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Response to Commercial Thinning in a 110-year-old Douglas-Fir Stand

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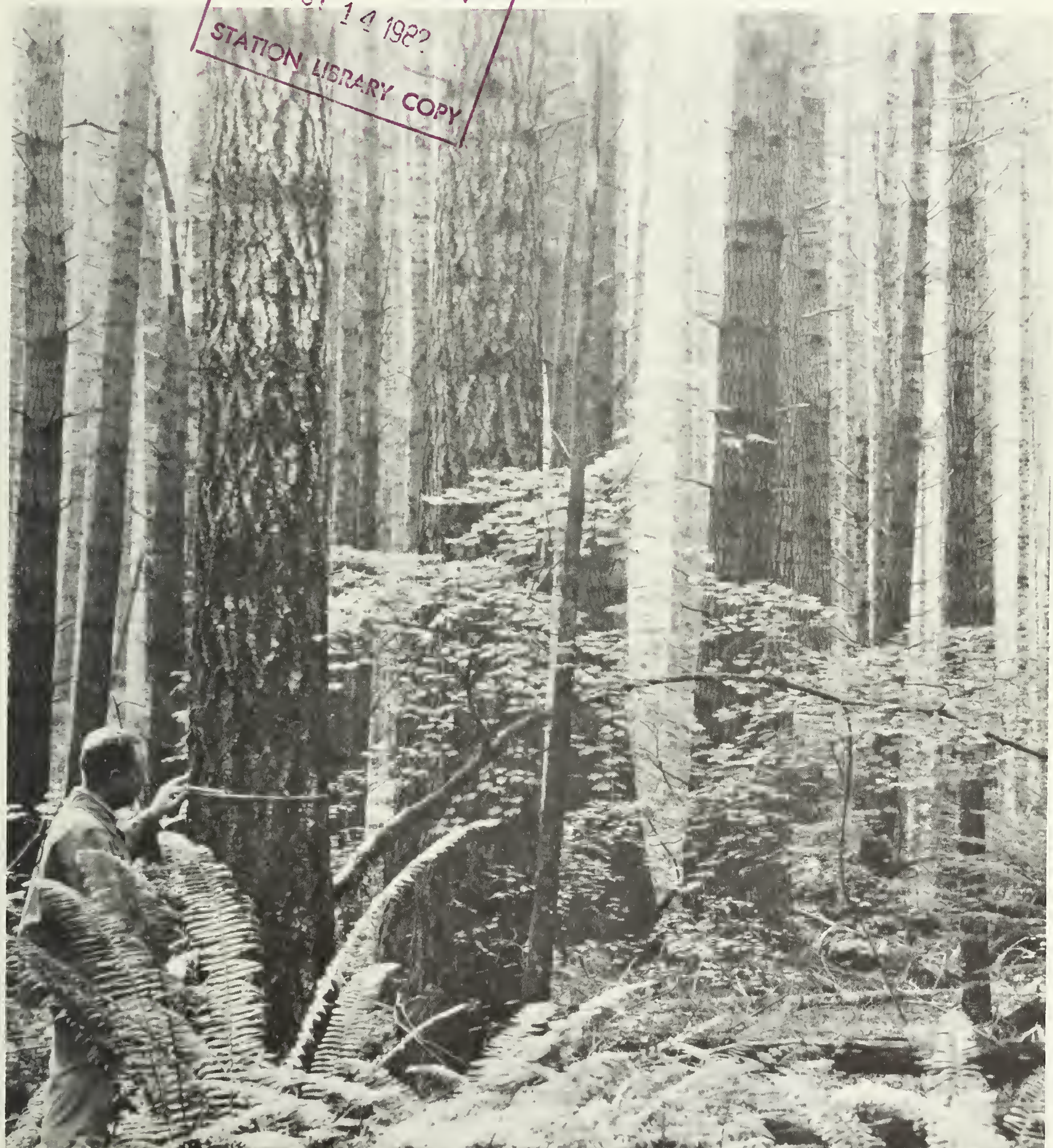

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Abstract

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During a 19-year period after a 110-year-old Douglas-fir stand was thinned, both standard plot compilations and stem analysis showed that growth of heavily and lightly thinned stands equaled growth of stands in control plots.

KEYWORDS: Thinning, Douglas-fir, volume increment of stands.

Summary

In 1952, the Pacific Northwest Forest and Range Experiment Station established a thinning study in a 110-year-old stand of Douglas-fir in southwest Washington. Density of lightly thinned stands was adjusted to about 75 percent of normal basal area, and heavily thinned stands to about 50 percent. Nominal treatments were confounded by initial differences among plots and treatments in site index, stocking, and density. After accounting for these confounding factors, gross growth of all plots—except a lightly thinned one—was about equal to normal gross growth during a 19-year period after thinning. The reason for poor growth on the lightly thinned plot is unknown.

