RESEARCH BULLETIN 38

JULY 1982

RESPONSE OF YOUNG DOUGLAS-FIR TO 16 YEARS OF INTENSIVE THINNING

J.C. TAPPEINER

J.F. BELL

J.D. BRODIE

FOREST RESEARCH LAB

SCHOOL OF FORESTRY

OREGON STATE UNIVERSITY

Since 1941, the Forest Research Laboratory--part of the School of Forestry at Oregon State University in Corvallis--has been studying forests and why they are like they are. A staff of more than 50 scientists conducts research to provide information for wise public and private decisions on managing and using Oregon's forest resources and operating its wood-using industries. Because of this research, Oregon's forests now yield more in the way of wood products, water, forage, wildlife, and recreation. Wood products are harvested, processed, and used more efficiently. Employment, productivity, and profitability in industries dependent on forests also have been strengthened. And this research has helped Oregon to maintain a quality environment for its people.

Much research is done right in the Laboratory's facilities on the campus. But field experiments in forest genetics, young-growth management, forest hydrology, harvesting methods, and reforestation are conducted on 12,000 acres of School forests adjacent to the campus and on lands of public and private cooperating agencies throughout the Pacific Northwest.

With these publications, the Forest Research Laboratory supplies the results of its research to forest land owners and managers, to manufacturers and users of forest products, to leaders of government and industry, and to the general public.

As a research bulletin, this publication is one of a series that comprehensively and in detail discusses a long, complex study or summarizes available information on a topic.

The Authors

J. C. Tappeiner is associate professor, J. F. Bell is professor, and J. D. Brodie is associate professor, Department of Forest Management, School of Forestry, Oregon State University, Corvallis.

Disclaimer

The mention of trade names or commercial products in this publication does not constitute endorsement or recommendation for use.

To Order Copies

Copies of this and other Forest Research Laboratory publications are available from:

Forest Research Laboratory
School of Forestry
Oregon State University
Corvallis, Oregon 97331

Please include author(s), title, and publication number if known.

CONTENTS

ABSTRACT

A 20-year-old Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] stand in the Oregon Coast Range was thinned from about 1,700 to about 350 trees/ac. At ages 23, 27, 30, and 32, trees were cut according to eight different thinning regimes; untreated plots with 1,610 to 1,885 trees/ac served as controls. Basal areas ranged from 55 ft^2/ac (heaviest thinning treatment age 23) to about 277 ft^2/ac (controls age 32). Average net periodic cubic-volume growth was strongly influenced by thinning regime, varying from about 220 ft^3/ac/yr (heavy thinning age 30) to over 550 ft^3/ac/yr (controls age 23). Evaluation of volume, diameter, and basal area growth indicates that young Douglas-fir on productive sites (site index 160 to 170 ft at 100 years) are extremely adaptable and will respond to frequent thinnings of various intensities.

Three representative treatments (after thinning at age 32) and the controls were projected and optimized with dynamic programming for financial analysis. In the first analysis, the cost and return of thinnings and the value of the standing timber at age 36 were highest for moderately thinned stands. In the second analysis, returns for stands with heavy early thinning were optimized by a short rotation and no further thinning, whereas returns for stands with conservative early thinning and the controls were optimized by a longer rotation and two to four thinnings after age 32. Adjusting rotation or commercial thinning can compensate for lack of early stand management or heavy early thinning.

INTRODUCTION

Knowing the response of forest stands to various thinning intensities is important for managing stands for wood products. Because comprehensive data on thinning young Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] were lacking, a regionwide cooperative study on levels of growing stock was begun in 1962 in the Pacific Northwest (Williamson and Staebler 1971). (A list of cooperators and related levels-of-growing-stock publications is furnished in Appendix A.) As part of this cooperative, the School of Forestry, Oregon State University, established a series of plots near Hoskins, Oregon, which were thinned 5 times to a wide range of stand densities during the period 1963-79. Two earlier reports have summarized the results to 1970 (Bell and Berg 1972) and 1975 (Berg and Bell 1979).

These studies, designed only to test the response of young Douglas-fir to intensive, frequent thinnings, have provided good information on the growth and yield of this species on highly productive sites. This bulletin presents the results of the last growth period (1975-79) and summarizes the findings from all five treatment periods over 16 years with particular reference to stand management implications, including a financial analysis of representative thinning regimes.

METHODS

STUDY AREA

The study was installed in a uniform, even-aged, natural, 20-year-old Douglas-fir stand in the Oregon Coast Range near Hoskins, Oregon, about 22 miles west of Corvallis. Number of trees ranged from 1,610 to 1,885/ac, basal area from 120 to 160 ft^2/ac, and average diameter from 3.6 to 4.2 in. on the 27 0.2-ac plots selected for study. Live-crown ratios were at least 75 percent.

Annual precipitation in the area is about 65 to 75 in. Temperatures average 50°F, and from

160 to 190 days each year are frost-free. Slopes range from 15 to about 55 percent. Soils are silty clay loams of the Apt series about 60 in. deep, with water-holding capacity of from 7 to 10 in.; parent material is sedimentary rock. Site index is 160 to 170 ft at 100 years (McArdle et al. 1961), or 130 to 135 ft at 50 years (King 1966).

TREATMENTS

Treatments were the same as those for all installations in the cooperative study (Williamson and Staebler 1971); eight different thinning regimes were tested.

In 1963, when trees were 20 years old, 80 well-formed, evenly spaced, dominant or codominant trees per acre were selected as crop trees on the assumption that they would be favored by thinning and would be the trees harvested at rotation. Trees growing better than those first selected could later be substituted as crop trees. A calibration thinning at age 20 removed about 80 ft^2/ac of basal area and 1,200 ft^3/ac of volume to reduce variability before treatment, leaving about 350 trees/ac and about 50 ft^2/ac on all plots except the controls, which were not treated.

Plots were thinned each time crop trees grew 10 ft in height so that thinnings would be frequent when height growth and crown development were most rapid (Staebler 1960). This resulted in thinning at ages 23, 27, 30, and 32. Plots were measured before each treatment and at age 36. Thinnings removed noncrop trees from all diameter classes such that average stand diameter[1] before thinning (d) was the same as that after thinning (D); thus, the d/D ratio of noncrop trees after thinning would be 1.

