

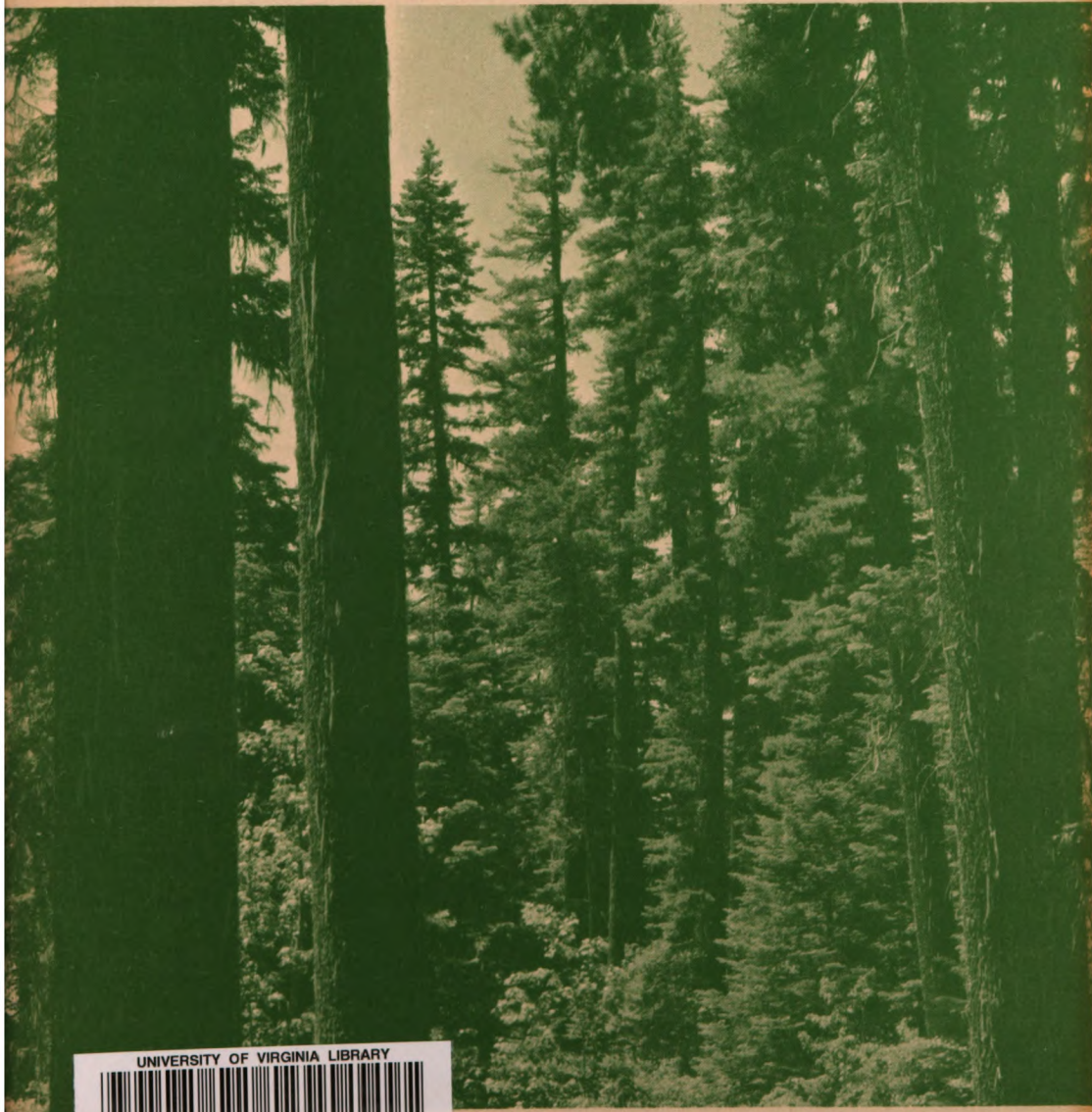
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SECOND-GROWTH WESTERN WHITE PINE STANDS—

- *Site Index and Species Changes*
- *Normality Percentage Trends*
- *Mortality*

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SECOND-GROWTH WESTERN WHITE PINE STANDS

- *Site Index and Species Changes*
- *Normality Percentage Trends*
- *Mortality*

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- Site Index and Species Changes*
- Normality Percentage Trends*
- Mortality*

By Richard F. Watt,¹ forester

INTRODUCTION

The western white pine type is the most valuable timber cover type of the Inland Empire (28).² The large volumes per acre, greater than those found in any associated type, and the high value of the type species, western white pine (*Pinus monticola* Dougl.), combine to give stumpage returns that greatly exceed those of other regional types. Logging in the mountainous country of Idaho north of the Salmon River, where 90 percent of the white pine sawtimber of the Northern Rocky Mountain Region is found (13, 15, 25), has often hinged upon the high value of the white pine. Similarly, the presence of white pine timber often has meant the difference between success and failure of lumber-milling enterprises.

Favorable market conditions since the early 1940's have increased the cut of associated species in northern Idaho to such volume that slightly less than 25 percent of the cut in 1952 was white pine (34). Even so, the marketability, or difference between the production cost and the selling price of lumber, of white pine still remains considerably greater than that of other species (12). Because of the excellent technical qualities of western white pine wood, the marketability of this species undoubtedly will remain high in years to come. In the event of less favorable market conditions, the industry again will depend more heavily upon white pine. Many acres that formerly

¹ Now with the Lake States Forest Experiment Station. The author expresses his thanks to C. A. Wellner and D. W. Lynch, Intermountain Forest and Range Experiment Station, for their aid in conducting this study. Mr. Wellner's extensive experience in the white pine type was especially valuable.

² Italic figures in parentheses refer to "Literature Cited," p. 58. This type is No. 215 as defined in Forest Cover Types of North America. A few of the plots used in this study have slightly less than the 20-percent minimum composition of western white pine, but their location and nature indicate that they are ecologically similar to adjacent stands containing at least 20 percent western white pine.

supported stands of white pine will not produce another crop because of white pine blister rust (*Cronartium ribicola* Fischer), but the present blister rust control program will insure white pine an important place in the future economy of this region in which forest industry is so vital (20).

Because of its value, the western white pine type has been studied extensively for a number of years. Valuable silvical, pathological, entomological, mensurational, and management information has been collected and has furthered better management of the type. Numerous plots have been installed in uncut second-growth western white



FIGURE 1.—A 40-year-old second-growth western white pine stand. Note the steep slopes found in the type, snags from the old stand, and the density of reproduction. The permanent sample plot on this excellent site had 70 percent of normal basal area stocking; white pine and Douglas-fir each comprise 35 percent of the stand.

pine stands for research purposes (fig. 1). Some of these plots were originally measured for the collection of data for U.S. Department of Agriculture Technical Bulletin 323, "Second-Growth Yield, Stand, and Volume Tables for the Western White Pine Type." Additional plots were installed either specifically for the study of growth in uncut stands or as check plots for various silvicultural operations.

The present study utilizes the accumulated data from a large number of these periodically measured plots to determine the adequacy of existing site index curves, trends in species composition, changes in normality percentage, and mortality by amount and cause. This information, not previously available, further increases the usefulness

of existing yield tables and aids in understanding the growth and development of stands in the western white pine type.

Four specific phases of growth and yield were studied. First, the repeated site index measurements on these plots were analyzed to investigate the accuracy of site index determinations. Recognition of site quality is fundamental to the many decisions that must be made by the forester. Second, changes in species composition of the stand were investigated to determine the course of stand development. Since white pine type includes many species and since they vary considerably in economic value and silvical characteristics, an understanding of the development of the various species is valuable. The third analysis was of changes in stand normality percentage, the density of the stand expressed as a percent of normal volume. This study was designed to see whether stand density changed with time and, if such changes occurred, to determine whether they could be predicted. The fourth or final study was of the mortality records collected on about half the plots. This analysis determined the amount, causes, and patterns of mortality.

BASIC DATA

Information Gathered on Permanent Plots

Measurements made every 5 years on 94 permanent plots located in the white pine type of northern Idaho supplied the basic data for this study. The plots can be divided into two groups according to the methods of measurement. In the first group of plots, each tree was individually identified by a numbered metallic tag; in the second group of plots, the trees were unnumbered.

Forty of the plots fell into the group with individually tagged trees. These plots were established to serve several different primary purposes, but all are well suited for the study of growth in uncut stands. Twenty-four of the forty plots were established specifically to study growth and yield in uncut stands. These plots are generally 1 to 2 acres in size; most were first measured in the early 1920's. The remaining 16 plots serve as uncut check plots for various experimental operations, such as thinnings, prunings, and improvement cuttings. These plots are one-half acre and smaller. Records for most of the 16 plots go back to the 1930's, but one plot has records commencing in 1919 and one in 1924. The data from the 40 plots having tagged trees cover growth on 47 acres for 144 5-year-measurement periods.

More exact measurement and more detailed observations could be made on the plots having tagged trees. Nailing the tags at breast height gave a permanent reference point that permitted diameter remeasurements to the nearest 0.1 inch of diameter. Trees that died were tallied with the cause of death, when determinable. Any changes in crown class, bole, or crown condition were recorded. Height remeasurements could be checked by referring to those previously taken.

On most of these plots, all trees 0.6 inch d.b.h. and larger were measured, but in some older stands the minimum size of tree tagged was larger. The error in basal area and volume that was introduced by disregarding trees having smaller diameters was unimportant.

The 54 plots containing untagged trees were established in 1922 and 1923 to furnish part of the data for the yield tables for second-growth western white pine stands (9). A stand tally was made of all trees 0.6 inch d.b.h. and larger at each remeasurement by 1-inch diameter classes, species, and crown class. Thus, the data from these plots are not quite as accurate as those from the plots of tagged trees, but they are sufficiently precise for the purposes of this study.

Because the untagged plots were established originally to provide data for the normal yield tables, they are, on the whole, somewhat different in stocking and size from the plots having tagged trees. Stocking ranges closer to normal on the untagged plots; they are also smaller in area—from 0.025 to 1.000 acre, with an average of 0.22 acre—because of the necessity of having plots without openings in the crown canopy. A total of 196 5-year-growth periods is represented by the data from this group of plots.

Range of Data

Each measurement period on the plots was used as a statistically independent observation in the analyses. These 5-year measurement periods are termed plot-measurement periods to denote a measured 5-year-growth period on an individual plot. Tables 1, 2, 3, and 4 show the distribution of the plot-measurement periods by various classifications.

The plot-measurement periods have a wide range in initial normality percentage, but 65 percent of the periods fall within the range from 80 to 120 percent. Generally, the range of stocking is widest in the younger age classes and narrows with increasing age. Distribution of plot-measurement periods is fairly even by age class, with somewhat more periods in the younger classes than in the older ones.

Table 2 shows the distribution of the sample plots according to the percentage of the total stand basal area in white pine. Naturally the proportion of white pine is high, but there is a wide range of variation in percentage of white pine.

Tables 2 and 3 show distribution of plot-measurement periods by species, but in table 3 the composition index, the percentage of white pine and grand fir in the total stand basal area, is used to classify the periods. The inclusion of grand fir results in considerable movement of the plot-measurement periods toward higher composition classes. Twenty-five percent of the periods contain less than 40 percent white pine, whereas only 11 percent of the periods have a composition index of less than 40 percent.

Distribution of plot-measurement periods by site index and age classes shows that the extremely good and extremely poor sites are much less numerous than the medium-quality sites (table 4). Distribution of site by age classes is fairly even, except for a few measurements on poor-quality site in the older age classes.

TABLE 1.—*Number of plot-measurement periods¹ by stand density and age class*

Stand density ² (percent)	Age class in years										Total all age classes	
	16-25	26-35	36-45	46-55	56-65	66-75	76-85	86-95	96-105	106-115		116-125
20.1-40.0			2	2	1							5
40.1-60.0	1	3	1	2								7
60.1-80.0		3	6	7	8	5	12	8				49
80.1-100.0		4	14	17	16	20	9	7	14	17	11	129
100.1-120.0	1	2	20	31	14	8	6	3	2	4	3	94
120.1-140.0	1	3	16	7	5	2	2			2		38
140.1-160.0		2	7	6								15
160.1-180.0			2									2
180.1-200.0			1									1
Total	3	17	69	72	44	35	29	18	16	23	14	340

¹ Based on values at beginning of 5-year measurement period.
² In percent of basal area of a normal stand; normal values obtained from Haig (9).

TABLE 2.—*Number of plot-measurement periods¹ by white pine composition and age class*

Proportion of white pine 2 (percent)	Age class in years										Total all age classes	
	16-25	26-35	36-45	46-55	56-65	66-75	76-85	86-95	96-105	106-115		116-125
0-10												0
11-20			1	2	3	1						7
21-30		3	12	11	5	3						34
31-40			14	15	5	5	3			1		43
41-50		3	13	13	7	4	5	4	2	1		52
51-60	2	7	14	9	7	9	11	7	1	1		68
61-70		3	9	15	9	8	8	5				57
71-80		1	6	5	8	4	2	2	1	1	2	32
81-90	1			2		1			8	14	12	38
91-100									4	5		9
Total	3	17	69	72	44	35	29	18	16	23	14	340

¹ Based on values at beginning of 5-year measurement period.² In percent of total basal area of plot.

TABLE 3.—*Number of plot-measurement periods¹ by composition index and age class*

Composition index ² (percent)	Age class in years											Total all age classes
	16-25	26-35	36-45	46-55	56-65	66-75	76-85	86-95	96-105	106-115	116-125	
0-10.....					1							0
11-20.....	1			1	2	1						2
21-30.....			2	5	3							2
31-40.....			10	6	3		2					10
41-50.....		3	12	17	11	5	4					24
51-60.....		3	12	6	6	7	5	1				53
61-70.....	1	3	12	6	4	5	8	3	2			47
71-80.....	1	2	8	6	4	5	6	4				38
81-90.....		4	14	19	8	6	6	6				63
91-100.....		5	10	10	9	8	3	2	7	8	2	64
	1		1	2			1	2	7	13	12	39
Total.....	3	17	69	72	44	35	29	18	16	23	14	340

¹ Based on values at beginning of 5-year measurement period.² Percentage of western white pine and grand fir in total stand basal area.

TABLE 4.—*Number of plot-measurement periods¹ by site index and age classes*

Site index class ² (feet)	Age class in years										Total all age classes	
	16-25	26-35	36-45	46-55	56-65	66-75	76-85	86-95	96-105	106-115		116-125
16-25		3	5	2								10
26-35		4	10	5								19
36-45		7	18	14	4	3						46
46-55			13	20	12	12	8	10	1			76
56-65	2	1	11	17	17	10	16	6	8	12	3	103
66-75	1	2	9	11	11	8	4	2	6	9	11	74
76-85			3	3		1	1		1	2		11
86-95						1						1
Total	3	17	69	72	44	35	29	18	16	23	14	340

¹ Based on values at beginning of 5-year measurement period.

² Site index at age 50.

Basic Calculations

Basal areas and cubic- and Scribner board-foot volumes were calculated from the summaries of field tallies and used for all subsequent analyses. The cubic- and board-foot volume tables used were derived by interpolation in published volume tables (9). The cubic-foot volumes give the total cubic volume inside bark including stump and tip. Board-foot volumes were calculated for all western white pine trees 7.6 inches d.b.h. and larger to a minimum top diameter of 6 inches inside bark; for other species, the board-foot volumes were for trees 9.6 inches d.b.h. and larger to a minimum top diameter of 8 inches inside bark. Total height-over-diameter curves were constructed to give the height values necessary for use of the volume tables.

The numbers of trees per acre were not used in analysis because the minimum size of tree measured on some plots was not always 0.6 inch d.b.h. Therefore, comparisons from plot to plot, or with normal yield tables using number of trees, could not be made. However, the plots on which the minimum size of tree measured was greater than 0.6 inch d.b.h. were in the older stands. In these stands, the small trees not measured formed only an insignificant part of the total stand basal area or volumes.

