GROWTH OF SELECTIVELY CUT PONDEROSA PINE STANDS IN THE UPPER COLUMBIA BASIN

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INTRODUCTION

Timber-management planning for the sustained production of ponderosa pine requires a knowledge of growth rates, responses to cutting, desirable cutting cycles, cutting practices, and regeneration requirements. In recent years, partial cutting has been widely practiced in ponderosa pine forests,[1] shorter cutting cycles have been viewed with more favor, and residual trees selected with considerable care. These practices result, of course, in uneven-aged residual stands to which normal yield tables for even-aged timber do not apply. Because forest managers have expressed a need for information that will help them predict growth for selectively cut uneven-aged ponderosa pine, data obtained from a study of western Montana stands are presented here. It is believed, however, that these data apply equally well to stands in eastern Washington, north Idaho, and British Columbia.

The growth of uneven-aged ponderosa pine has been studied by several methods. Krauch (*7*)[2] used a diameter-accretion method by which growth was computed for individual trees, and the aggregate represented stand growth. While this method accounted for variation in individual tree growth, other important variables were not considered. Hanzlik (*3*) adapted "growth percent" to predicting increment for residual stands, but concluded that it

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[1] Presentation of this report is not necessarily an endorsement of partial cutting in mature and overmature ponderosa pine.

[2] Italic numbers in parentheses refer to Literature Cited, on inside of back cover.

could not be used to predict future volume accurately since it is a function that decreases as age increases. He reduced the error from this source by introducing the principle of interpolating for future growth percent. Dunning (*2*) applied growth percent to residual trees in four vigor groups, which he had classified according to external characteristics.

Later studies were based on correlations that included a larger number of variables. Thus, Meyer (*9*) showed that growth after logging varies by size of reserve stand, elapsed time since logging, site quality, stand structure, degree of release, and mortality. Lexen (*8*) found a significant correlation between growth of the reserve stand and average diameter of the trees; ingrowth from pole-size trees was not considered to be important in the first cutting cycle. Initial reserve volume and elapsed time since cutting were highly important variables in preliminary yield tables developed by Hornibrook (*4*) for selectively cut stands in the Black Hills; site, number of poles in the reserve stand, and stand structure were also considered. And Briegleb (*1*) computed growth rate for individual trees in virgin stands in the Pacific Northwest by diameter and Keen tree classes (*6*), and converted the results to stand growth rates following logging. These rates were then adjusted according to factors derived from basic growth measurements made by Meyer in selectively cut stands: stand density and release (percent of stand cut), site quality, number and size of pole trees in the reserve stand, and mortality. Thus, the past studies show that growth of residual stands depends on many factors.

Basic data for this study were obtained during the 1947 field season on 60 half-acre, temporary, sample plots on 21 cut-over areas located throughout western Montana. The sampled stands ranged in volume from approximately 500 to 10,000 board feet an acre. Because growth was considered only for stands that had been cut once, it is not known to what extent the data apply to reserve stands after repeated cuts. Elapsed time since cutting on the sample plots varied from 5 to 50 years: 2 plots, 5 years; 9 plots, 10 years; 6 plots, 15 years; 5 plots, 20 years; 6 plots, 25 years; 11 plots, 30 years; 3 plots, 35 years; 5 plots, 40 years; 13 plots, 50 years.

The following information was recorded for each half-acre plot:

1. Diameter of all trees 7.6 inches in diameter at breast height and larger, measured with a tape.
2. Total height of all trees 7.6 inches d. b. h. and larger, measured with Abney level and tape.
3. Merchantable heights of all trees 10 inches d. b. h. and larger, measured with an Abney level and tape.
4. Increment by 5-year periods, for 20 years before logging as well as for all elapsed time after logging, averaged for cores from two opposite sides of all trees, 7.6 inches d. b. h. and larger.
5. Keen tree class of all ponderosa pine trees 7.6 inches d. b. h. and larger, estimated at the time of examination.
6. Keen tree class at the time of logging, estimated for all ponderosa pine trees 7.6 inches d. b. h. and larger.

7. Vigor and tree description of all trees other than ponderosa pine 7.6 inches d. b. h. and larger.
8. Species of all stumps.
9. Diameter and height of all stumps, measured with a tape.
10. D. b. h. and merchantable length of bole of all logged trees, measured with tape where these dimensions could be determined from stumps, long butts, top remains, or other evidences.
11. Species of all post-logging dead trees 7.6 inches d. b. h. and larger.
12. D. b. h. and total and merchantable length of all post-logging dead trees, measured with a tape.
13. Time of death to nearest 5 years, and cause of death where possible to determine, for all post-logging dead trees.
14. Site index, determined from trees dominant or codominant prior to cutting, or very young unsuppressed trees in more heavily cut stands.

On smaller plots within the half-acre sampling units, the following additional data were obtained:

1. Diameters and species of pole-size trees on $\frac{1}{10}$-acre plots.
2. Sizes, ages, and species of saplings and seedlings on five 4-milacre plots distributed around the centers of the major plot locations.

As a result of this study, yield tables have been constructed from which two kinds of estimates can be made: (1) A general estimate of growth for residual stands on areas where typical or average conditions prevail, to be used principally for broad planning; and (2) a more precise prediction of growth, which includes adjustments for stand competition, site index, and maturity. In addition to the yield tables, silvicultural information of considerable practical importance resulted.

HOW THE DATA WERE ANALYZED

Diameter changes by 5-year periods, based on increment core records and bark thickness curves, were computed, and heights were estimated from height over diameter curves prepared by site classes. Individual tree volumes on the plots were determined from tables currently in use in the region, and then summed to reconstruct the stand volumes by 5-year intervals. Growth was separated into three categories for analysis: Growth of residual trees that were 9.6 inches d. b. h. or larger at time of logging; ingrowth or volumes of trees that grew into the 10-inch d. b. h. class after logging; and mortality, which is negative growth.

Nearly all of the sampled stands included Douglas-fir trees growing in mixture with the ponderosa pine; Douglas-fir averaged 23 percent of the basal area on the plots. In analyzing the data, volumes for the two species were pooled without distinction. Because an admixture of Douglas-fir in ponderosa pine stands is typical in the Upper Columbia River Basin and growth rates of these species when in mixture do not differ greatly, separate analyses would probably not have significantly increased the reliability of the findings. Separate analyses would also have greatly complicated the computing as well as use of the results.

Growth of Residual Trees

Residual saw-timber trees and poles were observed separately because (1) the two differ in age and growth rates as well as in size, (2) ingrowth accrues in units of whole tree volumes and tends to be erratic, and (3) ingrowth varies greatly from stand to stand; this variation depends principally on the amount of advance reproduction present at the time of logging rather than on numbers and sizes of residual trees.

Four steps were followed in analyzing reserve tree growth. (1) Gross board-foot growth was related to reserve-stand basal area by computing a separate regression for each 5-year period.[3] (2) A first estimate of plot growth was then read from the regressions, and ratios of relative growth rates obtained by dividing estimated plot growth into actual plot growth. (3) Multiple regressions of relative growth rates on 10-foot, site-index classes and Keen's age classes (*6*) were computed, from which adjusted relative growth rates were derived. This step was taken after a study of these factors revealed a significant multiple correlation. (4) Adjustments of growth in the 7th, 8th, 9th, and 10th 5-year periods after logging were made. A study of the influence of growing season precipitation (April-August) on growth, by graphic methods, showed that this step was necessary.

Number and Size

Analysis of the effect of number and size distribution of residual trees showed that gross board-foot growth correlates better with reserve-stand basal area than with reserve-stand board-foot volume. Because of differences in diameter distribution and number of trees per acre, stands of equal board-foot volumes frequently have different basal areas. Thus, stands of small trees show a greater basal area than stands having the same board-foot volume per acre in larger but fewer trees. Stands composed of numerous trees of small diameter tend to grow faster.

The correlation of reserve-stand basal area and growth was further studied by relating board-foot growth per acre to reserve-stand basal area separately for each 5-year period after logging. In light reserve stands, the growth rate of individual trees was high but diminished with increased reserve-stand volume. This demonstrates the effect of competition. Trees in stands with light reserve, therefore, grow faster than trees in relatively well-stocked, heavy reserve stands. The trend of periodic growth by elapsed time after logging showed that 5-year board-foot increment per acre increases rapidly to the 3rd and 4th 5-year periods. In later periods, increment declines progressively.

