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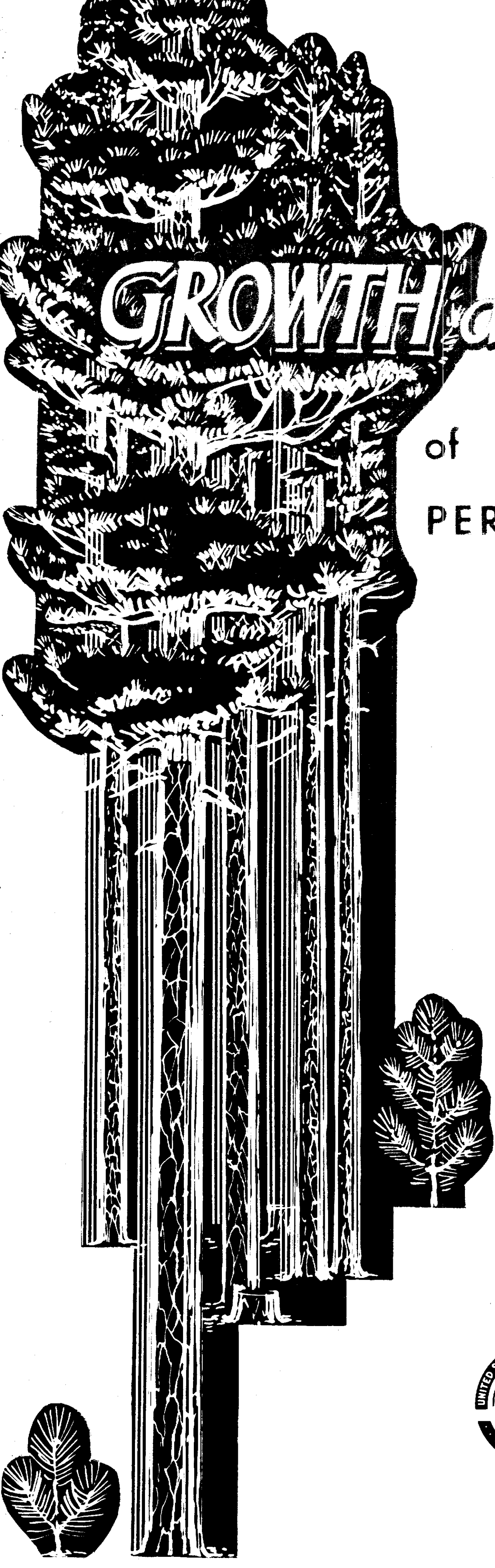

GROWTH after partial cutting of PONDEROSA PINE on PERMANENT SAMPLE PLOTS in EASTERN OREGON

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SUMMARY

Between the years 1913 and 1938, seven sets of permanent sample plots were established on the Whitman, Malheur, Rogue River, and Deschutes National Forests in eastern and central Oregon to study the results of various methods of selection cutting in old-growth ponderosa pine stands. This report briefly describes these studies and gives statistics on board-foot growth and mortality as related to method of cutting and other factors.

In a separate supplement, the study areas, methods of cutting, and statistical results are described in greater detail for each set of plots. This supplement is available upon request to those who are interested in specific areas or who wish to gain a broader background of experimental data and discussion than the main report provides.

With one exception, all cutting methods studied were partial cuts which removed from 22 to 86 percent of the original sawtimber volume. The exception was on a plot cut to a 14-inch diameter limit, which resulted in a virtual clear cutting of all merchantable trees.

During the most recent period of measurement, gross annual growth of reserve sawtimber ranged from 25 to 202 board feet per acre. Ingrowth to sawtimber size added from 1 to 30 board feet per acre per year. Mortality caused by bark beetles, wind, and other agents ranged from 0 to 74 board feet. The combination of these three elements left a net annual increment which ranged from a loss of 16 to a gain of 220 board feet per acre.

Variations in growth were associated more with spacing and reserve stand structure (composition by Keen tree class and diameter class) than with particular method of cutting or even with exact volume of reserve. Method and degree of cutting, of course, affected structure as well as volume of reserve growing stock. However, because of the predominance of overmature and relatively low-vigor trees in most virgin stands, the possible gain in net increment by trying to leave more growing stock, even of the most thrifty trees available, was often very limited. It was also found that marking practices which emphasized uniform distribution and tree thrift rather than value resulted in higher net increment. Growth of young trees often compensates for low increment of the merchantable trees in a stand.

Suggestions for applying results of this study to forestry practices and management planning begin on page 17.

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CONTENTS

BRIEF HISTORY OF PONDEROSA PINE CUTTING

Foresters in the Pacific Northwest are faced with the job of managing over 8 million acres of clear-cut and partial-cut ponderosa pine forests, together with some 4 million acres of virgin pine forests on which methods of cutting are yet to be prescribed. The results of a wide variety of partial cuttings on these lands and resulting inferences that may aid in management--the subject of this report--may be better understood if the history of change in cutting practices is first briefly reviewed.

Ponderosa pine forests of the Pacific Northwest often provided the most accessible timber to farms, mines, and towns; some cutting began with first settlement, about 1860. Commercial timber cutting for other than local use started between 1880 and 1890, chiefly on private lands, and increased only gradually for the next 25 years. The first extensive cuttings on national forests were made about 1910. Logging expanded at a moderate rate from 1915 until 1923 and then more rapidly, until by 1956 more than 60 percent of the 12,725,000 acres of ponderosa pine type in the region had been cut over. On Federal lands, practically all harvesting was by a partial-cutting method which left some reserve trees for later cuts and for a seed source.

In early years most cuttings removed from 75 to 90 percent of the merchantable volume. The apparent requirement of a heavy volume cut per acre to meet logging and development costs often left little opportunity for silviculture, and even the conservative cutting of 30 or 40 years ago seems heavy today. Thus, a cutting which removed 62 percent of the volume was labeled light selection in 1914. In general, forest managers planned on rotations of 140 to 180 years and cutting cycles of 30 to 60 years.