Good growth response of individual trees, in line with that to be expected by stand response, was illustrated by results of stem analyses.

Contents

Introduction

Foresters in the Pacific Northwest sometimes debate the merits of commercially thinning stands of mature young-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Yerkes (1960), writing about thinning in a 110-year-old stand at Boundary Creek, implied that growth response of residual trees was minimal, with little transfer of growth to residual trees, and that thinnings should remove only expected mortality.

My results from the same area were more positive, partly because of the longer period of observation (11, rather than 6 years), but mostly because the variation in site index among treatments was taken into account (Williamson 1966). When gross growth for the several treatments was compared with normal growth for their respective site indexes, only slight and nonsignificant differences were observed. This implied a substantial redistribution of growth from cut trees to residual trees, as did increased radial growth observed on increment cores.

All these results were based on stand volumes calculated from a regional d.b.h.—height volume table (McArdle et al. 1961, table 12), which could conceivably be biased as a result of thinning.[1]

A remeasurement and second thinning 19 years after the first provided a longer period to observe and compare effects of thinning. Trees cut during that second thinning at the end of this 19-year period provided information through stem analyses on individual-tree and stand response and reliability of standard techniques for compiling plot volume growth. This report describes results for the 19 years after the first thinning.

The Study Area

Location

The Boundary Creek thinning-study area is in the Panther Creek subdivision of the Wind River Experimental Forest near Carson, Washington, on the Wind River District of the Gifford Pinchot National Forest. The study area encompasses about 70 acres at an elevation of about 2500 feet. It occupies a slump basin with uneven topography. Slopes are generally less than 30 percent.

Study Design

The experiment tested heavy and light thinning against unthinned controls in a stand 110 years old in 1952 (table 1). Thinnings were "free,"[2] removing some trees in every crown class, but usually leaving the most vigorous dominants and codominants. Some dead and high-risk trees were also removed from the control plots and from the surrounding area in a sanitation-salvage cut made at the same time. Each treatment was replicated three times in a randomized block design. Each plot was rectangular, 1 by 10 chains (fig. 1), and surrounded by areas 1 to 3 chains wide that were sanitation-salvaged at time of initial thinning.

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[1] This hypothesis will be evaluated in a companion paper, in process.

[2] As described in Braathe (1957).

Table 1—Stand characteristics before and after thinning at Boundary Creek

Treatment	Site-index height at age 100	Normal[1] volume at age 110	Initial volume, 1952	Initial as percent of normal	Cut volume, 1952	Percent cut	d/D[2]	Residual, 1952	Residual as percent of normal
	Feet	-Cubic feet per acre-		Percent	Cubic feet per acre	Percent		Cubic feet per acre	Percent
Control									
Plot 1	152	15,532	15,171	97.7	[3]636	4.2	--	14,535	9.63
6	145	14,645	12,411	84.7	[3]902	7.3	--	11,509	78.6
7	143	14,387	8,892	61.8	0	0	--	8,892	61.8
Average	147	14,903	12,158	81.6	--	--	--	11,645	78.1
Light thinning									
Plot 3	150	15,290	14,403	94.2	3,078	21.4	0.83	11,325	74.1
4	151	15,411	13,557	88.0	2,431	17.9	.88	11,126	72.2
8	134	13,166	14,423	109.5	2,625	18.2	.85	11,798	89.6
Average	145	14,645	14,128	96.5	2,711	19.2	--	11,416	77.9
Heavy thinning									
Plot 2	121	11,233	9,535	84.9	3,208	33.6	.83	6,327	56.3
5	143	14,387	10,230	71.1	1,605	15.7	.75	8,625	59.9
9	114	10,132	10,224	100.9	2,989	29.2	.95	7,235	71.4
Average	126	11,917	9,784	82.1	2,426	24.8	--	7,395	62.0

[1] From McArdle et al. (1961).
[2] d = quadratic mean diameter of cut trees; D = quadratic mean diameter of all trees before cutting.
[3] Salvaged mortality.

