thinned plots. The three factors in the analysis of variance are as follows:

1) the treatment factor (A) measures the effect of thinning and takes two values: 0 = control, 1 = thinned;

2) the class factor (B) measures the effect of the social class of the tree and takes three values: 1 = upper, 2 = middle, 3 = lower;

3) the plot factor (C) measures the effect of individual plots.

Trees are assigned class values based on their height and DBH compared with the mean of the trees in the plot. Treatment and class factors are fixed, while the plot factor is random. In the analysis of variance for plots 1, 2, 3 and 4, the plot factor is nested within the treatment factor, and the class factor is nested within the plot factor. Consequently, the statistical model is:

$$y_{ijkl} = \mu + a_i + b_{j(i)} + g_{k(ij)} + e_{(ijk)l} \qquad [1]$$

Table 1. Ecological and forest characteristics of plots included in the study.

Plot	Stratum	Altitude (m)	Longitude	Latitude	Slope (%)	Deposit	Drainage	Vegetation	Exposure
1, 2, 3, 4, 5 Mature	SS B3 70	430	70°10'	48°29'	27	1aR	II	Dryopteris-Oxalis	S-W
1, 2, 3, 4 Thinned 1984	R6 and 10	350	69°56'	48°25'	27	1aR	III	Dryopteris-Oxalis	NNW
1, 2, 3, 4 Control 1984	MA5 and 10	250	69°56'	48°23'	23	1aR	III	Dryopteris-Oxalis	S
8, 9 Control, thinned 1988	RD5 and 10	180	69°42'	48°13'	25	1aR	III	Kalmia-Cornus	NE
11 Thinned, control 1988	RD5 and 30	130	69°26'	48°26'	8	1aR	II	Kalmia-Cornus	E
12 Thinned, control 1988	RD5 and 30	130	69°26'	48°26'	10	1aR	II	Kalmia-Cornus	S
14 Thinned, control 1988	RD5 and 30	135	69°26'	48°26'	8	1aR	III	Kalmia-Cornus	S

Table 2. Stand characteristics (values per hectare)

Plot		Age (years)	Number of stems	Total basal area (m^2)	Basal area* (m^3)	Volume* (m^3)	Mean diameter* (cm)	Stand height* (m)	Mean volume* (dm^3)
1	Mature in 1994	63	3,425	40.1	35.6	235.9	12.2	13.7	80.6
2	Mature in 1994	86	1,875	45.0	41.8	331.3	17.5	16.7	204.4
3	Mature in 1994	79	1,400	42.3	34.0	277.1	19.6	16.4	241.0
4	Mature in 1994	73	1,450	36.8	33.1	244.1	18.0	16.0	187.8
5	Mature in 1994	101	1,325	34.1	28.4	214.0	18.1	16.3	182.2
1	T (1984) in 1994	30	3,175	16.8	16.8	76.2	8.2	9.2	24.0
2	T (1984) in 1994	31	2,800	15.3	15.3	64.3	8.4	8.5	23.0
3	T (1984) in 1994	37	2,775	18.7	18.7	83.0	9.3	9.0	29.9
4	T (1984) in 1994	32	3,725	11.8	11.8	42.8	6.4	8.0	11.5
1	C (1984) in 1994	32	10,075	35.0	26.2	128.3	6.7	10.9	13.9
2	C (1984) in 1994	32	12,725	32.1	28.7	128.2	5.7	10.7	10.7
3	C (1984) in 1994	35	7,925	26.4	21.8	105.9	6.5	11.0	14.2
4	C (1984) in 1994	28	10,275	26.1	24.7	110.6	5.7	9.8	11.2
8	C in 1988	21	20,275	12.2	11.2	26.3	2.8	3.6	1.7
8	C in 1994	26	16,575	17.0	16.7	41.2	3.6	5.9	2.8
9	T BT in 1988	21	20,625	12.6	9.4	25.7	2.8	3.5	1.7
9	T AT in 1988	21	1,550	2.3	2.2	5.7	5.7	3.5	4.0
9	T in 1994	26	1,725	4.2	4.2	11.7	5.5	5.9	7.5
11	C in 1988	21	12,375	13.2	10.7	32.3	3.7	3.9	4.2
11	C in 1994	26	9,250	18.5	18.1	58.2	5.0	6.8	6.4
11	T BT in 1988	21	12,215	11.9	9.3	26.7	3.5	3.0	4.4
11	T BT in 1988	21	1,775	3.4	3.4	9.6	4.0	3.0	5.4
11	T in 1994	26	2,175	8.6	8.6	29.1	7.1	7.2	13.4
12	C in 1988	20	12,875	9.5	7.4	20.6	3.1	3.2	2.7
12	C in 1994	25	9,775	14.7	14.7	44.7	4.4	5.9	4.6
12	T BT in 1988	20	12,350	12.1	9.9	15.9	3.6	3.3	4.5
12	T AT in 1988	20	1,200	2.9	2.9	4.9	4.9	3.3	7.2
12	T in 1994	25	1,450	6.1	6.1	11.9	7.3	6.4	14.3
14	C in 1988	20	14,800	16.9	13.9	43.3	3.8	4.2	4.0
14	C in 1994	25	12,200	23.1	21.4	69.0	4.9	6.4	5.8
14	T BT in 1988	20	11,700	13.9	12.7	33.0	3.9	3.8	3.5
14	T AT in 1988	20	1,575	2.0	2.0	5.0	4.0	3.8	3.2
14	T in 1994	25	1,925	5.9	5.9	18.4	6.3	6.7	9.5

T - Thinned; C - Control; BT - before treatment; AT - after treatment; * softwood

where μ represents the general mean; a_i represents the treatment effect; $b_{j(i)}$ represents the plot within treatment effect; $g_{k(ij)}$ represents the class within plot within treatment effect; and $e_{(ijk)l}$ is the error term. Note that there are no interaction terms, since there can be no interaction between nested factors. These effects are tested as follows:

1) Treatment (A): H_0: $a_i = 0$ is tested by MS_A/MS_B;

2) Plot (B): H_0: $s^2{}_b = 0$ is tested by MS_B/MS_E;

3) Class (C): H_0: $g_{k(ij)} = 0$ is tested by MS_C/MS_E.

For example, the treatment factor is tested by the ratio between the mean square for treatment (MS_A) and the mean square for plot (MS_B). The effect of the other two factors is tested by the ratio between the mean square for the appropriate factor and the mean square for error (MS_E). In plots 8, 9, 11, 12 and 14, the plot factor is crossed with treatment (unlike plots 1, 2, 3 and 4), although the class effect is still nested within plot. The statistical model for this case then becomes:

$$y_{ijkl} = \mu + a_i + b_j + g_{k(j)} + (ab)_{ij} + (ag)_{ik(j)} + e_{(ijk)l} \qquad [2]$$

where μ is the general mean; a_i is the treatment effect; b_j is the plot effect; $g_{k(ij)}$ is the class within plot effect; $(ab)_{ij}$ is the treatment by plot interaction term; and $(ag)_{ik(j)}$ is the treatment by class interaction term. Finally, $e_{(ijk)l}$ is the error term. The appropriate tests are then:

1) Treatment factor (A), H_0: $a_i = 0$ is tested by MS_A/MS_{AB};

2) Plot factor (B), H_0: $s^2{}_b = 0$ is tested by MS_B/MS_E;

3) Class factor (C), H_0: $g_{k(ij)} = 0$ is tested by MS_C/MS_E.

where the treatment effect is tested using the ratio between the mean square for treatment (MS_A) and the mean square (MS_{AB}) for the interaction between treatment and plot.

The other two effects (plot and class) are tested using the ratio between the mean square for the appropriate factor and the error mean square (MS_E). Finally, interactions are tested by the ratio between the mean square for the appropriate interaction and the mean square for error.

Effect of thinning on radial increment

The reaction of trees to thinning is measured by the difference in radial increment before and after thinning. The significance of this difference was tested by measuring the difference in mean increment between thinned and control plots using an analysis of variance design that takes account of series structure. The data consist of short time series that were collected from the same trees at different times; hence, the data are autocorrelated.

The analysis included three factors (treatment, plot and class) as defined in the section on log quality. Treatment and class are fixed effects, while plot is a random effect. The dependent variable ir_{dif} is defined as:

$$ir_{dif} = ir_{avg}(1985 \text{ to } 1994) - ir_{avg}(1974 \text{ to } 1983) \qquad [3]$$

where ir_{avg}(x to y) is the mean periodic radial increment between years x and y. For plots 1, 2, 3 and 4, which were thinned in 1984, ir_{avg} was calculated for ten-year periods before and after thinning. For plots 8, 9, 11, 12 and 14, ir_{avg} was calculated using six-year periods before and after thinning, as follows:

$$ir_{dif} = ir_{avg}(1989 \text{ to } 1994) - ir_{avg}(1982 \text{ to } 1987) \qquad [4]$$

Finally, various patterns in the series were examined, since nonstationary means (due, for example, to increases or decreases over several consecutive years) could bias the analysis of variance. The possible effect of a nonstationary mean on the analysis of variance will be discussed for each case. Statistical models are identical to those used to study log quality.

Height growth and site index

Balsam fir stand height growth as a function of age is modelled using Korf's function (Zarnovican 1979), which is given by:

$$h_t = b_1 \, e^{(b_2/(1-b_3))\, t^{(1-b_3)}} \qquad [5]$$

where b_1 identifies the asymptote; b_2 and b_3 describe the form of the curve and define its inflection point; and h_t is the height at age t. Stand height growth for thinned and control plots is compared with the same growth from Vézina-Linteau tables and with mature stand growth, to determine the optimal model. For comparison purposes, height growth under 30 years for the Vézina-Linteau tables is estimated using Korf's function. This descriptive study uses a mean stand height growth curve for each plot. Model selection is based on a criterion of least squares difference between estimated and actual values.

Volume yield - predictive model

Annual volume increment (i_v) is estimated from the product of height (h) in decimetres and basal area increment (ig) in square decimetres using the following model:

$$i_{v\text{-}s} = b_0 + b_1\,(h.ig) + e \qquad [6]$$

Regression lines are compared using the test presented in Neter and Wasserman (1974, p. 164). Statistical tests were calculated using software from SAS Institute Inc. (1985).

RESULTS AND DISCUSSION

Thinning and log quality

One of the objectives of this study was to determine the effect of silvicultural treatment on log quality, as measured by a number of variables selected in cooperation with Boisaco Inc. These variables are as follows:

1) CLL: clear log length (m);
2) REL-CLL: ratio of clear log length to tree length (%);
3) LBFLL: clear live-branch-free log length (m);
4) REL-LBFLL: ratio of clear live-branch-free log length to tree length (%);
5) TAPER RATIO: decrease in diameter per metre of length of the first 8-ft log (cm/m);
6) LIVE-WHORL-8: number of live whorls in the first 8-ft log.