The economy and flexibility of tractor logging opened the way for lighter degrees of cutting. The leaving of more reserve trees was also favored by the squeeze on profit margin in the 1930's, which forced attention to the loss in logging small or low-grade trees. "Economic selection" methods held particular appeal during this period. The trend toward lighter cuttings has continued, and more recently partial cuts on the national forests have taken from 65 to 25 percent of the volume. Some recent operations have removed as little as 10 percent. These, however, were sanitation-salvage cuttings which removed only high-risk trees to reduce or salvage loss from bark beetle attack, a cutting practice which is considered the best first treatment for many virgin forest areas (12).[1]

GENERAL DESCRIPTION OF THE STUDIES

Throughout the years since large-scale cutting began, foresters have been striving to improve their marking policies and techniques of tree selection. In an effort to provide more definite information as a guide for their practices, studies of methods of cutting were started, mostly in the form of permanent sample plots

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[1] Numbers in parentheses refer to references, page 21.

on which results could be systematically measured and observed. On such plots, different degrees of cut and various ideas of marking could be compared. Several plots were simply carefully measured samples of prevailing marking practices, or what is called here Forest Service standard selection. Some cutting methods tested were minor variations of standard selection, designated by such terms as "light selection" and "bull pine-yellow pine selection." Other more distinct methods were so-called seed-tree cuttings, group selection, economic or value cuttings, maturity selection, and in one case a 14-inch diameter limit cutting. From 1913 to 1938, 32 study plots were established on four national forests and two experimental forests in eastern Oregon. This report describes these studies and their results to date.

Scope of Studies and Relation to Published Information

The stated objective of the earlier studies was very broad, for example: "to secure a reliable basis for the management of the western yellow pine and fir-larch types... ." In line with this broad scope, detailed records or maps of original and reserve stands, reproduction, other vegetation, soil, logging damage, soil disturbance, slash cover, and seed production were made for several plots. Different slash treatments were tested in some cases. Early publications on ponderosa pine for this region (7, 8, 13) included data on slash disposal, regeneration, volume, and growth obtained in part from these plots but based to a large extent on other special studies and general experience. Meyer's study of growth after partial cutting reported in Technical Bulletin 407 (3) and in part Briegleb's growth prediction data (1) were based largely on temporary "postmortem" studies of whatever cutover stands could be found.

The present report emphasizes growth and mortality but differs from previous published reports in that it is based upon complete historical records of planned tests for periods of from 10 to 36 years. For the most recent period of measurement, the data also represent a more comprehensive experience record of reserve trees classified by the Keen system (2) than has previously been available.[2]

The several sets of plots differ in so many respects--place, time, method of cutting, exact character of timber stand, size of plots, or scope of study--that they cannot be analyzed as one experiment, although many valid comparisons may be made as described later. In order to make the mass of information more digestible, the data have been assembled and plots described by groups (table 1) chiefly on the basis of the national forest or experimental forest where they are

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[2] A large amount of similar data on mortality and some data on increment are in the files of the Division of Forest Insect Research, Pacific Northwest Forest and Range Experiment Station, and unpublished reports by F. P. Keen, based on repeated examinations of some 92 10-acre plots in virgin and selectively cut stands in eastern Oregon and Washington.

Table 1.--Summary of selected statistics for ponderosa pine methods-of-cutting study plots (all species; per-acre basis)

Location	Plot No.	Year cut	Method of cutting	Percentage of original volume cut	Reserve volume: At time of cutting	Reserve volume: Beginning recent period	Periodic annual increment and mortality--recent period: Gross increment of reserve	Ingrowth	Total gross increment	Mortality	Net increment	Net growth
					--- Board feet ---		---------------- Board feet ----------------					Percent
Wallowa-Whitman National Forests	1	1914	Light selection	62	11,166	10,753	86	4	90	27	63	0.6
	2	1914	Group selection	70	7,197	7,652	78	10	88	9	79	1.0
	3	1914	Forest Service (heavy) selection	82	4,823	5,912	86	6	92	2	90	1.5
John Day Experimental Forest	1	1923	Current Forest Service selection	68	4,775	5,457	74	10	84	26	58	1.1
	2	1922	Current Forest Service selection	77	4,233	5,374	88	19	107	16	91	1.7
	3	1920	Current Forest Service selection	86	2,487	3,690	75	15	90	7	83	2.3
Malheur National Forest	5	1934	Economic selection	56	14,413	15,543	190	10	200	49	151	1.0
	4	1934	Light selection	59	11,252	12,656	180	5	185	28	157	1.2
	2	1934	Bull pine-yellow pine selection	62	9,454	10,541	202	9	211	3	208	2.0
	3	1934	Standard selection	68	7,196	8,513	196	24	220	0	220	2.6
	1	1930	Current Forest Service selection	76	5,031	5,788	86	6	92	44	48	.8
Malheur National Forest	8A	1938	Maturity selection (value)	29	11,719	11,719	99	14	113	74	39	.3
	8B	1938	Maturity selection (thrift)	32	13,864	13,864	116	11	127	62	65	.5
Rogue River National Forest	2	1927	Bull pine-yellow pine selection	66	11,399	12,571	153	13	166	38	128	1.0
	5	1929	Current Forest Service selection	74	8,227	9,291	170	16	186	21	165	1.7
	1	1927	Current Forest Service and bull pine thinning	76	8,392	9,729	182	8	190	0	190	2.0
	4	1927	Current Forest Service selection	83	5,405	6,153	140	18	158	1	157	2.6
	3	1927	Seed-tree cutting	84	4,778	4,884	121	8	129	0	129	2.6
	6	1924	Current Forest Service selection	89	7,020	9,142	155	15	170	11	159	1.7
Deschutes National Forest	6	1937	Value selection	47	9,885	8,633	47	2	49	65	-16	-.2
	2	1937	Bull pine-yellow pine selection	63	7,295	5,076	62	5	67	30	37	.7
	1	1937	Seed-tree cutting	66	5,269	4,408	43	1	44	26	18	.4
	4	1937	Current Forest Service selection	67	5,031	2,963	45	3	48	2	46	1.6
	3	1937	14-inch diameter limit	96	764	740	25	3	28	0	28	3.8
	5	1929	Current Forest Service selection	68	6,740	5,695	77	10	87	7	80	1.4
	7	1927	Current Forest Service selection	74	6,865	6,818	137	4	141	56	85	1.2
Pringle Falls Experimental Forest	30	1937	20-percent thrift selection	24	17,487	17,487	97	27	124	12	112	.6
	33	1937	20-percent value selection	22	17,811	17,811	103	29	132	11	121	.7
	35	1937	40-percent thrift selection	40	12,855	12,855	97	24	121	27	94	.7
	34	1937	40-percent value selection	41	12,344	12,344	74	21	95	13	82	.7
	31	1937	60-percent thrift selection	57	11,838	11,838	95	30	125	23	102	.9
	32	1937	60-percent value selection	66	6,637	6,637	62	30	92	36	56	.8
	36	1937	80-percent Forest Service selection	72	4,783	4,783	56	23	79	37	42	.9

located. Brief description and data on stand, growth, and mortality are given for each location series of plots in the supplement. Only a few of the summarized statistics are listed in table 1.