Thinning intensity was related to basal area growth on the controls and to predetermined thinning regimes (Table 1) designed to provide a range of densities. Basal area after thinning was calculated with the following equation:

$$BA_n = BA_{n-1} + GBAG(P)$$

where:

BA_n = basal area (ft^2/ac) at the beginning of a treatment period

BA_{n-1} = basal area (ft^2/ac) at the beginning of the preceding treatment period

$GBAG$ = average gross basal-area growth on the controls (that is, increase in basal area plus mortality on the control plots during the preceding period)

P = predetermined percentage of gross basal-area increment of the controls to be retained (Table 1).

TABLE 1.

PERCENTAGE OF GROSS BASAL-AREA INCREMENT OF THE CONTROLS USED IN CALCULATING BASAL AREA AFTER THINNING.

Stand age	Treatment 1	2	3	4	5	6	7	8
				%				
23	10	10	30	30	50	50	70	70
27	10	20	30	40	50	40	70	60
30	10	30	30	50	50	30	70	50
32	10	40	30	60	50	20	70	40

ANALYSES

Treatment and control plots were randomly selected, and each of the eight treatments and the controls was replicated 3 times. Comparisons among treatments were statistically treated with analysis of variance for a completely randomized design.

Treatments 1, 5, and 7 and the controls were selected for financial analysis to provide a relative comparison among treatments and

[1]Hereafter, average diameter is the diameter of the tree of mean basal area, or the quadratic mean diameter.

indicate the financial possibilities of thinning young Douglas-fir. Returns were based on a pond-value price that is sensitive to average stand diameter and on logging cost functions that are sensitive to stand diameter and volume removed (Sessions 1979). Because Sessions' cost functions were for a 600-ft skyline and 40-percent slope, a logging-cost reduction factor of 0.7 was used to adjust for the ground-based systems at the Hoskins site. A haul cost of $130/thousand ft^3 also was assumed.

RESULTS AND DISCUSSION

NUMBER OF TREES AND BASAL AREA

Number of trees per acre varied considerably among treatments (Fig. 1A, Table 2). Treatment 1, the most intensive thinning, had 210 to 225 trees/ac at age 23 but only 70/ac at age 32. Treatment 7, the lightest, had 310 to 330 trees/ac at age 23 but 240 to 280/ac at age 32. During this period, trees per acre on the controls had 1,395 to 1,770 at age 23 but 800 to 1,100 at age 32, the loss due to mortality.

Thinnings removed noncrop trees from a range of diameter classes. Average diameters of trees after thinning were within 0.2 in. of those before thinning on all plots except three, where they were 0.4 to 0.5 in. greater.

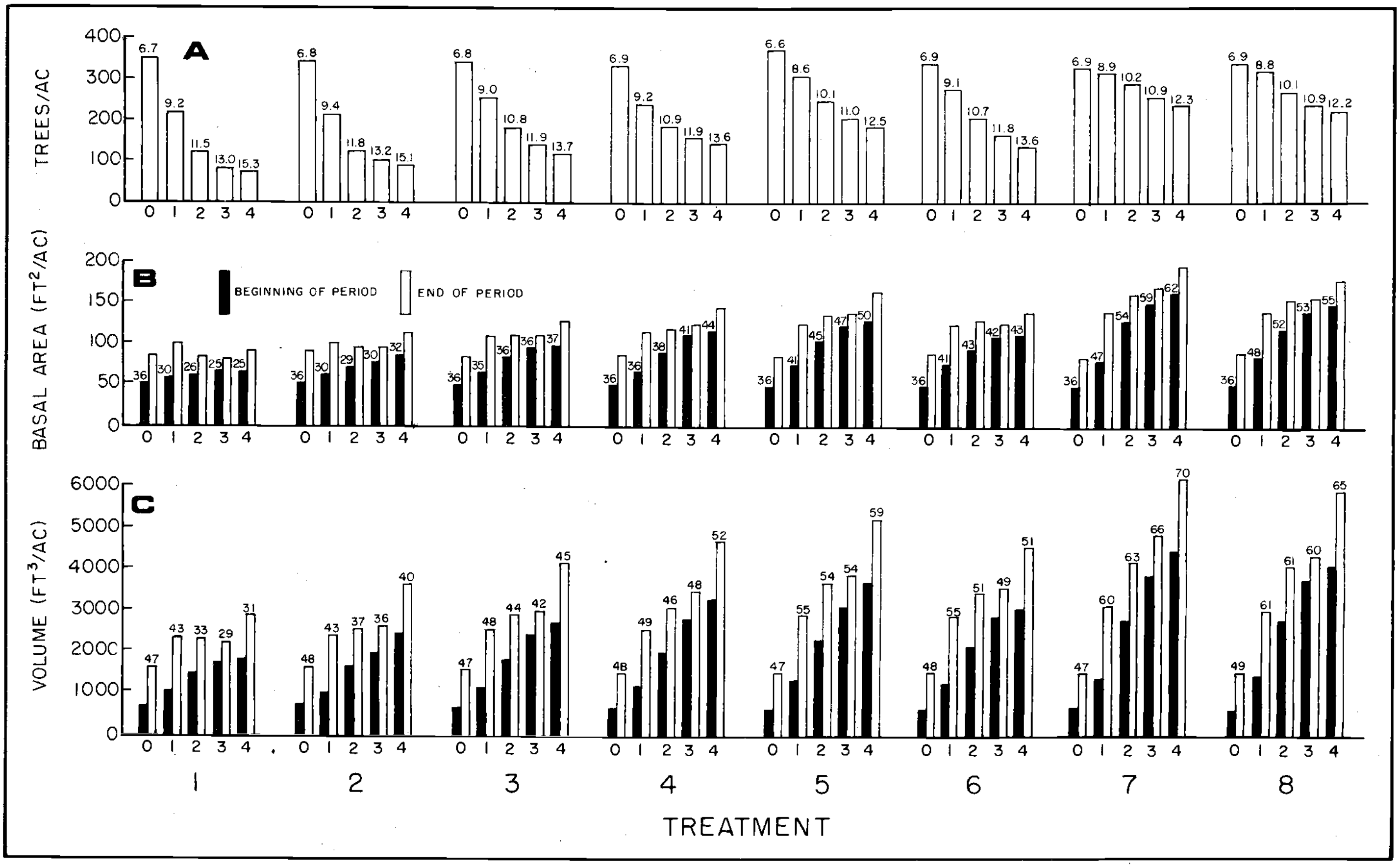

FIGURE 1.

