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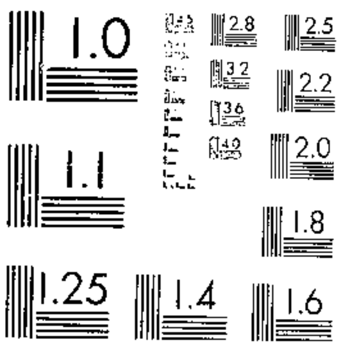

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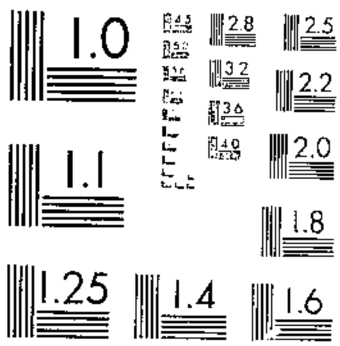

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GROWTH IN SELECTIVELY CUT PONDEROSA PINE FORESTS OF THE PACIFIC NORTHWEST

BY

WALTER H. MEYER
Associate Silviculturist
Pacific Northwest Forest Experiment Station
Branch of Research, Forest Service

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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INTRODUCTION

Forests of ponderosa pine (*Pinus ponderosa* Lawson)[1] cover a larger total area than those of any other conifer of the western United States. They occur in all the States west of the Great Plains and are the prevailing forest cover in eastern Oregon, eastern Washington, and parts of Montana, Idaho, Utah, Arizona, New Mexico, California, and South Dakota. In eastern Washington and eastern Oregon alone the area in this type is estimated at close to 10,000,000 acres, or almost 40 percent of the entire forested area in the two States. Of this total about 7,500,000 acres is located in Oregon and about 2,500,000 acres in Washington. The national forests of the two States contain the following areas of ponderosa pine timber: Oregon, 3,095,000 acres,

[1] Until 1931 the official common name for this species was western yellow pine.

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merchantable and 94,000 acres immature; Washington, 716,000 acres merchantable and 13,000 acres immature (*34*).[2]

According to Forest Service estimates made in 1930, ponderosa pine timber amounts to 15,000,000,000 board feet in Washington and 79,000,000,000 board feet in Oregon, forming 14 percent of the volume of timber of all species in the two States. This proportion is second only to that formed by Douglas fir. The ponderosa pine timber in Washington and Oregon constitutes about 38 percent of the entire stand of this species in the United States, estimated by the Forest Service in 1932[3] at 250,000,000,000 board feet.

Between 1911 and 1925 the annual cut of ponderosa pine rose in Oregon from 186,000,000 board feet to 1,000,000,000 board feet, and in Washington from 185,000,000 board feet to 441,000,000 board feet. At the present time, the annual cut in average years may be estimated roughly at 1,000,000,000 board feet for Oregon and 400,000,000 board feet for Washington. The present average cut in the two States amounts to 47 percent of the total average national cut of the species. (An additional 37 percent is contributed by the two neighboring States of California and Idaho.)

The general extent of the ponderosa pine forests in the Pacific Northwest[4] is shown in figure 1.

PURPOSE OF THE STUDY

The statistics just given indicate in a broad way the great extent of the ponderosa pine forests of Oregon and Washington and their industrial importance both to the two States themselves and to the Nation at large. If the industries dependent on these forests are to be perpetuated it will be necessary to adopt logging and silvicultural practices such as will provide against the present and potential forest lands' becoming depleted or unfit to produce further timber crops. The purpose of the present study is to answer questions on only one phase of this general problem, namely, the growth rates and yields that can be expected in managed ponderosa pine forests. This subject includes the producing capacity of forests that have been cut selectively and the relative practicability of different methods of cutting. The report gives rates of growth for reserve stands varying widely in volume, from those left by a practically clean cut to those constituting more than 50 percent of the original volume. It also provides means whereby the growth rates of uncut stands may be estimated. It discusses briefly the essential factors affecting the growth and yield of uneven-aged stands. It treats in some detail of the development of the single tree, showing the effect of such factors as tree class, site quality, and release distance.

THE FOREST

Excellent descriptions of the characteristic forms of ponderosa pine forests in the Pacific Northwest and other regions have been given in previous publications (*11, 16, 26, 28, 31, 36*). The typical ponderosa pine forest of the Pacific Northwest is fairly pure, fairly open, and many-aged. Over large areas it is absolutely pure. Among the more

[2] Italic numbers in parentheses refer to Selected References, p. 40.
[3] UNITED STATES DEPARTMENT OF AGRICULTURE, FOREST SERVICE. THE FOREST SITUATION IN THE UNITED STATES: A SPECIAL REPORT TO THE TIMBER CONSERVATION BOARD. 40 p. 1932. [Multigraphed.]
[4] "Pacific Northwest" in this bulletin refers to Washington and Oregon only.

common associates, which vary in importance in different parts of the region, are lodgepole pine (*Pinus contorta* Loudon), sugar pine (*P. lambertiana* Douglas), white fir (*Abies concolor* Lindley and Gordon), lowland white fir (*A. grandis* Lindley), Douglas fir (*Pseudotsuga taxifolia* (Lamarck) Britton), and western larch (*Larix occidentalis* Nuttall). Associates of lesser importance are incense cedar (*Libocedrus*

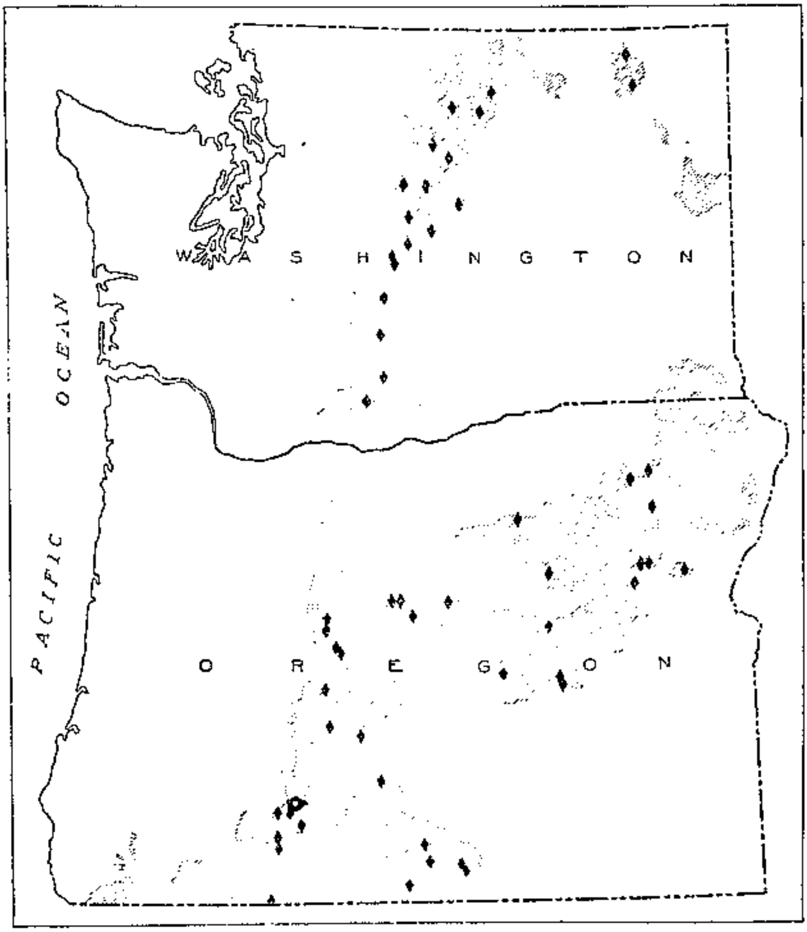


FIGURE 1.—Distribution of forests in Oregon and Washington in which ponderosa pine is the dominant species, and the location of areas studied in the investigation of growth. (Each dot represents one or more plots.)

decurrens Torrey), western red cedar (*Thuja plicata* D. Don), western juniper (*Juniperus occidentalis* Hooker), and Rocky Mountain red cedar (*J. scopulorum* Sargent).

Not all the component species listed are represented in equal degree in each part of the region; most of them occur to a varying extent and in some localities not at all. For instance, sugar pine and incense cedar are found only in the southern part near the Rogue River, Deschutes, and Fremont National Forests; western red cedar, only in the north on the Colville Forest; lodgepole pine, Douglas fir, and white fir, throughout but in widely varying quantities; and western larch, from the Blue Mountains and the Mount Hood National Forest north. The mixture varies greatly between the lowest portion of the ponderosa pine zone, adjacent to the desert, and the uppermost portion, which adjoins a zone occupied by more mesophytic forest types.

The pure stands are estimated to contain approximately 75 percent of all the commercial ponderosa pine timber in the region.

Uneven age is another outstanding characteristic of the ponderosa pine forest of the Northwest. Single scattered mature or overmature trees are continually dropping out and being replaced by groups of young trees. On most areas every age class from 1 year to 350 years or more is present. In nearly every stand seedlings are starting, saplings and poles are established singly or in clumps, and advance bull pines [5] and mature and overmature trees are scattered throughout. Typical age composition is illustrated in table 1. The counts given in the table are not complete, since they do not include the young unmerchantable trees and the reproduction classes, which may far outnumber the trees of merchantable sizes. A number of stumps with rotten or fractured centers, also, are omitted.

TABLE 1.—*Age composition of typical ponderosa pine stands*

Age class (years)	Number of stumps counted [1]		Age class (years)	Number of stumps counted [1]		Age class (years)	Number of stumps counted [1]	
	Area of 40 acres near Embody, Oreg.	Area of 26.17 acres near Bend, Oreg.		Area of 40 acres near Embody, Oreg.	Area of 26.17 acres near Bend, Oreg.		Area of 40 acres near Embody, Oreg.	Area of 26.17 acres near Bend, Oreg.
60–79	----------	1	260–279	23	83	440–459		8
80–99	----------	6	280–299	24	40	460–479		4
100–119	6	15	300–319	18	19	480–499		2
120–139	21	113	320–339	21	21	500–519	23	2
140–159	45	115	340–359	16	14	520–539		2
160–179	37	9	360–379	5	17	540–559		1
180–199	42	20	380–399	3	19	560–579		1
200–219	27	32	400–419	7	9			
220–239	30	23	420–439	3	3	Total	400	698
240–259	40	110						

[1] So far as possible, age class was determined for every stump present on the areas.

The fact that the relative representation of the age classes varies widely complicates the problems of management and cutting. Growth and mortality rates depend greatly upon age, as upon dominance and spacing. Marking practice that is not properly adapted to age composition leads to low rates of growth and high rates of mortality. Each stand is a special problem. In some stands the most practical and economical cutting method leaves a reserve volume of not more than 15 percent; in others it leaves 50 percent of the original volume.

Openness of the stand is a third characteristic of the usual ponderosa pine forest. Munger (*26*), Korstian (*18*), Krauch (*23*), and others in published and unpublished reports give instances of the relatively small number of trees per acre. In most of the stands in Oregon and Washington, trees of merchantable size number only 10 to 35 per acre. Behre (*7, 8*) shows that the fully stocked even-aged stand at 150 years of age and on a site comparable to the average eastern

[5] In the Pacific Northwest ponderosa pine trees less than about 150 years of age are called "bull pine", a term comparable to the "blackjack" of other regions. They have rough black bark, pointed crowns, and a good rate of growth. Mature trees are commonly called "yellow pine", because of the yellowish color of their bark.

Oregon site contains about 104 trees 12 inches or more in diameter per acre. At 250 years a fully stocked even-aged stand on such a site contains about 80 or 85 trees of this size per acre.

In the even-aged stand, especially if it is fully stocked, the yields per acre are much higher than in the uneven-aged stand and there is a richer, denser flora and a thicker, more complete mantle of litter and humus. In the open uneven-aged stand, the action of the sun and wind hinders the development and continuance of such conditions.

Much of the ponderosa pine timber forms an intermediate type between mixed coniferous forests and desert. Although the pine can grow where the annual precipitation is as low as 17 or 18 inches, heavy mortality sometimes occurs locally during periods of drought. Previously the openness of the stands was considered to be principally the result of damage by fire and insects. The experience of the past few years has shown that drought is an equally important cause. The even-aged stand is less likely to occur on areas where rainfall is deficient than in the upper ranges of the pine belt next to the areas occupied by the mixed conifer type, where rainfall is not a limiting factor.

METHODS OF CUTTING

Ponderosa pine, like other pines in general, responds well to many different silvicultural practices. At the beginning of national-forest management in the ponderosa pine type, the Forest Service adopted a type of cutting (*10*) that approximated a heavy grade of selection cutting. In different regions and at different times the cutting had characteristics of tree selection, of group selection, and of shelter-wood cutting. Marking instructions often stipulated that the faster growing trees and the trees less subject to windfall and insect damage be left. Emphasis was placed now and again upon one consideration or another such as spacing or type of tree, but in essence the principle remained the same. At present, in uneven-aged ponderosa pine stands on the national forests and the Indian reservations a system of partial cutting is employed that leaves from 15 to 30 percent of the merchantable volume for accelerated increment and insurance of seed supply and as the basis of a later cut after an interval of 40 to 75 years. A stand cut according to this system is shown in plate 1.

Cuttings made on privately owned land have in many instances constituted an unintentional selection cutting or culling. Several lumber companies have recently raised their diameter cutting limit and as a result are leaving reserve stands that, although of a lighter grade than those left under Forest Service practice, will form the nucleus of a later cut.

Careful protection of partially cut stands from fire assures a future merchantable stand, the time of the next cut depending largely upon the volume of the original reserve stand and upon market conditions.

The Forest Service cuttings just described will be called selection cuttings in the following discussion, although in a strict sense they cannot be so classified. This method of cutting will result in elimination of the older age classes within one or two cycles, conversion to younger and younger ages, and, probably, final transition into an even-aged stand. Increasing the percentage of reserve volume will postpone this final conversion; but unless present marking practice is greatly modified, a true selection forest with a wide range of age classes will not be maintained indefinitely.

The heavier the cut, the younger and the smaller will the reserve trees be. The average growth rate will be greater, because of the more responsive characteristics and increased growing space of the individual reserve trees. On areas heavily cut, however, the total volume growth per acre may not be sufficient to permit a later cut early enough or large enough to be profitable. In order to plan a cutting operation with a view to producing a successful later cut, one must be able to estimate the growth of the trees and the yields per acre.

METHODS USED IN FORMER STUDIES OF GROWTH IN SELECTIVELY CUT STANDS

Since the usual selectively cut forest of ponderosa pine is complex in character, with various age classes, tree classes, spacings, and increment and mortality rates, the prediction of its growth and yield is not a simple and clear-cut process. A number of methods have been used, each having certain distinct advantages and also certain disadvantages. These methods, which are more or less interrelated and all of which are based on measurement of the single tree, can be grouped under four general headings:

(1) Permanent sample plots, as used by Dunning (*13*), Korstian (*18*), and Krauch (*23*).
(2) Diameter accretion. Krauch (*20, 22, 23*).
(3) Growth percentage. Hanzlik (*17*), Dunning (*12*).
(4) Reserve-stand growth, based upon reconstructed temporary sample plots. Meyer.[6]

Although the permanent sample plot method gives the most accurate information for small areas and this information is directly applicable to areas where conditions are similar, it requires long periods to yield reliable results. Prolonged growth cycles and epidemics must be experienced before average effects are determinable. In addition, permanent sample plots at the most can actually represent only a small portion of the total region. It would be an enormous if not impossible task to cover by this method all the essential varieties of condition and stocking. Besides, if successful management plans are to be laid it is imperative to make the growth calculations at the present time, before the stands are cut.

The diameter-accretion method can be based upon permanent sample-plot data, but can equally well be based upon increment borings. To apply this method, a stand tally is needed. The more detailed the tally, the better will be the result, because trees that are of the same diameter class but differ as to age, dominance, and crown class grow at different rates, respond differently to release, and vary in mortality.

Growth-percentage methods, although they appear to be among the simplest, have a number of weaknesses and are opposed by many investigators. Growth percentages can be applied either to stand tallies or to the stand as a whole. One of their weaknesses is that with variation in size of tree a growth percentage comes to mean totally different absolute volume growth. For small fast-growing trees the growth-percentage curve falls so rapidly that a highly inaccurate result is obtained unless the time and size elements are very carefully considered.

[6] MEYER, W. H. PRELIMINARY ALINEMENT CHARTS FOR DETERMINING GROWTH IN SELECTIVELY CUT STANDS OF WESTERN YELLOW PINE. Pacific Northwest Forest Expt. Sta. Forest Research Notes, No. 6, 9 p., 1931. [Mimeographed.]

Each of the four methods outlined has advantages over other methods at certain times and in certain places. For this reason the basic tables of growth rates of the single tree are included in this report, in the section beginning on page 37.

METHODS USED IN THIS STUDY

In the present study an attempt is made to incorporate the virtues of several methods. In the initial computations diameter-accretion data, stand tables, plot records, and the like were combined. The result was a compound set of average values which show growth and yield, on the acre basis, according to the volume of the reserve stand. Then an analysis was made, one by one, of the factors that cause a departure of growth from the average, and methods were developed of correcting growth and yield estimates for these factors.

The basic data of this study were gathered in the course of the field seasons of 1928, 1929, and 1930, in eastern Oregon and eastern Washington. Measurements were made on 179 temporary sample plots in selectively cut stands. The location of each group of sample plots used in the study is given in figure 1 and in table 2, which gives also their acreage and their distribution as to site quality and age of cutting. The plots were located in representative stands scattered from southernmost Oregon to northernmost Washington and from the Cascade Range to the eastern boundaries of the two States. The extreme southwestern part of Oregon was excluded from the study because the ponderosa pine stands occurring there are of a different character from those typically occurring under average conditions in the central and eastern portions of the States, resembling rather the mixed pine forests of northern California.

TABLE 2.—*Summary of data by locality and site quality of plots and by age of cuttings*

DISTRIBUTION OF PLOTS BY LOCALITY

State	Vicinity of—	Number of plots	Acreage of plots
Oregon	Deschutes National Forest	31	45.76
	Rogue River National Forest	25	42.07
	Fremont National Forest	35	43.13
	Ochoco National Forest	13	18.75
	Malheur National Forest	6	10.00
	Whitman National Forest	18	30.75
	Umatilla National Forest	4	10.25
Washington	Yakima Indian Reservation	2	6.50
	Snoqualmie National Forest	18	35.60
	Wenatchee National Forest	15	37.00
	Chelan National Forest	9	28.75
	Colville National Forest	3	10.25
Total		179	327.81

DISTRIBUTION OF PLOTS BY SITE QUALITY AND BY YEARS SINCE CUTTING

Years since cutting	Number of plots, by site quality				
	II	III	IV	V	Total
10–19	4	9	34	13	60
20–29		7	31	16	54
30–39		6	26	9	41
40–49		3	11	2	16
50–59			7		7
60–69			1		1
Total	4	25	110	40	179

The plots were so chosen as to represent the greatest possible variety of reserve-stand conditions, on the assumption that the combination would result in data expressing general conditions. Each plot was chosen arbitrarily to represent a certain condition, and not as a sample of average conditions for the area of which it was a part.

The sampling was restricted almost entirely to site qualities III, IV, and V. Site quality VI was omitted from the analysis because no suitable cutting areas representing this quality were found.

On each plot the growth of each tree was analyzed separately by means of increment borings. Detailed descriptions and measurements were recorded for almost 6,000 trees, including such items as diameter, total height, age, and diameter growth by 10-year intervals from 30 years before the cutting to the date of examination. A stand map was prepared, locating all trees and stumps and also the reproduction. The board-foot and cubic-foot volumes and basal area of every tree were computed for every decade after cutting and the plot volumes reconstructed. From these plot data, yield alinement charts were constructed by a method similar to that outlined by Bruce and Reineke (*9*) for stand tables.

Since the alinement charts represented the elements of age and volume only, the effect of site quality, structure, and other factors remained to be determined. For this purpose the percentage differences between actual volumes at every decade and volumes estimated on the basis of the growth charts were subjected to statistical computation.

Several elements of error are undoubtedly present. But after the accumulation of data from a large number of plots and thousands of borings some of these elements become compensative; and in this instance none of them can have led to overestimation of yields, because a conservative view was adopted where there was any choice. The results of the study are intended for use in the Pacific Northwest, and in other regions having similar conditions, until the time when permanent sample plots have given reliable and consistent results.

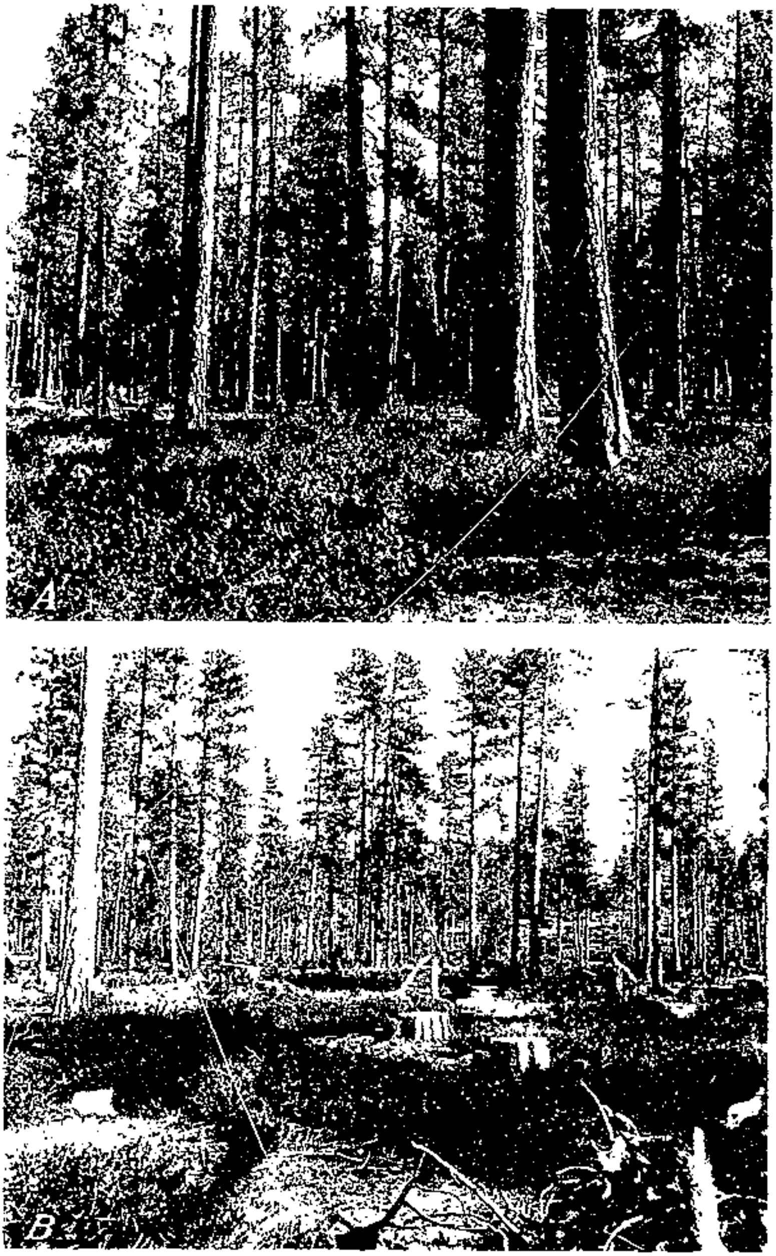
FACTORS INFLUENCING RATE OF GROWTH IN SELECTIVELY CUT STANDS

In a pure, even-aged stand only site quality, age, and stocking need be considered in predicting growth; but in a many-aged cut-over stand a number of other influences demand attention. The following factors will be discussed here, in the order given:

1. Site quality.
2. Reserve volume.
3. Tree class and stand structure.
4. Spacing and release.
5. Composition.
6. Growth cycles.
7. Length of cutting cycle.
8. Mortality.

SITE QUALITY

Every tree species is capable of enduring a wide range of site qualities, but even in the case of trees originating from the same parent tree the sizes attained depend largely upon the kind of soil, the moisture and drainage conditions, and other site features. In the ponderosa pine forests of the Pacific Northwest, the site quality of forest



A, Typical virgin forest of ponderosa pine in central Oregon. The four trees in the foreground are overmature, hence slow growing and less responsive to release than younger trees. Normally they would be removed in selection cuttings. *B*, The same forest 5 years after cutting. One of the four overmature trees was left, in order not to create a large blank in the reserve stand. The appearance of this area is similar to that of a large aggregate area of cut-over national forest land.

A, Unusually heavy reserve stand of 20,000 board feet per acre, on site quality IV. Such a stand on a site of this quality usually grows at the rate of 230 board feet per acre per year. *B*, Very light reserve stand, of about 700 board feet per acre, on private land. Practically all the trees are young and fast growing; 90 percent are of tree classes 1 and 2. With this stand structure (p. 12) the growth may be expected to be about 30 percent above the rate of 55 board feet per acre that is average for this site (IV) and stocking.

lands bearing mature timber crops is judged by the average height of the mature dominant trees. Figure 2 illustrates the classification. For the young age classes, the curves are based upon observations made by C. E. Behre in yield studies of even-aged stands in northern Idaho (*7*, *8*) and confirmed through similar unpublished studies by the author in Oregon and Washington. The central values of site qualities I, II, III, IV, V, and VI correspond to site indices 127, 112, 96, 80, 65, and 51 of Behre's classification, site index being the average height of dominant and codominant trees of even-aged stands at 100 years.