SITE INDEX STUDY

The reliable height measurements repeated at 5-year intervals, often using the same trees for each measurement, presented an excellent opportunity to investigate the accuracy of the site index curves used to measure site quality. These site index curves (9) allow the site to be expressed either as excellent, good, fair, or poor, or as a numerical value equal to the height of the dominant trees of the stand at 50 years. This study should be of interest outside the white pine type because it evaluates a basic concept of site index curve construction through the measured growth of trees on permanent plots.

Analysis of Data

Of the 94 permanent plots, 6 plots, each with only 1 remeasurement, had to be rejected because of obvious instrumental errors in the original height measurements. Fortunately, these six plots were not at the extremes of stocking, age, or site index. Therefore, the data used were collected in essentially those plot-measurement periods shown in tables 1, 2, 3, and 4.

At each 5-year remeasurement, sufficient height data were obtained to define the height-diameter relationships of the species forming an important part of the stand on each plot. Although intended primarily for volume computation, the height-diameter curves that were drawn for white pine were equally valuable for site index calculation.

A few of the early height measurements were made with transit and steel tape; all others were made with Abney level and tape. A circular slide rule (8), specially devised for calculating heights from degree measurements and slope distances, was used to compute heights in the field. On the permanent plots this instrument made possible a rapid check on the accuracy of measurement, for the newly deter-

mined height was immediately compared with the previously measured height of the tree. Obviously incorrect heights were immediately checked. On the plots of unnumbered trees, the only possible check upon accuracy of measurements was a comparison of the shape and position of the present height-diameter curve with previous ones. This comparison usually was made in the field as the work progressed. By these means, accuracy of measurement was maintained at a high level.

To determine site index, the average basal area of the white pine trees in the dominant stand (dominant and codominant crown classes) was calculated. The diameter corresponding to this basal area was found, and, from the height-diameter curve, the height of this average tree was noted. This use of height of dominant tree of average basal area, rather than the "average of heights of 15 to 20 dominant" trees as recommended by Haig (9), was used to obtain less variable site indexes. Age of stand was determined from the ring counts of increment cores taken at the time of plot establishment. By using the height of the dominant tree of average basal area and the age of the stand, the site index was determined to the nearest foot. In this manner a site index was determined for each remeasurement. Subtracting adjacent values of site index gave a total of 334 half-decade site index changes for analysis.

Inspection of the site index changes showed that on some plots changes did not follow any well-defined trend and implied that such changes were of a random nature. Such changes might have arisen from sampling different trees in the plots of untagged trees, or from variation in height growth from one 5-year period to the next. On other plots definite trends of site index change appeared. The problem was to determine whether there was a statistically valid trend in site index changes and, if such a trend was found, what stand conditions influenced it.

Four variables that might influence height growth were studied by multiple regression methods to determine their effects on changes in site index. These variables were stand density, stand age, site index, and stand composition. Density and composition were expressed in terms of basal area values.

The correlation method was used to calculate the regression, essentially as outlined by Snedecor (27). This method yields standard partial regression coefficients (27, p. 342) that are designated as "b'" (read "b-prime") to distinguish them from the regression coefficient "b." The "b-primes" are in terms of standard measure; that is, they are in units of standard deviation. The magnitude of the "b-primes," disregarding their algebraic sign, indicates the relative importance in the regression of the corresponding variable. Therefore, they are valuable in assessing the part played by each independent variable in the regression.

Results and Discussion

Density and composition index are not significant, but age is significant and site index highly significant as shown by values of "b-primes" (table 5). The multiple correlation coefficient, R , is also

TABLE 5.—*Values of “b-primes” and multiple correlation coefficients found in analysis of 5-year site index changes*

Statistic	Values found using—	
	4 independent variables	2 independent variables
b' ₁ = density.....	+0. 06851	
b' ₂ = age.....	*+. 17371	**+0. 17194
b' ₃ = site index.....	**-. 35034	**-. 33560
b' ₄ = composition index.....	+. 01999	
R= multiple correlation coefficient.....	** 32000	** 31558
R ²	. 10240	. 09959

* Significant at the 5-percent level.

** Significant at the 1-percent level.

highly significant, but the value of its square shows that a considerable amount of variability remains unaccounted for. Density and composition index, the factors that were nonsignificant, were rejected and the regression was recalculated to give the values of “b-primes” and the multiple correlation coefficient found in the second column of table 5. The small change in the size of the multiple correlation coefficient indicates that elimination of the two nonsignificant variables did little to change the amount of the total variation accounted for by regression. The relative magnitudes of the “b-primes” for age and site index show that site index has twice the importance of age in determining changes in site index.

The “b-primes” shown in table 5 were converted to ordinary units of measurement, and the following regression equation was derived:

$$\hat{Y}_5 = +2.81774 + 0.01670X_1 - 0.06709X_2$$

in which $\hat{Y}_5$ = estimated 5-year change in site index.

X_1 = age of stand in years at beginning of period

X_2 = site index in feet at beginning of period.

An alinement chart (fig. 2) was prepared for solving this equation graphically.

An additional analysis was made of 20-year changes in site index. Sixty-one observations were available for this study. Because density and composition index did not have any bearing upon 5-year changes in site index, these two factors were not included in this second analysis. Results showed that age was not significant, but that site index was highly significant. The following regression was derived for estimating the 20-year change in site index:

$$\hat{Y}_{20} = +9.18139 - 0.15106X$$

in which $\hat{Y}_{20}$ = estimated 20-year change in the site index and

X = site index in feet at the beginning of the period.

This study showed that the computed site indexes of the plots changed but little during the period of observation. Therefore, the published site index curves used in the white pine type provide a

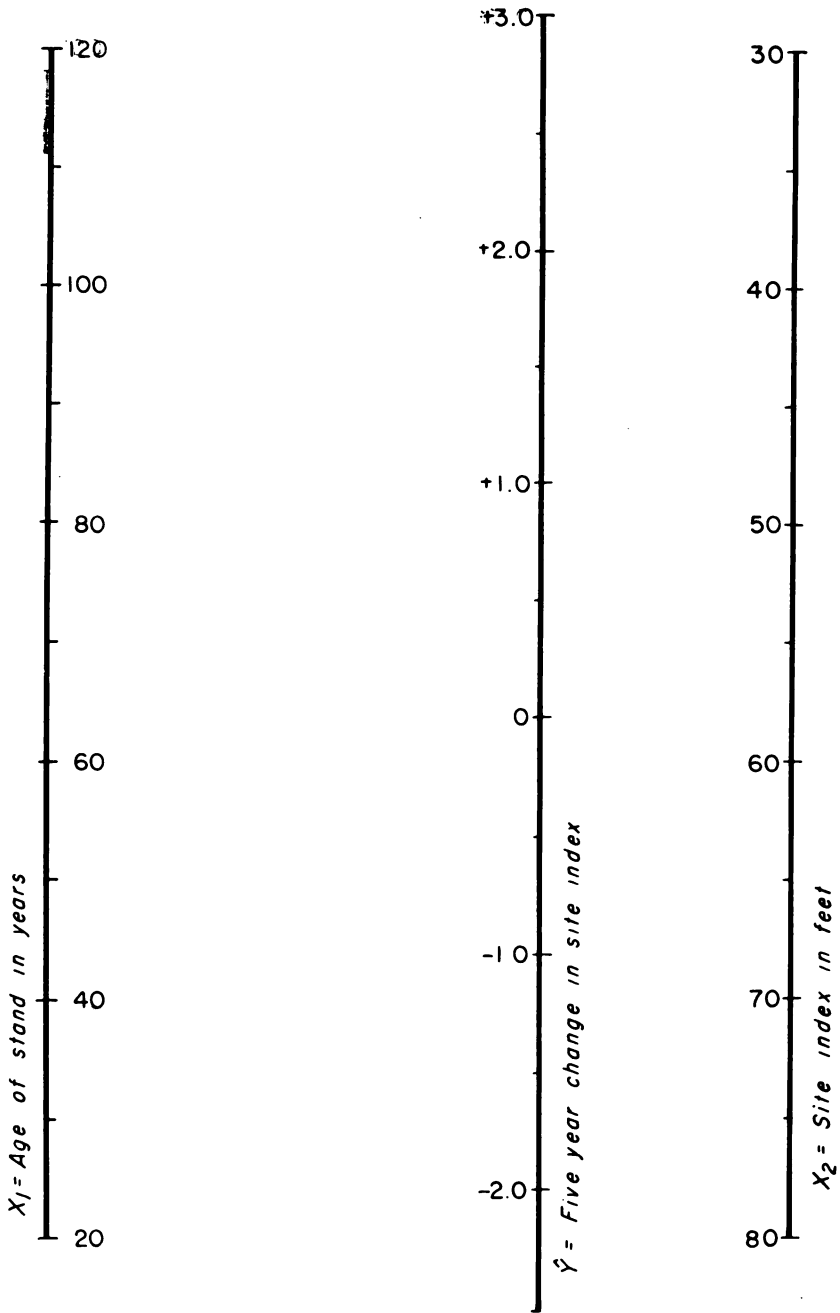


FIGURE 2.—Alinement chart for determining 5-year change in site index.

sufficiently accurate means of evaluating site quality for such purposes as prediction of yields, comparison of growth quality, and valuation of land.

These results are interesting to mensurationists working in other timber types because the method used in determining the western white pine site index curves followed a standardized method (26) that has been used, sometimes with slight modifications, in constructing curves for many other important timber species. This investigation, based upon accurately measured height growth on permanent plots, has shown that good results may be obtained by using standardized methods of collecting data for site index curve construction and for subsequent analysis of these data.

This analysis also shows, somewhat obliquely, that plot density does not affect site index determination within the range of density found on the plots. If, for example, white pine growth had stagnated on the denser plots, the changes in density toward lighter stocking that occurred on such plots, which was discovered in an analysis of density changes to be discussed later in this paper, would have resulted in some release of the trees. This release would have shown up in change in site index connected with stand density. This was not found to be so, as indicated by the nonsignificance of density. Apparently, the expression of dominance of western white pine is such that height growth is not reduced either in dense stands or in open stands.

SPECIES COMPOSITION CHANGES

An understanding of the silvical characteristics of the many species found in the western white pine type is especially important to the forest manager. Seven species—western white pine, western larch (*Larix occidentalis* Nutt.), Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), grand fir (*Abies grandis* (Dougl.) Lindl.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), western redcedar (*Thuja plicata* Donn), and lodgepole pine (*Pinus contorta* Dougl.)—commonly form the majority of the stands. Because of the varied properties of the wood of different species, the stumpage value of a mature stand may vary greatly depending upon its composition. Thus, from the viewpoint of the forester, who wants to establish and grow the stand offering the greatest financial returns or the stand with a maximum volume of a certain product, studies of trends in species composition are useful.

Although previous ecological studies in the white pine type help in understanding succession, they were not planned to indicate how species composition may change during the short period—short as compared to the time required for an area to progress from the pioneer species to climax species—during which a merchantable stand of seral³ timber species may be grown. Repeated measurements on the permanent plots in this study show the changes that may be expected to occur in 20 to 25 years in white pine stands from 30 to 100 years old.

³ A seral species is one found in the earlier stages of succession but not in the climax stand.

Analysis of Data

Eighty-six plots with growth records for at least 10 years supplied the data for this study. Of the 94 plots established in uncut western white pine stands, 8 having only 1 remeasurement giving change in composition for 5 years were not used because the change during such a short period was small. Because many of the plots were established for purposes of yield study that required full stocking and a high percentage of white pine—stand conditions that are present most often on the cool slopes of the region—the plots are unevenly distributed by aspect (table 6). However, it is believed that a good sampling of the five habitat types in which western white pine is a major seral species, as defined by Daubenmire (5), is available. Undoubtedly, most of the plots are found in the *Thuja plicata*-*Tsuga heterophylla* zone rather than in the *Picea engelmannii*-*Abies lasiocarpa* zone of the higher elevations. Unfortunately, the data on lesser vegetation were not complete enough to permit analysis of the plant associations present.

TABLE 6.— *Number of plots used in species composition study by site index class and aspect*

Aspect	Site index class					Total all sites
	Less than 36 feet	36-45 feet	46-55 feet	56-65 feet	Greater than 65 feet	
N.....	3	6	8	6	9	32
NE.....	4	2	4	2	2	14
E.....		1	2	3	2	8
SE.....				4	2	6
S.....		2	2		4	8
SW.....					1	1
W.....					1	1
NW.....		1	2	3	1	7
Level.....	1		2	4	2	9
All aspects.....	8	12	20	22	24	86

Stand composition varies greatly between plots. The composition of white pine in percent of total basal area ranged from a low of 19 to a high of 96 percent. Other individual species had a much wider range of proportions of the total stand; they comprised more than half the stand on certain plots but were completely absent on others.

The mean and range of total basal area composition for the seven major species on the plots are given in table 7. The intolerant seral species—white pine, larch, Douglas-fir, and lodgepole pine—form an average of 81 percent of the total stand on the plots. The tolerant climax species form the remaining 19 percent of the stand. These values reflect the predominance of temporary species which, because of their aggressive character on denuded sites, form the major part of young second-growth stands.

Because the basal area compositions of the dominant stand and the total stand were very similar, analysis of changes in composition was made in terms of total basal area percentages. Thus, change in composition is a composite change in number of trees and of diameter growth. Changes in composition during a 5-year measurement period were usually quite small. Therefore, in the analysis, changes in each age-site index class were averaged to give the results in terms of 20-year change in composition.

TABLE 7.—*Mean and range of stand composition for 7 important species in percent of total stand basal area*

Species	Mean	Range
	<i>Percent</i>	<i>Percent</i>
White pine.....	57	19-96
Larch.....	8	0-49
Grand fir.....	9	0-52
Douglas-fir.....	10	0-71
Hemlock.....	8	0-62
Redcedar.....	2	0-17
Lodgepole pine.....	6	0-50

Site index, age of stand, and aspect were believed to be the three factors that might influence the change in species composition in the white pine type. White pine, hemlock, and redcedar are more abundant and vigorous on the better sites; on these same sites, Douglas-fir and lodgepole pine are believed to be shorter lived and comparatively less vigorous than the aforementioned species. Age of stand was thought to influence composition changes because of the differences from species to species in longevity and the changes in growth rate that occur with age. Aspect, which is confounded somewhat with site quality, was also used as a means of classifying the data for analysis, for it might have some influence upon species changes.

After some experimentation with narrower classes of site index and age, broad classes were selected for compilation of data. The three site index classes used were (1) less than 46 feet, (2) 46 to 65 feet, and (3) greater than 65 feet. The age classes used were (1) less than 36 years, (2) 36 to 75 years, and (3) greater than 75 years. Although the data were repeatedly regrouped in attempts to get aspect groups containing both sufficient and comparable amounts of data, no satisfactory grouping could be obtained. Even when the data were divided into only two aspect groups—those aspects essentially north, or cool; and those essentially south, or warm—the lack of similarity in age-site classes between the two groups made valid comparisons impossible.

Results and Discussion

Two important results apparent from this analysis of species composition are (1) that stand composition in western white pine stands is established by the 30th year of growth, and (2) that changes in composition under natural conditions after that age are not sub-

stantial. Changes in stand composition after age 30 appear to vary with site index and age of stand, but these changes do not, for all practical purposes, alter stand composition enough to influence management decisions.

Despite the fact that most of the means for age-site classes are not significantly different from zero as determined by the "t-test," the trends displayed by the means reflect the known growth characteristics of the species. Therefore, a discussion of the trends seems justified.