<u>Location and Size of Study Plots</u>

The central Blue Mountain region is represented by two sets of plots, Whitman 1-3 (fig. 1) and John Day 1-3. Malheur plots 1-5 and 8 are toward the southern end of the timber zone in the Blue Mountains. Rogue River plots 1-6 are on deep pumice soils on the east slope of the southern Cascade Range. Deschutes plots 1-7 in central Oregon are also on pumice, but a much shallower layer and not far from the desert edge, thus representing a more marginal site for pine. Plots 30-36 on the Pringle Falls Experimental Forest are on pumice of moderate depth and in typical rainfall conditions for the central Cascade zone. Site quality of all plots is within the range of site IV (index 71 to 84) except Deschutes plots 1-6, which are on the upper limit of site V class. Areas picked for study were chiefly in pure ponderosa pine type, occasionally with light mixtures of western larch, Douglas-fir, white fir, and lodgepole pine in the Blue Mountains, and lodgepole pine areas east of the Cascade Range.

Most of the study plots are square or rectangular and range in area from 5 to 15 acres. Two are long, narrow strips totaling 32 and 50 acres. The Pringle Falls plots are tagged-tree samples averaging 27 acres each of larger cutting units. Malheur plots 8A and 8B are combinations of 395 2-chain-square subplots scattered along 50 miles of line which sample 35,000 acres of cutting area. The sample plots represent typical stands of average original stocking in each area; no large openings or patches of types other than mature ponderosa pine were included.

FACTORS AFFECTING GROWTH

Before comparing growth and mortality rates as related to cutting in these stands, it is desirable to review some of the factors affecting growth of ponderosa pine stands. Briegleb (1) listed the following as factors affecting growth of the sawtimber stand:

1. Tree age and vigor, as expressed in Keen tree class
2. Diameter within tree classes
3. Volume of residual stand
4. Percentage of original volume cut
5. Site quality
6. Species composition
7. Climatic cycles
8. Locality

The present study has provided additional information on the general magnitude of effect of some of these factors. It has particularly emphasized the importance of stand structure, or makeup of the stand by Keen tree classes.

Figure 1.--A, Virgin ponderosa pine forest on Whitman permanent sample plot 3, in 1913 before cutting; volume averaged 27,283 board feet per acre.

B, View from nearly the same point in 1914, after logging and slash disposal. The stand was cut by the standard Forest Service selection method of that time, leaving here an average of 10 sawtimber trees per acre with a volume of 4,823 board feet.

C, The same view in 1934. Seedlings which were barely visible in the preceding views, with some new seedlings, have grown to sapling size.

D, The same view in 1951, 37 years after logging. Reproduction in foreground has grown to small pole size, nearly obscuring the scattered reserve trees in background.

The study also furnished a close check on estimates of growth by the Briegleb system. The judgment of methods of cutting depends so much on an understanding of stand structure and growth estimates that it seems worth while to discuss them briefly in the following two sections.

GROWTH OF PONDEROSA PINE BY TREE CLASSES

As mentioned earlier, one of the valuable products of these studies is the historical record of growth and mortality in terms of Keen tree class for individual trees. General differences in structure of reserve stand by tree class and their relation to results on each area are mentioned in the Supplement (see Summary). While a detailed examination of these statistics for each plot is quite informative, it requires considerable study, and a summary obscures the important differences between plots. Therefore, the data for only two contrasting plots of the Malheur series are presented in table 2 as typical samples for discussion.

Plot 3 was marked for standard Forest Service selection and plot 5 for "economic selection," but the differences due to cutting method were far outweighed by differences in tree-class stand structure of original and reserve stands. The bulk of reserve volume and likewise of gross increment[3/] is in the immature class 2 trees on plot 3 (fig. 2), and in mature class 3B and 3C trees on plot 5 (fig. 3). As a result, plot 3 showed higher gross growth than plot 5, although its reserve volume in 1951 was only 70 percent of that on the latter. Growth percent averaged 2. 3 for plot 3 and only 1. 2 for plot 5. This is largely a reflection of the higher growth rates for class 2 than for class 3 trees. Average size of tree, which is lower for class 2 than class 3, is also involved in this comparison since a given diameter or volume increase for a small tree means a higher percentage growth rate than for a large tree. It is notable that growth percent for class 2 trees is higher on plot 5 than on plot 3, an anomaly which probably is due to relatively free-growing position of these particular trees on plot 5 compared with the nearly solid stand of this class on plot 3.

Volume added by ingrowth was also much greater on plot 3 because of the larger number of class 1 and 2 trees available there. No mortality occurred on plot 3 in this period, but loss was fairly heavy in the low-vigor class 3C and 3D trees on plot 5. Thus net increment was much higher for plot 3 than plot 5. If Forest Service marking had been applied on plot 5, a heavier volume including many low-vigor trees would have been cut. This might have reduced mortality and given better release to the remaining stand, but the possibility of much, if any, better increment was still limited by the scarcity of immature trees such as comprised most of the growing stock on plot 3.

3/ For definition of terms and units, see page 22.

