TECHNICAL BULLETIN NO. 286 APRIL, 1932

# DECAY AND OTHER LOSSES IN DOUGLAS FIR IN WESTERN OREGON AND WASHINGTON

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J. S. BOYCE
*Principal Pathologist*
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CONTENTS



## INTRODUCTION

Douglas fir, *Pseudotsuga taxifolia* (Lamb.) Britton, is the most important timber tree in the Pacific Northwest and, owing to ease of reproduction, rapidity of growth, and simplicity of management, will undoubtedly continue to hold a commanding position. In recognition of the fact that the species is necessary to the economic future of the region in which it attains optimum development—that is, in western Oregon and Washington west of the summit of the Cascade Mountains and north of the divide between the Umpqua and Rogue Rivers—and that it is extremely valuable to the country as a whole, investigations have been concentrated on its life history and habits, in order to provide a sound basis for its management.

Hofmann (*12*) [1] has studied the regeneration of Douglas fir. Munger (*24*) has outlined the procedure necessary to perpetuate timber production. Munger, years ago (*22*), and later McArdle (*15*) presented facts on the yield of younger stands up to 160 years of age. But since all stands suffer loss from breakage when the timber is felled, from shake, waste, fire, fungi, insects, or other cause, knowledge of prospective yield is of value only if correlated with knowledge of prospective loss and, while a clear understanding of the relative importance of the factors causing loss is needful, information on which the possible rate of loss throughout the life of the stand can be predicted is even more essential, since it is axiomatic

[1] Italic numbers in parentheses refer to Literature Cited, p. 58.

that loss increases with age. Consequently, for proper management and intelligent handling of Douglas fir in the future it is necessary to know not only the loss in second-growth stands up to 160 years old but also to have reasonably exact knowledge of the rate of deterioration of overmature stands. Although it is true that overmature stands, except when reserved in parks or when completely inaccessible, will disappear in the ultimate future, at present they cover large areas in this region, so that cutting in them will continue for some decades. Meanwhile the approximate rate at which such stands are deteriorating is of primary importance to owners of this class of timber.

Living Douglas fir in the region referred to is very little affected by insects, fungi (except heartwood destroyers), and mistletoe. The Douglas-fir bark beetle, *Dendroctonus pseudotsugae* Hopk., is everywhere present in felled trees, but so far has caused no important losses in living timber. A woolly aphid, *Chermes cooleyi* Gill., on the needles, is widespread but relatively harmless. Periodically the western-hemlock looper, *Ellopia fervidaria* Hbn., becomes epidemic and destroys considerable merchantable timber over localized areas before it subsides. The needle-cast fungus, *Rhabdocline pseudotsugae* Sydow, is locally prevalent, and during seasons favorable for its development may cause much defoliation. It usually confines itself to trees in the seedling, sapling, and small-pole stages, and is decidedly selective in its action, rarely attacking an entire stand but appearing on a greater or lesser number of scattered individuals. A particularly susceptible tree may repeatedly be defoliated so that it finally becomes badly suppressed and has strikingly shortened needles and an unhealthy yellow-green color. The inconspicuous and relatively harmless needle-rust fungus, *Melampsora albertensis* Arth., has not been found in the region. Seedlings and saplings are occasionally killed by the honey fungus, *Armillaria mellea* (Vahl) Fr., and it is probable that in the future, when planting of Douglas fir is more extensively carried on, this root rot will become increasingly serious. The conifer root fungus, *Fomes annosus* (Fr.) Cke., which frequently kills young Douglas firs in Europe, has not been found as a parasite in this region, although it occurs occasionally on old stumps, logs, and down trees. Douglas dwarf mistletoe, *Razoumofskya douglasii* (Engelm.) Kuntze, so destructive to Douglas fir throughout much of its range, and particularly in Oregon and Washington on the east slope of the Cascade Mountains, is unknown west of the summit of the range except in southern Oregon. For example, in the Hood River Valley, which lies east of the summit, the mistletoe is common. From this valley through the Columbia River Gorge has stretched an unbroken belt of Douglas fir extending practically to the Pacific Ocean. Yet the mistletoe has not followed through with its host. Neither has it followed through from southern Oregon to north of the divide between the Umpqua and Rogue Rivers. Climatically, the region with its high rainfall and cloudy weather in contrast to the much drier, more sunshiny weather east of the summit is not unfavorable to the dwarf mistletoes as a group, for hemlock dwarf mistletoe, *R. tsugensis* Rosend., is common on western hemlock, *Tsuga heterophylla* (Raf.) Sarg., and fir dwarf mistletoe, *R. abietina* (Engelm.)