White pine (table 8) tended to lose ground to other species in the youngest age class (less than 36 years) and in the poor site quality class (less than 46 feet). In other classes it gained in importance. Comparison with changes for Douglas-fir and lodgepole pine, and to a lesser extent western larch, shows approximately the reverse trend. Evidently these species, except for larch, are better adapted to the poor sites and will outgrow the white pine. But even on the better sites these species make rapid growth and outgrow the white pine. However, with increasing age white pine tends to gain in importance in the two better site classes. As the stands grow older, white pine growth continues at a rapid rate, but the growth rate of the competitors apparently decreases. Also, Douglas-fir and larch often start to drop out of white pine stands at about 70 years of age. Evidently the amount of white pine in a stand is determined very early in the life of the stand, and, barring some selective damage, such as white pine blister rust infection that kills only the white pine, large changes in the proportion of white pine cannot be expected.

Larch made gains in the young age class on sites of medium (site index 46 to 65 feet) and excellent (site index greater than 65 feet) quality (table 8). The gains in the young age class can be attributed to the very rapid growth rate of this pioneer species in young stands. As the stand grows older and competition becomes more intense, the crowns of the very intolerant larch are reduced by shading from trees alongside them, even by other light-crown larches. Growth then falls off rapidly as length and diameter of the live crown are restricted.

Douglas-fir (table 8) increased in importance in the young age class on all sites and in the medium age class (36 to 75 years) on the poor sites. In all other classes, it registered losses in percentage of the total stand basal area. Height growth of this species in young stands is less than that of white and lodgepole pines, larch, and grand fir, but this disadvantage is partly offset by the density and width of its crown, which permit it to grow successfully for a time in competition with these species. However, Douglas-fir is a short-lived species on the better white pine sites; root-rotting fungi often cause heavy mortality beginning in the sixth or seventh decade of life. As a result, it tends to lose out in the struggle for survival in older stands on the typical white pine sites. On the poor sites, to which it is better suited, it continues to make gains in the medium age class.

Grand fir changes (table 8) are, with one exception, positive. This species is one of the most tolerant of the white pine type and can grow rapidly when given a reasonable amount of space and light. Three studies (11, 16, 17) state that grand fir, hemlock, and redcedar form the climax stand in the white pine type, but one recent report (5) calls grand fir a seral species in all but one of the associations in which

TABLE 8.—20-year changes in the percent of each of 7 species in the total stand (basal area basis), by age and site index classes

Species and age class (years)	Site index			All sites
	Less than 46 feet	46 to 65 feet	Greater than 65 feet	
Western white pine:	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
Less than 36.....	-2.4	-0.7	*-6.6	*-3.1
36 to 75.....	** -5.7	+ .1	*+4.3	- .7
Greater than 75.....		+1.8	+1.0	+1.4
All ages.....	*-3.9	+ .5	*+1.8	- .1
Western larch:				
Less than 36.....	-4.4	+ .2	+ .1	-2.4
36 to 75.....	- .2	- .1	-3.0	- .8
Greater than 75.....		- .3	+ .2	- .1
All ages.....	-1.8	- .1	-1.9	*- .9
Douglas-fir:				
Less than 36.....	+ .4	+ .5	+1.3	+ .6
36 to 75.....	+ .5	- .8	-2.3	- .6
Greater than 75.....		** -2.6	*-3.1	** -2.8
All ages.....	+ .4	-1.1	** -2.1	-1.0
Grand fir: ¹				
Less than 36.....	+2.6	+1.0	+3.2	+2.6
36 to 75.....	- .6	+ .3	+1.6	+ .5
Greater than 75.....		+ .9	**+1.8	*+1.2
All ages.....	+1.2	+ .5	**+1.9	*+1.1
Western hemlock:				
Less than 36.....	-1.8	-3.7	+2.6	+ .1
36 to 75.....	*+3.0	**+1.0	+ .2	**+1.2
Greater than 75.....		-1.0	+2.4	+ .2
All ages.....	+1.3	+ .5	+1.0	*+ .8
Western redcedar:				
Less than 36.....	+2.2	**+3.6	+ .5	+1.9
36 to 75.....	+1.4	*+1.3	+1.8	**+1.5
Greater than 75.....		+ .2	+ .4	**+ .3
All ages.....	+1.8	*+1.1	*+1.2	**+1.3
Lodgepole pine:				
Less than 36.....	+3.8	+ .2	-1.0	+1.3
36 to 75.....	+2.3	- .9	-3.0	- .8
Greater than 75.....		- .4	- .9	*- .7
All ages.....	+2.7	- .8	-2.3	- .5

¹ Includes a small amount of alpine fir.

*Significant at the 5-percent level.

**Significant at the 1-percent level.

white pine is found. Because of its rapid height and diameter growth rates and its tolerance, which permits it to grow and reproduce under considerable shade, grand fir is one of the most aggressive trees of the type and continues to increase its proportion in the stands at all ages and on a wide range of sites.

Western hemlock and western redcedar, the two most tolerant trees of the type, gained in all site and age classes except three. Western hemlock thrives on cool, moist north slopes where its growth may equal that of white pine and grand fir (10). Because its seed, which is produced in large numbers in frequent seed years, can germinate and grow

under heavy shade, it will increase in numbers under established stands. Because of these two characteristics, rapid growth of individuals favorably situated at the time of stand establishment, and a steady increase in the number of young trees in the understory, hemlock slowly forms an increasing part of the stand of the plots. Redcedar also can reproduce in large numbers under established stands. Well-established redcedars, if they have a reasonable amount of growing space, make good growth in the understory. They seldom form a part of the overstory in young stands because the initial growth of young seedlings is very slow. This table gives strong evidence that white pine stands slowly tend toward a climax composed largely of western hemlock and western redcedar.

Trends in species composition for lodgepole pine, one of the most intolerant trees of the type, indicate that it was a successful competitor on the poor-site and young-age classes (table 8). This results from its very rapid growth rate in young stands, a characteristic typical of such pioneer species. In the two older age classes, except in the poor-site class, this species declined in importance. This was due in part to its decline in growth rate at a comparatively young age and to its short life span on cool white pine sites.

The changes in stand composition, as reflected in the seven most important species of the type, indicate that composition is established during the first 30 years of life, perhaps in the first two decades of this period. Changes in composition between the ages of 30 and 120 years, except for unusual circumstances, are not large enough to affect management decisions. Among such circumstances will be diseases that affect only one species in the stand, such as blister rust and pole blight of white pine, and selective insect attacks, such as those by the Douglas-fir beetle. A forest manager cannot view a stand having undesirable stand composition and conclude that the desirable species in time will gain ascendancy over the undesirable species in some unexplained but hoped-for way. If a change in composition is desired, such change can be brought about only by man's action in some type of systematic cutting. Such action should be undertaken when the stand is in the seedling stage. Then the cost of treatment is least, and sufficient stems having desirable characteristics are available (31).

NORMALITY PERCENTAGE TRENDS

Concepts of Normality

Foresters visualize land productivity in terms of the normal or fully stocked stand of trees. According to this concept, any site when stocked with a sufficient number of well-distributed trees of a given species will produce wood at a predictable rate, provided there is no unusual mortality. Yield tables for the important commercial forest types of this country show normal growth values for fully stocked stands of various ages growing on land having different site qualities. Although difficulties arise in making an arbitrary decision of selecting the fully stocked stand, the basic concept behind normal yield tables is sound and defensible.

Despite this fundamental soundness, use of normal yield tables to predict growth of forest stands is not a simple, straightforward procedure that invariably gives the correct answer. Actually, because of the nature of forest growth, which usually produces stands that are less than normally stocked, a forester encounters difficulties in applying yield tables for fully stocked stands to the commonly found understocked stands (fig. 3).

Does the growth of an understocked stand bear the same relationship to the growth of the normal stand as its volume does to that of the normal stand? Logically, assuming that the understocking is caused by an insufficient number of trees rather than by openings in the stand, individual trees in the less dense stand have more space available for growth than do the trees in normally stocked stands; therefore, trees in less dense stands grow more rapidly. Also, understocked stands suffer less mortality through suppression and other causes brought about by crowding. Of little practical importance but of scientific interest is the growth of overstocked stands. Do such stands, because of the limited opportunity for development of the individual tree and increased mortality due to intense competition, tend to grow somewhat slower than is indicated by their normality percentages? If this theorizing be correct, both understocked and overstocked stands change in normality percentage with time, and both changes are toward normal stocking.

In practice, however, such trends usually are disregarded in predicting growth when yield tables are used as a basis. Common prac-



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FIGURE 3.—Although natural reproduction is often dense in the western white pine type, understocking does occur. Contrast this 45-year-old stand with its 64 percent of normal basal area stocking on a poor site with the fully stocked stand in figure 13. This understocked stand was 58 percent of normal when first measured in 1925, but attained 73 percent normality by 1950.

tice assumes that the estimated growth of a nonnormal stand will be reduced in proportion to its deficiency in stocking. Thus, if a cruised stand shows only 65 percent of normal volume, predicted growth and future yields are assumed to be an unvarying 65 percent of normal. Many yield tables intimate that this method results in estimating values somewhat below the actual growth of the stand, but they justify this procedure as introducing a desirable conservatism in estimating growth—desirable because it will cover unpredictable losses that may be caused by mortality, defect, or logging breakage.

Despite such assurance, predicting growth by using yield tables was questioned early in American forestry. In 1914 Carter (3) expressed doubt that stand density remains constant. He concluded that if density changes with time, the existing methods of using yield tables to estimate growth should be modified. However, at that time, no investigations were undertaken to discover whether change in density of stands can be predicted.

In recent years, several projects have been initiated to study normality percentage-time relationships. The several lines of approach used in these studies can be grouped into three main classes.

1. Collection and analysis of data from temporary once-measured sample plots located in stands of various ages and densities.
2. Analysis of data obtained by repeated measurement of permanent sample plots.

3. Use of Gehrhardt's formula for predicting growth of nonnormal stands and thus, indirectly, of changes in normality percentage.

In terms of time and expense required, the use of temporary plots is much more economical than the use of permanent plots that must be maintained and remeasured over a long period before sufficient data are available. Several studies have used temporary plot data. Meyer (22), in a study of growth in young Douglas-fir stands, examined density changes in addition to other phases of growth. His analysis of data from a series of plots and strips showed that normality percentage was changing at the rate of 4 percent per decade toward normal density. Chaiken's study (4) of 306 mechanically selected plots in stands of loblolly and Virginia pine also showed changes in density with increasing stand age. The younger and less dense the stand, the more rapid is the rate of change in stand density.

Wellwood's (33) analysis of data from 144 temporary plots in second-growth loblolly pine stands showed that these stands were approaching normal stocking, but that density changes were not so great as to move stands from one percentile class to another. He found that stand age, site index, and stocking influenced density changes. He used these variables plus percentile class to formulate an equation to predict changes in normality percentage. A study of spruce-fir stands in Michigan disclosed that density increases more rapidly on good sites than on poor ones (1).

Fewer studies have been based upon permanent plot data than upon temporary plot data, but, because permanent plot studies dem-

onstrate changes measured accurately over a period of time, they are less open to question. In 1928, Meyer (21) showed that 10 permanent plots in Douglas-fir stands were approaching normal stocking, but that the limited data available did not permit the development of equations to predict trends in normality percentage. In 1933 (23), when additional data were available, he found that changes in normality percentage in terms of cubic, Scribner, and International board-foot volumes were well correlated with initial normality percentage, but that changes in basal-area normality percentages were not. These stands were not approaching normal density but, rather, approximately 115 percent of normal volume. This indicated that yield-table values were somewhat less than truly normal.

Briegleb (2), working with additional measurements collected on essentially the same plots in second-growth Douglas-fir stands, concluded that initial normality percentage, age, and site determine changes in density on these plots. He derived multiple regression equations using these three independent variables to predict normality percentage changes in a 5-year period. The final product of this series of studies was a revision (18) of the Douglas-fir yield-table bulletin that incorporated tables to be used in estimating changes in stand density.

An analysis of several methods of predicting growth in Douglas-fir, including use of equations for predicting changes in normality percentages, concluded that simply assuming that stands make normal growth would be the most accurate, at least when the stands do not "deviate markedly from normal" (14). Growth records collected on permanent plots in second-growth western white pine stands showed a predictable trend in density changes that depended upon the density at the start of the 5-year prediction period (29). Investigation of the growth on permanent plots in loblolly pine stands in northern Louisiana showed that the stands were approaching 115 percent of normal and that initial normality percentage determined the rate of approach (24).

Notice of the third method mentioned, the use of Gehrhardt's formula for predicting growth and thus, indirectly, changes in density, has appeared infrequently in American forestry literature. Gevorkiantz (7), and later Duerr (6), both showed that this formula, when modified for Lake States hardwood species and tested against Forest Survey growth data, accurately predicted growth and thus indirectly predicted changes in normality percentage. Briegleb (2) tested the formula against growth records collected on permanent plots in second-growth Douglas-fir stands, but found it valueless. Gehrhardt's formula presupposes mortality to be a constant percentage of growth, a condition that did not hold for these Douglas-fir plots.

As a result of these studies, and many others to be found in the literature, foresters now generally agree that stands do change in normality percentage toward normal or near-normal values and that knowledge of the rate of such change may be used to improve estimation of future growth.

Preliminary Analyses

All the 94 plots described earlier in this paper were used in this study of normality percentage changes. Normality percentages were calculated in terms of basal-area stocking, cubic-foot volume, and Scribner board-foot volume. The computation of the volumes used is described under Basic Calculations.

Tables 5, 6, and 13 in Haig's "Second-Growth Yield, Stand, and Volume Tables for the Western White Pine Type" (9) were used to supply normal stand values. Values were interpolated in these tables to the nearest unit of age and site index. Actual plot value, expressed as a percentage of interpolated normal value, gave the relative density or normality percentage of the stand. The determination of normality percentage for each remeasurement allowed calculation of 5-year changes in normality percentage that were used as the dependent variable in analysis of normality percentage trends.

Two short analyses were necessary before the exact method of analyzing all the data could be selected.

The first preliminary analysis was concerned with the influence of climatic cycles upon growth. Cyclic climatic changes are known to affect the rate of growth of forest stands, especially in areas where moisture is a limiting factor. Old-growth western white pine stands showed variations in diameter growth that were attributed to precipitation cycles (19). If the precipitation cycles that occurred during the observation period influenced growth and, thus, changes in normality percentage, such cyclic growth changes would seriously confound any analysis of normality percentage trends that did not consider them. Therefore, a short analysis was made to see whether any changes in normality percentage coincided with known precipitation cycles. Data from 55 plots, all established in the years 1925 and 1926, were used for this work. The changes in basal-area normality percent on these plots were arranged by 5-year calendar periods, and the average change for each period computed. This arrangement of data showed no trends correlated with the known dry period in the 1930's and the wetter period of the 1940's.

A second exploratory analysis concerned the influence of species composition upon growth rate. Analysis of data assembled for the construction of the normal yield tables for the western white pine type (9) showed stand composition to have "a definite though ill-defined effect upon timber yield." Stands containing a high percentage of western white pine, grand fir, and, to a lesser extent Douglas-fir tended to produce higher volumes than stands otherwise comparable that had a high percentage of western hemlock, larch, and western redcedar. Therefore, stands with a high percentage of white pine and grand fir might have different normality percentage trends than stands containing only a small proportion of these two species.

If this reasoning were valid, an investigation of the factors determining normality percentage trends should include species composition as a variable. Therefore, an analysis was made of the influence of the proportion of white pine and grand fir, termed "composition index," on change in normality percentage. Two groups of data were

assembled, one group from plots having a composition index less than 50 percent, the second from plots having a composition index greater than 50 percent. Both groups were comparable in other respects. The regressions of change in normality percentage on initial normality percentage for each group were different. Although this test did not conclusively answer the question posed, it did indicate that composition index should be included in subsequent analyses. This comparison of two discontinuous sets of data could have hidden some trends that might show up when using a single continuous range of data.

