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THINNING PONDEROSA PINE IN THE PACIFIC NORTHWEST

A SUMMARY OF PRESENT INFORMATION

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THINNING PONDEROSA PINE IN THE PACIFIC NORTHWEST

A SUMMARY OF PRESENT INFORMATION

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INTRODUCTION

Proper thinning of dense young stands of ponderosa pine increases the growth rate of remaining trees and thereby shortens the time required to grow timber of any desired size. The extent of improvement in growth is shown by thinning studies in the Pacific Northwest covering periods of 10 to 24 years. These studies, together with general experience and research in other pine regions, are summarized in this paper. The discussion is largely confined to stands of premerchantable size, which now means stands not yet producing saw logs at least 8 inches in diameter.

Why Thin?

To understand why thinnings may be needed in young pine stands calls for a brief description of the development of "pine thickets." With the right combination of good seed years, favorable seedbed conditions, and sufficient moisture to bring the seedlings through the first critical years, ponderosa pine reproduces abundantly on most sites. This combination has occurred in many parts of the Pacific Northwest, especially during the 1890's and early 1900's. Where deep litter or heavy vegetation hindered reproduction, a more favorable seedbed was often provided by fire, heavy grazing (16)[2], or a combination of the two.

1/ Grateful acknowledgment is made to the many staff members of the Experiment Station and of the Chelan, Deschutes, Fremont, Malheur, Ochoco, Umatilla, and Whitman National Forests who assisted in the planning, establishment, remeasurement, or analysis of the several thinning studies. Special credit is due W. G. Dahms for assistance on remeasurements and for several of the recent progress reports, and E. Skinner for analysis of recent data.

2/ Figures in parenthesis refer to Literature Cited, page 23.

Protection during the past fifty years has prevented the destruction of these young trees by fire and they have developed into seedling, sapling, or pole stands. Occurrence, size and density of these young stands vary widely, depending on the site and particular history of each spot and on the amount of overwood. Where the mature stand was very dense, few pine seedlings have survived. But where the stand was more open as a result of fires, bark beetles or other causes, reproduction has often grown into dense patches of saplings or poles. In many places the young growth has now been fully released by logging of the overstory trees; elsewhere it is still held back by the remaining overstory.

In most of the ponderosa pine zone soil moisture is too limited to permit good growth in dense stands that may contain 10,000 or more trees per acre. Even though ponderosa pine is intolerant, such dense stands often fail to thin themselves naturally. Where young trees are too close together and of similar size, they tend to stagnate, and growth remains negligible for many years (fig. 1A). Even where there is a greater range in tree height and a better expression of dominance, entirely too many trees persist in crowded groups. As a result, growth of the few individuals that will become merchantable crop trees is greatly retarded.

Mature stands rarely contain more than 100 trees per acre, but a much larger number is, of course, needed at earlier ages to allow for accidental losses, to promote better tree form and quality, and to provide for intermediate harvest cuttings.

Conditions other than overcrowding sometimes call for improvement cuttings in young stands to better the composition and quality of the future timber crop. On certain sites pine is crowded out by less desirable species. White fir, for example, often reproduces abundantly in mixed-pine stands but has a lower value and is subject to heart rot at an early age. Elsewhere trees badly deformed or injured by mistletoe, porcupines, or fire, are a detriment to the stand. Strictly speaking, the removal of weed species or diseased, defective, and deformed trees is not a thinning, but is usually a part of the thinning operation.

Extent of Pine Thinnings

Confronted with overstocked spots, poor form, and competition from other species, ponderosa pine foresters have been repeatedly tempted to thin dense stands and reap the benefits demonstrated by European practice. But both practice and research on methods and results have been limited and spasmodic in all the western national forest regions. Thinning on private lands has been negligible. On most ponderosa pine sites, growth and potential yields seemed relatively low, calling for long rotations and thus doubtful returns from intensive practices in young stands.

The first reported pine thinning was on a small trial plot in Idaho in 1911 (8). Several other test plots were thinned from 1925 to 1931, but the chief activity came during the Civilian Conservation Corps program of 1933-41. In this 9-year period, 21,986 acres of young pine in the Pacific Northwest were given "stand improvement," which included thinning, pruning, and general cleanup or sanitation cutting. This covered only a fraction of the area that could have been treated. The most extensive thinning of ponderosa pine was in the Black Hills (18), where some 250,000 acres were covered.

THINNING STUDIES IN THE PACIFIC NORTHWEST

Effects of thinning have been studied on 25 permanent sample plots in eastern Oregon and Washington. Most of the older plots were established by national forest personnel as administrative studies, beginning as early as 1927 on the Whitman and Fremont Forests. In order to harmonize methods of measurement and analysis, the Pacific Northwest Forest and Range Experiment Station has taken a leading part in recent remeasurements and compilation for all of the plots. Detailed progress reports on growth and other changes following thinning have been prepared periodically for each set of plots (14, 22). In this paper the results of the various tests are brought together for the first time to see what general conclusions can be drawn.

Kind and Degree of Thinning

The studies cover two general types of thinning: (1) complete or area thinnings, in which stems are removed throughout the stand, and (2) crop tree release, in which competing trees are removed only around selected trees that are judged likely to make up the final crop. Unthinned plots or unreleased trees provide check measurements in each location.

Most of the complete thinnings would be classed as low thinnings of a heavy (C) or very heavy (D) grade, as commonly defined (6 or 17) Some were a compromise between typical low thinnings and mechanical thinnings (uniform spacing). On two plots (Fremont No. 3 and Malheur No. 6) a mechanical spacing was followed rather closely (fig. 1B). The number of trees left in the several thinned stands varied from 455 to 1,172 per acre. This is equivalent to spacings of about 6 x 6 to 9 x 9 feet. One plot (Fremont No. 4) represents strip thinning in a small sapling stand; here cleared lanes 6 feet wide alternate with 4-foot strips of trees.

The crop tree thinnings vary chiefly in the amount of release given each tree, which ranged from the removal of only trees with interlacing crowns to the cutting of all trees whose crowns were within about three feet of the crop tree.