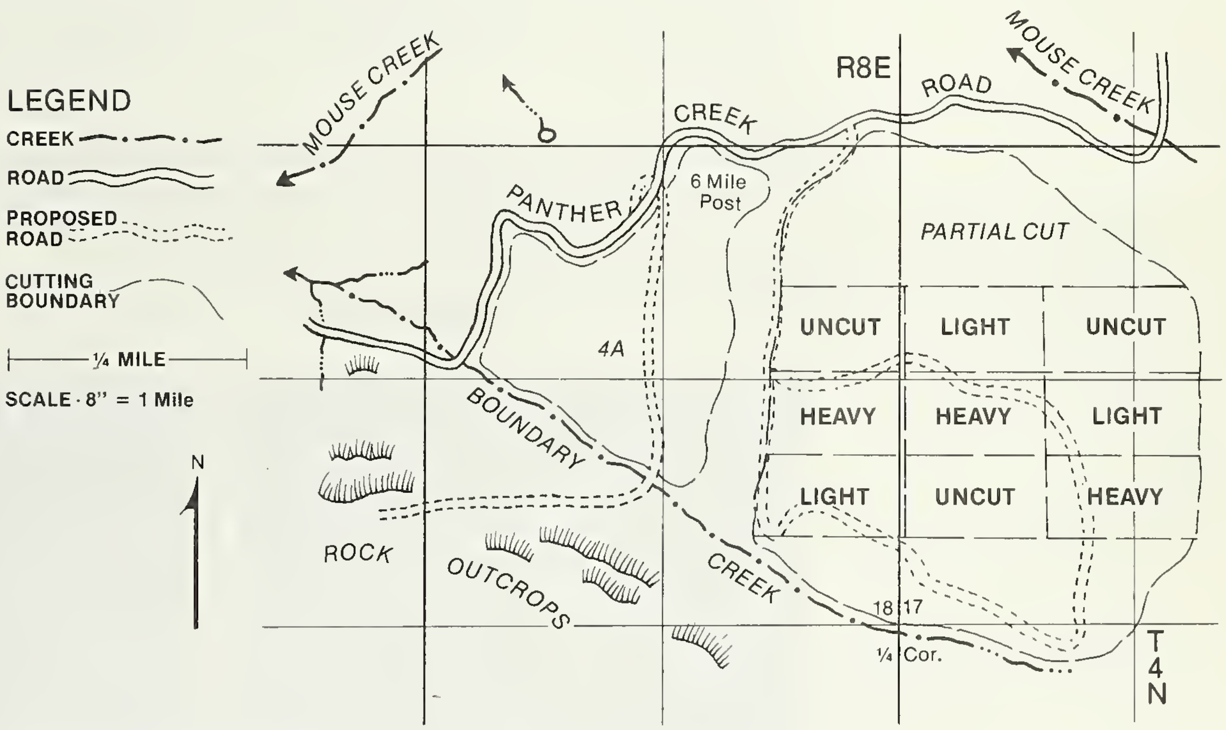


Figure 1.—Boundary Creek thinning study, Wind River Experimental Forest near Carson, Washington.

Stand Variability

Site index.—Total heights and ages were obtained for sufficient numbers of trees on each plot to give a standard error of site index for each plot of 6 feet or less. Site index (McArdle et al. 1961) ranged from 114 to 152, with six of the nine plots between 140 and 150 (table 1). The two plots of lowest site index were in the heavily thinned group.

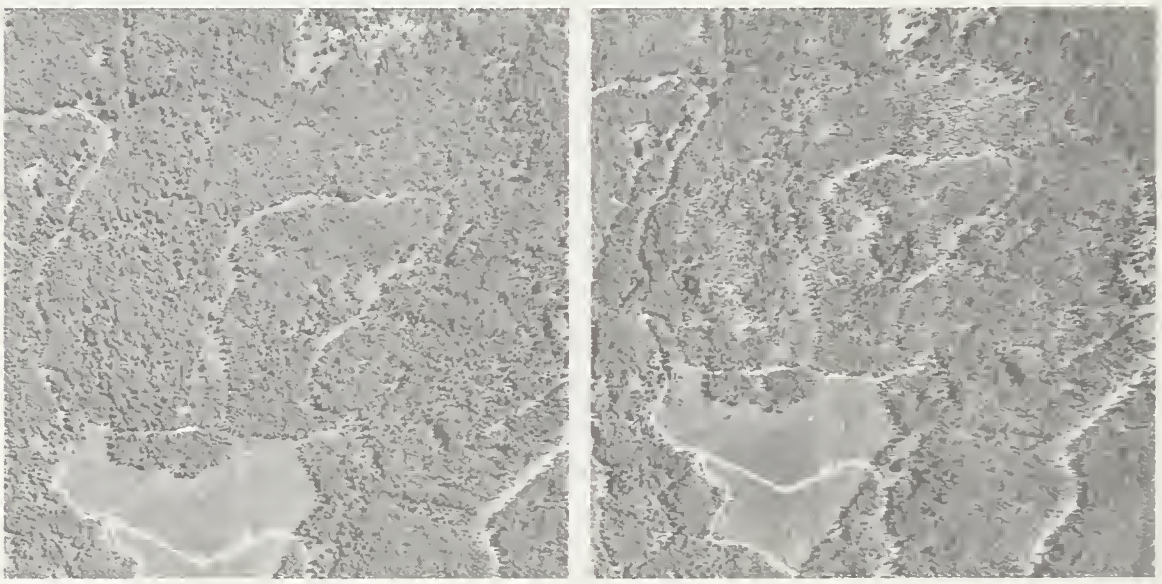
Mortality.—Bark beetles (*Dendroctonus pseudotsugae* Hopkins) and root rot (*Phellinus weirii* (Murr.) Gilb.) were causing mortality when the study began in 1952. The second thinning, which made trees available for stem analysis, was instigated by mortality from these agents 16-18 years later. Mortality in 1968 was much more severe than in 1952 (fig. 2). The range in initial stocking is probably wide because similar mortality occurred in the area before the experiment began.