The question of the validity of treating repeated observations on a given plot as statistically independent measurements arose early in the analysis, but could not be adequately answered until the regression equations had been calculated. This analysis used 55 plots with 4 consecutive changes in normality percentage. The estimated change in normality percentage, computed from the equation for changes in basal-area normality percentage, was calculated and the differences, termed "residuals," between paired values of actual and computed normality percentage were found. The correlation between the paired residuals of the first and second measurement periods, the second and third, and the third and fourth were calculated. If the correlation coefficient thus computed was found to be statistically significant, the two contiguous changes in normality would not be statistically independent, and the method of analysis of the data would be invalid. Two of the three correlation coefficients thus calculated were very small, 0.153 and 0.158, and were not significant; the third was significant at the 5-percent level. Hence, it was concluded that repeated measurements are essentially independent statistically.

Analyses of Changes in Density

Multiple regression analysis was selected to determine the role of the four independent variables that were deemed likely to have an important influence upon changes in density. These independent variables were initial normality percentage, age, site index, and composition index. A previous analysis of white pine growth (29) showed that initial normality percentage was very important in influencing both the direction and rate of change in density. Age was included in this earlier analysis. It significantly influenced changes in board-foot density, although it did not have a significant influence upon change in basal-area or cubic-foot volume densities. Therefore, initial normality percentage and age were used in analysis.

Site index was used as the third independent variable, for it has been found important in similar studies in other forest types. Composition index, the percentage of white pine and grand fir in the stand, was included, for the preliminary analysis showed some differences in changes of normality percentage with composition index. These considerations led to the final selection of the four independent variables.

Undoubtedly, other factors affect normality percentage trends, but they are not susceptible to easy measurement or manipulation. For example, spatial distribution of trees on an area must influence growth and, consequently, changes in density; but distribution is difficult to express mathematically for use in statistical analysis.

A separate regression analysis was made for changes in density as measured in three units—basal area, total cubic-foot volume, and Scribner board-foot volume. An analysis based upon the number of trees was not undertaken, mainly because the minimum size of tree measured was not always the same on every plot. Although most of the measurements included all trees 0.6 inch d.b.h. and larger, some data collected in older stands did not include such small trees.

The correlation method of calculating the multiple regression, as mentioned under Site Index Study, Analysis of Data, was also used for analysis of normality percentage trends. Data for all 340 5-year remeasurement periods were used in the basal-area and cubic-volume analyses; information from only 257 periods could be used in the board-foot analysis, for a number of plots in the younger stands had little or no board-foot volume.

Results of Analysis

The multiple regression analysis of change in normality percentage on the four independent variables of initial normality percentage, age, site index, and composition index showed that initial normality percentage was highly significant for the analysis of changes in stand normality percentage for each three units of measurement. Age of stand was highly significant for two of the three analyses. Composition index was significant at the 1-percent level for the cubic-foot volume analysis and between the 5- and 10-percent levels for the other two analyses. Site index was not significant in any analysis. In all three analyses the multiple correlation coefficient was highly significant.

The regressions were then recalculated with site index eliminated. Table 9 presents the values of "b-primes" and multiple correlation coefficients, R, obtained in these recalculations. Since the values of the multiple correlation coefficients found when using three independent variables were only slightly smaller than those obtained when using four independent variables, the elimination of site index made no difference in the amount of variability explained by the regression. The three values of "b-primes" in table 9 that are not highly significant have significance between the 5- and 10-percent levels. Therefore, all three independent variables of initial normality percentage, age, and composition index were retained, and the multiple regression equation computed. These three equations are as follows:

$$\begin{aligned}\hat{Y}_{\text{basal area}} &= +16.51873 - 0.16165X_1 - 0.07555X_2 + 0.04267X_3 \\ \hat{Y}_{\text{cubic-foot volume}} &= +16.09442 - 0.21703X_1 - 0.08160X_2 + 0.12730X_3 \\ \hat{Y}_{\text{board-foot volume}} &= +13.53481 - 0.30171X_1 + 0.06408X_2 + 0.08220X_3\end{aligned}$$

in which

$\hat{Y}$ = estimated change in normality percentage in 5 years
 X_1 = normality percentage at start of 5-year period
 X_2 = age at beginning of 5-year period
 X_3 = composition index at start of 5-year period.

TABLE 9.—*Values of “b-primes” and multiple correlation coefficients for calculating normality percentage regressions using 3 independent variables*

Statistic	Basal area	Cubic-foot volume	Board-foot volume
b' ₁ =normality percentage-----	**—0. 46507	**—0. 55223	**—0. 64565
b' ₂ =age-----	**— . 23318	**— . 21061	+ . 08998
b' ₃ =composition index-----	+ . 10258	**+ . 25397	+ . 10480
R ² -----	. 18934	. 24962	. 41936
R-----	** . 43513	** . 49963	** . 64758

**Significant at the 1-percent level.

Alinement charts (figs. 4, 5, and 6) present these equations in graphical form for quick solution. These alinement charts are used as follows:

1. Lay a straightedge on the stand values for initial normality percentage and age of stand on the axes giving these values, and establish the point of intersection of the straightedge with the turning axis, marked $X_1 + X_2$.

2. Then place the straightedge on this point on the turning axis and the value of composition index for the stand.

3. The intersection of the straightedge with the axis marked “Y—5-year change in normality in percent” gives the solution of the equation for the stand values substituted.

Because stand normality percentage has overwhelming importance in prediction of normality percentage changes, as shown by the relative values of the “b-primes” in table 9, the regression of normality percentage changes on initial normality percentage was calculated to give these three equations:

$$\begin{aligned}\hat{Y}_{\text{basal area}} &= +11.86804 - 0.13530X_1 \\ \hat{Y}_{\text{cubic-foot volume}} &= +15.66115 - 0.17836X_1 \\ \hat{Y}_{\text{board-foot volume}} &= +23.53975 - 0.29264X_1\end{aligned}$$

in which $\hat{Y}$ and X_1 have the same meaning as in the multiple regression equations shown previously.

Coefficients of correlation showing the relationship between the two variables used in these regressions are, respectively, -0.38927 , -0.45383 , and -0.62568 . The squares of these values, indicative of the amount of variation in change in normality percentage explained by the dependent variable, initial normality percentage, are, respectively, 0.15153 , 0.20596 , and 0.39147 . These values are somewhat smaller than the values shown in table 9 for the square of the multiple correlation coefficient, and indicate the loss of precision brought about by the elimination of the variable of age and composition index from the regression.

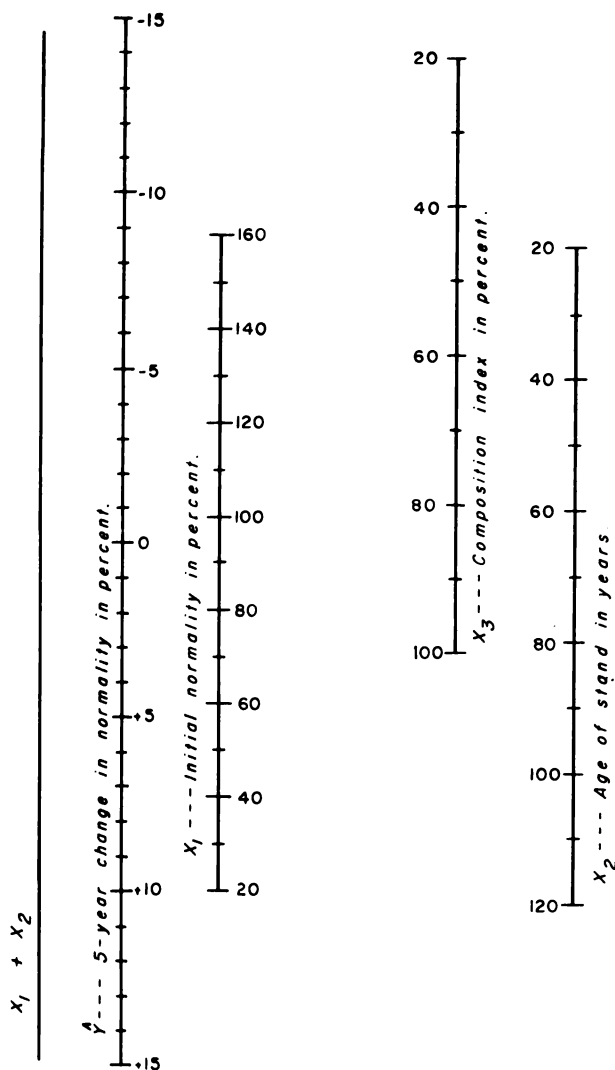


FIGURE 4. Allment chart for determining 5-year change in basal-area normality percentage.

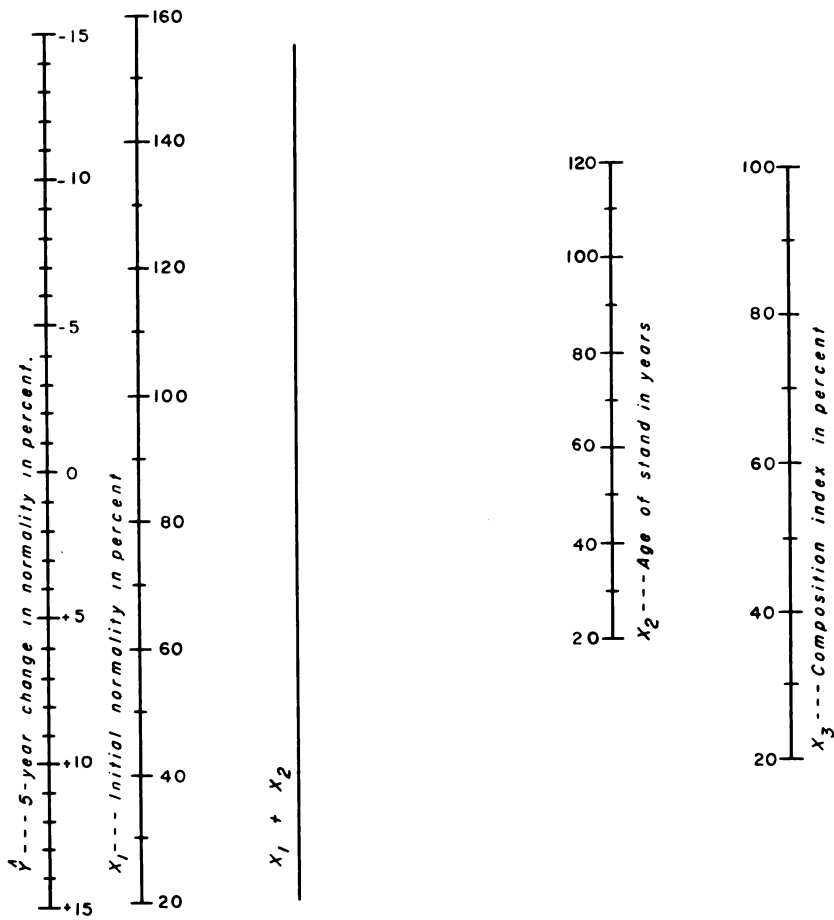


FIGURE 5.—Allnement chart for determining 5-year change in cubic-foot volume normality percentage.

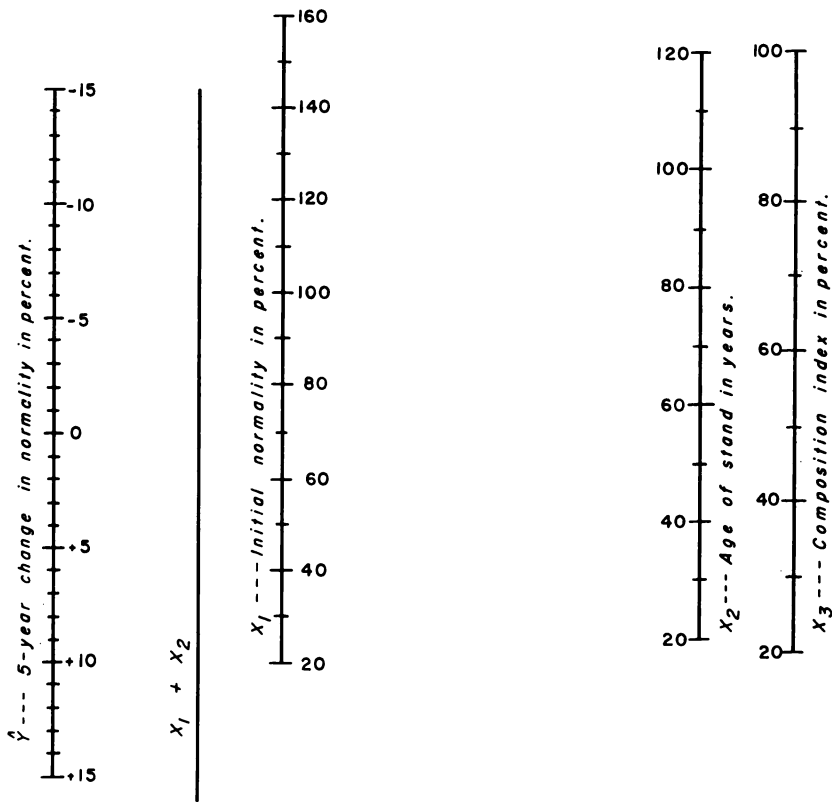


FIGURE 6.—Alinement chart for determining 5-year change in board-foot normality percentage.

Discussion of Results

Initial normality percentage, as shown by the values of "b-primes" in table 9, has twice the importance in influencing changes in normality percentage as do the other highly significant variables. When compared with those variables having significance between the 5- and 10-percent levels, initial normality percentage has even greater importance.

This predominating influence of normality percentage might well be expected, for the greater the difference between the normal and actual stocking, the greater the advantage of the individual tree in the understocked stand relative to that in the normal stand in respect to growing space and the probability of mortality. This difference in growing space and mortality expectancy between trees in the understocked and normal stands is the basis for anticipating an approach toward normal values of stocking. The influence of site and age on normality percentage changes should naturally be somewhat subordinate to that of stocking, for normal yield tables are designed to account for variation in growth due to age and site differences.

Age of stand had a highly significant role in the regression of basal-area and cubic-foot volume normality percentage, but did not have great importance in the regression of board-foot normality percentage. This difference in significance may be due largely to the narrow range of ages in the board-foot analysis. The board-foot analysis could not include the younger stands, for they contained no trees of board-foot size. In these younger stands the trees of the white pine type can respond most rapidly to additional growing space afforded by understocking. Therefore, the necessary elimination of young stands from the board-foot analysis well may have eliminated the very stands in which age does have a significant influence upon changes in normality percent.

Composition index, the percent of white pine and grand fir in the total stand, is highly significant in the cubic-foot volume analysis but not in the other two analyses. These two species combine to produce high volume stands for they grow rapidly in both height and diameter, have a bole with little taper, and even in relatively dense stands maintain a good rate of growth. Therefore, the greater the percentage of these species in a stand, the more rapidly the normality percentage of the stand changes. Apparently this holds true for cubic-foot volume normality percentage to a high degree but to a lesser extent for board-foot and basal-area normality percentage changes. The effect of composition index naturally would be expected to be least for the basal-area regression, for the advantage of better form and greater height growth of white pine and grand fir is lost when only basal area is considered. The low significance of composition index in the board-foot regression cannot be explained.

The positive value of the regression coefficient for composition index indicates that the greater the amount of white pine and grand fir in a stand, the greater the volume produced by the stand. The lesson to the forester is obvious: these species should be favored to produce the

maximum yield from an area. Production of stands having a high proportion of white pine has long been the goal in the white pine type, mainly because it produces high income. This study shows that the long-suspected greater volume production of white pine is a fact, and gives additional justification for controlling blister rust in selected drainages (20). Where blister rust control is not practicable, encouraging grand fir may be justified because it also produces large volumes.