For estimating the site quality of lands occupied by uneven-aged ponderosa pine forests, the procedure is as follows:

Measure the total height, in feet, of 15 to 30 mature, dominant trees of Dunning's tree class 3 (*14*). Average these values and enter

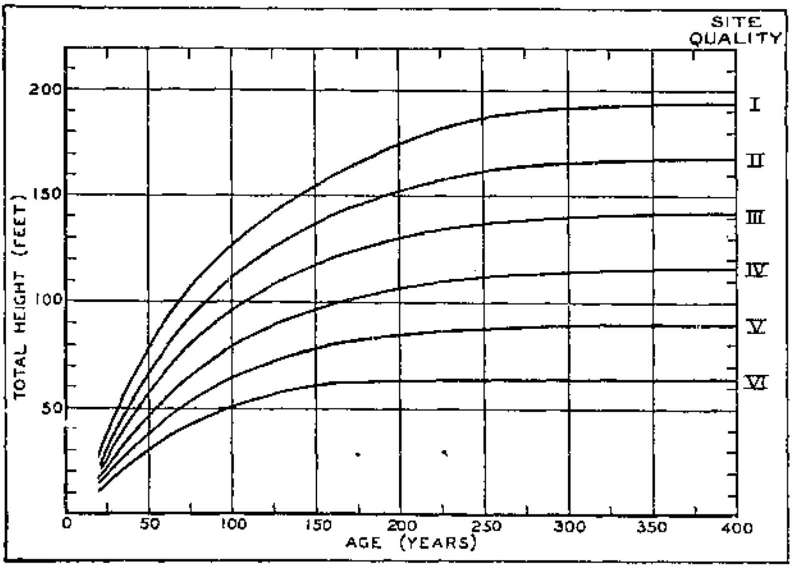


FIGURE 2.—Site-quality classification of ponderosa pine lands, based upon average total height of dominant trees.

the average value upon the chart at the approximate average age of the trees. For mature trees exact age is not necessary, since height changes little after maturity is reached. The curved line nearest to the point entered upon the chart indicates the site quality. For instance, an average height of 110 feet at maturity—about 300 years—indicates site quality IV.

For immature even-aged stands, the procedure is slightly modified. In this case the average heights of the dominant and codominant trees are taken and the exact age of the stand is found by means of stump counts or by increment borings. The height is then entered upon the chart at the determined age. If a certain even-aged stand is 75 years old and the dominant and codominant trees average 78 feet, for instance, the site quality is III.

The relations shown in figure 2 are expressed in terms of merchantable height in table 3.

TABLE 3.—*Site qualities of ponderosa pine land as defined by total height or by merchantable height of average dominant tree*

Site quality	Total height		Merchantable height at maturity, in 16.3-foot logs
	At 100 years	At maturity	
	Feet	*Feet*	*Number*
II	112	166	8 to 9.
III	96	138	7.
IV	79	114	5 to 6.
V	65	89	3 to 4.
VI	51	63	Less than 3.

In Oregon and Washington the most common site qualities of pine lands are III, IV, and V. A little land of site quality II is found in southern Oregon, and some land of site quality VI is found in the poorest situations throughout the two States. At least 75 percent of the entire pine-forest area in the two States is estimated to be of site quality IV.

RESERVE VOLUME

The volume of the reserve stand largely determines its rate of growth and its yield. On one plot, for instance, on which the reserve stand amounted to only 4,617 board feet per acre, in the 16 years after cutting the annual growth per acre averaged only 71 board feet. On a neighboring plot with the same general site conditions but with a reserve stand of 9,540 board feet per acre, the annual growth per acre during the same period averaged 134 board feet. The volume on the first area increased at the rate of 1.54 percent a year and that on the second at the rate of 1.40 percent a year. The percentage rates of growth are on the whole most rapid for the stands of small reserve, since in these stands the trees are wider spaced and usually younger. The larger the reserve, the lower is the percentage rate of growth on the whole, but the higher the absolute rate of growth. Thus in 30 years' time the average stand with an initial reserve volume of 2,000 board feet will increase to 4,000 board feet, while a stand with three times that initial reserve will increase to 8,900 board feet. The stand volume increases in the first instance by 100 percent and in the second by only 48 percent, although the annual growth rate is 67 board feet in the first as compared with 97 board feet in the second. An example of a heavy reserve stand and one of a light reserve stand are shown in plate 2.

TREE CLASS AND STRUCTURE

A system of classifying ponderosa pine trees that was introduced by Dunning (*14*) for California conditions has been generally adopted in the Pacific Northwest and other regions. It distinguishes seven types of trees, which are illustrated in figure 3. Dunning's descriptions of the different tree classes are as follows:

Class 1. Age class, young or thrifty mature; position, isolated or dominant (rarely codominant); crown length, 65 percent or more of the total height; crown width, average or wider; form of top, pointed; vigor, good.

Class 2. Age class, young or thrifty mature; position, usually codominant (rarely isolated or dominant); crown length, less than 65 percent of the total height; crown width, average or narrower; form of top, pointed; vigor, good or moderate.

Class 3. Age class, mature; position, isolated or dominant (rarely codominant); crown length, 65 percent or more of total height; crown width, average or wider; form of top, round; vigor, moderate.

Class 4. Age class, mature; position, usually codominant (rarely isolated or dominant); crown length, less than 65 percent of the total height; crown width, average or narrower; form of top, round; vigor, moderate or poor.

Class 5. Age class, overmature; position, isolated or dominant (rarely codominant); crown of any size; form of top, flat; vigor, poor.

Class 6. Age class, young or thrifty mature; position, intermediate or suppressed; crown of any size, usually small; form of top, round or pointed; vigor, moderate or poor.

Class 7. Age class, mature or overmature; position, intermediate or suppressed; crown of any size, usually small; form of top, flat; vigor, poor.

In the field, if the classification is observed strictly it may seem that a large proportion of the trees are border-line specimens. After a

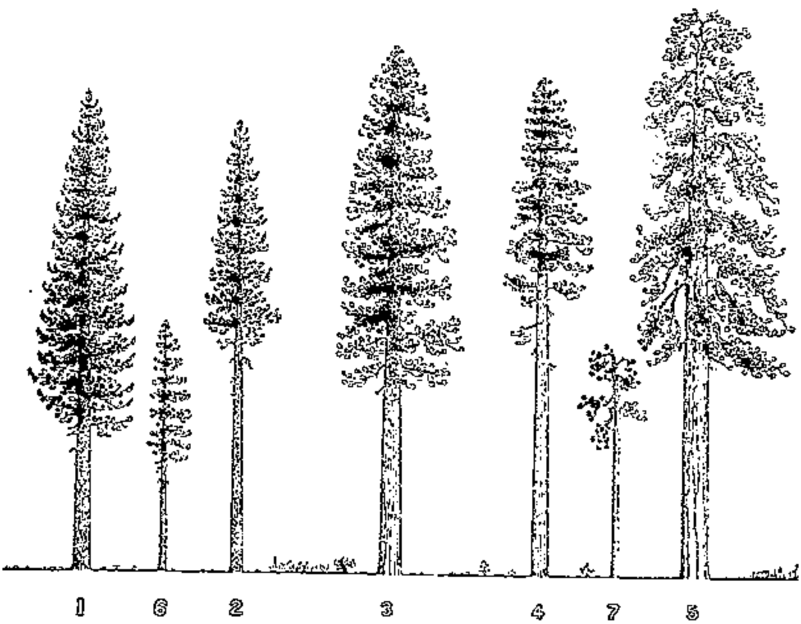


FIGURE 3.—Tree classes in uneven-aged stands of ponderosa pine, as defined by Dunning.

little practice with an experienced estimator, however, the determination is easily made at a glance. In border-line cases age and vigor are given more weight than some of the other factors.

On site quality IV in Oregon and Washington, in the virgin stands tree class 1 has the best growth rate and is followed as a rule by the other classes in this order: 2 and 3, 4, 5 and 6, 7. In selectively cut stands, although the trees respond individually to release according to spacing, tree class, and diameter, the rank of tree classes as to growth is little changed from that in the uncut forest, being 1, 3, 2, 4, 6, 7, 5.

In rate of mortality, these tree classes have been ranked by Dunning for California conditions as follows, with the least susceptible first: 1, 6 and 3, 2, 5 and 4, 7. Studies by the Division of Forest Insects, Bureau of Entomology, discussed on pages 30–31, have revealed a more complicated ranking, shown in table 15.

The composite of the proportion of each of the seven tree classes in a stand is indicated in this report by the term "structure." A perfect expression of structure would cover all tree classes, but a compound factor of this nature would be too unwieldy for practical use. Thorough investigation of the influence of each tree class and of groups of tree classes upon the rate of growth of the stand has shown that the percentages of cubic-foot volume or of basal area contained

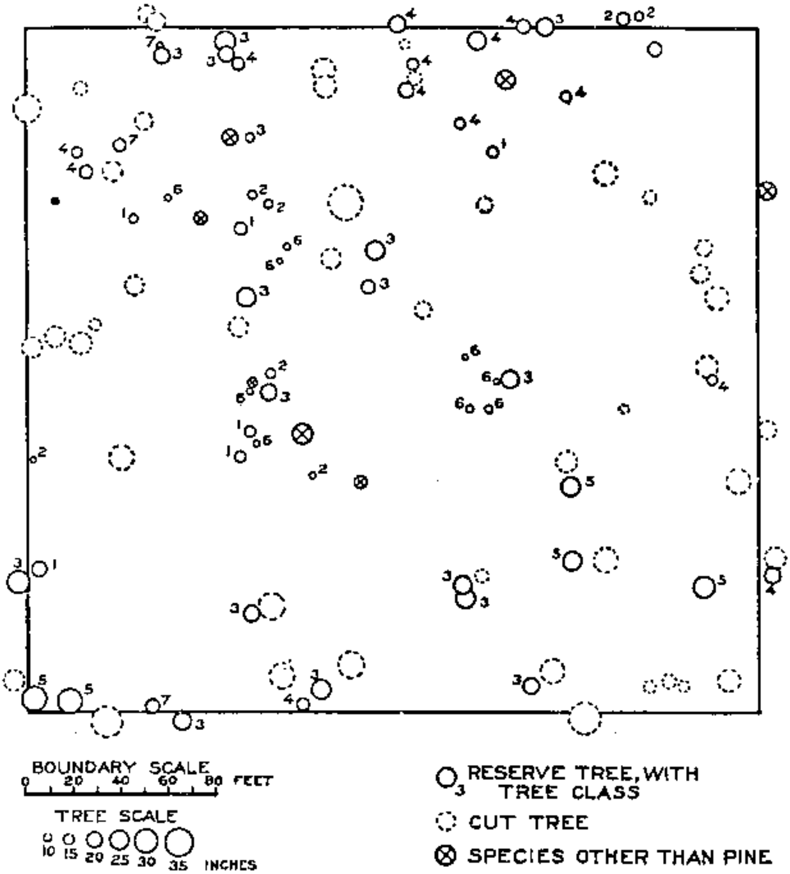
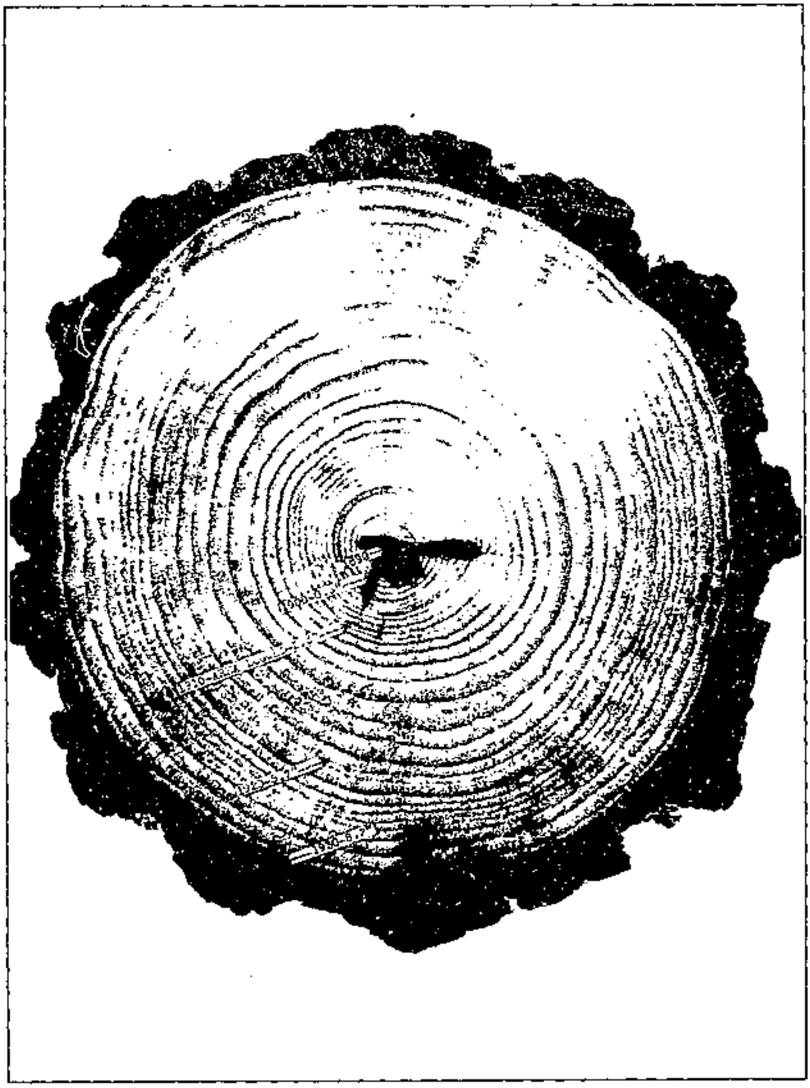


FIGURE 4.—Reserve stand unsatisfactorily spaced and containing an unusual percentage of old trees, which showed growth somewhat below average for selectively cut stands. Sample plot no. 52, Odessa, Oreg. Original stand per acre (of pine only), 24,600 board feet; original reserve per acre, 8,360 board feet; volume per acre 20 years after cutting, 10,833 board feet.

in tree classes 1 and 2 on the one hand and in tree class 3 on the other hand exert the most powerful influence upon volume growth next to site quality and total volume of the reserve stand. These two groups include three of the fastest-growing tree classes. The larger the percentage of tree classes 1 and 2 in relation to the percentage of all other classes, the faster is the growth. The larger the percentage of tree class 3 in relation to the percentage of all other classes, also, the faster is the growth, but in this instance the effect is less pronounced.

In this study, structure is expressed in terms of the percentages of the stand composed by these two groups of tree classes. The struc-



Cross section of the stem of a ponderosa pine tree released from competition by selective cutting in 1900, when it was 20 years old. During the first 2 years after release the thickness of the growth rings increased slightly. A marked acceleration in growth then began, and increased growth continued until the tree was cut in 1930.

ture expression 25–50, as an example, means that of the total cubic-foot volume or basal area of the stand 25 percent is composed of tree classes 1 and 2 and 50 percent of tree class 3.

SPACING AND RELEASE

The effect of release upon the growth of ponderosa pine has been measured frequently (*12, 13, 14, 18, 22, 24, 26, 29*),[7] and the results stated both in absolute growth rates and in percentage of acceleration. For the purposes of this study percentage of acceleration is hardly to the point, since all the computations have been made in absolute values.

It must be remembered that the removal of part of the stand in the general vicinity of a given tree does not invariably constitute release and cause acceleration in the tree's rate of growth. To be susceptible of release, a tree must be in actual competition with other trees for moisture and nutrients.

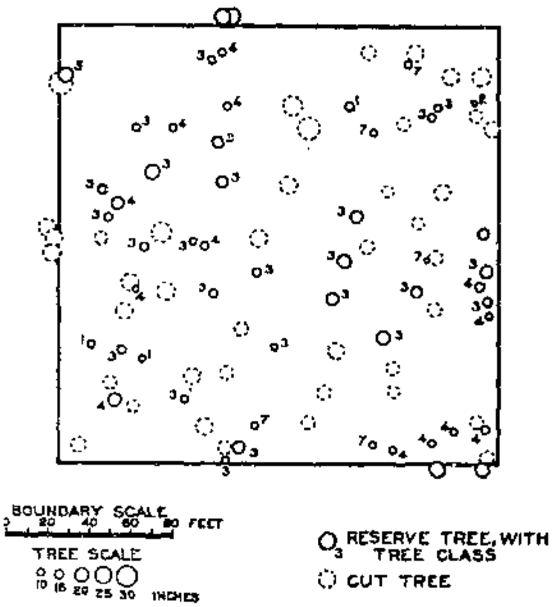


FIGURE 5.—Stand composed chiefly of immature and young mature trees, in which extraordinarily complete release conditions resulted in a yield far above average for selectively cut stands. Sample plot no. 128, near Starkey, Oreg. Original stand per acre, 27,128 board feet; original reserve per acre, 7,001 board feet; volume per acre 32 years after cutting, 14,760 board feet.

The growth acceleration resulting from release varies somewhat according to the condition and vigor of the tree. The most vigorous trees respond almost immediately to a slight extent; their growth accelerates for about 5 years and then maintains a new level for several decades, unless other factors destroy the balance. A cross section of a ponderosa pine tree showing marked acceleration in growth after release appears as plate 3. Figure 4 shows a reserve stand containing an unduly large proportion of old trees and unsatisfactorily spaced, the growth of which in the 20 years following cutting was below average for selectively cut stands. Figure 5 shows in contrast with this a stand in which the trees reserved were principally immature or in an early stage of maturity and release was extraordinarily complete, and which in the 32 years following cutting grew at a rate much above average. Figure 6 illustrates the progress of growth in a stand that was selectively logged in 1898; of 10 sample trees, all except 1 responded to a certain degree within 2 years, and the growth rate increased rapidly for several years with variations between climatically favorable and unfavorable years. The marked decline in radial growth starting about 1917 was due not to a cessation of the effect

[7] MEYER, W. H. See footnote 6.

of release but to a period of generally unfavorable climatic conditions, which is reflected in the growth rates of ponderosa pine throughout the Pacific Northwest. In a period of average climatic conditions, growth increase due to release can be expected to persist for 40 years or more.

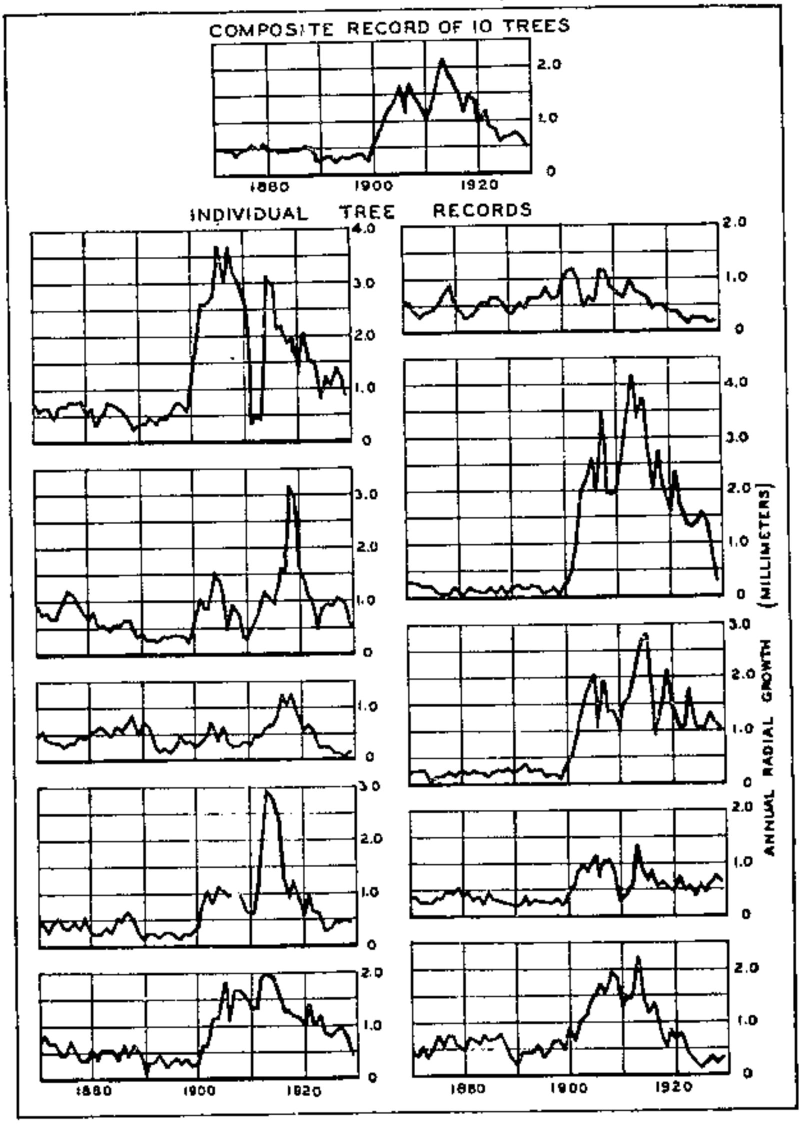


FIGURE 6.—Progress of growth following release in a ponderosa pine stand logged in 1898, as shown by the radial growth of 10 trees separately and combined.

Removal of a single sizable tree from a clump has a beneficial effect on the surrounding trees with which it has been competing directly for nutrients, soil moisture, and, to a lesser degree, light.

The distance to which release is effective varies somewhat with tree class and with site quality. In general (see table 21), trees that have been liberated on one or more sides within a distance of 40 feet on site qualities III and IV show approximately the same acceleration in growth rate as other trees of the same class released on the same number of sides and within that distance. Acceleration is discernible in trees released at distances as great as 50 feet or sometimes even greater.

COMPOSITION

Several of the species commonly found in mixture with ponderosa pine, such as white fir, Douglas fir, and sugar pine, grow faster than ponderosa pine, but do not respond so readily to release (*13*). Others, such as western larch, grow at approximately the same rate as ponderosa pine and still others, such as lodgepole pine and juniper, grow more slowly. The effect of mixture upon the accelerated growth rate of the stand depends therefore entirely upon what species contribute to the mixture. The tables developed in this study apply very well to the ponderosa pine of mixed stands in which other species constitute not more than 25 percent of the total volume, and their application even to the total volume of all species in such stands is well within the acceptable limits of error.

GROWTH CYCLES

It is not an easy matter to evaluate climate and growth relationships, especially the occurrence, intensity, and extent of climatic cycles as shown by tree-ring patterns. So numerous are the factors that can affect the rate of tree growth, so involved is the history of a forest stand, that the final ring pattern of a single tree is highly individualistic. Tree-ring patterns record certain major events in the life history of the stand, but rarely agree throughout a stand in any marked degree. Only agreement in general ring-pattern characteristics in tree after tree and on area upon area can be taken as evidence of general climatic changes.

In searching for evidence of growth cycles in the ponderosa pine region of the Pacific Northwest it was impossible to cover all the available data, taken from some 8,000 increment cores; it was therefore decided to choose arbitrarily 24 localities representative of the region and in each of these to select a few cores of mature trees, usually 10, for examination. In case evidence of growth cycles was found, the plan was to endeavor to determine whether they were sufficiently distinct to affect yield predictions and how regularly they could be expected to recur during the interval between successive cuts. Whether a separate correction for climatic cycles had to be introduced into the growth predictions depended upon the results of this determination.

If this growth study had been made 10 years earlier, the importance of this information might not have been appreciated. Soon after the inception of the study, evidence was found of a major reduction in growth rate extending over a number of recent years. As more and more areas were investigated, it became increasingly certain that this retardation of growth was well defined over the two States. The period of retarded growth seemed in a general way to start about 1917; on some areas it did not begin until several years later, and on a very few areas the retardation was hardly observable. If this phenomenon recurs repeatedly, at regular or irregular intervals, as a phase of a natural sequence, yield predictions extending over a long span of years should take into account periods of slow growth as well as periods of good growth. The inclusion or noninclusion of the period of slow growth therefore hinges upon the existence or nonexistence of growth cycles.

The method of dealing with the data is shown in figure 7. The curves shown in the chart indicate that there was a wavelike pro-

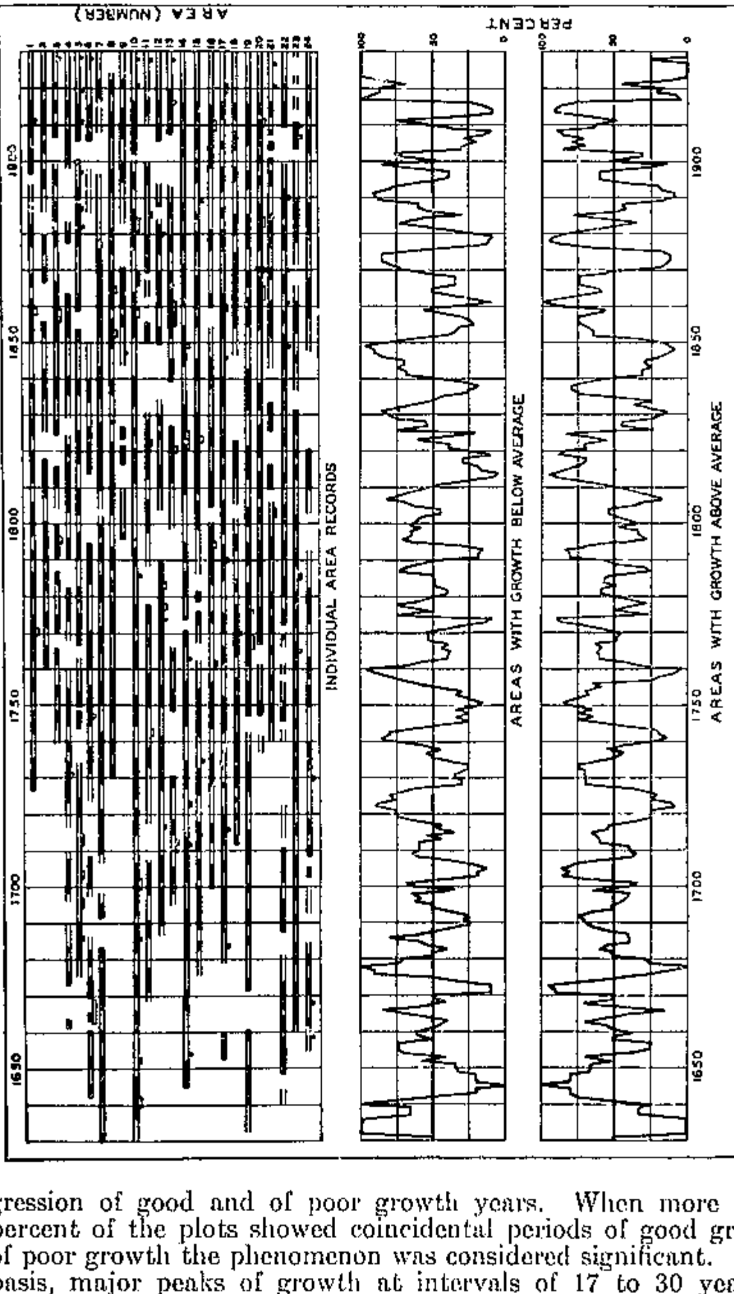


FIGURE 7.—Periods of poor and of good growth on 24 areas widely distributed through central and eastern Oregon and Washington. Black bars represent periods of good growth. Unfilled bars represent periods of poor growth. Blanks represent indeterminate growth. Curves represent occurrence of poor and of good annual growth, expressed in percentages of the whole number of plots for which periods of poor or good growth were determinable.

gression of good and of poor growth years. When more than 50 percent of the plots showed coincidental periods of good growth or of poor growth the phenomenon was considered significant. On this basis, major peaks of growth at intervals of 17 to 30 years were distinguished. These are listed in table 4.