Figure 1A.--A stagnated stand of ponderosa pine on the Malheur National Forest, Oregon (unthinned plot No. 7). In spite of heavy losses from snow bending, there are still more than 3,000 living trees per acre. Although 65 years old, average diameter and height correspond to a normal stand only 25 years old. (Photo in 1951)

Figure 1B.--If the stand shown in 1A had been thinned to a 6 x 6-foot spacing in 1930, it would now resemble this adjoining stand (thinned plot No. 6). These trees have been growing twice as fast in diameter as comparable trees in the unthinned stand. They are also growing faster in height and have added more volume per acre than all of the trees in the untreated stand.

Age and Size of Trees

Most of the stands studied originated from about 1885 to 1900 and were from 31 to 53 years old at time of thinning. Several of them had been partly suppressed by overstory trees for a number of years. As a result of this suppression and overdensity, trees were far below normal in size and development for their age. Three sets of plots (Chelan 1-2, Fremont 3-5, and Umatilla 2-3) still have a scattered overstory of large trees which has doubtless reduced growth and affected thinning results. Trees ranged in original size from an average of only 5 feet high on Fremont plots 3-5 to 5.8 inches d.b.h. and 28 feet high on Pringle Falls plot 40. The completely thinned stands were mostly in the sapling stage, with trees averaging from 2 to 4 inches d.b.h. Site quality of all study plots was within the range of poor to good site IV, when based on height of nearby overstory trees. This is the prevailing site in eastern Oregon and Washington.

Results of Area Thinnings

Effects of complete thinning are presented in two ways, for the entire stand (table 1) and for selected larger trees (table 2). The 100 largest trees per acre were used to represent the eventual crop trees in the second analysis. This is about the average number that may be expected to survive to an age of 200 years on average site IV.

Because of the variety of sites, tree ages and sizes, degrees of thinning, years since thinning, and modes of study, it is not logical to average the data for all plots or even for groups of plots. The several sets of plots do serve, however, as a series of case studies, from which general trends and a range of growth figures may be derived.

Volume Growth

Total cubic-foot growth per acre was greater on the thinned plot in only one case (Malheur, table 1). Volume growth was greater on the unthinned plots in four cases and about equal in a fifth. Annual growth rates generally ranged from 28 to 64 cubic feet per acre; one doubtful extreme of 130 was based on only 1/40 acre. However, periodic growth rate has been climbing relatively fast on nearly all thinned plots. For the most recent measurement period the rate is superior to that of comparable unthinned plots in three out of six cases. Figures are not available for the Chelan, Umatilla, and Whitman unthinned plots because only part of the trees were tagged and the stand tallies were incomplete. Total periodic growth is of course not a very satisfactory measure of thinning effects, because a large proportion of the increment in unthinned stands occurs in small trees that will die before they reach merchantable size.

For the 100 largest trees per acre, volume and volume increment, as of the latest period of measurement, were greater on thinned than on unthinned plots in every test except one (table 2). Total cubic volume of these trees was 13 to 66 percent higher, and their increment was 15 to 450 percent greater than for comparable trees on the unthinned plots. The one exception (Whitman 5-6) is due to the presence of larger trees on the unthinned plot when the study was started.

Table 1.--Stand statistics and growth data for ponderosa pine thinning plots in eastern Oregon and Washington, complete thinnings

Location	Plot No.	Thinning treatment or spacing	Age when thinned	Av. d.b.h. after thinned [1]	Trees left per acre	Basal area per acre after thinning	Period of measurement since thinning	Net annual increment in period since thinning: D.b.h. per tree	Height per tree	B. A. per acre	Volume per acre
			Years	Inches	Number	Sq. ft.	Years	Inches	Feet	Sq.ft.	Cu.ft.
Pringle Falls	14	9 x 9	46	4.4	532	54	15	.11	.65	3.0	45
	16	7 x 7	46	3.9	850	61	15	.08	.53	2.9	38
	15	Unthinned	46	3.7	2,538	102	15	.04	.47	3.6	57
	18	9 x 9	46	5.3	518	77	15	.09	.63	3.0	50
	17	Unthinned	46	4.4	1,604	129	15	.04	.44	2.9	56
Chelan	2	Released dominants	34 [4]	2.4	652	17	16	.13	.66	2.9	34
	1	Unthinned	34 [4]	2.4 [2]	-	-	16	.08 [2]	.62 [2]	-	-
Fremont	1	8 x 8	31	3.2	480	14	22	.16	.59	4.4	64
	2	Unthinned	31	2.2	8,520	16	22	.05	.52	5.6	130
	5	6 x 6	31	-	990	5	22	.11	.24	3.2 [3]	22 [3]
	4	Strip	31	-	5,356	4	22	.07	.20	4.3 [3]	36 [3]
	3	Unthinned	31	-	11,900	4	22	.06	.19	3.4 [3]	35 [3]
Malheur	6	6 x 6	44	2.6	1,172	44	20	.08	.53	3.7	41
	7	Unthinned	44	1.9	7,844	133	20	.04 [2]	.41 [2]	3.8	37
Ochoco	1	8 x 8	43	3.2	705	40	18	.11	.44	2.8	36
	2	Unthinned	43	2.1	5,000+	108	18	.04 [2]	.29 [2]	2.3	36
Umatilla	3	Released dominants	-	2.6	455	17	21	.10	.43	1.5	-
	2	Unthinned	-	2.9 [2]	-	12 [2]	21	.05 [2]	.41 [2]	0.3 [2]	-
	5	Trees under 3" cut	-	4.2	362	36	20	.05	.36	1.0	-
	4	Unthinned	-	4.0 [2]	-	22 [2]	20	.04 [2]	.41 [2]	0.5 [2]	-
Whitman	5	7 x 7	33	3.2	812	45	24	.06	.41	1.9	28
	6	Unthinned	33	1.9	5,664	111	24	.03 [2]	.37 [2]	0.8 [2]	23 [2]

1/ Average diameter, basal area, and volume are for trees 0.6 inches d.b.h. and larger only on each plot.

2/ This statistic is for tagged sample of trees on unthinned plot, usually a number and size of trees comparable with those left on thinned plot.