Although density of the stands in the white pine type is changing, the central values being approached are somewhat below normal stocking. These values can be determined easily by equating the three simple regression equations on page 25 to zero and solving for the unknown values of X_1 . This computation shows that white pine stands approach 88 percent of normal basal-area and cubic-foot volume, but only 80 percent of normal board-foot volume. Apparently, natural second-growth western white pine stands generally do not attain 100 percent of normal stocking. This may indicate that the white pine yield tables have set the normal volumes too high. On the other hand, it might be argued that, because of the openings that are produced by mortality agents, such as wind, snow, insects, and diseases, a stand seldom fully occupies a site and, therefore, the trend is to a stocking lower than that obtained in the yield table studies. Naturally, the stands measured to provide data for the normal yield tables did not include any that had openings in the crown canopy or had suffered considerable recent mortality.

The computation of central values of 80 to 88 percent that the stands on the sample plots are approaching ignored the effects of age and stand composition. When these two factors are considered for a given stand, the central value toward which that stand is moving may be greater or less than that computed for all stands when age and composition are disregarded. The average composition index of the plots supplying the normality trend data was about 70 percent, so that stands having a composition index greater than that value approached a normality somewhat greater than the 80 or 88 percent given above. Similarly, as is indicated by the negative regression coefficient for age in the multiple regression equations, the greater the age of the stand, the lower the central value that it will approach, other factors being equal.

The approach toward normal stocking is a dynamic affair. When a stand reaches the central values indicated by the regression equations, normality percentage probably will not remain at that value for long. Depending upon a number of factors, chiefly mortality, the stand may for a time remain at, exceed, or fall below that value, but the general trend is toward it.

The progression toward these central values of stocking is not steady but is, instead, erratic and extremely variable. Figure 7 shows the normality percentage values for 20 stands having different ages and characteristics selected from the 94 plots studied. These plots display a variety of patterns of normality percentage changes. Some show a steady progression of normality percentage; the change in

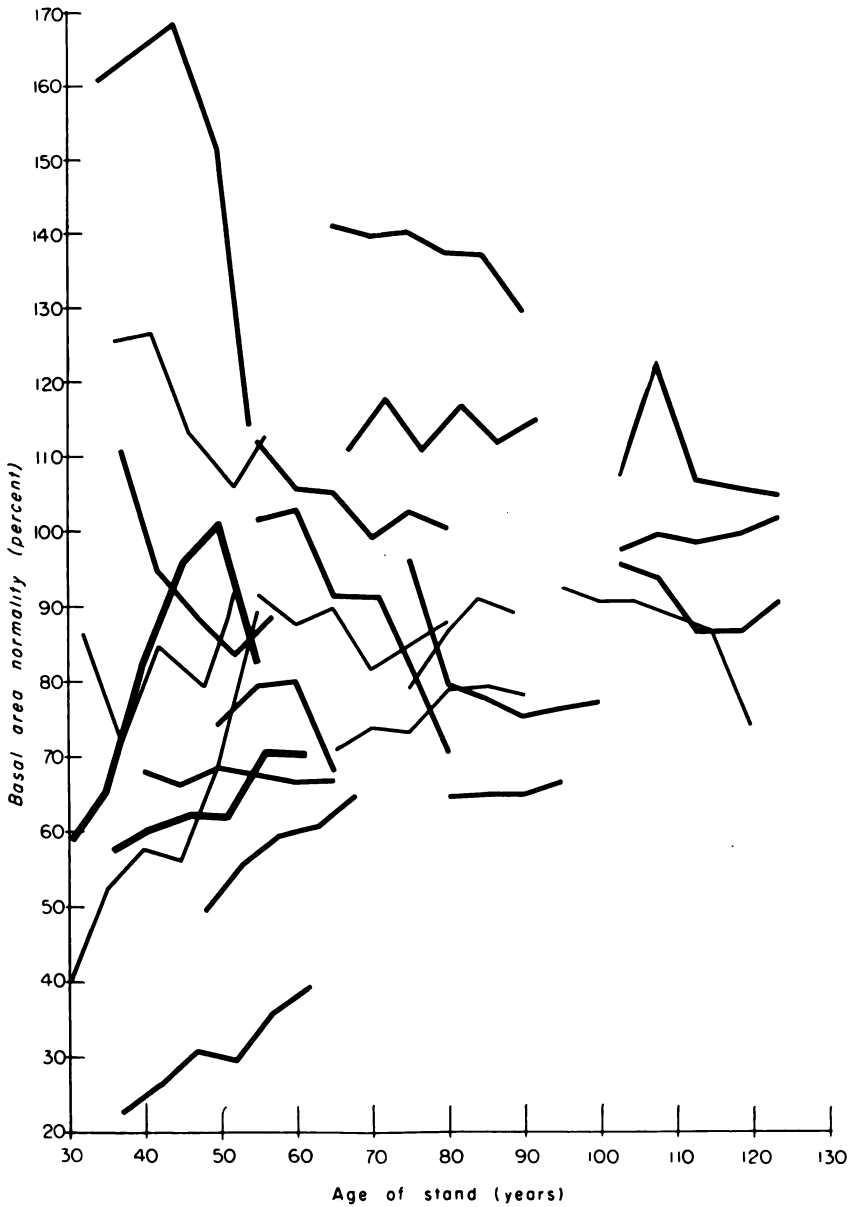


FIGURE 7.—Normality percentage trends on 20 selected plots.

density for other plots varies radically from period to period, now being positive and then negative.

Such variability in the movement toward central values results in difficulty in predicting changes in normality percentage. This difficulty is reflected in the magnitude of the squares of the multiple correlation coefficients (table 9). From 58 to 81 percent of the variation is not explained by the independent variables used in the regressions. This unexplained variation is due to several factors, chiefly the variability of mortality.

About half the mortality in the second-growth stands is caused by wind and snow (table 11), factors as variable as the weather conditions that cause snow and wind storms. Other important causes of mortality, insects and diseases, also are subject to violent fluctuations. In addition, factors not yet evaluated may contribute to the unaccounted-for variation, but they probably have considerably less importance than mortality. Spacing of the trees in the stand, whether uniform or patchy, site differences not fully accounted for by site index curves, edaphic or topographic factors, past history of the stand, and the innumerable differences in distribution of trees by diameter class, crown class, and species all may have some effect.

The failure of the regression equations to explain a large part of the variability present in the dependent variable, change in normality percentage, appears in the error that may be expected in any attempt to predict future normality percentage of a stand. Standard errors of estimate for the multiple regression equation for basal area, cubic-foot and board-foot volumes are, respectively, ± 7.42 , ± 8.56 , and ± 13.01 . Thus, as was also found in Douglas-fir stands (2), prediction of change in normality percentage cannot be made with precision for an individual stand.

However, the fiducial limits about the regression line indicate that prediction of changes in normality percentages for a large number of stands similar to those in the original data may be made with success. For example, the fiducial limits about the basal area simple regression range from ± 2.21 for initial normality percentage of 40, to ± 0.8 at 100, and ± 1.6 at 140.

Thus, if normality percentage changes are predicted for large areas that have a multitude of stand conditions, sites, ages, and compositions, the actual normality percentage changes and those predicted generally should be quite similar. The precaution should also be taken to confine predictions to a reasonable period of time, perhaps 20 to 30 years, which is comparable to the length of time the permanent plots were under observation for the collection of the basic data.

The accuracy of growth predictions based upon normal yield tables will be increased when changes in normality percentage are included in the prediction process. Especially important is the fact that, since natural stands of any extent are understocked, estimates assuming no change in normality percentage invariably are below the actual growth that will accrue. In the Inland Empire, where the mill capacity and the volume cut exceed the growth of the more valuable and desirable

species, underestimation of growth in stands below normal may seriously hamper the industry by establishing an allowable cut lower than necessary.

By assuming values for a hypothetical stand, the difference between the growth predicted with the use of normality percentage change and that predicted assuming no change in normality percentage can be determined. Such a calculation is shown for 30 years' growth of a 40-year stand with 70 percent of normal stocking, a composition index of 70 percent, and a site index of 60 feet (table 10). The predicted changes in normality percentage are +18.9 percent in cubic-foot volume and +5.1 percent in board-foot volume. These normality percentage changes result in differences in volume of 1,418 cubic feet and 1,148 board feet over that given by the predictions based upon constant normality percentages. These are increases of 27 and 7 percent, respectively, for cubic- and board-foot-volume yields. Such differences, if cumulated over an extensive area, result in volumes of considerable magnitude and importance.

The prediction of changes in normality percentage does not require collection of any information that is not ordinarily collected in any standard inventory of forest areas, so that no additional fieldwork is necessary. To apply the multiple regression equations for the predictions of changes of normality percentage for making growth estimates, the present age, volume or basal area, site index, and stand composition of each stand would be determined. The appropriate values are inserted in the regression equations, and the 5-year change in normality percentage is calculated. This can be performed most readily by using the alinement charts (figs. 4, 5, and 6).

The calculated change in normality percentage is then added to the present normality percentage. If the change in normality percentage and the predicted growth are desired for several decades into the future, this process is repeated for the requisite number of 5-year periods. Of course, the age of the stand and the initial normality percentage must be changed for each successive calculation. When the estimated normality percentage at the end of the desired period is found, this value is applied to the normal yield-table value to give the expected volume of the stand. The difference between the original volume given by the inventory and the volume for the estimated future normality percentage is the predicted net growth on the area.

If somewhat less exact predictions are suitable, the simple regression equations based only upon normality percentage may be used for prediction of normality percentage changes. However, the slight extra work necessary in the use of the multiple regression equations is believed to be justified.

This method of growth prediction takes into account what might be termed "average mortality" as found on the plots that were used in the normality regression analysis. Thus, the use of the regression equation for normality obviates the difficulties of estimating mortality that are necessary in many growth-prediction methods. It cannot be emphasized too strongly that mortality is the factor that makes predicting growth so difficult, regardless of the methods used.

TABLE 10.—*Comparison of growth estimates assuming no change in density with estimates using density changes predicted with multiple regression equations. Composition index of 70 percent, site index of 60 feet*

Age of stand (years)	Cubic-foot values				Board-foot values			
	Changing normality percentage		Constant normality percentage		Changing normality percentage		Constant normality percentage	
	Normality percentage	Volume per acre	Normality percentage	Volume per acre	Normality percentage	Volume per acre	Normality percentage	Volume per acre
	Percent	Cu. ft.	Percent	Cu. ft.	Percent	Rd. ft.	Percent	Rd. ft.
40	70.0	1,855	70.0	1,855	70.0	1,190	70.0	1,190
45	76.7	2,631	70.0	2,401	70.7	2,722	70.0	2,685
50	81.5	3,431	70.0	2,947	71.4	4,284	70.0	4,200
55	84.8	4,278	70.0	3,532	72.3	6,905	70.0	6,685
60	87.0	5,116	70.0	4,116	73.2	9,589	70.0	9,170
65	88.3	5,907	70.0	4,683	74.1	13,190	70.0	12,460
70	88.9	6,668	70.0	5,250	75.1	16,898	70.0	15,750

MORTALITY STUDY

As stands progress from the seedling stage through the sapling and pole stages to the mature stand ready to be harvested, mortality continually operates to reduce the number of trees in the stands. Foresters working in many different parts of the country have long wondered what part of the total wood grown on an area is lost to use through mortality. They have also been concerned about the causes of mortality and their relative importance in a given timber type. The distribution of mortality by size class of the tree and the influence of such stand factors as age, composition, and vigor are also questions that have been raised about the subject of mortality.

The data gathered from tagged trees on the permanent plots provided an opportunity to answer some of the questions on mortality that have been raised in the past by foresters working in the white pine type. The causes of mortality and their relative importance, the amount of wood lost during growth of white pine stands from 30 to 100 years, its distribution by size classes, and the stand factors that influence mortality were the major facets of mortality that were investigated in this study. Some of the findings have already been reported briefly (30).

Analysis of Data

Thirty-eight of the forty permanent plots having tagged trees were used for this phase of the study of growth on permanent white pine plots. The other two could not be used because mortality records had not been kept for them. Of course, the plots having untagged trees could not be used, for a stand tally of live trees was all the information that was recorded at each remeasurement.

The 38 plots used included a total of slightly more than 45 acres; 142 5-year-remeasurement periods are represented by the data. A wide range of site quality, age, and stand density is covered. At the time of each remeasurement, any tree that had died since the previous remeasurement was tallied as dead and was examined to ascertain the cause of death.

The following causes were recognized: Suppression, snow, insects, diseases, top broken out, windthrow, other injuries, and unknown. The previous records for each tree were carried into the field and often gave clues as to the probable cause of death. For example, a tree that exhibited no visible signs of the cause of death but which, according to the records, had practically ceased diameter growth for a number of years previously and had been recorded as being "suppressed" for an equal period, would be listed as "killed by suppression." The cause of death of some trees could not be determined; consequently, "cause of death unknown" was recorded for them. For most trees, the cause of death listed was the immediate and most obvious one. For example, a tree listed as "windthrown" might have been weakened by wood-rotting fungi.

The original field data included eight known causes of mortality plus a category for unknown causes. These eight causes were combined to give the following five groups into which all data were distributed: (1) Suppression; (2) snow, windthrow, and top broken out; (3) in-

sects; (4) diseases; and (5) unknown causes and other injuries. Snow, windthrow, and top broken out were combined, because, for many trees, it was impossible to distinguish these causes with certainty. For example, a tree that was found thrown over and uprooted might have been blown over by wind or might have been overbalanced by an accumulation of ice and snow on its crown, sometimes with the aid of violent wind. Similarly, the breaking out of the top of a tree might have been caused by wind or snow, or by both of these agents acting in conjunction. The category "other injuries" comprised only a very small proportion of the total mortality; several miscellaneous and unrelated causes were included.

The first mortality analysis was of the causes of death. The calculations were made by broad age and site classes to yield final values of the percentage of mortality due to each of the agents of mortality.

The second analysis was a graphic one to determine the cumulative net and gross growth and mortality. This analysis gave the volumes in live trees present in the stands at ages from 30 to 100 years. It also gave the total production of the stands at 10-year intervals throughout this range of ages. This total production is the volume in live trees present at any age plus all the mortality that has occurred since the origination of the stand but excluding any mortality that occurred before age 30. Total cumulative mortality, of course, also was determined: It is the difference between total production and volume present in live trees at a given age.

At first, an attempt was made to analyze mortality by site index classes, but the scarcity of data for certain site-age classes and the great variability of mortality made it impossible to construct curves for each site index class. Therefore, the data for all sites were combined and the resultant values fitted with a freehand curve. Periodic net and gross growth were accumulated as if no mortality had occurred before the stands reached 30 years of age, because the data for stands below this age class were represented by only two measurements. However, both of these measurements showed very slight basal-area and cubic-foot volume losses, and, of course, no board-foot losses in these young stands. The error introduced by disregarding the small losses that occur in very young stands is not important; this is indicated by the convergence of the net and gross growth curves at young ages. This second analysis gave a good figure of the net and gross growth at any age and the mortality that had occurred, but was not designed to yield any indication of the distribution of mortality by size class.

Therefore, a third analysis was made of cubic- and board-foot losses by diameter classes. For cubic-foot mortality, three diameter classes were used: (1) Less than 4.6 inches d.b.h., (2) 4.6 to 10.5 inches d.b.h., and (3) greater than 10.5 inches d.b.h. Board-foot mortality was divided between two diameter classes: (1) Less than 10.6 inches d.b.h., and (2) 10.6 inches d.b.h. and larger. The smaller of these two diameter classes was composed of western white pines down to 7.6 inches d.b.h. and other species to a minimum diameter of 9.6 inches d.b.h. Generally, 11 inches is considered to be the minimum diameter for merchantable saw-log trees in the Inland Empire area. Mortality values were grouped in these size classes by 10-year age classes.