Table 2.--Ponderosa pine reserve volume in 1941, and periodic annual growth and mortality (1941-48) per acre, by Keen tree class; Malheur plots 3 and 5

Tree class	Plot 3						Plot 5							
	Reserve volume	Gross increment reserve	Growth percent	In-growth	Total gross= net increment	Diameter growth per tree	Reserve volume	Gross increment reserve	Growth percent	In-growth	Total gross increment	Mor-tality	Net increment	Diameter growth per tree
	Bd.ft.	Bd.ft.		Bd.ft.	Bd.ft.	Inches	Bd.ft.	Bd.ft.		Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Inches
1A	96	9.0	9.4	--	9.0	0.19	21	2.0	9.5	1.8	3.8	--	3.8	0.23
1B	31	2.9	9.4	10.7	13.6	.16	63	3.5	5.6	--	3.5	--	3.5	.19
1C	--	--	--	1.1	1.1	.10	--	--	--	.8	.8	--	.8	.12
All 1's	127	11.9	9.4	11.8	23.7	.14	84	5.5	6.5	2.6	8.1	--	8.1	.16
2A	1,226	32.1	2.6	--	32.1	.18	376	11.3	3.0	--	11.3	--	11.3	.20
2B	3,433	82.7	2.4	7.4	90.1	.14	304	10.4	3.4	--	10.4	--	10.4	.17
2C	810	17.8	2.2	2.8	20.6	.10	315	8.7	2.8	.7	9.4	--	9.4	.12
2D	--	--	--	2.4	2.4	.04	--	--	--	.8	.8	--	.8	.06
All 2's	5,469	132.6	2.4	12.6	145.2	.12	995	30.4	3.1	1.5	31.9	--	31.9	.14
3A	786	13.6	1.7	--	13.6	.15	246	5.1	2.1	--	5.1	--	5.1	.18
3B	1,666	31.3	1.9	--	31.3	.14	6,538	82.4	1.3	--	82.4	--	82.4	.12
3C	386	4.6	1.2	--	4.6	.09	4,517	38.5	.9	--	38.5	41.5	-3.0	.08
3D	--	--	--	--	--	--	442	1.3	.3	.7	2.0	7.6	-5.6	.04
All 3's	2,838	49.5	1.7	--	49.5	.13	11,743	127.3	1.1	.7	128.0	49.1	78.9	.09
4A	--	--	--	--	--	--	608	4.0	.7	--	4.0	--	4.0	.09
4B	--	--	--	--	--	--	842	5.4	.6	--	5.4	--	5.4	.07
4C	--	--	--	--	--	--	119	--	--	--	--	--	--	--
All 4's	--	--	--	--	--	--	1,569	9.4	.6	--	9.4	--	9.4	.07
Total	8,434	194.0	2.3	24.4	218.4	.13	14,391	172.6	1.2	4.8	177.4	49.1	128.3	.11

Figure 2.--Immature or so-called bull pines, as seen in the center and right parts of this view of Malheur plot 2 before cutting, make choice reserve trees that will grow rapidly after partial cutting. Reserve stand of this character left after a 68-percent cut on adjoining plot 3 made the best net annual growth of any plot studied, 220 board feet per acre in a recent 8-year period. Quality growth is low, however.

Figure 3.--This original stand of ponderosa pine on Malheur plot 5 was composed chiefly of mature and overmature trees (Keen age classes 3 and 4). After partial cutting, residual trees grew slowly and many were killed by windthrow and bark beetles. Recent net annual increment was 151 board feet per acre.

The rates of diameter growth listed in the last column for each plot in table 2, which may be easier for readers to visualize, show more distinct differences between tree-vigor classes than the growth percents. However, difference between general plot averages (0.13 inch vs. 0.11 inch) is not as large as one might expect.

COMPARISON WITH ESTIMATED GROWTH

For the most recent period of measurement, estimated or predicted growth and mortality were computed by the Briegleb system (1) for each plot. This system provided estimates of three elements: (1) growth of initial reserve, (2) ingrowth, and (3) mortality. The basis for mortality estimate was admittedly weak, and for most plots actual mortality was much lower than predicted. Thus mortality comparisons are omitted in the summary of actual and estimated growth in table 3. The system also provided a rough estimate of growth of other species, but since other species were absent or comprised only a small fraction of the stand on most plots, the comparison is confined to ponderosa pine.

Since this system of estimating growth takes into account site quality, reserve volume, percentage cut, and structure of stand by diameter and Keen tree classes, it furnishes a kind of "normal" with which actual performance may be compared. Of course the scheme is not perfect and it is based on regionwide averages, but checks against actual growth on these plots and elsewhere show that it does give a reasonable average estimate for broad areas.

Departures of actual from estimated values may reflect:

1. Dry or wet climatic period, either local or regional
2. General locality differences for which no explanation is available
3. Method of cutting and particular character of original stand,
    a. which left better or poorer vigor trees than average within tree classes, or
    b. which left trees distributed in especially clumpwise or uniform pattern
4. Unusually heavy competition from understory trees or from other vegetation.

The general average of estimated gross growth of reserve, 99 board feet per acre per year (table 3), is remarkably close to the actual average, 100 board feet. But by individual plots, the actual varies from 43 percent below to 44 percent above the estimated value. If the 33 pairs of plot values are considered as a random sample, the coefficient of correlation between actual and estimated is 0.97 (highly significant, with confidence limits at the 99-percent level of 0.93 to

Table 3.--Comparison of actual with estimated annual growth of ponderosa pine only on methods-of-cutting plots, most recent period of measurement (per-acre basis)