TABLE 4.—*Peaks of good growth and of poor growth in ponderosa pine forests of Oregon and Washington* [1]

Major peaks of poor growth				Major peaks of good growth			
Approximate dates	Interval in years	Approximate dates	Interval in years	Approximate dates	Interval in years	Approximate dates	Interval in years
1633	.....	1807	19	1645	.....	1814	21
1655	22	1831	24	1673	28	1838	24
1678	23	1849	18	1692	19	1861	23
1701	23	1873	24	1705	13	1878	17
1722	21	1891	18	1733	28	1908	30
1741	19	1924	33	1751	18		
1760	19			1774	23	Average	21.9
1788	28	Average	22.4	1793	19		

[1] Table based on increment-core data for 24 areas, representing in general 10 trees on each area.

The locations of the areas on which the increment-core data presented in figure 7 and table 4 were taken are as follows: 1, Pokegama, Oreg.; 2, Odessa, Oreg.; 3, Lakeview, Oreg.; 4, Lakeview, Oreg.; 5, Lakeview, Oreg.; 6, Lakeview, Oreg.; 7, Silver Lake, Oreg.; 8, Fort Rock, Oreg.; 9, Sisters, Oreg.; 10, Prineville, Oreg.; 11, Ochoco National Forest, Oreg.; 12, Malheur National Forest, Oreg.; 13, Austin, Oreg.; 14, Sumpter, Oreg.; 15, North Powder, Oreg.; 16, Starkey, Oreg.; 17, Heppner, Oreg.; 18, Yakima Indian Reservation, Wash.; 19, Wenas, Wash.; 20, Cle Elum, Wash.; 21, Wenatchee, Wash.; 22, Wenatchee Lake, Wash.; 23, Chelan, Wash.; and 24, Knowlton, Wash.

An average interval of approximately 22 years between major peaks of good growth or of poor growth is indicated. Each of these periods includes several subsidiary fluctuations. As compared with the cycle averaging 22 years, this minor cycle shows a much greater variation. Its recurrences are shown in table 5.

TABLE 5.—*General periods of good and of poor growth in ponderosa pine forests of Oregon and Washington*

Approximate dates	Approximate duration, in years	Character of growth	Approximate dates	Approximate duration, in years	Character of growth
1630–42	13	Below average (except 1637–38).	1776–79	4	Below average.
1643–53	11	Above average.	1780–85	6	Above average.
1654–59	6	Below average.	1786–88	3	Below average.
1660–63	4	Above average.	1789–94	6	Above average.
1664–67	4	Below average.	1795–1810	16	Below average (except 1803–4)
1668–74	7	Above average.	1811–26	16	Above average.
1675–87	13	Below average (except 1684).	1827–34	8	Below average.
1688–94	7	Above average.	1835–40	6	Above average.
1695–1701	7	Below average.	1841–51	11	Below average.
1702–7	6	Above average.	1852–68	17	Above average.
1708–12	5	Below average.	1869–75	7	Below average.
1713–16	4	Above average.	1876–81	6	Above average.
1717–27	11	Below average.	1882–94	13	Below average (except 1885).
1728–38	11	Above average.	1895–97	3	Above average.
1739–44	6	Below average.	1898–1902	5	Below average.
1745–55	11	Above average.	1903–16	14	Above average.
1756–62	7	Below average.	1917–30	14	Below average.
1763–65	3	Above average (except 1768–70).			

Tables 4 and 5 represent only general tendencies, evidence of which appeared on the majority of the 24 areas. The data presented in them are based on about 217 ring patterns, no one of which was exactly identical with any other. These data establish the fact that a growth cycle having a duration of approximately 22 years occurs in the Pacific Northwest ponderosa pine region. This cycle tends to recur about three times during a 60-year cutting cycle, and should therefore be taken into account in growth estimates. It has been taken into account in this study. Hence the rates that were derived are adapted to long-term predictions. Should the term be short or overlap a partial cycle, the chances are that the prediction will be somewhat low, since the recent period of slow growth has been observed to be one of the most extreme in the entire record.

LENGTH OF CUTTING CYCLE

The length of the cutting cycle, or the interval between cuts, has a subordinate effect upon the average rate of growth, since in a selectively cut stand where many trees have been released the growth rate reaches a maximum in the second decade after cutting and then gradually tapers off, approaching the rates previous to release. For instance, if a reserve stand of 2,000 board feet is held 30 years, the average annual increment will be 67 board feet; if it is held 60 years, the average annual increment will be only 60 board feet. (See table 8.) A reserve stand of 6,000 board feet over a period of 30 years will give 100 board feet a year, but over 60 years will give only 92 board feet a year. The decrease is much more evident when growth is expressed in diameter measurements, as in tables 18 and 19 or figure 11.

MORTALITY [5]

The factors in growth rate thus far discussed determine gross yields. Since gross yields can be utilized fully in only a few cases, it is necessary to estimate mortality and net yield. Even casual observation in the various sections of the Pacific Northwest shows that the rate of mortality is highly variable. In some sections it is so high, at least at the present time, as to cause gradual depletion of the stand. In other sections it is remarkably low. Mortality is a local factor, to be evaluated each time a new area is examined. In part this variation is due directly to variations in the proportion of susceptible classes of trees in the stand. The fact that certain tree classes are more susceptible to insect damage than others has been shown by Dunning (*14*) and Krauch (*23*). It has been shown by Weidman (*35*), and by Smith and Weitknecht (*32*), that tall, full-crowned trees, and trees standing on exposed places or lee slopes, are more likely to be wind-thrown than others.

Surface fires take their toll in the destruction of seedling and sapling growth and in the butt scarring and subsequent wind-felling of large mature trees. Experience of the past few years has taught that recurrent drought alone causes immense damage, especially on areas near the lower limits of tree growth. Over and above these effects is the effect of climatic cycles on the vigor and susceptibility of trees. Mortality rates of the past decade are probably maximum rates, because of the severe climatic conditions.

In California, damage by insects alone has created doubt as to the advisability of leaving reserve stands on the poorer ponderosa pine sites, which are comparable to the average site in the Pacific Northwest. In the Pacific Northwest, insect damage to ponderosa pine is less severe. In this region, apparently, the climatic range of

[5] Mortality is discussed at greater length in a section beginning on p. 29.

the western pine beetle (*Dendroctonus brevicomis* Lec.), the most damaging of the western bark beetles, does not include the climatic range of ponderosa pine. North of the zone of *D. brevicomis* infestation, however, occasional heavy infestations of the mountain pine beetle (*D. monticolae* Hopk.) have been observed lapping over from lodgepole pine stands into stands of ponderosa pine.

Windfall is a more important factor in ponderosa pine mortality in the Pacific Northwest than it seems to be in any other region of the United States. In this region, it has been asserted (*32, 35*), within the first 20 years after cutting as much as 25 percent of the volume may be eliminated by windfall. Even with this heavy loss, selection cuttings cannot be considered a failure. Most of the windfall occurs within the first 4 or 5 years after cutting, when some salvage is possible.

Fire can be controlled to a large extent in the ponderosa pine type, through suitable slash-disposal and other measures. Insect damage can be partially controlled by choice of trees for cutting and by systematic eradication of infested trees. Windfall can be partially controlled by removing the very tall, long-crowned trees and by cutting more heavily in exposed places than in protected places. It is plain that the mortality rates prevailing in virgin stands may be only a slight indication of the rates to which management may reduce the mortality in selectively cut stands.

PREDICTING GROWTH OF SELECTIVELY CUT STANDS

The statistical method followed in this study leads to a simple procedure in predicting growth. By means of the stand-growth tables developed in the study the gross yield for any length of cutting cycle up to 60 years is predicted on the basis of the volume of the reserve stand, the percentage of the total volume in a few selected tree classes, and the site quality. In order to arrive at the net yield, a separate adjustment is made for mortality. The reproduction stand is considered by itself, since its condition is one of the most variable features of the ponderosa pine forest.

The steps in making growth predictions can be listed as follows:

1. The forest survey, determining—
    - *a.* Area, by types.
    - *b.* Site quality.
    - *c.* Reserve volume.
    - *d.* Structure.
    - *e.* Density of reproduction.
2. Estimating average gross yields.
3. Adjusting for site quality and structure.
4. Adjusting for mortality.
5. Adjusting for number of poles.

Each of these steps will be discussed in turn, and two examples will be given illustrating the necessary computations.

THE FOREST SURVEY

The usual form of strip estimate, with slight modifications, forms the most satisfactory forest survey. Field data should be recorded separately for the various sites and types. A change in tally is not justified by a change in site or type affecting an area smaller than 20 acres. An open area such as a meadow or prairie should be treated as a separate type and in the final treatment such open areas should be deducted from the total. If it is apparent that decided variations in the reserve stand occur over large areas, these should be treated like a change in type and recorded on the map. The tree data should be recorded by type, site, diameter class, and tree class, separate records being kept for each species. Three groups of tree classes should be recognized: (1) classes 1 and 2; (2) class 3; and (3) the remaining four classes. If the survey is made before the stand is cut, the trees to be cut should be tallied separately.

Site-quality determinations should be made according to the procedure described on page 9, and where one site quality merges into another the different qualities should be blocked out.

The term "reproduction", as used in connection with the field survey, covers the established seedlings below the smallest "pole" size, 3.6 inches at breast height. This portion of the stand approximates an even-aged condition and may be treated as a modified form of an even-aged stand. The easiest way to gather information on the condition of the reproduction is the stocked quadrat system. This system as used in the Pacific Northwest consists in taking a block of four quadrats each 13.2 feet square at definite intervals along the survey line. Each quadrat is 4 milacres, or one two hundred and fiftieth of an acre. The estimator, who may be either the compassman or the tallyman, stops at regular intervals, usually of 1 chain, considers himself at the center of a block of four 13.2-foot squares, looks into one quadrat until he finds an established seedling or sapling, then into the next quadrat, and so on. If each of the four quadrats is occupied by one or more seedlings the block is given a count of 4, if only three are occupied it is given a count of 3, and so forth. When the survey is completed, these tallies are totaled and the number of occupied quadrats is expressed as a percentage of the total number observed; this percentage can then be related directly to any defined stocking classification.

After the survey has been completed in the field, the data should be computed in basal area or in various units of volume as may be desired. After the stand volume is computed, the structure factor is obtained as described on pages 12–13. For use in cases in which neither basal areas nor cubic-foot volumes are computed, but only board-foot volumes, a simple conversion from the structure percentages obtained by board-foot calculations is given in the following tabulation. The exact relationship hinges somewhat upon the average size of the trees, but the values here given will compensate on the average.

Structure percentage by board-foot volume	Corresponding percentage by basal area or cubic-foot volume
5	9
10	15
15	20
20	25
30	34
40	43
50	52
60	61
70	70
80	78

ESTIMATING AVERAGE GROSS YIELDS

In the preparation of the following series of stand-growth charts and tables, the stand was treated as a unit and as many of the factors as possible were disposed of in preliminary calculations not appearing in this bulletin.

Table 6 and figure 8 give the growth in terms of basal area, table 7 and figure 9 in terms of cubic feet, and table 8 and figure 10 in terms of board feet, Scribner rule. In the case of board-foot volume it has been assumed that the upper limit of utilization is a top diameter of 8 inches inside bark and that the lower limit is a breast-height diameter of 11.6 inches. Each table and chart gives the total stand at the end of 10, 20, 30, 40, 50, and 60 years for any reasonable size of reserve. If the reserve stand is of a size not directly given in the tables, it is much easier to use the alinement charts of figures 8, 9, and 10 than to interpolate.

The method of reading the charts is simple. First the number of years after cutting is located on the left-hand scale, then the initial reserve volume is found on the center curved scale. A straight edge spanning these two points and projecting over to the right-hand scale gives the reading for the predicted gross volume. For instance, if the average reserve volume per acre is 2,500 board feet, the reading in figure 10 is 4,700 board feet in 30 years or 6,500 board feet in 60 years.

TABLE 6.—*Basal-area growth in selectively cut stands of ponderosa pine*[1] *of average structure, site quality IV*

Basal area of reserve stand per acre							Average annual increase in basal area per acre for 60-year cycle	
At time of cutting (square feet)	After an interval of—							
	10 years	20 years	30 years	40 years	50 years	60 years		
	Square feet	*Square feet*	*Square feet*	*Square feet*	*Square feet*	*Square feet*	*Square feet*	*Percent*[2]
5	7	9	11	12	13	14	0.15	3.00
10	13	15	18	20	21	22	.20	2.00
15	18	21	24	27	28	30	.25	1.67
20	24	28	31	34	36	37	.28	1.40
25	29	33	37	40	43	44	.32	1.28
30	34	39	43	46	49	51	.35	1.17
35	39	44	49	52	55	57	.37	1.06
40	45	50	55	58	61	63	.38	.95
45	49	55	60	63	66	69	.40	.89
50	54	60	65	70	72	75	.42	.84
55	59	65	70	74	78	80	.42	.76
60	64	70	75	80	83	86	.43	.72

[1] All trees included.

[2] Simple growth percentage.

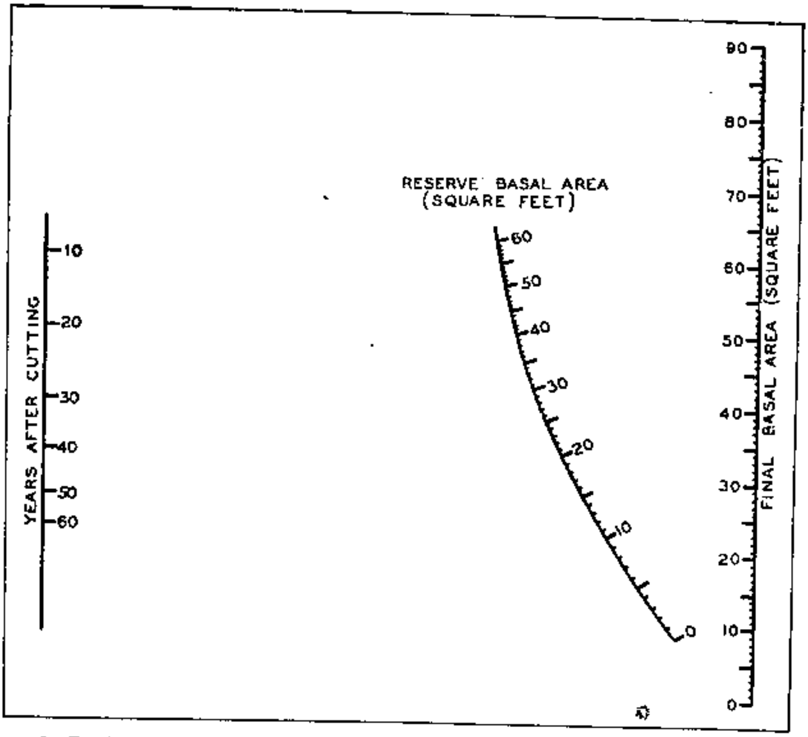


FIGURE 8.—Basal-area growth in selectively cut stands of ponderosa pine in the Pacific Northwest, site quality IV.

TABLE 7.—*Cubic-foot volume growth in selectively cut stands of ponderosa pine*[1] *of average structure, site quality IV*

Volume of reserve stand per acre							Average annual increase in volume per acre for 60-year cycle	
At time of cutting (cubic feet)	After an interval of—							
	10 years	20 years	30 years	40 years	50 years	60 years		
	Cubic feet	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Percent*[2]
200	260	330	420	490	550	660	7.7	3.85
400	500	600	720	810	900	970	9.5	2.38
600	720	840	1,000	1,110	1,210	1,300	11.7	1.95
800	920	1,060	1,240	1,360	1,470	1,570	12.8	1.60
1,000	1,150	1,320	1,500	1,640	1,770	1,890	14.8	1.48
1,200	1,350	1,530	1,730	1,890	2,030	2,150	15.8	1.32
1,400	1,560	1,750	1,970	2,140	2,300	2,430	17.2	1.23
1,600	1,780	1,980	2,200	2,390	2,540	2,700	18.3	1.14
1,800	1,990	2,200	2,440	2,640	2,800	2,950	19.2	1.07
2,000	2,200	2,420	2,690	2,870	3,040	3,220	20.3	1.02
2,200	2,410	2,650	2,920	3,120	3,310	3,490	21.5	.98
2,400	2,630	2,880	3,170	3,400	3,570	3,750	22.5	.94
2,600	2,870	3,120	3,410	3,650	3,850	4,020	23.7	.91
2,800	3,080	3,350	3,650	3,900	4,100	4,300	25.0	.89
3,000	3,320	3,600	3,910	4,150	4,370	4,610	26.8	.89

[1] All trees included.

[2] Simple growth percentage.

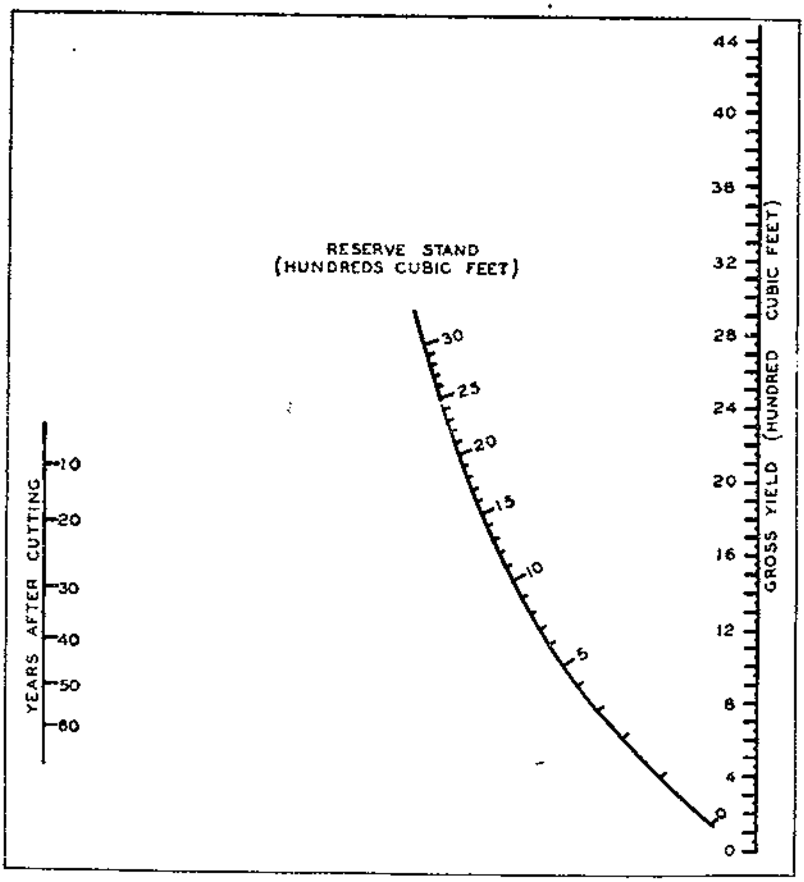


FIGURE 9.—Cubic-foot volume growth in selectively cut stands of ponderosa pine in the Pacific Northwest, site quality IV.

TABLE 8.—*Board-foot volume growth, Scribner rule, in selectively cut stands of ponderosa pine* [1] *of average structure, site quality IV*

Volume of reserve stand per acre							Average annual increase in volume per acre for 60-year cycle	
At time of cutting (board feet)	After an interval of—							
	10 years	20 years	30 years	40 years	50 years	60 years		
	Board feet	*Board feet*	*Board feet*	*Board feet*	*Board feet*	*Board feet*	*Board feet*	*Percent* [2]
1,000	1,400	1,800	2,300	2,800	3,200	3,600	43.3	4.33
2,000	2,700	3,300	4,000	4,600	5,200	6,000	60.0	3.00
3,000	3,900	4,500	5,400	6,100	6,700	7,300	71.7	2.39
4,000	4,900	5,700	6,700	7,400	8,100	8,700	78.3	1.96
5,000	6,000	6,800	7,800	8,700	9,500	10,200	88.7	1.73
6,000	7,000	7,900	9,000	9,900	10,800	11,500	91.7	1.53
7,000	8,000	9,000	10,200	11,200	12,100	13,000	100.0	1.43
8,000	9,100	10,200	11,400	12,500	13,500	14,400	106.7	1.33
9,000	10,200	11,300	12,700	13,800	14,900	16,000	116.7	1.30
10,000	11,300	12,500	14,000	15,300	16,400	17,500	125.0	1.25
11,000	12,300	13,600	15,100	16,400	17,700	18,800	130.0	1.18
12,000	13,300	14,700	16,300	17,800	19,200	20,300	138.3	1.15
13,000	14,300	15,800	17,600	19,200	20,600	21,800	146.7	1.13
14,000	15,400	17,000	19,000	20,600	22,100	23,400	156.7	1.12
15,000	16,500	18,300	20,300	22,100	23,700	25,100	168.3	1.12
16,000	17,800	19,700	21,900	23,700	25,600	27,000	183.3	1.15

[1] All trees 11.6 inches or more in diameter at breast height included.
[2] Simple growth percentage.

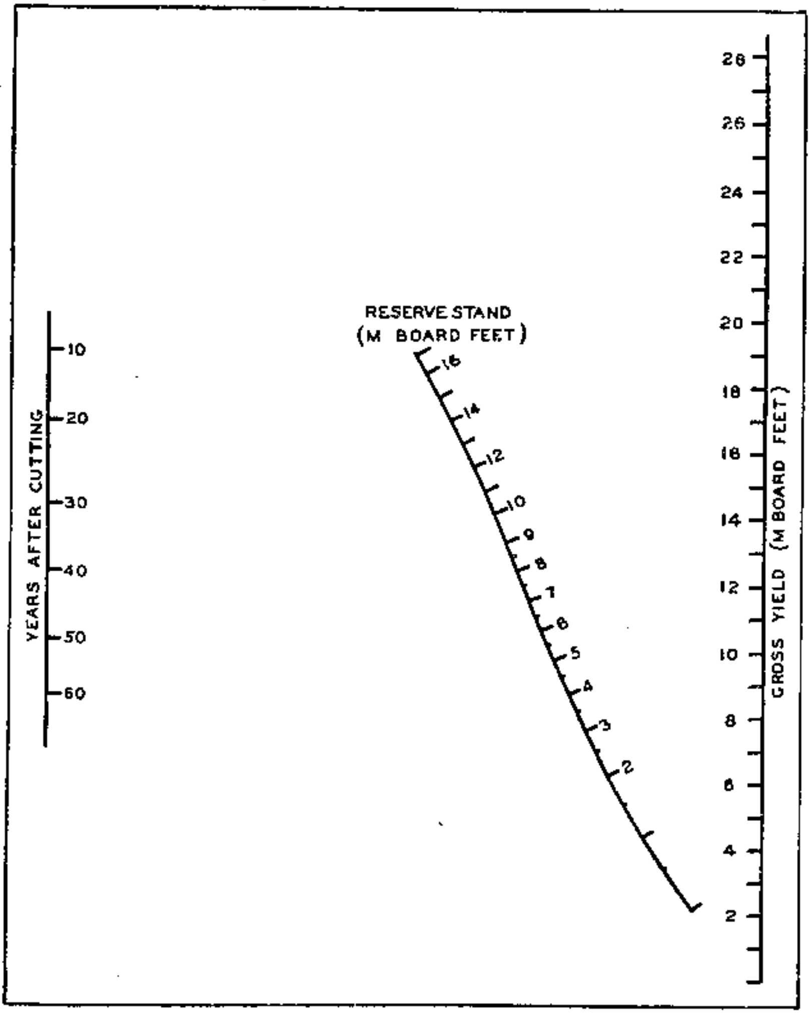


FIGURE 10.—Board-foot volume growth, Scribner rule, in selectively cut stands of ponderosa pine in the Pacific Northwest, site quality IV.

ADJUSTING FOR SITE QUALITY AND STRUCTURE

The gross yield found by reading from the alinement charts or by interpolation from the tables applies to the average structure and site quality of the entire collection of sample plots. It has been shown previously that stands vary widely in structure and that no average condition is valid for every stand in the entire region. Adjustments must therefore be made for variations in structure and site. Tables 9, 10, and 11, based upon a thorough statistical study of the variations of the growth of plots of different site quality and structure from growth averages, give simple correction percentages by which the preliminary estimated gross yield must be multiplied. For instance if the volume of a reserve stand, on site quality IV, is composed 50 percent of tree classes 1 and 2, and 20 percent of tree class 3, the preliminary estimated board-foot yield at the end of 60 years is multiplied by 1.11. If, furthermore, the stand were on site quality III instead of IV the correction percentage would be increased by 15, or to 126. For instance, if the 2,500-board-foot stand mentioned in the preceding paragraph, which according to the preliminary estimate will have grown to 6,500 board feet in 60 years, has a 50-20 structure, and if it is on site quality III, the predicted gross volume at 60 years is $6{,}500 \times 1.26$, or 8,190 board feet. If calculations are made for periods shorter than 60 years, the differences between the correction percentages which tables 9, 10, and 11 give and 100 percent should be correspondingly reduced. If the period is 40 years, for instance, the total correction percentage in the example cited will be 117 instead of 126.