Changes in (A) trees/ac, (B) basal area, and (C) volume for all thinning treatments. 0 is calibration period; 1-4 are treatment periods 1 through 4. Number above bar is (A) quadratic mean diameter; (B) basal area after treatment divided by basal area of control x 100; and (C) volume in live trees at the end of a treatment period divided by volume of control x 100.

Basal areas on all plots increased from about 50 to as much as 87 ft^2/ac during the calibration period. Basal areas after thinning ranged from about 55 ft^2/ac at age 23 (30 percent of controls) to about 66 ft^2/ac at age 32 (25 percent of controls) for treatment 1 and from about 86 ft^2/ac at age 23 (47 percent of controls) to as much as 162 ft^2/ac at age 32 (62 percent of controls) for treatments 7 and 8 (Fig. 1B, Table 2). Basal areas after

TABLE 2.

NUMBER OF TREES (N) AND BASAL AREA (BA) (FT^2/AC), MEASURED AFTER TREATMENT AT EACH AGE, AND GROSS PERIODIC ANNUAL INCREMENT (PAI)($FT^3/AC/YR$)[a] FOR THE PERIOD BETWEEN TREATMENTS FOR ALL 27 PLOTS.

	Stand age, yr														
Treat-	20			23			27			30			32		
ment	N	BA	PAI	N	BA	PAI	N	BA	PAI	N	BA	PAI	N	BA	PAI
1	345	50	277	210	56	319	115	60	300	85	65	222	70	65	256
	380	50	269	225	55	333	120	60	291	80	65	208	70	66	255
	335	48	290	210	55	313	120	61	289	85	64	240	70	66	256
2	360	50	291	220	56	331	135	66	331	105	77	271	95	84	333
	325	50	327	185	57	334	100	66	336	75	77	302	70	86	282
	345	50	269	215	55	317	140	66	308	110	75	284	105	84	289
3	390	49	263	295	65	346	200	82	401	160	92	306	145	98	362
	340	49	283	240	65	379	160	82	381	125	93	310	105	98	350
	300	49	288	220	63	321	165	81	375	135	92	330	120	97	320
4	390	51	277	285	67	346	205	87	364	180	106	309	160	115	347
	320	50	296	245	66	373	185	87	384	165	105	378	150	116	366
	290	51	306	200	64	350	150	87	404	135	105	382	125	116	372
5	355	48	294	315	75	417	250	103	438	215	121	408	195	131	411
	345	51	293	280	75	375	230	108	438	200	121	362	180	130	414
	395	49	263	340	75	400	270	104	441	225	121	455	205	130	422
6	325	50	280	275	75	385	210	98	419	170	108	381	145	112	355
	360	51	285	300	75	386	225	98	419	180	108	363	150	112	387
	330	49	291	275	75	416	195	98	444	155	109	384	130	112	364
7	330	49	267	330	84	420	300	125	486	275	150	441	260	162	464
	325	51	292	310	85	426	270	125	513	245	149	418	230	162	477
	330	50	265	330	85	438	290	124	484	265	150	452	240	162	472
8	375	51	287	360	87	415	300	119	489	260	137	366	240	146	469
	330	51	273	320	86	403	270	119	457	240	137	348	220	144	434
	305	49	309	300	85	452	255	119	508	225	137	419	205	144	456
Control	1,885	134	468	1,830	178	491	1,425	219	511	1,205	244	264	1,100	250	545
	1,610	158	497	1,430	202	627	1,110	246	680	965	275	619	800	277	609
	1,685	122	441	1,660	174	600	1,280	221	560	1,090	250	437	915	256	576

[a]PAI is total volume growth during a treatment period divided by years in the period. Mortality was less than 1 percent of PAI for all treated plots except treatment 7 from age 32 to 36, when it was 5 percent. On the controls, mortality was about 10 percent except for the last two growth periods, when it was 17 and 22 percent respectively.

thinning were generally within 1 ft^2/ac of each other for all plots receiving the same treatment.

DIAMETER GROWTH

Even after growing at high densities (over 1,700 trees/ac) for 20 years, the Douglas-fir on the study site responded immediately to thinning. During the calibration period, diameter growth rate at breast height (4.5 ft) was about 0.55 in./yr on all treatments, as compared to 0.21 in./yr on the controls.

As expected, diameter growth was greatest on the most heavily thinned plots. Average diameters did not differ significantly (P = 0.05) until age 30, when they ranged from 11.9 to 10.1 in. on the treated plots to 6.6 in. on the controls. At age 36, average diameter ranged from 15.3 to 12.2 in. on the treated plots to 8.2 in. on the controls (Table 3). Because number of trees varied considerably among plots within the same treatment (Table 2), so did average diameter. At age 36, average diameters were not significantly different (P = 0.05) among treatments 1 through 4 and 6 nor among treatments 3 through 8 (Table 3).

TABLE 3.

AVERAGE NUMBER OF TREES PER ACRE, DIAMETER, AND VOLUME MEASUREMENTS AT AGE 36 FOR EACH TREATMENT AND THE CONTROLS.

Treatment	Trees/ac	Avg. diameter, in.[b]	Cumulative volume[ab]	Volume removed[c]	Remaining volume[b]	PAI	MAI[d]
			- - - - - - ft^3/ac		- - - - - -	- $ft^3/ac/yr$	-
1	70	15.3e	5,220e	2,310	2,910	256	145
2	90	15.1e	5,690ef	2,000	3,690	301	158
3	123	13.7ef	6,140fg	1,920	4,220	344	171
4	145	13.6ef	6,370g	1,510	4,860e	361	185
5	193	12.5f	6,960hi	1,480	5,480	416	193
6	142	13.6ef	6,690gh	1,970	4,720e	368	186
7	238	12.3f	7,530i	900	6,630	471	209
8	220	12.2f	7,350i	1,320	6,030	453	204
Control	767	8.2g	10,620j	1,310	9,310	577	295

[a] Includes volume thinned in treatments and mortality in the controls. Does not include approximately 1,200 ft^3/ac removed at age 20 in treatments.

[b] For each age, means followed by the same letter within a column are not significantly different (P = 0.05), Tukey's test (Steel and Torrie 1960).

[c] Thinning in treatments and mortality in the controls. Mortality in treatments was generally less than 1 percent.

[d] MAI is the average annual volume growth (cumulative volume divided by stand age).