3/ For most recent 5-year period only; because of small size of trees or other reason data not available for entire period since thinning.

4/ Approximate age.

Table 2.--Size, volume, and increment of 100 largest trees per acre on ponderosa pine thinning plots (data for latest measurement or latest 5- to 10-year period)

Location	Plot No.	Treatment	Size and volume				Annual increment	
			Av. d.b.h.	Av. ht.	Volume	Volume (Int'l.)	D.b.h.	Volume
			Inches	Feet	Cu. ft.	Bd. ft.	Inches	Cu. ft.
Pringle Falls	14	Thinned	8.2	39	502	770	.15	24.4
	16	Thinned	7.3	36	382	394	.12	19.9
	15	Unthinned	7.0	36	338	251	.09	14.4
	18	Thinned	9.0	41	640	1312	.12	28.3
	17	Unthinned	8.5	39	545	893	.09	24.6
Fremont	1	Thinned	9.1	37	650	-	.20	-
	2	Unthinned	7.4	42	510	-	.08	-
	5	Thinned	4.4	16	-	-	.22	-
	4	Thinned	3.4	15	-	-	.15	-
	3	Unthinned	2.8	14	-	-	.10	-
Malheur	6	Thinned	7.3	30	318	-	.14	33.0
	7	Unthinned	6.5	31	274	-	.07	6.0
Ochoco	1	Thinned	7.9	35	440	602	.14	18.8
	2	Unthinned	6.2	30	265	179	.08	8.6
Umatilla	3	Thinned	6.0	28	218	-	.13	12.1
	2	Unthinned	4.7	26	137	-	.07	5.4
	5	Thinned	7.2	31	356	-	.07	16.2
	4	Unthinned	5.9	30	228	-	.07	9.3
Whitman	5	Thinned	7.5	39	422	500	.09	14.5
	6	Unthinned	8.8	43	700	1644	.06	15.3

Diameter Growth

Diameter growth at breast height of all tagged trees has been 25 to 220 percent greater in fully thinned than in unthinned stands. Usually the rate was about 2 to 3 times as much where comparison was made with all trees of the unthinned plot.3/ The average rate for all trees, however, somewhat exaggerates the benefit from thinning, since elimination of the suppressed and poor vigor trees automatically increases average diameter growth. This is true whether or not thinning accelerates the growth of the reserve trees. Where only part of the trees on the unthinned plots were tagged (those originally comparable in number and size with reserve trees left on the thinned plot) a fairer comparison is obtained. But even this does not always credit the unthinned stand with the best it produces.

A better measure is obtained by comparing the growth of trees of similar initial diameter. This comparison can be made graphically, by plotting either class averages or computed linear regressions of diameter increment on original d.b.h. Graphs for the Ochoco plots (fig. 2) are fairly typical of the differences in diameter growth between thinned and unthinned plots. Umatilla plots 4 and 5 are an exception and the curves for thinned and unthinned stands nearly coincide. In this case original differences in site and stand structure probably have obscured the true thinning effect.

Another fair comparison of diameter growth is that for the 100 largest trees per acre (table 2). In the latest measurement period this rate was from 1-1/3 to 2-1/2 times as great on thinned as on unthinned plots; it was commonly nearly twice as great (with the exception of Umatilla plots 4-5). In absolute terms, the rate was 0.09 to 0.22 inch per year for thinned plots, 0.06 to 0.10 inch for unthinned plots.

Since thinning, periodic rates of diameter growth have fluctuated moderately on both thinned and unthinned plots without any consistency or special significance. The advantage for thinned plots was usually evident in the first 5-year period and held up fairly well through the third or fourth periods, which are the limits of available data. Some unexplained variations in trend are of interest. For Fremont thinned plot No. 1 diameter growth has declined from 373 percent of that of the unthinned plot in the first period to 263 percent in the fourth period after thinning. But in a stand of smaller trees on the same forest, thinned plot No. 3 has increased its advantage over check plot 5 from 106 percent to 323 percent in the same periods. The maintenance of a comparatively good rate on the thinned plots is encouraging, since we might normally expect that acceleration would subside as competition increases over the years.

3/ In six of the series listed in table 1 only selected trees were individually tagged and measured.