Although growth correlates better with reserve-stand basal area than with board-foot volume of reserve, the latter has considerable utility in predicting growth because it is a more commonly available statistic. Some of the prediction methods pre-

[3] Since the relationship between reserve-stand basal area and periodic growth was linear in the early periods and did not tend to become curvilinear until the 9th and 10th periods, a more complex method of analysis was not justified.

sented later therefore are based on board-foot reserve. Although predictions based on board-foot reserve are less precise than those using basal-area reserve, they are reasonably accurate for large areas containing a variety of stand conditions.

Site Productivity and Age

Productivity of a given area, as expressed by site-quality classes or site index, has long been recognized as a variable affecting growth rates. Each of the sample plots was classified according to Meyer's site index on the basis of average age and total height of dominant and codominant trees (appendix table 11, *10*). Site index for the plots at 100 years ranged from as low as 52 feet to as high as 92, and the average for all plots was 71 feet. Grouping of the plots by Meyer's interregional ponderosa site-quality classes (appendix table 12) placed 98 percent of them in classes III, IV, and V. Stands on sites of high quality grow more rapidly, of course, than those on poor sites, and growth estimates must therefore be adjusted for such variations.

Growth rate varied by 12 percent between adjacent site classes with the higher site class growing faster than the lower by that amount in each case. Because the study included only stands ranging from site index 52 to 92 feet (site classes III–VI), it is not known to what extent adjustment factors can safely be applied to stands outside of that range. The 12 percent difference closely approaches the 15 percent found in the Pacific Northwest by Briegleb (*1*).

In the analysis, age was found to be another factor strongly influencing the growth rate. Young trees grow faster than old ones. Thus, age of the reserve stand affects the relative growth rates. To determine the average physical age of uneven-aged ponderosa pine stands in actual years would be difficult. Therefore, to provide a simple means of quickly assessing the relative age of these stands, the Keen system of tree classes was used.

Keen's tree classification (*6*), which is commonly used in the northern Rocky Mountain region, distinguishes four classes of physiological age. They are designated as class 1, young blackjacks usually less than 80 years of age; class 2, immature trees still making rapid growth, approximately 80 to 180 years of age; class 3, mature trees, approximately 180 to 300 years; and class 4, overmature trees 300 years or more in age. The use of Keen age reduces need for increment borings and difficult, time-consuming annual ring counts to determine age. Because Keen age classes and growth showed a straight-line relationship for the stands studied, average age was quickly approximated by taking an average weighted by the number of trees in each of the individual Keen age classes of a group of sample trees. The average age class of the stands from which the data were collected was 2.4, indicating an age nearly midway between classes 2 and 3. Average age class on individual plots ranged from 1.0 to as high as 4.0.

The adjustment factor between any two adjacent Keen stand-age classes was found to be 30 percent. Thus a stand in age class 3 grows 30 percent less than a stand in age class 2, providing other conditions are equal. The 30-percent factor is applicable to the full range of age classes because all ages were represented in the sample data.

Precipitation

The effect of precipitation partially obscures the true trend of growth response after logging. In general, growth slows down during drier periods and accelerates during wetter periods. Consequently, abnormal precipitation tends to exaggerate the effects of logging in some instances and nullify it in others. To remove this masking effect and provide average growth rates for approximately normal precipitation, it was necessary to evaluate the influence of rainfall and adjust the growth rates. The influence of rainfall was first observed in the data for the period 1943-47 (fig. 1).[4] Almost without exception, growth accelerated in that period, independently of elapsed time after logging or plot condition.

To facilitate comparison of growth on all plots, as influenced by precipitation and time since logging, the curves in figure 1 are brought to the left in figure 2 so that all plots have a common base line for the 1st 5-year period. Also, each curve in figure 2 reflects the wet cycles and dry cycles experienced by the plots the curve represents. For example, on the 13 50-year plots growth from the 1st period to the 4th was made when annual growing-season precipitation was above average; from the 5th to the 8th, when precipitation was below average; and in the 9th and 10th, above average. Thus, in using all the curves, we find that from the 1st to the 6th 5-year period the number of plots representing growth in wet and dry cycles was nearly equal. On the average, therefore, abundance of precipitation did not have a net effect on growth. However, during the 7th and 8th periods, the number of plots representing growth in dry cycles was greater than that representing wet-cycle growth; and in the 9th and 10th periods, only wet-cycle growth was represented. Thus, growth fluctuations in the last 4 periods were attributed mainly to the effects of precipitation.

In making the adjustment for more abundant or less abundant precipitation for the 7th to 10th periods, the average growth pattern for the 13 plots that had been cut 50 years prior to measurement was used. It was believed that the effect of logging release on those plots had largely diminished. If the decline in growth rates during the 7th and 8th 5-year periods had continued, growth in the last period would have been only 87 percent of what was

[4] Precipitation statistics in figure 1 are based on records of western Montana weather stations at locations reasonably similar to, although somewhat lower in elevation than, ponderosa pine stands. Most of the records were not continuous for the whole 50-year period, and records from only 2 to 8 stations were used for different 5-year periods. Although the records show trends in only a general way, they support observations that 1918-37 was a generally dry period. April through August probably does not correspond exactly to the period when rainfall has its greatest influence on growth of ponderosa pine, but it is believed to be approximately correct; a detailed study would have been outside the scope of the project. Because the precipitation data are relatively crude, it is not possible to determine the statistical significance of the correlation.