TABLE 9.—*Correction for effect of site quality and structure upon basal area of selectively cut stands of ponderosa pine 60 years after cutting*

Percentage of basal area in tree class 3	Correction percentages for site quality IV [1] when the percentage of basal area in tree classes 1 and 2 is—										
	0	10	20	30	40	50	60	70	80	90	100
0	69	76	84	91	99	106	114	121	129	136	144
10	73	80	88	95	103	110	118	125	133	140	
20	77	84	92	99	107	114	122	129	137		
30	81	88	96	103	111	118	126	133			
40	85	92	100	107	115	122	130				
50	89	96	104	111	119	126					
60	93	100	108	115	123						
70	97	104	112	119							
80	101	108	116								
90	105	112									
100	109										

[1] For site quality III, add 8 to the above percentages; for site quality V, subtract 8 from the above percentages.

TABLE 10.—*Correction for effect of site quality and structure upon cubic-foot yield of selectively cut stands of ponderosa pine 60 years after cutting*

Percentage of basal area in tree class 3	Correction percentages for site quality IV [1] when the percentage of basal area in tree classes 1 and 2 is—										
	0	10	20	30	40	50	60	70	80	90	100
0	65	73	82	90	98	106	115	123	131	140	148
10	70	78	87	95	103	111	120	128	136	145	
20	75	83	92	100	108	116	125	133	141		
30	80	88	97	105	113	121	130	138			
40	85	93	102	110	118	126	135				
50	90	98	107	115	123	131					
60	95	103	112	120	128						
70	100	108	117	125							
80	105	113	122								
90	110	118									
100	115										

[1] For site quality III, add 12 to the above percentages; for site quality V, subtract 12 from the above percentages.

TABLE 11.—*Correction for effect of site quality and structure upon board-foot yield, by Scribner rule, of selectively cut stands of ponderosa pine 60 years after cutting*

Percentage of basal area in tree class 3	Correction percentages for site quality IV [1] when the percentage of basal area in tree classes 1 and 2 is—										
	0	10	20	30	40	50	60	70	80	90	100
0	62	69	77	85	93	101	108	116	124	132	140
10	67	75	83	90	98	106	114	122	129	137	-----
20	72	80	88	96	103	111	119	127	135	-----	-----
30	78	85	93	101	109	117	124	132	-----	-----	-----
40	83	91	98	106	114	122	130	-----	-----	-----	-----
50	88	96	104	112	119	127	-----	-----	-----	-----	-----
60	93	101	109	117	125	-----	-----	-----	-----	-----	-----
70	99	107	114	122	-----	-----	-----	-----	-----	-----	-----
80	104	112	120	-----	-----	-----	-----	-----	-----	-----	-----
90	109	117	-----	-----	-----	-----	-----	-----	-----	-----	-----
100	115	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

[1] For site quality III, add 15 to the above percentages; for site quality V, subtract 15 from the above percentages.

ADJUSTING FOR MORTALITY

Pending the time when average mortality rates over long periods will be definitely determined, a mortality correction of 15 percent of the total gross annual increment has been tentatively adopted for areas where insect infestations can be held to the endemic stage and where wind and drought are not serious considerations. In the example previously cited, if a 2,500-board-foot reserve has given in 60 years a gross yield of 8,190 board feet or a gross increment of 5,690 board feet, the net increment is estimated as $5{,}690 \times 0.85$, or 4,836 board feet, equivalent to an annual growth of 80.6 board feet.

In cases in which the mortality is extraordinarily high or extraordinarily low the percentage must be adjusted according to the information in a later section (p. 29) which summarizes the best available data on mortality.

The reduction for mortality estimated directly after cutting need not be a final value. There are other ways in which a more accurate value may be obtained. Experience has shown that the greatest mortality occurs within 5 years after the cutting. At the end of that period the areas should be gone over, an estimate of mortality made and applied to the original tally, and new computations of growth made on the basis of the corrected tally.

ADJUSTING FOR NUMBER OF POLES

One of the main differences between the sample plots upon which this study is based and individual extensive stands to which the results of the study are applied lies in the proportionate number of poles, trees between 3.6 and 11.5 inches in diameter at breast height. In some stands groups of poles are scattered throughout. Where this condition prevails, the growth rates are higher and the prospects of a satisfactory future stand are enhanced. The growth tables take into account the average number of poles, shown in table 12. The number diminishes with heaviness of reserve stand, being 7 for a stand of 1,000 board feet per acre and 2.3 for a stand of 10,000 board feet per acre. Where the number departs widely from the average, an adjustment in the gross estimate is needed.

TABLE 12.—*Average number of trees that grow into the 11.6-inch breast-height diameter class during a 60-year cycle*

Volume of reserve stand per acre (board feet)	Number of study plots	Number of trees per acre growing into 11.6-inch class	Volume of reserve stand per acre (board feet)	Number of study plots	Number of trees per acre growing into 11.6-inch class
0-1,000	20	7.0	5,000-6,000	16	3.2
1,000-2,000	31	5.8	6,000-8,000	20	2.9
2,000-3,000	22	5.3	8,000-10,000	20	3.3
3,000-4,000	13	4.5	Over 10,000	16	2.3
4,000-5,000	19	3.7			

For every extra pole that will enter into the 11.6-inch breast-height diameter, or merchantable-volume, class during a 60-year period the estimate of growth for that period can be increased by from 1 to 4 board feet, according to the initial size and vigor of the pole. If the poles occur in dense groups and were small in size at the time of cutting, the lower value must be taken; if they were large, standing free, and vigorous, a value nearer the larger one is more suitable.

EXAMPLES OF GROWTH PREDICTIONS

To illustrate the sequence of computations involved in obtaining an estimate of future growth under this plan two sample cases are presented.

CASE 1

Reserve-stand conditions

Site quality	IV.
Area	350 acres.
Stand per acre:	
Basal area	30 square feet.
Cubic measure	600 cubic feet.
Board measure	3,000 board feet.
Structure	40–40.
Pole condition	Average.
Mortality	Do.
Length of cutting cycle	60 years.

Computations

Item	Basal area	Cubic measure	Board measure
	Square feet	*Cubic feet*	*Board feet*
Gross yield at 60 years (from tables 6, 7, 8)	51	1,300	7,300
	Percent	*Percent*	*Percent*
Correction for structure (from tables 9, 10, and 11)	115	118	114
	Square feet	*Cubic feet*	*Board feet*
Corrected gross yield	58.6	1,534	8,322
Total gross increment	28.6	934	5,322
Reduced (15 percent) for mortality	24.3	794	4,524
Average net annual growth per acre	.405	13.2	75.4
No correction necessary for poles.			
Average net annual growth, entire area	141.8	4,620	26,390

CASE 2

Reserve-stand conditions

Structure	Site quality	Acres	Reserve
			Board feet
35–0	III	500	4,000
25–50	IV	2,000	3,500
25–25	V	1,000	3,000

Cutting cycle, 40 years; mortality, average; pole condition, average.

In this case each type is considered separately and the example breaks down into three separate divisions, for each of which a separate estimate is made in exactly the same manner as in case 1.

Computations

Item	Site quality III	Site quality IV	Site quality V
Gross yield at 40 years (as for site quality IV) ... board feet	7,400	6,750.0	6,100
Correction for site quality and structure at 40 years ... percent	103	105	86
Corrected yield ... board feet	7,622	7,088	5,246
Total gross increment ... do	3,622	3,588	2,246
Reduced (15 percent) for mortality ... do	3,079	3,050	1,909
Average net annual growth, per acre ... do	77	76.2	47.7
Average net annual growth, entire area ... do	38,500	152,400	47,700
Grand total ... do		238,600	

ACCURACY OF GROWTH ESTIMATES

No yield prediction is perfect. Every yield table for even-aged stands now prepared is accompanied by a table of errors showing the range about the tabular values through which the yields of the fully stocked stand may vary. In this study of selectively cut stands of ponderosa pine the statistical error was computed by a different and probably more correct method. The volume was definitely determined at the time of cut, and hence had a 0-percent error at 0 age. With advance in age, on many of the plots the volume gradually diverged more and more from the tabular values, becoming in some instances proportionately greater and in others less. These differences were due in part to site quality, to structure, to release conditions, and to changes in plot conditions since the time of cutting. From the percentage differences at each decade a standard error was computed for each decade. Table 13 lists these errors for basal-area, cubic-foot, and board-foot values. The errors listed do not take into account the corrections for site quality and structure given in tables 9 to 11.

TABLE 13.—*Standard errors of yields as estimated for small areas at each decade without correction for site quality and structure*

Years after cutting	Standard errors around values of tables 6, 7, and 8		
	Basal area	Cubic-foot volume	Board-foot volume
	Percent	*Percent*	*Percent*
10	7.2	8.0	9.0
20	10.9	11.7	12.2
30	12.9	12.0	13.1
40	8.0	11.6	12.7
50	14.5	16.9	19.9
60	22.3	20.6	31.0

The estimates of error at 40 to 60 years given in table 13 are unreliable, since they are based on a very small number of plots. (See table 2.) By projecting the growth values of younger plots to 40 years and recomputing the errors, the values at this age were revised to 18.6, 19.4, and 20.8 percent, respectively. About 25 percent of the total variation was removed by the application of the correction percentages for site quality and structure. Of the remaining 75 percent of the variation, 17 percent was traced directly to the character of the data, because the age of the cutting was in some cases 60 years, in others around 50 and 40 years, and in still others 30 and 20 years. The serious growth disturbance previously mentioned as occurring on many of the plots during the last 14 years has affected the error calculation at different points, according to the age of the cutting. The final residual 55 to 60 percent of the variation, corresponding to a final standard error at 40 years of ±10 to ±12 percent, is due to a large number of minor factors, chiefly local, that cannot be successfully introduced into the growth calculations and that may to some extent be compensative when large areas are surveyed.

In the computations on accuracy of estimate, no erratic data were eliminated. Even known eccentric plots with exceptionally large individual errors of estimate were included. A few examples will show how local variations lead to erratic plot-growth values. Plot 161, in Washington, cut 27 years ago, was located in a river bottom, through which an irrigation ditch was dug a number of years after the cutting. Normally, at 30 years after the cutting the plot would have a volume of only 2,290 board feet per acre; owing to the exceptional moisture conditions, its predicted volume at that time is 2,660 board feet, an overrun of 16 percent. Plot 135, in another part of Washington, cut 24 years ago, which had a heavy advance stand of reproduction at the time of cutting, would normally have had a volume of 3,740 board feet per acre at the 20-year mark; because of the undue competition, its volume at 20 years was only 2,615 board feet, an underrun of 30 percent. Many another instance could be cited in which some extraordinary condition is producing unusual growth. Although these special conditions greatly affect yields on single study plots, on extensive tracts they are undoubtedly largely balanced out. The result is that in contrast with the errors given in table 13 and in the foregoing paragraph, based on the deviations of small areas, on large tracts the errors of growth estimate probably amount only to from 5 to 10 percent.

To forestall any question as to whether this or that factor can be used to decrease the error of estimate, it may be said here that the average size of the tree, the volume of the reserve stand, the structure percentage, and the site quality have no effect beyond those indicated. Greater accuracy in yield predictions can be achieved only by considering minor local factors, as in the two examples just cited.

MORTALITY

Although the general effect of mortality upon gross yields has already been discussed, because the subject is of so much importance a separate section is here devoted to summarizing some of the mortality information now available that can be applied to conditions in the Pacific Northwest. Since data on cut-over stands are few, a number of deductions will be made from records taken in uncut stands.

Tallies of trees that died after the cutting were made on all the plots measured for this study. When the total volume of these trees is divided by the number of years since the cutting and again by the number of acres in the plots, the average annual mortality loss per acre is found to be 0.115 square foot basal area, 4.13 cubic feet, or 21.2 board feet. Elimination of nine very erratic plots reduces these values to 0.089 square foot, 1.08 cubic feet, and 15.1 board feet, which can be considered a fair average for the areas studied. At this rate the average gross annual increment of 91 board feet that can be expected over a period of 30 years in the average reserve stand, the volume of which is 4,370 board feet, is reduced by 16.6 percent. This reduction is but slightly in excess of the 15 percent correction in annual increment for mortality recommended here for growth calculations covering long periods.

The Division of Forest Insects, United States Bureau of Entomology, has been carrying on since 1920 in southern Oregon and northern California an interesting series of studies of mortality of ponderosa pine, directed by F. P. Keen, chiefly to determine the damage caused by insects but secondarily to determine damage from other causes. The ponderosa pine forests of southern Oregon and northern California undoubtedly have a greater insect hazard than any other pine forests of the Pacific coast, but they are the only ones in the region for which comprehensive and reliable figures have been obtained. Some of the findings, for example those as to the relative susceptibility of the different tree classes, are applicable to the remainder of the region, although the absolute mortality rates are not. The mortality rates for the 10 years 1921–30 given in table 14 are based upon sample plots, usually of 640 acres each, which are examined annually; they can be considered average for the period in question on a large area of the virgin forests in and near the Rogue River, Fremont, and Modoc National Forests. The rates vary greatly from site to site and from stand to stand. In general, they reached a maximum in 1926 and 1927 and then declined rapidly. The values show plainly that the live volume of most of the stands must have temporarily decreased during the major part of this period, but that if the trend of the last years of the period continues there is promise of a balance, if not of a positive increase.

TABLE 14.—*Annual mortality of ponderosa pine in virgin forests on and near the Rogue River, Fremont, and Modoc National Forests in the period 1921–30* [1]

Mortality	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930
Average loss per acre ..board feet..	144	177	142	254	386	477	417	345	333	226
Range of loss per acre (section averages) ..board feet..	30–317	38–396	19–430	27–600	124–800	148–985	103–1,082	116–720	58–685	69–717
Acreage of plots.	53,080	53,080	45,080	39,960	20,920	19,640	17,400	16,120	10,760	7,000

[1] Table based on observations taken by the Division of Forest Insects, U.S. Bureau of Entomology.

Rates of mortality in cut-over stands cannot be deduced from the data upon which table 14 is based even if the values are converted to percentages of the total stand, since the average reserve tree is more resistant than the average tree in the virgin stand. A better idea of the situation in cut-over stands is deducible from table 15, which shows for the same areas the relative susceptibility of the seven tree classes and of subclasses.

TABLE 15.—*Relative susceptibility of ponderosa pine by tree classes to mortality from all causes* [1]

Tree class	Dominance	Age class (years)	Relative susceptibility [2]	Rank
1	Dominant	75−	0.15	1
	do	75+	.30	2
2	Codominant	75−	.44	4
	do	75+	.97	6
	Intermediate	75−	1.69	12
	do	75+	2.58	16
3	Dominant	150–300	.39	3
4	Codominant	150–300	1.11	7
	Intermediate	150–300	1.72	13
5	Dominant	300+	.47	5
	Codominant	300+	1.22	8
	Intermediate	300+	2.38	14
6	Suppressed	75−	2.50	15
	do	75+	1.28	9
7	do	150–300	1.36	10
	do	300+	1.45	11

[1] The chief cause of mortality was action of the western pine beetle (*Dendroctonus brevicomis* Lec.). Table based on observations taken by the Division of Forest Insects, U.S. Bureau of Entomology, in southern Oregon and northern California over 4 years, 1928–31.

[2] A factor of 1 indicates that the tree class forms the same percentage of the dead stand as it does of the live stand.

In table 15 a factor of 1 indicates that the tree class is represented among the dead trees in the same percentage as among the live trees. For instance, if this tree class forms 10 percent of the dead stand by number of trees, it also forms 10 percent of the live stand. The factor of 2 indicates that if the tree class forms 10 percent of the dead stand it forms only 5 percent of the live stand, and so forth. In other words, the higher the factor, the greater the susceptibility indicated, in direct ratio. All the dominant full-crowned trees, whether of class 1, 3, or 5, are well on the safe side, the class 1 trees less than 75 years of age being the best risk. The codominant trees seem to be about an average risk. The intermediate trees, those with the long thin crowns, are evidently the most subject to mortality, the danger being greatest for intermediate trees of classes 2 and 5.

According to the data given in table 15, the practice of leaving dominant trees uncut, with a supplement of codominant trees, should do much toward immunizing a selectively cut stand to insect attack. A reserve stand composed chiefly of dominant trees with scattered codominant trees should suffer only one third to one half the mortality of a reserve stand in which the tree classes are represented in the same proportion as in the virgin stand. On the other hand a stand that is stripped of its best timber, only the smaller intermediate and suppressed trees being left, may suffer up to eight times as much mortality as the wisely cut stand.

COMPARISON OF RELEASE CONDITIONS IN EXTENSIVE STANDS WITH THOSE ON PLOTS

It is a possible weakness of this study that each sample plot was chosen not as typical of a large surrounding area but simply as exemplifying certain conditions of reserve-stand structure and of site quality, and that measurements were made on the plots only once. A check was needed to determine whether the resulting data express general conditions. Such a check was made, consisting of 17 random strip surveys of extensive virgin and cut-over areas, for which stand maps similar to those made for the sample plots were constructed. Comparisons were made with the plots as to the spacing of trees, their division into release classes, and the number of poles. The strips included from 4 to 50 acres each, and had a total area of 211 acres. In some of the virgin stands three grades of theoretical markings were made and the effect upon release conditions was observed. Table 16 shows the range of release distances and their average, for trees of different sizes, on the sample plots and on the survey strips.

Table 16.—*Release conditions on sample plots and on surveyed strips*

Average release distance [1] (feet) for trees of size indicated	Plots [2] with—		Strips [3] with—	
	Trees 11.6 inches or more in d.b.h.	Trees 11.5 inches or less in d.b.h.	Trees 11.6 inches or more in d.b.h.	Trees 11.5 inches or less in d.b.h.
6–10 .... number	3	3	....	....
11–15 .... do	3	8	....	....
16–20 .... do	32	15	2	1
21–25 .... do	73	34	6	5
26–30 .... do	45	44	7	4
31–35 .... do	19	20	2	4
36–40 .... do	2	15	....	....
41–45 .... do	1	7	....	....
46–50 .... do	....	2	....	....
Average release distance,[1] by size groups, of trees on plots and on strips, respectively .... feet	24	27	25	28
Average number of trees beyond 50-foot release distance, in percentage of total number .... percent	9.5	12.1	20.3	28.9

[1] Computed only for trees released within a 50-foot radius.
[2] Plots enumerated as having trees 11.6 inches or more in d.b.h. include 178 of the total 170 study plots. Plots enumerated as having trees below that size include 154 of the total 170.
[3] Strips enumerated as having trees 11.6 inches or more in d.b.h. include all the 17 strips surveyed. Strips enumerated as having trees below that size include 14 of the total 17.

The expression "release distance" as here used signifies the average distance from a reserve tree to a stump more than 12 inches in diameter with no other standing tree intervening. Trees beyond the 50-foot limit are considered unreleased, although release has some effect beyond that distance. Equal average release distances are considered to signify equivalent release conditions. Release conditions and their effect upon growth are dealt with in detail in a later section.

On the sample plots the release distance for the trees included in the board-foot volume calculations (that is, the trees 11.6 inches or more in diameter at breast height), not including trees beyond the 50-foot limit, averaged approximately 24 feet, and that for the smaller trees averaged 27 feet (table 16). Of the total number of trees on the plots, 9.5 percent of those of merchantable size and 12.1 percent of those of unmerchantable size were beyond the 50-foot limit. On the strips, the release distance averaged 25 feet for the larger trees and 28 feet for the smaller trees, and the proportion of the trees beyond the 50-foot limit was 20.3 and 28.9 percent for the two size classes, respectively. The contrast between the two groups of data as to percentage of trees beyond the 50-foot limit, especially in the unmerchantable class, was one reason why in predicting growth a correction was made for the number of poles that would grow into merchantable size during the cutting cycle. The difference as to percentage of trees outside the 50-foot limit gives a distorted picture, however. From 27 to 53 percent of such trees are free on two or more quadrants before the cutting, many of them being completely isolated and hence having a growth rate far above the average rate in the virgin stand; and many of the others occur in uncut clumps such as were purposely excluded from sample plots because they did not represent a good selection condition.

The average release conditions for extensive stands were first computed for the marking system now used in the Pacific Northwest by the Forest Service, in which 20 to 30 percent of the volume is left as a reserve stand. Then trial markings by one or both of two other systems were made on nine of the strips. One of these systems provided for a reserve of 30 to 40 percent; the second provided for a reserve of 10 percent or less. The heavy reserve contained all trees that could possibly succeed in the selection stand; the light reserve contained all trees with diameters not greater than 18 inches, which, according to certain studies, is the cutting limit that permits maximum present profit without consideration of future benefits.

As is shown in table 17, average release distance for trees within the 50-foot distance is practically independent of grade of cutting. Percentage of trees not released within 50 feet, especially in the small sizes, varies somewhat with grade of cutting; the lighter the reserve, the fewer the unreleased trees. Even in the heavy reserves only one fifth of the merchantable trees are outside effective release distance, a fact that augurs well for improved growth following selective cutting of any grade. Unbroken groups of small trees in the heavy reserves, indicated by the large percentage of trees in this class, should be thinned to improve the growth rates of selected trees and enable a large proportion of them to reach merchantable size.

TABLE 17.—*Release conditions in heavy, medium, and light reserve stands of ponderosa pine on surveyed strips*

Item	Heavy reserve	Medium reserve	Light reserve
Volume, in percentage of volume before cutting .... percent	30–40	20–30	0–10
Average release distance: [1]			
Trees 11.6 inches or more in diameter at breast height .... feet	24	25	25
Trees 11.5 inches or less in diameter at breast height .... do	20	28	20
Trees unreleased [2] or free growing:			
Trees 11.6 inches or more in diameter at breast height .... percent	19	29	14
Trees 11.5 inches or less in diameter at breast height .... do	37	29	20

[1] Computed only for trees released within a 50-foot radius.
[2] Including all trees not released within a 50-foot radius.

USE OF STAND-GROWTH TABLES IN CHOOSING GRADE OF CUTTING

The greatest use of the tables presented in this bulletin is in connection with making growth predictions for selectively cut stands. A secondary value lies in the assistance they give in determining what grades of cutting conduce to maximum production. The following tabular statement shows the growth rates obtainable in four different stands under three different grades of cutting. Altogether, tests were made in 17 different stands. The four examples were chosen because they showed distinct types of selection stands. The effect of grade of cutting on average release conditions has already been discussed, but the suitability of each grade for different stands has not been shown. The removal of all trees 18 inches or more in diameter, for instance, may leave as low as 100 board feet per acre in one stand and as high as 1,750 board feet in another. At the other extreme, cutting to a high diameter limit may leave from 6,000 to 14,000 board feet per acre. Medium to heavy cuttings leave stands ranging from 2,000 to 11,000 board feet per acre, usually in the neighborhood of 4,000 to 5,000 board feet.

Illustrations of application of growth tables to strip-survey data and the effect of several methods of cutting

STRIP NO. 7

Original stand data:	
1. Acres in strip ... number	9. 0
2. Average site quality	III
3. Volume per acre ... board feet	37, 003
Structure:	
4. Percentage of 1's and 2's	. 3
5. Percentage of 3's	31. 6
6. Percentage of 4's, 5's, 6's, and 7's	68. 1

Reserve stand data:	*Heavy reserve*	*Medium reserve*	*Light reserve*
7. Volume per acre ... board feet	14, 119	11, 105	122
Structure:			
8. Percentage of 1's and 2's	. 9	1. 2	53. 8
9. Percentage of 3's	73. 7	82. 5	------
10. Percentage of 4's, 5's, 6's, and 7's	25. 4	16. 3	46. 2
11. Structure and site correction percentage	117	121	119
12. Poles per acre ... number	1. 2	1. 0	. 9
Average release distance:			
13. Trees 11.6 inches or more in d.b.h ... feet	31	25	26
14. Trees 11.5 inches or less in d.b.h ... do	35	36	34
Percentage unreleased:			
15. Trees 11.6 inches or more in d.b.h ... do	22	28	0
16. Trees 11.5 inches or less in d.b.h ... do	46	33	25
Growth and yield estimates:			
17. Gross volume at 60 years as read from chart ... board feet	23, 700	21, 000	1, 800
18. Gross volume at 60 years, adjusted ... do	27, 730	25, 410	2, 140
19. Gross annual increment ... do	227	238	33. 6
20. Estimated net annual increment ... do	193	202	28. 6
21. Estimated net annual increment corrected for poles ... board feet	193	202	28. 6

STRIP NO. 10

Original stand data:	
1. Acres in strip ... number	14. 5
2. Average site quality	IV
3. Volume per acre ... board feet	15, 766
Structure:	
4. Percentage of 1's and 2's	6. 0
5. Percentage of 3's	27. 8
6. Percentage of 4's, 5's, 6's, and 7's	66. 2

Reserve stand data:	*Heavy reserve*	*Medium reserve*	*Light reserve*
7. Volume per acre ... board feet	5, 577	4, 391	1, 098
Structure:			
8. Percentage of 1's and 2's	14. 5	16. 9	46. 9
9. Percentage of 3's	53. 4	55. 6	11. 4
10. Percentage of 4's, 5's, 6's, and 7's	32. 1	27. 5	41. 7
11. Structure and site correction percentage	101	104	105

Illustrations of application of growth tables to strip-survey data and the effect of several methods of cutting—Continued

STRIP NO. 10—Continued

	Heavy reserve	Medium reserve	Light reserve
Reserve stand data—Continued.			
12. Poles per acre ____ number	2.5	2.4	2.5
Average release distance:			
13. Trees 11.6 inches or more in d.b.h ____ feet	24	28	26
14. Trees 11.5 inches or less in d.b.h ____ do	32	33	28
Percentage unreleased:			
15. Trees 11.6 inches or more in d.b.h ____ do	18	23	6
16. Trees 11.5 inches or less in d.b.h ____ do	34	35	12
Growth and yield estimates:			
17. Gross volume at 60 years as read from chart ____ board feet	11,000	9,300	3,800
18. Gross volume at 60 years, adjusted ____ do	11,110	9,670	3,990
19. Gross annual increment ____ do	92	88	48
20. Estimated net annual increment ____ do	78	75	40.8
21. Estimated net annual increment corrected for poles ____ board feet	78	75	40.8

STRIP NO. 14

Original stand data:	
1. Acres in strip ____ number	16
2. Average site quality	IV
3. Volume per acre ____ board feet	22,918
Structure:	
4. Percentage of 1's and 2's	5.4
5. Percentage of 3's	33.2
6. Percentage of 4's, 5's, 6's, and 7's	61.4

	Heavy reserve	Medium reserve	Light reserve
Reserve stand data:			
7. Volume per acre ____ board feet	7,732	4,877	1,856
Structure:			
8. Percentage of 1's and 2's	15.5	24.4	41.8
9. Percentage of 3's	69.1	64.4	13.2
10. Percentage of 4's, 5's, 6's, and 7's	15.4	11.2	45.0
11. Structure and site correction percentage	111	116	106
12. Poles per acre ____ number	6.8	6.4	7.7
Average release distance:			
13. Trees 11.6 inches or more in d.b.h ____ feet	24	27	26
14. Trees 11.5 inches or less in d.b.h ____ do	32	33	27
Percentage unreleased:			
15. Trees 11.6 inches or more in d.b.h ____ do	18	23	6
16. Trees 11.5 inches or less in d.b.h ____ do	34	35	12
Growth and yield estimates:			
17. Gross volume at 60 years as read from chart ____ board feet	14,000	10,000	5,400
18. Gross volume at 60 years, adjusted ____ do	15,540	11,600	5,720
19. Gross annual increment ____ do	130	112	64.4
20. Estimated net annual increment ____ do	111	95	54.7
21. Estimated net annual increment corrected for poles ____ board feet	119	104	62.7

STRIP NO. 15

Original stand data:	
1. Acres in strip ____ number	10
2. Average site quality	IV
3. Volume per acre ____ board feet	16,976
Structure:	
4. Percentage of 1's and 2's	4.1
5. Percentage of 3's	20.6
6. Percentage of 4's, 5's, 6's, and 7's	75.3

Illustrations of application of growth tables to strip-survey data and the effect of several methods of cutting—Continued

STRIP NO. 15—Continued

	Heavy reserve	*Medium reserve*	*Light reserve*
Reserve stand data:			
7. Volume per acre board feet	5,417	4,151	1,501
Structure:			
8. Percentage of 1's and 2's	12.6	16.4	37.9
9. Percentage of 3's	55.3	57.2	7.8
10. Percentage of 4's, 5's, 6's, and 7's	32.1	26.4	54.3
11. Structure and site correction percentage	101	105	96
12. Poles per acre number	5.5	5.5	5.7
Average release distance:			
13. Trees 11.6 inches or more in d.b.h. feet	28	31	25
14. Trees 11.5 inches or less in d.b.h. do	37	37	33
Percentage unreleased:			
15. Trees 11.6 inches or more in d.b.h. do	23	26	12
16. Trees 11.5 inches or less in d.b.h. do	42	42	20
Growth and yield estimates:			
17. Gross volume at 60 years as read from chart board feet	10,800	9,000	4,700
18. Gross volume at 60 years, adjusted do	10,910	9,450	4,510
19. Gross annual increment do	92	88	50.2
20. Estimated net annual increment do	78	75	42.5
21. Estimated net annual increment corrected for poles board feet	82	78	42.5

On strip 7 the heavy reserve stand gives a smaller annual increment than the medium stand, owing to the fact that the influence of the less desirable trees left restricts the growth rates of the thriftier trees. On the other hand, a light reserve left by the removal of all trees more than 18 inches in diameter is decidedly handicapped as to growth and will probably be a complete failure, especially since poles average only one to the acre, far less than the average.