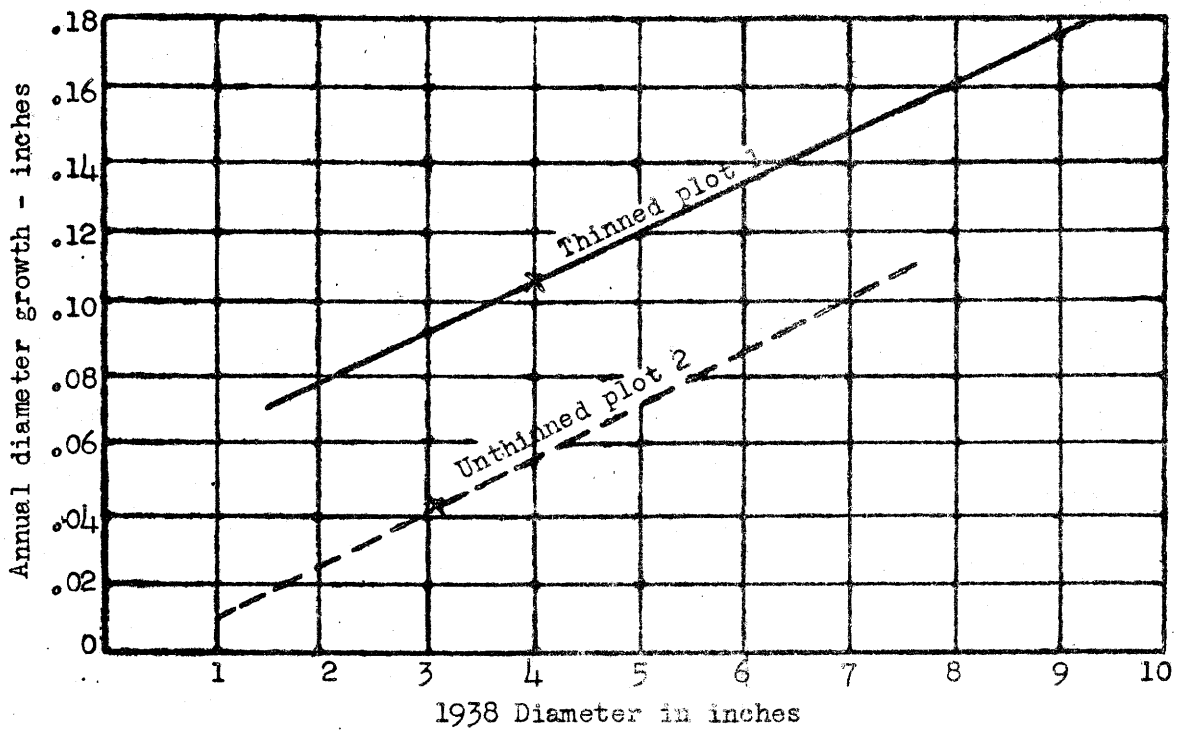

Figure 2.--Regression of annual diameter growth (1938-48) on diameter (1938): Ochoco thinning plots 1 and 2

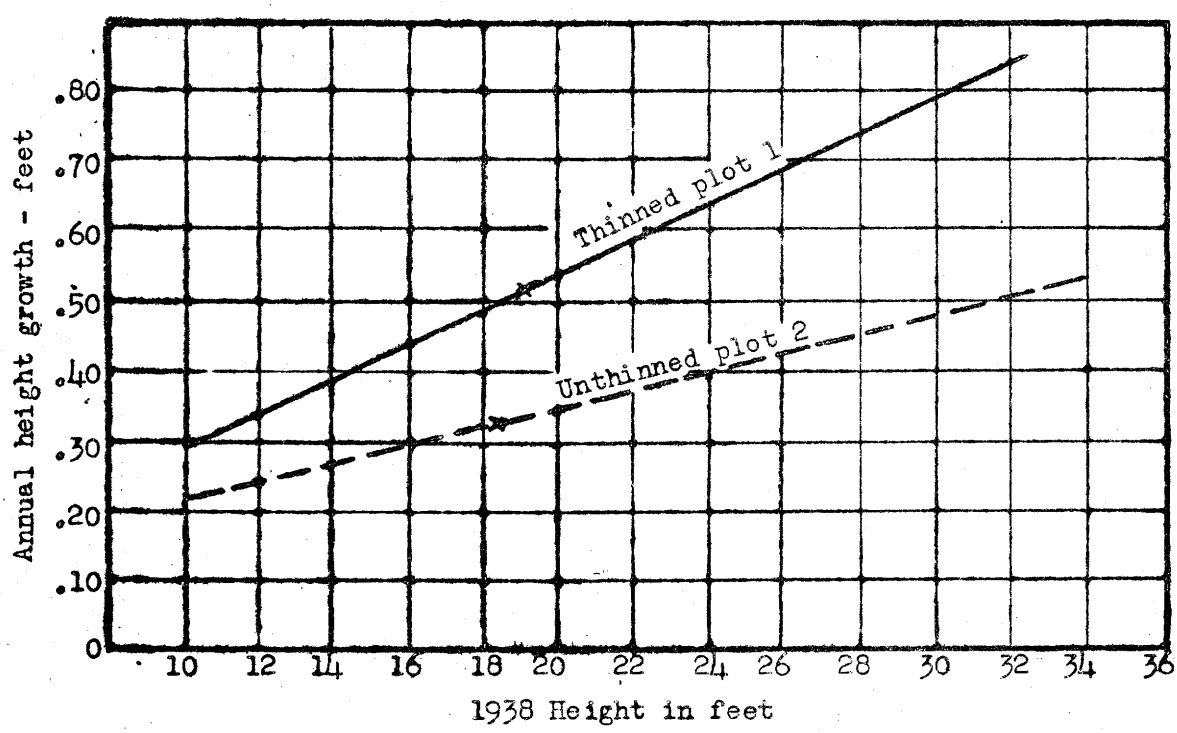

Figure 3.--Regression of annual height growth (1938-48) on height (1938): Ochoco thinning plots 1 and 2

Height Growth

In ponderosa pine, as in other species, height growth is less affected by thinning than diameter growth. Several early progress reports stated that there had been little or no influence on height growth. This conclusion resulted from either a form of computation that did not properly show true height growth, or too short a growth period to outweigh errors in measurement and delay in response. For the full period since thinning, height growth has averaged better on completely thinned than on unthinned plots in every case except Umatilla 4 and 5 (table 1). The difference is generally small, but has amounted to 2 feet or more over the 15- to 24-year period.

As with diameter growth, a more sensitive comparison is made graphically, with initial height taken into account. The curves for the Ochoco plots (fig. 3) are also fairly representative of other series. In general the difference in favor of the thinned plot tends to be greater for larger than for smaller trees, although this is not true of every pair of plots.

Acceleration in rate of height growth after thinning became more pronounced during the later periods of measurement. During the first 5 to 10 years after thinning only two sets of plots (Malheur and Ochoco) showed a significant increase in height increment. On other study areas either the thinned and unthinned rates were about equal or the rate for check trees was slightly superior. The growth periods representing more than about ten years after thinning consistently show better height growth for thinned stands (again with the exception of Umatilla plots 4 and 5). A similar trend in height growth was experienced where a lodgepole pine overstory was removed from very suppressed ponderosa seedlings and saplings at Pringle Falls. During the first 6 to 8 years the small pines grew little better than unreleased trees, but subsequent height growth has been four times as rapid (13).

There is a suggestion in these results that promptness and degree of response in height growth are greater where stagnation was most evident, and that where natural stand development was more normal and dominance was being expressed, less acceleration in height may be expected.