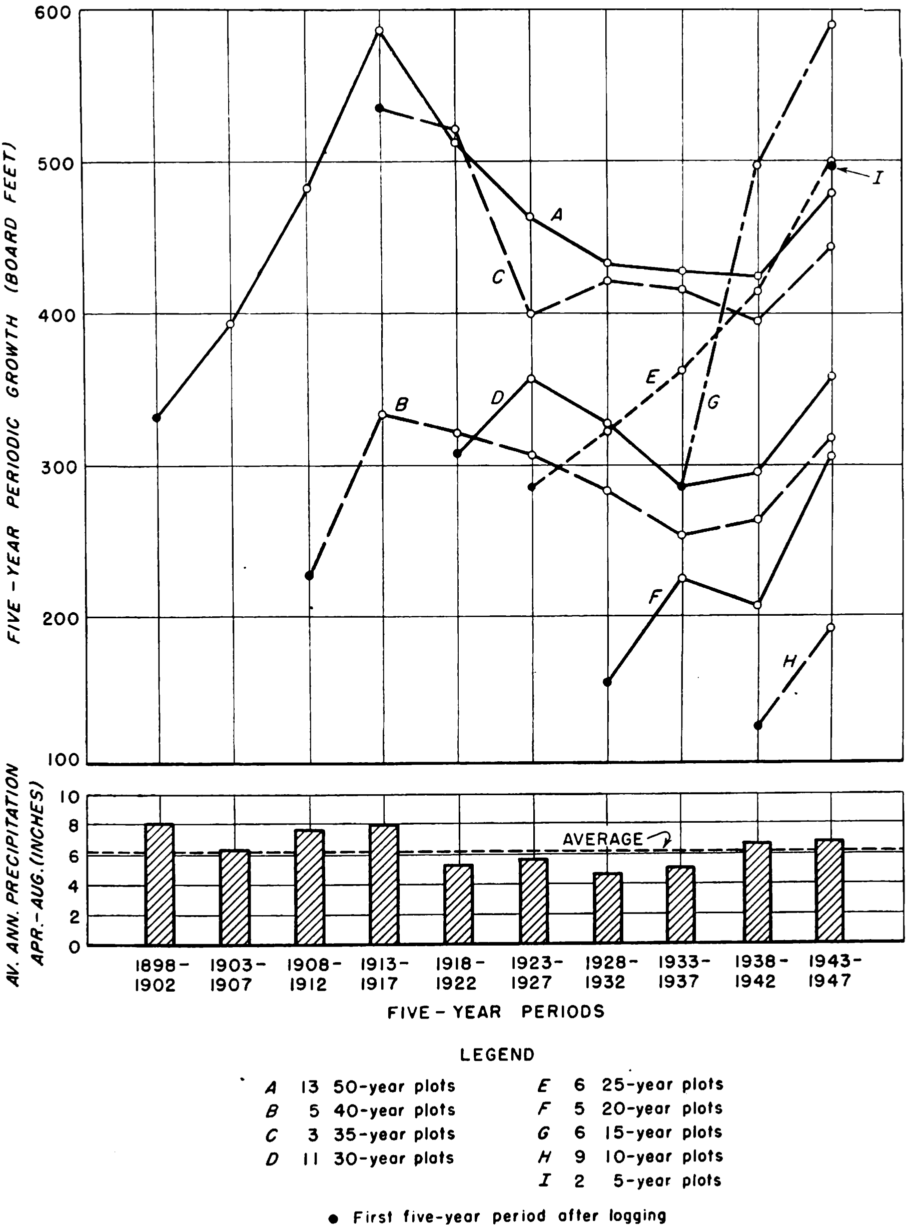
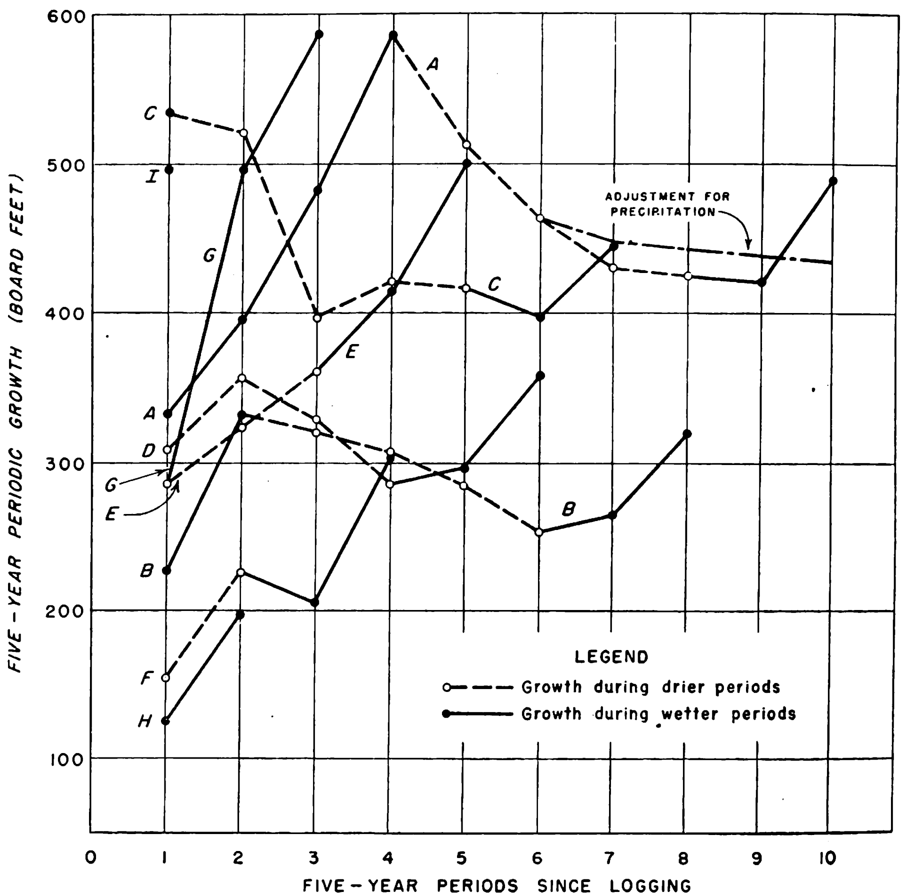


FIGURE 1.—Five-year periodic growth and growing season precipitation for ponderosa pine sample plots, 1898-1947.

found. Even though the 9th period included only growth made during wetter than average years, it continued the slight downward trend. However, the decline ended abruptly in the sudden increase of growth in the 10th period which is believed to be at least partly an accumulated or delayed effect of the increased precipitation during the 9th period. The downward trend displayed by the 7th to 9th periods was probably a normal decline owing to increasing competition after logging. Therefore, a line paralleling that trend was fitted between the points of the 7th, 8th, 9th, and 10th periods (fig. 2). In this way, above-average growth in the 10th period was leveled off against below-average growth in the other periods. As a consequence of this analysis, growth in the 7th, 8th, and 9th periods was raised by approximately 4 percent, and growth in the last period was reduced to 89 percent of the actual. These adjustment factors were applied to all of the plots.



LEGEND

A	13	50-year plots	*E*	6	25-year plots
B	5	40-year plots	*F*	5	20-year plots
C	3	35-year plots	*G*	6	15-year plots
D	11	30-year plots	*H*	9	10-year plots
			I	2	5-year plots

FIGURE 2.—Growth of ponderosa pine sample plots, by 5-year periods since logging, with an adjustment for precipitation for the 50-year plots.

Vigor

The correction for average stand age according to the Keen tree-classification system largely accounted for differences in vigor and left comparatively little pure-vigor effect for separate correlation. After adjusting for stand age, however, attempts to correlate board-foot growth with tree vigor were unsuccessful because of the correlation of age and vigor in the basic data. The analysis method used was not sensitive enough to separate pure age and vigor effects from their interaction.

Vigor classes A and B included 64 percent of the basal area of ponderosa pine trees on the sample plots—13 percent in class A and 51 percent in class B which was approximately the average. Twenty-nine percent was in class C and 7 percent in class D.

Since the vigor of reserve stands will improve under intensive management, future volume predictions based on data in this study may underestimate growth if there is a larger percentage of high-vigor trees than shown here. On the other hand, an over-estimate may result if a stand is of less than the average vigor.

Reliability of the Data

By correlating gross growth with reserve-stand basal area, 48 to 63 percent of the total variation of growth within 5-year periods was removed. Adjustment for the additional variables of site and age accounted for 70 to 77 percent of the variation. Some of the remaining unaccounted variation probably was due to the effect of precipitation, for which an adjustment was also made as described earlier.

To evaluate the efficiency of these data for predicting growth, fiducial limits were computed for the regressions of periodic growth on reserve-stand basal area in the 1st, 5th, and 10th 5-year periods, respectively. The solid lines in figure 3 show computed average growth and the dotted lines outline the fiducial limits or confidence bands at the 95-percent level. The probabilities are 95 out of 100 that the true regression lines for the stands studied fall within the confidence bands shown.

Ingrowth

Trees below 9.6 inches d. b. h. in a reserve stand contribute board-foot volume for the first time when they reach the 10-inch class. Because of the highly variable nature of ingrowth on a per-acre basis, computation of average ingrowth per acre seems pointless. To use such average figures in growth predictions would introduce large errors into the estimates. However, knowledge of the approximate rate of ingrowth expected is important because it helps to determine the rate at which the old stand may be cut. The average volume of pole-size trees was, therefore, determined by 5-year periods and 1-inch d. b. h. classes for trees of average age and vigor. These volumes can be applied to the actual number and size of poles in a stand to determine the volume of ingrowth expected in future periods.

In collecting the field data, trees that contributed to ingrowth were taken as they were found, and an attempt was made to ac-

