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growth of western hemlock stands after precommercial thinning

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contents

Professor Rudolph Kangur, the scientist who initiated and directed the hemlock precommercial thinning study through the calibration period, is shown on the Eckman Creek light-thinning plot in 1960. His leadership and diligent efforts on this project are gratefully acknowledged.

summary

A precommercial thinning study was begun in 1959 in stands of 18- to 22-year-old natural western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] located in the Oregon Coast Range to determine the effect of four levels of growing stock on stem count, stand structure, and growth. This bulletin reports the growth of the stands during the first 10 years after thinning. Mean stand age at the end of the period was 38 years.

Periodic annual increments and growth percentages for diameter, basal area, and cubic foot volume were greater on stands heavily thinned to 10- by 10-foot (3.05 x 3.05 m) spacing than on stands moderately thinned to 8- by 8-foot (2.44 x 2.44 m) spacing or lightly thinned to 6- by 6-foot (1.83 x 1.83 m) spacing.

Ten years after thinning, mean diameters were significantly larger in heavily thinned stands. Basal areas and volumes were larger on the lightly thinned and control stands; however, those that were heavily thinned were rapidly narrowing the gap.

In two crop-tree populations, 450 trees and 150 trees per acre, total basal areas and volumes on heavily thinned stands exceeded those on lightly thinned and control stands by 34 percent and 38 percent, respectively. Mean height growth of dominant and codominant trees did not correlate with stand density; however, thinned stands were significantly taller than control stands. Mortality was much greater on the unthinned plots during both the calibration and post-thinning periods. In the 20th year after the initial thinnings, the volumes on all the thinned replications will have equaled or exceeded that on the control.

The strategy chosen for precommercial thinning should depend on length of rotation, commercial thinning plans, minimum diameter and volume for a profitable harvest, and stand age. If precommercial thinning is the forest manager's choice, thinnings should begin when stands are 10 to 18 years old and 20 to 25 feet tall. The better sites (I and II) should be thinned at the younger age to spacings of 10 by 10 feet to 12 by 12 feet (3.05 x 3.05 m to 3.65 x 3.65 m). If commercial thinnings are planned, precommercial thinnings may be moderate to heavy. The larger the mean stand diameter required for commercial thinning, the heavier the required precommercial thinning.

introduction

Little was known about the effect of precommercial thinning on young hemlock stands in 1959. Western hemlock was still considered an inferior commercial species highly susceptible to damage from logging activities.

A precommercial thinning study was begun in 1959 in stands of 18- to 22-year-old natural western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] located in the Oregon Coast Range (Fig. 1). The purpose of the study was to determine the effect of four levels of growing stock, based on stem count, on stand structure, mortality, and growth in diameter, basal area, and volume of the residual stands and two crop-tree components. The initial results of the study through 1969 have been reported by Kangur (1970) and Dilworth (in press). The continuation has sought to fill a gap in the scientific knowledge that would eventually be required for intensive management, particularly in the Oregon Coast Range.

Griffith (1959) studied precommercial thinning in British Columbia and found that thinning young hemlock stands to 6- by 6-foot spacing increased diameter growth 84 percent and basal-area growth 173 percent over control stands eight growing seasons after thinning. The mean gross volume of the thinned stands equaled that of control stands 10 years after the last thinning.

Osborn (1968) studied the influence of stocking density upon growth and yield of coastal western hemlock largely in British Columbia. Malmberg (1966) reported early thinning trials on western hemlock in the coastal forests of northwestern Oregon. He tested 12- by 12-foot spacing and one, two, and eight thinnings.

The findings of Osborn and Malmberg, like those in this study, show that young hemlock stands respond to manipulations of stand density and that slow diameter growth can be avoided with early thinnings. They also found greater gross volumes but lower stumpage values on lightly thinned or unthinned stands 6 years after cutting. Both authors stress that for intensive management, stands should be thinned initially at 10 to 15 years.

The calibration periods for this report were completed in 1966 and 1967 (Dilworth in press) at an average stand age of 28 years. The quadratic mean diameter, based on average basal area per stem, was 5.2 inches, an increase of about 3 inches in 8 years. A significant correlation existed between stand density and growth. The heavier the thinning, the larger the mean stand diameters, periodic mean annual increment (PAI)[1], and percent of periodic annual increment (PAI%). The PAI for basal area and volume was smaller with heavier thinning. The stands were remeasured after the 1977 growing season to provide further evidence of the effect of thinning.

The purpose of this bulletin is to show the relation of growth, mortality, and stand structure to stand density during the post-thinning period, 1967-1977. Yield tables were not developed because data were limited, but comparison of the recovery rate of thinned and control stands as revealed by relative diameter growth, basal area, and volume is of special interest.

[1]Periodic annual increment is generally synonymous in forest management with periodic annual growth.

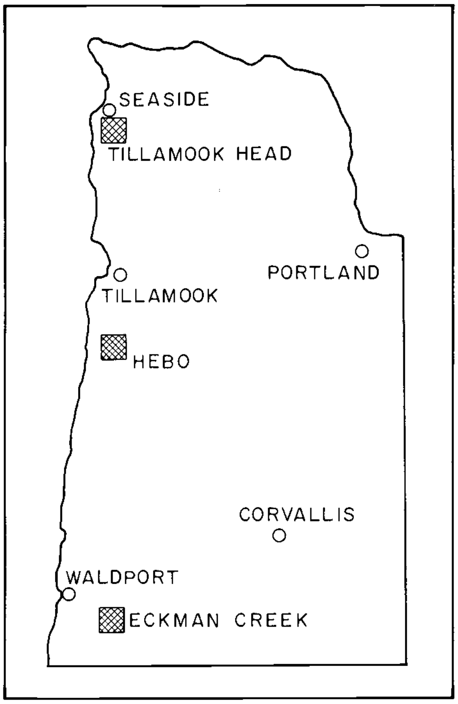

Figure 1.

Location of the study areas. Each of the three areas contained a 0.1-acre control plot and a 0.1-acre plot for each of the four thinning treatments.

study plan

plot selection

The study areas for this report (Fig. 1) were at Hebo, Tillamook Head, and Eckman Creek. At each location, five square 0.1-acre plots were established in an irregular cluster. All plots were on bench-type sites with slopes under 5 percent and west-to-southwest exposures 100 to 400 feet above sea level. Stands were pure western hemlock. Stand conditions at the beginning of the post-thinning period are given in tables throughout the text.

thinning treatments

Each location included a control plot and a plot for each of four treatments (Dilworth in press):

Heavy thinning	10 x 10 ft (3.05 x 3.05 m)
Moderate thinning	8 x 8 ft (2.44 x 2.44 m)
Light thinning	6 x 6 ft (1.83 x 1.83 m)
Field choice	9.3 x 9.3 ft (2.83 x 2.83 m) (mean at end of calibration period)

Field choice was based on individual tree condition and spacing. Stem counts were at, or very close to, the prescribed spacings (Table 1).