Comparison with Normal Stands

One other measure of stand development on the thinned plots is afforded by comparison with statistics for fully stocked stands as given in normal yield tables for ponderosa pine (11). Determining an appropriate site index for the study plots has been one difficulty in such comparisons. Height of the young stand, because of past suppression, stagnation, or other cause, often indicates a site as much as 20 to 30 points lower than is indicated by nearby older trees. When the lower site index value is used, most unthinned stands were near normal in most respects and percentages of normality have increased slowly

over the years of measurement. Using the higher, or what might be considered the potential site index shown by older trees, the numbers of trees in unthinned stands were usually several times normal but basal area and cubic volume below normal. Using either index, thinned plots were, of course, far below normal but consistently show a rapid increase toward normality through the successive growth periods. The thinned stand pictured in figure 1B has a basal area of 117 square feet per acre, which is 62 percent of normal based on potential site index, or 81 percent if based on height of trees in the young stand.

Mortality after Thinning

Since relatively few trees have died in the thinned stands, mortality has had little effect upon net growth. In some stands a number of trees were killed by bark beetles (*Ips* spp.) soon after thinning, and in other stands a few were victims of snowbreak or unusual accident such as breakage by a falling snag. Thinned ponderosa pine stands usually suffer little snow damage except where spindly trees are left and heavy wet snows occur before the trees have time to develop a more sturdy form.

Losses in the unthinned plots have varied widely. On Fremont No. 2, for example, losses during the 22-year period were equivalent to 5,400 trees per acre, or 63 percent of the original number. During the same period not one tree died on the adjacent thinned plot No. 1. Losses were largely from suppression and snowbreak. On the other hand, Ochoco unthinned plot No. 2 lost only 7 tagged trees per acre (plus an unknown small number of untagged trees) in 18 years out of a total stand of about 5,000 trees per acre. Failure of stands to thin themselves naturally may be evidence of continuing stagnation.

Other Effects of Thinning

Some results of thinning are not supported by measurement data but are evident from photographs and from notes by various observers. In some stands thinning has definitely relieved stand stagnation and stimulated the expression of dominance that is considered essential to good growth. Most trees have larger, denser, and more vigorous crowns than before thinning or in comparison with trees on unthinned plots. Similar but less striking improvement is also shown by some of the unthinned plots; others show little progress in the development of good "crop trees" (fig. 1A).

Boles of trees in thinned stands tend to develop more taper than those in comparable unthinned stands. No stem measurements have been taken but the change in height-diameter relationship shows the trend. Because diameter growth at breast height responds more quickly and positively than height growth, trees of a given diameter are shorter on the average in thinned than in unthinned stands.

Thinning has generally resulted in an appreciable increase in the density and vigor of ground vegetation - brush, grass, or weeds. This change might be significant in parts of the ponderosa pine type where livestock grazing is an important use of forest land. However, improvement in palatable forage species has been so slight in the stands studied that this possible benefit can be given very little weight. Competition from other vegetation generally tends to reduce growth of trees, but full control of undergrowth is not feasible. When stands are opened up enough to permit rapid growth of ponderosa pine trees they are also open enough to favor at least some understory vegetation. The effect on forage and other plants is still an open question and needs more systematic study.

Results of Crop Tree Release

Thinning around only selected crop trees has accelerated diameter growth 8 to 43 percent in the relatively few studies where this method was tested (table 3). On Whitman plot 8, which is the most clear-cut test, released crop trees grew at an average rate of 0.10 inch in d.b.h. per year compared to 0.07 inch for unreleased trees over a 13-year period. The "heavy" thinning here consisted of the removal of all trees whose crowns were within about 3 feet of the crop tree crown. The "moderate" thinning was similar, but left the poorer intermediate and suppressed trees.

Table 3.--Stand statistics and growth data for ponderosa pine thinning plots in eastern Oregon and Washington; "crop tree release" or spot thinnings

Location	Plot No.	Year established	Treatment	Age when thinned	Average d.b.h. 1/ after thinning	Period of measurement since thinning	Net annual increment in period since thinning	
							D.b.h.	Ht.
				Years	Inches	Years	Inches	Feet
Pringle Falls	40	1941	Heavy release	53	5.8	10	0.14	0.53
			Mod. release	53	5.6	10	.13	.51
			No release	53	5.8	10	.12	.63
Whitman	8	1938	Heavy release	40	4.2	13	.10	.60
			Mod. release	40	3.9	13	.10	.59
			No release	40	3.9	13	.07	.66
Whitman	7	1932	Spot release	-	1.4	19	.13	.53
			No release	-	1.5	19	.10	.66

1/ Diameter and increment statistics are for tagged crop trees only.

Apparently the trees in the lower crown classes had little effect, since crop trees grew at about the same rate under both degrees of thinning. The smaller advantage shown for released trees on Pringle Falls plot 40 is due in part to an unintended effect of thinning upon check trees, which were located too close to the released trees. Whitman plot 7 is in a mixed stand where white fir and other species were cut in spots to release crowded or overtopped ponderosa pines. Although diameter growth has averaged better for released than for nonreleased trees, the spot treatment was not extensive enough in many places to insure continued dominance of the pines.

Although spot thinning seems to have resulted in slightly lower height growth on all three study plots (table 3), the difference is not significant for all plots and subperiods. Furthermore, an eventual reversal of the effect is indicated on Whitman plot 7, where the adjusted height increment was slightly greater for released trees during the latest 6 years of its 19-year record. Thus, the lack of a positive acceleration in height growth, as contrasted with complete thinning, may be partly a delay in response, but also must be related to other factors such as the fact that these tests of crop tree release resulted in a very light degree of thinning in the stand as a whole.

A much more comprehensive study of crop tree thinning was recently started in the Metolius area of the Deschutes National Forest (plots 12-15). A wider spread in degrees of thinning and variations in spacing of crop trees are being tested. Effects of overstory trees will also be isolated, and measurements will be taken of total stand as well as individual tree growth. The Snoqualmie National Forest has installed another new study to test heavy crop tree release. These new studies should greatly strengthen our knowledge of crop tree thinning in ponderosa pine.

Results of Strip Thinning

The one test of thinning by strip cutting (Fremont plot 4) showed a little benefit in both diameter and height growth, either for all trees or selected larger trees (tables 1 and 2). Growth is probably being retarded by scattered mature trees on and near the plot. If there were no overstory trees present, the response might have been stronger. This is a weak basis for a general conclusion on the merits of strip thinning, which might be done by running a tractor back and forth through a stand, but the practice appears of questionable value. There might be an added advantage just in the partial breakup of a stagnated conditon which strip thinning seems to provide.