Plot designation		Method of cutting[1/]	Gross increment of reserve		Ratio actual to estimated	Ingrowth	
			Actual	Estimated		Actual	Estimated
			---- Board feet ----		Percent	---- Board feet ----	
Whitman	1	Light selection	85	109	79	3	2
	2	Group selection	77	101	76	10	8
	3	Forest Service selection	82	98	84	4	2
Group average[2/]			81	103	79	6	4
John Day	1	Forest Service selection	61	80	76	9	--
	2	Forest Service selection	68	87	78	13	--
	3	Forest Service selection	68	80	85	13	--
Group average			66	82	80	12	--
Malheur	5	Economic selection	173	129	134	5	1
	4	Light selection	177	123	144	5	1
	2	Bull pine-yellow pine selection	202	147	137	9	4
	3	Forest Service selection	194	168	115	24	7
	1	Forest Service selection	86	87	99	6	2
Group average			166	131	127	10	3
Malheur	8A	Maturity selection (value)	80	93	86	6	--
	8B	Maturity selection (thrift)	86	98	88	4	--
Group average			83	96	86	5	--
Rogue River	2	Bull pine-yellow pine selection	152	126	121	13	4
	5	Forest Service selection	168	157	107	12	5
	1	Forest Service plus bull pine thinning	178	131	136	5	3
	4	Forest Service selection	140	108	130	17	7
	3	Seed-tree cutting	121	88	137	8	3
	6	Forest Service selection	155	137	113	15	9
Group average			152	124	123	12	5
Deschutes	6	Value selection	47	82	57	2	1
	2	Bull pine-yellow pine selection	62	62	100	5	1
	1	Seed-tree cutting	43	74	58	1	1
	4	Forest Service selection	45	52	87	3	2
	3	14-inch diameter limit	25	24	104	3	2
	5	Forest Service selection	76	96	79	7	2
	7	Forest Service selection	136	107	127	2	1
Group average			62	71	87	3	1
Pringle Falls	30	20-percent thrift selection	89	122	73	6	4
	33	20-percent value selection	93	100	93	7	3
	35	40-percent thrift selection	90	98	92	7	4
	34	40-percent value selection	62	85	73	4	3
	31	60-percent thrift selection	83	110	75	8	4
	32	60-percent value selection	47	58	81	5	3
	36	80-percent Forest Service selection	41	42	98	5	2
Group average			72	88	82	6	3
All plots average			100	99	101	7	3

[1/] See table and text description for each area for explanation of methods.

[2/] Group averages and grand average are unweighted.

0.99). Each series tends to show either consistently high or consistently low ratio of actual to estimated growth--group averages range from 21 percent low to 27 percent high.

Within a series the deviation from a group average in some cases has a satisfactory explanation on the basis of method of cutting and natural stand distribution. For example, plot 1 of the Rogue River series had a fairly uniform distribution of trees, and the method of marking gave some release to almost every reserve tree; thus its ratio (136 percent) was high, its growth performance better than "normal." Relatively low ratio (113 percent) of growth on plot 6 of the same series may be partly due to presence of a heavy reproduction understory on parts of the plot. In some other cases no explanation is apparent.

Estimate of ingrowth was consistently low, regardless of location and varying ratio for reserve stand growth. Average actual ingrowth volume was more than twice as large as estimated (table 3). Even allowing for the possibility of slight bias associated with errors of measurement, local volume table used, short or long period of measurement, etc., it appears that the estimating scheme itself is too conservative for this element. Estimates of ingrowth might safely be doubled.

This check against actual performance may provide a basis for further adjustment and refinement of the prediction system, but this involves intensive analysis and detailed comparison by tree and size classes and is beyond the scope of this paper.

RELATION OF METHOD OF CUTTING TO GROWTH

In the supplement describing each series of plots, the various conditions affecting board-foot growth and mortality are discussed. While method of cutting is one of these factors, in some cases it is a relatively minor one. It was shown above (page 4) that structure of reserve stand, which may be expressed approximately in terms of composition by Keen tree class and diameter of trees, is a major determinant of growth, often outweighing wide differences in volume of growing stock.

Structure of reserve is limited in turn by structure of original virgin stand. Gross growth of the virgin stand is thus a kind of ceiling rate which, for the first few decades after logging, is difficult to surpass under any method or degree of cut that may be applied.

Other stand factors being equal, greater growth can be made by heavier reserves of growing stock. But in this region virgin stands are often deficient in number of younger trees of good vigor. Thus trying to gain increment by leaving heavier volumes often defeats itself because the additional trees left may be of poorer vigor, older age, and usually of larger size--the less efficient producers of the stand. Such trees often include the high-risk element, but it is assumed that any method of cutting should aim to remove the truly high-risk trees to minimize mortality. Light cutting also gives but little release to overcrowded trees. Some of the disadvantages of light cutting may be overcome by frequent returns on a short cutting cycle.

On the other hand, trying to gain increment by removal of all or most of the mature, overmature, and low-vigor trees often results in reduction of growing stock to such a low level that the site is not fully utilized. Individual trees are well released and grow at relatively high rates but are unable to compensate for low volume per acre.

The degree of selection cutting that will result in near-maximum board-foot increment and an acceptable low level of mortality usually lies somewhere between these two extremes. Obviously, the "optimum" volume varies widely with stand conditions. If there is a large proportion of immature and thrifty mature trees present, a much higher volume may be reserved; or vice versa. In many stands similar increment may be obtained from a fairly wide range of reserve volumes because of the counterbalancing of elements as explained above.

Of course other considerations than maximum increment have dictated cutting practices of the past, i.e., need for high volumes or select quality to justify logging development, desire to obtain reproduction or to promote growth of that already present, etc.

With these ideas as a background, the methods of cutting represented on the study plots may be reviewed in a general way.

A Forest Service standard selection method in vogue at the time of cutting is represented in all but one series of plots. Although the exact definition and interpretation of this policy of marking varied somewhat over the span of years from 1913 to 1936, the general aim of leaving most of the immature and only the thriftiest mature trees prevailed. Percentage of volume cut ranged from 67 to 86 percent of original stand volume (table 1). Reserve volumes were from 2,487 to 8,227 board feet per acre, but all except 2 of the 13 plots were in the range of 4,200 to 7,196 board feet.

Highest reserve but with only average percentage cut was on Rogue River plot 5, which had a high original volume with a comparatively large proportion of young thrifty trees. It produced a net annual growth of 165 board feet per acre.

Second highest in volume but with low percentage cut was Malheur plot 3, in which most of the reserve volume was in immature (Keen age class 2) trees. This Malheur plot is not a typical condition. Its recent net growth rate, 220 board feet per acre per year, is highest of any plot studied, and perhaps more nearly represents what may be expected in the future than an average for present reserve stands. With this exception, net annual increment in the latest period of measurement ranged from 42 to 165 board feet per acre.

The variation of marking called bull pine-yellow pine selection, which left somewhat heavier volumes than standard selection (7,295 to 11,399 board feet per acre), resulted in gross annual increments of 62 to 202 board feet per acre. These were a little higher than for corresponding standard selection plots but lower in terms of growth percents. Mortality was comparatively high among the additional medium-vigor trees that were reserved, so that net increment was lower than for standard selection.