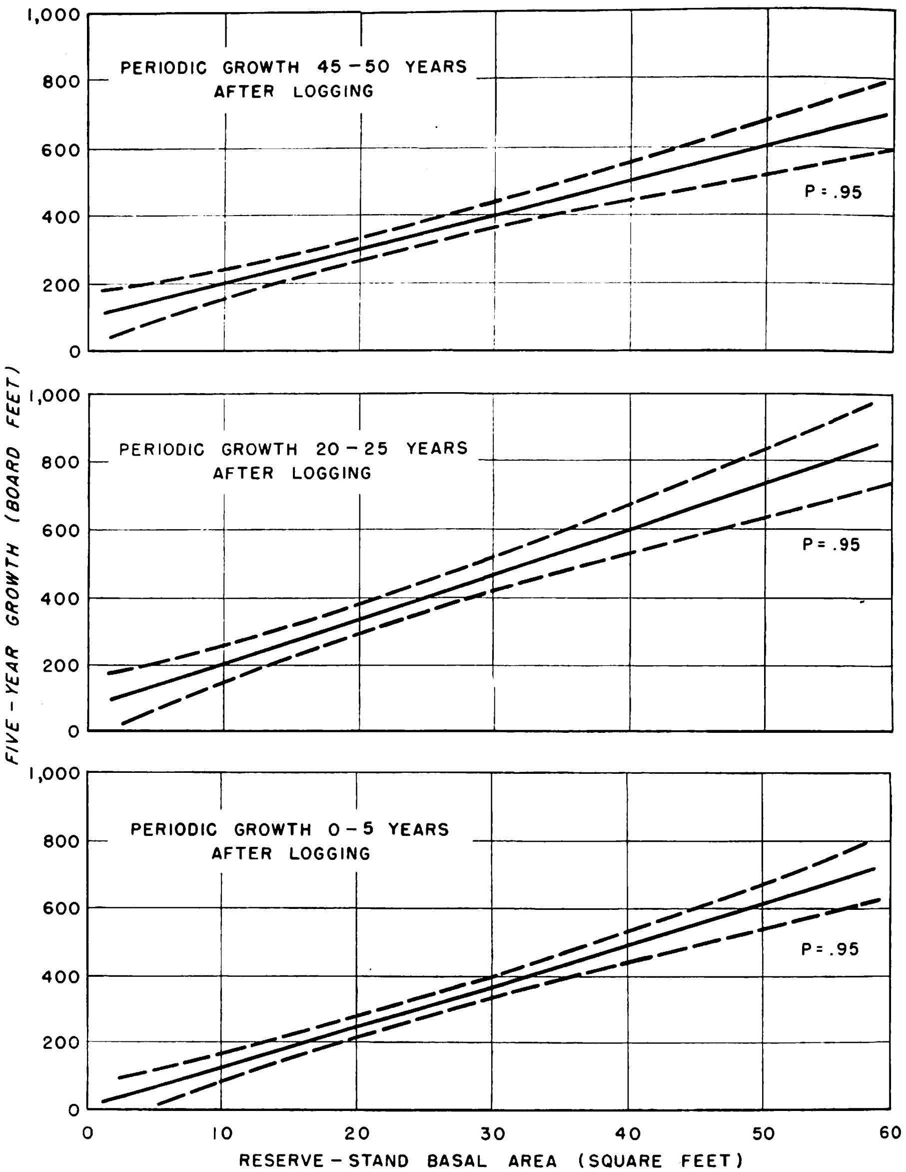


FIGURE 3.—Fiducial limits of regression lines.

count for small dead trees. The ingrowth tables presented later, therefore, represent average net growth to the extent that the field measurements were accurate and representative. However, it is probable that conditions will be found where exceptional numbers of small saplings exist in dense thickets. In such instances, growth will be far slower and mortality far higher than indicated in the tables. In future volume predictions, therefore, these small trees should be eliminated, but *only* when they occur in numerous thickets.

Mortality

Although mortality is a highly important factor in timber management, its erratic occurrence from acre to acre makes the achievement of a high degree of accuracy in predicting such losses difficult. Over large areas, however, average values should approximate true values except in instances of catastrophe, such as insect epidemics or violent storms. Even though average mortality figures are sometimes inaccurate, adjustment for this factor will generally give the results of growth computations more realism than if it is ignored. In the analysis of the data presented here, mortality was handled as a percentage loss of gross growth. No attempt was made to determine the growth on the dead trees from the time of logging until death. However, in order to give the results of the analysis the smoothing influence of data from a large area, mortality data from a 2,000-acre selective cutting in Lick Creek on the Bitterroot National Forest were included.

An attempt was made to correlate mortality with reserve-stand volume and 5-year periods after logging, but the experimental error was so high that the correlations were not statistically significant. Consequently, mortality was computed as an average percent of the gross growth and found to be 15 percent, which agreed with that found in the Pacific Northwest (*9*). Under good management, it is probable that much of the mortality will be anticipated and the trees harvested before they die or lose their value. In such instances, growth predictions may underestimate actual growth to some extent.

THE GROWTH TABLES AND HOW TO USE THEM

General Estimates

Growth can be estimated as an average figure that is applicable to average or typical residual stands. The average volume per acre of residual ponderosa pine, by reserve-stand classes and 5-year intervals after cutting is shown in tables 1 to 3. Because mortality has been deducted, the volumes given are net. Table 1 represents growth estimates for typical or average site-class conditions on cut-over areas, and tables 2 and 3 show values for site classes IV and V, respectively. The values given in these tables can be converted to other site classes by using a 12-percent adjustment factor. For example, a value in site class IV when multiplied by 112 percent is converted to a corresponding value for site class III.

In order to use tables 1 to 3, the board-foot volume of a reserve-stand (trees 10 inches d. b. h. and larger at logging) and site class[5] are the only stand statistics needed. As an example of how to use the tables, assume that selective cutting in a ponderosa pine stand averaging site class IV left a reserve of 4,500 board feet per acre, and that the predicted volume of this stand in 30 years is required. (1) Enter table 2 at the 4,500 board-foot reserve-stand

[5] Site classification tables are presented in the appendix, p. 28.

TABLE 1.—*Net board-foot volume per acre, Scribner rule, in selectively cut ponderosa pine stands of average structure, by board-foot reserve-stand classes*[1]

Volume at time of cutting (board feet)	Volume per acre after an interval of—									
	5 years	10 years	15 years	20 years	25 years	30 years	35 years	40 years	45 years	50 years
	Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*
1,000	1,120	1,290	1,460	1,650	1,820	2,020	2,210	2,400	2,590	2,770
2,000	2,170	2,400	2,640	2,890	3,130	3,380	3,620	3,860	4,100	4,330
3,000	3,230	3,520	3,820	4,140	4,440	4,740	5,030	5,320	5,610	5,890
4,000	4,290	4,640	4,990	5,380	5,750	6,100	6,440	6,780	7,120	7,440
5,000	5,340	5,750	6,170	6,620	7,060	7,460	7,860	8,240	8,630	9,000
6,000	6,400	6,870	7,350	7,870	8,360	8,820	9,270	9,700	10,140	10,550
7,000	7,460	8,000	8,530	9,120	9,670	10,140	10,680	11,160	11,640	12,110
8,000	8,510	9,100	9,710	10,360	10,980	11,540	12,100	12,620	13,150	13,660
9,000	9,570	10,220	10,880	11,600	12,290	12,900	13,510	14,090	14,660	15,220
10,000	10,630	11,340	12,060	12,850	13,600	14,260	14,920	15,540	16,170	16,780

Basis: 60 one-half acre plots.

[1] These values were obtained on all residual trees 9.6 inches d. b. h. and larger; ingrowth is not included. Average site index of basic data was 71 feet at 100 years, ranging from as low as 52 feet to as high as 92 feet.

TABLE 2.—*Net board-foot volume per acre, Scribner rule, in selectively cut ponderosa pine stands of average structure, site-quality class IV, by board-foot reserve-stand classes*[1]

Volume at time of cutting (board feet)	Volume per acre after an interval of—									
	5 years	10 years	15 years	20 years	25 years	30 years	35 years	40 years	45 years	50 years
	Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*
1,000	1,120	1,300	1,490	1,690	1,870	2,080	2,280	2,490	2,690	2,890
2,000	2,180	2,430	2,680	2,950	3,200	3,460	3,720	3,980	4,230	4,480
3,000	3,240	3,550	3,870	4,210	4,530	4,850	5,160	5,470	5,770	6,070
4,000	4,300	4,680	5,060	5,470	5,860	6,230	6,600	6,960	7,320	7,660
5,000	5,360	5,800	6,250	6,730	7,180	7,610	8,040	8,450	8,860	9,250
6,000	6,420	6,920	7,440	7,990	8,510	9,000	9,480	9,940	10,400	10,840
7,000	7,480	8,050	8,620	9,250	9,840	10,340	10,920	11,430	11,940	12,430
8,000	8,540	9,170	9,810	10,510	11,170	11,770	12,360	12,920	13,480	14,020
9,000	9,600	10,300	11,000	11,770	12,500	13,150	13,790	14,410	15,020	15,610
10,000	10,660	11,420	12,190	13,030	13,820	14,530	15,230	15,890	16,560	17,200

Basis: 60 one-half acre plots.

[1] These values were obtained on all residual trees 9.6 inches d. b. h. and larger; ingrowth is not included.