Annual increment is not always the deciding factor in the choice of grade of marking; quality of timber, quantity of cut, and total stand at time of second cut, also, must be considered. Under certain conditions of market and logging practice a stand of at least 10,000 board feet per acre may be requisite to a second cut. On strip 10 this will be obtained in 60 years by leaving a reserve of 5,000 board feet per acre, between the heavy and medium reserve conditions. So far as annual growth rates alone are concerned, on this strip there is little choice between the heavy and the medium reserve.

Strict application of the 18-inch limit will leave a sufficiently large reserve in only a few stands, of which strip 14 is an example. Here a stand of 1,856 board feet per acre is left, which in 60 years will produce a gross volume of 5,720 board feet.

Medium reserves, of 20 to 30 percent, probably give the largest proportionate yield in the average stand. They have practically the same annual growth rate as the reserves of 30 to 40 percent, although the latter may at times be more desirable because they give larger ultimate volume.

On the whole, if a stand has a moderate proportion of overmature trees a medium reserve of 20 to 30 percent is best. In a stand having the greater part of its volume in thrifty mature trees, a medium to heavy reserve is advisable. Only if a fair proportion of the volume is in advance young growth and the number of poles is well above the average shown in table 12 will a light reserve succeed.

These conclusions are based solely on considerations of growth. Other considerations, economic and silvicultural, will tend to modify them.

GROWTH OF THE INDIVIDUAL TREE

DIAMETER GROWTH RATES FOR AVERAGE RELEASE CONDITIONS

Tables 18 to 22, based upon analysis of 3,586 trees, give the essential values from which average diameter growth rates can be found for the

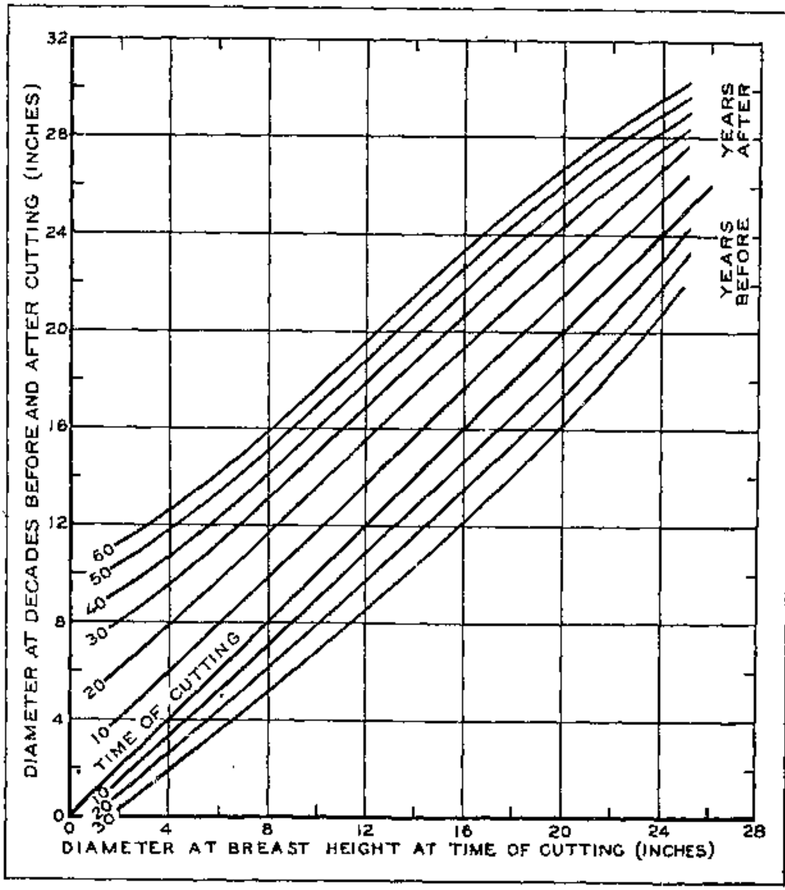


FIGURE 11.—Diameter growth of ponderosa pine, tree class 1, on site quality IV before and after a partial cutting of the stand, by decades.

complete range of diameters in each of the tree classes defined by the Dunning system, as affected by several conditions of release and nonrelease and by different site qualities. Table 18 gives the diameters at 10-year intervals from 30 years before release to 60 years after release for site quality IV. Figure 11 illustrates the method of plotting out the table data for closer interpolation. (Almost any cross-section paper with fine enough divisions can be used for this purpose.) The trees upon analysis of which the tables are based included 479 for site quality III, 2,197 for site quality IV, and 910 for site quality V.

TABLE 18.—*Average diameter growth at breast height, in inches, of ponderosa pine on site quality IV, before and after a partial cutting of the stand*

TREE CLASS 1

Diameter indicated number of years before release			Diameter at time of release	Diameter indicated number of years after release					
30	20	10		10	20	30	40	50	60
0.3	0.9	1.5	2.0	4.0	6.1	8.0	9.2	10.4	11.2
1.9	2.6	3.3	4.0	6.0	7.9	9.5	10.7	11.8	12.6
3.5	4.4	5.2	6.0	7.9	9.8	11.2	12.3	13.4	14.1
5.1	6.2	7.1	8.0	9.9	11.6	13.0	14.1	15.1	15.8
6.8	7.9	9.0	10.0	11.8	13.6	15.0	16.0	17.0	17.7
8.5	9.7	10.9	12.0	13.7	15.5	16.9	17.9	18.8	19.6
10.3	11.6	12.8	14.0	15.6	17.4	18.8	19.8	20.7	21.5
12.2	13.5	14.7	16.0	17.6	19.4	20.6	21.6	22.6	23.4
14.1	15.4	16.6	18.0	19.6	21.2	22.5	23.4	24.4	25.1
16.1	17.4	18.6	20.0	21.5	23.0	24.3	25.2	26.1	26.7
18.3	19.5	20.7	22.0	23.5	24.8	26.0	26.8	27.6	28.2
20.7	21.8	23.0	24.0	25.4	26.6	27.5	28.2	28.9	29.5
23.4	24.4	25.3	26.0	27.1	28.4	29.2	29.7	30.3	30.9
26.0	26.7	27.4	28.0	29.0	30.0	30.8	31.4	32.0	32.4
28.3	28.8	29.4	30.0	30.8	31.0	32.7	33.3	33.8	34.3
30.3	30.8	31.4	32.0	32.8	33.8	34.6	35.3	35.8	36.3
32.3	32.9	33.4	34.0	34.8	35.8	36.6	37.3	37.8	38.3

TREE CLASS 2

0.2	0.8	1.4	2.0	3.9	5.8	7.2	8.3	9.3	10.0
2.1	2.7	3.3	4.0	5.4	7.1	8.3	9.2	10.3	11.0
4.0	4.6	5.3	6.0	7.2	8.6	9.8	10.7	11.7	12.4
5.8	6.6	7.2	8.0	9.1	10.4	11.6	12.5	13.0	14.2
7.6	8.4	9.2	10.0	11.2	12.4	13.5	14.5	15.5	16.2
9.5	10.4	11.2	12.0	13.2	14.4	15.4	16.4	17.3	18.0
11.4	12.3	13.1	14.0	15.2	16.3	17.2	18.1	18.9	19.5
13.4	14.3	15.1	16.0	17.2	18.1	18.9	19.6	20.2	20.7
15.8	16.5	17.2	18.0	18.8	19.6	20.4	20.9	21.4	21.9
18.0	18.6	19.3	20.0	20.7	21.4	22.0	22.5	23.0	23.5
20.0	20.6	21.3	22.0	22.7	23.3	23.9	24.4	24.8	25.2
22.0	22.6	23.3	24.0	24.7	25.3	25.9	26.4	26.8	27.2
24.0	24.6	25.3	26.0	26.7	27.4	27.9	28.4	28.8	29.3
26.0	26.6	27.3	28.0	28.7	29.4	29.9	30.4	30.8	31.3
28.0	28.6	29.3	30.0	30.7	31.4	31.9	32.4	32.9	33.3

TREE CLASS 3

5.0	5.4	5.7	6.0	7.8	10.4	12.4	14.5	16.5	18.2
6.8	7.2	7.6	8.0	9.7	12.0	13.8	15.4	17.1	18.5
8.3	8.8	9.4	10.0	11.6	13.6	15.2	16.6	17.9	19.1
9.9	10.6	11.3	12.0	13.6	15.4	16.8	17.9	18.9	20.0
11.7	12.4	13.2	14.0	15.5	17.1	18.4	19.4	20.2	21.1
13.8	14.5	15.3	16.0	17.4	18.9	20.1	21.0	21.8	22.5
15.8	16.5	17.2	18.0	19.4	20.6	21.8	22.7	23.5	24.1
17.7	18.5	19.2	20.0	21.3	22.6	23.6	24.5	25.2	25.8
19.7	20.4	21.2	22.0	23.2	24.4	25.4	26.3	27.0	27.6
21.7	22.4	23.2	24.0	25.1	26.3	27.3	28.2	29.0	29.6
23.7	24.5	25.2	26.0	27.1	28.2	29.2	30.1	30.9	31.5
25.7	26.5	27.3	28.0	29.0	30.0	31.0	32.0	32.8	33.4
27.8	28.5	29.3	30.0	30.9	31.8	32.9	33.8	34.6	35.1
30.1	30.7	31.4	32.0	32.8	33.7	34.6	35.5	36.1	36.6
32.5	33.0	33.5	34.0	34.6	35.5	36.1	36.9	37.5	38.0
34.8	35.2	35.6	36.0	36.6	37.3	37.9	38.5	39.1	39.6
36.8	37.2	37.6	38.0	38.6	39.1	39.7	40.3	40.9	41.4
38.8	39.2	39.6	40.0	40.6	41.1	41.7	42.3	42.8	43.3

TREE CLASS 4

4.3	4.8	5.4	6.0	8.5	11.0	12.4	13.0	14.8	15.5
6.3	6.8	7.4	8.0	9.8	11.7	13.0	14.2	15.3	16.0
8.3	8.8	9.4	10.0	11.3	12.8	14.0	15.1	16.1	16.7
10.3	10.8	11.4	12.0	12.9	14.2	15.2	16.2	17.3	17.8
12.3	12.8	13.5	14.0	14.8	15.9	16.8	17.7	18.6	19.1
14.3	14.9	15.5	16.0	16.8	17.8	18.7	19.5	20.3	20.8
16.3	16.9	17.5	18.0	18.8	19.8	20.7	21.4	22.2	22.7
18.3	18.9	19.5	20.0	20.8	21.8	22.6	23.4	24.2	24.7
20.3	20.9	21.5	22.0	22.8	23.7	24.5	25.3	26.1	26.6
22.3	22.9	23.5	24.0	24.7	25.6	26.5	27.3	27.9	28.4
24.4	25.0	25.6	26.0	26.7	27.5	28.2	28.9	29.5	30.0
26.5	27.1	27.6	28.0	28.6	29.2	29.8	30.3	30.8	31.3
28.6	29.2	29.6	30.0	30.5	30.9	31.4	31.9	32.3	32.8
30.8	31.2	31.6	32.0	32.4	32.8	33.2	33.6	34.1	34.5
32.8	33.2	33.6	34.0	34.4	34.8	35.2	35.5	35.9	36.4

TABLE 18.—*Average diameter growth at breast height, in inches, of ponderosa pine on site quality IV, before and after a partial cutting of the stand*—Continued

TREE CLASS 5

Diameter indicated number of years before release			Diameter at time of release	Diameter indicated number of years after release					
30	20	10		10	20	30	40	50	60
12.6	13.1	13.5	14.0	14.9	16.3	17.4	18.3	18.9	19.5
14.6	15.1	15.5	16.0	16.8	17.8	18.7	19.4	20.0	20.6
16.6	17.1	17.5	18.0	18.7	19.6	20.2	20.8	21.4	22.0
18.6	19.1	19.5	20.0	20.5	21.4	22.0	22.6	23.1	23.7
20.6	21.1	21.5	22.0	22.6	23.4	24.0	24.6	25.1	25.6
22.5	23.1	23.5	24.0	24.6	25.3	26.0	26.6	27.1	27.6
24.5	25.1	25.5	26.0	26.6	27.3	27.9	28.5	29.1	29.6
26.5	27.0	27.5	28.0	28.6	29.2	29.8	30.4	31.0	31.5
28.5	29.0	29.5	30.0	30.6	31.2	31.8	32.4	33.0	33.4
30.5	31.0	31.5	32.0	32.6	33.2	33.8	34.3	34.9	35.4
32.5	33.0	33.5	34.0	34.5	35.1	35.7	36.2	36.8	37.4
34.5	35.0	35.5	36.0	36.5	37.1	37.6	38.2	38.8	39.3
36.5	37.0	37.5	38.0	38.5	39.0	39.6	40.1	40.7	41.2
38.4	39.0	39.5	40.0	40.5	41.0	41.6	42.1	42.7	43.2
40.4	41.0	41.6	42.0	42.5	43.0	43.5	44.0	44.6	45.1
42.4	43.0	43.6	44.0	44.5	45.0	45.5	46.0	46.6	47.1
44.4	45.0	45.6	46.0	46.5	47.0	47.5	48.0	48.6	49.1
46.5	47.1	47.6	48.0	48.5	49.0	49.5	50.0	50.6	51.1

TREE CLASS 6

0.9	1.4	1.8	2.0	3.1	4.5	5.7	6.6	7.5	8.3
2.7	3.2	3.6	4.0	4.9	6.0	7.1	8.0	8.9	9.7
4.5	5.0	5.5	6.0	6.8	7.7	8.7	9.6	10.5	11.2
6.4	7.0	7.5	8.0	8.8	9.7	10.6	11.5	12.2	12.9
8.4	9.0	9.5	10.0	10.8	11.6	12.6	13.4	14.1	14.8
10.4	11.0	11.5	12.0	12.8	13.6	14.5	15.3	16.0	16.6
12.4	13.0	13.5	14.0	14.7	15.6	16.4	17.2	17.9	18.5
14.5	15.0	15.5	16.0	16.7	17.5	18.4	19.1	19.8	20.4
16.6	17.1	17.6	18.0	18.7	19.5	20.3	21.0	21.7	22.3

TREE CLASS 7

0.8	1.2	1.6	2.0	3.8	5.2	6.4	7.2	7.8	8.4
2.8	3.2	3.6	4.0	5.2	6.4	7.5	8.2	8.9	9.5
4.8	5.2	5.6	6.0	6.9	7.9	8.8	9.6	10.3	10.9
6.8	7.2	7.6	8.0	8.6	9.5	10.5	11.2	11.8	12.4
8.7	9.2	9.6	10.0	10.6	11.4	12.2	12.9	13.5	14.1
10.7	11.2	11.6	12.0	12.6	13.4	14.2	14.9	15.4	16.0
12.7	13.2	13.6	14.0	14.6	15.4	16.2	16.8	17.4	17.9
14.6	15.1	15.6	16.0	16.6	17.3	18.1	18.8	19.4	19.9
16.6	17.1	17.6	18.0	18.6	19.3	20.1	20.7	21.3	21.9
18.6	19.1	19.6	20.0	20.6	21.3	22.0	22.7	23.3	23.8
20.6	21.1	21.6	22.0	22.6	23.3	24.0	24.6	25.2	25.8
22.6	23.1	23.6	24.0	24.6	25.2	25.9	26.6	27.2	27.7

The growth data given in table 18 for the 30 years before release are applicable to trees in virgin stands or to other unreleased trees. They can be applied to the present diameter tallies of uncut forests in order to estimate the future sizes of the trees. Then the gross increment can be computed by the use of volume tables on the two tallies.

The term "after release" as used in the table is not strictly accurate; the values given under this heading represent the average condition for the whole of a reserve stand that constitutes in some instances as high as 40 or 50 percent of the original stand by volume and in which not all the trees have been released.

Table 18 is in terms of total diameter; to determine the differences in growth rate due to differences in tree class, spacing, release, and site quality as shown in tables 19 to 22, only the diameter increment was taken. This procedure eliminated the size of the tree as a variable, with the result that small differences were more easily discernible. The percentage relationships given in tables 19 to 22 should therefore be applied solely to diameter increment; to apply them to total diameter would lead to gross error.

TABLE 19.—*Rank of tree classes as to diameter growth before and after selection cutting, and acceleration in diameter growth by tree classes after the cutting, for ponderosa pine on site quality IV*

Tree class	Average diameter growth for 20 years previous to release			Average diameter growth for 20 years after release			Acceleration for 20 years' growth
	Rank	Absolute growth	Relation to fastest	Rank	Absolute growth	Relation to fastest	
		Inches	*Percent*		*Inches*	*Percent*	*Percent*
1	1	2.10	100	1	3.54	100	69
2	2	1.48	70	3	2.48	70	68
3	2	1.48	70	2	2.70	76	82
4	3	1.18	56	4	1.92	54	63
5	4	.98	47	7	1.29	36	32
6	5	.92	44	5	1.73	40	88
7	6	.84	40	6	1.45	41	73

Table 19 throws a number of interesting sidelights on the diameter-growth table preceding it, by ranking the tree classes as to diameter growth. In respect to growth rate before release, tree class 1 stands first and is followed by the other classes in this order: 2 and 3, 4, 5, 6, 7. After release the order is as follows: 1, 3, 2, 4, 6, 7, 5.

Information as to the degree to which the average growth rate of a tree class increases after a selection cutting is often interesting, although of no practical use. In this study, for the 20-year period after cutting the tree classes 1 to 7 on the average show the following acceleration percentages, respectively: 69, 68, 82, 63, 32, 88, and 73. Classes 3 and 6 show the greatest average acceleration, and class 5 the least. An anomaly exists here in that some of the tree classes showing only a medium percentage acceleration, like class 1, do so because in the uncut forest they had a much larger absolute growth rate than other classes.

CORRELATION OF SITE QUALITY, RELEASE DISTANCE, AND NUMBER OF SIDES RELEASED WITH DIAMETER GROWTH

An intensive study of the variations in diameter growth involves tree class, site quality, spacing, release distance, number of sides released, and number of years after cutting. To simplify the calculations and the explanation only one interval after cutting, 20 years, and often only two tree classes, 1 and 3, were taken. In the following discussion and tables, the actual diameter increment for the 20 years after release is compared with the actual diameter increment for the 20 years before release; in addition the actual increments are compared with the increments for site quality IV as read from table 18. This double comparison shows the differences due to the several factors studied.

In defining release conditions not every minute variation could be observed, since application of the results would depend not upon detail but upon broad conditions. The following binumeral factor was adopted as giving the best working basis: Release factor = distance to nearest stump, number of quadrants released within 50 feet.

The distance to the nearest stump 12 inches or more in diameter was expressed in 5-foot belts, up to a maximum of 50 feet. As "nearest" stump was taken the nearest between which and the tree in question no other tree intervened. The number of quadrants was expressed directly. For instance, a release factor of 6, 2 meant that the nearest stump 12 inches or more in diameter was located 25 to 30 feet away and that within 50 feet stumps were located in two quadrants. Two stumps in one quadrant counted no more than a single stump. Plot upon plot and stand after stand were examined in this fashion in order to evaluate release conditions. Tables 20, 21, and 22 give the substance of the data on effects of various release conditions, comparing actual values with estimated values based on averages given in table 18.

Table 20, which gives diameter increment for the 20 years before and the 20 years after release for the two fastest growing tree classes, 1 and 3, shows that retardation of growth before release and acceleration of growth after release were progressively greater according to the number of sides released. A tree with only 1 side released, for example, often had had no near neighbors except on 1 or 2 sides and had grown faster before release than trees growing in more crowded conditions, and for this reason its growth rate was less susceptible of improvement through release.

TABLE 20.—*Diameter growth of ponderosa pine in selectively cut stands on site quality IV, by number of sides released*

Tree class	Trees examined	Sides released	Actual average 20-year diameter increment		Actual diameter-growth acceleration following release	Estimated 20-year diameter increment		Differences between actual and estimated 20-year diameter growth			
			Before release	After release		Before release	After release	Before release		After release	
	Number	*Number*	*Inches*	*Inches*	*Percent*	*Inches*	*Inches*	*Inches*	*Percent*	*Inches*	*Percent*
1	251	1	2.26	3.34	46	2.12	3.51	+0.14	+6.6	−0.17	−4.8
	122	2	2.14	3.45	61	2.19	3.50	−.05	−2.3	−.05	−1.4
	81	3	1.71	3.72	118	2.19	3.47	−.48	−21.9	+.25	+7.2
	13	4	1.52	4.09	169	2.25	3.50	−.73	−32.4	+.59	+16.9
3	258	1	1.71	2.34	37	1.43	2.53	+.28	+19.6	−.19	−7.5
	208	2	1.51	2.61	73	1.49	2.73	+.02	+1.3	−.12	−4.4
	153	3	1.34	3.10	131	1.48	2.85	−.14	−9.5	+.25	+8.8
	31	4	1.39	2.97	114	1.48	2.79	−.09	−6.1	+.18	+6.5

According to the data presented in table 20, the rates of increment after release for single trees of classes 1 and 3 depart from the average rates given for those classes in table 18 in proportions varying from −5 to +17 percent for tree class 1 and from −8 to +9 percent for tree class 3, the variation in growth corresponding closely with variation in number of sides released. The number of cases in which trees are released on three or more sides forms only one sixth to one quarter of the total number of trees released within 50 feet. (It should be noted that the percentage differences stated apply to increment alone, not to total diameters.)

Tree class 1, which has been shown in table 19 to increase its growth after release on the average by 69 percent, is shown by table 20 to increase it by 48, 61, 118, or 169 percent according as release takes place on 1, 2, 3, or 4 sides, respectively. Tree class 3, which increases its growth after release by an average of about 82 percent, increases it by 37, 73, 131, or 114 percent accordingly as release takes place on 1, 2, 3, or 4 sides, respectively. In both instances, the difference between actual and estimated diameter increment is smallest for the trees released on two sides. Consequently, the improvement that follows release on two sides approximately corresponds to average improvement.

The effect of release varies not only with number of sides released but also with distance of release, or distance to the nearest stump. Table 21 shows just how far the actual growth rates corresponding with different release distances exceed or fall short of the estimated rates. The table contains a number of irregularities, since the values are uncurved and no erratic material has been eliminated. Even in as large a number of trees as that used in this study, each of 126 subdivisions is necessarily small. The principal deductions can be briefly stated as follows:

Release distance depends to a large degree upon spacing in the virgin stand. For the most part, the growth rates in uncut stands increase regularly from a narrow to a wide spacing or, in terms of the headings of table 21, from what will be short release distances after cutting to what will be long release distances.

Since the estimated growth values of table 21 are for site quality IV, the differences in increment due to site quality are the direct differences in the average values from 100. In virgin stands, diameter increments for all tree classes and release distances combined are 21 percent better on site quality III than on site quality IV and those on V are only about 6 percent poorer than those on IV. After release, the growth on site quality III is 37 percent better, and that on V is 9 percent poorer, than that on site quality IV previous to release. (Again, these percentages apply solely to the increment and not to the diameters.)