Descriptive statistics (mean, standard deviation) calculated for these variables appear in Table 3.

Clear log length

Clear log length (CLL) of a tree is a direct indicator of lumber quality, as it measures that portion of the trunk that is free of branches and knots. The greater this quantity, the higher the proportion of good-quality wood. Table 4 presents ANOVA (analysis of variance) results for CLL in plots 1, 2, 3 and 4. The treatment and plot effects are significant at the 5% level, while the class effect is not significant. Figure 2 presents average CLL for thinned plots 1, 2, 3 and 4 as well as their control counterparts. CLL in control plots exceeds that in thinned plots. When plots were grouped, average CLL was 0.59 m for thinned plots, compared with 1.21 m for control plots, indicating that, on average, CLL is shorter by 60 cm in thinned plots, probably causing knots at a lower height in these trees.

Table 3. Morphological characteristics of the trees studied

Plot		Number	L (m)		CLL (m)		CLL (%)		LBFLL (m)		LBFLL (%)		TP (cm/m)		NLW	
			$\bar{x}$	s_x	$\bar{x}$	s_x	$\bar{x}$	s_x	$\bar{x}$	s_x	$\bar{x}$	s_x	$\bar{x}$	s_x	$\bar{x}$	s_x
1	Thinned	15	8.5	1.3	0.74	0.52	9.5	7.7	2.3	0.5	27.8	5.4	1.78	0.41	1.1	1.3
1	Control	15	9.9	1.5	1.23	0.51	12.4	5.2	4.2	0.7	42.9	7.6	1.17	0.45	0	0
2	Thinned	15	7.4	1.6	0.22	0.38	3.7	7	1.4	0.4	20.3	9.3	1.82	0.43	4.5	1.8
2	Control	15	9.2	1.7	1.18	0.29	12.9	3.1	3.6	0.7	39.8	6.3	1.38	0.49	0	0
3	Thinned	15	7.9	1.8	0.65	0.53	8	6.3	2.4	0.7	31.5	8.8	1.72	0.53	1.4	2.1
3	Control	15	9.9	1.7	1.31	0.59	13	5	3.7	0.9	37.7	6.4	1.19	0.44	0	0
4	Thinned	15	7.1	1.5	0.75	0.24	11	4.3	1.9	0.6	28	8.8	1.67	0.44	3	3.3
4	Control	15	9.2	1.4	1.13	0.39	12.4	4.1	3	0.8	33.3	8.1	1.34	0.44	0.4	1
9	Thinned	15	5.4	0.9	0.41	0.37	7.5	6.5	1.1	0.7	19.1	10.9	2.05	0.35	6.3	4
8	Control	15	5.5	0.8	0.34	0.3	6	5	1.3	0.5	24.1	10.7	1.66	0.39	4.7	2.4
11	Thinned	15	6.3	1.4	0.22	0.36	3.4	5.2	0.9	0.4	14.6	7.1	2.03	0.46	6.7	2.7
11	Control	15	6.1	1.4	0.38	0.48	6.3	7.9	1.6	0.6	25.6	8	1.95	0.28	4.7	3.6
12	Thinned	13	5.7	1.1	0.26	0.31	4.3	5.2	0.8	0.4	15.7	8.2	2.19	0.48	8.6	3.3
12	Control	15	5.5	0.9	0.37	0.3	6.5	5.2	1.4	0.5	25.5	8.5	1.67	0.34	5.7	3.5
14	Thinned	15	5.5	1.5	0.25	0.37	4.8	6.7	0.9	0.6	17.3	9.1	2.05	0.31	8.4	4.1
14	Control	14	5.7	1.1	0.82	0.46	14	5.7	1.9	0.6	33.6	8	1.85	0.39	3.6	2.9

L: tree length; CLL: clear log length; CLL (%): ratio CLL/L; LBFLL: clear live-branch-free log length; LBFLL (%): ratio LBFLL/L; NLW: number of live whorls; TP: taper ratio; $\bar{x}$: mean; s_x: standard deviation

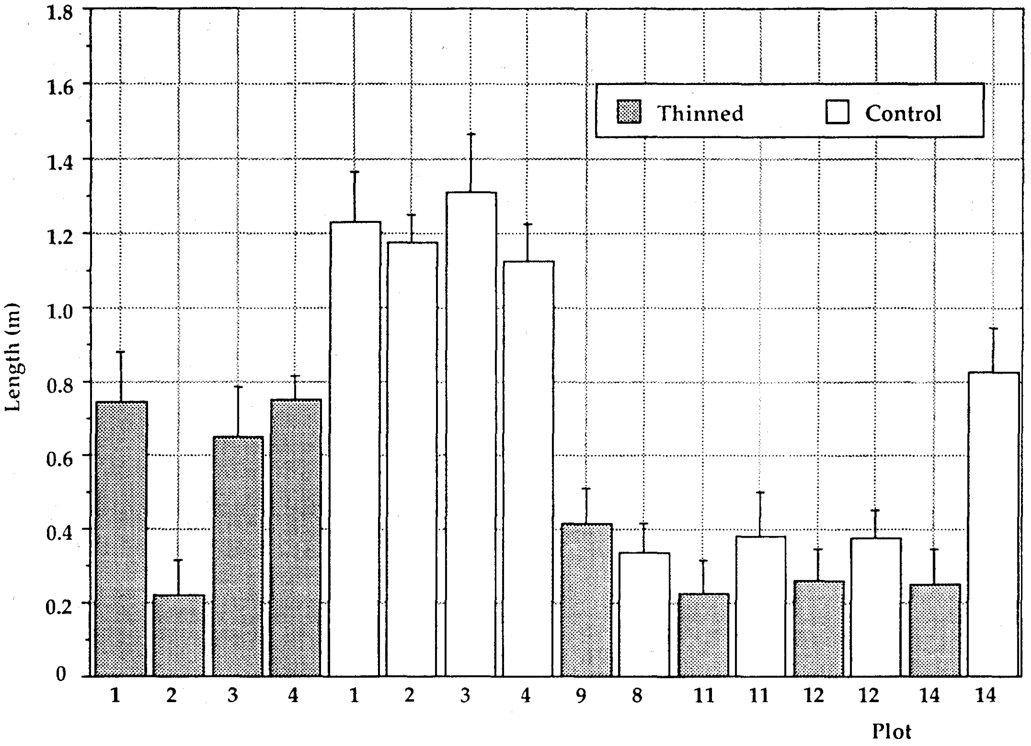

Figure 2. Clear log length (mean and standard error) by plot and treatment status.

Table 4. ANOVA table for CLL; plots 1, 2, 3 and 4

Source	df	SS	MS	F value	Prob >F
Treatment	1	11.54	11.54	21.91	0.0034
Plot (treatment)	6	3.16	0.53	2.59	0.023
Class (plot)	16	3.02	0.19	0.93	0.54
Error	96	19.49	0.20		

df=degrees of freedom, **SS**=sum of squares, **MS**=mean square, **Prob>F**=probability of obtaining a more extreme F-statistic under H_0. Parentheses indicate a nested effect. These abbreviations are used throughout the text.

However, the ANOVA results for plots 8, 9, 11, 12 and 14 (Table 5) suggest that thinning had no significant effect, however the significant interaction term (treatment x class) indicates that thinning did not have the same effect in all plots and require a study of treatment effect for each plot.

Table 5. ANOVA table for CLL; plots 8, 9, 11, 12 and 14

Source	df	SS	MS	F value	Prob >F
Treatment	1	1.03	1.03	2.00	0.25
Plot	3	0.92	0.31	2.45	0.033
Class (plot)	8	2.22	0.28	2.21	0.069
Treatment x plot	3	1.54	0.51	4.09	0.009
Treatment x class	8	1.29	0.16	1.29	0.26
Error	93	11.69	0.13		

Figure 2 illustrates mean clear log length for plots included in the study. The treatment x class interaction stands out clearly: log lengths in plot 9 (thinned) are slightly longer than those in plot 8 (control), and are slightly shorter in thinned plots (11, 12) than in control plots (11, 12). Finally, Student's t-test in plot 14 revealed that thinning has a significant effect on clear log length, which is much greater in the control plot than it is in the thinned plot.

Results on CLL indicate the following: CLL varies from one plot to another; it does not vary between social classes; and (with the exception of plots 9, 11 and 12) it is significantly shorter in thinned plots.

Ratio of clear log length to tree length

The ratio of clear log length to tree length (REL-CLL) indicates the portion of the tree that is branch free, as well as the degree of natural pruning of the tree with respect to its total height. Clear log length compared to total tree length can be compared between plots. Table 6 presents the ANOVA table for plots 1, 2, 3 and 4.

Table 6. ANOVA table for REL-CLL; plots 1, 2, 3 and 4

Source	df	SS	MS	F value	Prob>F
Treatment	1	0.07	0.0650	8.71	0.026
Plot (treatment)	6	0.04	0.0075	2.53	0.025
Class (plot)	16	0.06	0.0037	1.25	0.25
Error	96	0.28	0.029		

These results are similar to those for absolute clear log length (Table 4). In addition, Figure 3 appears to indicate that tree length has no effect on clear log length, or that total lengths are not sufficiently different between thinned and control plots to distinguish clear log lengths.

Results for combined plots indicate that this ratio is 8% in thinned plots and 12.7% in control plots. As is apparent from Table 3, trees in control plots are longer than those in thinned plots, which explains why thinned and control plots are more similar with respect to relative clear log length than absolute length (Figures 2 and 3).

Results for plots 8, 9, 11, 12 and 14 (Table 7) indicate that only the treatment x plot interaction is significant. This interaction term was also significant for absolute clear log length. Figure 3 presents average clear log length/tree length ratios for these four plots.

Table 7. ANOVA table for REL-CLL; plots 8, 9, 11, 12 and 14

Source	df	SS	MS	F value	Prob>F
Treatment	1	0.03	0.0303	2.18	0.23
Plot	8	0.03	0.0115	3.27	0.30
Class (plot)	3	0.03	0.0043	1.21	0.48
Treatment x plot	8	0.04	0.0139	3.95	0.01
Treatment x class	3	0.03	0.0039	1.12	0.36
Error	93	0.33	0.0035		

As with absolute clear log length, the treatment x plot interaction is readily apparent: the ratio is slightly higher in thinned plot 9; the ratio is slightly higher in control plots 11 and 12; the ratio is much higher in control plot 14 than in the corresponding thinned plot. Student's t-test indicates a significant thinning effect in plot 14 only.

As with clear log length, there were no differences in ratios between social classes; furthermore, treatment effects are significant in plots 1, 2, 3, 4 and 14. The hypothesis that clear log lengths are the same for all plots is rejected.