TABLE 3.—*Net board-foot volume per acre, Scribner rule, in selectively cut ponderosa pine stands of average structure, site-quality class V, by board-foot reserve-stand classes*[1]

Volume at time of cutting (board feet)	Volume after an interval of—									
	5 years	10 years	15 years	20 years	25 years	30 years	35 years	40 years	45 years	50 years
	Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*
1,000	1,110	1,270	1,430	1,610	1,780	1,960	2,140	2,330	2,510	2,680
2,000	2,160	2,380	2,600	2,840	3,070	3,300	3,530	3,760	3,990	4,200
3,000	3,220	3,490	3,770	4,070	4,360	4,640	4,920	5,200	5,470	5,730
4,000	4,270	4,600	4,940	5,300	5,650	5,990	6,310	6,630	6,950	7,260
5,000	5,320	5,710	6,110	6,540	6,940	7,330	7,700	8,070	8,430	8,780
6,000	6,380	6,820	7,280	7,770	8,240	8,670	9,110	9,500	9,910	10,310
7,000	7,430	7,930	8,450	9,000	9,530	9,970	10,480	10,940	11,390	11,830
8,000	8,480	9,040	9,610	10,230	10,820	11,350	11,880	12,380	12,870	13,360
9,000	9,540	10,160	10,780	11,460	12,110	12,690	13,270	13,810	14,360	14,880
10,000	10,590	11,270	11,950	12,690	13,400	14,040	14,660	15,250	15,840	16,410

Basis: 60 one-half acre plots.
[1] These values were obtained on all residual trees 9.6 inches d. b. h. and larger; ingrowth is not included.

TABLE 4.—*Gross board-foot growth per acre, Scribner rule, in selectively cut ponderosa pine stands of average site quality and age,*[1] *by basal-area reserve-stand classes*

Basal area at time of cutting[2] (sq. ft.)	Volume growth per acre after an interval of—									
	5 years	10 years	15 years	20 years	25 years	30 years	35 years	40 years	45 years	50 years
	Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*
10	130	330	520	740	940	1,160	1,380	1,610	1,820	2,030
15	190	450	710	990	1,260	1,540	1,810	2,090	2,360	2,620
20	250	570	900	1,250	1,590	1,920	2,250	2,570	2,890	3,200
25	310	690	1,090	1,510	1,910	2,300	2,680	3,060	3,430	3,780
30	370	820	1,270	1,760	2,230	2,680	3,120	3,540	3,960	4,370
35	430	940	1,460	2,020	2,560	3,060	3,550	4,020	4,490	4,950
40	490	1,060	1,650	2,280	2,880	3,440	3,980	4,510	5,030	5,540
45	550	1,180	1,830	2,540	3,200	3,820	4,420	4,990	5,560	6,120
50	610	1,310	2,020	2,790	3,530	4,200	4,850	5,470	6,100	6,700
55	670	1,430	2,210	3,050	3,850	4,570	5,280	5,960	6,630	7,290
60	730	1,550	2,400	3,310	4,170	4,950	5,720	6,440	7,170	7,870

Basis: 60 one-half acre plots.

[1] All trees 9.6 inches d. b. h. and larger are included. To correct the values in this table for mortality, reduce by 15 percent or multiply by the conversion factor 85 percent.

[2] Basal area computed on trees 9.6 inches d. b. h. and larger in the reserved stand.

class (interpolate between 4,000 and 5,000 board feet); (2) read the values in the 30-year column. The volume will be 6,920 board feet 30 years after logging, representing a net growth of 2,420 board feet (6,920 bd. ft. –4,500 bd. ft.) in 30 years, or 80.7 board feet periodic annual growth. Ingrowth must be computed independently because it is not included in these tables.

Adjusting Growth Estimates for Additional Variables

To refine the growth prediction, the following information will be needed:

1. A stand table of the residual trees in the 1-inch d. b. h. class and larger. *Do not* include exceptional numbers of small trees that occur in numerous dense thickets. Occasional thickets, which are typical of overmature stands in western Montana, should be included.
2. Basal area of the reserve stand 9.6 inches d. b. h. and larger.
3. Site index (height in feet of the average dominant and codominant trees at 100 years—see appendix tables 11 and 12).
4. Age of residual trees, based on a sample of residual trees classified by Keen tree classes.

After basal area has been derived from the stand table, summarize the survey data from the cut-over stand, as in the following example:

1. Volume, 5,000 board feet.
2. Basal area, 50 square feet.
3. Site index, 70 feet at 100 years (site class V).
4. Keen age, 2.6.
5. Cutting cycle, 35 years.

Growth is then computed as follows:

1. Derive gross growth by reading from table 4 for the correct basal area (50) and cutting cycle (35). In this instance, gross growth is 4,850 board feet. Interpolate when values are intermediate to those shown in the table.
2. Obtain a correction factor (94 percent) for age (2.6) and site index (70) from table 5. This reduces growth to 4,559 board feet (4,850 × 0.94).
3. Take out mortality with the 15 percent average found in the study. 4,559 – (0.15 × 4,559) or 4,559 × 0.85 = 3,875 board feet. This is net growth of the residual trees. If a more exact mortality correction factor is available for a particular stand, it should be used instead of the 15 percent average.
4. Sum the reserve stand volume and net growth to obtain net volume of the residual trees at the end of the cutting cycle—5,000 + 3,875 = 8,875 board feet per acre. Periodic annual growth is 3,875/35 = 111 board feet.
5. Set up a stand table for determination of ingrowth, using field survey data, as shown in the following tabulation:

D.b.h. class (inches)	*Trees per acre*[1]	
	Ponderosa pine	*Douglas-fir*
5	0.19	2.75
6	—	2.17
7	.37	1.90
8	—	1.28
9	.92	.83
Total	1.48	8.93

[1] Trees in the 1- to 4-inch d.b.h. classes not recorded in this instance because, as shown in tables 7 and 8, ponderosa pine and Douglas-fir do not attain merchantable size in 35 years.

TABLE 5.—*Correction percentages for effect of age and site index upon board-foot growth of selectively cut ponderosa pine stands*

Average age (Keen class)	Average site index				
	50	60	70	80	90
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
1.0	125	133	142	150	158
1.1	122	130	138	147	155
1.2	118	127	136	144	152
1.3	116	124	133	141	149
1.4	112	121	130	138	146
1.5	110	118	127	135	143
1.6	106	115	124	132	140
1.7	104	112	120	129	137
1.8	*100*	109	118	126	134
1.9	98	106	114	123	131
2.0	95	103	112	120	128
2.1	92	*100*	108	117	125
2.2	89	97	105	114	122
2.3	86	94	102	111	119
2.4	83	91	*100*	108	116
2.5	80	88	97	105	113
2.6	77	85	94	102	110
2.7	74	82	90	*99*	107
2.8	70	79	87	96	104
2.9	68	76	84	93	*101*
3.0	65	73	81	90	97
3.1	62	70	78	87	95
3.2	59	67	75	84	92
3.3	56	64	72	81	89
3.4	53	61	69	78	86
3.5	50	58	66	75	83
3.6	47	55	63	72	80
3.7	44	52	60	69	77
3.8	41	49	57	66	74
3.9	38	46	54	63	71
4.0	35	43	51	60	68

6. Compute ingrowth from tables 6, 7, and 8 and the stand table prepared in step 5. Tables 6, 7, and 8 show the board-foot volume of pole-size trees by 5-year intervals after logging. In our problem, both ponderosa pine in site class V and Douglas-fir are present. Therefore, values are taken from table 7 for ponderosa pine and from table 8 for Douglas-fir. Values, read from the proper diameter class and 5-year interval in the table, should be multiplied by the number of trees in the corresponding diameter class in the stand table. Thus, in the example there is 0.37 ponderosa pine tree per acre in the 7-inch d. b. h. class. A volume of 41 board feet is shown in table 7 for the volume of a 7-inch tree 35 years after logging. This volume multiplied by the number of trees per acre in the stand table will give the volume per acre

TABLE 6.—*Volume, Scribner rule, for individual pole-size ponderosa pine trees in selectively cut stands, by d. b. h. classes, site-quality class IV (site index 78)*[1]

D. b. h. class at time of cutting (inches)	Volume per tree after an interval of—									
	5 years	10 years	15 years	20 years	25 years	30 years	35 years	40 years	45 years	50 years
	Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*
3	—	—	—	—	—	—	—	—	28	31
4	—	—	—	—	—	—	27	32	40	45
5	—	—	—	—	—	28	40	46	55	59
6	—	—	—	—	31	45	57	64	72	77
7	—	—	—	37	50	63	74	83	92	96
8	—	27	37	53	68	81	94	104	115	124
9	27	41	56	70	89	104	118	134	144	154

[1] These volumes are for trees 9.6 inches d. b. h. and larger; they have been reduced by 5 percent to account for average mortality of poles in the stand.