VOLUME PRODUCTION

In contrast to diameter growth, volume growth was greatest on the controls and lightly thinned plots and smallest on the heavily thinned plots. At age 36, cumulative volume on treatment 1 averaged 5,220 ft^3/ac, on treatment 7 7,530 ft^3/ac, and on the controls 10,620 ft^3/ac (Table 3). Mortality ranged from about 10 to 22 percent on the controls, but it was less than 1 percent of total volume in all treatments. Volume removed for all treatments was greatest from age 23 to 30 (Table 4), when volume growth was highest (Fig. 2, Table 2).

The periodic annual increment, or PAI (total cubic-foot volume growth from one thinning to the next, divided by the number of years between the thinnings), on the controls and treated plots was quite high (Fig. 2, Table 2) but decreased as trees aged. From age 23 to 36, PAI averaged 273 ft^3/ac/yr on treatment 1, 457 ft^3/ac/yr on treatment 7, and 543 ft^3/ac/yr on the controls. These values are well above those for mean annual increment, or MAI (total volume produced at a particular age, divided by the age), at age 36 of 145, 210, and 295 ft^3/ac/yr for treatments 1 and 7 and the controls, respectively (Table 3). So far, mortality on the controls has been only 12 percent of total production; their MAI, if computed on net volume at age 36, is 260 ft^3/ac/yr. Although not yet at culmination, net MAI for the controls is already within the range of maximum potential MAI at culmination for managed Douglas-fir as estimated by Bruce (1969) and may exceed the estimated potential.

TABLE 4.
VOLUME THINNED AT THE BEGINNING OF EACH TREATMENT PERIOD AND MORTALITY FOR THE CONTROLS.

Treatment	Volume removed: Stand age, yr 23	27	30	32	Total	%[a]
	- - - - - ft³/ac - - - - -					
1	550	890	560	310	2,310	44
2	570	785	445	200	2,000	35
3	380	690	520	330	1,920	31
4	390	600	320	200	1,510	23
5	200	540	460	280	1,480	21
6	230	680	620	440	1,970	29
7	20	350	315	215	900	12
8	40	490	470	320	1,320	18
Control	25	270	475	540	1,310	12

[a]Ratio of total volume removed to total volume produced.

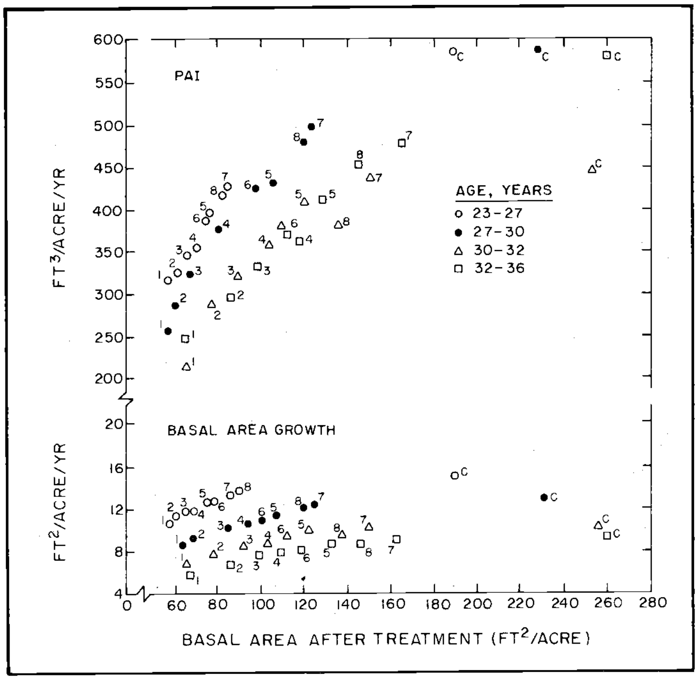

FIGURE 2.
PAI (ft^3/ac/yr) and basal area growth (ft^2/ac/yr) after thinning for the four treatment periods based on basal area at the beginning of each period. Values 1 through 8 are the eight treatments; C is the controls.

RELATION OF VOLUME AND BASAL AREA GROWTH TO BASAL AREA AFTER THINNING

PAI was strongly related (R^2 = 0.89 to 0.97) to basal area after treatment in all but the third treatment period (age 30 to 32)

(Table 5). PAI on the treated plots increased as basal area increased from about 50 to about 120 ft^2/ac for ages 23 to 30 and from about 60 to 160 ft^2/ac for ages 30 to 36 (Fig. 2). Thus, all treatments reduced stand density below the level required for maximum volume growth. It appeared that PAI would increase with basal areas up to those of the controls (180 to 280 ft^2/ac) (Fig. 2). However, managing stands 20 to 30 years old at these densities may not be practical; they are about 50 percent above "normal" (McArdle et al. 1961) and quite likely are at the biological limit for this area.

Although volume growth on the treated plots was high, it did not keep pace with that of the controls. The calibration treatment (essentially a precommercial thinning) at age 20 and the subsequent thinnings probably reduced stand density too much for growth to occur at the rate of the controls. For treatments 7 and 8, the first thinnings after calibration were quite light, and volume thinned from age 23 to 32 was less than or the same as that lost to mortality in the controls (Table 4). Nevertheless, standing volume, cumulative volume, MAI, and PAI were all less in those two treatments than in the controls, indicating they had not yet "recovered" from calibration. In addition, because thinning removed trees of all sizes, some of the better growing dominants or codominants probably were thinned, whereas only suppressed or intermediate trees died in the controls.

Among plots in the same treatment, the differences in PAI varied from as little as 1 ft^3/ac/yr to as much as 93 ft^3/ac/yr even though basal areas at the beginning of each period were usually within 1 ft^2/ac of each other (Table 2). The variability in growth within a treatment probably represents a minimum--far less than would occur in practice when thinning a larger, more variable stand, with necessarily less attention to basal area and tree marking guides. The reasons for this variation among similarly treated plots are unknown, but it may be attributed partly to stand structure: the numbers of trees among such plots differed by as much as 40 trees/ac at age 32 (Table 2). Slight differences in site caused, for example, by slope form (Tarrant 1950) also might cause differences in PAI.

Variation in volume growth among plots treated the same was greatest from age 30 to 32 (third growth period), for which basal area explained only 49 percent of the variation in PAI (Table 5). This may have been due to below-normal precipitation the winter and spring of 1973 at the beginning of the period. Also, this was the shortest growth period in the study.

Like PAI, periodic basal-area growth decreased steadily from age 23 to 36 (Fig. 2), but was not as strongly related to basal area as was PAI (Table 5). At age 27, trees in treatment 7 grew at the same rate (12 ft^2/ac/yr) as those in the controls; by age 32, trees in treatments 5 through 8 were all growing at the same rate (8.5 ft^2/ac/yr) as those in the controls.