Density or stocking.—Plot 5 ("heavy thinning") was of low density (71 percent of normal) at study establishment, but without obvious unstocked[3] openings in the stand.

Mortality from bark beetles and root rot caused unstocked openings in plot 7—a control plot—accounting for its low initial volume. The unstocked openings in the area are mostly in control plots or otherwise simply sanitation-salvage areas. One other control plot (plot 6) was only 79 percent of normal after removal of mortality in 1952.

These differences in initial stocking or density, and the "cut" values in table 1, suggest that low- and medium-density are better descriptors than "light" and "heavy" thinning, but I will use these terms to be consistent with previous reports.

[3] An unstocked area is here defined as one where resources are not being fully utilized by neighboring trees.



1968 1973

Figure 2.—The Boundary Creek study area, 1967 (left) and 1973 (right) illustrating much poorer stocking after the 1968-70 mortality than before.

Study Objectives

My objectives were to compare response to thinning among treatments, as expressed by conventional plot totals of volume and volume growth, for the 19 years after initial thinning; to compare response to thinning of residual trees, as determined by stem analyses, for the same period; and to compare the estimates of response to thinning calculated for the stand with those obtained from stem analyses of residual trees.

Stand Comparisons

Standard plot computations.—On each 1-acre plot, diameter breast high (d.b.h.) was measured on all trees. Total height of 12 sample trees was measured on each plot, about 8 having diameters above the plot quadratic mean. Volumes of sample trees were determined from the volume table by Bruce and DeMars (1974). Regressions of sample-tree volume on d.b.h. were used to estimate individual tree volumes, and these estimates were summed for total plot volumes. Gross growth is the difference in volumes of the live stand at beginning and end of the growth period, plus volume in mortality.

Expression of thinning response.—Because of the wide range in site index among plots and because of potential problems with stocking differences on the control plots, thinning results were tested by comparing ratios of gross volume growth to normal gross growth for the same site index (Staebler 1955). Therefore, the variable

$$\frac{\Delta V}{\Delta V_{normal}} \qquad (1)$$

was used as the dependent variable in the analysis of variance.

Response can also be expressed as a ratio of growth of thinned stands to that of controls. Average gross growth relative to the average of controls, adjusted for differences in normal growth because of site-index differences, can be expressed as the ratio:

$$\frac{(\Delta V/\Delta V_{normal})\ \text{thinned}}{(\Delta V/\Delta V_{normal})\ \text{control}} \qquad (2)$$

where, again, normal gross-growth values are from Staebler (1955), using the treatment average, site-index value.

Similarly, volume relative to control, adjusted for differences related to site index in normal net volume (McArdle et al. 1961) can be expressed by the ratio:

$$\frac{(V/V_{normal})\ \text{thinned.}}{(V/V_{normal})\ \text{control}} \qquad (3)$$

Dividing (2) by (3) gives

$$\frac{(\Delta V/\Delta V_{normal})/(V/V_{normal})\ \text{thinned.}}{(\Delta V/\Delta V_{normal})/(V/V_{normal})\ \text{control}} = \text{“response.”} \qquad (4)$$

For treated and control plots with the same site index, the two values of ΔV_{normal} are identical, as are those of V_{normal}. Expression (4) then reduces to:

$$\frac{(\Delta V/V)\ \text{thinned}}{(\Delta V/V)\ \text{control}}$$

which is simply the ratio of volume-growth percent of treated to volume-growth percent of control.

The response ratio (4) can thus be regarded as a ratio of volume-growth percentages of treated plots relative to control, adjusted for differences in site index and stocking. A response value greater than 1.0 indicates an increase in increment per unit of growing stock relative to control. Such an increase could result from either the removal of slow-growing trees in thinning or an actual increase in growth rate of the remaining trees (or, usually, both).

Analysis.—The study was designed as a randomized block experiment with three replications. The analysis of variance for the ratio of plot gross-volume growth to normal growth for the plot site index is illustrated in table 2.

Table 2—Analysis of variance on gross growth as a percentage of normal gross growth

Source of variation	Degrees of freedom	Mean square	F
Thinning	2	22.484	0.139
Blocks	2	19.631	.120
Error	4	161.311	--

[1]Differences were considered significant if $p \leq 0.10$.

Individual-Tree Comparisons

Selection of sample trees.—I examined 72 trees, two in each of the four major crown classes, as of 1971, on each plot. All stem-analysis trees were alive at time of felling, had vigor commensurate with their crown class, and release typical of the thinning treatment.

Volume computations.—Volume of each tree was estimated at time of thinning and for 19 years before and after thinning.