On site quality V, the average growth rates of the young tree classes 1, 2, and 6 and of the overmature class 5 of the selected data are within 6 percent of those on site quality IV in both uncut and selectively cut stands. On site quality III, the growth rates of tree classes 6 and 7 before release are the only ones within 5 percent of those on site quality IV, all other classes growing much faster than on site quality IV.

On site quality III, the growth rates after release for all tree classes are 136 to 143 percent, averaging roughly 140 percent, of the rates estimated for site quality IV for trees released to distances as great as 40 feet. Beyond this distance the rates are 124 to 127 percent, averaging roughly 125 percent, of those estimated for site quality IV. On site quality IV, up to 40 feet release distance, the average growth rate after release for all tree classes combined closely approximates the estimated average rate. For greater distances the rate falls off somewhat. On site quality V, the decrease of actual growth as compared with estimated growth after release begins in the 31–40-foot release class instead of beyond 40 feet as on the other two sites.

TABLE 21.—*Actual diameter growth of ponderosa pine in selectively cut stands as compared with estimated growth for site quality IV, by site quality, tree class, and release distance*

Site quality	Tree class	Number of trees examined	Ratio percent of actual growth in 20 years preceding release to estimated growth in 20 years preceding release, by release distance—							Ratio percent of actual growth in 20 years following release to estimated growth in 20 years following release, by release distance—						
			1-10 feet	11-20 feet	21-30 feet	31-40 feet	41-50 feet	Over 50 feet	Average	1-10 feet	11-20 feet	21-30 feet	31-40 feet	41-50 feet	Over 50 feet	Average
III	1	96	109	104	117	112	126	121	113	118	147	151	126	124	125	133
	2	48	143	120	115	109	144	162	131	190	167	126	129	129	130	146
	3	163	118	128	123	147	147	176	132	143	127	131	106	114	140	138
	4	80	97	101	131	114	142	208	114	147	149	153	149	175	146	151
	5	36	74	118	89	117	142	157	115	95	188	149	178	152	153	142
	6	20	90	86	89	106	112	130	101	94	148	158	139	110	23	124
	7	36	97	88	93	132	106	85	90	106	166	105	90	89	95	110
Average			106	113	119	123	133	150	121	136	143	138	142	124	127	137
IV	1	494	71	92	94	92	118	115	100	95	97	99	98	93	88	95
	2	192	70	86	105	127	114	110	104	87	99	100	108	101	91	98
	3	666	85	94	108	119	130	139	105	94	99	97	109	93	87	98
	4	456	76	89	99	113	117	125	93	103	101	107	112	86	91	102
	5	106	121	99	95	104	90	103	102	112	109	97	89	84	88	101
	6	88	90	91	108	82	121	110	101	114	110	99	81	96	81	98
	7	188	71	76	98	102	117	134	87	101	97	103	97	116	88	100
Average			79	91	101	107	119	121	100	98	99	100	103	93	88	98
V	1	207	71	90	91	106	120	121	90	94	98	95	83	103	95	94
	2	141	70	100	80	131	114	151	95	105	107	86	88	94	77	95
	3	172	85	88	93	96	90	127	91	85	76	82	69	68	85	79
	4	138	68	75	85	86	101	125	78	86	91	88	107	69	56	87
	5	34	48	110	95	102	103	122	101	79	90	138	106	72	158	97
	6	85	74	65	108	125	98	130	99	110	92	93	92	54	80	96
	7	65	79	58	68	60	76	125	69	95	105	92	69	87	64	94
Average			74	86	90	108	110	123	94	94	92	95	85	89	88	91

CORRELATION OF CROWN LENGTH WITH DIAMETER GROWTH

Crown length is another of the factors used in Dunning's tree classification. In practical classification of border-line cases, the exact definition of crown length is often dropped in favor of the general vigor and age of the tree. It is interesting therefore to know how crown length is correlated with diameter growth. Table 22 gives the necessary data on tree classes 1 and 3.

TABLE 22.—*Correlation of crown length with diameter growth in ponderosa pine before and after release*

Ratio of crown length to total height (percent)	Tree class 1					Tree class 3				
	Trees examined	Diameter growth in 20 years—				Trees examined	Diameter growth in 20 years—			
		Preceding release		Following release			Preceding release		Following release	
	Number	*Inches*	*Percent of estimated value* [1]	*Inches*	*Percent of estimated value* [1]	*Number*	*Inches*	*Percent of estimated value* [1]	*Inches*	*Percent of estimated value* [1]
95	50	2.84	123	3.60	102	10	1.90	127	2.99	123
85	235	2.14	103	3.52	101	160	2.00	135	3.08	110
75	90	2.01	94	3.19	90	114	1.44	97	2.65	96
65	106	2.16	97	3.17	91	268	1.51	101	2.58	88
55	9	1.36	63	2.49	71	28	1.55	103	1.85	78
45 or less	4	1.18	52	2.70	70	24	1.45	97	2.00	70

[1] Estimated values shown in table 18.

The sharpest change, with tree class 1, comes between 65 and 55 percent in both virgin and cut stands. For tree class 3 the best growth in virgin stands is that of trees with 85- and 95-percent crown lengths; in cut stands there is a steady decrease in growth rate with shortening of the crown, with a decided diminution when 65-percent crown length is reached. The desirability of avoiding cutting trees having crown lengths of more than 65 percent is therefore indicated by these data.

HEIGHT GROWTH IN SELECTIVELY CUT STANDS

Basal-area increment and height increment together determine volume growth. Height growth can be taken into consideration in estimating volume growth of uncut stands by using a diameter-height curve. If the same height curve is used for earlier and later ages, the calculations of increase in diameter over a period of years will be accompanied by a calculation of height increment that will approximate the truth. In cut-over stands, acceleration of diameter growth is not accompanied by an acceleration of height growth similar to that which takes place in uncut stands. The final average effect is a dropping of the height curve throughout its length by 5 to 10 feet.

For single trees the approximate age and growth rate of which are known, table 23 gives the relationships between height and diameter growth as accurately as these can be determined by analyzing felled sample trees in cut-over stands.

TABLE 23.—*Height growth in selectively cut stands of ponderosa pine by age class, site quality IV*

Age of tree (years)	Height growth per inch diameter growth	Height growth per decade	Age of tree (years)	Height growth per inch diameter growth	Height growth per decade	Age of tree (years)	Height growth per inch diameter growth	Height growth per decade
	Feet	*Feet*		*Feet*	*Feet*		*Feet*	*Feet*
40	5.8	9.0	140	2.1	3.7	240	1.7	1.8
60	4.2	7.8	160	2.0	3.1	260	1.6	1.6
80	3.3	6.8	180	1.9	2.6	280	1.5	1.4
100	2.7	5.7	200	1.8	2.3	300	1.4	1.2
120	2.3	4.6	220	1.7	2.0	320	1.3	1.1

CHANGE IN FORM AFTER RELEASE

A common conception is that the rapid diameter growth at the base of a tree is not accompanied by similarly rapid diameter growth higher in the tree, and therefore introduces deterioration in form (*29*). This is only half the truth, as has been brought out in a study of the form of ponderosa pine (*24*). In the first place, for a tree of average form, approximately form class [9] 0.70, the diameter growth at half height need be only slightly more than 0.7 of that at breast height for the same form to be maintained. Tree classes having a lower form class were found to grow into this average form after release, and those having higher form class to reduce to it. Several years after cutting, the stands studied were much more homogeneous in form class than at any time previous. Even for a relatively small number of trees chosen at random, the volumes at the time of cut or

[9] The method by which form class is derived is described in the Appendix, p. 52.

at any later time can be estimated from a volume table based upon virgin conditions, providing the distribution of form classes has not been changed materially.

BARK THICKNESS

A refinement in the technic of computing the growth of individual trees, when diameter at breast height is taken outside the bark, consists in making an allowance for the change in bark thickness. The allowance will increase the apparent growth rates of most stands by about 10 percent. In this study such an allowance was not made, omission to make it being considered a desirable element of conservatism.

Figure 12 shows three plottings of bark thickness, based upon 3,327 trees. One plotting is for the immature trees, classes 1, 2, and

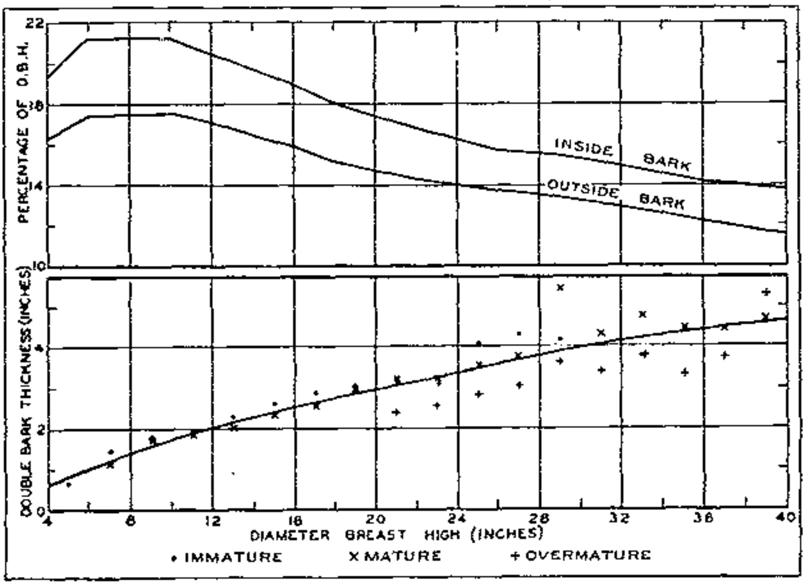


FIGURE 12.—Double bark thickness of ponderosa pine at breast height.

6; the second for the mature trees, classes 3, 4, and 7; and the third for overmature trees, class 5. The first two agree fairly closely and for many purposes can be represented by a single curve, but the bark thickness for class 5 underruns those of the first two classes by one half inch to an inch throughout. Site quality has no effect upon the relative position of the curves.

THE REPRODUCTION STAND

To be complete, the growth prediction of a selectively cut stand must take the reproduction into account, even though this requires separate treatment. The quantity and distribution of the reproduction largely determine the character of the third and subsequent cuts. In the following sections, some of the essential considerations are taken up.

In ponderosa pine forests, usually a light to dense understory of advance seedlings is present at the time of cutting, and this is augmented slightly by new seedlings following the cutting. Successful natural reproduction is difficult to establish after the cutting is once made. Reproduction existing upon the ground at the time of cutting sometimes is so heavy and develops so well upon release that it assumes the characteristics of an even-aged stand. More or less advance reproduction is found in every well-managed stand. Unfortunately it very often occurs in patches or clumps too dense for proper development. Since natural thinning is a very slow process, in such cases stagnation sets in and a need arises for some form of artificial thinning, either during the logging operations or at any time thereafter. An example of good development of ponderosa pine reproduction is shown in plate 4.

HEIGHT GROWTH

Ponderosa pine seedlings in uncut stands progress very slowly in height growth (*26*), needing from 20 to 25 years to reach breast height. In cut-over stands the dominant free-growing seedlings grow at a considerably higher rate, as is shown in table 24. On the average site in Oregon the seedlings reach breast height in 12.0 years, taking almost 7 years to grow the first foot. On the plots studied in Washington the seedlings required 7.6 years to reach 1 foot, and 13.5 years to reach breast height. When the 700 seedlings used in these calculations

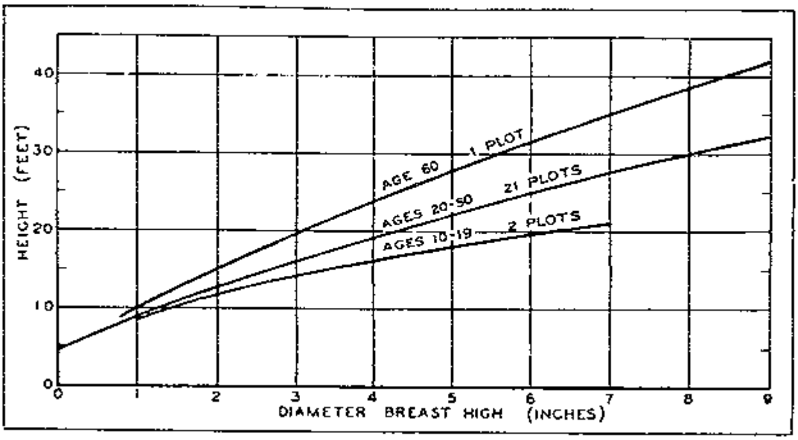


FIGURE 13.—Height-on-diameter relation in reproduction stands in selectively cut ponderosa pine.

were arranged into site-quality classes it was found that the periods required to reach breast height on site qualities IV and V averaged 12.8 years and 14.0 years, respectively.

Figure 13 shows the height curves for average reproduction stands aged 10 to 60 years. For the age classes between 20 and 50 years, height varies only slightly with age, varying to a greater degree with diameter. In true even-aged stands that are not stagnated this condition does not prevail, the height curve on the whole gradually shifting upward. In other words, if the stands for which the data of figure 13 were taken were developing normally the height curves for age classes 20 to 50 years, instead of being nearly coincident, would be spaced at regular intervals; the fact that they almost coincide is evidence of the stands' stagnation.

TABLE 24.—*Growth of dominant ponderosa pine seedlings on site qualities IV and V*

Site	Years required to grow from ground level to 1 foot			Years required to grow from 1 foot to breast height			Average number of years required to grow from ground level to breast height
	Average	Total range	Standard deviation	Average	Total range	Standard deviation	
Oregon:							
All sites	5.2	3-16	1.9	6.8	3-18	2.6	12.0
Washington:							
All sites	5.9	3-16	2.4	7.6	2-29	3.5	13.5
Both States:							
Site IV	5.6	3-16	2.2	7.2	2-29	3.1	12.8
Site V	6.0	3-16	2.4	8.0	2-23	3.8	14.0

VOLUME GROWTH

The slowness with which the reproduction stand develops is one of the most discouraging phases of the management of selectively cut ponderosa pine forests in the Pacific Northwest. After the first spurt following release, the rate of development of clumps of heavy reproduction lags far behind the rate that is normal for free-growing seedlings and saplings. Examples of reproduction stands that are growing poorly because of stagnation are shown in plate 5. A tally of the reproduction was made on most of the selectively cut plots. On some plots there was no reproduction at all; on a few the reproduction stand covered the entire area. The site quality of the land was determined from the height of the mature timber growing on it, or from the heights of adjacent timber in case the plots were practically clean cut. As previously defined, site quality IV is equivalent to Behre's site index 80 and site quality V is equivalent to his site index 65.

Figure 14, *B* and *C*, shows the volume and average heights of a few fully stocked reproduction stands in selectively cut forests and of several reproduction stands on areas completely cut over. The volumes and heights of the reproduction, shown by the irregular lines and crosses, are compared with the volumes and heights of normally developed even-aged second-growth stands as determined by Behre (*8*).

Both volume and height for average fully stocked stands of reproduction on site quality IV lie far below the normal curves for site quality IV. In fact, they are considerably below those of site quality V. The evidence is striking that the reproduction stands are stagnating and are developing at a rate comparable to the rate that is normal for a site quality 1 to 1½ classes poorer. Overstocking and clumpiness may be the principal causes; the oft-mentioned poor growth conditions of the last decade or two may be also a factor.

Figure 14, *A* is based upon many reproduction tallies, taken in a number of selectively cut stands. It shows how small a volume is being produced, especially in comparison with the full productive capacity of the land as indicated by the normal yield curves in figure 14, *B* and *C*. On the average, the reproduction stand can be counted upon only to produce about 10 percent of the normal yields for site index 80. This situation is deplorable. If stagnation is allowed to persist, it will imperil the cuts at the end of the second and subsequent

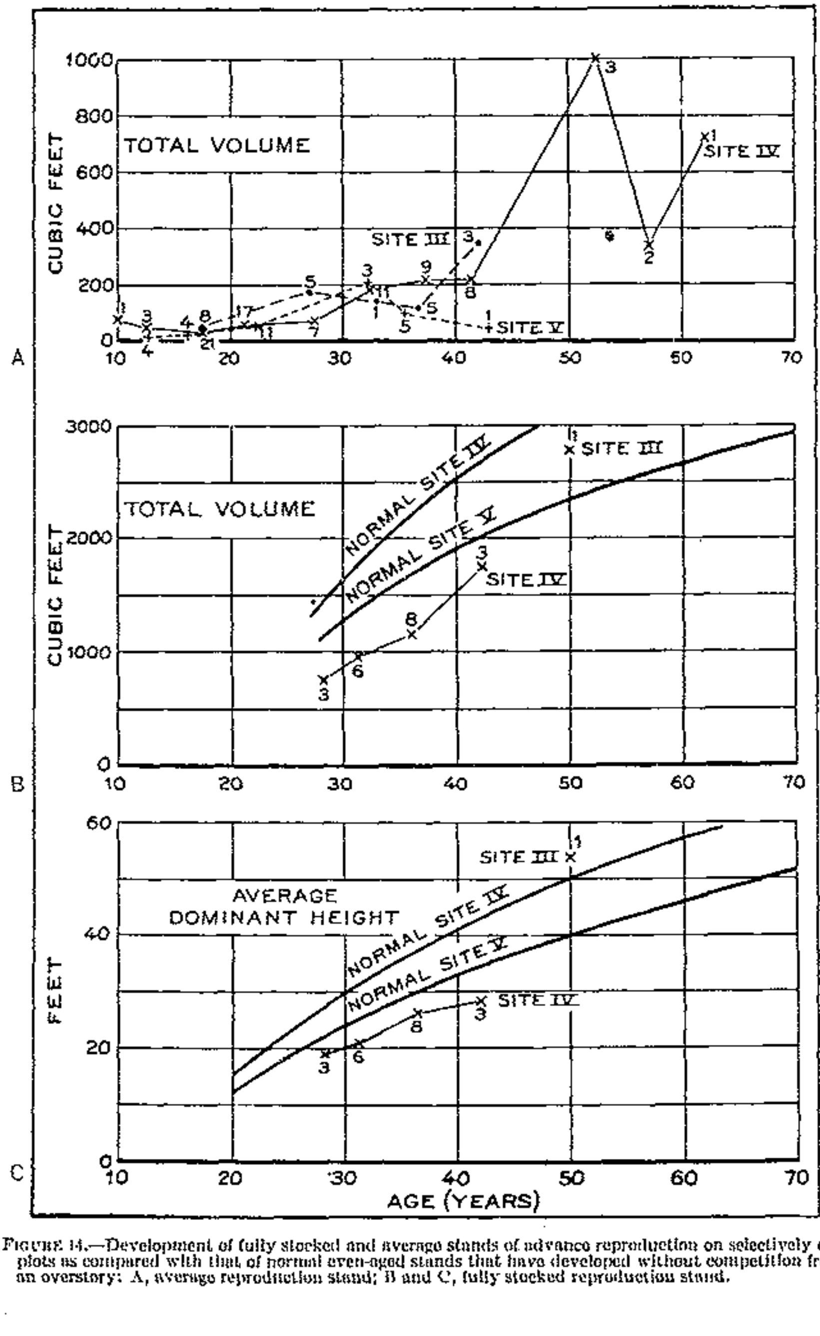


FIGURE 14.—Development of fully stocked and average stands of advance reproduction on selectively cut plots as compared with that of normal even-aged stands that have developed without competition from an overstory: A, average reproduction stand; B and C, fully stocked reproduction stand.

Ponderosa pine stand immediately after a selection cutting in 1914 (A), and 15 years after the cutting, in 1929 (B). Much advance reproduction was present in 1914, although it was too small to be discernible in the photograph. In 1929 the reproduction had developed well and was not so dense as to stagnate.

Sapling stands about 30 years old, on land of site quality IV, that are stagnating. Because of overdensity, they are growing only at a rate corresponding to site quality V or poorer. Stand A, near Sumpter, Oreg., was left undisturbed after the original heavy selection cutting. Stand B, near Cle Elum, Wash., was selectively cut, but was repeatedly recut for fuel wood until the overstory was completely removed.

cutting cycles. Although ponderosa pine reproduction endures stagnation for a long time, it does not do so indefinitely; drought, mistletoe, and insects take their toll, and the remaining saplings are unable to benefit by any liberation that may be given them.

SELECTED REFERENCES

(1) Anonymous.
1923. an analysis by species and counties of the privately and publicly owned timber in washington. West Coast Lumberman 44 (518): 83.

(2) ———
1923. analysis of dominant oregon species. West Coast Lumberman 44 (518): 84, illus.

(3) ———
1923. timber statistics for the national forests of district 6. Timberman 24 (10): 48.

(4) ———
1928. softwoods of the pacific greater west. Timberman 29 (6): 36.

(5) Baker, F. S., and Korstian, C. F.
1931. suitability of brush lands in the intermountain region for the growth of natural or planted western yellow pine forests. U.S. Dept. Agr. Tech. Bul. 256, 83 p., illus.

(6) Behre, C. E.
1927. form-class taper curves and volume tables and their application. Jour. Agr. Research 35: 673–744, illus.

(7) ———
1928. preliminary yield tables for second-growth western yellow pine in the inland empire. Idaho Forestry Expt. Sta. Bul. 1, 19 p., illus.

(8) ———
1928. preliminary normal yield tables for second-growth western yellow pine in northern idaho and adjacent areas. Jour. Agr. Research 37: 379–397, illus.

(9) Bruce, D., and Reineke, L. H.
1929. the use of alinement charts in constructing forest stand tables. Jour. Agr. Research 38: 289–308, illus.

(10) Clapp, E. H.
1912. silvicultural systems for western yellow pine. Soc. Amer. For. Proc. 7: 168–176.

(11) Cooper, A. W.
1906. sugar pine and western yellow pine in california. U.S. Dept. Agr., Forest Serv. Bul. 69, 42 p., illus.

(12) Dunning, D.
1922. relation of crown size and character to rate of growth and response to cutting in western yellow pine. Jour. Forestry 20: 379–389.

(13) ———
1923. some results of cutting in the sierra forests of california. U.S. Dept. Agr. Bul. 1176, 27 p., illus.

(14) ———
1928. a tree classification for the selection forests of the sierra nevada. Jour. Agr. Research 36: 755–771, illus.

(15) Gibbons, W. H., Johnson, H. M., and Spelman, H. R.
1929–30. the effect of tree sizes on western yellow pine lumber values and production costs. 16 p. Reprinted from Timberman 30 (12): 44, 46, 48–49, illus., 1929; 31 (1): 241–244, illus.; (2): 49–50, 52, 54–55, illus.; (3): 54–56; (4): 49–50, 52; (5): 194 196, 198, 1930.

(16) Hanzlik, E. J.
1926. trees: a study for lumbermen. western yellow pine (pinus ponderosa). Four L Lumber News 8 (19): 6–7.

(17) ———
1927. more about growth percent. Jour. Forestry 25: 443–447, illus.

20888°—34——4

(18) KORSTIAN, C. F.
1924. GROWTH ON CUT-OVER AND VIRGIN WESTERN YELLOW PINE LANDS IN CENTRAL IDAHO. Jour. Agr. Research 28: 1139–1148, illus.

(19) KRAUCH, H.
1920. THE USE OF STAND GRAPHS IN DETERMINING THE LIMITATION OF CUT. Jour. Forestry 18: 719–722.

(20) ———
1922. THE USE OF DIAMETER AGE CHARTS IN YIELD STUDIES. Jour. Forestry 20: 390–392, illus.

(21) ———
1923. A METHOD OF DETERMINING TECHNICAL ROTATION FOR YELLOW PINE STANDS OF ARIZONA AND NEW MEXICO. Jour. Forestry 21: 273–277.

(22) ———
1924. ACCELERATION OF GROWTH IN WESTERN YELLOW PINE STANDS AFTER CUTTING. Jour. Forestry 22: 39–42.

(23) ———
1926. THE DETERMINATION OF INCREMENT IN CUT-OVER STANDS OF WESTERN YELLOW PINE IN ARIZONA. Jour. Agr. Research 32: 501–541, illus.

(24) MEYER, W. H.
1931. EFFECT OF RELEASE UPON THE FORM AND VOLUME OF WESTERN YELLOW PINE. Jour. Forestry 29: 1127–1133, illus.

(25) MILLER, J. M., and PATTERSON, J. E.
1927. PRELIMINARY STUDIES ON THE RELATION OF FIRE INJURY TO BARK-BEETLE ATTACK IN WESTERN YELLOW PINE. Jour. Agr. Research 34: 597–613, illus.

(26) MUNGER, T. T.
1917. WESTERN YELLOW PINE IN OREGON. U.S. Dept. Agr. Bul. 418, 48 p., illus.

(27) PEARSON, G. A.
1912. THE INFLUENCE OF AGE AND CONDITION OF THE TREE UPON SEED PRODUCTION IN WESTERN YELLOW PINE. U.S.Dept.Agr., Forest Serv. Circ. 196, 11 p.

(28) ———
1923. NATURAL REPRODUCTION OF WESTERN YELLOW PINE IN THE SOUTHWEST. U.S. Dept. Agr. Bul. 1105, 144 p., illus.

(29) ——— and FOLWEILER, A. D.
1927. ACCELERATION OF GROWTH IN WESTERN YELLOW PINE AFTER CUTTING. Jour. Forestry 25: 981–988.

(30) SHOW, S. B.
1925. YIELD CAPACITIES OF THE PURE YELLOW PINE TYPE ON THE EAST SLOPE OF THE SIERRA NEVADA MOUNTAINS IN CALIFORNIA. Jour. Agr. Research 31: 1121–1135, illus.

(31) ——— and GREELEY, W. B.
1926. TIMBER GROWING AND LOGGING PRACTICE IN THE CALIFORNIA PINE REGION. U.S. Dept. Agr. Bul. 1402, 75 p., illus.

(32) SMITH, K., and WEITKNECHT, R. H.
1915. WINDFALL DAMAGE IN SELECTION CUTTINGS IN OREGON. Soc. Amer. Foresters Proc. 10: 263–265.

(33) UNITED STATES DEPARTMENT OF AGRICULTURE, FOREST SERVICE
1927. AMERICAN FORESTS AND FOREST PRODUCTS. U.S. Dept. Agr. Statis. Bul. 21, 324 p. (revised, 1928).