Abrams, is occasionally met with on lowland white fir, *Abies grandis* Lindl. The factors limiting the distribution of the mistletoe on Douglas fir present an interesting and unsolved problem.

What is most to be feared, however, is the introduction of some foreign insect or fungous parasite, which, freed from its natural enemies and finding itself adapted to the moderate temperatures and high precipitation characterizing the region, will become epidemic and destructive throughout the thousands of square miles of almost pure stands of Douglas fir.

Douglas fir is also affected by a form of winter injury known as parch blight (*23*). During the winter months, which are characterized by long periods of rainy and cloudy weather, with westerly winds and moderate temperatures, sudden changes occur, and usually, once or twice a winter for periods of a few days to a week or more, cold, clear weather prevails, accompanied by very dry easterly winds from east of the Cascade Mountains. Almost immediately the foliage on the Douglas firs turns reddish brown, and the stands affected, those on the east slopes or ridge tops being especially susceptible, present a "scorched" appearance. Often the injury, if not severe, passes unnoticed until spring. While the parch blight is alarming in appearance, the trees rarely suffer serious effects, and by the end of the next growing season at the latest, signs of the injury have practically disappeared. Parch blight is particularly prevalent in the low passes through the mountains, such as the Columbia River Gorge and Snoqualmie Pass. In these locations the trees, owing to repeated injury, often have thinner foliage, shorter branches, and more dead branches on their east sides.

Young stands are sometimes severely damaged by ice storms, locally known as "silver thaws" or by wet-snow storms. The heavy load of snow or ice breaks off the tops of the trees, and a severe storm may injure the majority of the trees in a stand. This condition is shown in Figure 1. The missing top of a damaged tree is replaced by a limb which then becomes a "volunteer" top; but the crook in the trunk, at the point where the original top broke off and the limb replaced it, finally disappears only after decades. Furthermore, the broken top, while it slowly heals over, is an entrance point for wood-destroying fungi.

But the foregoing causes of loss, although they must be recognized, do not result in an alarming reduction in the volume of stands. However, the principal impression made by the older Douglas fir forests is of great density and enormous gross volume per unit of area and then of the enormous loss from decay indicated by conks on the living trees, and, to the initiated, by other signs. A visit to a logging operation and a sight of the large amount of slash left on the ground confirms the impression. Because of the seriousness of the decay in Douglas fir, a thorough investigation was begun in 1917. The results of one intensive study of the decay in relation to individual trees have been published (*4*), but the concluding paragraphs of that paper show that the author realized that this was only a preliminary study which would have to be followed by a more intensive investigation into the relation of decay to stands. These paragraphs were as follows:

**The biggest problems remain unsolved. Our half-formulated ideas of control of decay in Douglas fir are based on observation without a sound backing**

of exact data. Furthermore, while it is a well-established fact that young stands or second growth are relatively immune from decay, it is not yet determined at what age in the life of the stand this immunity ceases and the trees become subject to extensive decay. Establishing this age will enable us in the future to cut stands before there is any real loss and at the same time permit the trees to attain the maximum size.

Equally important is the periodic rate of increase in the loss through decay after the above age has been passed. Such information is of the highest value