Then these values were converted to percentages that were plotted over age and smoothed with freehand curves. Percentages read from these curves were then applied to the previously computed values of periodic mortality. This procedure segregated the periodic mortality by size class. The periodic values were accumulated to show cumulative mortality by age and size class.

The final major analysis of mortality data was concerned with the correlation of mortality with stand normality percentage, age, site index, composition index, basal area, and cubic- and board-foot volumes. The data were also analyzed to see if a given calendar half-decade was a period of heavy or light mortality, considering all the plots. No such relationship was found.

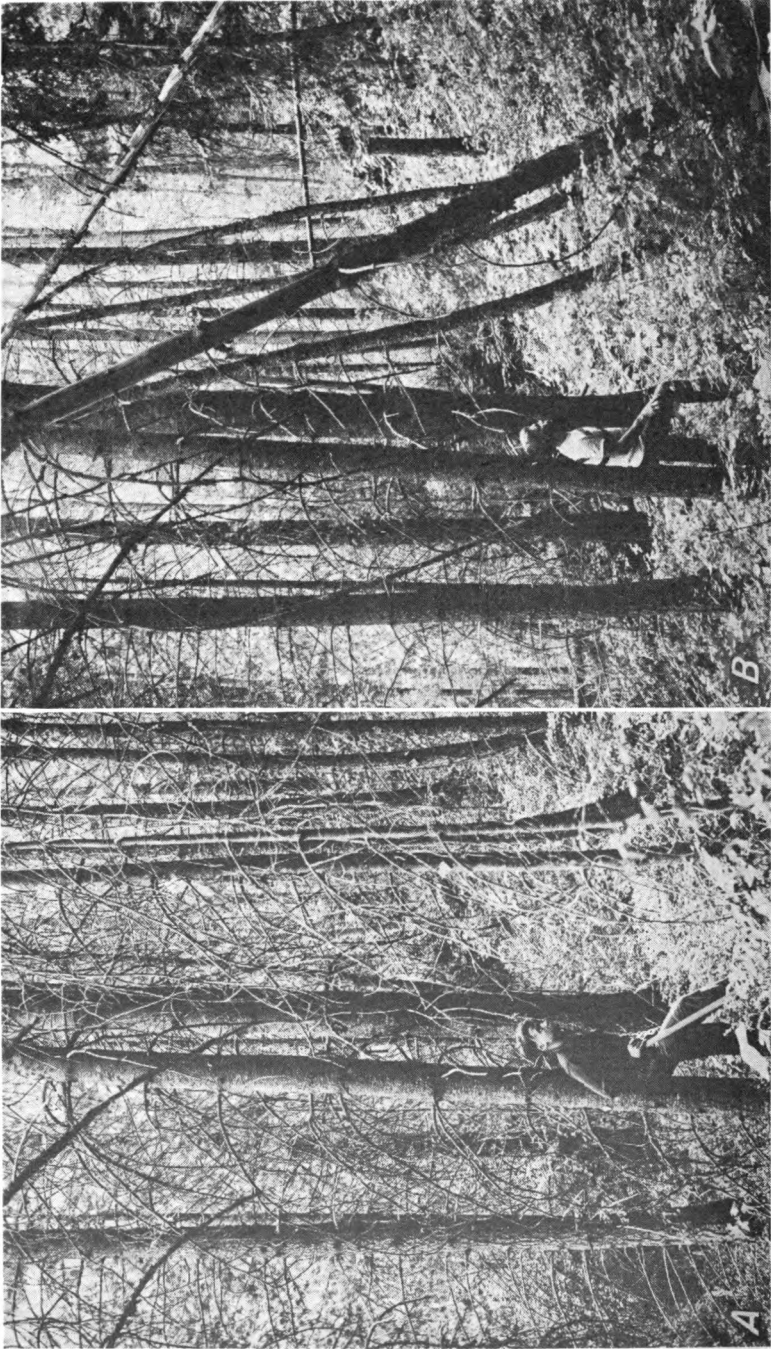
Other calculations made possible by the results of these four major analyses gave the annual mortality, the percentage of growing stock lost annually, and the percentage of annual growth nullified by mortality, by age classes.

Results of Analysis

Analysis of the cause of death was first made by age and site classes, but no discernible influence of these two variables upon the relative importance of the cause of death was discovered. For this reason, the data were combined to give the values shown (table 11). This table of the relative importance of each cause of mortality, as measured in basal area, cubic- and board-foot volumes, indicates that nearly half of all mortality was caused by wind and snow, irrespective of the unit of measurement used (fig. 8). Suppression is the second most important of the identified causes of mortality, followed by insects and diseases. About 17 percent of the total mortality was due to unidentified causes.

The analysis was designed to give net and gross cumulative production for stands from ages 30 to 100 years (table 12). This table is drawn from the data from plots on all sites, because sufficient mortality data were not available to define the trends of mortality by site index classes. Net and gross production vary with site, but this study could not define the mortality by site class. The table shows the volumes present in living trees at a given age and the total wood production, trees living plus mortality in the past, of the stands. At age 100, 30 percent of the basal-area production, 22 percent of the cubic-foot volume, and 10 percent of the board-foot production had been lost to mortality.

The analysis of mortality by broad diameter classes showed, quite naturally, that as the age of the stand increases, an increasing proportion of the mortality occurs in larger diameter trees, and the contribution by smaller trees to the volume lost diminishes (table 13). These values were obtained by applying percentage distribution values for mortality by diameter classes to the mortality figures obtained from table 12. At the end of 100 years' growth, only 20 percent of the cubic-foot mortality is from trees smaller than 5 inches, 52 percent from trees 5 to 10 inches, and 28 percent from trees more than 10 inches in diameter. In the same period, one-third of the board-foot loss was from trees smaller than 11 inches in diameter and



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FIGURE 8.—Mortality increases rapidly after about 60 years of age: *A*, A 66-year-old stand; *B*, the same spot 20 years later. Much of the mortality was due to snow and wind; insect damage was an important secondary cause.

TABLE 11.—*Mortality due to each cause of death*

Cause of death	Mortality measured in—		
	Basal area	Cubic-foot volume	Board-foot volume
	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
Suppression.....	25	19	5
Wind and snow.....	46	47	45
Insects.....	5	8	19
Disease.....	9	10	12
Unknown.....	15	16	19
All causes.....	100	100	100

TABLE 12.—*Cumulative net and gross production per acre for all sites*

Age of stand (years)	Basal-area production		Cubic-foot volume production		Board-foot production	
	Net	Gross	Net	Gross	Net	Gross
	<i>Square feet</i>	<i>Square feet</i>	<i>Cubic feet</i>	<i>Cubic feet</i>	<i>Board feet</i>	<i>Board feet</i>
30.....	86	86	990	990	180	180
40.....	147	152	1, 890	1, 940	680	680
50.....	187	204	3, 090	3, 320	2, 980	3, 380
60.....	214	247	4, 330	4, 830	7, 280	8, 080
70.....	232	286	5, 530	6, 400	13, 080	14, 480
80.....	246	321	6, 670	8, 010	19, 880	22, 080
90.....	260	355	7, 750	9, 650	27, 380	30, 480
100.....	273	389	8, 770	11, 310	35, 380	39, 380

TABLE 13.—*Cumulative mortality per acre by diameter classes*

Age class (years)	Diameter class						
	Less than 4.6 inches	4.6 to 10.5 inches	Greater than 10.5 inches	Total, all sizes	Less than 10.6 inches	Greater than 10.6 inches	Total, all sizes
	<i>Cubic feet</i>	<i>Cubic feet</i>	<i>Cubic feet</i>	<i>Cubic feet</i>	<i>Board feet</i>	<i>Board feet</i>	<i>Board feet</i>
30.....	0	0	0	0	0	0	0
40.....	44	6	0	50	0	0	0
50.....	152	74	4	230	204	196	400
60.....	260	220	20	500	400	400	800
70.....	360	442	68	870	664	736	1, 400
80.....	435	729	176	1, 340	952	1, 248	2, 200
90.....	480	1, 043	377	1, 900	1, 186	1, 914	3, 100
100.....	499	1, 331	710	2, 540	1, 339	2, 661	4, 000

two-thirds from trees 11 inches and larger. This change in the diameter of the trees that are dying is shown graphically in figure 9.

Correlations of mortality with the various stand factors (table 14) show that mortality is highly correlated with volume and age of stand, two closely related variables. Composition index, site index, and stand density were significantly correlated with mortality in isolated instances.

Several less important results were obtained incidentally to the calculation of the four major findings given above. Uncurved values of average periodic annual mortality by age class are shown in table 15. This table also gives some indication that age and the amount of mortality that occurs in second-growth western white pine stands may be related.

TABLE 14.—*Correlation of coefficients of mortality with 5 stand factors*

Stand factors	Mortality measure		
	Basal area	Cubic-foot volume	Board-foot volume
Normality percentage.....	*+0. 21308	-0. 13691	+0. 10248
Age.....	**+. 38518	**+. 44126	**+. 70909
Site index.....	- . 06080	+ . 15828	**+. 30213
Composition index.....	**+. 24629	+ . 19929	+ . 09998
Volume.....	**+. 41335	**+. 45205	**+. 75573

* Significant at the 5-percent level.

**Significant at the 1-percent level.

TABLE 15.—*Average periodic annual mortality*

Age class (years)	Annual mortality per acre		
	Basal area	Volume	
	<i>Square feet</i>	<i>Cubic feet</i>	<i>Board feet</i>
Less than 36.....	0. 50	4. 4	0
36-45.....	1. 21	14. 5	2
46-55.....	1. 42	24. 2	9
56-65.....	2. 16	49. 1	42
66-75.....	2. 48	59. 3	82
76-85.....	2. 16	62. 1	157
86-95.....	1. 10	31. 3	95
96-105.....	1. 79	70. 4	335
106-115.....	7. 19	338. 9	1, 478

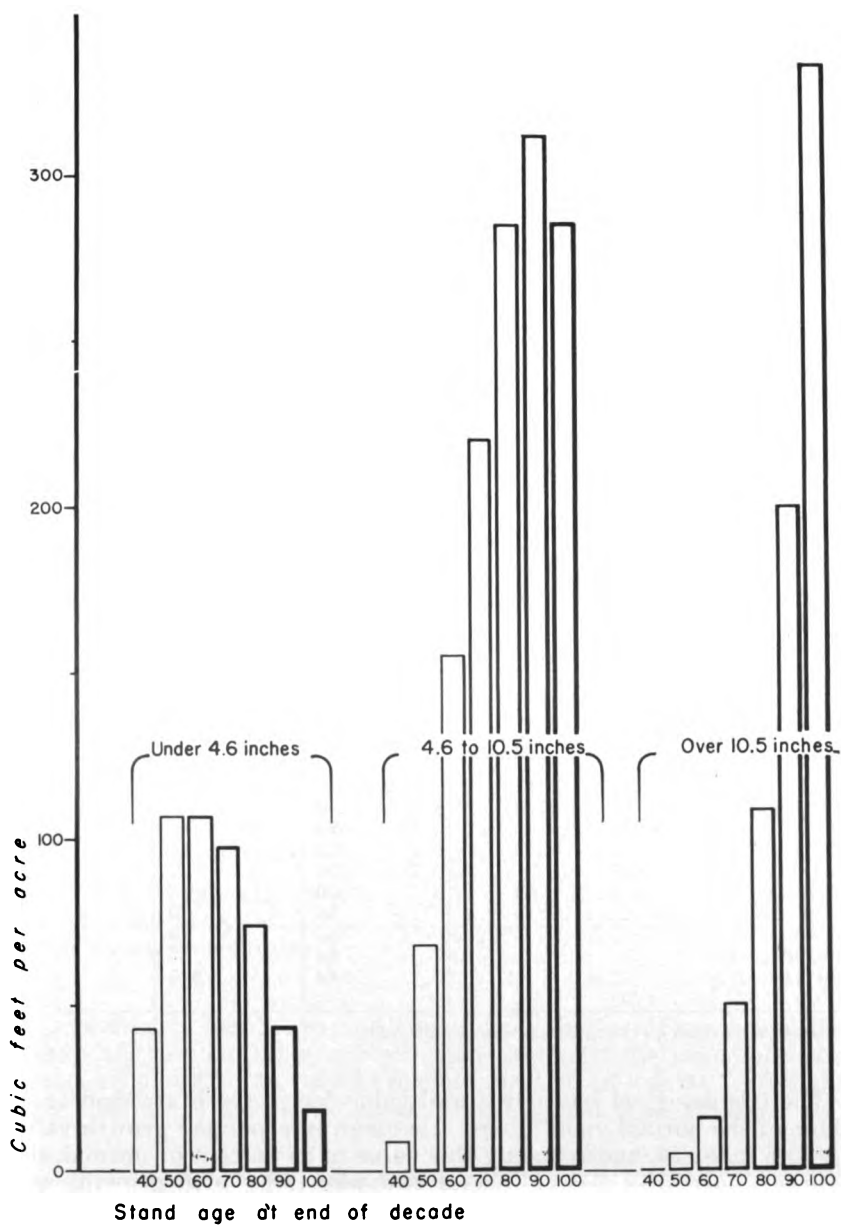


FIGURE 9.—Decadal mortality in cubic feet by age and diameter classes.

The proportion of the annual gross growth nullified by mortality (table 16) was calculated by using the mortality figures of table 15 and the periodic annual gross growth. A considerable but variable part of the gross annual growth is lost to mortality. The percentage loss of board-foot growth is least. The trees containing board-foot volume are the largest trees of the stand and probably the most vigorous and resistant to agents causing death. The large loss shown for the 106- to 115-year classes was recorded on one plot that composed this class and was caused by heavy wind and insect mortality. Probably it is not a good indication of losses that occur in this age class.

Again using the mortality figures of table 15, the percentage loss of growing stock was calculated and is shown in table 17. As in the preceding table, the percentage loss measured in board-foot volume is the least for the same reasons stated in the above paragraph. Annual mortality tends to be somewhat less than 1 percent of the basal area and cubic-foot volume growing stock. Annual board-foot mortality fluctuates about one-half of 1 percent of the growing stock.

Uncurved values of net and gross periodic annual growth are shown in table 18. Basal area growth is at a peak at the age of 30 years; it drops rapidly and tends to level off at about 60 years. Net cubic-foot growth peaks at about 40 to 50 years of age, but gross growth reaches its maximum 20 or 30 years later. Gross board-foot growth appears to level off at about 70 years of age; net board-foot growth on the plots fluctuated considerably after this age and no generalization appears valid.

TABLE 16.—*Proportion of annual gross growth nullified by mortality*

Age class (years)	Basal area	Cubic-foot volume	Board-foot volume
	Percent	Percent	Percent
Less than 36.....	8	5	0
36-45.....	24	10	1
46-55.....	33	16	2
56-65.....	58	32	7
66-75.....	66	35	10
76-85.....	58	39	20
86-95.....	36	19	10
96-105.....	89	59	44
106-115.....	¹ 384	¹ 228	89

¹ Mortality exceeded growth on the single plot in this class.

The trends of net basal-area and cubic-foot growth are similar to those of the normal yield tables. Using an interpolated growth value for site index 55, and reducing this value to 85 percent of normal, the average normality percentage of the plots, the plot growth, and growth predicted in this manner with the yield tables are about the same magnitude. This is in line with the findings reported above that the plots are approaching about 88 percent of normal density

TABLE 17.—*Annual loss of growing stock*

Age class (years)	Growing stock measure		
	Basal area	Cubic-foot volume	Board-foot volume
	Percent	Percent	Percent
Less than 36.....	0. 6	0. 4	0. 0
36-45.....	1. 0	. 7	. 1
46-55.....	. 9	. 7	. 2
56-65.....	1. 1	1. 0	. 4
66-75.....	1. 1	. 9	. 4
76-85.....	. 9	. 8	. 5
86-95.....	. 5	. 4	. 3
96-105.....	. 7	. 6	. 5
106-115 ¹	2. 7	2. 6	2. 1

¹ Data for this class from only 1 plot.