Sections were cut from each stem at stump height, breast height, base of live crown, and at 0.1, 0.3, 0.5, 0.7, and 0.9 of total height.[4] Radius of each section was calculated as the quadratic mean of eight regularly spaced radii, with the initial radius randomly oriented. Volume of stem sections was calculated as that of a frustrum of a cone. As Grosenbaugh (1954) has demonstrated, the particular conic shape assumed for stem segments makes little practical difference as long as small diameters are at least 70 percent of the larger.

Periodic growth was calculated as the difference between volumes so determined at the beginning and end of each 19-year growth period.

Expression of individual-tree response.—Volume growth for the 19 years after thinning can be expected to reflect the known differences in plot site indexes, and it is not a suitable variable for comparison of thinning effects. The periodic-growth ratio,

$$\frac{\Delta V \text{ for 19 years after thinning}}{\Delta V \text{ for 19 years before thinning}}$$

was therefore used as the variable for testing thinning response.

The quotient obtained by dividing the value of this ratio for a specified class of trees in thinned plots by the corresponding value for control plots will be described as "relative response."

Analysis.—Analysis of variance of these periodic-growth ratios obtained by stem analysis followed the randomized block design of the main experiment. Each major plot, however, was split into the four crown classes, giving a split-plot randomized block analysis (table 3)

[4] This procedure is similar to that given in Altherr (1960).

Table 3—Analysis of variance on periodic-growth ratios of individual trees

Source of variation	Degrees of freedom	Mean square	F
Thinning	2	3,846	5.193
Blocks	2	2,768	3.738
Major plot error	4	740	--
Crown class	3	227	.757
Thinning x crown class	6	797	2.659
Minor plot error	18	300	--

Results

Stand Comparisons

Gross growth.—The most recent (19-year period) estimates of volume growth for the stand at Boundary Creek (table 4) indicated good response to thinning, similar to that reported previously (Williamson 1966), after differences in site index and stocking were taken into account. Gross growth of plots, relative to normal growth, did not differ significantly among treatments (table 2).

The "response" variable (equation 4, table 5) suggests that gross growth of heavily thinned plots was 27 percent better than that expected if growth were directly proportional to growing stock. The lightly thinned plots showed no improvement, which probably reflects the fact that residual growing stock on the lightly thinned plots was nearly the same as that on controls (table 1).

Some apparent exceptions were found to the statement that gross growth was about normal, for these individual plots:

Plot 1 (control):—78 percent. This plot contained a large unstocked opening because of mortality during 1964-71.
Plot 3 (light thinning):—84.5 percent. The reason for poor growth on this plot is not known.
Plot 5 (heavy thinning):—84.8 percent. This plot had quite uniform low density (71 percent of normal) before thinning, for unknown reasons, as though stand density had always been open. Only 15.7 percent of volume was removed in thinning. A slow return to normal density (Briegleb 1942) is probably all that could be expected in a stand under these conditions.
Plot 7 (control):—85.3 percent. An unstocked opening existed in the east half at time of study establishment. The west half was widely spaced.

The block F (table 2) was nonsignificant. Clearly, the blocks, which were established on the basis of slope position, had little relation to the actual pattern of site index in the area and were ineffective in accounting for the considerable differences in site index there.

Mortality.—As reported previously (Williamson and Price 1971), thinning sharply reduced all types of mortality in mature young-growth stands. The latest measurements at Boundary Creek support this conclusion. Average mortality on control plots was five times the mortality on heavily thinned plots and about three times that on lightly thinned plots. Mortality on control plots has averaged 100 cubic feet per acre per year, but on lightly and heavily thinned stands was only 33 and 20, respectively.

The principal causes of nonsuppression mortality are thought to have been drought in combination with *Phellinus weirii* root rot and Douglas-fir bark beetle. Mortality in the general area has typically been in patches, killing trees of all crown classes.

Mortality in the control plots was 86 percent of gross growth and was patchy, resulting in unstocked openings. Mortality in lightly and heavily thinned stands was only 30 and 23 percent of gross growth, respectively, and generally widely scattered.

Net growth.—The relation of stand density to mortality also implies a corresponding and inverse relation to stand net growth (table 4). Although lightly thinned stands averaged 119 percent of normal net growth and heavily thinned stands averaged 136 percent, unthinned stands averaged much less than normal.