Next lighter in degree were so-called light selection cuttings, which removed from 40 to 62 percent of volume and left reserves of 11,166 to 12,855 board feet per acre. The marking policy of reserving the younger and more vigorous trees of the stand prevailed here as in standard selection, but to hold the desired volume on some plots this unavoidably included some older and slow-growing trees. Gross increment of reserve ranged from 74 to 180 board feet per acre per year; net, from 63 to 157. These rates were generally, but not consistently, higher than comparable standard selection within the same series. Ratio of actual to estimated growth was also variable. The variability in relations expressed above suggests differences in stand structure and spacing distribution rather than any conclusive advantage from cutting method. Also, growth percents were lower than for standard selection

The lightest degrees of removal were the two 20-percent cuts at Pringle Falls, which left reserves of 17,487 and 17,811 board feet per acre. Gross increments were the highest of that series but only slightly higher than for two other plots which had only two-thirds as heavy reserve volumes. It is notable that nearby virgin stands grew at closely similar gross rates, but because of heavy mortality net increments were much lower. Apparently both the light and very light cuts are running close to the ceiling increment rate of virgin stands, as described above.

Economic or value selection methods (including maturity selection) varied in degree but generally left rather heavy reserve volumes. Marking rules varied considerably for the several economic cuts, but all emphasized the removal of high-value trees, especially if slow growing, as are the majority of large clean-stemmed trees. Gross increment rate varied over a wide range from 47 to 190 board feet per acre per year, in general similar to the other light selection cuttings.

In every case except for two of the Pringle Falls plots, mortality was much above average, so that net increment was relatively low. Apparently under the marking rules that gave primary consideration to immediate returns, many high-risk and other low-vigor trees were left in the stand. At Pringle Falls most of the high-risk trees were cut even if they did not fall within the limits set for value cuttings. In each series where there was a fair comparison of value and thrift marking, the latter showed greater growth and less mortality, except for one of the three pairs of plots at Pringle Falls.

Other methods of cutting are represented by only one or two plots each, so general conclusions are rather weak. A modification of standard selection that seems to have had a definite advantage was the bull pine thinning on Rogue River plot 1. An initial reserve stand of 8,392 board feet per acre grew at the rate of 182 board feet per year, which with ingrowth and no mortality made a net of 190 board feet. This was highest of that series, and was exceeded in the entire group only by Malheur plots 2 and 3, where the reserve was made up principally of thrifty immature trees. Release within immature groups, which means better spacing, seems to be the key to the superior performance of this plot. Of course, it had to have a favorable original stand structure in order to fit the method.

If group selection may be judged by the one plot in the Whitman set, growth results were relatively unfavorable. With a reserve of 7,197 board feet, it grew at a gross rate of only 78 board feet per acre per year in the recent period. This was poorest of that series, and one of the lowest gross growth rates of the entire group for comparable volume of reserve, except for the desert-edge Deschutes plots. This form of cutting would seem to have some offsetting advantage in that reproduction and young stand might develop more freely in the wide spaces between reserve groups.

The seed-tree cutting on the Rogue River National Forest showed a gross increment rate below that of standard selection because of slightly lower reserve volumes and poorer structure (trees of older age and larger size). Tree distribution was unusually uniform (fig. 4), however, so that growth in relation to that

Figure 4.--Scattered thrifty trees left after cutting by the "seed-tree method" on Rogue River plot 3; in 1937, 10 years after logging. The four large trees are growing well as individuals--in 10 years their average increase in diameter was 2.2 inches and their growth in volume totaled 1,164 board feet. Practically no new reproduction has become established; snowbrush in center foreground and bitterbrush (gray color) are abundant on this site.

predicted was high (table 3). The seed-tree cutting on the Deschutes resembles more a group selection cutting than the usual conception of a seed-tree cutting. Thus its slow growth rate, in either absolute or relative terms, is not typical of the method. It may illustrate the difficulty of trying to apply a prescribed method in a stand to which it is not suited.

The heaviest cut of the entire group, intended as a 14-inch diameter limit cutting, left such a low reserve volume, only 764 board feet per acre, that it grew at the net rate of only 28 board feet per year. Mortality was low and individual trees of course grew well. Net growth percent was highest of the group, 3.8 percent.

In any judgment of the growth rates cited here for various cutting methods, the fact should be emphasized that these results are for a relatively short time after logging, and that over a longer term the picture will change materially. On none of the plots, even the oldest, have trees of seedling-sapling size at time of cutting or subsequent seedlings had time to grow to board-foot size. There should be a strong wave of ingrowth within a few decades especially on the heavier cut plots, even sooner on such older plots as the John Day and Whitman series (fig. 1). (Note statistics for young stand on latter area, page 16.)

At suitable intervals further cuts will also be made. As the proportion of young trees in the growing stock increases over the years, growth rate may approach the periodic or mean annual rates for even-aged stands given in yield tables (4).

Factors other than board-foot volume growth must be considered in a complete evaluation of cutting methods. One of these is the development of young growing stock, which will be treated in the next section. Another factor is quality or value of the board-foot increment. Most of these studies did not include measurements of quality, but it is generally true that the greater the reserve volume the more valuable per unit it is.[4/] This is so today because reservation of more volume usually means keeping more older and larger trees, some of which are cleaner boled and hence of higher quality than younger trees. This relation will not hold if the larger trees are limby throughout, as in a young stand.

There should also be a slight gain in stumpage value because of cheaper logging and milling costs for larger trees. Thus slow growth of the additional trees kept in heavier reserves is usually partly offset by increased value of that increment, but to what extent is not known. It could be approximated by a quality cruise and growth estimate for any given stand.

[4/] As an example, stumpage value of reserve ponderosa pine was estimated at $27 per thousand board feet on Pringle Falls plots with 20-percent cut (16,942 board feet reserve), compared with $22 per thousand on plots with 60-percent cut (7,899 board feet reserve). This estimate was on the basis of log grades in 1936, with values adjusted to average 1959 stumpage prices.

Other factors, such as how the results of various cutting methods fit in with the general objectives and plan of management for a given forest property, are of real importance but are beyond the scope of this paper.