TABLE 7.—*Volume, Scribner rule, for individual pole-size ponderosa pine trees in selectively cut stands, by d. b. h. classes, site-quality class V (site index 64)*[1]

D. b. h. class at time of cutting (inches)	Volume per tree after an interval of—									
	5 years	10 years	15 years	20 years	25 years	30 years	35 years	40 years	45 years	50 years
	Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*
4	—	—	—	—	—	—	—	—	—	21
5	—	—	—	—	—	—	—	19	26	30
6	—	—	—	—	—	19	26	32	38	42
7	—	—	—	19	27	34	41	48	52	56
8	—	—	24	33	42	50	58	64	67	71
9	18	37	39	49	58	69	78	82	86	93

[1] These volumes are for trees 9.6 inches d. b. h. and larger; they have been reduced by 5 percent to account for average mortality of poles in the stand.

TABLE 8.—*Volume, Scribner rule, for individual pole-size Douglas-fir trees in selectively cut ponderosa pine stands, by d. b. h. classes, site-quality classes IV and V*[1]

D. b. h. class at time of cutting (inches)	Volume per tree after an interval of—									
	5 years	10 years	15 years	20 years	25 years	30 years	35 years	40 years	45 years	50 years
	Bd.ft.	*Bd.ft.*	*Bd.ft.*	*Bd.ft.*	*Bd.ft.*	*Bd.ft.*	*Bd.ft.*	*Bd.ft.*	*Bd.ft.*	*Bd.ft.*
1	—	—	—	—	—	—	—	—	—	25
2	—	—	—	—	—	—	—	—	28	32
3	—	—	—	—	—	—	—	27	33	39
4	—	—	—	—	—	—	25	32	40	45
5	—	—	—	—	—	27	31	39	47	50
6	—	—	—	—	25	32	39	45	52	57
7	—	—	—	27	32	40	45	50	59	64
8	—	—	27	34	41	48	53	58	65	70
9	21	28	35	43	48	55	60	65	71	76

[1] These volumes are for trees 9.6 inches d. b. h. and larger; they have been reduced by 5 percent to account for average mortality of poles in the stand.

(41 × 0.37 = 15.17 bd. ft.). A tabulation like the following will result when volumes for the other diameter classes have been computed.

D.b.h. class (inches)	*Net ingrowth per acre*[1]	
	Ponderosa pine (bd. ft.)	*Douglas-fir (bd. ft.)*
5	[2]0.00	85.25
6	—	84.63
7	15.17	85.50
8	—	67.84
9	71.76	49.80
Total	86.93	373.02

[1] The products derived are net because average mortality has been deducted from pole volumes in the tables.

[2] Negative value because a 5-inch ponderosa pine does not attain merchantable size in 35 years (table 7).

7. Obtain total volume of the stand 35 years after logging by summing the volume of residual trees and ingrowth. The computations for this and the periodic annual growth follow:

	Board feet
Volume of residual trees at end of 35-year cutting cycle	8,875
Ingrowth:	
Ponderosa pine	87
Douglas-fir	373
Total predicted volume of stand 10 inches d.b.h. and larger at end of 35-year cutting cycle	9,335

Periodic annual growth:

$$\frac{3{,}875 \text{ bd. ft.} + 87 \text{ bd. ft.} + 373 \text{ bd. ft.}}{35} = 124$$

Limitations on Use of Tables

Two limitations, which the user should remember, apply to prediction of growth from the tables presented here. One pertains to the species composition of stands. Since sample stands contained, on the average, 77 percent ponderosa pine and 23 percent Douglas-fir by basal area, the tables should be used only for stands that are predominantly ponderosa pine. The other limitation applies to predicting growth in stands that have been cut two or more times. An estimate from the tables should not be applied directly to a cut-over stand unless growth has dropped back to about the prelogging rate. When a stand is still benefiting from the stimulating effect of thinning caused by a previous logging, its initial growth rate at the time of the second cutting will be higher than the one given in the tables. Therefore, the tables will generally underestimate growth after a second cutting. If an adjustment is made for higher initial growth, the accuracy of the estimate will be improved but the degree of improvement and the reliability of the estimate will be unknown.

The values in tables 1 to 4 should not be extended to predict growth in stands more heavily stocked than shown in the tables. It is probable that growth in such stands is severely retarded by the greater stand density.

SILVICULTURAL SIGNIFICANCE OF THE FINDINGS

The results obtained in this study, aside from their value for predicting growth, have some important silvicultural implications. Forest managers will find the data useful in evaluating (1) the effect of various intensities of cutting upon growth of reserve stands, (2) the growth response by stands composed of trees of differing age and vigor and on lands of varying degrees of site quality, (3) the fitness of trees to reserve from cutting, and (4) the relative merits of various cutting cycles.

Intensity of Cutting

The quantity of growing stock left on cut-over areas determines in a large measure the amount of growth that can be expected for the next two or three cutting cycles. Low-volume reserve stands grow less than heavier reserve stands. For example, table 1 shows that the residual trees in a typical 2,000-board-foot reserve stand will reach a volume of 3,380 board feet in 30 years, but a 10,000-board-foot reserve stand will increase to 14,260 board feet in the same time. In other words, the light stand will add only 46 board feet per acre per year of periodic growth as contrasted with 142 board feet in the heavier stand.

However, board-foot growth on reserve stands does not represent the maximum potential growth return from the soil. Reserve stands are usually understocked because logging has removed part of the stand. Moreover, they usually contain mature and overmature trees that are incapable of growing as fast as younger trees. Cutting off the old trees and starting a new fully stocked stand of young trees would, over the rotation period, probably yield the highest mean annual growth.

On the other hand, several advantages will be gained by leaving residual trees. Relatively high board-foot growth rates may be obtained from such growing stock following logging until the younger age classes begin to produce merchantable volume. Thus, cuts can be taken at relatively short intervals. The growth obtained on the old boles yields high-quality wood because these stems have been pruned naturally, and a large portion of the new growth will be in the form of clear wood. In addition, the residual trees provide a source of seed for natural regeneration of the stand.

Cutting should be heavy enough to make possible the prompt establishment of adequate numbers of seedlings, provide conditions for seedling development, and yet leave enough reserve trees for one or more cuts during the next 20 to 50 years. The following tabulation shows the reproduction success obtained on 300 4-milacre plots sampled in this study.

Number of residual trees per acre 10 inches d.b.h. and larger	*Percent of plots stocked with 300 or more seedlings and saplings per acre*	
	Ponderosa pine	*Douglas-fir*
Under 10	20	40
10–19	26	39
20–29	56	44
30 or more	20	60

Two-thirds of the pine and three-fifths of the Douglas-fir reproduction shown was established subsequent to cutting; therefore, these figures reflect largely the influence of the density and composition of the residual stand. The residual trees were mainly ponderosa pine with less than one-third of the board-foot volume in Douglas-fir. However, because Douglas-fir is a very aggressive seed producer, that species became established in proportionately greater quantities than ponderosa pine.

The tabulation indicates that 20 to 29 ponderosa pine trees per acre (3,500 to 5,400 bd. ft.) bore sufficient seed to stock a majority of the areas sampled to the extent of 300 or more seedlings and saplings per acre. Less than 20 trees per acre apparently did not produce enough ponderosa pine seed to counteract negative factors in seedling establishment as successfully. Reserve stands containing from 30 to 53 trees per acre, with volumes ranging from about 6,300 to 9,700 board feet, showed much less general stocking of ponderosa pine but much more general stocking of Douglas-fir. Thirty to fifty-three trees per acre, therefore, appears to be the threshold above which conditions favor a greater seedling establishment rate for Douglas-fir than for ponderosa pine. Evidently ponderosa pine seedlings did not survive as well in heavy reserve stands as they did in somewhat lighter tree cover.

In typical western Montana ponderosa pine stands, a reserve of about 5,000 board feet per acre will provide (1) an adequate seed source, (2) conditions favoring survival of ponderosa pine seedlings, and (3) moderately good growth rates in the residual timber. The study indicates that larger reserve volumes are likely to encourage establishment of Douglas-fir instead of pine. Of course, special reproduction measures, such as seedbed preparation coordinated with a seed crop and rodent control can assist in establishing pine, but without seedbed preparation Douglas-fir will probably dominate the reproduction in heavier stands.