(34) ———
1929. FOREST FIGURES—NORTH PACIFIC DISTRICT. U.S. Dept. Agr. Unnumbered Bul. 56 p.

(35) WEIDMAN, R. H.
1920. A STUDY OF WINDFALL LOSS IN WESTERN YELLOW PINE IN SELECTION CUTTINGS FIFTEEN TO THIRTY YEARS OLD. Jour. Forestry 18: 616–622.

(36) WOOLSEY, T. S.
1911. WESTERN YELLOW PINE IN ARIZONA AND NEW MEXICO. U.S.Dept. Agr., Forest Serv. Bul. 101, 64 p., illus.

APPENDIX

SUMMARY FORM USED FOR PLOT DATA

The following tabular statement illustrates the final summary form used in this study to give the complete picture of plot development.

Plot No. 52.—*Location, Odessa. Nat. For. Crater. Area, 2.0 acres. Yrs. cut, 20*

	Item			Stand value				
				Number trees	Basal area	Cubic feet	Board feet	Average d.b.h.
1	Original stand per A.	Pine		42.5	101.0	4,002	24,000	20.8
2		Others		2.5	10.6	524	3,424	27.8
3	Reserve stand per A.	Pine		20	42.7	1,520	8,361	17.4
4		Others		0				
5		Percent reserve		58	38	34	30	
6		Reserve composition by tree class, percent.	1	12		6	5	14.0
7			2	10		2		10.6
8			3	27		42	43	21.1
9			4	19		14	14	15.6
10			5	9		31	36	28.5
11			6	17		2		8.6
12			7	6		3	2	14.0
13	Increment since cutting.	M.A.I. by tree class per A.	1			2.4	12.8	
14			2			.8	0.6	
15			3			8.5	56.4	
16			4			4.0	21.8	
17			5			3.0	20.8	
18			6			.9	3.9	
19			7			.5	1.3	
20		Whole stand per A.				20.1	123.6	
21	Total loss since cutting per A.	Pine		2.5	3.72	124	609	16.5
22		Others		1.0	3.65	166	1,060	25.8
23	Net M.A.I. per A.	Pine				13.9	88.6	
24	Increment percentages since cutting.	By tree class	1			2.47	3.08	
25			2			2.79	22.37	
26			3			1.33	1.58	
27			4			1.84	1.86	
28			5			.63	.68	
29			6			3.16		
30			7			1.39	1.00	
31		Whole stand				1.32	1.45	
32	Decadal value per acre.	Decade after cutting	1		47.35	1,714	9,641	
33			2		52.30	1,922	10,833	
34			3					
35			4					
36			5					
37			6					
38	Value read from growth tables.	Decade after cutting	1		47.1	1,680	9,280	
39			2		52.5	1,875	10,560	
40			3					
41			4					
42			5					
43			6					
44	Reproduction	Pine		34				
45		Others by species		18				
46		Total		52	1.18	11.75		

VOLUME TABLES

Tables 25 to 39 are standard volume tables applicable to ponderosa pine through most of its range except on the very best sites, such as are not found in Oregon and Washington. Tables 27 to 30 give the cubic-foot volume of the entire bole inside bark for mature trees. Tables 31 to 34 and 36 to 39 give board-foot volume to an 8-inch top inside bark for mature trees. Tables 26 and 35 give cubic-foot and board-foot volume for immature trees or bull pine on site quality IV. Table 25 gives cubic-foot volumes applicable to the small sizes in reproduction stands. All the tables are based upon average form, and so will not apply with sufficient accuracy to certain stands that are unbalanced as to form classes. A partial remedy can be found in observing form-class averages. In general, the degree to which the volume of a tree departs from the average

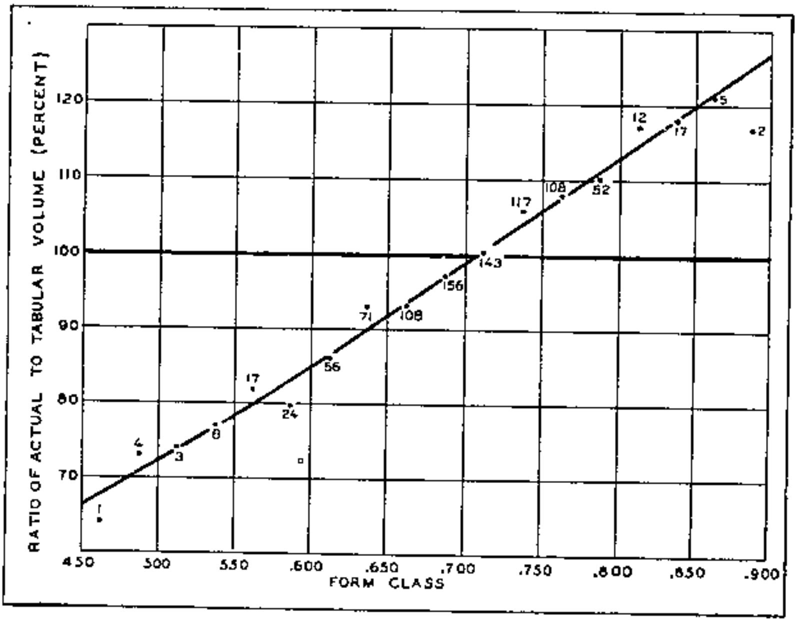


FIGURE 15.—Relation between form class and volume of the average ponderosa pine tree.

depends upon its form class or quotient, a ratio between the diameter inside bark at a point half-way between breast height and the tip and the diameter inside bark at breast height. (For instance, a form class of 0.70 on a tree that has a diameter at breast height inside bark of 15 inches and is 80 feet tall means that the diameter at $\frac{80-4.5}{2}$ feet above breast height or 42.3 feet above the ground is 0.70×15 inches, or 10.5 inches.) Figure 15 illustrates the relationship between form class and average volume. Tree class 1 averages about 0.675, classes 2 and 3 about 0.70, and class 4 about 0.725, although in each instance the range on either side of the average may be about 0.15 to 0.20. By determining the average form of 10 to 20 trees selected at random in a stand and using the correction percentage corresponding to it in figure 15, a more accurate estimate can be obtained.

CUBIC-FOOT VOLUMES

TABLE 25.—*Cubic-foot volume table for small-sized ponderosa pine in reproduction stands*

Diameter breast high (inches)	Volume (cubic feet) by total height of trees in feet						
	10	15	20	25	30	35	40
1	0.051	0.076	0.101	0.126	0.152	0.178	0.203
2	.137	.206	.275	.321	.412	.481	.550
3	.252	.380	.508	.635	.760	.880	1.02
4	.40	.60	.80	.99	1.20	1.39	1.59
5	.58	.86	1.16	1.45	1.74	2.02	2.32
6	.82	1.22	1.63	2.04	2.45	2.85	3.26
7	1.08	1.62	2.17	2.70	3.25	3.77	4.32
8	1.38	2.00	2.75	3.45	4.15	4.85	5.55
9	1.73	2.58	3.45	4.35	5.20	6.05	6.90
10	2.10	3.15	4.20	5.25	6.30	7.35	8.40

Data collected in reproduction stands in eastern Oregon and eastern Washington. Basis, 84 trees. Volume includes peeled stump, stem, and top. Tree volumes computed by planimeter method. Table prepared by form-factor method, 1930. Aggregate deviation from basic data, —0.11 percent.

TABLE 26.—*Cubic-foot volume table for second-growth ponderosa pine in eastern Oregon and eastern Washington; site quality IV*

Diameter breast high (inches)	Volume (cubic feet) by total height of tree in feet												
	30	40	50	60	70	80	90	100	110	120	130	140	150
5	1.4	2.1	2.6	3.1	3.3								
6	2.0	3.0	3.7	4.4	5.4								
7	2.7	4.0	5.0	6.0	7.2								
8	3.6	5.2	6.6	7.8	9.2								
9	4.6	6.6	8.2	9.8	11.7								
10	5.8	8.1	10.0	12.0	14.0								
11	7.2	9.9	12.1	14.5	16.8								
12	8.8	11.9	14.5	17.0	20.1								
13	10.1	13.9	16.6	20.1	23.8	26.0	30.0						
14	12.0	15.9	19.5	23.7	27.2	31.0	35.8						
15	13.9	18.2	22.8	27.0	31.9	35.5	40.0	45.0	50.5				
16	15.3	20.8	25.5	30.7	35.1	40.1	45.1	51.0	56.5	62.0			
17	17.0	23.5	28.9	34.2	39.5	45.1	51	57	63	70			
18	19.1	25.9	31.8	37.1	44	51	57	63	70	78	86		
19	22.5	29.0	35.0	41.2	48	56	63	70	78	87	96		
20	24.0	32.0	39.8	46.5	53	61	70	78	87	96	106	115	
21	26.0	35.0	43	51	59	67	77	86	95	105	115	125	136
22	28.9	38.5	47	56	65	74	84	94	104	114	125	136	149
23	31.2	41.5	51	61	71	81	92	103	113	124	138	148	162
24	33.5	45	56	66	77	88	99	111	123	136	150	161	175
25		50	61	72	84	96	107	120	133	147	162	176	189
26		54	66	78	92	104	116	130	145	159	176	189	205
27		58	71	85	100	112	125	140	156	172	188	205	220
28		63	77	92	107	121	135	151	168	185	200	220	240
29		68	84	100	115	130	145	162	181	198	215	235	250
30		73	90	107	124	140	156	174	193	211	230	250	264
31		79	96	115	133	150	167	186	206	225	240	262	280
32		84	103	122	141	160	180	199	218	239	258	276	296
33		90	110	130	150	170	190	210	231	252	272	290	305
34		95	116	137	159	180	200	220	242	265	285	300	315
35		100	121	145	168	190	210	230	252	275	295	310	325
36		105	127	152	177	199	220	240	262	285	305	320	340
37		110	134	159	186	207	230	255	273	295	315	330	350
38		116	141	167	195	215	240	265	285	305	325	345	365
39		123	148	176	205	225	250	275	297	315	340	360	380
40		130	155	185	215	235	260	285	310	330	350	370	390

Data collected in eastern Oregon. Basis, 767 trees. Volume includes peeled stump, stem, and top. Tree volumes computed by planimeter method. Table prepared by alinement-chart method, 1930. Aggregate deviation from basic data, —0.32 percent.

TABLE 27.—*Cubic-foot volume table for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain 8.6 to 10.0 logs, or medium and good site III, poor site II*

Diameter breast high (inches)	Volume (cubic feet) by total height of trees in feet																	
	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
4	0.75	1.4																
5	1.3	2.15																
6	1.9	3.0																
7	2.7	4.0	4.7															
8	3.6	5.1	6.1															
9	4.6	6.3	7.7	9.2	10.5													
10	5.6	7.7	9.5	11.2	13.0													
11	7.0	9.3	11.4	13.0	15.5													
12	8.1	10.9	13.4	15.8	18.5	21	24											
13	9.6	12.6	15.3	18.5	22.0	25	28											
14		14.3	18.0	22.0	25.5	29	32	36	40									
15		16.5	21	25.5	29.5	34	38	43	48									
16			24	28.5	33	38	44	49	54									
17			27	32	38	44	50	55	61	66	72	78						
18			30	36	43	49	56	62	68	75	82	89						
19			34	41	48	56	63	70	77	84	92	100						
20			37	45	53	62	69	77	85	93	102	110						
21			42	50	59	68	76	85	94	103	113	121	128	137				
22			46	55	65	75	84	94	104	113	123	132	140	150				
23			50	60	71	81	92	104	114	123	133	144	153	165				
24			55	66	77	89	101	112	124	134	145	156	167	180				
25			59	72	84	97	109	121	134	144	157	168	181	195				
26			64	78	91	106	118	130	144	156	170	182	195	210	225	240		
27			69	84	99	114	126	140	155	168	183	195	210	227	240	255		
28			74	91	107	122	136	150	167	181	196	211	228	246	260	275		
29			80	98	115	130	147	162	178	195	213	230	248	265	285	300		
30			85	105	122	139	157	174	190	207	230	246	265	285	305	320		
31					129	150	167	185	205	224	245	262	285	305	325	340	360	385
32					138	160	178	198	220	241	260	280	305	325	345	365	385	410
33					147	170	189	211	235	255	279	300	325	345	370	390	415	440
34					156	180	200	225	249	270	298	320	340	365	390	415	440	465
35					164	189	210	238	265	285	315	335	360	385	410	440	465	490
36					173	199	223	251	280	302	330	355	380	410	435	465	495	520
37					183	210	236	265	295	320	348	375	400	435	465	490	520	545
38					193	223	250	280	310	338	365	395	425	460	490	520	545	575
39					203	236	265	297	328	355	390	420	450	490	520	545	575	610
40					215	250	282	315	345	380	410	445	480	515	545	575	610	645
41									360	397	435	470	500	540	575	610	645	675
42									380	420	460	495	525	560	600	640	675	705
43									400	440	482	520	555	595	635	675	700	745
44									425	465	510	545	583	625	665	705	740	785
45									445	490	525	570	610	655	700	740	775	820
46									470	510	550	579	640	685	730	770	810	860
47									490	530	580	625	670	720	760	810	855	900
48									510	550	605	650	700	750	800	850	900	950
49									530	575	630	680	725	780	840	895	940	990
50									550	600	655	710	752	805	875	925	975	1,030
51									575	630	685	740	780	850	910	960	1,020	1,075
52									600	660	715	770	820	890	945	1,000	1,060	1,120
53									625	680	740	800	860	920	980	1,050	1,100	1,165
54									650	710	770	830	900	960	1,020	1,100	1,150	1,210
55									675	735	800	860	925	995	1,070	1,140	1,200	1,260
56									700	760	830	900	960	1,015	1,110	1,180	1,240	1,310
57									725	790	860	935	1,000	1,080	1,150	1,210	1,285	1,360
58									750	820	900	970	1,035	1,120	1,190	1,250	1,330	1,410
59									775	850	930	1,010	1,070	1,160	1,230	1,300	1,380	1,460
60									805	880	960	1,030	1,110	1,200	1,280	1,350	1,430	1,510
61									835	910	990	1,070	1,150	1,240	1,330	1,400	1,485	1,565
62									870	940	1,030	1,110	1,190	1,290	1,380	1,450	1,535	1,620
63									900	970	1,070	1,150	1,240	1,340	1,430	1,500	1,590	1,670
64									930	1,000	1,110	1,200	1,280	1,390	1,480	1,550	1,645	1,720
65									960	1,040	1,150	1,250	1,320	1,440	1,530	1,600	1,700	1,780

Data collected from Crater, Payette, Lassen, and Plumas National Forests. Basis, 392 trees. Volume includes peeled stump, stem, and top. Tree volumes computed by Huber's formula from taper curves Table prepared by alinement-chart method, 1930. Aggregate deviation from basic data, +0.70 percent.

TABLE 28.—*Cubic-foot volume table for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain 6.6 to 8.5 logs, or medium and good site IV, poor site III*

Diameter breast high (inches)	Volume (cubic feet) by total height of trees in feet: 20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170
4	0.3	0.7	1.3	1.8	2.3	2.6										
5	.5	1.2	2.0	2.8	3.5	4.0										
6	.8	1.8	2.9	4.0	4.9	5.7										
7	1.1	2.4	3.9	5.3	6.7	7.6										
8	1.5	3.2	5.1	6.9	8.6	9.8										
9	2.0	4.2	6.4	8.6	10.7	12.3										
10	2.6	5.2	8.0	10.6	13.0	15.0										
11		6.5	9.7	12.8	15.5	17.6										
12		7.8	11.5	15.2	18.0	21.0	21									
13		9.3	13.4	17.3	21.0	24.6	28									
14		10.6	15.3	20	24.5	28	32	36								
15		12.2	17.2	23	28	32	37	42								
16		13.8	19.3	26	31	37	42	48	53							
17		15.3	21.8	29	35	41	48	55	60							
18		16.7	24.4	32	40	46	54	61	68	74	81					
19		18.6	27	36	45	52	61	68	70	83	90					
20		20.5	30	40	50	58	67	75	84	93	101					
21		22.6	33	45	55	64	74	83	93	103	112					
22		25	36	49	60	70	81	90	102	112	122	132	142	150		
23		27	39	55	66	76	88	100	112	122	133	145	155	165		
24			43	59	72	84	97	110	122	134	145	158	170	180		
25			47	64	78	92	106	119	132	145	158	172	185	196		
26			51	69	85	100	114	129	112	156	172	186	200	211		
27			56	75	92	108	123	139	154	170	186	202	215	230		
28			61	82	100	117	134	150	167	184	200	217	230	249		
29			66	88	108	126	145	162	182	198	215	235	255	270		
30			70	95	116	135	155	175	191	212	230	252	272	289	308	
31				102	124	144	165	187	207	228	247	272	290	310	330	
32				109	132	153	177	200	220	243	266	290	310	332	354	
33				116	140	164	188	212	235	260	273	310	332	355	378	
34				122	149	174	200	225	250	276	300	330	354	375	400	
35				128	158	184	211	237	265	293	320	350	375	400	425	
36				135	167	195	222	252	282	310	340	370	396	428	450	
37					177	206	236	268	298	330	360	390	422	453	475	
38					188	210	255	295	320	352	384	420	450	480	505	
39					200	234	270	303	342	375	410	450	478	510	542	
40						249	285	322	362	398	435	474	505	540	570	600
41						262	300	343	382	421	460	498	535	570	600	640
42						275	320	360	405	443	482	525	560	595	640	680
43						290	338	380	428	466	508	550	590	630	665	715
44						305	356	400	450	488	530	580	620	660	700	750
45						320	372	420	468	510	558	610	650	690	735	785
46						337	390	440	488	535	585	640	685	725	775	820
47						355	410	460	510	560	615	665	715	760	810	860
48						370	430	480	532	585	640	690	750	800	845	900
49							450	500	555	615	665	720	780	835	880	940
50							470	520	580	642	695	760	815	865	920	980
51							490	545	605	670	730	795	850	905	960	1,020
52								570	632	695	760	832	885	945	990	1,060
53								590	652	725	790	863	920	980	1,030	1,100
54								610	682	750	825	895	955	1,010	1,070	1,140
55								630	708	785	855	930	990	1,045	1,110	1,180
56								650	735	815	885	960	1,020	1,085	1,150	1,220
57									770	850	915	990	1,050	1,125	1,190	1,260
58									805	880	950	1,030	1,090	1,170	1,230	1,310
59									835	920	985	1,070	1,140	1,210	1,280	1,370
60									870	950	1,025	1,110	1,185	1,250	1,335	1,425

Data collected from Crater, Salmon, Lassen, Whitman, Payette, Shasta, Weiser, Boise, Coconino, and Umatilla National Forests. Basis, 4,085 trees. Volume includes peeled stump, stem, and top. Tree volumes computed by Huber's formula from taper curves. Table prepared by alinement-chart method, 1930. Aggregate deviation from basic data, —0.0 percent.

TABLE 29.—*Cubic-foot volume table for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain 4.6 to 6.5 logs, or good site V, poor site IV*

Diameter breast high (inches)	Volume (cubic feet) by total height of trees in feet												
	30	40	50	60	70	80	90	100	110	120	130	140	150
5	2.0	2.4	3.0	3.7									
6	2.8	3.5	4.3	5.3									
7	3.7	4.8	5.8	7.2									
8	4.7	6.2	7.6	9.2									
9	5.9	7.8	9.6	11.5									
10	7.2	9.6	11.8	14.0									
11	8.7	11.3	14.0	17.0									
12	10.0	13.3	16.8	20.0	23.0	26							
13	11.8	15.6	19.1	23.0	26.7	30	34	38					
14	13.4	18.0	22.2	26.5	30.8	35	40	44	48	53	58		
15	15.5	20.5	25.5	30.5	35.2	40	46	51	56	62	67		
16	17.5	23.3	28.9	34.5	40	46	52	58	64	70	75	80	87
17	19.3	26.0	32	38.5	45	52	59	66	72	78	85	91	98
18	22.0	29.0	36	43	51	59	66	74	80	86	96	104	112
19	24.5	32.5	40	49	58	67	74	82	90	100	108	117	126
20	26.8	35.5	45	54	64	75	82	91	101	111	120	130	130
21	29.5	39	50	60	70	82	90	101	112	123	133	144	154
22	32	43	55	66	76	89	100	111	124	134	145	157	168
23	35	47	60	72	83	97	109	122	135	146	159	171	183
24	38	52	65	78	91	105	119	133	146	158	173	185	200
25	41	56	70	85	100	115	130	144	158	172	187	202	216
26	45	61	76	92	108	125	140	156	171	186	203	220	235
27			81	100	117	135	150	168	184	201	220	236	253
28			88	107	126	145	160	180	198	216	236	253	275
29			95	115	136	155	173	195	214	233	255	280	298
30			102	124	145	165	186	210	230	250	275	295	318
31			110	132	155	177	200	224	245	270	295	315	338
32			118	141	165	190	215	238	262	289	314	335	360
33			126	150	175	202	230	254	280	306	334	360	385
34			133	159	185	214	243	270	298	323	355	380	405
35			140	168	195	226	256	286	315	340	375	400	425
36			148	177	206	238	270	302	330	360	395	420	450
37			155	187	218	250	284	318	350	380	415	440	470
38			163	198	232	272	298	337	370	400	438	465	495
39			172	209	246	284	313	355	390	420	458	488	520
40			182	221	259	296	332	372	410	445	480	515	545
41			192	232	273	312	352	390	430	470	505	540	572
42				243	287	330	370	408	450	490	528	560	600
43				255	301	347	388	436	470	510	550	585	625
44				270	315	364	406	454	490	535	575	615	650
45				287	330	381	425	472	510	555	600	640	680
46				295	346	398	445	490	530	580	625	670	710
47				312	363	416	465	510	550	605	650	700	740
48				330	380	434	485	530	575	630	680	730	770
49					395	452	505	550	600	655	710	760	805
50					410	468	525	570	620	690	740	790	840
51					425	485	545	590	645	705	770	820	870
52					445	505	565	610	665	735	800	850	900
53					460	525	585	635	695	765	825	880	930
54					475	540	600	655	725	795	850	910	960
55					490	560	620	675	755	820	880	940	1,000
56					505	580	640	710	785	845	910	970	1,035
57					520	600	660	740	810	870	940	1,005	1,065
58					540	620	690	770	830	895	970	1,040	1,100
59					555	640	710	800	855	925	1,000	1,075	1,140
60					575	660	740	825	885	960	1,040	1,110	1,180

Data collected from Montezuma, Missoula, Carson, San Juan, Coconino, and Bitterroot National Forests. Basis, 6,176 trees. Volume includes peeled stump, stem, and top. Tree volumes computed by Huber's formula from taper curves. Table prepared by alinement-chart method, 1930. Aggregate deviation from basic data, +0.5 percent.

TABLE 30.—*Cubic-foot volume table for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain less than 4.5 logs, or site VI, poor and medium site V*

Diameter breast high (inches)	Volume (cubic feet) by total height of trees in feet									
	30	40	50	60	70	80	90	100	110	120
5	1.9	2.5	3.4							
6	2.8	3.6	4.9							
7	3.9	5.0	6.0							
8	5.4	6.6	8.4							
9	6.6	8.4	10.5							
10	8.4	10.2	12.8	15	17					
11	10.2	13.0	15.3	17	20					
12	13.0	15.5	17.6	20	24					
13	15.0	17.5	20.5	24	28					
14	17.0	19.5	23	28	33	38	43			
15	18.9	23	27	31	36	44	50			
16	21	26	30	36	42	50	58			
17	24	29	35	41	48	58	65			
18	27	32	39	46	55	65	73	82	90	
19	30	36	43	51	62	73	82	91	101	
20	33	40	47	57	69	80	90	102	113	123
21	37	44	52	64	76	88	100	113	124	134
22	40	49	58	70	83	96	110	123	135	146
23	43	54	64	76	90	106	120	133	146	158
24	47	59	70	83	99	116	129	145	158	173
25			76	90	108	124	139	155	171	188
26			82	97	116	134	150	167	185	204
27			88	105	124	144	160	180	200	220
28			95	114	132	154	174	194	214	235
29			102	122	141	164	187	210	230	250
30			109	130	152	177	200	223	245	268
31			117	137	160	189	213	237	260	284
32			125	145	170	200	225	252	278	304
33			132	154	182	211	235	270	295	325
34			138	162	190	223	250	285	311	344
35			145	170	200	235	270	300	330	360
36			152	180	213	247	285	315	345	380
37			159	190	225	265	298	335	365	400
38			166	200	235	280	312	350	385	420
39			176	212	245	296	335	370	405	440
40			187	223	255	310	350	390	428	460

Data collected from Custer and Black Hills National Forests. Basis, 818 trees. Volume includes peeled stump, stem, and top. Tree volumes computed by Huber's formula from taper curves. Table prepared by alinement-chart method, 1930. Aggregate deviation from basic data, +0.2 percent.