REPRODUCTION AND PREMERCHANTABLE STAND

Although the principal aim of this paper is to present information on saw-timber growth, the picture is not complete without at least brief mention of the understory stand of seedlings, saplings, and poles. Pearson (9) emphasized that development of growing stock should be a major objective, and that low board-foot increment immediately after cutting may not be of serious concern if young trees become established and grow as desired. Most of the earlier plot studies included measurement of the premerchantable stand and of reproduction, but these were not followed up consistently in all cases. In some later studies this feature was covered only by general observation.

The oldest set of plots, Whitman 1-3, provides one of the most complete records of reproduction, as described briefly in the Supplement, page 1. At the time of cutting in 1914, these plots contained few trees of sapling and pole size, but were stocked rather irregularly with inconspicuous seedlings (fig. 1A). Of these an average of 2,905 per acre survived to 1939. These advance seedlings were supplemented by the addition of 7,500 new seedlings per acre, of which 6,200 were established in the first 5 years after logging. Of the total new seedlings, 693 survived to 1939. The old and new seedlings together had by 1951 developed into an irregular understory of saplings and small poles (fig. 1D). Conditions were not uniform, however--some spots were overstocked while others had still failed to restock 37 years after cutting.

Another index of the development of the premerchantable stand on Whitman plots 1-3 is average number of trees per acre in the 4- to 10-inch d.b.h. classes in the successive years of measurement, as follows:

	Trees per acre
1914	7.2
1919	7.6
1924	9.2
1929	10.6
1939	82.9
1951	269.3

Basal area of 4- to 10-inch trees averaged 49 square feet per acre in 1951, which was greater than the 37 square-foot basal area of larger trees.

The regeneration picture is less favorable on some other areas, such as Rogue River plots 1-5 and Deschutes 1-6. Advance reproduction was scarce at time of logging, and very few new seedlings have been established since that time (fig. 4). Number of trees in the 4- to 10-inch d.b.h. group has shown a modest increase, but entirely inadequate to fully stock the areas. Of course, not as long a time has elapsed since cutting these areas as on the Whitman area, but since most of the reproduction there was evident within a few years after logging, the prospects on the Rogue River and Deschutes plots are not too promising. Causes for scarcity of seedlings have not been identified in these "regeneration problem areas," although deep, coarse pumice soil on the Rogue River and low precipitation on the Deschutes are possibilities.

Most of the other plots appear to have fairly adequate stocking of young growth. For example, on Deschutes plot 7, for which reproduction records are more complete than on most plots, stocking by milacre quadrats averaged 73 percent in 1954. Nearly two-thirds of this stocking was provided by seedlings already present at time of logging. Reproduction is predominantly ponderosa pine, but there has been a trend toward a slight increase in proportion of other species where present, such as lodgepole pine on Whitman 1-3 and Deschutes 7 and Douglas-fir on Malheur 5.

APPLICATION

The type of information presented in this report may be applied in several ways.

It may be used as a partial guide to marking policy for various conditions and purposes. Within the limitations imposed by volume, structure, and distribution of original stand, a fairly wide choice in degree and methods of cut may be available; the choice then often depends upon the objectives of management.

Approximate expected results in terms of growth, mortality, regeneration, etc., of several possible forms of cutting may be inferred from the conclusions developed here and from inspection of statistics for plots that seem to represent conditions most similar to those in question.

Except for very small areas, the final choice will rarely be a finely prescribed marking rule, but instead a set of flexible guides based upon management objectives and the various stand conditions that will be encountered in the area. Some guiding principles are proposed on page 18.

The information may also be used as a basis of growth estimation for management purposes. The data resulting from these studies provide general checks on local growth information or on specific growth estimates by the Brieg-leb or other prediction schemes. They should also lead to improvement in accuracy of these estimates. If more extensive data are lacking, the study plot results may be taken as roughly representative of similar stand conditions in that locality. For the large territory sampled by Malheur plot 8, the direct estimates of growth and mortality which it provides should be relatively accurate.

A third way in which this information may be applied is as a general guide for selection of cutting areas in unit area control.

Most ponderosa pine management of the past has been predicated upon continuing selection cutting in uneven-aged stands. In some parts of the pine region the current trend is toward unit area control, usually resulting in small clear-cuttings and eventually a series of even-aged stands.

Although attaining a desired distribution of age classes is of first importance in this system, in most cases it is necessary to hold some older stands for a considerable period. To obtain high increment and minimum mortality in these older reserves requires a skillful choice of unit areas to cut, to leave intact, or to partially cut. Growth behavior of trees and stands such as revealed on these study plots should aid in that choice.

The study data, together with other recent evidence, suggest at least five principles that may be applied in the pine type to improve forest cutting practices of the future:

1. The highest net growth that can be obtained during the first few decades following cutting will not exceed gross growth obtained in the virgin stand.

   Since in many virgin stands one-half or more of this gross growth is lost to current mortality, this principle argues for a first objective of reducing losses by: (1) sanitation-salvage cutting--the removal of high-risk trees wherever they occur, and (2) frequent salvage of dead and dying trees--beetle or lightning killed or windthrown. Thus, by reducing losses, highest current net growth can be secured; by harvesting potential and current losses, total yield is increased.

2. Net growth under management can exceed gross growth of virgin forests two to three times when, in the years ahead, they are composed of thrifty, well-spaced, young or young-mature trees free of overstory competition.

   This principle indicates that greatest increase in growth above gross virgin growth can be secured by: (1) harvest cuttings which release young trees from overstory and side competition; (2) by intermediate or improvement cuttings which leave stands of thrifty, well-spaced trees which will supply additional intermediate harvests during the last half of rotation period--plus final harvest; (3) precommercial thinning (6) in thrifty young-growth free of overstory competition, which will speed up ingrowth.

   Thus, directing emphasis first (after losses have been reduced) to those stands where these silvicultural improvements can be made will hasten the time when net growth will exceed gross virgin growth.

In applying this principle, those unit areas where overstory is to be clear cut should be chosen where maximum increment of younger age classes will result and, if possible, where overmature or decadent trees predominate in the overstory rather than mature or immature trees. It is also important that cutting of old trees in such units be complete so as to obtain full release of the young stand.

Units chosen for holding uncut or for improvement cutting should preferably be those with enough well-distributed, immature or thrifty mature trees to utilize the site reasonably well. In sawtimber-size stands this usually means a reserve of at least 15 to 20 trees (depending on average size) and a reserve volume of 7,000 or more board feet per acre.