Table 4—Periodic, annual gross growth per acre by treatment, plot, and period at Boundary Creek

Treatment	Site-index height at age 100	Gross growth, annual, 1952-63	Normal[1] growth	Gross, growth 1952-63 relative to normal	Gross growth, annual, 1964-71	Normal[1] growth	Gross growth 1964-71 relative to normal	Gross growth, annual, 1952-71	Normal[1] growth	Gross growth 1952-71 relative to normal	Normal gross growth relative to control	Net growth, annual, 1952-71	Normal[2] growth	Net growth relative to normal
	Feet	- - Cubic feet - -		Percent	- - Cubic feet - -		Percent	- - Cubic feet - -		- - Percent - -		- - Cubic feet - -		Percent
Control														
Plot 1	152	135	134	100.7	98	126	78.0	119	130	91.5	—	-148	65	-228
6	145	127	123	103.2	115	115	100.0	122	119	102.8	—	59	60	98
7	143	107	120	89.2	88	112	78.6	99	116	85.3	—	-84	59	-142
Average	147	123	126	97.6	100	118	85.0	113	122	93.2	100	-58	61	-91
Light thinning														
Plot 3	150	102	130	78.5	104	123	84.5	103	127	81.1	—	85	64	133
4	151	128	132	97.0	129	124	104.0	129	128	100.8	—	123	64	192
8	134	92	106	86.8	95	99	96.0	93	103	90.3	—	17	54	32
Average	145	107	123	87.0	109	115	94.8	108	119	90.7	98	75	61	119
Heavy thinning														
Plot 2	121	79	88	89.8	88	81	108.6	83	84	98.8	—	79	47	168
5	143	95	120	79.2	95	112	84.8	95	116	82.2	—	72	59	122
9	114	83	79	105.1	78	72	108.3	81	75	107.6	—	49	42	117
Average	126	86	94	91.5	87	88	98.9	86	92	96.2	100	67	49	136

[1] Staehler (1955).
[2] McArdle et al. (1961).

Table 5—Calculation of stand response to light and heavy thinning

	Control	Light thinning	Heavy thinning	Light thinning response		Heavy thinning response	
	1	2	3	4 (2÷1)	5 (4a÷4b)	6 (3÷1)	7 (6a÷6b)
a. Percent of normal[1] gross growth	93.1	90.7	93.5	0.9742	0.98	1.0043	1.27
b. Percent of normal[2] net growing stock	78.1	77.9	62.0	.9974	--	.7938	--

[1] Staebler (1955).
[2] McArdle et al. (1961).

Among individual plots, note: relatively poor net growth by thinned plot 8, which had an initial density above normal and residual density 90 percent of normal, with mortality in a portion of the plot that received little thinning; relatively good net growth by control plot 6, which had an initial density of only 85 percent of normal with fairly uniform stem distribution; and negative net growth for plot 7, where the east half with heavy mortality was about twice as dense (145 trees/acre) as the west half (78 trees/acre), which had little mortality.

Individual-Tree Comparisons

Average thinning effects.—Ratios of gross volume growth for 19 years after thinning to that for the 19 years before thinning differed significantly among treatments (table 3). Average relative response of all 24 sectioned trees in the heavily thinned stands was 30 percent greater than that of controls, but that of lightly thinned stands was 8 percent greater (table 6). Evidently, the response found in the stand comparisons was not solely or primarily the result of removal of slow-growing tres, but a real response by the residual trees.

Table 6—Comparison of response[1] and relative response[2] in volume growth treatment (arithmetic mean for 24 trees each in control, lightly thinned, and heavily thinned plots, based on stem analysis)

Treatment	Response	Relative response
Control	0.82	100
Light thinning	.89	108
Heavy thinning	1.07	130

1/Response = volume growth 19 years after thinning relative to that 19 years before.
2/Relative response = response of trees in thinned plots relative to that in controls.

Response by different crown classes.—Thinning had a significantly different effect on periodic growth ratios of different crown classes, as shown by the significant T x CC interaction (table 3). Particularly impressive is the relative response of suppressed trees in heavily thinned stands, almost double the control (table 7). Though suppressed trees should be expected to grow more slowly than superior crown class trees—and these did (table 8)—growth percent (periodic growth divided by initial volume) suggests that all crown classes in the heavily thinned stands contributed about as much to plot growth as they did to plot growing stock (table 9). Volume growth of these trees is low compared to that of trees in the other two treatments because of the lower site index in these plots. Good response by suppressed trees is not too surprising because they were under the most competition initially and should benefit more from release than would a dominant tree. Diameters of these suppressed trees averaged 60 percent of the dominant tree diameters, and live-crown ratios averaged 27 percent.

Table 7—Comparison of average response[1] and relative response[2] in volume growth for the 6 trees in each thinning treatment, crown-class category at Boundary Creek, based on stem analysis

		Light thinning		Heavy thinning	
Crown class	Control	Response	Relative response	Response	Relative response
Dominant	0.80	0.95	118	1.04	130
Codominant	.93	.91	98	1.05	112
Intermediate	.89	.79	90	.96	108
Suppressed	.68	.91	135	1.23	182

1/Response = volume growth 19 years after thinning relative to that 19 years before.
2/Relative response = response of trees in thinned plots relative to that in controls.