BOARD-FOOT VOLUMES, SCRIBNER RULE

TABLE 31.—*Board-foot volume table (Scribner rule—total height) for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain 8.6 to 10.0 logs, or medium and good site III, poor site II*

Diameter breast high (inches)	Volume (board feet) by total height of trees in feet															
	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
10	23	37	54													
11	28	45	65													
12	34	55	78	103												
13	41	66	91	121												
14	49	78	108	141	173											
15	57	92	127	163	198	240										
16	66	107	146	187	226	270	310									
17	76	123	168	213	257	305	350	390	420	445						
18	87	140	191	240	290	345	395	435	470	500						
19	99	158	214	269	324	385	440	485	525	555						
20	112	178	240	301	360	430	490	540	585	620						
21	125	198	267	335	400	450	540	600	650	690	725	765				
22	139	219	295	370	445	530	600	660	720	760	800	845				
23	156	242	325	410	485	580	660	725	790	835	880	925				
24	173	266	355	450	535	635	725	795	870	915	970	1,020				
25	191	290	390	490	585	695	790	865	950	1,000	1,070	1,120				
26	211	315	430	535	640	755	860	945	1,040	1,110	1,175	1,230	1,310	1,380		
27	232	345	465	580	700	820	935	1,035	1,130	1,220	1,290	1,350	1,440	1,520		
28	253	370	505	630	760	875	1,020	1,130	1,240	1,330	1,410	1,480	1,570	1,660		
29	276	400	550	680	825	955	1,115	1,230	1,350	1,450	1,540	1,625	1,710	1,810		
30	300	435	595	740	890	1,040	1,210	1,340	1,470	1,580	1,675	1,775	1,860	1,970		
31			640	800	960	1,130	1,310	1,450	1,590	1,710	1,820	1,925	2,020	2,140	2,275	2,410
32			690	860	1,040	1,220	1,415	1,570	1,720	1,850	1,970	2,075	2,190	2,320	2,465	2,600
33			740	925	1,120	1,315	1,520	1,690	1,850	2,000	2,120	2,240	2,370	2,510	2,655	2,820
34			800	1,000	1,210	1,420	1,630	1,820	1,990	2,150	2,280	2,420	2,560	2,710	2,860	3,035
35			855	1,075	1,300	1,525	1,750	1,960	2,140	2,315	2,450	2,610	2,760	2,920	3,080	3,260
36			920	1,150	1,390	1,630	1,880	2,100	2,290	2,480	2,620	2,800	2,960	3,140	3,300	3,500
37			980	1,230	1,490	1,740	2,010	2,240	2,450	2,650	2,800	2,990	3,175	3,360	3,540	3,750
38			1,055	1,320	1,590	1,860	2,140	2,380	2,620	2,825	2,990	3,180	3,390	3,590	3,790	4,000
39			1,130	1,410	1,695	1,980	2,275	2,530	2,790	3,000	3,180	3,380	3,610	3,825	4,040	4,260
40			1,205	1,500	1,810	2,110	2,410	2,680	2,965	3,200	3,380	3,600	3,840	4,065	4,290	4,520
41							2,550	2,840	3,140	3,375	3,585	3,825	4,080	4,320	4,550	4,790
42							2,690	3,000	3,320	3,575	3,800	4,050	4,320	4,580	4,820	5,080
43							2,845	3,170	3,500	3,775	4,020	4,280	4,570	4,850	5,100	5,380
44							3,000	3,340	3,680	3,975	4,240	4,530	4,830	5,120	5,390	5,680
45							3,155	3,520	3,870	4,190	4,470	4,780	5,100	5,390	5,690	6,000
46							3,310	3,690	4,070	4,405	4,700	5,040	5,380	5,680	6,000	6,320
47							3,470	3,870	4,270	4,620	4,930	5,320	5,660	6,000	6,320	6,670
48							3,630	4,050	4,470	4,840	5,175	5,600	5,960	6,320	6,650	7,020
49							3,795	4,260	4,680	5,070	5,430	5,880	6,260	6,640	6,990	7,370
50							3,970	4,470	4,900	5,300	5,680	6,160	6,560	6,960	7,330	7,720
51							4,145	4,680	5,120	5,530	5,930	6,440	6,860	7,280	7,670	8,070
52							4,320	4,890	5,340	5,770	6,200	6,720	7,160	7,610	8,010	8,445
53							4,510	5,100	5,560	6,010	6,475	7,000	7,470	7,940	8,410	8,820
54							4,700	5,310	5,800	6,250	6,750	7,280	7,790	8,280	8,780	9,105
55							4,890	5,520	6,040	6,500	7,025	7,570	8,110	8,620	9,160	9,570
56							5,080	5,730	6,280	6,800	7,300	7,860	8,430	8,960	9,540	9,915
57							5,280	5,950	6,520	7,100	7,580	8,150	8,750	9,300	9,930	10,320
58							5,490	6,160	6,760	7,350	7,880	8,450	9,070	9,650	10,250	10,700
59							5,700	6,470	7,000	7,600	8,180	8,760	9,390	10,100	10,600	11,100
60							5,900	6,690	7,240	7,850	8,480	9,070	9,710	10,450	10,950	11,500
61							6,100	6,900	7,480	8,100	8,780	9,350	10,030	10,800	11,300	11,900
62							6,300	7,050	7,730	8,350	9,080	9,690	10,380	11,150	11,650	12,300
63							6,500	7,270	7,980	8,600	9,380	10,000	10,700	11,450	12,000	12,700
64							6,700	7,480	8,230	8,850	9,690	10,330	11,050	11,750	12,350	13,100
65							6,900	7,710	8,480	9,150	10,000	10,670	11,400	12,100	12,700	13,500

Data collected from Crater, Payette, Lassen, and Plumas National Forests. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance. Top utilization, 8 inches inside bark. Table prepared by adjusting table 36 for top length, 1930.

TABLE 32.—*Board-foot volume table (Scribner rule—total height) for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain 6.6 to 8.5 logs, or medium and good site IV, poor site III*

Diameter breast high (inches)	Volume (board feet) by total height of trees in feet												
	50	60	70	80	90	100	110	120	130	140	150	160	170
10	18	32	45										
11	26	42	59										
12	33	52	75	110									
13	41	65	94	128									
14	50	78	114	150	180								
15	60	92	133	174	206								
16	71	108	154	198	235	278							
17	84	125	177	225	268	318							
18	97	143	200	254	302	360	407	442					
19	110	162	225	284	338	402	452	498					
20	124	184	252	315	380	450	505	560					
21	138	208	280	350	423	500	565	621					
22	154	233	312	387	466	555	630	690	750	790	840		
23	171	257	345	427	512	610	692	760	825	872	925		
24	190	282	380	470	565	675	762	840	910	960	1,030		
25	210	310	415	515	622	738	837	925	1,000	1,070	1,140		
26	232	340	455	562	682	810	910	1,015	1,100	1,180	1,260		
27	254	372	496	615	744	880	995	1,115	1,210	1,300	1,380		
28	278	400	540	669	808	955	1,080	1,220	1,325	1,425	1,510		
29	304	442	584	726	875	1,035	1,180	1,325	1,445	1,550	1,650		
30	332	482	632	793	951	1,130	1,290	1,435	1,575	1,695	1,790	1,880	
31	360	524	687	856	1,025	1,220	1,400	1,560	1,710	1,840	1,945	2,040	
32	390	568	737	918	1,115	1,320	1,515	1,685	1,840	1,980	2,100	2,210	
33	420	615	795	988	1,200	1,425	1,635	1,815	1,975	2,130	2,260	2,380	
34	455	664	860	1,060	1,300	1,535	1,755	1,960	2,115	2,285	2,430	2,570	
35	495	710	920	1,140	1,400	1,645	1,890	2,100	2,265	2,455	2,600	2,770	
36	531	773	988	1,225	1,500	1,755	2,020	2,240	2,425	2,620	2,775	2,970	
37		832	1,058	1,315	1,600	1,875	2,160	2,380	2,590	2,790	2,965	3,170	
38		895	1,130	1,410	1,700	2,000	2,300	2,530	2,765	2,970	3,165	3,370	
39		958	1,205	1,510	1,810	2,120	2,440	2,690	2,945	3,155	3,365	3,590	
40			1,280	1,600	1,925	2,240	2,580	2,850	3,125	3,340	3,570	3,810	4,050
41			1,355	1,700	2,010	2,365	2,715	3,020	3,305	3,530	3,780	4,030	4,300
42			1,435	1,800	2,150	2,490	2,855	3,200	3,485	3,730	3,990	4,260	4,550
43			1,520	1,900	2,260	2,620	3,000	3,370	3,675	3,940	4,200	4,500	4,800
44			1,600	2,000	2,375	2,750	3,150	3,550	3,875	4,150	4,420	4,750	5,050
45			1,685	2,100	2,490	2,880	3,300	3,725	4,080	4,360	4,640	5,000	5,320
46			1,770	2,200	2,600	3,015	3,460	3,900	4,290	4,575	4,880	5,250	5,600
47			1,860	2,300	2,720	3,160	3,625	4,080	4,490	4,800	5,130	5,500	5,900
48			1,950	2,410	2,850	3,310	3,785	4,270	4,700	5,035	5,390	5,775	6,200
49				2,520	2,980	3,450	3,950	4,470	4,910	5,275	5,650	6,050	6,500
50				2,630	3,110	3,600	4,120	4,680	5,125	5,500	5,910	6,330	6,800
51				2,745	3,250	3,760	4,290	4,870	5,340	5,730	6,180	6,610	7,100
52					3,400	3,930	4,470	5,070	5,550	5,960	6,450	6,890	7,400
53					3,550	4,100	4,660	5,280	5,790	6,210	6,730	7,190	7,700
54					3,690	4,270	4,850	5,490	6,030	6,460	7,020	7,500	8,000
55					3,840	4,440	5,030	5,695	6,260	6,710	7,310	7,810	8,300
56					3,980	4,615	5,210	5,900	6,480	6,970	7,600	8,100	8,600
57					4,130	4,795	5,400	6,110	6,700	7,240	7,890	8,400	8,950
58						4,975	5,600	6,330	6,940	7,520	8,170	8,700	9,300
59						5,155	5,800	6,550	7,180	7,800	8,440	8,990	9,650
60						5,330	6,000	6,770	7,430	8,080	8,700	9,250	9,950

Data collected from Crater, Salmon, Lassen, Whitman, Payette, Shasta, Weiser, Boise, Coconino, and Umatilla National Forests. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance. Top utilization, 8 inches inside bark. Table prepared by adjusting table 37 for top length, 1930.

TABLE 33.—*Board-foot volume table (Scribner rule—total height) for mature ponderosa pine: sites on which the tallest 10 percent of the trees contain 4.6 to 6.5 logs, or good site V, poor site IV*

Diameter breast high (inches)	Volume (board feet) by total height of trees in feet											
	40	50	60	70	80	90	100	110	120	130	140	150
10	18	30	44	63								
11	23	36	54	76	95	117	140	160				
12	28	44	65	91	112	139	166	190	215	236		
13	34	52	78	107	135	164	194	222	250	274		
14	40	62	92	125	158	192	226	260	290	317		
15	47	72	108	147	186	224	260	298	332	366		
16	54	84	125	170	215	258	300	344	382	420	465	515
17	63	96	145	195	247	296	340	392	438	480	535	590
18	72	108	165	220	279	335	385	445	494	545	605	670
19	82	125	187	250	315	375	439	500	560	615	685	755
20	92	142	212	282	355	425	494	565	630	692	770	855
21		160	237	314	395	475	552	630	702	772	860	955
22		178	266	352	440	530	615	702	785	860	960	1,060
23		200	295	390	480	585	682	780	870	955	1,070	1,170
24		222	328	430	537	650	756	865	965	1,065	1,180	1,290
25		244	362	470	593	715	832	950	1,060	1,175	1,290	1,410
26		267	397	517	650	785	920	1,045	1,160	1,285	1,410	1,540
27		292	432	568	708	860	1,010	1,145	1,270	1,400	1,540	1,670
28		318	470	618	768	940	1,095	1,240	1,385	1,525	1,670	1,820
29		346	510	670	830	1,020	1,185	1,340	1,500	1,655	1,800	1,970
30		376	557	728	895	1,100	1,280	1,450	1,640	1,790	1,950	2,120
31		406	602	780	965	1,180	1,375	1,560	1,760	1,935	2,100	2,270
32		440	647	840	1,035	1,265	1,470	1,680	1,885	2,075	2,250	2,430
33		474	695	900	1,110	1,350	1,570	1,800	2,020	2,220	2,400	2,600
34		510	745	965	1,190	1,440	1,675	1,920	2,160	2,365	2,550	2,770
35			797	1,035	1,265	1,530	1,785	2,050	2,300	2,520	2,725	2,960
36			848	1,100	1,345	1,620	1,900	2,180	2,440	2,675	2,900	3,140
37			900	1,165	1,420	1,715	2,015	2,310	2,585	2,840	3,075	3,330
38			955	1,225	1,500	1,815	2,130	2,440	2,735	3,005	3,250	3,530
39			1,010	1,295	1,580	1,920	2,250	2,575	2,885	3,175	3,430	3,720
40			1,065	1,365	1,670	2,025	2,370	2,710	3,040	3,345	3,615	3,920
41			1,120	1,440	1,765	2,130	2,490	2,845	3,200	3,515	3,805	4,120
42			1,175	1,510	1,855	2,240	2,615	2,980	3,360	3,695	4,000	4,320
43			1,235	1,580	1,950	2,350	2,745	3,125	3,520	3,875	4,200	4,510
44			1,300	1,655	2,045	2,460	2,875	3,275	3,680	4,055	4,400	4,700
45			1,365	1,730	2,140	2,575	3,010	3,425	3,845	4,235	4,600	4,900
46			1,430	1,810	2,235	2,690	3,145	3,575	4,015	4,420	4,810	5,230
47			1,495	1,890	2,340	2,810	3,280	3,730	4,185	4,610	5,030	5,480
48			1,560	1,975	2,445	2,935	3,425	3,890	4,360	4,800	5,250	5,710
49			1,630	2,060	2,550	3,065	3,575	4,050	4,540	5,000	5,480	5,960
50			1,700	2,145	2,660	3,195	3,725	4,215	4,720	5,210	5,710	6,210
51			1,770	2,225	2,770	3,320	3,875	4,385	4,900	5,420	5,940	6,460
52				2,310	2,880	3,450	4,020	4,560	5,090	5,640	6,180	6,730
53				2,400	2,990	3,580	4,175	4,740	5,280	5,860	6,420	7,000
54				2,490	3,100	3,725	4,330	4,920	5,470	6,080	6,670	7,270
55				2,590	3,210	3,860	4,490	5,105	5,680	6,300	6,920	7,530
56					3,320	4,000	4,650	5,300	5,890	6,520	7,170	7,800
57					3,435	4,140	4,810	5,495	6,100	6,750	7,425	8,070
58					3,555	4,280	4,980	5,685	6,320	6,990	7,680	8,370
59					3,675	4,420	5,140	5,870	6,520	7,220	7,950	8,690
60					3,795	4,560	5,300	6,050	6,740	7,450	8,220	8,960

Data collected from Montezuma, Missoula, Carson, San Juan, Coconino, and Bitterroot National Forests. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance. Top utilization, 8 inches inside bark. Table prepared by adjusting table 38 for top length, 1930.

TABLE 34.—*Board-foot volume table (Scribner rule—total height) for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain less than 4.5 logs, or site VI, poor and medium site V*

Diameter breast high (inches)	Volume (board feet) by total height of trees in feet								
	40	50	60	70	80	90	100	110	120
10	16	26	41	58					
11	21	33	52	74					
12	26	40	66	91					
13	31	50	82	110					
14	38	61	100	130	170	200			
15	46	73	117	154	196	235			
16	55	87	135	175	227	270			
17	66	101	155	207	260	305			
18	78	117	177	236	295	348	410	470	
19	91	134	200	208	334	395	465	538	
20	104	152	226	304	378	450	520	605	675
21	116	170	253	340	425	505	595	675	752
22	130	192	283	380	475	565	660	750	840
23	144	214	315	420	528	630	730	830	930
24	158	237	350	465	585	700	815	915	1,025
25		262	385	512	645	770	895	1,005	1,125
26		288	425	562	705	845	980	1,100	1,225
27		314	465	615	765	920	1,070	1,190	1,325
28		342	505	670	825	1,000	1,160	1,280	1,430
29		371	548	727	890	1,080	1,250	1,385	1,540
30		400	595	782	956	1,160	1,340	1,485	1,655
31		429	640	837	1,025	1,240	1,435	1,590	1,775
32		458	685	895	1,100	1,320	1,535	1,700	1,900
33		488	735	955	1,170	1,400	1,640	1,815	2,025
34		520	790	1,015	1,240	1,490	1,745	1,935	2,150
35		552	840	1,080	1,315	1,585	1,850	2,060	2,275
36		587	895	1,145	1,390	1,680	1,950	2,180	2,400
37		627	950	1,210	1,470	1,775	2,070	2,300	2,530
38		675	1,005	1,275	1,555	1,875	2,175	2,425	2,665
39		712	1,060	1,345	1,645	1,970	2,280	2,555	2,800
40		755	1,125	1,420	1,730	2,070	2,390	2,680	2,935

Data collected from Custer and Black Hills National Forests. Stump height 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance. Top utilization, 8 inches inside bark. Table prepared by adjusting table 39 for top length, 1930.

TABLE 35.—*Board-foot volume tables (Scribner rule—merchantable height) for second-growth ponderosa pine; site IV, eastern Oregon and eastern Washington*

Diameter breast high (inches)	Volume (board feet) by total number of 16-foot logs									
	1	2	3	4	5	6	7	8	9	10
8	20	50	80							
9	20	50	85							
10	20	55	90							
11	25	55	95	135						
12	25	60	105	145						
13	25	65	110	160						
14	25	70	120	180	230					
15	25	75	135	200	255	325				
16	25	85	145	220	285	360				
17	25	90	160	240	320	400				
18	30	100	175	260	355	445	540			
19	30	110	195	285	390	490	590			
20	30	115	215	315	425	535	645			
21	30	125	235	340	465	585	700			
22	30	135	255	370	510	635	760	920		
23	30	150	275	405	555	690	830	1,000		
24	35	160	300	440	600	745	900	1,075		
25	35	175	325	480	645	805	970	1,160		
26	35	190	350	520	695	865	1,040	1,245	1,460	
27	35	205	375	560	745	930	1,120	1,335	1,560	
28	40	220	400	600	800	1,000	1,205	1,430	1,660	
29	45	235	430	640	860	1,070	1,295	1,530	1,760	
30	45	255	460	685	920	1,140	1,385	1,635	1,870	2,140
31		275	490	730	980	1,215	1,480	1,740	1,985	2,265
32		295	515	775	1,040	1,290	1,575	1,845	2,100	2,395
33			545	820	1,100	1,365	1,670	1,955	2,225	2,525
34			575	870	1,165	1,445	1,765	2,065	2,355	2,660
35			605	920	1,230	1,525	1,860	2,175	2,485	2,795

TABLE 35.—*Board-foot volume tables (Scribner rule—merchantable height) for second-growth ponderosa pine; site IV, eastern Oregon and eastern Washington*—Continued

Diameter breast high (inches)	Volume (board feet) by total number of 16-foot logs									
	1	2	3	4	5	6	7	8	9	10
36			630	970	1,295	1,600	1,960	2,285	2,610	2,935
37			660	1,015	1,360	1,680	2,055	2,395	2,740	3,060
38			690	1,060	1,430	1,760	2,150	2,505	2,870	3,225
39			720	1,115	1,500	1,840	2,250	2,615	3,000	3,375
40			750	1,160	1,565	1,920	2,350	2,725	3,125	3,530
41			780	1,210	1,635	2,000	2,445	2,840	3,255	3,690
42			810	1,260	1,700	2,090	2,545	2,950	3,385	3,860

Data collected from Wallowa and Whitman National Forests. Basis, 186 trees. Stump height, 1.5 feet. Trees scaled in 16-foot lengths with 0.3-foot trimming allowance. Top utilization, 6 to 9 inches inside bark. Table prepared by frustum form factor method, 1925. Aggregate deviation from basic data, −0.69 percent.

TABLE 36.—*Board-foot volume table (Scribner rule—merchantable height) for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain 8.6 to 10.0 logs, or medium and good site III, poor site II*

Diameter breast high (inches)	Volume (board feet in tens) by total number of 16-foot logs											Basis (trees)
	1½	2	3	4	5	6	7	8	9	10	11	
10	3	6	10	14	18							
12	4	7	12	17	22							5
14	5	8	14	21	27	33						2
16	6	10	17	25	33	40	47	54	60			23
18	7	11	20	30	39	48	56	66	73			38
20		13	24	36	47	58	69	80	90			64
22		15	28	42	55	70	82	96	109			49
24		17	33	49	65	82	98	115	130			86
26		20	38	58	76	96	116	136	154			77
28		23	44	67	89	113	138	159	182	205		98
30			51	77	102	131	158	185	212	240		100
32			58	88	118	151	182	213	244	275	306	98
34			66	100	135	172	208	242	278	313	351	80
36			76	113	154	196	236	276	316	358	397	59
38			85	127	173	220	265	309	355	402	447	41
40				142	193	246	295	346	398	448	498	59
42				158	214	273	328	385	438	498	552	46
44				175	238	300	363	424	485	552	610	24
46				192	261	330	398	466	532	605	672	21
48				210	286	361	430	510	583	664	734	21
50				229	311	392	473	554	636	722	802	14
52				247	337	427	515	603	691	783	873	4
54				266	363	462	555	649	746	845	943	6
56						497	599	698	802	907	1,010	1
58						534	642	747	858	969	1,080	1
60						572	687	803	916	1,030	1,160	2
62						610	731	857	977	1,100	1,240	
64						648	775	914	1,040	1,180	1,320	
66						687	820	969	1,100	1,250	1,400	1
68						727	869	1,020	1,170	1,320	1,470	
70						766	921	1,080	1,230	1,390	1,550	
72						805	975	1,130	1,300	1,460	1,630	
Basis (trees)		12	18	95	170	250	192	192	73	15	3	1,020

Block indicates extent of basic data. Data collected from Crater, Payette, Lassen, and Plumas National Forests. Stump height, 1.5 feet. Trees scaled in 16-foot logs with 0.3-foot trimming allowance. Top utilization, 8 inches inside bark. Table prepared by frustum form factor method, 1928. Aggregate deviation from basic data, −0.4 percent. Average deviation, 13.0 percent.

TABLE 37.—*Board-foot volume table (Scribner rule—merchantable height) for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain 6.6 to 8.5 logs, or medium and good site IV, poor site III*

Diameter breast high (inches)	Volume (board feet in tens) by total number of 16-foot logs										Basis (trees)
	1¼	2	3	4	5	6	7	8	9	10	
10	3	6	10	14							3
12	4	7	12	17	22						56
14	5	8	15	21	27	34					123
16	6	10	18	26	34	41	49				201
18	7	12	21	31	40	49	59				332
20	8	13	25	37	48	60	72				421
22	9	16	30	44	58	73	86	100			565
24	10	18	35	52	70	87	104	121			605
26		21	41	61	81	102	123	145	165		548
28		24	47	71	95	120	145	170	195		560
30		28	55	82	110	140	169	199	227		370
32		32	63	94	126	162	195	220	261		371
34		36	71	107	145	184	222	260	298	335	273
36		40	80	122	164	209	251	295	336	381	207
38		45	90	136	184	234	282	328	375	425	123
40			100	151	204	260	313	365	417	471	97
42			110	167	226	286	345	402	460	523	42
44				184	250	315	380	443	509	576	32
46				201	272	345	415	485	556	633	16
48				219	297	375	453	530	608	692	7
50				237	322	408	490	575	659	748	4
52				256	340	441	531	624	714	818	3
54				275	375	475	573	671	770	870	
56					402	510	616	723	827	934	
58					431	546	660	771	882	995	1
60					460	584	704	823	937	1,060	
62					480	622	749	875	997	1,130	
64					510	661	794	932	1,060	1,200	
66					550	701	840	992	1,120	1,280	
Basis (trees)	12	102	338	663	1,257	1,449	891	219	27	2	4,960

Block indicates extent of basic data. Data collected from Crater, Salmon, Lassen, Whitman, Payette, Shasta, Weiser, Boise, Coconino, and Umatilla National Forests. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance. Top utilization, 8 inches inside bark. Table prepared by frustum form factor method, 1928. Aggregate deviation, +0.4 percent. Average deviation, 14.8 percent.

TABLE 38.—*Board-foot volume table (Scribner rule—merchantable height) for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain 4.6 to 6.5 logs, or good site V, poor site IV*

Diameter breast high (inches)	Volume (board feet in tens) by total number of 16-foot logs								Basis (trees)
	1¼	2	3	4	5	6	7	8	
10	3	6	10						36
12	4	7	12	18					398
14	5	9	15	22	28				603
16	6	10	18	27	34	42			770
18	7	12	22	32	42	52			855
20	8	14	26	39	51	64	75		835
22	10	17	31	46	62	78	91		802
24	11	20	37	56	74	94	112		773
26		23	44	66	89	112	134		651
28		27	52	78	105	132	160	186	508
30		31	60	90	121	154	187	218	379
32		35	68	103	139	177	214	250	278
34		39	77	116	157	200	242	282	157
36		43	87	129	176	224	270	315	97
38		48	95	144	195	248	297	348	54
40			104	156	215	272	326	382	29
42			114	173	235	298	357	417	23
44			124	189	257	325	391	455	12
46			135	205	279	353	425	495	9
48				223	303	384	462	538	8
50				240	328	415	500	583	5
52				259	354	449	540	632	1
54				278	380	483	580	678	
56				298	408	518	622	727	
58				319	435	554	665	777	2
60				340	462	590	710	830	
62				361	491	627	755	884	
64				382	520	668	800	939	
Basis (trees)	143	593	2,066	2,545	1,542	348	50	4	7,291

Block indicates extent of basic data. Data collected from Montezuma, Missoula, Carson, San Juan, Coconino, and Bitterroot National Forests. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance. Top utilization, 8 inches inside bark. Table prepared by frustum form factor method, 1928. Aggregate deviation from basic data, −0.6 percent. Average deviation, 14.8 percent.

TABLE 39.—*Board-foot volume table (Scribner rule—merchantable height) for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain less than 4.5 logs, or site VI, poor and medium site V*

Diameter breast high (inches)	Volume (board feet in tens) by total number of 16-foot logs						Basis (trees)
	1¼	2	3	4	5	6	
10	4	6					8
12	4	8	13				134
14	5	9	16	24			151
16	6	11	19	28	37		178
18	8	13	23	34	45	56	126
20	9	15	28	42	55	68	108
22	10	18	34	51	67	84	57
24	12	21	41	61	81	102	30
26		25	48	72	96	121	4
28		29	56	84	112	142	2
30		33	64	96	128	164	
32		37	72	108	146	186	
34		41	81	121	165	209	
36		45	89	134	183	233	
38		49	98	148	202	257	
40		54	107	163	221	282	
Basis (trees)	19	165	325	247	41	1	798

Block indicates extent of basic data. Data collected from Custer and Black Hills National Forests. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance. Top utilization, 8 inches. Table prepared by frustum form factor method, 1928. Aggregate deviation from basic data, +0.6 percent. Average deviation, 15 percent.

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