The mean site indices in 1967 were 145 for the control and 144 for heavy, 145 for field choice, 146 for moderate, and 143 for light thinning. The site indices of individual plots ranged from 116 to 180.

analysis

The three populations analyzed were all-trees and the segments including the largest 450 crop trees (P450) and the largest 150 crop-trees (P150) per acre at the end of calibration. P450 was the most heavily thinned segment studied and P150 arbitrarily represents final harvest. The growth of the crop-tree populations is, of course, most important commercially.

Tree diameters were measured on all plots. Quadratic mean stand diameters were derived from mean basal area per stem; therefore, diameter in the text refers to quadratic diameter at breast height (d.b.h.). Tree volumes were computed by the combined-variable equations developed for each plot in 1967 (Dilworth in press). All volumes in the text are expressed in cubic feet. Total heights of dominant and codominant trees were measured on all Eckman Creek plots. It has been established that stand density does not correlate with height, so it was not necessary to measure all locations.

Analysis of variance and covariance were used to determine significance of differences within and between treatments. Multiple linear regression and logarithmic curve-fitting methods were used in conjunction with graphs to find the coefficient of determination and to predict stand growth after 1977.

Table 1.

NUMBER OF TREES PER ACRE AT THE BEGINNING AND END OF THE POST-THINNING PERIOD (1967-1977).

Plot location and thinning treatment[a]

Diameter breast height (in.)	Tillamook Head FC	10	8	6	C
1967					
1					100
2				20	890
3	30	10	90	380	1,020
4	130	70	170	300	630
5	210	170	200	300	360
6	110	120	100	120	260
7	40	50	60	70	80
8		20	40	10	40
9			10		30
10		10			
11					
18					
Total	520	450	670	1,200	4,410
1977					
1					
2					10
3					200
4				90	340
5	10		40	150	350
6	10	10	80	270	310
7	50	10	100	230	170
8	100	40	160	240	100
9	170	140	120	70	80
10	100	100	70	40	20
11	50	90	70	40	10
12	10	40	20		10
13			10		
14		20			
15	10				
16					
19					
22					
Total	510	450	670	1,200	1,600

Diameter breast height (in.)	Eckman Creek FC	10	8	6	C
1967					
1					260
2					720
3				130	650
4	10	10	50	500	630
5	60	80	190	240	330
6	120	130	220	170	220
7	170	130	110	130	140
8	70	60	70	20	60
9	50	20	20	10	10
10		10	10		10
11	10	10	10		10
18					10
Total	490	450	680	1,200	2,950
1977					
1					
2					10
3				20	70
4				80	150
5			30	200	350
6	20		80	300	180
7	30	30	120	110	160
8	40	50	120	130	100
9	80	90	120	100	90
10	130	10	90	100	80
11	110	10	40	20	30
12	20	20	40	30	10
13	40		20		
14		40	10		
15					
16		10			
19	10				
22					10
Total	480	440	670	1,090	1,240

Diameter breast height (in.)	Hebo FC	10	8	6	C
1967					
1					1,310
2				10	1,700
3	20		20	220	1,100
4	130	50	200	420	580
5	100	170	300	330	340
6	100	150	120	160	50
7	110	60	49	30	40
8	10	20			20
9	20				
10					
11					
18					
Total	490	450	680	1,170	5,140
1977					
1					10
2					200
3				30	650
4				180	440
5	10		40	150	380
6	70	10	90	260	280
7	70	20	180	260	160
8	40	100	180	180	40
9	110	100	90	70	40
10	50	90	50	20	40
11	20	70	40	10	10
12	70	40			
13	10	10			
14	10				
15					
16					
19					
22					
Total	460	440	670	1,160	2,250

[a] Field choice (FC), control (C). Digits are spacing in feet.

effect of thinning treatments

What happened during the 10 years after thinning? The heavily thinned and field choice plots for all three populations showed greater PAI and PAI% in stand diameter, basal area, and volume than moderately and lightly thinned plots or control plots. The increases in mean stand volume were substantially larger than those reported for thinned commercial stands of Douglas-fir (Reukema 1972). The differences between treatments were significant (P = 0.05) to highly significant (P = 0.01) except in P150. Another exception was that the PAI% in diameter of the all-trees population on control plots exceeded that of treated plots.

diameter growth

At the end of the calibration period, the control plots averaged 3.3 trees per acre 11.6 inches in diameter or larger. The thinned plots had no trees of that size. By 1977, the heavily thinned plots averaged 60 trees per acre 11.6 inches or larger, field choice plots averaged 60, moderately thinned plots 33, lightly thinned plots 10, and control plots 10 (Table 1). Trees on heavily thinned plots increased an average 3.5 inches during the post-thinning period, which brought the mean diameter to 10 inches at an average stand age of 38 years (Table 2, Fig. 2). Diameters on all other treated plots increased at a slower rate. Trees on control plots reached a mean diameter of 5.9 inches during the same period.

The crop-tree populations increased mean diameters substantially (Table 2, Fig. 3) but not as dramatically as the all-trees population. Crop trees on plots with heavier thinnings had average diameters significantly larger than those on lightly thinned or control plots, although the differences were not as large as for the all-trees population. The differences between light thinning and control and between heavy thinning and field choice were not significant at the 5-percent level for either crop-tree population. Stand diameters for P150 were from 1.3 to 2.0 inches larger than those for P450.

The PAI% in diameter (Table 3) showed the same relationships as 10-year increases. The heavier the treatment, the larger the growth percentages. Differences were highly significant (P = 0.01). The exceptions, as stated before, were control plots, which had a higher PAI% than any of the treated plots in the all-trees population. The high mortality on control plots, particularly in the smaller diameter classes, resulted in a substantial increase in final mean stand diameter (Tables 2, 4). This, combined with a relatively small initial stand diameter, gave a higher PAI% (Table 3).

Growth curves (Fig. 3) show that trees will require approximately 7 years (1984) to reach 10 inches mean diameter on moderately thinned plots, 16 years (1993) on lightly thinned plots, and 18 years (1995) on control plots.

Table 2.

MEAN VOLUME, BASAL AREA, AND DIAMETER BREAST HEIGHT FOR ALL STANDS AT THE BEGINNING AND END OF THE POST-THINNING PERIOD.