Live-branch-free log length

This is another quality indicator, in that live branches generally signify large knots. Therefore, greater live-branch-free log length (LBFLL) indicates better quality wood. As is apparent from the ANOVA results for plots 1, 2, 3 and 4 (Table 8), the treatment and plot effects are significant.

As illustrated in Figure 4, mean live-branch-free log lengths are greater in control plots (3.65 m) than in thinned plots (2.02 m), which is a difference of 1.63 m. This indicates that branches and large knots are closer to the ground in thinned plots.

Table 8. ANOVA table for LBFLL; plots 1, 2, 3 and 4

Source	df	SS	MS	F value	Prob>F
Treatment	1	79.77	79.77	23.49	0.0029
Plot (treatment)	6	20.38	3.40	6.70	0.0001
Class (plot)	16	5.52	0.35	0.68	0.81
Error	96	48.64	0.51		

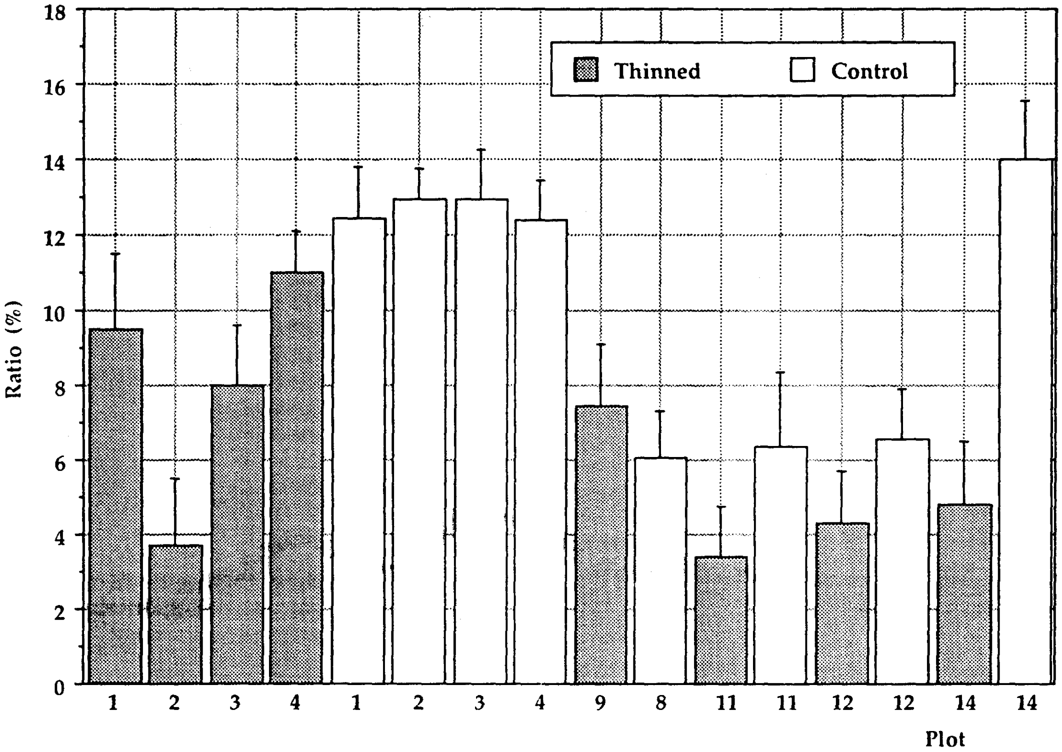

Figure 3. Ratio of clear log length to tree length (mean and standard error) by plot and treatment status.

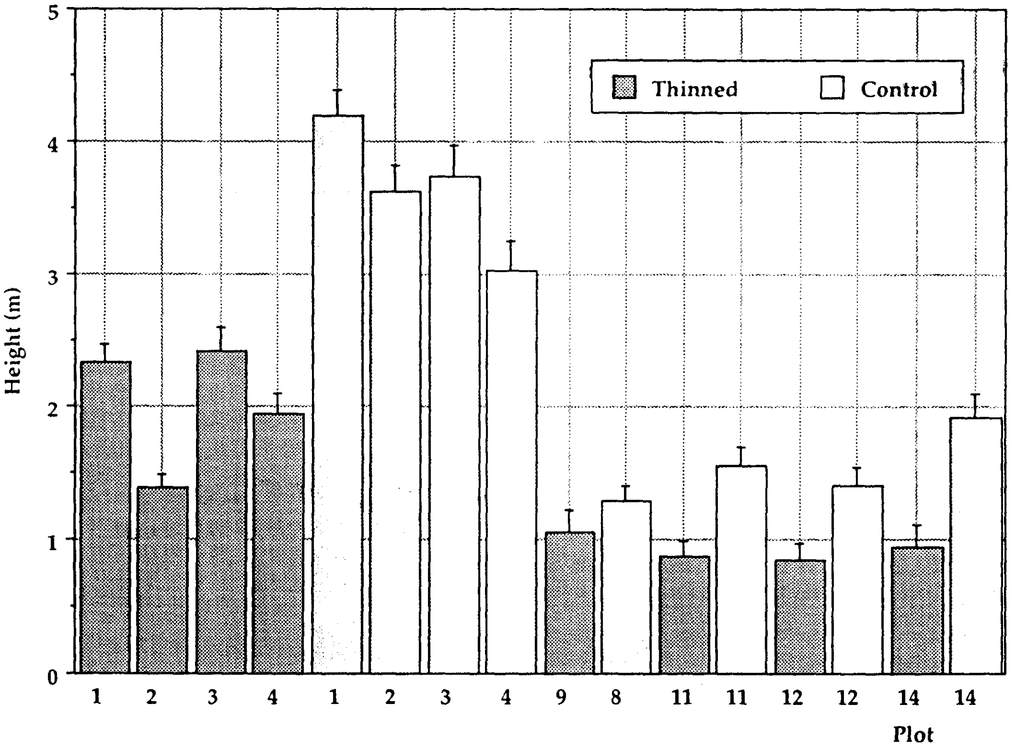

Figure 4. Live-branch-free log length (mean and standard error) by plot and treatment status.

ANOVA results for plots 8, 9, 11, 12 and 14 appear in Table 9. The treatment and class factors are significant, while the interactions are not.

Table 9. ANOVA table for LBFLL; plots 8, 9, 11, 12 and 14

Source	df	SS	MS	F value	Prob>F
Treatment	1	10.43	10.43	15.61	0.029
Plot	3	1.51	0.50	1.98	0.12
Class (plot)	8	5.64	0.70	2.77	0.0085
Treatment x plot	3	2.01	0.67	2.63	0.055
Treatment x class	8	3.23	0.40	1.59	0.14
Error	93	23.63	0.25		

Figure 4 illustrates the lack of a treatment x plot interaction, in that the treatment effect is similar in all plots (although somewhat greater in plot 14 than in plot 8). Furthermore, mean branch-free log lengths are fairly similar (2.9 m for upper class trees, 2.9 m for middle class trees and 2.7 m for lower class trees).

Comparison of branch-free log lengths (Figure 4) indicates that lengths are shorter in plots 8, 9, 11, 12 and 14 than in plots 1, 2, 3 and 4.

Ratio of branch-free log length to tree length

Much like the clear log length/tree length ratio, the branch-free log length/tree length ratio (REL-LBFLL) reflects the true significance of the treatment effect, since trees in control plots are longer than those in thinned plots. Table 10, which presents the ANOVA table for plots 1, 2, 3 and 4, suggests that all three effects are significant. Therefore, the significance of the treatment and plot factors is not affected by tree length within plots. Results were different for the class factor, however: adjusting for tree length reveals that relative branch-free log lengths differ significantly from one social class to another.

Table 10. ANOVA table for REL-LBFLL; plots 1, 2, 3 and 4

Source	df	SS	MS	F value	Prob>F
Treatment	1	0.40	0.3975	13.80	0.0099
Plot (treatment)	6	0.17	0.0288	6.04	0.0001
Class (plot)	16	0.21	0.0131	2.74	0.0013
Error	96	0.46	0.0048		

Figure 5 illustrates the mean branch-free log length/tree length ratios for thinned and control plots. All control plots show larger ratios than do thinned plots. When plots are grouped, mean branch-free log length for thinned plots is 26.9% of tree length, compared with 38.4% for control plots. This suggests that, on average and in proportion to total tree length, height growth is 11.5% lower in control plots than in thinned plots.

The significant social class effect is apparent from the widely differing values between classes. For example, mean branch-free log length/tree length ratios are 27% for upper class, 34% for middle class and 37% for lower class. Therefore, mean branch-free log length is related not so much to tree length itself as it is to plot characteristics.

The ANOVA results for plots 8, 9, 11, 12 and 14 are presented in Table 11, which indicates that the treatment effect alone is significant at the 5% level. Figure 5 presents average relative branch-free log lengths for the four thinned-control plot pairs. The high degree of homogeneity of tree lengths within paired plots explains the strong similarity between Figures 4 and 5, as well as the treatment effect in Tables 9 and 11.

Table 11. ANOVA table for REL-LBFLL; plots 8, 9, 11, 12 and 14

Source	df	SS	MS	F value	Prob>F
Treatment	1	0.321	0.3210	19.03	0.022
Plot	3	0.052	0.0174	2.45	0.069
Class (plot)	8	0.109	0.0136	1.92	0.067
Treatment x plot	3	0.051	0.0169	2.38	0.075
Treatment x class	8	0.100	0.0125	1.75	0.096
Error	93	0.660	0.0071		

Taper ratio

Taper ratio refers to the decrease in diameter per linear metre in the first 8 ft (2.44 m) log. It is a measure of the quality of a stem, particularly its form (cylindrical or conic). Table 12, which presents the ANOVA table for plots 1, 2, 3 and 4, indicates that treatment and class effects are significant for this variable. When plots are grouped by treatment level, mean taper ratio is 1.75 cm/m in thinned plots, compared with 1.27 cm/m in control plots. When plots are grouped by social class, however, mean taper ratio is 1.94 cm/m for upper class, 1.48 cm/m for middle class and 1.10 cm/m for lower class. Taken as a whole, these data suggest that taper ratio increases with the size of the tree.

Figure 6 presents mean taper ratio for plots 1, 2, 3 and 4 (thinned and control). Taper ratio is most similar among control plots and among thinned plots. The results on taper ratio in plots 8, 9, 11, 12 and 14 contained in Table 13 are identical to those in Table 12. When plots are grouped by treatment status, mean taper ratio is 2.08 cm/m in thinned plots, compared with 1.78 cm/m in control plots.