Cost of Thinning by Hand Methods

Although some 8,000 acres of young growth have been thinned on the national forests of eastern Oregon and Washington, the work was mostly done by the Civilian Conservation Corps prior to 1942 and provides very few cost data useful at the present time. Recent complete thinnings on the Ochoco National Forest cost from $10 to $17 per acre. On the Snoqualmie Forest two small projects, which included some pruning, cost $15 and $25 per acre. One reason for the variation in costs was the difference in density and distribution of the sapling and small pole stands within the project areas. Complete thinning on the Fremont Forest, in continuous stands of small pole size where most trees were felled with a power saw, cost about $39 per acre. Spot thinnings on two other areas of the Fremont Forest cost $5 and $17 per acre, but here only 18 and 25 crop trees per acre were released. Without a detailed consideration of tree size and stand distribution and composition, both in spots and over the general area, and of methods, crew efficiency, pay rates, and working conditions, these gross averages are not too meaningful, but give at least a rough idea of the range of total current costs.

On the Deschutes cooperative study area 64 acres of thinning cost $34.77 per acre. About 80 percent of the area was occupied by a dense young stand. Crop tree diameter averaged 3.4 inches for the entire area but varied from 2.6 to 5.1 inches by 4-acre subplots. Four intensities of crop tree release were applied. The heaviest (cutting all competing trees in a circle 15 feet in diameter around crop trees spaced about 15 feet apart) was practically a complete thinning, and cost $41.78 per acre. The lightest (10-foot circle of release and 30-foot spacing) cost $18.44 per acre. All cutting was done with axes during the winter, mostly when snow was on the ground. Cut trees were left where they fell. Disposal of thinning slash is desirable from the standpoint of fire risk and appearance but is too expensive for general practice in thinning operations. Slash disposal may, of course, be justified on roadside strips, and near habitations and campgrounds.

Although no large unusual expenses were incurred on this operation, only 54 percent of the total cost was spent for actual man-days of thinning work in the field. Average rate of pay was $12.22 per man-day. Average field time per acre was 1.54 man-days. Of this field time, 72 percent was "net thinning time"; the other 28 percent was used mostly in travel, supervision, and warming periods. Average net thinning time per crop tree was 7.9 minutes. This included travel between trees, normal short rests, and an estimated 1 minute per tree for pruning the lower dead branches. Average net time per tree cut was 37 seconds.

Any sizeable operation can be expected to involve supplementary and overhead costs comparable to this one. But if these overhead costs could be avoided or reduced or if cheaper labor (of equal efficiency) were available, the total might be held down to much less than for the Deschutes operation. A woodlot owner, for example, might do his own

work at spare times with no outlay of cash. For conditions similar to those in the Deschutes area, his investment in thinning might be placed at not more than ten or fifteen dollars per acre. Good thinning practice requires skill, thought, and care, however, and should not be left entirely to untrained workers with the intention of merely doing the job cheaply.

Thinning by Prescribed Burning

The results of thinning by the controlled use of fire have been measured on only one permanent plot in the Northwest. This study was established by Weaver (19, 20) on the Colville Indian Reservation in 1942. The burn was effective in reducing the number of stems in dense sapling thickets from an average of 2,430 to 690 per acre, but results were far from uniform. The fire burned too hot in some spots and not hot enough in others. During the 6 years since burning, annual diameter growth of selected crop trees averaged 0.25 inch, compared to 0.18 inch for crop trees in an adjacent unburned stand. Height growth of unscarred trees was slightly greater in the burned than in the unburned area. Fire scars were noted on 22 percent of the crop trees alive in 1950. Some of these scars will eventually lead to a loss in value of at least the butt logs by causing deformity, degrade, and heart rot. Such loss was observed at Pringle Falls during the recent logging of a 105-year-old stand which had been accidentally thinned by fire at an early age.

Weaver (20) reports the cost of controlled burning on the Colville plot as $1.22 per acre, but believes it can be done for much less (1942 dollar values). Prescribed burning would thus appear to be a cheap, quick, wholesale method, but in practice it is difficult to get exactly the right intensity of fire to accomplish the desired thinning. Proper weather conditions for safe but effective burning are infrequent, and forest fuels vary widely from spot to spot. The method needs further systematic test and study of results.

INFORMATION FROM OTHER STUDIES

Two additional sources of information are available for comparison with results obtained in the Pacific Northwest. The thinning studies most directly comparable are those with ponderosa pine in other western regions. A second source is the general literature on the subject of thinning.

Other Ponderosa Pine Regions

Tests of thinning ponderosa pine in other parts of its broad range have furnished results similar to those in Oregon and Washington. The age and type of stands and degrees of thinning tested were about the same as in the Northwest. In the Southwest, Pearson (15) reported that crop trees in a 40-year-old, completely thinned stand grew an average of 1.3 inches in diameter in the first 10 years compared to 0.8 inch for similar trees in the unthinned stand. In the second 10-year period,

following a light and heavy rethinning on portions of the same plot, Krauch (9) noted that crop trees in the twice thinned stands grew 1.13 and 1.17 inches respectively, while trees on unthinned plots grew about the same as before, 0.81 and 0.84 inch. For this second period height growth averaged about 2 feet greater on the thinned than on unthinned plots. In another Arizona study (7), similar increase in diameter growth resulted from thinning to about 10-foot spacing, but a slight gain from thinning to 7-foot spacing was not significant.

Stuart and Roeser (18) showed that diameter growth of remaining trees was nearly doubled for a 6- or 7-year period after thinning on the Harney and Black Hills National Forests. On a fair site (IV) in western Montana, Fahnestock and Wellner (3) found that for the first 5-year period, diameter growth of comparable trees was 60 percent greater in a lightly thinned and 80 percent greater in a heavily thinned stand than in the adjacent unthinned stand. A moderate thinning in the same area, however, failed to show better growth. On a poor site (VI), light and heavy thinnings resulted in 42 and 125 percent greater diameter growth than for the comparable trees of the unthinned plot. Effect of thinning on height growth was negligible in these Montana studies, but not much response would be expected in the first 5-year period.