Thinning treatment	Diameter (in.) 1967	Diameter (in.) 1977	Basal area (ft^2/acre) 1967	Basal area (ft^2/acre) 1977	Volume (ft^3/acre) 1967	Volume (ft^3/acre) 1977
ALL TREES						
Field choice	6.5	9.6	116	242	2,427	5,695
10 ft	6.5	10.0	108	246	2,232	5,774
8 ft	6.0	8.4	133	259	2,819	6,068
6 ft	5.1	7.0	172	296	3,568	6,812
Control	3.6	5.9	254	300	5,405	6,505
450 CROP TREES						
Field choice	6.6	9.7	110	234	2,312	5,538
10 ft	6.6	10.0	108	246	2,224	5,774
8 ft	6.5	9.3	106	211	2,276	4,984
6 ft	6.3	8.5	97	178	2,102	4,291
Control	6.2	8.3	96	168	2,141	4,130
150 CROP TREES						
Field choice	8.0	11.7	53	111	1,131	2,689
10 ft	7.8	11.7	52	112	1,076	2,655
8 ft	7.3	10.8	50	96	1,099	2,295
6 ft	7.2	9.8	42	78	936	1,913
Control	7.1	10.0	42	82	982	2,049

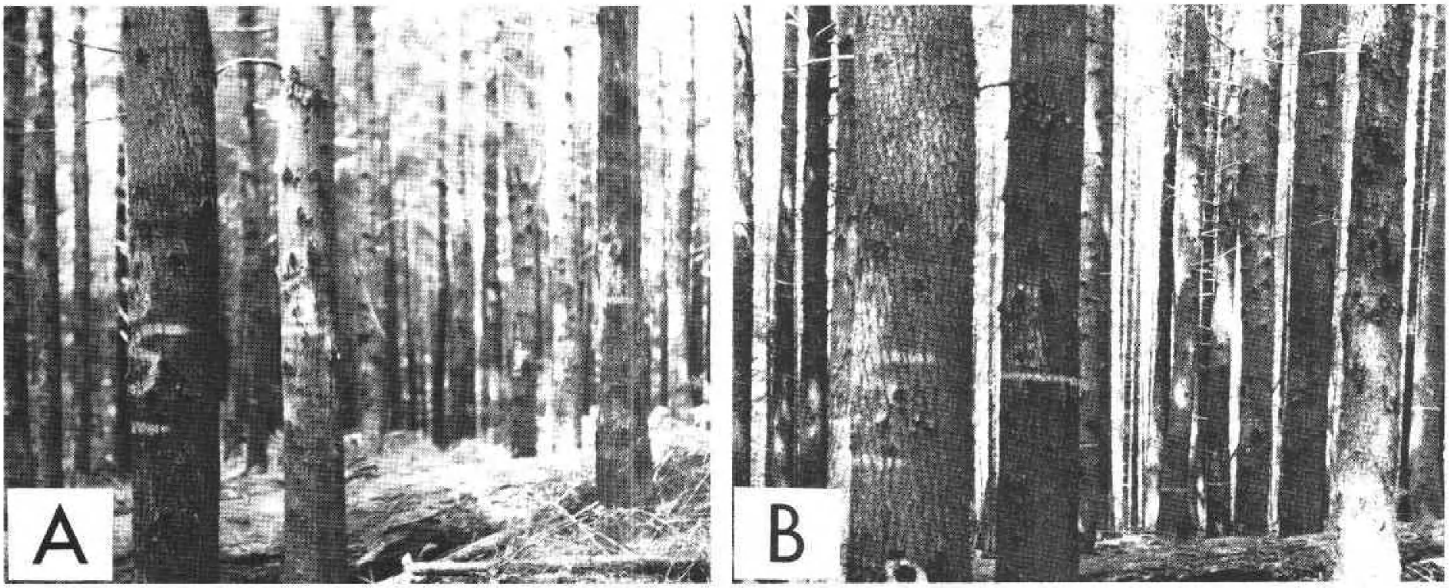

Figure 2.

The 29-year-old heavily thinned plot (A) at Eckman Creek after calibration thinnings averaged 7.2 inches diameter breast height. (B) Ten years later, the stand averaged 10.3 inches diameter breast height.

Table 3.

PERIODIC MEAN ANNUAL INCREMENT AND PERCENTAGE OF GROWTH IN DIAMETER BREAST HEIGHT (D.B.H.), BASAL AREA (B.A.), AND VOLUME (VOL.) DURING THE POST-THINNING PERIOD (1967-1977).[a]

Stand variables	Thinning treatment: Field choice	10 ft	8 ft	6 ft	Control
ALL TREES					
Stems per acre	483	450	670	1,150	1,697
D.b.h. (in.)	0.31	0.35	0.24	0.19	0.23
(%)	4.8	5.4	4.0	3.7	6.4
B.A. (ft^2)	12.6	13.8	12.6	12.4	4.6
(%)	10.9	12.8	10.1	7.2	1.8
Vol. (ft^3)	327.0	354.0	325.0	324.0	110.0
(%)	13.5	15.5	11.5	9.1	2.0
450 CROP TREES PER ACRE					
D.b.h. (in.)	0.31	0.35	0.28	0.22	0.21
(%)	4.7	5.4	4.3	3.5	3.4
B.A. (ft^2)	12.4	13.8	10.5	8.1	7.2
(%)	11.3	12.8	9.9	8.3	7.5
Vol. (ft^3)	323.0	354.0	271.0	219.0	199.0
(%)	14.0	15.5	11.9	10.4	9.3
150 CROP TREES PER ACRE					
D.b.h. (in.)	0.37	0.39	0.35	0.26	0.29
(%)	4.6	5.0	4.8	3.4	4.1
B.A. (ft^2)	5.8	6.0	4.6	3.6	4.0
(%)	10.9	11.5	9.2	8.6	9.5
Vol. (ft^3)	156.0	158.0	120.0	98.0	107.0
(%)	13.8	14.7	10.9	10.4	10.9

[a]Stand populations are trees per acre in 1977.

Table 4.

TOTAL AND PERIODIC ANNUAL MORTALITY (PAM) DURING THE POST-THINNING PERIOD (1967-1977).

Thinning treatment	Stem count			D.b.h.[a] (in.)	Basal area			Volume		
	Total	PAM	%		Total ft²	PAM	%	Total ft³	PAM	%
TILLAMOOK HEAD										
Field choice	10	1	0.2	6.9	2.6	0.3	0.2	54	5.4	0.3
10 ft	0	0	0	0	0	0	0	0	0	0.0
8 ft	0	0	0	0	0	0	0	0	0	0.0
6 ft	70	7	0.6	4.3	7.1	0.7	0.4	118	11.8	0.3
Control	1,790	199	5.8	2.3	71.8	8	2.9	441	49	0.8
ECKMAN CREEK										
Field choice	10	1	0.2	8.7	4.1	0.4	0.3	102	9.3	0.3
10 ft	10	1	0.2	9.6	5.0	0.5	0.4	56	5.1	0.2
8 ft	10	1	0.1	5.3	1.5	0.1	0.1	32	2.9	0.1
6 ft	110	10	0.8	4.0	9.5	0.9	0.5	103	9.4	0.3
Control	1,780	162	5.4	3.7	53.8	4.9	1.9	731	66.5	1.3
HEBO										
Field choice	30	3	0.6	3.8	2.4	0.2	0.3	44	4.4	0.2
10 ft	10	1	0.2	5.7	1.8	0.2	0.2	38	3.8	0.2
8 ft	10	1	0.1	4.2	1.0	0.1	0.1	18	1.8	0.1
6 ft	10	1	0.1	2.9	0.5	0.1	0.04	9	0.9	0.03
Control	2,780	278	5.5	2.0	43.2	4.3	2.0	834	83.4	4.6
ALL PLOTS										
Field choice	17	1.7	0.33	6.5	3.0	3.0	0.3	66.7	6.4	0.27
10 ft	7	0.7	0.13	5.1	2.3	2.3	0.2	31.3	3.1	0.13
8 ft	7	0.7	0.07	3.2	0.8	0.8	0.1	16.7	1.6	0.03
6 ft	63	7.0	0.03	3.7	5.7	5.7	0.3	45.3	7.4	0.21
Control	2,117	213	5.60	2.7	56.3	56.3	2.3	669	66.9	3.1