TABLE 18.—*Periodic annual net and gross growth per acre, all plots combined*

Age class (years)	Basal-area growth		Cubic-foot volume growth		Board-foot growth	
	Net	Gross	Net	Gross	Net	Gross
	<i>Square feet</i>	<i>Square feet</i>	<i>Cubic feet</i>	<i>Cubic feet</i>	<i>Board feet</i>	<i>Board feet</i>
Less than 36.....	6. 2	6. 7	90	95	158	158
36-45.....	3. 9	5. 1	126	140	290	292
46-55.....	2. 8	4. 3	125	149	476	485
56-65.....	1. 6	3. 7	104	153	536	578
66-75.....	1. 3	3. 8	112	171	735	816
76-85.....	1. 5	3. 7	96	158	628	785
86-95.....	2. 0	3. 1	131	162	843	938
96-105.....	. 2	2. 0	49	119	421	756
106-115 ¹	— 5. 3	3. 9	— 170	149	178	1, 655

¹ Data for this class from only 1 plot.

as measured in basal area and cubic-foot volume. When board-foot values of the yield tables are adjusted similarly, the yield table and measured plot-growth values are close until about age 80. After this age, plot values tend to be lower than the yield-table values.

Discussion of Results

Changes in the relative importance of a specific agent of mortality, when mortality is measured in different units, indicate the relative

size of tree generally killed by that agent. Smaller trees have smaller cubic-foot volume basal-area ratios and board-foot volume basal-area ratios than do larger trees. Therefore, if an agent kills predominantly large trees, the proportion of the total board-foot loss caused by that agent will be larger than the proportion of the total basal-area loss caused by the same agent. Conversely, an agent of mortality that kills mainly the smaller trees of a stand will account for a larger proportion of the basal-area loss than of the board-foot loss. The relative importance of the causes of mortality are measured in three different units, and these figures should be examined with these relationships in mind (table 11).

Suppression accounted for 25 percent of the total basal-area loss, 15 percent of the cubic-foot volume loss, but only 9 percent of the board-foot loss. Obviously, suppression results in death of the smaller trees of the stand.

Snow and wind damage caused the same percentage of the total mortality, whatever the unit of measurement. Thus, the average tree killed by snow and wind is about the same size as the average killed by all causes.

Insects, as shown by the increase in percentage of the total mortality caused by them when measured in basal area, and cubic- and board-foot volumes, tend to kill the larger trees of those that die. The mountain pine beetle (*Dendroctonus monticolae* Hopk.) undoubtedly caused most of the insect mortality on the plots. This beetle kills white and lodgepole pines; largest trees in second-growth stands are often of these two species.

The proportion of mortality caused by diseases changed little from one unit of measurement to another. This uniformity indicates that trees of all sizes are killed by the diseases found on the plots. The plots were essentially free from white pine blister rust and pole blight. The honey mushroom (*Armillaria mellea* (Vahl ex Fr.) Quel.) probably caused most of the mortality attributed to diseases. This fungus is found on the roots and about the root collar where it destroys the tissues of the tree and eventually causes death. Its presence was detected in the field by examining the cambial region of the root collar for the typical mycelial mats of the fungus.

Mortality in stands containing white pine blister rust or pole blight is much different from that reported here. Blister rust, when uncontrolled, eventually kills all the white pine in a stand. In a young stand, the rate of kill is rapid and might overshadow other causes until most of the pine has succumbed. In older stands, however, blister rust mortality might not be a major cause of death in any one period. Pole blight, caused by unknown factors, results in death of white pine also. The pattern of mortality and the time required to kill a tree are largely unknown. Thus, the losses reported here for diseases, as well as the other factors, are probably similar to those that have occurred for many centuries in the past during the maturing of white pine stands.

Unknown agents, including "other injuries," caused 15 to 19 percent of the total mortality. Undoubtedly, some of this mortality was

brought about by ordinarily recognizable agents that could not be identified because of the lapse of time between death of the tree and its observation. Frequently, even recently killed trees were encountered for which the field examination could not disclose the cause of death, although a more detailed autopsy might have unearthed the cause.

Both the absolute and the relative importance of loss by a given agent of mortality may, and usually does, vary considerably from one measurement period to the next, even on the same plot. For example, figure 10 shows the cubic-foot mortality on plot 2 for five consecutive 5-year measurement periods. This 2-acre plot was 56 years old when first measured in 1922. Of the five causes of death recorded on this plot, suppression displays the greatest constancy. Other causes of death result in more variable losses.

The importance of damage from wind and snow justifies further discussion. In the western white pine type, much of the annual precipitation falls as snow, which often accumulates to a depth of 4 or 5 feet, and occasionally more. When weather conditions result in a fall of wet, heavy snow that adheres to the twigs and needles of the trees and then is frozen firmly in place by falling temperatures, the stage is set for heavy damage. Additional snowfall or strong wind that might otherwise cause little injury is likely to result in considerable bending, breaking, or uprooting of the heavily burdened trees.

During the winter of 1948-49, a season of unusually heavy snowfall, mortality was heavy, thought to be due to conditions such as described above. Sample plot 14, in an 80-year stand at an elevation of 4,300 feet, is located in an area that sustained severe injury. Because this plot had been remeasured in the fall of 1948, opportunity was presented to determine accurately how much and what types of damage were caused by that winter's snow and wind. The 2-acre stand on the plot and seventeen $\frac{1}{10}$ -acre temporary plots systematically spaced in the surrounding stand were observed in July 1949, to determine the extent of damage. The 17 temporary plots were measured to determine the injury over a wider area. These measurements gave a better idea than the 2-acre plot of the mortality of the stand in general.

The basal-area and cubic-foot mortality and the basal-area density, in percent of normal, of plot 14 have been measured since its establishment in 1923 (table 19). The records show that extremely severe and crippling losses may be sustained during a single winter, possibly as a result of only one storm. For example, the loss of basal area during the winter was very nearly equal to the total of all losses during the preceding 25 years. The loss of more than 2,000 cubic feet of wood was one-half greater than the total volume lost between 1923 and 1948. The 17 temporary plots indicated that the damage in the surrounding stand was somewhat lighter, for only 21 percent of the trees were lost on them as contrasted with 37 percent of the trees on plot 14.

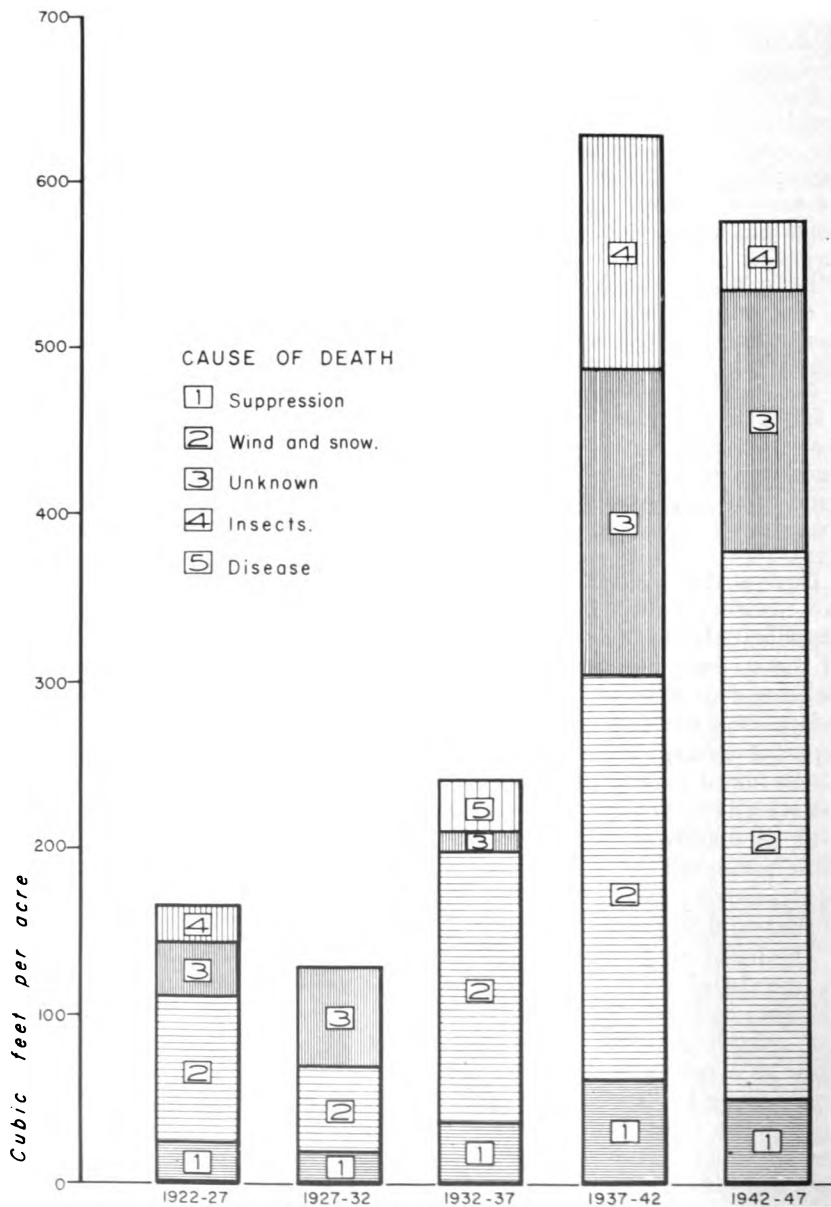


FIGURE 10.—Five-year mortality in cubic feet on plot 2, by cause of death. Stand was 56 years old in 1922.

TABLE 19.—*Mortality and basal-area density per acre, in percentage of normal, on plot 14, 1923-49*

Measurement period	Basal-area mortality	Cubic-foot volume mortality	Basal-area density at beginning of period
	<i>Square feet</i>	<i>Cubic feet</i>	<i>Percent</i>
Fall 1923 to fall 1928.....	16	277	93
Fall 1928 to fall 1933.....	10	187	89
Fall 1933 to fall 1938.....	22	401	90
Fall 1938 to fall 1948.....	24	469	85
Fall 1948 to summer 1949.....	70	2, 112	85
Fall 1949.....	-----	-----	58
Total.....	142	3, 446	-----

The loss of merchantable and near-merchantable material is probably the most important result of the damage. The reduction of growing stock with the subsequent diminution of yields is also serious. Although snow damage is sometimes considered to have the effect of a crude thinning (10), mortality as heavy as that on plot 14 is clearly destructive. Not only has the growing stock been reduced below a desirable level, but also the groupwise distribution of mortality has opened holes in the crown canopy so large that surrounding trees do not realize the growth potential of these vacant areas. Natural pruning of trees about the openings will be poor and timber quality below that which otherwise would have been present. Many of the remaining trees in the stand will increase their growth rate because of reduced competition, but their more rapid growth will not compensate for the present and potential losses attributable to the winter's damage.

The exact manner of death was classed either as windthrow, where the root system was wrenched from the ground, or breakage, where all or enough live crown was removed by breaking of the bole to cause death. Thirty-nine percent of the fatal injuries were classed as windthrow; 61 percent were caused by breakage of the bole. Obviously, the majority of the trees were firmly rooted. Decay of the bole did not contribute materially to the breakage, for most of the stand was fairly sound.

In addition to these injuries that caused death, much damage occurred that affected the growth of the stand and the quality of the wood. Many trees had live branches and foliage broken off in quantities sufficient to reduce the growth of the tree. Breaking off the leaders and sometimes larger parts of the main stem were common injuries. The long, stout, and relatively stiff leaders of vigorous white pines were especially susceptible to this type of damage. Removal of the leader or parts of the main stem may cause forked or crooked trees, which, of course, are less desirable for saw-log production than those unforked.

Patches of bark were knocked off standing trees by falling limbs and trees. Small barked areas may heal over with perhaps no more damage than an irregularity in the grain of the wood or a small pitch or bark pocket; large ones may permit wood-rotting fungi to enter the tree. Severe bending stresses may have produced ring shake or may result in the growth of compression wood, defects that are not discovered until after the stand is cut.

Stand composition showed all species to be equally susceptible to damage. The only change in stand composition was a gain of 2 percent in the proportion of grand fir and the same percentage loss for white pine.

Mortality as heavy as that on plot 14 presents additional protection problems to the forest manager. The fire hazard on the plot was greatly increased by the large volume of down timber. Opening the stand produced somewhat more favorable conditions for rapid drying of the litter and down material. Blister rust control was made more expensive because the disturbance of the soil, coupled with the creation of scattered openings, resulted in germination and establishment of ribes seed stored in the duff. The stands in which plot 14 was located had to be reworked to remove the newly established ribes plants.

Although extremely heavy losses do occur occasionally, as shown by plot 14, mortality during the growth of a stand from 30 to 100 years of age is not as heavy as many have believed it to be. Table 12 shows that cubic-foot volume production could be increased by 23 percent and board-foot production by 10 percent if all the mortality were recovered. These gains are not spectacular but are nevertheless substantial. Naturally, all this mortality will never be recovered, for some occurs in trees too small to be merchantable and some occurs in individual trees too widely scattered to be logged economically.

Table 13 shows that 80 percent of the cubic-foot volume mortality has occurred in trees 4.6 inches d.b.h. and larger, material that is merchantable for pulpwood in other parts of the Nation where closer utilization is the rule. Of the total board-foot mortality occurring up to the age of 100 years, only 33 percent has been in trees less than 10.6 inches d.b.h., the present minimum size of merchantable saw-log trees.

The increasing dependence of the lumber industry on second-growth stands in this region will inevitably mean that the minimum size of the merchantable saw-log tree will slowly decrease. Before many years have passed, it is likely that all the saw-log material that died on these plots will be considered merchantable. But, as with cubic-foot mortality, the scattered nature of much of the mortality will prevent recovery of an unknown portion of the total.

Several stand factors are correlated significantly with mortality (table 14). Volume shows the highest correlation and is followed by age of stand. Evidently the greater the volume present, the greater the likelihood of loss. The significance of the correlation of mortality with age is certainly due in part to the high correlation, +0.8, of age and volume. In addition, trees in older stands may be more susceptible to death because of changes in structure of the individual

tree that occur with increased age. Rot of the root system and bole becomes more prevalent and extensive with increasing age and makes the tree more liable to mechanical injury.

The influence of each independent variable was evaluated by the use of partial correlation coefficients. Such an analysis showed that age and volume of stand influenced greatly the correlation of all other independent variables with mortality, and with one another, but that the correlations of mortality with age and volume were essentially independent of the variations in the other independent variables.

Multiple correlation coefficients were calculated for various combinations of stand variables to see if some combination would explain considerably more of the variation in mortality than would any single factor. In no calculation was the multiple correlation coefficient appreciably larger than the simple correlation between volume of the stand and the mortality.

Despite the established correlation of mortality with volume of stand, mortality predictions cannot be made accurately. This is indicated by multiple regression equations that were calculated for estimation of mortality. By using these equations with several values substituted for the various stand conditions, estimated mortality and corresponding variances were calculated. The variance was always large in comparison with the estimated mortality; this indicated that the estimate was not reliable.

This inability to predict mortality is due to the erratic occurrence of mortality. Cubic-foot volume mortality measurements used in this analysis were plotted over age of stand (fig. 11). Although this figure displays an increase of mortality with age, it also shows that mortality does vary greatly within a given age class. This variation, in turn, can be attributed to the factors causing much of the mortality in the western white pine type. Wind and snow are the most important causes of mortality. Obviously, mortality resulting from these causes cannot be anticipated because of the difficulty of predicting far into the future the weather conditions that cause them. Of the other known causes of mortality recorded on these plots, insect and disease damage also is difficult to predict. Suppression, the agent most susceptible to prediction, caused only a minor part of the total mortality. Prediction of suppression mortality would not be of much aid to the forester managing a tract of land.