Table 8—Periodic growth, 1952-71, by thinning treatment and crown class, stem-analysis trees only

Treatment	Crown class			
	Dominant	Codominant	Intermediate	Suppressed
	Cubic feet			
Control	40.8	17.8	21.2	4.7
Light thinning	37.6	23.0	12.1	6.4
Heavy thinning	20.0	17.1	9.7	5.8

Table 9—Periodic growth percent, 1952-71, by thinning treatment and crown class, stem-analysis trees only

Treatment	Crown class			
	Dominant	Codominant	Intermediate	Suppressed
	Cubic feet			
Control	19.3	17.9	22.0	10.1
Light thinning	21.1	19.6	12.8	12.8
Heavy thinning	19.9	21.4	17.9	19.8

Codominant and intermediate trees had the lowest relative responses, 112 and 108 percent, respectively. Dominant trees responded less than suppressed trees, but better than intermediate and codominant trees with a gain of 30 percent, slightly above the overall average weighted response.

On the control plots, response for codominant trees generally was higher than for trees in the other crown classes. Response for suppressed trees invariably was the poorest.

Naturally, a lot of variation occurred in the growth ratios between trees within a given crown class on the thinned plots. This variation could result from differing amounts of competition before and after release by thinning. Some consistencies are apparent, however, among all thinned plots.

Although response of suppressed trees was invariably poorest in the control plots, it was better than all other crown classes on five of the six thinned plots. Codominant and intermediate trees had the lowest response on five of the six thinned plots. On the one plot (5) where codominant or intermediate trees were not the poorest responders, the dominant trees were. This plot is the heavily thinned one where the initial stand density was considerably below average for that treatment, and where little stand response was expected.

Comparison of Estimates of Stand and Individual-Tree Responses

To convert the stem-analysis estimates of individual-tree response to per-acre estimates of stand response, responses by crown class (table 7) were weighted by volume of trees in these classes on the plots. After thinning in 1952, growing stock of heavily thinned plots was only 79.4 percent of that of controls (both relative to normal). Therefore, if growth after thinning were equal to that of control plots, an average tree in a heavily thinned plot would have a relative response of 126 percent (1/.794). In fact, the stem analyses give a weighted average relative response of 120 percent, in good agreement.

This result also indicates (as did average thinning effects) that the observed stand response is not solely or primarily because of removal of slow-growing trees, but also includes a substantial real response by the residual stand.

Basal-Area Growth as an Estimator of Volume Growth

Stand-volume growth is a function of basal-area growth, form change, and height growth (Evert 1964). In young stands, where height and form are changing rapidly, basal-area growth can be a poor predictor of volume growth. In older (70- to 150-year-old) stands, where height growth is much reduced and form changes slowly, basal-area growth should be a much better predictor of volume growth (Williamson and Price 1971).

Williamson and Price (1971) expressed periodic, annual, gross basal-area increment as a percent of prethinning basal-area growing stock (technique 1), and assumed that such a percent for volume growth should be about the same. This provides a sort of self-calibration. Alternatively, standard growth percents (periodic annual growth divided by postthinning growing stock—technique 2) could be used. Both techniques tend to eliminate confounding influences of site and stocking. Technique 2 is useful primarily for deciding if thinning has caused any growth response, technique 1 for deciding if growth of thinned stands equals that of controls.

Volume growth ($\Delta\Sigma V$) may be expressed as a function of average form factor ($\bar{F}$), plot basal area and its increase ($\Sigma\beta$ and $\Delta\Sigma\beta$, respectively), and Lorey's height[5] and its increase ($\bar{H}$ and $\Delta\bar{H}$, respectively), as follows:

$$\Delta\Sigma V = \bar{F}(\Sigma\beta \bullet \Delta\bar{H} + \bar{H} \bullet \Delta\Sigma\beta + \Delta\Sigma\beta \bullet \Delta\bar{H}),$$

neglecting terms that involve change in form factor (Evert 1964). Volume may be expressed as $\Sigma V = \bar{F} \bullet \Sigma\beta \bullet \bar{H}$. Dividing the volume increment expression by that for volume, yields:

$$\frac{\Delta\Sigma V}{\Sigma V} = \frac{\Delta\bar{H}}{\bar{H}} + \frac{\Delta\Sigma\beta}{\Sigma\beta} + \frac{\Delta\Sigma\beta \bullet \Delta\bar{H}}{\Sigma\beta \bullet \bar{H}}$$

Therefore, volume-growth percent must always be greater than basal-area growth percent.

If $\Delta\bar{H}$ is small enough so that its effects can be ignored, then volume-growth percent should be very close to basal-area growth percent, neglecting changes in form factor.

These data illustrate that incorrect inferences can be derived from basal-area data whichever technique is used (table 10). Agreement between basal-area and volume percents is within 10 percent for control and lightly thinned stands. For heavily thinned stands, however, differences go up to 22 percent, with most over 10 percent. Basal-area growth grossly underestimates volume growth. Changes in form factor of the stem-analyzed trees were significant. Very likely, Williamson and Price (1971) underestimated volume growth of their more heavily thinned stands.