[a]Average diameter at breast height at time of mortality.

basal area growth

The growth percent for basal area showed a highly significant negative correlation (R = 0.98) with stand density. As the stems per acre decreased, the growth percentages increased (Table 3). Differences between light, moderate, and heavy thinning were highly significant (P = 0.01), but differences between field choice and heavy thinning were not statistically significant.

The same general relationships were found in changes in the mean basal area for P150 and P450 (Fig. 4) but not for the all-trees population. Figure 4 shows that the total basal area for the all-trees population was largest on control plots and smallest on heavily thinned plots, but that treated plots were gaining on control plots.

The data show that the all-trees population receiving the three heaviest treatments increased total basal area by 110 percent between 1967 and 1977, which is similar to the range within the three populations (105%-113%). By the end of 1978, basal area in the lightly thinned stands should have equaled the basal area in the control stands (Fig. 4). A projection from 1967, 1969, and 1977 data showed that basal area on moderately and heavily thinned stands should equal the control basal area within 5 and 6 more years, respectively. (This and all other projections are made with the assumption that no intermediate cutting or catastrophic mortality will take place and that growth will continue at the same rate.)

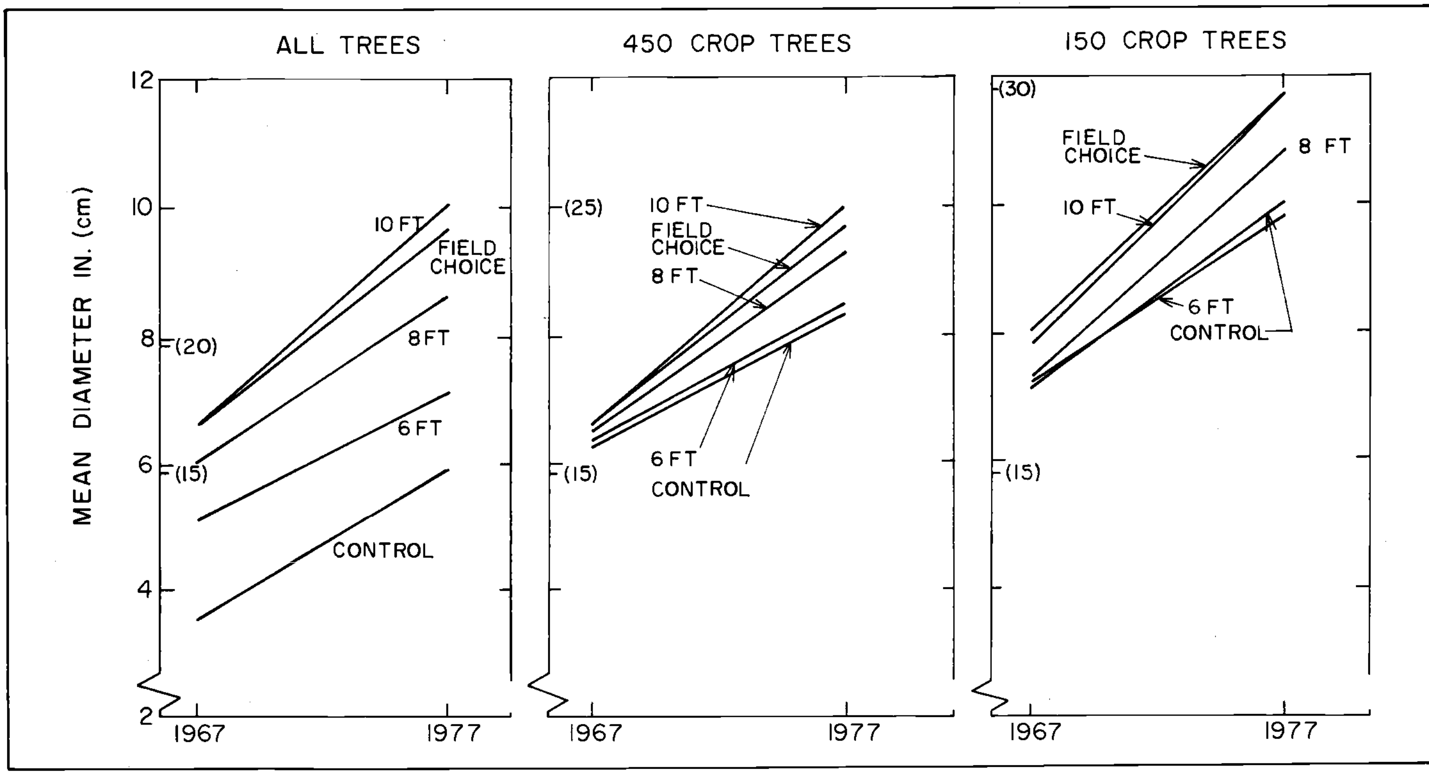

Figure 3.

Mean diameter growth for the three stand populations with each treatment during the 10 years after thinning.

volume growth

Volume growth was dynamic during the post-thinning period (Table 2, Fig. 5). Total stand volumes showed highly significant (P = 0.01) increases with all treatments. The heavily thinned stands increased an average 147 percent during the 10 years while control stands increased only 22 percent. The PAI% (Table 3) shows the same relationship.

Figure 5 illustrates the rapid growth of all trees with all treatments during the post-thinning period. Although growth percentages (Table 3) were higher for the heavily thinned stands, control stands and lightly thinned stands had larger total volumes. In 1967, the total volume of the lightly thinned stands was 34 percent smaller than the control volume (Table 2). It is significant that by 1977, the total volume for lightly thinned stands exceeded the control volume.