Not all ponderosa pine stands contain enough thrifty trees to justify leaving large reserves. Many old stands support few trees that are suitable to reserve for an appreciable length of time. In such instances, the chief silvicultural job is to regenerate the stand as quickly as practicable. Where large areas of such stands exist, a light salvage cut can be made first, harvesting high-risk trees and opening up the stand to easy access for later salvage. The residual stand can then be removed within a 20- to 30-year period. If reproduction does not become established during the period of removal, other measures such as planting will be necessary. Since growth on these old stands will probably be low, reserving such trees serves mainly to (1) spread the cut of old timber to fill in gaps in age-class distribution, (2) protect the old stand from loss while placing a larger area under management, and (3) maintain a seed source for regenerating the stand.

Growth of Reserve Stands by Average Stand Age and Site Quality

Average stand age and quality of site strongly influence the growth of residual stands. In general, the younger the stand and the better the site, the smaller the reserve stand which is required to produce a given quantity of growth. Table 9 shows the amounts of reserve-stand growing stock required to produce a periodic annual growth of 100 board feet for different ages and sites. The selection of 100 board feet annual growth was arbitrary and should not be construed as a general goal. On some sites the objective may be to obtain considerably higher growth, while on other sites, 100 board feet may be too optimistic, depending upon the stand condition.

TABLE 9.—*Reserve stand needed to obtain 100 bd. ft.*[1] *periodic annual growth per acre in 30 years, by age class and site quality*

Age class[2] of reserve stand	Volume of residual trees per acre		
	Site III	Site IV	Site V
	Bd. ft.	*Bd. ft.*	*Bd. ft.*
1	2,600	3,000	3,400
2	3,700	4,200	4,900
3	5,400	6,400	7,600
4	8,400	10,500	([3])

[1] Includes average periodic annual ingrowth of 14 board feet per acre.

[2] Age class is determined as an average Keen age class weighted by the numbers of trees 9.6 inches d. b. h. and larger in each of the individual Keen age classes comprising the sample.

[3] A stand considerably in excess of 40,000 board feet would be needed here.

The table shows that only about one-half as much reserve volume will be needed in age-class 1 stands as in age-class 3 stands to produce a periodic annual increment of 100 board feet per acre in a 30-year cutting cycle. Thus, for example, on site IV land, a 3,000-board-foot age-class 1 stand will produce the same growth as a 6,400-board-foot age-class 3 stand. However, reserve stands comprised of all age-class 1 trees are rare. The majority of the stands have enough older trees in them to raise the average age of the reserve stand to at least class 2. On the other hand, it is also unlikely that reserve stands comprised of all age-class 4 trees will occur because large old overmature trees are usually removed in cutting. Thus, the average age of most reserve stands will fall between age classes 2 and 3. The trees in this study averaged 2.4. In age classes between 2 and 3, reserve stands ranging from 4,550 board feet per acre on site III up to 6,250 board feet per acre on site V will be required to produce 100 board feet per acre periodic annual increment for 30 years after logging.

The study indicates the value of concentrating intensive forest management on the better sites. For example, an age-class 3 reserve stand having a volume of 5,400 board feet on site III land will produce as much growth (100 board feet per year) as a stand of 7,600 board feet of the same age on class V site. Thus, approximately 40 percent more volume is required on site V than on site III for the same production. Whenever the forest manager has a choice between encouraging growth by silvicultural measures on less productive or more productive lands, he will be wise to concentrate first on the better sites.

Selecting Trees to Reserve From Cutting

Reserve-stand growth comprises the aggregate growth of all the individual trees in the stand. Therefore, the age and vigor of the trees have an important bearing on the reserve-stand growth rate. High growth rates can be obtained by reserving, where practicable, young vigorous trees. Reserving trees capable of growing rapidly and producing quality material is the responsibility of the tree marker.

Ponderosa pine trees tend to grow in a groupwise pattern with small even-aged patches varying in size from a small fraction of an acre to several acres scattered through the stand. Variation in the ages of these small groups creates the uneven-aged condition that is characteristic of virgin ponderosa pine stands. The well-qualified marker will vary his marking with the conditions he encounters as he works through the stand. Marking may vary from clear cutting groups comprised of old low-vigor trees to thinning of bull pine groups and release of poles and saplings. The marker must have enough knowledge of individual tree growth to choose intelligently in the various kinds of groups encountered.

Growth rates of ponderosa pine residual trees vary greatly. Variation may be due to several causes such as competition and site quality, but a large part of it is caused by differences in age and vigor of the trees. Diameter growth in the first decade after

TABLE 10.—*Diameter-breast-high growth for 10-year period before logging and after logging, by Keen tree class*

Age class		Vigor class A	Vigor class B	Vigor class C	Vigor class D	Unweighted average
		Inches	*Inches*	*Inches*	*Inches*	*Inches*
1	Prelogging	1.60	1.25	0.81	0.64	1.08
	Postlogging	1.99	1.65	1.09	.97	1.42
2	Prelogging	1.35	.99	.69	.56	.90
	Postlogging	1.91	1.26	1.11	.70	1.24
3	Prelogging	.97	.74	.54	.44	.67
	Postlogging	1.38	1.14	.90	.69	1.03
4	Prelogging	[1].72	.60	.42	.38	.53
	Postlogging	[1].88	.70	.46	.35	.60
Unweighted average	Prelogging	1.16	.90	.62	.50	.80
	Postlogging	1.54	1.19	.89	.68	1.07

Basis: 926 sample trees.
[1] No 4A trees were obtained in the sample. Values shown for this class were obtained by extrapolation.

logging may vary from as low as 0.35 inch per decade to as high as 1.99 inches per decade (table 10). Table 10 shows the diameter growth of 926 ponderosa pine trees for 10 years before and 10 years after logging in relation to the Keen tree classification. Growth varied inversely with age, but directly with vigor. Thus, as age increases growth decreases, and as vigor declines growth decreases.

Residual trees also vary in their ability to respond to release. The response or increase in growth rate due to logging release is represented by the difference between prelogging and postlogging diameter growth rates shown in table 10. Trees in age-classes 1, 2, and 3 responded well, but those in age-class 4 responded only a little in actual board-foot growth. Trees in the A vigor class showed the best response in board-foot growth, while trees in class D showed the least. Based on past growth, the lower vigor trees make the largest percentage-wise response. The response of the trees to logging, however, is not as important to the marker as the total growth expected on the trees after logging. It is interesting to note that the average response of age-class 3 trees in the A, B, and C vigor classes about equals the class 1 and 2 trees (table 10). The total growth after logging, however, is different because the trees in the younger age classes were making better growth before as well as after logging.

The expected growth rate after logging provides a better criterion to use for selecting trees to reserve from cutting than the response to release does. In the following tabulation, Keen tree classes have been arranged in four groups of expected diameter-growth rates for the first decade after logging. The marker will find this information helpful, along with other considerations, in making his selections of trees to cut and trees to leave.

Range of diameter-growth rate (inches)	*Keen tree class*
1.6–2.0	1A, 2A, 1B
1.1–1.5	3A, 2B, 3B, 1C, 2C
.6–1.0	[1D, 3C, 4A, 2D, 4B, 3D]
0.0– .5	[4C, 4D]

The tree classes in the right-hand column are arranged in descending order by growth rates. The brackets include those classes in which the trees grew less than the average. On the basis of this tabulation, trees in the groups showing the lower growth rates should be designated for cutting first. The trees within the brackets might be cut leaving only those which are expected to grow average or better. The extent to which other trees might be cut, or trees in classes within the brackets left, would depend upon the condition of the stand in other respects.

Markers should not adhere strictly to vigor and age classes when selecting reserve trees, but should also consider quality, form, insect and disease susceptibility, and other important silvicultural characteristics. In many instances, trees in the A vigor class have large crowns extending far down the bole. Such trees will not produce high-quality lumber, yet they will grow at fast rates. The marker will face situations where volume growth should be sacrificed for quality growth. One of the objectives of silviculture is to improve quality; therefore, when selecting trees to reserve, the marker should appraise the quality of the stem and form of the tree before considering expected growth rates.