During the fourth treatment period, even though basal area growth was similar, especially for treatments 3 through 8 and the controls (7.2 to 8.8 ft^2/ac), average volume growth ranged from 344 to 577 ft^3/ac/yr (Table 2). Evert (1964) reported similar results for red pine (*Pinus resinosa* Ait). He explained that if height growth among treatments is similar (as it is in this study), stands with greater density (basal area) will produce more volume than those that are less dense, even if their basal area growth is the same.

CROP-TREE GROWTH

Of the 384 crop trees selected at age 20, only 24 (6 percent) had to be replaced by other trees. By age 30, treatment 1 had only crop trees remaining and treatment 2 had crop trees plus 10 others for an average of 90 trees/ac. At age 36, crop trees in treatments 1 and 2 composed over 90 percent of the standing volume, those in treatments 7 and 8 40 and 43 percent, respectively, and those in the controls 15 percent (Table 6). The proportion of standing volume in crop trees increased between ages 30 and 36 because noncrop trees were removed, and thinning probably favored crop-tree growth.

In treatments 3 through 8 (average of 123 to 238 trees/ac at age 36), thinning did not substantially change the average diameter of the 80 crop trees compared to that of the

TABLE 5.

REGRESSION EQUATIONS FOR ESTIMATING ANNUAL VOLUME AND BASAL AREA GROWTH PER ACRE BASED ON BASAL AREA (BA) AT THE BEGINNING OF THE GROWTH PERIOD.

Growth period	Regression equation	SE of estimate	R^2
	Volume		
1	$98.32 + 4.77\ BA - 0.012\ BA^2$	25.37	0.89
2	$59.19 + 4.73\ BA - 0.010\ BA^2$	30.02	0.89
3	$53.60 + 3.61\ BA - 0.0077\ BA^2$	62.33	0.49
4	$41.73 + 3.60\ BA - 0.0058\ BA^2$	17.38	0.97
	Basal area		
1	$2.06 + 0.21\ BA - 0.00089\ BA^2$	0.45	0.82
2	$2.23 + 0.12\ BA - 0.00032\ BA^2$	0.37	0.93
3	$-1.50 + 0.16\ BA - 0.00054\ BA^2$	0.53	0.83
4	$2.04 + 0.067\ BA - 0.00016\ BA^2$	0.46	0.81

entire stand. In these treatments, average stand diameter was 89 to 97 percent of that of crop trees. The greatest differences between average stand diameter and crop-tree diameter occurred in treatments 5, 7, and 8, where they averaged 1.6, 1.2, and 1.1 in., respectively.

HEIGHT GROWTH AND SITE DETERMINATION

Height growth was independent of stand density for the range of densities tested; the growth rate on the treated plots was the same as that on the controls. Curtis and Reukema (1970) reported that height growth of Douglas-fir in plantations decreased as density increased; however, their study was conducted on a poorer site (site index of 120; McArdle et al. 1961) than the one reported here.

Height growth from age 20 to 36 did not correspond closely to site curves for young

TABLE 6.

AVERAGE DIAMETER AND VOLUME OF CROP TREES FOR ALL TREATMENTS AT AGE 36.

	Diameter		Volume	
Treatment	in.	Stand: crop tree,[a] %	ft^3/ac	Crop tree,[b] %
1	15.3	100	2,870	99
2	15.5	97	3,320	90
3	14.3	96	3,020	72
4	14.4	94	3,046	63
5	14.1	89	2,850	52
6	14.3	95	2,970	63
7	13.5	91	2,620	40
8	13.3	92	2,600	43
Control	9.9	83	1,420	15

[a]Ratio of average stand diameter (Table 3) to average crop-tree diameter x 100.

[b]Proportion of the standing volume (Table 3) in crop trees x 100.

stands (King 1966). At age 20, estimates of site index ranged from 99 to 128 (Table 7). However, estimates of site index at age 36 ranged from 115 to 141. The same trend occurred on treated plots and the controls and thus seems independent of stand treatment or density. We cannot explain why height growth on the study plots did not follow the site curves for young stands. Possibly, height of young (age 20 to 30) stands is not a reliable site indicator, and site estimates of stands near the base age of 50 may be the most accurate.

TABLE 7.

RANGE OF AVERAGE HEIGHTS OF THE EIGHT TALLEST TREES ON EACH OF THE THREE PLOTS IN EACH TREATMENT; SITE INDEX FOR EACH AGE AND HEIGHT (KING 1966).

Treatment	Stand age, yr						Site index					
	20	23	27	30	32	36	20	23	27	30	32	36
	Height, ft						Site index					
1	36-39	45-49	57-62	67-71	75-76	84-89	112-122	114-124	116-127	121-128	126-128	124-132
2	34-39	44-51	60-65	71-75	74-82	87-92	106-122	112-130	122-133	128-136	124-138	130-136
3	35-37	46-47	61-62	70-73	74-77	88-89	109-115	116-119	125-127	126-132	124-130	131-132
4	35-41	45-54	56-67	65-78	68-83	79-95	109-128	115-137	115-137	117-141	114-140	115-141
5	32-39	44-52	57-67	67-74	72-79	84-91	99-122	112-131	116-137	121-134	121-131	124-135
6	37-38	46-48	59-62	69-73	74-78	87-89	115-119	116-120	121-127	125-132	124-131	130-132
7	35-37	45-49	59-62	71-75	76-78	86-89	109-115	115-124	121-127	128-136	128-131	128-132
8	35-37	45-48	59-62	70-73	75-78	86-88	109-115	115-120	121-127	126-132	126-131	128-131
Control	37-40	47-51	59-64	68-73	71-78	82-86	115-125	119-130	121-131	123-132	120-131	130-131

IMPLICATIONS FOR STAND MANAGEMENT

THINNING PRESCRIPTIONS

Although the thinning schedules and techniques in this study were not designed for practical use, the results have important implications for stand management. One of the most important concerns precommercial thinning. At age 20, the stand was very heavily stocked (over 1,700 trees/ac and 130 ft^2/ac of basal area); it was then intensively thinned to about 350 trees/ac and 50 ft^2/ac of basal area. The trees on the thinned plots responded immediately by growing 1.5 in. in diameter in 3 years, as compared with 0.7 in. for the controls. However, although volume growth was remarkably high on the treated plots, it did not keep pace with the controls. Within 7 years of calibration (precommercial thinning), the lightly thinned plots (treatments 5 through 8) were growing over 400 ft^3/ac/yr, as compared with 570 ft^3/ac/yr for the controls. Although precommercial thinning succeeded in increasing diameter growth and merchantability while still maintaining excellent volume growth, it was too late (and possibly too heavy) for maintaining volume growth near site potential. If the plots had been precommercially thinned earlier (perhaps at age 10), as recommended by Reukema (1975), the trees would have been even larger, and volume growth on the lightly thinned plots would likely have been much closer to that on the controls.