The average volume per tree in 1977 was 12.8 cubic feet on plots heavily thinned, 9.1 cubic feet on those moderately thinned, and 3.8 cubic feet on control plots. If growth trends continue, by 1980 the total volume on heavily thinned plots will equal that on the controls,[2] and within 13 years after the last thinning to 450 trees per acre, it will again have recovered to equal total control volume. Volume on plots receiving moderate and field-choice treatments should equal the control volume by 1980 and 1981, respectively. Moderately thinned plots will reach equilibrium with controls before heavily thinned plots do, but within the same growing season.

An analysis by area and site quality, instead of by composite, shows that volume on the Hebo plots (site index 180) exceeded the volume on control plots (site index 162) by 183 cubic feet in 1977. Volumes for heavily thinned Eckman Creek and Tillamook Head plots were substantially lower than their respective controls (Table 5). A projection of data from 1967, 1969, and 1977 (see footnote 2) shows that volumes from heavily thinned plots at Eckman Creek (site index 136) and Tillamook Head (site index 129) should equal the volumes of the controls (site index 135) in 1982 and 1981, respectively. The data also show that equilibrium between volumes of treated plots and control plots will be reached sooner on better sites. At Hebo (site quality II), all treatments should have equaled or exceeded the control by 1978. At Tillamook Head (site quality III) and Eckman Creek (site quality III), an additional 5 years will be required.

[2] Logarithmic curve-fit and graphical methods gave identical results from 1967, 1969, and 1977 measurements.

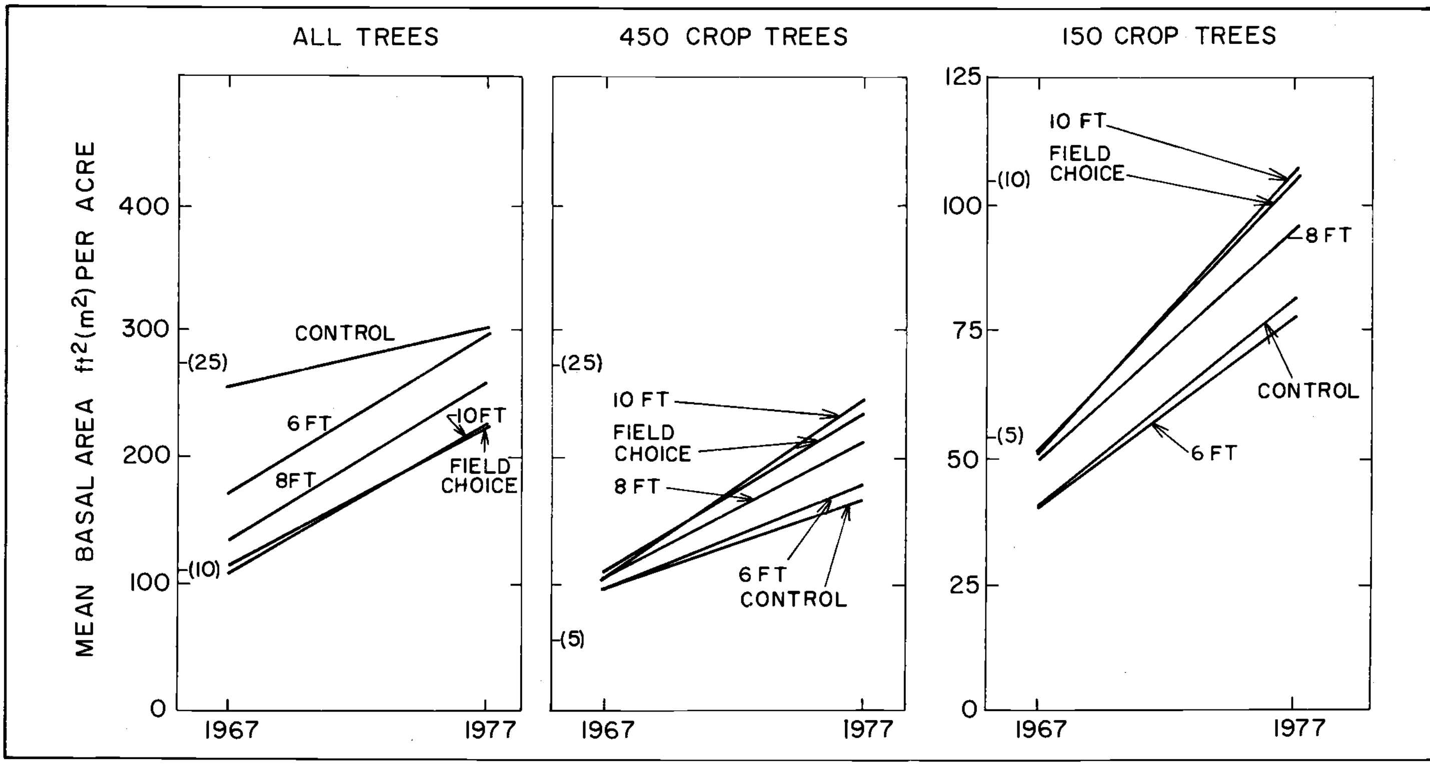

Figure 4.

Mean basal-area growth for the three stand populations with each treatment during the 10 years after thinning.