Table 12. ANOVA table for taper ratio; plots 1, 2, 3 and 4

Source	df	SS	MS	F value	Prob>F
Treatment	1	6.93	6.93	57.20	0.0003
Plot (treatment)	6	0.73	0.12	1.45	0.21
Class (plot)	16	15.17	0.95	11.32	0.0001
Error	96	8.04	0.08		

When plots are grouped by social class, mean taper ratio is 2.21 cm/m for upper class, 1.79 cm/m for middle class and 1.77 cm/m for lower class.

Table 13. ANOVA table for taper ratio; plots 8, 9, 11, 12 and 14

Source	df	SS	MS	F value	Prob>F
Treatment	1	2.524	2.524	10.88	0.046
Plot	3	0.274	0.091	0.89	0.450
Class (plot)	8	5.438	0.680	6.64	0.0001
Treatment x plot	3	0.696	0.232	2.27	0.09
Treatment x class	8	0.608	0.076	0.74	0.65
Error	93	9.523	0.102		

As with plots 1, 2, 3 and 4, taper ratio increases with tree size. Comparison of plots 1, 2, 3 and 4 with plots 8, 9, 11 and 12, however, suggests that taper may increase with treatment intensity. For example, although trees in plots 1, 2, 3 and 4 are larger, they display less taper than trees in plots 8, 9, 11, 12 and 14 whose diameters are smaller nonetheless.

LIVE-WHORL-8: number of live whorls

The final variable used to assess the effect of thinning on young stand log quality is the number of live whorls on the first 8-ft log. Table 14 presents ANOVA results for plots 1, 2, 3 and 4, indicating significant treatment and plot effects. When plots are grouped by treatment level, there is an average of 2.5 whorls on the first 8-ft log in thinned plots, compared with 0.1 whorls on similar logs in control plots.

Table 14. ANOVA table for LIVE-WHORL-8; plots 1, 2, 3 and 4

Source	df	SS	MS	F value	Prob>F
Treatment	1	172.4	172.40	8.92	0.0244
Plot (treatment)	6	116.0	19.33	7.10	0.0001
Class (plot)	16	36.9	2.31	0.85	0.63
Error	96	261.5	2.72		

Figure 7 illustrates means and standard errors for plots 1, 2, 3 and 4. The almost complete absence of live branches on the first 8-ft logs in control plots is apparent, while there are between 1.1 and 4.5 live whorls on the same log in control plots. Table 15 contains the ANOVA table for the number of whorls in plots 8, 9, 11, 12 and 14, and highlights the significant treatment and class effects for this variable.

Table 15. ANOVA table for LIVE-WHORL-8; plots 8, 9, 11, 12 and 14

Source	df	SS	MS	F value	Prob>F
Treatment	1	235.5	235.46	17.12	0.026
Plot	3	46.4	15.48	1.86	0.14
Class (plot)	8	342.9	42.87	5.14	0.0001
Treatment x plot	3	41.3	13.76	1.65	0.18
Treatment x class	8	101.3	12.67	1.52	0.16
Error	93	774.9	8.33		

When plots are grouped by treatment level, there are 7.5 live whorls in the first 8-ft log from trees in thinned plots, compared with 4.7 live whorls on trees from control plots. On average, there are 2.5 more live whorls on the first 8-ft log from trees in thinned plots than on those in control plots. Figure 7 indicates that the thinning effect is fairly consistent from one plot to another, with the exception of plot 14 where the difference is greater.

Thinning and log quality - conclusions

The analysis of variance results clearly demonstrate that precommercial thinning has an effect on qualitative log characteristics. For example, mean clear log length is 60 cm (4.6% of the tree) shorter in thinned plots 1, 2, 3 and 4. The effect of thinning is less general in plots 8, 9, 11, 12 and 14; the only significant difference, in plot 14, was about 60 cm or 10% of the tree.

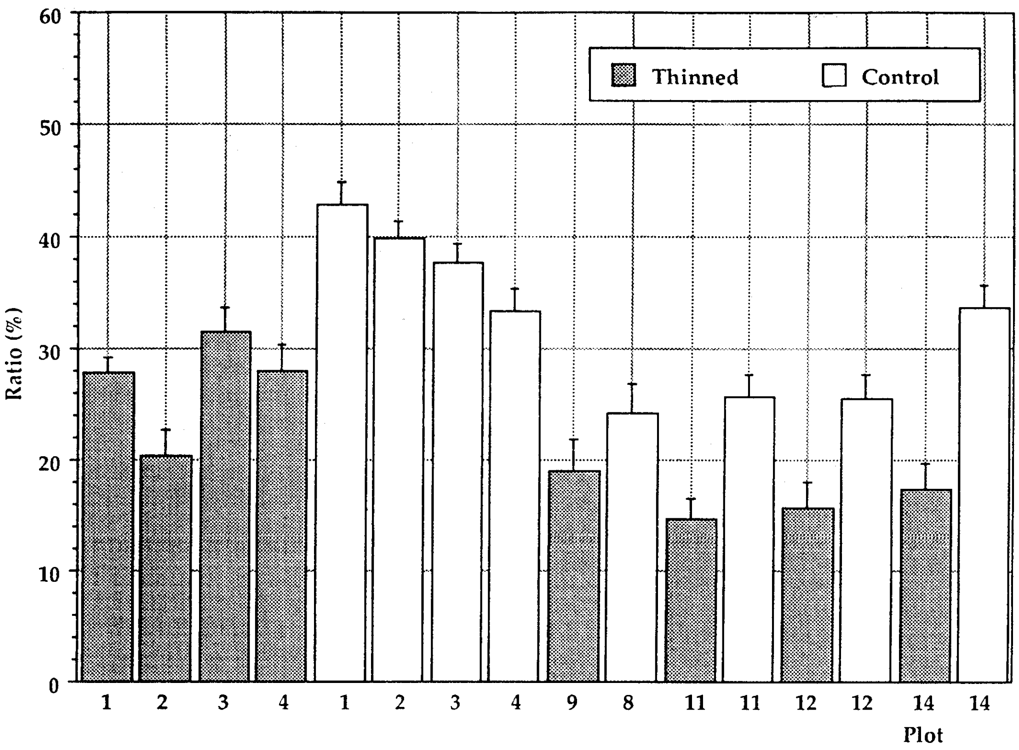

Figure 5. Ratio of branch-free log length/tree length (mean and standard error) by plot and treatment status.

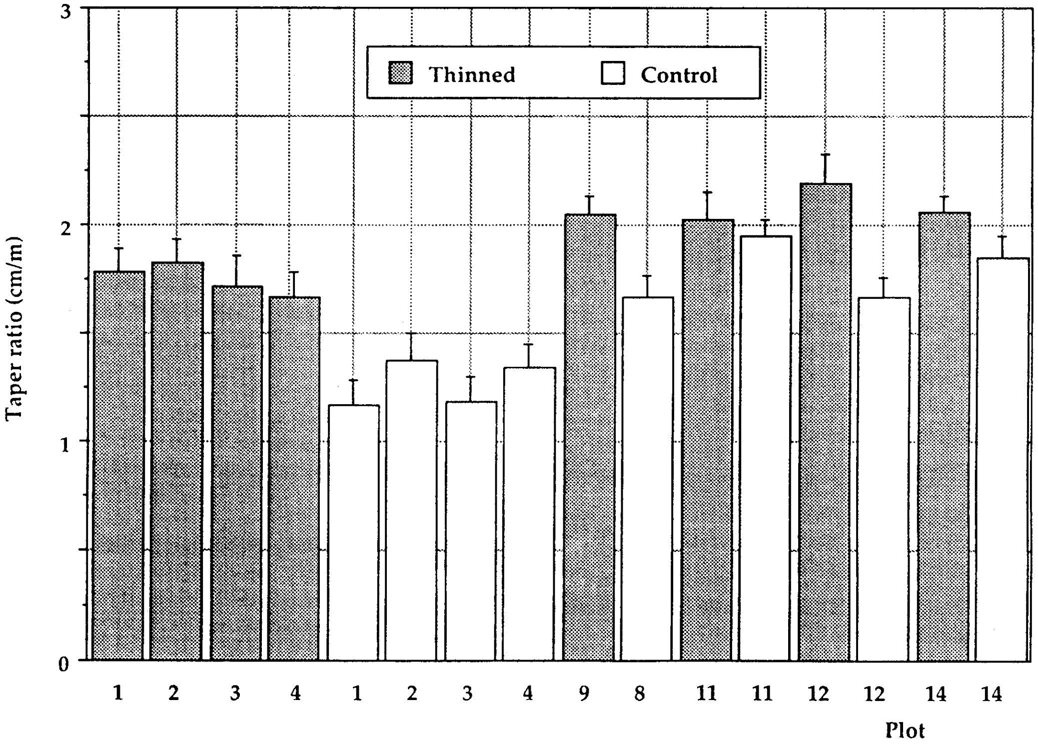

Figure 6. Taper ratio in first 8-ft segment (mean and standard error) by plot and treatment status.

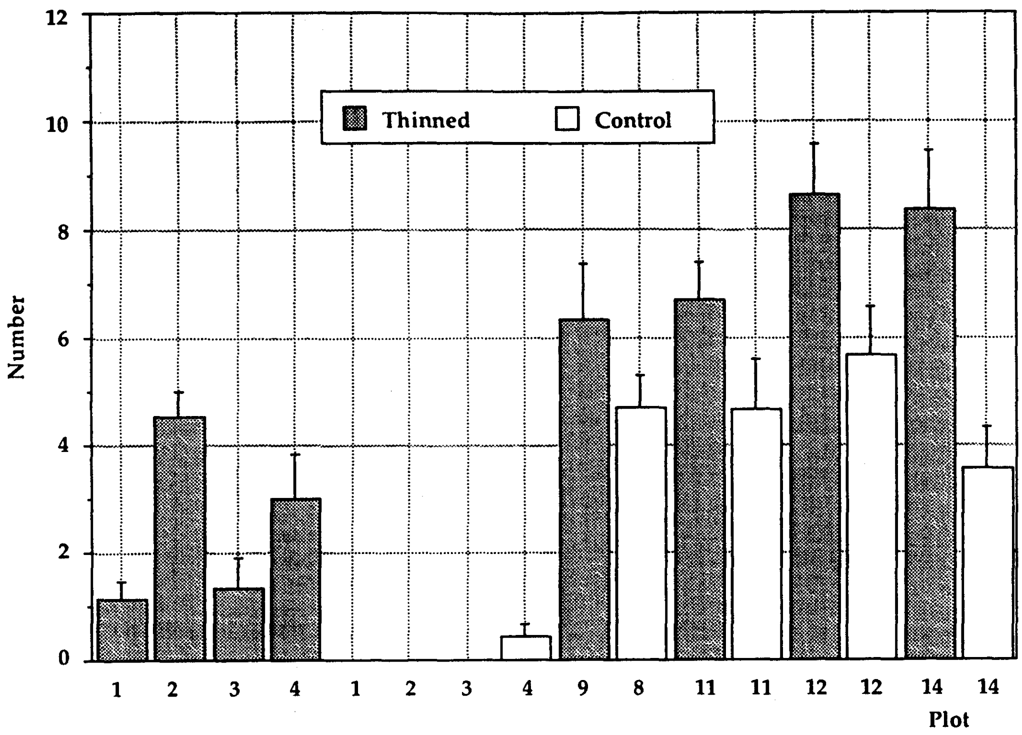

Figure 7. Number of live whorls in first 8 ft (mean and standard error) by plot and treatment status.