The results suggest that there is considerable flexibility in the timing, intensity, and grade of thinning of young Douglas-fir stands on productive sites. Thinning at 10-ft height increments led to shorter (3 to 4 years) thinning intervals than would generally occur in practice. Basal area reduction was great, ranging from 25 to 62 percent of the controls after thinning; yet, over a fairly broad range of stand densities, volume growth was high. For example, treatments 5 through 8 had basal areas after treatment of about 50 ft^2/ac at age 20 and 112 to 162 ft^2/ac at age 32 (43 to 62 percent of the controls) (Table 2), and still their cumulative volume production at age 36 was 6,690 to 7,350 ft^3/ac (63 to 71 percent of controls) (Table 3). The thinning in this study was not conservative, removing not only intermediate and suppressed trees but also faster growing dominants and codominants. Therefore, even with late precommercial thinning followed by frequent heavy thinnings that removed trees from all crown classes, productivity remained high over a wide range of basal areas--all of which indicates that considerable flexibility is possible in managing young Douglas-fir on productive sites.

FINANCIAL ANALYSIS

The treatments in this study represented a range of possibilities for stand management. Treatment 1 (representative of heavy early thinning) produced early volume yield and large diameter trees, but because its stocking was only 70 trees/ac at age 36 and volume growth had been reduced, its future thinning options seem limited. Treatment 7 (representative of conservative thinning) yielded little volume from thinning and an average tree diameter smaller than that of treatment 1. But because its stocking (238 trees/ac at age 36) and volume growth were high, its future management options seem considerable. Treatment 5 was intermediate to 1 and 7. The controls had trees with small diameters and high stocking and growth. However, a financial analysis of the treatments to date (Table 8) and their projected values (Table 9) shows substantial differences among them.

TABLE 8.

CASH FLOWS FROM SELECTED TREATMENTS; FINAL HARVEST AT AGE 36 IS ASSUMED.

Age, yr	Average diameter, in.	Trees/ac remaining	Volume cut, ft^3/ac	Return, $
		Treatment 1		
23	6.7	215	552	-241.35
27	9.2	118	891	86.24
30	11.5	83	558	70.90
32	13.0	70	308	62.23
36	15.3	0	2,113	2,112.77
				2,090.79
		Treatment 5		
23	6.6	312	194	-143.33
27	8.6	250	529	- 31.45
30	10.1	213	445	27.64
32	11.0	193	279	- 28.60
36	12.5	0	5,475	3,003.24
				2,827.50
		Treatment 7		
23	6.9	323	---	
27	8.9	287	348	- 26.40
30	10.2	262	317	4.81
32	10.9	243	214	- 41.49
36	12.3	0	6,526	3,445.75
				3,382.67
		Control		
36	8.2	0	9312	182.52

Returns from the thinnings are generally low due to the combination of low volume removal and small diameter. At age 36, the approximately 3 extra inches of diameter growth in treatment 1 (as compared to treatments 5 and 7) did not compensate for the reduced volume of this treatment regime. In contrast, the high volume and small diameter of the controls resulted in only minimal return at age 36 (Table 8). Treatments 5 and 7, which produced modest increases in diameter along with considerable volume growth, resulted in better financial returns. We are not suggesting age 36 as a rotation age--it is simply the oldest age for which data are available and a common point of comparison for the four treatments.

Table 9 was developed to determine possible future treatments for stands like those at Hoskins on the basis of investment efficiency. Projections are from age 32 onward, with thinning consideration beginning at age 40 and continuing at 10-year intervals thereafter. Cost assumptions are the same as those in Table 8 with the addition of a 3-percent real interest cost. Regeneration cost was ignored because analysis showed that it would have to be high to affect the comparisons among treatments.

Data from the Hoskins plots were entered in a non-normal stand option of DOPT, a forest-stand optimization model for Douglas-fir (Brodie and Kao 1979, Kao 1980), which searches for the optimal thinning regime and rotation based on the highest soil expectation value using dynamic programming. The growth projection assumptions of this model come from the DFIT model, a Douglas-fir stand growth model (Bruce et al. 1977). The actual numbers of trees and basal areas of plots were entered for treatments 1, 5, and 7; the controls were represented by a DFIT normal stand.[2] Two runs were made for the controls, assuming first thinning at age 40 (A) and then at age 30 (B).

The larger diameters attained with treatment 1 resulted in a short rotation (50 years) and no further thinning before final harvest (Table 9). The soil expectation value for treatment 1 ($2,218/ac) is about 15 percent less than that for treatment 7 ($2,604/ac). The residual number of trees prescribed by the model for treatments 5 and 7 is roughly the same. Treatment 5 has slightly larger trees at each entry, but because the age 40 entries showed a positive return and substantially higher volume was removed on treatment 7, the soil expectation value for treatment 7 ($2,604/ac) is some 6 percent higher than that for treatment 5 ($2,447/ac). The soil expectation value for each of the controls is about half of that of treatment 7. The difference in value for controls A and B is small because the return from the first entry for B is a negative $405/ac whereas that for A is a positive $372/ac. If we had used the actual number of trees rather than those from DFIT, each of these values would have been somewhat lower.

Treatment 1, the most intensive, had the lowest value if harvested at age 36 (Table 8) and the lowest soil expectation value and shortest rotation age (Table 9) for the treated stands. As compared with treatment 7, treatment 1 sacrificed a modest amount ($386) for rapid diameter development and early harvest of larger trees. Treatments 5 and 7 are financially similar and had similar diameter development and prescribed optimal treatments. However, treatment 7 produced higher returns due to substantially more value and volume at the age 40 entry. It also produced a higher valued stand for harvest at age 36 (Table 8).

The control was barely merchantable at age 36 (Table 8). Diameter development had been extremely slow, and future development of high quality trees will take considerable time. It is this delay in production of grade material that accounts for the lower soil expectation value.