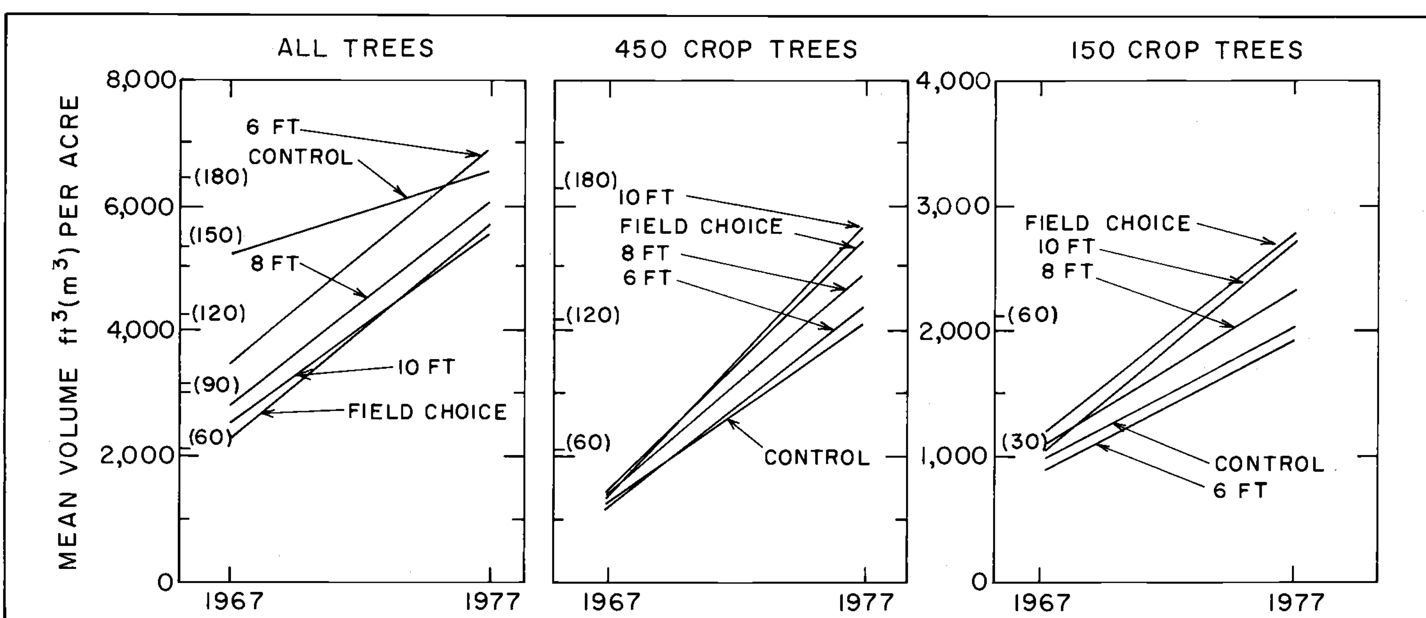

Figure 5.

Mean volume growth for the three stand populations with each treatment during the 10 years after thinning.

Analysis of P450 (Tables 2, 3, Fig. 6) showed different results. The heavier treatments had the largest total volumes and PAI%. The differences between treatments were significant (P = 0.05), and the relationship was linear. The average tree volumes for the three treatments were 12.8, 11.1, and 9.2 cubic feet.

The differences in total volumes between treatments for P150 were not significant (P = 0.05), but the data do show dynamic volume growth and obvious benefits of heavy thinning. The average tree volumes for P150 were 17.7, 15.3, and 13.6 cubic feet, respectively, for heavy and moderate thinnings and the control.

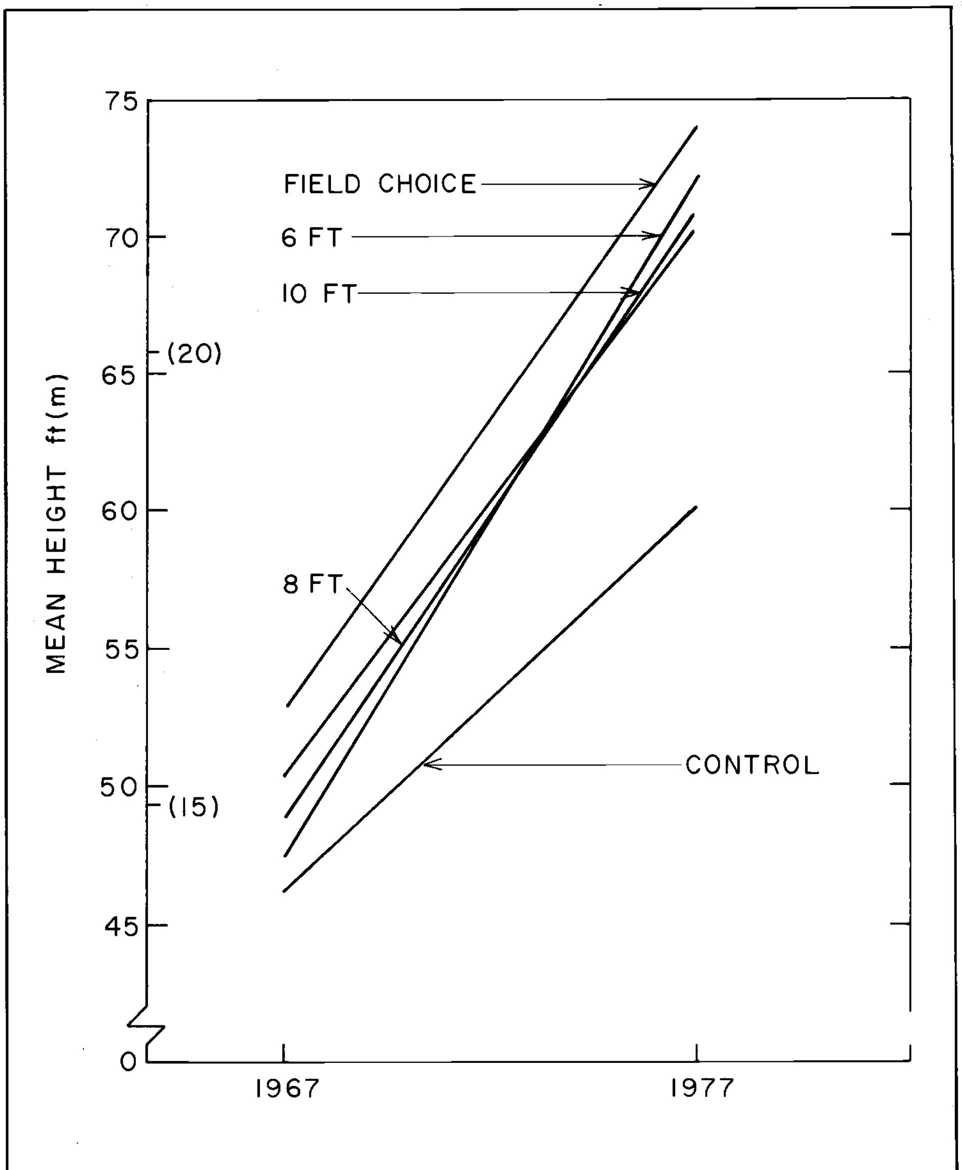

Figure 6.

Mean height growth of dominant and codominant trees with each treatment on Eckman Creek plots during the 10 years after thinning.

Note that growth patterns for basal area and volume are similar (Fig. 4, 5). Basal areas and volumes of the all-trees population thinned heavily are not likely to equal the basal areas or volumes of those thinned lightly within the predictable future.

height growth

The mean height growth of the dominant and codominant trees on the thinned Eckman Creek plots did not correlate significantly with stand density at either the beginning or end of the post-thinning period. Malmberg (1966), Osborn (1968), and Wiley (1978) came to the same conclusion about the relationship of stand density to height growth. But height growth on control plots was significantly smaller (P = 0.01) than on treated plots (Table 6). The relationships are the same as those found for all plots after the first 10 years of the study (Dilworth in press). Figure 6 shows the changes in total stem height, 1967-1977, at Eckman Creek. A consistent relationship is the low height growth rate of control plots compared to treated plots. PAI during calibration averaged 2.25 feet compared to 2.20 feet during 1967-1977, a difference not statistically significant.

Table 5.

MEAN DIAMETER BREAST HEIGHT (D.B.H.),[a] BASAL AREA (B.A.), AND GROSS VOLUME (VOL.) AT THE BEGINNING AND END OF THE POST-THINNING PERIOD.