[5] Lorey's height is the height of the tree of mean volume.

Table 10—Comparisons of periodic, annual-growth percent derived from stand basal area or cubic volume

Item	Control				Light thinning				Heavy thinning			
	1	6	7	Mean	3	4	8	Mean	2	5	9	Mean
							Percent					
					TECHNIQUE 1 (Pretreatment)							
Basal area	0.830	0.886	1.080	0.909	0.713	0.972	0.610	0.763	0.677	0.860	0.647	0.722
Volume growth	.784	.983	1.113	.929	.715	.952	.645	.764	.870	.990	.792	.879
$\frac{(BA-V)}{V}$[1] X 100	5.87	-9.87	-2.96	-2.15	-.28	2.10	-5.43	-.13	-22.18	-13.13	-18.31	-17.86
					TECHNIQUE 2 (Posttreatment)							
Basal area	.865	.954	1.080	.969	.912	1.187	.719	.934	1.053	1.080	1.004	1.057
Volume growth	.819	1.060	1.113	.970	.909	1.159	.788	.946	1.312	1.115	1.119	1.163
$\frac{(BA-V)}{V}$[1] X 100	5.62	-10.00	-2.96	-.10	.33	2.42	-8.76	-1.27	-19.74	-3.14	-10.28	-9.11

[1] The percentage difference between estimates of the basal-area and cubic-volume growth percents.

Discussion

Whether growth is measured for stands or individual trees, thinned plots at Boundary Creek have responded well to thinning, exhibiting very nearly normal gross growth in the latest period (1964-71) and with growth for the total 19 years just slightly reduced. This result—better than previously reported (Williamson 1966, Yerkes 1960)—is because of the longer period of observation and the better recognition and use of differences among the plots and treatments in site index and in stocking and density levels.

Beneficial effects of thinning were illustrated here, although plots were only 1 chain wide and 10 chains long, and entirely surrounded by areas that were only sanitation-salvaged in 1952. Perimeter is 74 percent greater than that of a square plot and 96 percent greater than that of a round one. Any adverse effects of unbuffered surroundings should be proportional to perimeter length. Very likely, the beneficial effects of thinning have been underestimated somewhat at this study area.

This long-term record and long-term records at five other study areas (Williamson and Price 1971) suggest that reductions in gross growth from thinning in these older stands are usually minor.

In contrast, Reukema (1972) and Reukema and Bruce (1977) estimated 15- to 20-percent reduction in gross growth for commercial thinning in younger stands over 20-year periods. Worthington (1966) found a 25-percent reduction in gross growth for 30 years after thinning that removed about 50 percent of initial volume in a 60-year-old, site IV stand.

The apparent discrepancies in results may be partly because of differences in initial stand density, kind of cutting, growing-stock levels, and the semantic ambiguities in terms such as "heavy thinning" and "light thinning."

Lower average initial density at Boundary Creek (compared to Worthington's (1966) study area, in which heavily thinned plots were reduced to 50 percent of normal by removal of half the growing stock) was probably associated with larger crowns and greater capacity to respond. The lower average initial density, of course, called for correspondingly lighter removals.

A similar comparison is appropriate to Reukema's (1972) study area, where initial density of thinned plots averaged about 117 percent of normal volume. In addition, periodic thinnings allowed only about 10 percent of gross increment to accrue to growing stock, resulting in final densities about 60 percent of normal. These various data suggest that best results of initial thinnings in mature young-growth stands will be obtained when stand density is between about 80 and 100 percent of normal (McArdle et al. 1961) density. If stands already exceed normal density, with accompanying crown restriction, initial thinnings should be light—about 30 percent or less by basal area—to minimize windthrow and mortality from snow-or-ice load.

This study illustrates vividly the advantages of thinning stands that are this old, rather than simply sanitizing them and salvaging mortality. The control stands were sanitation-salvaged in 1952 at the start of the experiment when mortality from bark beetle and root rot were occurring. Only dead or morbid trees were removed; no additional thinning was done. Natural mortality has been much greater on control plots than on thinned plots. The most unfortunate aspect of this mortality in unthinned stands is that it has occurred primarily in clumps of ever-increasing size. This has resulted in unstocked openings that were quickly taken over by brush.

Thinning, in contrast, forestalled much mortality and resulted in fairly uniform spacing with little loss of stocking, while maintaining about normal gross growth.

Metric Equivalents

1 foot = 0.3048 m
1 chain = 20.12 m
1 square foot per acre = 0.2295 m^2/ha
1 cubic foot per acre = 0.0700 m^3/ha
1 acre = 0.4047 ha

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During a 19-year period after a 110-year-old Douglas-fir stand was thinned, both standard plot compilations and stem analysis showed that growth of heavily and lightly thinned stands equaled growth of stands in control plots.

KEYWORDS: Thinning, Douglas-fir, volume increment of stands.

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