Clearly, the results indicate that a wide range of treatments will produce high volumes and values and that early growing stock control in young stands on productive sites is desirable. Adjusting rotation, future commercial thinning, or both can compensate considerably for failure to control stocking early (as in the controls) or for excessive, early thinning (as in treatment 1).

---

[2]The actual number of trees in the controls was about 50 percent greater than that in the DFIT normal stand.

TABLE 9.

VALUE OF THE CURRENT STAND MANAGED TO OPTIMAL SOIL EXPECTATION[a] ROTATION FOR SELECTED TREATMENTS.

Age, yr	Average diameter, in.	Merchantable trees/ac	Merchantable basal area, ft^2/ac	Volume cut, ft^3/ac	Soil expectation/ ac, $
			Treatment 1 Rotation age 50		
40	16.8	70	116	0	2,218
50	22.1	0	0	6,496.0	
			Treatment 5 Rotation age 60		
40	13.8	120	125	2,623	2,447
50	17.5	45	75	3,985	
60	21.9	0	0	4,782	
			Treatment 7 Rotation age 60		
40	13.5	120	118	3,992	2,604
50	17.2	45	74	3,860	
60	21.5	0	0	4,636	
			Control A Rotation age 80		
40	9.7	195	101	3,054	1,327
50	12.7	150	132	884	
60	15.4	120	155	865	
70	17.8	45	78	5,199	
80	20.8	0	0	5,035	
			Control B Rotation age 70		
30	7.6	240	76	1,694	1,333
40	10.6	150	91	1,996	
50	14.0	105	112	1,340	
60	17.3	45	73	3,609	
70	20.9	0	0	4,780	

[a]Soil expectation is the discounted revenues minus costs for this rotation and all future similarly managed rotations, evaluated at time zero. The discount rate was 3 percent, and a regeneration cost of zero was assumed.

CONCLUSIONS

Our conclusions must be interpreted judiciously because we assessed only one uniform stand on a productive site under intensive thinning regimes. Also, the treatments were very carefully applied on small (0.2-ac) plots. Nevertheless, stand development was closely followed for 16 years under a range of thinning regimes and densities, and the information gained provides important insights for managing Douglas-fir on productive sites:

- **Precommercial thinning.** Douglas-fir 20 years of age in heavily stocked (1,700 trees/ac) stands can respond to precommercial thinning by substantially increasing diameter growth (Reukema 1975) and maintaining high volume growth (300 ft^3/ac/yr). However, to ensure that volume growth is near site potential, trees should be precommercially thinned early (at age 10 to 15) to avoid a heavy reduction in stand density and stocking at later ages.

- **Management flexibility.** Young Douglas-fir on productive areas apparently can be thinned frequently (2- to 4-year intervals) to a wide range of stand densities and still maintain high volume growth rates (300+ ft^3/ac/yr). Large diameter can be achieved at the expense of some volume production while relatively high volume growth (200 to 250 ft^3/ac/yr) is sustained. Thinning need not be too conservative; apparently, some of the better trees may be removed in a crown thinning or free thinning.

- **Financial returns.** According to our financial evaluation, thinning young, rapidly growing Douglas-fir can be profitable and can increase returns compared to unthinned stands. From a financial standpoint, management flexibility also is acceptable in thinning regimes. Lighter thinnings can yield higher volume and more value on a longer rotation than initially heavy thinnings. However, low density regimes that produce large diameter trees and provide more volume earlier in the rotation can still be financially viable.

REFERENCES CITED

BELL, J.F., and A.B. BERG. 1972. Levels-of-growing-stock cooperative study on Douglas-fir. Report no. 2--The Hoskins study, 1963-1970. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Research Paper PNW-130. 19 p.

BERG, A.B., and J.F. BELL. 1979. Levels-of-growing-stock cooperative study on Douglas-fir. Report no. 5--The Hoskins study, 1963-1975. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Research Paper PNW-257. 29 p.

BRODIE, J.D., and C. KAO. 1979. Optimizing thinning in Douglas-fir with three-descriptor dynamic programming to account for accelerated diameter growth. Forest Science 15:446-451.

BRUCE, D. 1969. Potential production in thinned Douglas-fir plantations. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Research Paper PNW-87. 23 p.

BRUCE, D., D.J. DEMARS, and D.L. REUKEMA. 1977. Douglas-fir managed yield simulator--DFIT user's guide. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. General Technical Report PNW-57. 26 p.

CURTIS, R.O., and D.L. REUKEMA. 1970. Crown development and site estimates in a Douglas-fir plantation spacing test. Forest Science 16:287-301.

EVERT, F. 1964. Components of stand volume and its increment. Journal of Forestry 62:810-813.

KAO, C. 1980. A study of optimal timing and intensity of silvicultural practices--commercial and precommercial thinning, fertilization and regeneration effort. Ph.D. Thesis, School of Forestry, Oregon State University, Corvallis. 219 p.

KING, J.E. 1966. Site index curves for Douglas-fir in the Pacific Northwest. Weyerhaeuser Company, Centralia, Washington. Weyerhaeuser Forestry Paper Number 8. 49 p.

McARDLE, R.E., W.H. MEYER, and D. BRUCE. 1961. The yield of Douglas-fir in the Pacific Northwest. USDA Technical Bulletin 201 (Revised). 74 p.

REUKEMA, D.L. 1975. Guidelines for precommercial thinning of Douglas-fir. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. General Technical Report PNW-30. 10 p.

SESSIONS, J. 1979. Effects of harvesting technology upon optimal stocking regimes of forest stands in mountainous terrain. Ph.D. Thesis, School of Forestry, Oregon State University, Corvallis. 259 p.

STAEBLER, G.R. 1960. Theoretical derivation of numerical thinning schedules for Douglas-fir. Forest Science 6:98-109.

STEEL, R.G.D., and J.H. TORRIE. 1960. Principles and procedures of statistics. McGraw-Hill Company, New York. 481 p.

TARRANT, R.F. 1950. A relation between topography and Douglas-fir site quality. Journal of Forestry 48:723-724.

WILLIAMSON, R.L., and G.R. STAEBLER. 1971. Levels-of-growing-stock cooperative study on Douglas-fir. Report no. 1--Description of study and existing study areas. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Research Paper PNW-111. 12 p.