Thinning treatment[b]	All trees[c]						450 crop trees per acre					
	D.b.h. (in.)	B.A. (ft^2)	Vol. (ft^3)	D.b.h. (in.)	B.A. (ft^2)	Vol. (ft^3)	D.b.h. (in.)	B.A. (ft^2)	Vol. (ft^3)	D.b.h. (in.)	B.A. (ft^2)	Vol. (ft^3)
TILLAMOOK HEAD												
	1967			1977			1967[d]			1977		
FC	6.1	107.4	2,030	9.2	237.1	5,015	6.4	99.6	1,892	9.5	222.8	4,722
10	6.7	111.4	2,215	10.1	249.3	5,619	6.7	111.4	2,215	10.1	249.3	5,619
8	6.2	141.0	2,933	8.6	269.6	6,378	6.8	113.7	2,418	9.5	220.7	5,266
6	5.5	200.0	4,085	7.1	309.7	7,236	6.8	112.1	2,328	8.6	179.6	4,279
C	3.6[e]	279.1	6,209	5.8	290.7	6,704	6.3[a]	103.9	2,510	8.0	155.5	4,022
ECKMAN CREEK[f]												
	1966			1977			1966[d]			1977		
FC	7.2	137.3	3,056	10.3	278.1	7,247	7.3	132.2	2,957	10.5	271.0	7,096
10	6.9	113.0	2,406	10.3	261.8	6,371	6.9	113.0	2,406	10.3	261.8[g]	6,371[g]
8	6.4	150.0	3,223	8.8	285.8	6,929	7.0	120.4	2,578	9.8	234.8	5,769
6	5.1	168.1	3,538	7.2	305.3	7,318	6.3	98.5	2,222	9.0	198.0	5,069
C	4.0	260.6	5,194	6.9	321.1	7,663	6.6	106.8	2,224	9.3	211.4	5,298
HEBO												
	1967			1977			1967[d]			1977		
FC	5.8	88.7	1,807	9.2	210.8	4,820	5.9	86.4	1,749	9.2	209.5	4,795
10	5.7	82.4	1,671	9.6	228.1	5,331	5.8	82.4	1,671	9.6	228.1[g]	5,331[g]
8	5.1	95.8	1,928	7.8	223.7	4,898	5.5	75.0	1,536	8.5	177.3	3,916
6	4.6	134.2	2,685	6.6	273.5	5,882	5.5	73.3	1,496	8.0	158.5	3,526
C	2.8	217.4	4,344	4.9	288.8	5,148	5.4	72.9	1,480	7.5	137.5	3,070

[a]Quadratic mean diameter based on average basal area.
[b]Field choice (FC), control (C). Digits are spacing in feet.
[c]See Table 3 for number of trees per plot.
[d]End of growth year following last thinning.
[e]Interpolation between 1966 and 1968 measurements.
[f]Eckman Creek data are interpolations between 1966 and 1968 measurements.
[g]Adjusted from 440 to 450 trees per acre.

150 crop trees per acre					
b.h. (n.)	B.A. (ft^2)	Vol. (ft^3)	D.b.h. (in.)	B.A. (ft^2)	Vol. (ft^3)
	1967			1977	
.4	46.3	863	11.0	98.2	2,096
.2	55.1	1,060	11.6	110.8	2,503
.1	54.2	1,190	11.1	100.1	2,403
.8	49.1	1,024	9.8	78.0	1,876
.8	49.4	1,231	9.4	73.0	1,923
	1966			1977	
.8	63.3	1,388	12.4	126.0	3,410
.3	56.4	1,199	12.2	121.9	3,026
.3	57.1	1,303	11.6	110.0	2,750
.3	43.9	959	10.5	90.0	2,366
.9	39.5	945	11.5	108.6	2,751
	1967			1977	
.4	44.8	981	11.6	110.0	2,562
.6	38.1	791	11.2	103.0	2,435
.3	32.5	678	9.7	77.6	1,733
.2	31.0	638	9.0	66.9	1,497
.4	33.7	686	9.0	65.6	1,474

Table 6.

MEAN HEIGHT AND HEIGHT GROWTH ON ECKMAN CREEK STANDS DURING THE POST-THINNING PERIOD.

Thinning treatment	No. trees	Height 1967 (ft)	Height 1967 (m)	Height 1977 (ft)	Height 1977 (m)	Periodic annual increment (ft)	Periodic annual increment (m)	Periodic annual increment (%)
Field choice	17	52.8	16.1	73.8	22.3	2.10	0.64	4.0
10 ft	18	48.8	14.9	70.9	21.6	2.21	0.67	4.5
8 ft	21	50.4	15.4	70.4	21.5	2.00	0.61	4.0
6 ft	21	47.5	14.5	72.4	22.1	2.49	0.76	4.9
Control	11	46.2	14.1	60.2	18.3	1.40	0.43	3.0

conclusions

How much gross stem volume—including mortality, thinning loss, and residual volume—was produced under various thinning treatments and the control? The 1977 data give a reasonably accurate answer (Table 7) for gross stem biomass production:

Control	9,336 ft^3
Heavy thinning	9,317 ft^3
Light thinning	9,187 ft^3
Field choice	8,995 ft^3
Moderate thinning	8,730 ft^3

Control plots and those heavily thinned show no significant difference. A similar comparison for 1969 showed control plots had 8,001 cubic feet and heavily thinned plots 25 percent less, 6,390 cubic feet, so that a substantial increase has occurred on the thinned plots. Such disproportionate increases occurred with other treatments as well. Volumes for control and light treatment differed by 21 percent in 1969 and only 1.6 percent in 1977. It appears that thinned stands can produce as much stem fiber as unthinned stands, or perhaps more, and that wood fiber will be concentrated in trees of larger diameter and faster growth—a fact of particular importance to the forest manager.

The specific findings from this 10-year study were:

- Heavy thinning of young fully-stocked stands of western hemlock resulted in substantially larger growth percentages in diameter, basal area, and volume than did lighter thinning. The differences resulting from different treatments were significant ($P = 0.05$) to highly significant.
- Heavy thinning decreased substantially the time required to bring the mean stand diameter of the all-tree population to commercial size, 10 inches. The heavy and field-choice treatments brought mean stand diameters of the all-trees population (mean age 38 years) to 10 inches by 1977 and 1979, respectively.
- Total basal areas for the all-trees population were largest on lightly thinned and control plots in 1977. Total basal area of control plots was slightly larger than that of lightly thinned plots, but growth curves show they should have been about equal by the end of 1978.
- Volume growth in cubic feet was dynamic after thinning. The heavily thinned stands increased an average of 147 percent, compared to 20 percent for control stands. However, lightly thinned stands had the largest total stand volume.
- The control stands had the largest average total volume until 1976, when the average volume of the lightly thinned stands exceeded them.
- Gross volume productivity of heavily thinned stands, including the residual stand, mortality, and thinning loss, was equal by 1977 to the total productivity of the control stands. The control stands produced 21 percent more than lightly thinned stands in 1969 and only 1.6 percent more in 1977.
- Stand volumes were concentrated in the larger diameter classes in heavily thinned stands. By 1977, an average 63 percent of the stand volume on the heavily thinned stands was in trees 9.6 inches in diameter or larger. The field choice treatment had 58 percent, the moderate treatment 38 percent, the light treatment 18 percent, and the control 15 percent of stand volumes in trees 9.6 inches and larger.
- In 1977, the average volume per tree of the all-tree population on heavily thinned plots was more than three times that of the control plots. The average tree volumes for P450 were 12.8 for heavy thinning, 11.1 for moderate thinning, and 9.2 for the control. The average cubic-foot volumes for P150 were 17.7 for heavy and 15.3 for moderate thinning and 13.6 for the control.
- P450 and P150 showed the largest volume PAI% and PAI with heavier thinning. Differences between treatments were highly significant for P450 but not statistically significant for P150.
- The lighter the thinning, the shorter the time required for treated stands to recover the volumes of unthinned stands. The heavily thinned stands required an average of 8.8 years to regain the volume lost through initial thinning and mortality (Dilworth in

press). The field choice stands required 8.2 years, moderately thinned stands 7.0 years, and lightly thinned stands 5.0 years to recover. By 1977, at a mean stand age of 38 years and after a calibration and post-thinning period of 18 years, the heavily thinned stands had increased mean stand volume 90 percent over the initial stand volume. The field choice stands increased 103 percent, and the moderately and lightly thinned stands increased 106 percent and 143 percent, respectively.

- Treatments and mean total stand heights did not correlate; however, thinned stands were significantly taller than control stands.

- Mortality was greater on control plots, averaging 213 stems per acre annually. Lightly thinned stands lost more basal area, volume, and stems than more heavily thinned stands. Snow and wind damage on treated plots during the 10 years was small. The periodic annual volume loss did not exceed 0.27 percent for any of the thinned plots during the post-thinning period.

thinning strategies

The strategy chosen for precommercial thinning of young stands of western hemlock will depend on several factors: length of the rotation, commercial thinning plans, minimum stand diameter and volume for a profitable harvest, and stand age. The data indicate that for stands 18 to 22 years old averaging 2 inches d.b.h. and 4,000 to 8,000 trees per acre, rotations of 50 or 60 years and moderate to heavy precommercial thinnings will be required for a profitable d.b.h.-to-volume ratio.

If no commercial thinnings are planned, heavy precommercial thinnings will be necessary to

Table 7.

ANALYSIS OF VARIANCE OF PERIODIC ANNUAL GROWTH PERCENTAGES.

Source of	All trees				450 crop trees				150 crop trees			
variation	D.F.	S.S.	M.S.	F value	D.F.	S.S.	M.S.	F value	D.F.	S.S.	M.S.	F value
							VOLUME					
Location	2	37.00	18.50	4.83*	2	55.71	27.86	6.32**	2	63.01	31.50	3.37 N.S.
Thinning	4	400.55	100.00	26.2**	4	111.28	27.82	6.31*	4	48.05	12.01	1.28 N.S.
Control versus other	(1)	305.55	305.55	79.8**	(1)	46.29	46.29	10.50*	(1)	8.36	8.36	0.89 N.S.
Field choice versus 10 ft	(1)	11.76	11.76	3.1 N.S.	(1)	8.64	8.64	1.96 N.S.	(1)	3.53	3.53	0.38 N.S.
Residual	8	30.62	3.83		8	35.28	4.41		4	74.85	9.36	
							BASAL AREA					
Location	2	46.92	23.46	15.96**	2	47.34	23.67	9.54**	2	67.60	33.80	3.56 N.S.
Thinning	4	250.02	62.50	42.51**	4	73.16	18.29	7.37**	4	23.14	5.78	0.61 N.S.
Control versus other	(1)	191.53	191.53	130.26**	(1)	33.60	33.60	13.54**	(1)	1.47	1.47	0.15 N.S.
Field choice versus 10 ft	(1)	7.04	7.04	4.79 N.S.	(1)	4.68	4.68	1.89 N.S.	(1)	1.50	1.50	0.16 N.S.
Residual	8	11.76	1.47									
							DIAMETER BREAST HEIGHT					
Location	2	6.63	3.32	15.92**	2	5.92	2.96	9.98**	2	7.40	3.70	3.15 N.S.
Thinning	4	17.02	4.25	20.42**	4	7.70	1.92	6.49*	4	3.07	0.77	0.65 N.S.
Control versus other	(1)	11.44	11.44	54.91**	(1)	3.04	3.04	10.24*	(1)	0.15	0.15	0.13 N.S.
Field choice versus 10 ft	(1)	0.28	0.28	1.35 N.S.	(1)	0.54	0.54	1.82 N.S.	(1)	0.06	0.06	0.05 N.S.
Residual	8	1.67	0.21		8	2.37	0.30		8	9.38	1.17	

* P = 0.05.
** P = 0.01.
N.S. = Not significant.

bring the stand to a harvestable size in a reasonable rotation period. The crop-tree data, and the experiences of forest managers, suggest that a stand density of 300 to 450 crop trees per acre is most effective. The spacings may range from 10 by 10 feet to 12 by 12 feet. The younger the stand and the smaller the mean stand diameter, the larger the number of crop trees.

If commercial thinnings are planned, precommercial thinnings may be moderate to heavy. The larger the mean stand diameter required for commercial thinnings, the heavier the precommercial thinning should be.

Although this study did not include stands under 18 years old, the results indicated that younger stands responded better to precommercial thinning, as did plots on the better sites. The 18- to 22-year-old stands studied would have profited from earlier thinnings. It appears the silviculturist should consider precommercial thinning when the fully stocked stand is 10 to 18 years old and the mean stand height is approximately 20 to 25 feet. Thinnings should begin earlier on Sites I and II.

British/metric conversions

1 inch (in.)	= 2.54 centimeters
1 foot (ft)	= 0.3048 meter (m)
1 ft^2	= 0.0929 m^2
1 ft^3	= 0.0283 m^3
1 acre	= 0.405 hectare

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Young western hemlock stands in the Coast Range of Oregon will contribute to the commercial timber supply of the region in the future, the extent of the contribution depending on environmental and cultural factors. The relative diameter and volume growth of crop-trees in the stands will be increased substantially by precommercial thinning. Heavy precommercial thinning in fully stocked stands will bring individual crop-trees to a commercial size more rapidly than those in lightly thinned or unthinned stands.

Key words: precommercial thinning, western hemlock, *Tsuga heterophylla*, silvicultural practices, stand density, tree mortality, stand growth rates, Oregon Coast Range forests, thinning impacts, site factors.

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