Thus, studies in other localities confirm both the general nature and magnitude of response found in the Northwest. They strengthen confidence in the wide applicability of local findings. They also point up local variations to be expected; in the Black Hills study, for example, response was found to be best on limestone sites, poorest on coarse granite sites.

Other Species

The general subject of thinning, its benefits, and effects in Europe and the United States are well summarized in forestry textbooks such as Hawley's (6). Some of this general information applies to ponderosa pine, but this species is not well adapted to the standardized systems, rules, and schedules of thinning that have been developed for other species and types. This is due largely to its intolerance, the patchy nature of its stands, and the dry sites on which it grows. Another basic difference is the lack of markets for small trees such as permit repeated thinnings at frequent intervals in European forests. We hoped that measurements of growth and yield for thinned stands in European forests which have been carried through to final harvest would indicate what could be expected from ponderosa pine stands. But the nature of foreign species and the management of those stands are so different that comparisons are meaningless.

The literature does give some hints on certain thinning effects which are still in question for ponderosa pine. Thus Weidemann (21) shows that moderate to heavy thinnings of pine, spruce, and beech in Germany increased height growth, but that a limit was reached above

which further reduction in stand density did not increase the rate. With extremely wide spacing, the rate of height growth begins to fall. For stands about 100 feet high, the difference in height for various thinnings was generally not more than 3 feet. Since Weidemann was comparing heavy with light thinnings rather than unthinned stands, a greater degree of improvement should result from thinning stagnated ponderosa pine thickets. Hawley (6) holds that thinning should produce a significant gain in height as well as diameter.

Only a few studies of effect of thinning on form of tree bole have been reported. Meyer(10) showed that form class of older ponderosa pine trees tends to move toward a narrow central range after release by partial cutting, but concluded that the change was not of practical significance. The change in height-diameter relationship of ponderosa pine after thinning is apparently common to most coniferous species. Bickerstaff (2) has shown that thinning resulted in a significant increase in taper of red pine within 5 years. However, Gehrhardt (4) claims that distinct increase of taper occurs only when thinning is very severe. Other European studies, as reviewed by Behre (1), indicate that over a period of several decades heavier thinnings did not result in deterioration of form. Thus, increase of taper may be more or less temporary, but generalizations are not safe without further evidence.

As a general rule, proper thinnings increase total usable wood production and in many cases, total volume production. But there is little agreement on what "proper thinning" should be in terms of type, degree, and timing even after experience and study covering full rotations in Europe and periods up to 40 years in the United States. Not only opinion but statistical evidence itself is contradictory as to growth and yield under different forms of thinning. As for other forest practices, there is little hope for universal rules or guides. However, for given species and sets of economic and biological conditions, desirable thinning practice can be defined within a fairly narrow range.

A few inferences for ponderosa pine may be drawn from results with other species, but even these need testing. For example, Hansen (5) found that, over a 20-year period following a single thinning in 15-year-old red pine, growth and yield in total or merchantable volume was best for 6 x 6-foot spacing, compared to 4 x 4, 7 x 7, 9 x 9 and an unthinned stand. This is a wider range of densities than in any of the series of ponderosa pine study plots. However, it could not be concluded without checking that 6 x 6-foot spacing would be best for ponderosa pine, because there are differences in climate, rate of growth and prospects for early commercial thinning.

EVALUATION OF BENEFITS AND PROFITS

Eventual results of thinning can be roughly estimated by extension of measured growth rates and trends, using normal yield tables for ponderosa pine (11) as a partial guide. Pringle Falls plot 14 (9 x 9-foot spacing) will be used as an example. The 100 largest trees per acre now average 8.2 inches d.b.h. and have grown 0.8 inch more in 15 years than corresponding trees on unthinned plot 15 (table 2). Past trends indicate that this difference in diameter growth may reasonably be expected to continue for about 30 years more, or until the stand attains a normal basal area and number of trees. After 30 years diameter growth can be assumed to proceed at a normal rate. A further gain would also result from better height growth in the thinned stand.

Under these assumptions the thinned stand should reach the stage where sawtimber trees (those 12 inches and larger) average 18 inches d.b.h. in about 150 years from time of thinning. The unthinned stand would require about 55 additional years to reach this size. A conservative value of $20 per thousand board feet or $700 per acre could be assumed for the final timber crop. Discounting the gain in time when this return will be available indicates that an expenditure of as much as $23 per acre for thinning can be expected to return about 2 percent compound interest on the investment. The cost used is near average for recent complete thinnings by hand methods. Further saving would result from the reduced period over which costs of protection, administration and taxes would have to be paid. This kind of evaluation of future benefits cannot be very precise, of course, as none of the studies have been carried through to the time of stand harvesting or even to the age when commercial thinnings might be feasible.

In this example no further thinnings or intermediate harvest cuts were contemplated. Under actual management, thinnings of merchantable trees would be made long before final harvest. Commercial thinnings could be made sooner in the thinned stand and might help repay the cost of the original premerchantable thinning. This consequence of intensive management can be predicted in general terms with fair confidence, but the calculation of estimated returns is complicated and would require too many assumptions as to stand development, yields, and values of products.

The example used is not an extreme one. The gain depends largely upon the increase in growth that may be attributed to thinning. Similar computations for some of the plots, such as the Malheur and Ochoco, would indicate a greater advantage from thinning; others, such as the crop tree release plots, would show a much smaller gain. Of course the investment in a crop tree release thinning is also lower.

For computing profits, both the thinning operation and computations can, of course, be based on a wide variety of assumptions. A lower rate of interest, or none at all, would increase the profit. On a large forest property, cost of thinning might be considered a current expense necessary to maintain maximum production rather than an

investment being carried forward at interest. Different assumptions could also be made on future stumpage values or probable trends in growth and yield. Lighter degrees of thinning should be cheaper but would lower the gain in growth. The development of cheaper methods of thinning which would still provide adequate release of good crop trees offers one of the most promising avenues for increasing profits from thinning.