Results concerning branch-free log length indicate that thinning caused an increase of live crown, on average, by 1.63 m (11.5%) in plots 1, 2, 3 and 4 and by 0.60 m (10.4%) in plots 8, 9, 11, 12 and 14. As size and length of live crown govern wood production, particularly in young timber (Elliott 1970), there is almost no latewood in the live crown zone (Larson 1962).

By increasing spacing among residual stocking, intense thinning does not encourage natural pruning, maintains low live crown, extends formation of juvenile wood and, consequently, affects lumber production. Writing about Sitka spruce in Great Britain, Brazier *et al.* (1985) report that spacing above 2 m, while economically desirable, is viewed as harmful to lumber yields in view of the proportion of juvenile wood and resulting technical defects.

Precommercial thinning does increase taper in 8-ft segments. Taper ratio was 1.75 cm/m in thinned plots 1, 2, 3 and 4, compared with 1.27 cm/m in control plots. In thinned plots 9, 11, 12 and 14, taper ratio was 2.08 cm/m compared with 1.78 cm/m in control plots, even though trees were smaller in plots 1, 2, 3 and 4.

By way of comparison, data collected by Corneau (personal communication) on taper of 51 balsam fir in New Brunswick (d_{avg} = 19.3 cm, minimum = 15.2 cm, maximum = 24.1 cm) indicate a taper ratio of 1.01 cm/m in the first 2 m segment and 0.84 cm/m in the first 3 m segment. Barbour *et al.* (1992) report that 15 years after intensive thinning (2.4 m spacing) of red spruce, taper ratio had doubled.

Finally, thinning encourages growth of live whorls in the first 8 ft: while 2.5 whorls were observed in thinned plots 1, 2, 3 and 4, only 0.1 were observed in the corresponding control plots. In plots 8, 9, 11, 12 and 14, the number of live whorls is 7.5 in thinned plots and 4.7 in control plots. Intensity of thinning (i.e., spacing among residual stocking) appears to be a determining factor for the height of the first live whorl. This confirms Johansson's (1992) results for spruce in Sweden, in which an increase in spacing from 1 m to 2 m decreased sawlog yield of a 78-year-old spruce stand from 86% to 16% of standing volume per hectare. The present results clearly indicate that intensive precommercial thinning can affect log quality.

Dendrochronological analysis of the thinning effect

The purpose of this dendrochronological analysis is to examine the size and temporal effects of thinning on radial increment of balsam fir. It has been shown (Vézina 1964, Vézina and Doucet 1969, Ker 1981, Lavigne and Donnelly 1989) that thinning stimulates radial growth of residual trees. In this regard, the present study compares radial increment in thinned stands with that in control stands. Despite the positive effect of thinning on radial growth, however, there are few data on the distribution of the radial increment between the breast height and the stump as a result of thinning. This study attempts to fill that gap.

Effect of thinning on radial increment

The reaction of trees to thinning in plots 1, 2, 3 and 4 is described by ANOVA results presented in Table 16 and plotted in Figure 8. Treatment and plot have a strong influence on radial increment, as demonstrated by the significant difference between the ir_{dif} in thinned and control plots. When plots are grouped by treatment level, the data reveal a mean increase of 0.19 mm/year following thinning in thinned plots, compared with a decrease of 0.48 mm/year in control plots.

Table 16. ANOVA table for ir_{dif}; plots 1, 2, 3 and 4

Source	df	SS	MS	F value	Prob>F
Treatment	1	12.65	12.65	17.52	0.0058
Plot (treatment)	6	4.33	0.72	6.30	0.0001
Class (plot)	16	2.90	0.18	1.58	0.090
Error	89	10.20	0.11		

The significance of the plot effect can be traced to variations in amplitude reaction from one plot to another. Finally, the nonsignificance of the class effect reflects similar behaviour among trees in different social classes (Figure 8). A study of time series patterns sheds further light in this regard. Figure 9 reproduces time series for social classes in plots thinned-2 and control-2 to illustrate the radial growth pattern.

In general, radial growth in control stands is a monotone decreasing series; after thinning, however, stands react with a significant jump in radial growth. A reaction to 1984 thinning was visible as early as 1985; the increase is very pronounced until 1987-1988, after which the thinning effect declines. Radial growth reaches its peak 4 years after thinning, with maximal increase of about 2 mm/year for the upper class and 1 to 1.5 mm/year for the lower class. The effect of thinning on radial growth disappears after seven years, as annual increment returns to pre-treatment levels. Given the differences in growth between thinned and control plots, climate may be excluded as a possible explanation for these results.

Results from the analysis of variance for plots 8, 9, 11, 12 and 14 are presented in Table 17 and plotted in Figure 10. These results indicate highly significant treatment and plot effects. Therefore, there is a significant difference in radial growth between thinned and control plots. Grouping of plots by treatment level indicates a mean increase of 0.30 mm/year for thinned plots following thinning, compared with a 0.91 mm/year decrease for control plots in the same period.

The significance of the plot factor can be explained by variations in amplitude reactions from one plot to another (Figure 10); the lack of significance of the class factor appears to be caused by similar reactions to treatment in all social classes (Figure 11).

Table 17. ANOVA table for ir_{dif}; plots 8, 9, 11, 12 and 14

Source	df	SS	MS	F value	Prob>F
Treatment	1	38.38	38.38	93.09	0.002
Plot	3	2.78	0.93	4.01	0.010
Class (plot)	8	2.18	0.27	1.18	0.32
Treatment x plot	3	1.24	0.41	1.78	0.16
Treatment x class	8	1.31	0.16	0.71	0.68
Error	88	20.32	0.23		

The time series (Figure 11) is monotone decreasing for control plots, but shows a clear increase for thinned plots after the 1988 thinning. In addition, the thinning effect begins to dissipate after the fourth year.

Since thinning was more recent in these plots, it is impossible to specify the duration of this effect; it appears reasonable to assume, however, that it is identical to that in plots 1, 2, 3 and 4. Finally, the results appear to be sufficiently clear to exclude the climate effect as a possible cause of the increase. The immediate effect of thinning on plots 9 and 14 is reflected by an increase in radial growth of about 2 mm/year in all social classes, while it is more modest in plots 11 and 12.

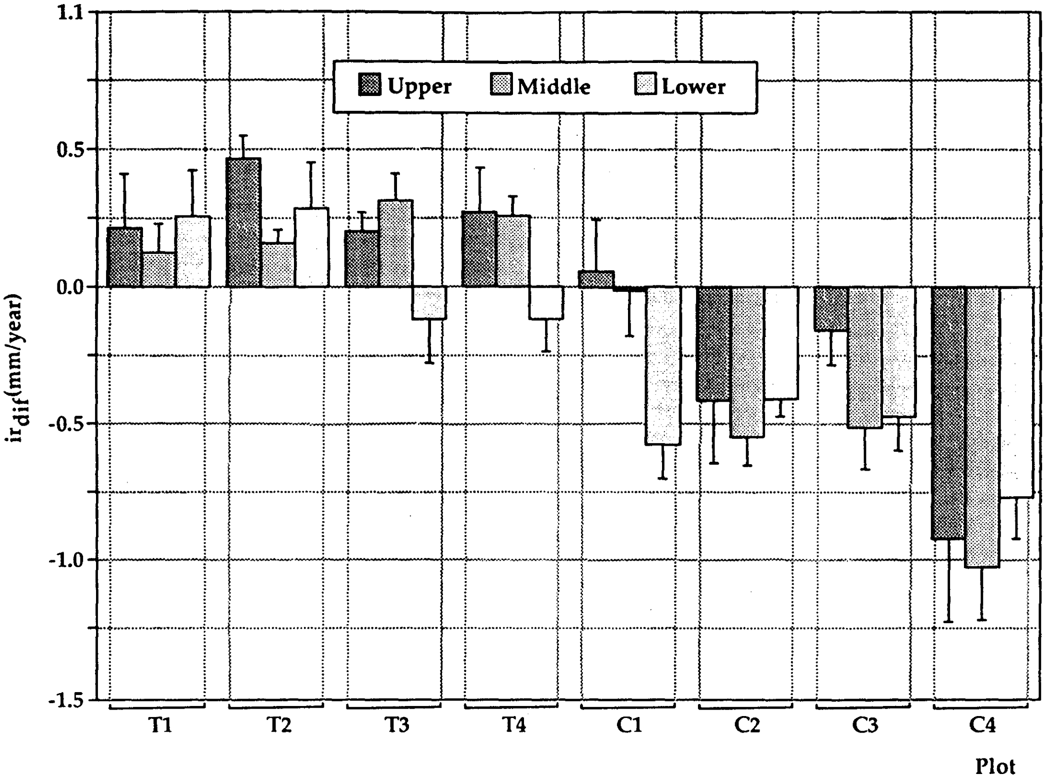

Figure 8. Differences between periodic radial increment (mean and standard error) before and after treatment, for plots 1, 2, 3 and 4 (T-treatment, C-control), by social class.