Length of Cutting Cycle

The length of the cutting cycle bears upon the growth to be obtained. Ponderosa pine trees respond very well to release. Trees that have been suppressed for many years take advantage of additional growing space provided by cutting. Dominant and codominant trees will continue high growth rates longer when root competition is reduced. On the average, the effect of logging release lasts for about 30 years, after which growth falls off to prelogging rates. By that time, the growing space is occupied by the spreading roots and crowns of residual trees, pole-size trees, saplings released by logging, new reproduction, and other vegetation. Competition is then reflected in reduced growth rates (fig. 4). Periodic growth rates therefore indicate that 20- to 30-year cutting cycles will yield the maximum growth on residual trees in average stands.

Density of the reserve stand influenced the length of the cutting cycle. The smallest reserve stands (1,000 board feet or less) showed little if any decline in board-foot volume increment during the 50-year postlogging period. Apparently 50 years is too short a period for these light stands to reoccupy the land fully. In the heavier reserve stands volume increment by 5-year periods increased rapidly to the second decade but dropped off significantly to the third decade. This trend became more pronounced with increasing reserve volume.

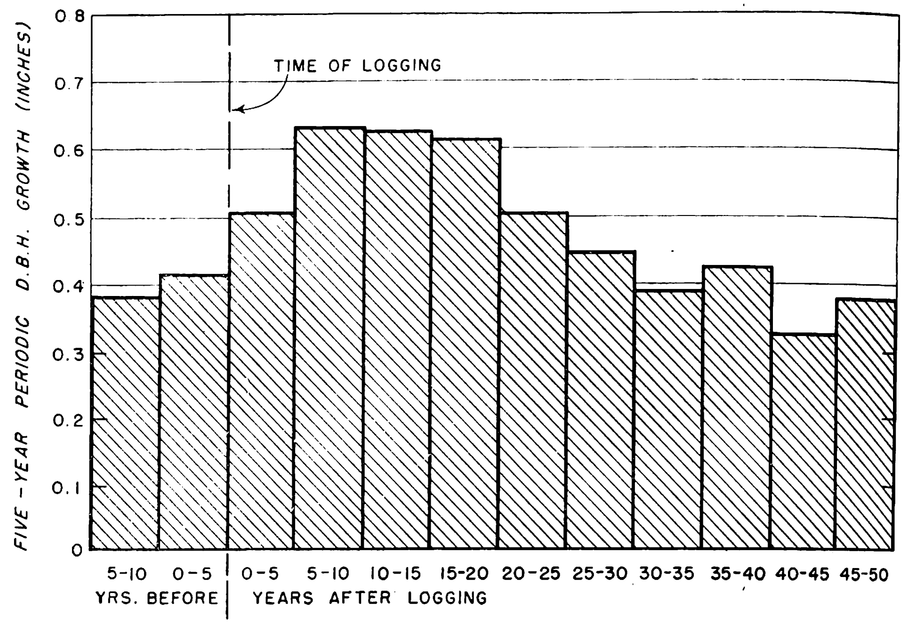


FIGURE 4.—Diameter growth by 5-year periods before and after logging.

Shorter cutting cycles provide an opportunity to anticipate mortality and to harvest trees before they die. This study showed an average mortality rate of 15 percent of the gross annual growth. While cutting cycles shorter than 30 years may not increase the growth rates of individual trees materially, they provide an opportunity to salvage trees that are about to die. Thus, while individual tree growth may not be affected, the total yield of wood will be increased by the amount of annual mortality prevented through cutting. However, we need to learn the characteristics by which we can more effectively identify the trees that are about to die (insects, root rots, senility, etc.). "California risk marking" represents an attempt to identify short-term mortality for purposes of salvage (*5*). The system gives rules for judging likelihood of survival by such signs as color and length of needles, needle retention, and dead twigs and branches or weak spots in the crown. With a more discerning selection of trees to cut, mortality will be reduced and yields increased.

SUMMARY

A study of cut-over ponderosa pine stands in western Montana was made in 1947 to learn of growth responses to different intensities of cutting, and to obtain information concerning the best methods of cutting in mature and overmature stands. Although the study was conducted in western Montana, it is believed that the results apply equally well to the Upper Columbia Basin. Sixty half-acre temporary sample plots, with volumes from approximately 500 to 10,000 board feet an acre, were studied.

Growth was considered only for stands that had been cut once, and elapsed time following cutting varied from 5 to 50 years. The effects of the following factors on per-acre growth were evaluated: Volume, number, and size of residual trees in reserve stands; site quality and stand age class; growing-season precipitation; vigor; ingrowth; and mortality.

Eight tables for predicting growth after cutting were developed. The first predicts growth by 5-year periods on the basis of reserve-stand board-foot volume for average site conditions; the second and third distinguish two degrees of site productivity. Estimates obtained from these three tables do not take into account the important factors of stand age, and number and size of residual trees. Therefore, the predictions are suitable only for relatively large areas where variations tend to compensate. Tables 4 and 5 are used together to predict growth with considerably greater precision. Reserve stand is measured in terms of basal area to evaluate number and size of trees more accurately than when reserve stand is expressed in terms of board-foot volume. Adjustments for stand age and site quality are provided. Mortality can be deducted either with an average factor (15 percent) or from data based on the user's knowledge. Tables 6 to 8 give data for estimating ingrowth separately on the basis of number and size of poles present at time of logging.

The principal conclusions of the study concerning silvicultural implications follow:

Residual stands of ponderosa pine of about 5,000 board feet per acre in the Upper Columbia Basin will yield moderate growth and provide suitable overstory conditions and seed production for seedling establishment.

Younger, relatively thrifty stands on better sites grow much faster than older stands on poorer sites. On site IV, a Keen age-class 2 reserve stand with a volume of 4,200 board feet per acre will grow as much in 30 years as a 7,600-board-foot reserve in a Keen age-class 3 stand on site V. Silvicultural efforts should be concentrated first on encouragement of relatively young trees on better sites.

Diameter growth rates of individual ponderosa pine trees vary from as low as 0.35 inch per decade to as high as 1.99 inches per decade during the first 10 years after logging. The variation is caused largely by the age and vigor of the trees. Tables are presented that show the relationship of growth rates to Keen tree classes. Markers should reserve the trees that will grow most rapidly, after first considering quality and form.

Cutting cycles of 20 to 30 years will sustain high growth rates on individual trees. However, more frequent cutting will aid in reducing losses by permitting the identification and utilization of trees that are likely to die within a relatively few years. Short cutting cycles should be the rule. Light reserve stands will require longer cutting cycles than heavy reserve stands.

APPENDIX

TABLE 11.—*Height of average dominant and codominant trees by age and site index (10)*

Age (years)	Height, by site index—												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
20	6	9	12	16	20	25	30	35	40	45	50	55	60
30	11	15	20	26	32	38	44	51	57	64	70	77	84
40	16	22	28	35	42	49	55	63	70	77	85	93	100
50	21	28	35	43	51	58	65	73	80	89	97	105	113
60	26	34	42	50	58	66	73	81	90	99	107	115	124
70	30	39	47	56	64	73	80	89	98	108	116	125	134
80	34	43	52	61	70	79	88	97	106	116	124	133	143
90	37	47	57	66	75	85	94	104	113	123	132	142	152
100	40	50	60	70	80	90	100	110	120	130	140	150	160
110	42	53	63	74	84	95	106	116	127	137	147	158	168
120	44	55	66	77	88	100	111	122	133	144	154	165	175
130	45	57	69	80	92	104	116	128	139	151	161	172	182
140	46	59	71	83	96	108	121	133	145	157	167	179	189
150	47	60	73	86	99	112	125	138	151	163	173	185	195
160	48	61	75	89	102	116	129	143	156	169	179	191	201
170	48	62	77	91	105	119	133	147	161	174	184	196	206
180	49	63	78	93	108	122	136	151	165	179	189	201	211
190	49	63	79	95	110	125	139	154	169	183	194	205	216
200	50	64	80	97	112	128	143	157	172	187	198	209	220

TABLE 12.—*Site-quality classification for ponderosa pine, with corresponding heights at maturity in terms of logs (10)*

Site-quality class	Site index [at 100 years]		Logs in dominant trees at maturity[1]
	Central value	Range	
	Feet	*Feet*	*Number*
I	120	+113	10 or more.
II	106	99–112	8 to 9.
III	92	85–98	7.
IV	78	71–84	5 to 6.
V	64	57–70	3 to 4.
VI	50	43–56	2.
VII	36	43–	2–.

[1] Estimated in terms of 16-foot logs to 8-inch top. Maturity is assumed to begin at the age of 250 years.

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