The variability of mortality emphasizes the importance of a good permanent road system for the management of forest lands. In an area with an extensive permanent road system, the discovery and salvage of irregularly occurring heavy mortality may be possible. The amount of mortality that can be salvaged will depend, of course, upon proximity to roads and market conditions. Thinnings and intermediate cutting may also be made possible by a good road system. Such operations may result in a stand composed of trees of such crown shape and vigor that they will be more resistant to the action of mortality agents (32).

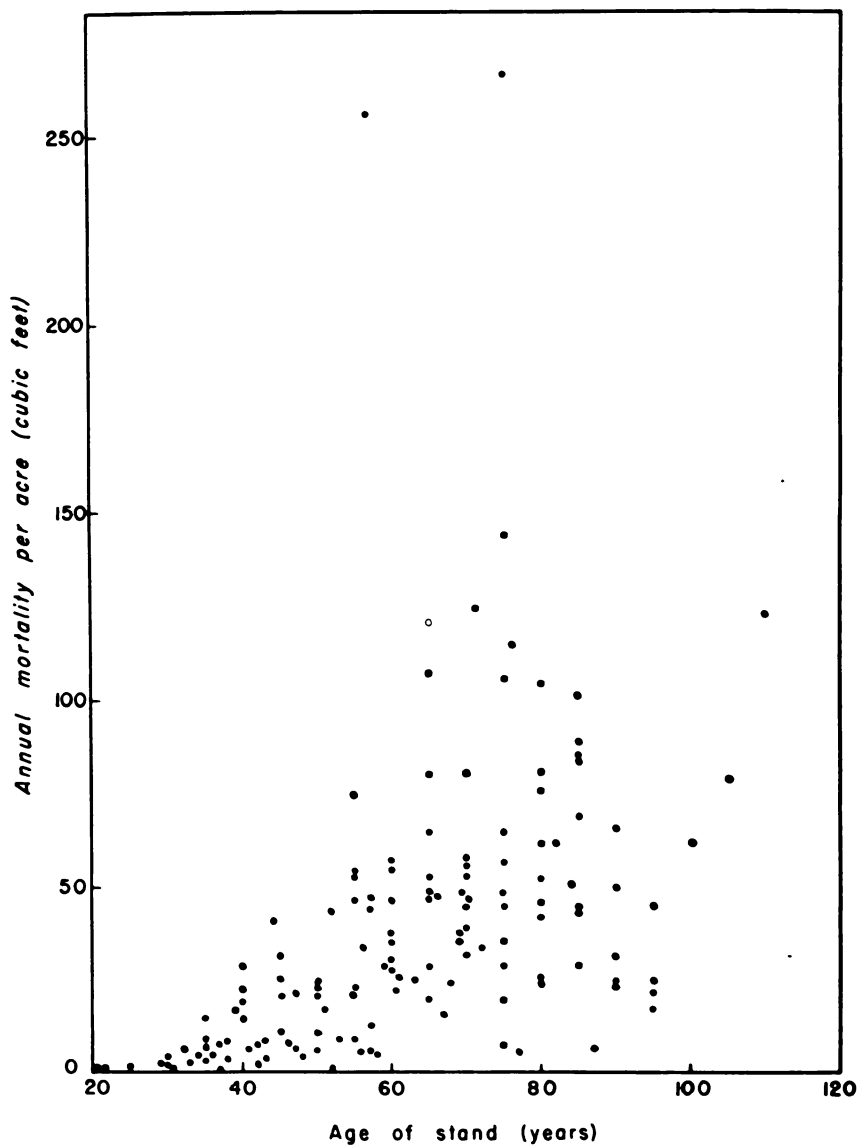


FIGURE 11.—Annual cubic-foot volume mortality over age of stand.

SUMMARY

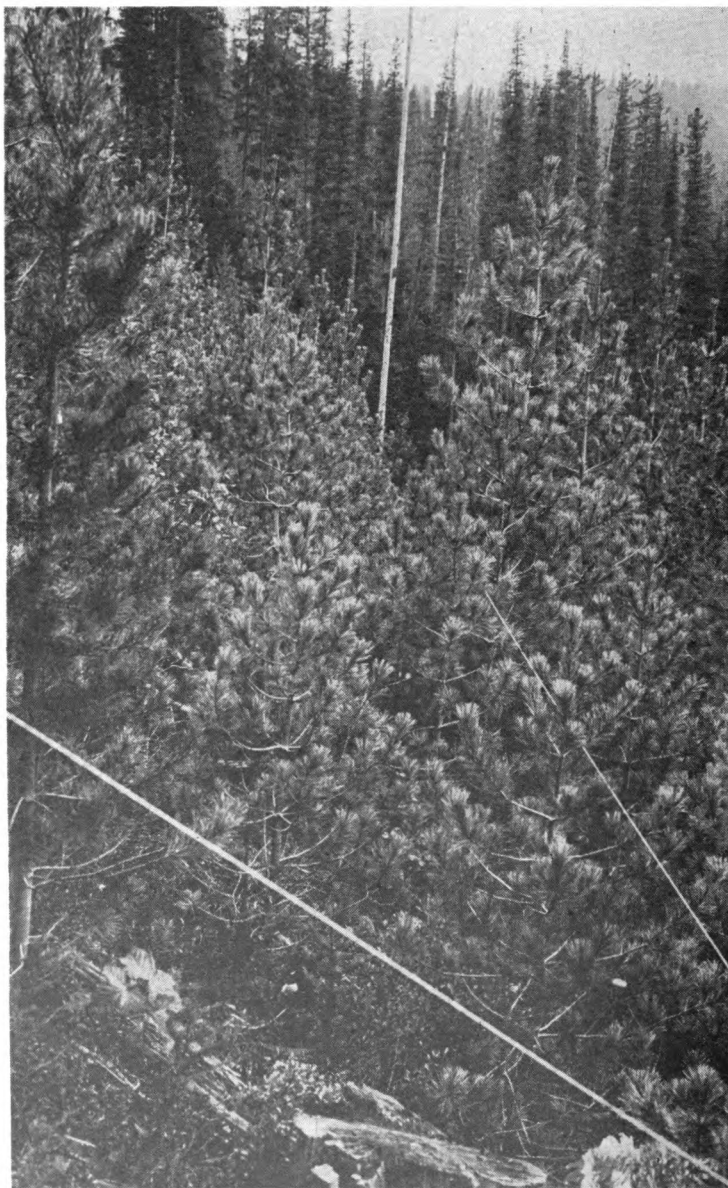
Several analyses of data gathered on 94 permanent plots in second-growth western white pine stands from 20 to 100 years old were made. The plots, which represent a variety of age, site, density, and composition conditions, were remeasured periodically to give information for 340 5-year growth periods. The economic importance of second growth western white pine is well established in the Inland Empire. The development of stands of this species is illustrated in figures 12-16. Diameter and height measurements, and on 38 of the plots mortality information, were the most important data taken at each remeasurement.

Four principal analyses were made. First, repeated site index determinations were analyzed to see if site index changed with time and, if so, what factors influenced the rate of change. Second, an analysis was made to determine the changes in species composition with time to aid in understanding the development of second-growth stands. Third, the trends in density, in terms of normal stocking and methods of predicting such trends, were investigated. Finally, the mortality records were studied to determine the causes of mortality, the amount that occurs during growth from 30 to 100 years of age, and the stand factors that bear on the volume of mortality.

The study of site index changes determined that a statistically valid trend in site index occurred, but that the changes in site index were too small to have practical significance. Probably these changes are due to some slight differences in the height growth of the trees on the plots from that predicted by the site index curves, rather than to an actual change in the quality of the site for the growth of white pine trees. This study of site index changes should be of widespread interest because it involves a basic concept of site index curve construction and use evaluated by an analysis of repeated growth measurements.

Analysis of species composition changes showed that the composition of western white pine stands is established by the time the stands reach 30 years of age, and that changes in composition up to the age of 100 years are small. This information is important for the forest manager working with white pine stands, for the many species in the type vary widely in their stumpage value, wood properties, productivity, longevity, and silvical properties; all these give rise to a wide variation in stand values and volumes. Any changes desired in the composition of stands that have passed the age of 30 years will require some purposeful management methods, such as improvement cutting, to change the composition toward that desired.

The trends in species composition are in accord with the known silvical characteristics of the species. The very intolerant seral species, western larch and lodgepole pine, registered gains in the young-age class and on the poor site. White pine, in contrast, showed losses in these same classes. However, the advantage of early rapid growth of larch and lodgepole pine was lost with increasing age, and these two species decreased in importance in older stands.



F-298549

FIGURE 12.—Development of western white pine stands: A 20-year-old stand of nearly pure white pine averaging 10 feet high. This stand, photographed when 53 percent of normal, reached 100 percent of normal basal area 10 years later.



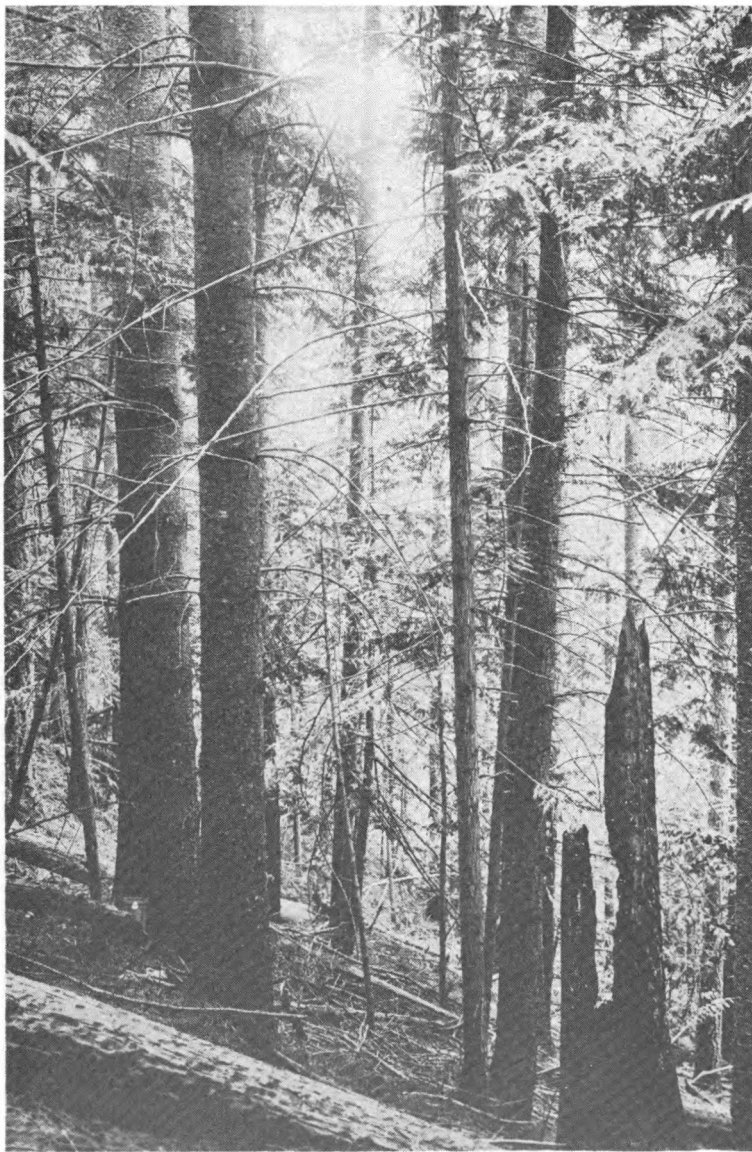
F-184611

FIGURE 13.—A 35-year-old fully stocked stand on an excellent site. Note the small suppressed but still surviving white pine in the left foreground.



F-470675

FIGURE 14.—Normal stocking in a 62-year-old stand on excellent site. The understory of tolerant species that is often found in white pine stands is absent from this one.



F-313634

FIGURE 15.—A 77-year-old stand on a good site with 114 percent of normal basal-area stocking. Understory is almost exclusively western redcedar.



FIGURE 16.—This 100-year-old stand on a fair site has about one-fifth of the basal area of the dominant stand in western hemlock; one is shown in the left foreground. The down stems are largely the result of wind and snow action. Stocking is 80 percent of normal.

In contrast, white pine increased its proportion of the stand. Douglas-fir showed about the same pattern of gains and losses as the larch and lodgepole pine. The tolerant species that form the climax in the white pine type—grand fir, western hemlock, and western red-cedar—gained in almost all age classes. Apparently, these species slowly increase in importance in the stand long before the seral species yield dominance to them.

These changes in composition are for stands free from white pine blister rust and pole blight, two diseases that are specific to white pine. Of course, stands having these diseases show different changes in composition, for much, if not all, of the white pine in a stand eventually will be removed by these two diseases.

Any changes in composition desired by the forester in a young stand of white pine must be brought about by some methods of cultural treatment, for the changes in composition that occur naturally are not sufficiently large to have economic importance.

The study of changes in normality percentage, the density in terms of normal yield-table values of stocking, showed that stands do change in density with age. The factors that influence changes in normality percentage over a 5-year period are initial normality percentage, age, and composition index. By using these three factors, multiple regression equations were developed for predicting normality percentage changes. Because of the overwhelming importance of initial normality percentage, equations were also derived for the prediction of normality percentage changes based solely on the initial normality percentage. The multiple regression equations can be solved quickly by alignment charts that are presented.

These regression equations can be used in conjunction with the normal yield tables for the western white pine type to give improved estimates of growth. However, because of the variability of mortality in this type, growth predictions for a single stand, especially if made for a short period, cannot be made with much probability of accuracy. But if predictions are made for 20 to 30 years for large areas with a variety of stand conditions, such as represented by the plots used in this study, the predicted and actual growth should be in good agreement. It should be emphasized that variability of mortality is the factor that makes any method of growth prediction so liable to error. These plots experienced what is believed to be "normal mortality" during the years of measured growth. Such mortality might reasonably be expected to recur in the future.

The fourth major analysis, that of mortality, showed that about half of the total mortality was attributed to wind and snow damage. Other important causes of mortality were insects, diseases, and suppression. Probably much of the wind and snow damage was due to these two agents acting together during the winter months when heavy snowfalls are usual in the Inland Empire.

Mortality caused the loss of 30 percent of the basal area, 22 percent of the cubic-foot volume, and 10 percent of the board-foot volume produced as the stands grew from age 30 to 100 years.

Much of this loss is in timber that may become merchantable if the trend toward use of smaller trees continues in this region. Eighty

percent of the cubic-foot volume lost was in trees 4.6 inches and larger, which may in the future be salable for pulp and fiber products. One-third of the board-foot mortality was of trees in the 8- to 10-inch-diameter classes; the remaining two-thirds was in trees 11 inches and larger, trees now of merchantable size. Of course, an unknown proportion of the mortality occurs as comparatively small annual volumes per acre that cannot be harvested economically regardless of diameter.

The volume of mortality in a stand during a 5-year period was found to be correlated with the age and volume of the stand, two closely correlated stand variables. Of these two variables, stand volume was the more important.

Regression equations were developed to see whether mortality could be predicted. However, the great variability of mortality from period to period did not permit any mortality prediction because wind and snow, the most important agents of mortality, are as variable in their actions and results as the weather conditions that determine them. Insect and disease losses are also highly variable and irregular. Suppression produces the losses most capable of prediction, but does not produce a significant proportion of the total mortality. The great variability of mortality in the white pine type emphasizes the importance of a permanent road system if these losses are to be salvaged economically and promptly.

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