APPENDIX A:
COOPERATORS AND PUBLICATIONS COOPERATIVE LEVELS-OF-GROWING-STOCK STUDY

List of Cooperators in Regionwide Levels-of-Growing-Stock Study Begun in 1962:

Forestry Research Center
Weyerhaeuser Company
Centralia, Washington

School of Forestry
Oregon State University
Corvallis, Oregon

USDA Forest Service
Region 6 and Pacific Northwest Forest and Range Experiment Station
Portland, Oregon

Washington State Department of Natural Resources
Olympia, Washington

Canadian Forestry Service
Department of the Environment
Victoria, British Columbia

Related Levels-of-Growing-Stock Reports Published Since The Cooperative Study Was Initiated:

Williamson, R.L., and G.R. Staebler. 1965. A cooperative level-of-growing-stock study in Douglas-fir. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Research Paper PNW-111. 12 p.

Describes purpose and scope of a cooperative study investigating the relative merits of eight different thinning regimes. Main features of six study areas installed since 1961 in young stands also are summarized.

Williamson, R.L., and G.R. Staebler. 1971. Levels-of-growing-stock cooperative study on Douglas-fir: Report no. 1--Description of study and existing study areas. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Research Paper PNW-111. 12 p.

Describes thinning regimes in young Douglas-fir stands and some characteristics of individual study areas in the cooperative study.

Bell, J.F., and A.B. Berg. 1972. Levels-of-growing-stock cooperative study on Douglas-fir: Report no. 2--The Hoskins study, 1963-1970. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Research Paper PNW-130. 19 p.

Describes a calibration thinning and the first treatment thinning in a 20-year-old Douglas-fir stand at Hoskins, Oregon. Data tabulated for the first 7 years of management show that growth changes in the thinned stands were greater than anticipated.

Diggle, P.K. 1972. The levels-of-growing-stock cooperative study in Douglas-fir in British Columbia: Report no. 3--Cooperative LOGS study series. Canadian Forestry Service, Pacific Forest Research Center, Victoria, British Columbia. Information Report BC-X-66. 46 p.

Williamson, R.L. 1976. Levels-of-growing-stock cooperative study in Douglas-fir: Report no. 4--Rocky Brook, Stampede Creek, and Iron Creek. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Research Paper PNW-210. 39 p.

Describes effects of calibration thinnings for three installations maintained by the USDA Forest Service in the cooperative study. Results of first treatment thinning are presented for one area.

Berg, A.B., and J.F. Bell. 1979. Levels-of-growing-stock cooperative study on Douglas-fir: Report no. 5--The Hoskins study, 1963-1975. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Research Paper PNW-257. 29 p.

Presents growth data for the first 12 years of managing a young Douglas-fir stand at Hoskins, Oregon. The second and third treatment periods are described, and summary data from the calibration and first treatment periods are given. The study dramatically demonstrates the capability of young Douglas-fir to transfer the growth from many trees to few trees. It also indicates that at least some of the treatments could equal or surpass the gross cubic-foot volume of the controls during the next treatment periods.

Arnott, J.T., and D. Beddows. 1981. Levels-of-growing-stock cooperative study on Douglas-fir: Report no. 6--Sayward Forest, Shawnigan Lake. Canadian Forestry Service, Pacific Forest Research Center, Victoria, British Columbia. Information Report BC-X-223. 54 p.

Presents data for two installations maintained by the Canadian Forestry Service in the cooperative study. Effects of the calibration thinnings are described for the first 8 years at Sayward Forest and the first 6 years at Shawnigan Lake. Results of the first treatment thinning at Sayward Forest for a 4-year response period also are included.

Tappeiner, John C., John F. Bell, and J. Douglas Brodie. RESPONSE OF YOUNG DOUGLAS-FIR TO 16 YEARS OF INTENSIVE THINNING. Forest Research Laboratory, Oregon State University, Corvallis. Research Bulletin 38. 17 p.

A 20-year-old Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] stand in the Oregon Coast Range was thinned from about 1,700 to about 350 trees/ac. Subsequent thinnings, under eight different regimes, occurred at ages 23, 27, 30, and 32. Average net periodic cubic-volume growth was strongly influenced by thinning regime, varying from about 220 ft /ac/yr (heavy thinning age 30) to over 550 ft /ac/yr (controls age 23). The results indicate that young Douglas-fir on productive sites (site index 160 to 170 ft at 100 years) are extremely adaptable and will respond to frequent thinnings of various intensities. Three representative treatments (after thinning at age 32) and the controls were projected and optimized with dynamic programming for two financial analyses. Adjusting rotation or commercial thinning can compensate for lack of early stand management or heavy early thinning.

Key Words: Growth, yield, stand management, stand density, precommercial thinning, economic analysis.

Tappeiner, John C., John F. Bell, and J. Douglas Brodie. RESPONSE OF YOUNG DOUGLAS-FIR TO 16 YEARS OF INTENSIVE THINNING. Forest Research Laboratory, Oregon State University, Corvallis. Research Bulletin 38. 17 p.

A 20-year-old Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] stand in the Oregon Coast Range was thinned from about 1,700 to about 350 trees/ac. Subsequent thinnings, under eight different regimes, occurred at ages 23, 27, 30, and 32. Average net periodic cubic-volume growth was strongly influenced by thinning regime, varying from about 220 ft^3/ac/yr (heavy thinning age 30) to over 550 ft^3/ac/yr (controls age 23). The results indicate that young Douglas-fir on productive sites (site index 160 to 170 ft at 100 years) are extremely adaptable and will respond to frequent thinnings of various intensities. Three representative treatments (after thinning at age 32) and the controls were projected and optimized with dynamic programming for two financial analyses. Adjusting rotation or commercial thinning can compensate for lack of early stand management or heavy early thinning.

Key Words: Growth, yield, stand management, stand density, precommercial thinning, economic analysis.

BRITISH/METRIC CONVERSIONS

1 inch (in.) =	2.54 centimeters (cm)
1 foot (ft) =	0.305 meter (m)
1 acre (ac) =	0.405 hectare (ha)
1 square foot (ft^2) =	0.093 square meter (m^2)
1 cubic foot (ft^3) =	0.028 cubic meter (m^3)
1 ft^2/ac =	0.230 m^2/ha
1 ft^3/ac =	0.070 m^3/ha

OREGON STATE UNIVERSITY, CORVALLIS

FOREST RESEARCH LABORATORY
SCHOOL OF FORESTRY
OREGON STATE UNIVERSITY
CORVALLIS, OR 97331-5704

Non-Profit Org.
U.S. Postage
PAID
Permit No. 200
Corvallis, OR 97331

ADDRESS CORRECTION REQUESTED