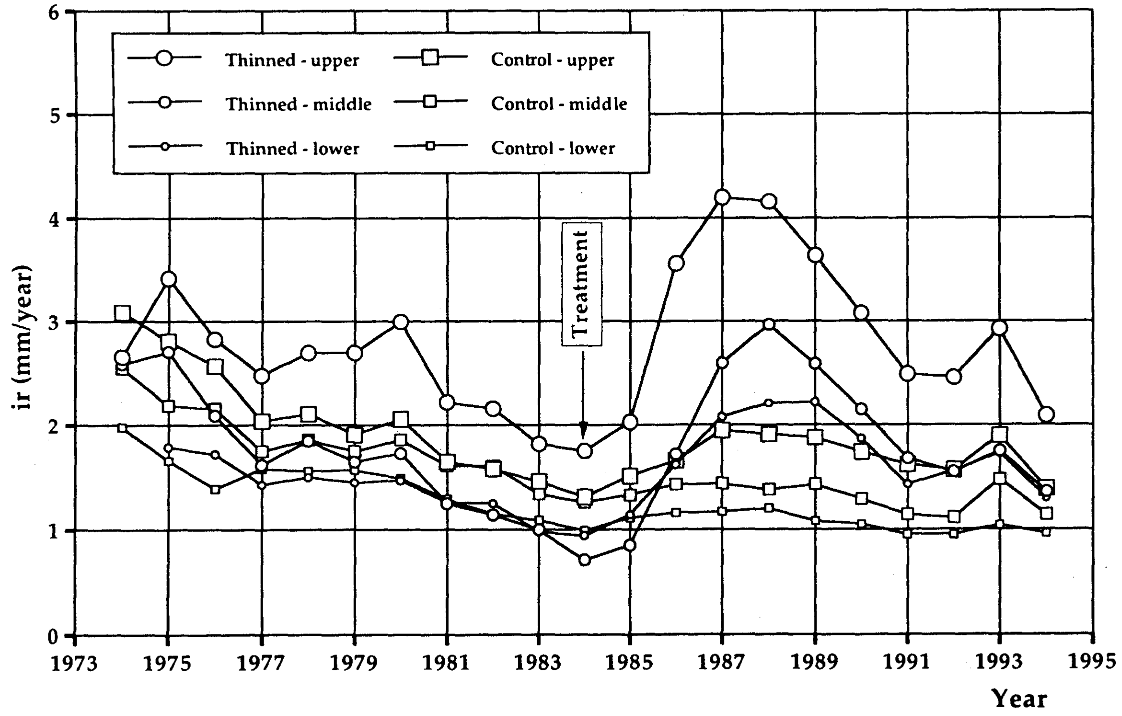

Figure 9. Radial increment (mean by social class), plot 2.

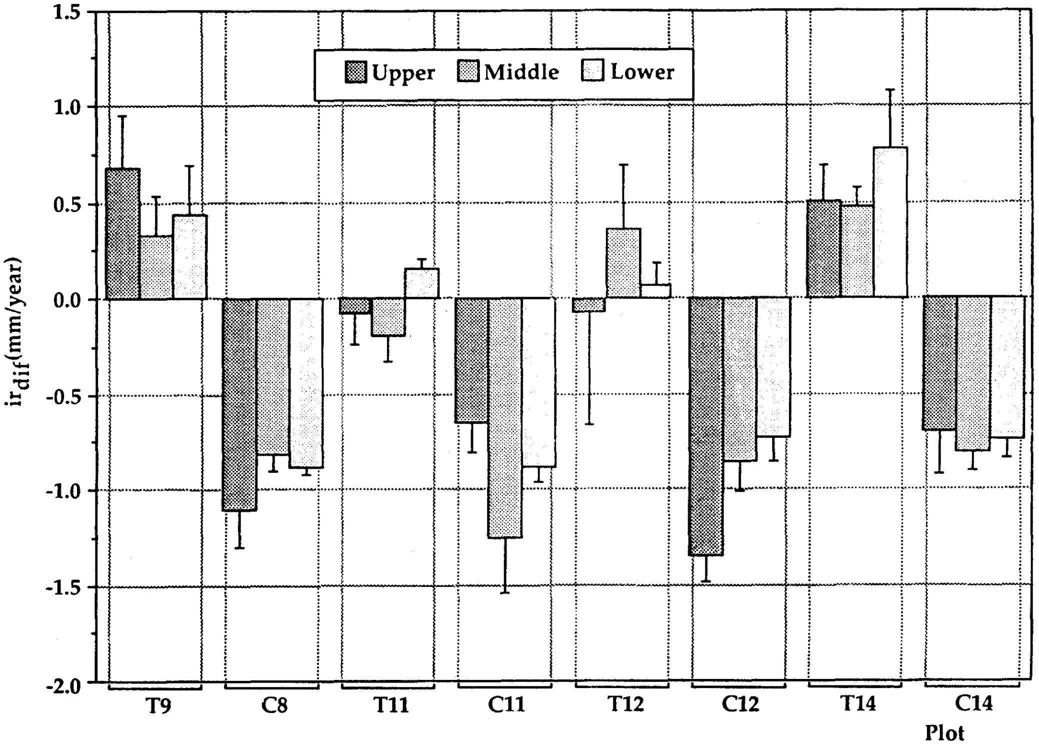

Figure 10. Differences between periodic radial increment (mean and standard error) before and after treatment, for plots 8, 9, 11, 12 and 14 (T-thinned, C-control), by social class.

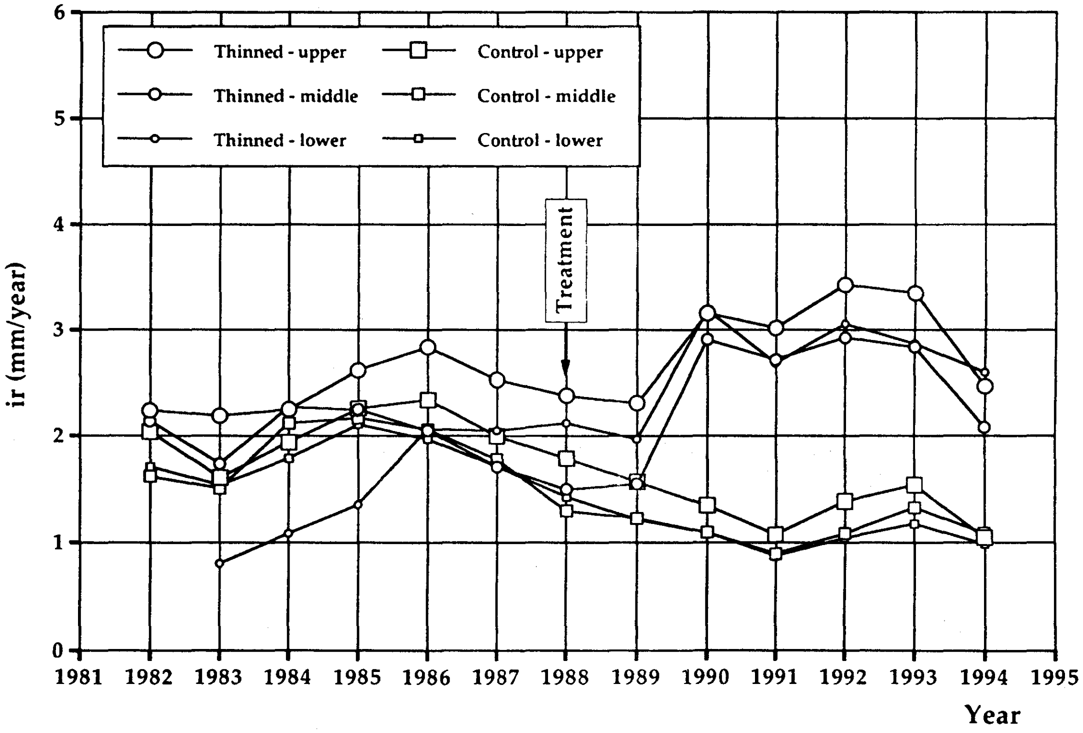

Figure 11. Radial increment (mean by social class), plot 14.

Breast height/stump radial increment ratio

The above results clearly show that thinning stimulates radial growth at breast height. This section compares the change (p_{diff}) in the ratio of radial increment measured at stump to that measured at breast height, ir_s/ir_{BH}, before and after thinning between thinned and control plots, using ANOVA tests similar to those applied to differences in radial increment. For plots 1, 2, 3 and 4, the dependent variable p_{diff} is defined by:

$$p_{diff} = p_{mean}(1985 \text{ to } 1994) - p_{mean}(1974 \text{ to } 1983) \quad [7]$$

For plots 8, 9, 11, 12 and 14, this quantity is defined by:

$$p_{diff} = p_{mean}(1989 \text{ to } 1994) - p_{mean}(1982 \text{ to } 1987) \quad [8]$$

In plots 1, 2, 3 and 4, the ANOVA results (Table 18) indicate that thinning significantly affects the distribution of radial increment between stump and breast height, suggesting that thinning differentially favours the former over the latter. This increases both the lower butt and taper of individual trees.

When the ir_s/ir_{BH} ratio after thinning is compared with that calculated before thinning (Figure 12), it is apparent that increment at stump exceeds increment at breast height by 30% in thinned plots and by 12% in control plots. A similar comparison of social classes (Figure 12) confirms the nonsignificance of the class factor.

Table 18. ANOVA table for p_{diff}; plots 1, 2, 3 and 4

Source	df	SS	MS	F value	Prob>F
Treatment	1	0.50	0.50	26.87	0.0020
Plot (treatment)	6	0.11	0.02	1.44	0.21
Class (plot)	16	0.18	0.01	0.87	0.60
Error	89	1.15	0.01		

ANOVA results for plots 8, 9, 11, 12, 14 (Table 19) are similar to those for plots 1, 2, 3 and 4. The significance of the treatment and plot factors confirms that thinning increases the lower butt due to an increase in radial growth at the stump.

Grouping plots by treatment level reveals a mean increase of 26% (Figure 13) since thinning for thinned plots, compared with an increase of 14% for control plots. There is no significant difference between social classes.

Table 19. ANOVA table for p_{diff}; plots 8, 9, 11, 12 and 14

Source	df	SS	MS	F value	Prob>F
Treatment	1	0.28	0.279	29.97	0.012
Plot	3	0.19	0.064	4.93	0.003
Class (plot)	8	0.13	0.016	1.23	0.29
Treatment x plot	3	0.03	0.009	0.72	0.54
Treatment x class	8	0.08	0.009	0.73	0.66
Error	88	1.13	0.013		

Thinning and radial increment - conclusions

This comparison of radial increment indicates that plots 1, 2, 3 and 4 and plots 8, 9, 11, 12 and 14 are very similar. In general, radial increment increases significantly after thinning. This increase, however, is greater at stump than at breast height, thus causing a significant increase of the lower butt. The thinning effect is identical for all trees, regardless of social class, and it drops off after the fourth year.

For plots 1, 2, 3 and 4, radial increment returned to prethinning levels after about seven years; the same should be true for plots 8, 9, 11, 12 and 14.

Height growth and site index

This section analyzes height growth of balsam fir to assess site quality and applicability of the Vézina and Linteau (1988) site index model to the plots under study.

Mature stands

The Vézina-Linteau and mature stand curves were fitted using Korf's function. Parameter estimates for this function are presented in Table 20 and plotted in Figure 14. Modelling results using Korf's function are entirely consistent. The only apparent difference from the Vézina-Linteau curves is in the asymptote, which might suggest an anamorphic structure over time. The mature stand and Vézina-Linteau curves cross; the mature stand curve predicts greater height growth between 20 and 60 years than does the Vézina-Linteau curve.