3. Cutting methods thus far tried have had little influence on establishment of new reproduction.

   Most reproduction on cutover areas was established prior to cutting. Cutting simply released whatever vegetation was on the ground following logging, whether grass, brush, weeds, or trees. This indicates additional research is needed, and in the meantime caution should be exercised in removing existing old-growth trees (excepting high-risk trees or those which should be removed to improve spacing) from these "problem regeneration areas."

   Fortunately, these problem areas account for a relatively small proportion of the ponderosa pine type in eastern Oregon and eastern Washington. There is enough area needing treatment as suggested under items 1 and 2 above to absorb the sustained allowable cut for many decades.

4. Loss of merchantable volume will continue under good management, unless it can be salvaged promptly.

   This is especially true during the transition period from a virgin to a managed forest, as shown by the evidence presented in this paper. This points again to the need for frequent salvage of dead and dying trees. It also indicates the desirability of short cutting cycles, and the necessity for planning to make them both possible and effective.

5. Where ponderosa pine grows in mixture, other species tend to reproduce more freely and take over the site--a trend which can be reversed only by aggressive management practices.

   The question of what species to favor is not settled, but most foresters believe that ponderosa pine should be maintained on sites where it grows well. Techniques for accomplishing this are not fully tested, but several logical ones appear promising: heavy partial cutting or clear cutting, removal of overstory seed source of undesired species, prescribed burning, scarifying surface, weeding young stands, or planting. Brush species, notably manzanita and snowbrush, also tend to take over certain pine sites after fire or logging; control by spraying with herbicides may be required for this condition.

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REFERENCES

(1) Briegleb, Philip A.
1945. Calculating the growth of ponderosa pine forests. U.S. Forest Serv. Pac. NW. Forest and Range Expt. Sta., 60 pp., illus. (Processed.)

(2) Keen, F. P.
1943. Ponderosa pine tree classes redefined. Jour. Forestry 41: 249-253, illus.

(3) Meyer, Walter H.
1934. Growth in selectively cut ponderosa pine forests of the Pacific Northwest. U.S. Dept. Agr. Tech. Bul. 407, 64 pp., illus.

(4) ________
1938. Yield of even-aged stands of ponderosa pine. U.S. Dept. Agr. Tech. Bul. 630, 60 pp., illus.

(5) Mowat, Edwin L.
1948. Selection cutting reduces ponderosa pine losses at Pringle Falls. U.S. Forest Serv. Pac. NW. Forest and Range Expt. Sta. Res. Note 45, 3 pp. (Processed.)

(6) ________
1953. Thinning ponderosa pine in the Pacific Northwest; a summary of present information. U.S. Forest Serv. Pac. NW. Forest and Range Expt. Sta. Res. Paper 5, 24 pp., illus. (Processed.)

(7) Munger, Thornton T.
1917. Western yellow pine in Oregon. U.S. Dept. Agr. Bul. 418, 48 pp., illus.

(8) ________ and Westveld, R. H.
1931. Slash disposal in the western yellow pine forests of Oregon and Washington. U.S. Dept. Agr. Tech. Bul. 259, 58 pp., illus.

(9) Pearson, G. A.
1950. Management of ponderosa pine in the Southwest. U.S. Dept. Agr. Monog. 6, 218 pp., illus.

(10) Roe, Arthur L.
1952. Growth of selectively cut ponderosa pine stands in the upper Columbia Basin. U.S. Dept. Agr. Handb. 39, 28 pp., illus.

(11) Society of American Foresters.
1950. Forestry terminology. Ed. 2, 93 pp. Washington, D.C.

(12) Sowder, James E.
1951. A sanitation-salvage cutting in ponderosa pine at the Pringle Falls Experimental Forest. U.S. Forest Serv. Pac. NW. Forest and Range Expt. Sta. Res. Paper 2, 24 pp., illus. (Processed.)

(13) Weidman, R. H.
1936. Timber growing and logging practice in ponderosa pine in the Northwest. U.S. Dept. Agr. Tech. Bul. 511, 92 pp., illus.

DEFINITIONS OF TERMS

Although nearly all technical terms are used in accordance with their standard definitions (11), further explanation and specification here may aid the reader.

Volume:

Volume is given in board feet, Scribner rule, to an 8-inch top d.i.b., for sawtimber trees, which are those 11.1 inches d.b.h. and larger. Local volumes for ponderosa pine for each plot or set of plots are based on Meyer's interregional tables for site IV (3). No deductions for defect in living trees were made.

Growth:

Growth or increment (terms used interchangeably) is the increase in diameter, basal area, height, volume, quality or value of individual trees, classes of trees, or stands in relation to time. Unless otherwise modified, it here refers to increase in board-foot volume, and is usually reduced to a per-acre-per-year basis for specified periods.

Gross increment of reserve stand is the increase in volume of all trees which were of sawtimber size at the beginning of a period of measurement and which lived through the period.

Ingrowth is the volume of trees that grew into sawtimber size, that is, past 11.1 inches d.b.h., during a specified period.

Total gross increment is the sum of gross increment of reserve and ingrowth, as defined above.

Mortality is the volume of trees that die during a specified period.

Net increment (unless otherwise modified) is the net increase in sawtimber volume from the beginning to the end of a specified period; it is equal to total gross increment less mortality.

Growth percent is the ratio, expressed as a percentage, of the periodic annual increment in volume to the volume of the stand or of a class of trees at the beginning of the period in question. It may be either gross or net, as specified.

Other Terms:

Stand distribution, as used in this paper, refers principally to spatial arrangement of trees on the ground, whether uniformly scattered as individuals, in small groups, or in large groups; the groups may be more or less densely stocked.

Stand structure is the constitution of a stand with respect to age, crown, diameter, and tree classes. For ponderosa pine stands, these characteristics are expressed as number of trees or volume in various diameters and Keen tree classes (2).

Methods of cutting for each set of plots are defined in the Supplement. The broad term "partial cutting," in which any proportion of the original merchantable stand is left as reserve, includes all the methods tested in this study. Although most of the cuttings were called selection cuttings of one form or another, it may well be questioned whether some would qualify under the standard definition of the selection method because of close similarity to other methods of cutting.

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