THINNING AS A TOOL OF FOREST MANAGEMENT

On the basis of what we know now, what part will premerchantable thinnings play in the management of our present and future ponderosa pine forests? Unfortunately, the answer is not simple or unqualified. In extremely dense stands where stagnation has reduced growth almost to a standstill, thinning is obviously in order. Even where young stands are overdense only in patches, the possible shortening of rotation is a potent argument for thinning. Under sustained yield management, if we can shorten the rotation age of young stands through thinning, there is an immediate benefit since we can also start cutting our mature forests at a more rapid rate. But trying to say just what this means region-wide or even for a given working circle or property reveals a serious gap in our knowledge: we do not know enough about the limit of stand density above and below which thinning will or will not have substantial benefits. Even if this were known, we do not now have an inventory of young stands and reproduction classified as to density.

Nevertheless, action need not await the accumulation of this detailed information. For a given forest area a brief reconnaissance will show where the obviously overdense young stands are located and something of their extent. Current growth rates of probable crop trees may be measured and the possible degree of improvement roughly estimated by comparing with the rates given for study plots in this report. Thinnings may then be undertaken for stands with the greatest promise of benefit. Doubtful areas should usually be deferred until we gain further information and experience.

The increasing practice of pruning young ponderosa pine has brought to new attention the unsatisfactory growth rate of many otherwise prunable crop trees. Thinning done either at the same time as pruning, or preferably earlier in the life of the stand, would increase the growth rate of selected trees and help assure that they would live through to merchantable size, thus making the pruning investment more profitable. The problem of combined treatment needs careful analysis and further trial.

As forestry becomes more intensive, restocking may be so controlled that a minimum of premerchantable thinning will be required. However, perfect control of stocking will probably be rare, and it is also questionable whether holding number of seedlings down to the minimum needed at merchantable size is really desirable. The development of a large-scale market for smaller trees would allow profitable thinnings to be made at a younger age, and thus in some stands reduce the need for premerchantable thinnings, or in other stands provide added incentive for

thinning in the sapling stage. The increased use of smaller trees may come relatively slowly for ponderosa pine, because of scattered location of young stands, distance from markets and pulp and hardboard plants, and low production per acre. Thus it appears there will be a place for early thinnings for a long time into the future. And, of course, knowledge of thinning effects will apply whether the cut material is used or not.

As a tool of management, thinning should be planned and executed with future forest practices and the end product in mind. Our best guess is that saw logs will be the primary product of ponderosa pine forests, and that intermediate harvest cuttings will be made to obtain maximum production. A reasonable aim might be to make the first intermediate cutting when a fair number of trees have produced a log 16 feet long with a minimum top diameter of 8 inches. Or other standards of minimum merchantability could be assumed. To fit into this general scheme of management, the main purpose of a premerchantable thinning in an overly dense stand should be to bring the stand to the size where commercial thinnings or intermediate harvest cuttings can begin in a reasonably short time. In most cases one fairly heavy premerchantable thinning should suffice. Further research is needed to test the costs and advantages of repeated early thinnings.

Assuming that one early thinning of overdense stands is believed adequate, the most advantageous timing of the operation becomes an important matter. Most pine thinnings have been made in stands where trees average 2 to 6 inches d.b.h. The best age or size class for a single thinning is probably below this range, since stands only 2- to 5-feet high could be thinned much more cheaply and perhaps just as effectively. The one small sample of such a thinning, Fremont plot 5, is promising but the data are not adequate for general conclusions.

Of course, we must work with what we have, and for overdense stands already in the sapling or small pole stage, thinnings should be made as soon as feasible to avoid further stagnation. For older pole stands the existence of an upper limit of tree size for profitable premerchantable thinning should be recognized, although such a limit was not established by the studies reported here. With increasing tree size, it may be reasoned that: (1) cost of thinning increases; (2) a more dangerous and lasting fire hazard is created by thinning slash; (3) more stems are sacrificed which might be marketable if left a few years longer; and (4) the time is reduced over which growth gains occur before commerical thinnings begin. Thus, if even part of the cut trees might be utilized if left standing for a few years, immediate thinning may be unwise. Where other benefits may accrue, such as release of pruned trees, aesthetic improvement, or correction of a deficiency in age classes, thinning of larger trees may still be justified.

Research and experience have provided some useful information on desirable method and degree of thinning for ponderosa pine, but a number of basic questions remain to be answered before a guiding policy for best practice can be formulated. The need for standards of stand density has been mentioned. Another important question is: Should

thinning favor dominants and "superdominants" in a stand, or should thinning eliminate these two classes and favor a larger number of codominants, as is done in parts of Sweden? There are valid arguments for either side of the question and the answer will have far-reaching implications in pine management.

SUMMARY AND CONCLUSIONS

The facts and conclusions on premerchantable thinning in ponderosa pine of the Northwest are summarized as follows:

1. Overstocked stands are not growing satisfactorily, but through thinning diameter growth of crop trees can be increased about 30 to 150 percent. Thinning usually also accelerates height growth, but to a lesser degree than diameter growth. Trees of poor form or undesired species may also be eliminated.

2. Eventual results of thinning are not yet proved, but rough calculations based on measured trends indicate that cost of early thinning may well be repaid by shortening of the time required to grow merchantable trees.

3. The long duration of release effect and the cost of premerchantable treatment suggest that one early thinning should be enough to bridge the period until first commercial thinnings can be made.

4. Although not enough is yet known to enable us to prescribe exact methods and schedules of thinning, studies have indicated that: (1) practically all forms and degrees of thinning tested have been beneficial; (2) degree of thinning should be fairly radical where only one operation appears feasible for several decades; and (3) if possible, thinning should start when stands are only 2 to 5 feet high to lower costs and avoid stagnation.

5. The area and exact condition of pine stands which could be thinned profitably in the Pacific Northwest are not known. The most critical areas of overstocking are rather localized, but even these would make a substantial total; additional large areas are overstocked in spots or patches.

6. In spite of all the unknowns and uncertainties, the need for a continuing supply of good ponderosa pine sawtimber warrants: (1) continued research to fill the many gaps in our knowledge, and (2) application of thinning to at least the unmistakably overstocked areas now.

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