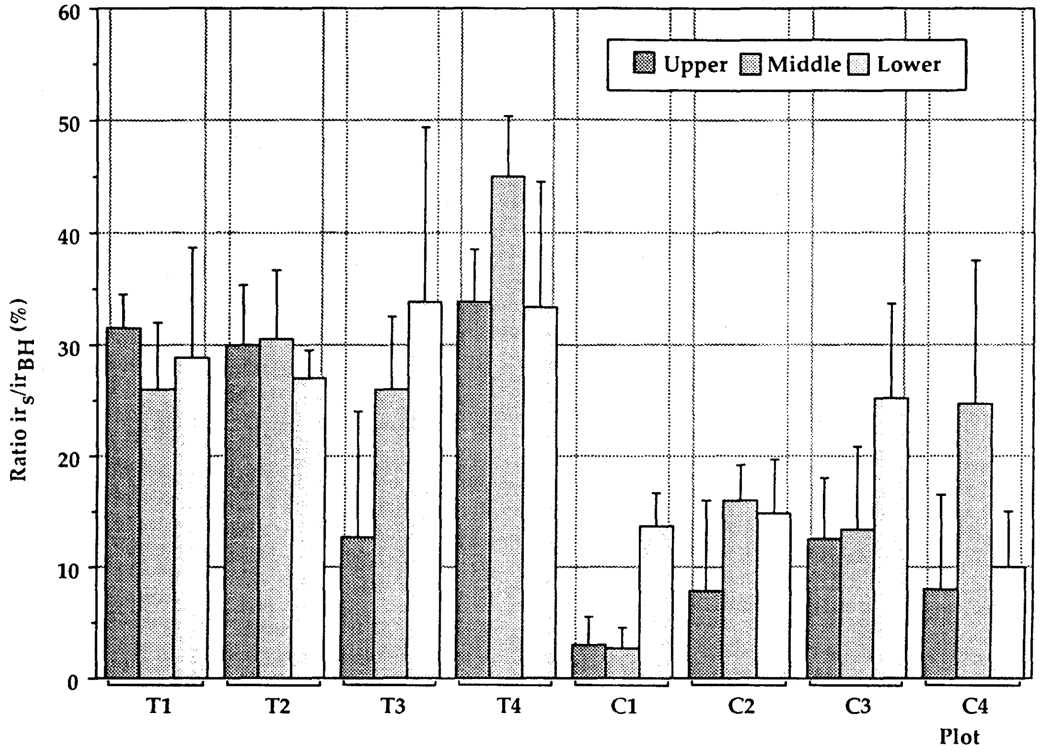

Figure 12. Change in the ratio ir_s/ir_{BH} after thinning (mean and standard error) for plots 1, 2, 3 and 4 (T-treatment, C-control), by social class.

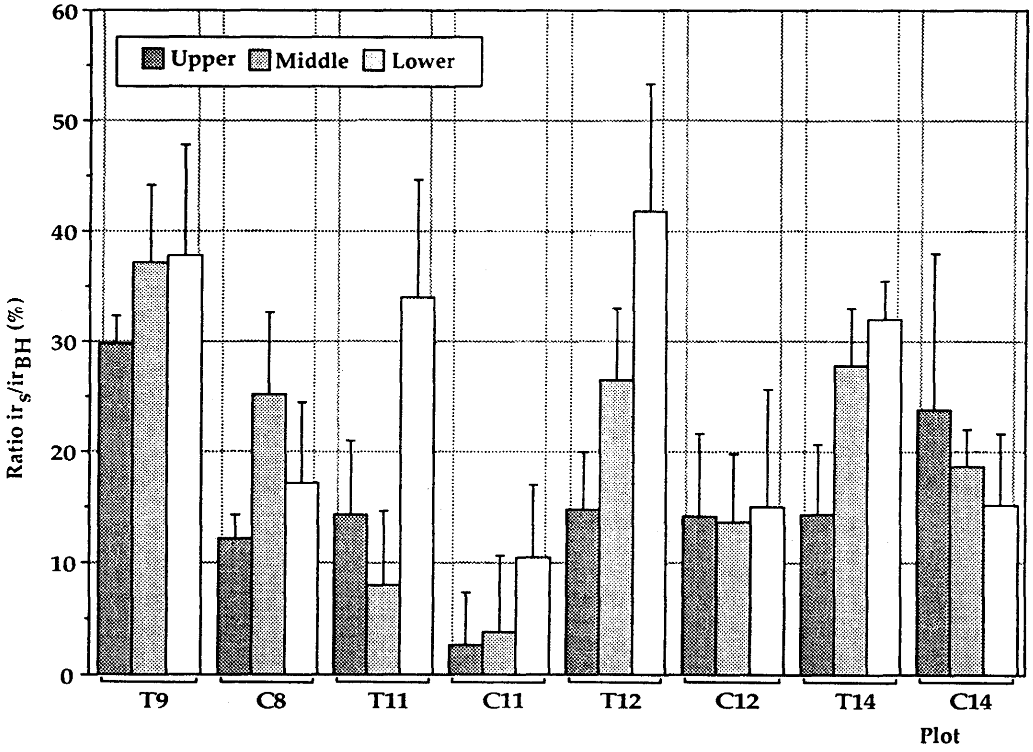

Figure 13. Change in the ratio ir_s/ir_{BH} after thinning (mean and standard error) for plots 8, 9, 11, 12 and 14 (T-treatment, C-control), by social class.

Table 22. Sums of square errors (SSQ) and mean square errors (MSE) for thinned plots with respect to mature stands and Vézina and Linteau (VL)

Plot	N	VL.I SSQ	VL.II SSQ	Mature SSQ	VL.I MSE	VL.II MSE	Mature MSE
TEM-1	17	6.35	23.80	36.39	0.37	1.40	2.14
TEM-2	16	3.76	17.69	32.33	0.24	1.11	2.02
TEM-3	17	12.49	22.20	30.75	0.73	1.31	1.81
TEM-4	15	3.52	44.32	69.81	0.23	2.95	4.65
TEM-8	14	23.30	0.75	5.79	1.66	0.05	0.41
TEM-11	14	19.37	0.46	5.50	1.38	0.03	0.39
TEM-12	14	35.24	2.85	4.96	2.52	0.20	0.35
TEM-14	14	49.90	6.83	1.62	3.56	0.49	0.12

Shaded areas indicate the best fit model for the period under study.

Table 23. Results of linear regression of volume increment (i_v) on the product ($h.i_g$) for plots under study

Plot	Estimate of b_0	Estimate of b_1	R^2	SEE	i_v - mean ($dm^3.y^{-1}$)
Control-1	0.30	0.67	0.99	0.19	3.59
Control-2	0.14	0.72	1.00	0.10	2.63
Control-3	0.39	0.65	0.99	0.21	3.51
Control-4	0.18	0.70	0.99	0.18	2.79
Control-8	0.09	0.67	0.99	0.05	1.25
Control-11	0.13	0.64	0.99	0.12	1.59
Control-12	0.14	0.74	0.99	0.05	1.16
Control-14	0.01	0.70	0.95	0.11	1.05
Thinned-1	0.04	0.65	0.99	0.16	3.41
Thinned-2	0.18	0.61	0.99	0.17	2.91
Thinned-3	0.14	0.64	0.99	0.15	2.63
Thinned-4	0.11	0.63	1.00	0.10	2.16
Thinned-9	0.14	0.60	0.99	0.10	2.03
Thinned-11	0.11	0.60	0.99	0.23	3.05
Thinned-12	0.19	0.56	1.00	0.09	2.30
Thinned-14	0.26	0.59	0.98	0.21	2.25

Model [9] is very similar to individual models for these plots. The mean error of prediction suggests that the model can estimate volume increment with satisfactory precision. Specifically, a prediction accurate to ± 0.15 dm^3 (about 5%) could be expected two times out of three, and a prediction accurate to ± 0.30 dm^3 (about 10%) 19 times out of 20.

2. Predictive model for control plots 1, 2, 3 and 4.

The following regression was obtained using data from these four plots:

$$i_v = 0.27 + 0.68\,(h.i_g) + e \qquad [10]$$

The model explains 99% of variation in volume increment for the four plots, with a SEE of 0.18 dm^3. As the test to compare regression lines revealed no significant difference between them, model [10] can be used to study volume yield from these plots.

From Table 23, it is evident that model [10] is very similar to models for each plot. Furthermore, the SEE indicates that it will estimate volume increment with considerable accuracy. Prediction within ± 0.18 dm^3 (about 5%) could be expected two times out of three; a prediction to within ± 0.36 dm^3 (about 10%) could be expected 19 times out of 20.

3. Predictive model for thinned plots 9, 11, 12 and 14

The following regression was obtained using data from these plots:

$$i_v = 0.14 + 0.59\ (h.i_g) + e \qquad [11]$$

This model explains 99% of the variation in volume increment for the four plots, with a SEE of 0.17 dm^3. A comparison of regression lines indicates that they are not significantly different from one another, so that model [11] can be used to estimate volume yield from these plots. The SEE suggests that the model's accuracy is slightly inferior to that used for plots 1, 2, 3 and 4. Prediction to within ± 0.17 (about 7%) could be expected two times out of three, and to within ± 0.34 dm^3 (about 14%) 19 times out of 20.

4. Predictive model for control plots 8, 11, 12 and 14

The following regression model was obtained from data of these four plots:

$$i_v = 0.11 + 0.66\ (h.i_g) + e \qquad [12]$$

This model explains 98% of variation in volume increment for the four plots, with a SEE of 0.09 dm^3. Since the test to compare regression lines suggests that they are not significantly different, model [12] can be used for control plots 8, 11, 12 and 14. The SEE indicates that the relative precision of the estimate for volume increment will be similar to that for thinned plots 8, 11, 12 and 14. Specifically, prediction to within ± 0.09 dm^3 is expected two times out of three, and prediction to within ± 0.18 dm^3 (about 14%) 19 times out of 20.

Relationships obtained for the four site x treatment combinations reveal interesting properties. Before these models can be applied generally, however, they must be validated (and their applicability established) to ensure their stability over time. A comparison of models [9], [10], [11] and [12] indicates that control plots yield greater volume for a given value of ($h.i_g$). Similarly, plots 1, 2, 3 and 4 yield a greater volume for a given ($h.i_g$) value than do plots 8, 9, 11, 12 and 14. In view of these differences, separate estimation models must be used for each site-treatment combination.

Applicability of production table PL275

The MU uses Table PL275 to predict volume yield of thinned fir stands. The forest management manual (Ministère de l'Énergie et des Ressources du Québec 1989) indicates that this table is one of a series compiled to simulate fir, spruce, jack pine and larch plantation production in the mixed forest ecological zone. The manual suggests that, up to 50 years, volume yields grow in accordance with curves from tables by Bolghari and Bertrand (1984); after 50 years, yields follow curves from tables in Vézina and Linteau (1968). As there are no tables for balsam fir plantations (Bolghari and Bertrand 1984), it is reasonable to assume that tables from Vézina and Linteau may apply to the entire prediction period.

Actual production from this study was compared with that predicted from Table PL275. Total softwood volume production was established for each plot using a single tariff table. There is only one observation per plot for plots 1, 2, 3 and 4, as data are only available from the 1994 survey. For plots 8, 9, 11, 12 and 14, however, data were available from two inventories (1988 and 1994) for control plots, and from three inventories (before and after treatment in 1988 and again in 1994) for thinned plots.

Actual volume yield and that predicted from Table PL275 are plotted in Figure 15. Note that the time scale has been compressed to facilitate comparison. This plot suggests that actual volume yield may be similar to (plots T-1, T-2 and C-3), less than (plots T-3 and T-4) or greater than (plots C-1, C-2 and C-4) that predicted from Table PL275, but gives no indication as to how yields will develop over time.

In the other plots, production comparisons can be supplemented by short-term yield predictions based on volume increments over the last five years. For example, production from plots C-11 and C-12 appears consistent with the table. Production from plot C-14 (which exceeds the value predicted from Table PL275) and T-11 (which is below the table value) appear to follow trends indicated in the table. Finally, production from plot C-8 (currently similar to the value from Table PL275) and plots T-9, T-12 and T-14 (far below the table value) appear to go against the trend established in the table.

This comparison over time indicates that several control plots (C-3, C-11, C-12 and C-8) produce yields comparable to table values even without commercial thinning. It also indicates, however, that treatment intensity in some plots was either appropriate (T-1, T-2), even if more intensive than that in Table PL275 (T-3, T-4, T-11), or clearly excessive (T-9, T-12 and T-14).

This observation raises questions regarding silvicultural treatment of young stands for purposes of sawlog production development, particularly:

- when should initial thinning take place?
- how intensive should thinning be?
- finally, what stand characteristics should define the optimal treatment?

This is a complex problem, to which the present study can only suggest answers based on its own and related results.

Thinning of fir stands - selecting a method

Balsam fir is a shade-tolerant species that regenerates abundantly. It grows under canopy and following clearcut, new seedlings gradually join survivors from the preceding regeneration to form a frequently irregularly structured community that, in consequence, takes several years to reach the pole stage.

Therefore, without subsequent release of seedlings, initial cleaning should be restricted to simple elimination of dangerous or defective subjects rather than qualitative selection, even during precommercial thinning. In particular, it is relatively easy to show that, 5 years after very intensive thinning (75-80% of basal area removed), the stand was still in completion since the number of stems of 1.5 cm DBH and over had once again increased (Table 2). Because the stand is still forming, initial cleaning should focus more on species selection and mix based on site characteristics, rather than volume gains.

In this regard, systematic elimination of deciduous species and constitution of pure softwood stands could be very risky. A study by Batzer *et al.* (1987) of commercial thinning in Wisconsin indicated that balsam fir growth following a spruce budworm outbreak is directly related to cut volume of deciduous species, especially aspen.

Furthermore, it appears desirable to plan initial thinning for lumber production when stands have had an opportunity to form and social differentiation of stems is under way (Schütz 1990). It appears that mean or dominant stand height is a favoured characteristic (Thivole-Cazat 1986). Finally, to optimize production of quality lumber, treatment intensity must be consistent with the desired lumber assortment. According to the results of the present study, it is important to set up a better thinning regime than existing ones (intensive and schematic, designed essentially to reduce stand density to 2,500 stems per hectare).

As few studies provide information on how to thin stands to improve lumber production, it would be reasonable to begin by establishing a preliminary density model for this type of softwood production. In the model proposed here, the thinning regime is based on the relationship between the dominant height of the stand and the stem spacing factor (see Figure 16). This is the square spacing factor (SF) from Wilson (1979), which is calculated from the number of stems per hectare (n) and the dominant height in metres (h) using the following expression:

$$SF(\%) = 10{,}000/(h.n^{0.5}) \quad [13]$$

In the case of managed stands, the SF (which characterizes each species and is independent of site quality) varies from 15% for highly tolerant species to 30% for very intolerant species (Day and Connor 1984, Wilson 1979, Harper 1977, Hoellinger 1986).

Control plots and mature plots included in this study fall within 15% or 10% of the spacing factor, which confirms the very tolerant nature of fir and confirms results of authors cited above. While plots thinned in 1984 show an SF of about 20%, plots thinned in 1988 demonstrate an SF well in excess of 30%. In view of defects on stems subject to heavy thinning, an SF above 30% appears to carry clear risks for lumber production. In particular, increased taper, shift of growth toward the stump of the tree, long live crowns and heavy knotting are directly responsible for a substantial decline in log quality.

The lack of natural pruning encourages formation of thick branches that remain on the trunk even when dead. Although heavy thinning in plots 9, 11, 12 and 14 has an economic rationale (low operating cost), the resulting loss of production is hard to justify in a context where this resource is increasingly rare.

Therefore, thinning of fir stands should be better controlled to maintain residual stand density at roughly a 25% SF. Once SF values have been determined experimentally, it becomes possible to establish the number of residual stems using the following expression:

$$n = [10{,}000/SF.h]^2 \quad [14]$$

Finally, initial qualitative selection is clearly inappropriate before the stand has achieved a dominant height of 5 m.

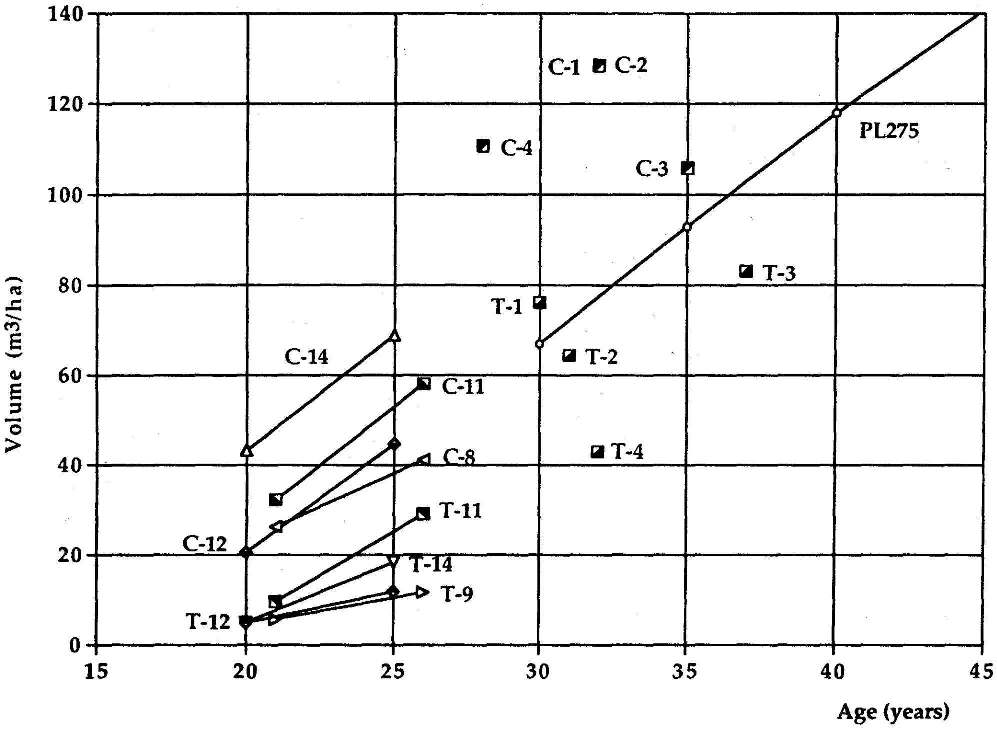

Figure 15. Softwood volume calculated from Table PL275 and from actual data.

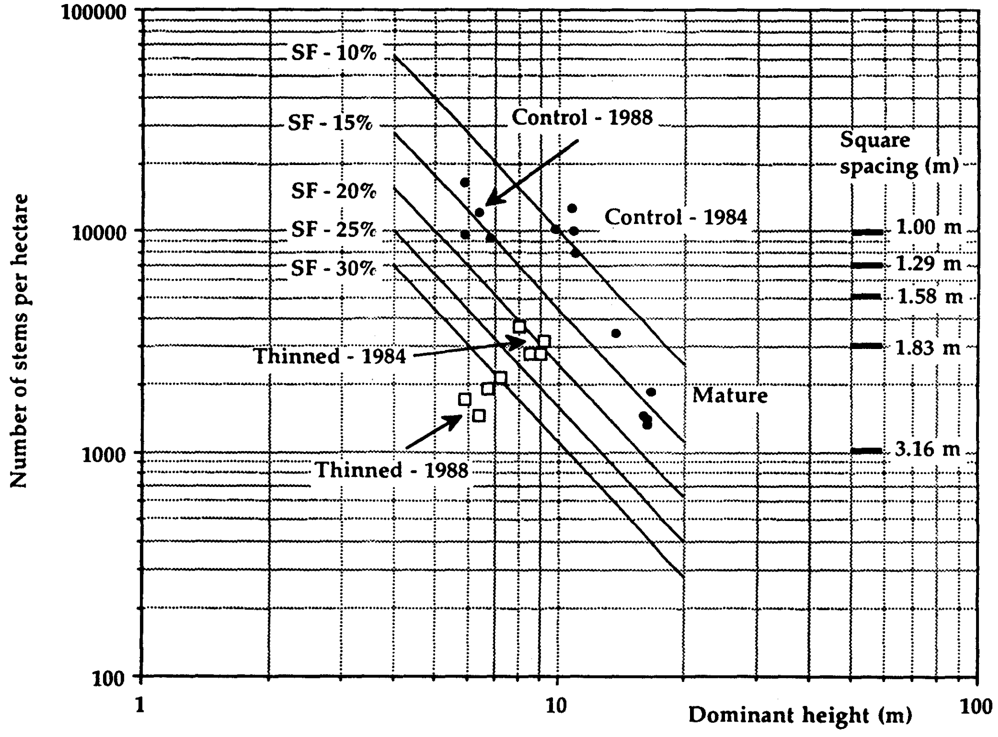

Figure 16. Number of stems and spacing factor, by dominant height.

ACKNOWLEDGMENTS

This study was made possible through the cooperation of Jean DeGrâce (MRNQ-Les Escoumins MU) and Claude Gagné (Boisaco Inc.) for planning and organization of site work; Carole Imbeault and André Lamontagne (Boisaco Inc.) for data collection in the field; Jean-B. Breton (CFS) for laboratory data collection; and Yvan Corneau and Jean McDonald (Forintek Canada Corp.) for comparative taper data.

Finally, the authors thank Pierre Ricard (CEGEP de Sainte-Foy), Jacques Savard (Ministère des Ressources naturelles du Québec) and Tony Zhang (Forintek Canada Corp.) for constructive comments on the manuscript.

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