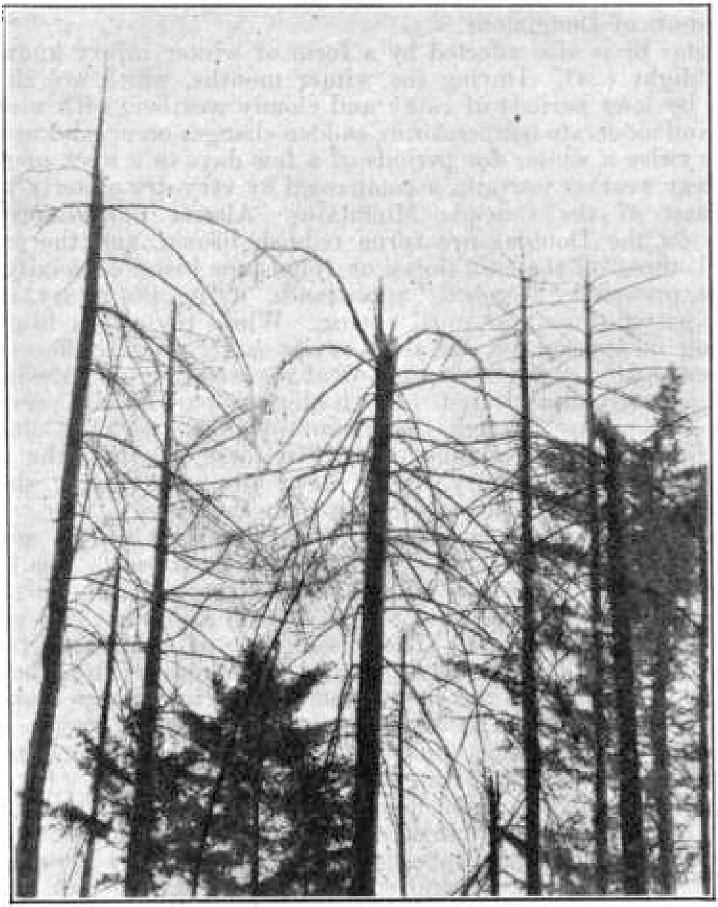

FIGURE 1.—Douglas firs with the tops broken off by a severe ice storm, Most of this young stand had been killed by fire before the picture was taken

to organizations holding extensive stands of mature or overmature timber, enabling them to estimate the loss in their holdings and adapt plans accordingly. But these questions can only be answered by a study of all the trees felled and left standing on a wide range of plots in stands of different ages and conditions selected on logging operations throughout the Douglas fir region of the Pacific Northwest.

The purpose of the present study was to solve as far as possible the problems outlined in these paragraphs.

## METHOD OF STUDY

Since it is known (*22*) that second-growth Douglas fir up to 140 years old is essentially even aged, it was assumed that stands would remain so throughout their life; consequently, in order that this study of decay might be of the greatest value it was for the most part based on all the trees on an area, and these areas, whatever their size, were resolved to acre plots. In other words, fundamentally the study should follow the same general method as the yield study for this species (*15*) already completed. Naturally, since it was necessary to make the study on felled and bucked timber in order to evaluate decay correctly, it was not feasible, owing to the exigencies of logging operations, to lay out acre plots or strips. In fact, during the four field seasons, from 1921 to 1924, in which the field data were collected by a party of three men,[2] it was frequently difficult to find felled and bucked timber of the needed age classes. Furthermore, measuring felled and bucked timber consumes much time, so that it was possible to obtain data on only a small number of plots as compared with the number used in a yield study in which standing timber alone is measured, since standing timber can be measured very rapidly.

In measuring the trees the average height of the stump was taken. On slopes this point of measurement was halfway between the upper and lower sides of the stump. The first log was measured at 16.3 feet above the stump height to reduce as much as possible the error in figuring cubic volume caused by the butt swell. Beyond this the logs were measured where bucked or broken, except that in accordance with the United States Forest Service practice in this region, which does not permit the scaling of a single log more than 32 feet in length, longer logs were divided into equal parts to the nearest 2 feet. A 40-foot log, for example, was considered as two 20-foot logs, while a 42-foot log would be measured as a 20 and a 22. These measurements were carried to a fixed diameter limit of 8 inches inside the bark, while beyond this the bole was considered too small to be merchantable and classed as top, one lineal measurement being taken. Many trees had portions of their tops missing, broken up and lost in the general accumulation of débris incident to felling. A set of taper curves, arranged by 2-inch diameter breast high and 20-foot height classes, based on 912 trees on which complete lineal measurements were obtained, was used to complete the measurements on such trees. Where the logs were bucked or broken the average diameter inside the bark and the average width of bark were determined at each log length, while measurements were made on decay and other defects and descriptive notes taken. Where there was no buck or break, only diameter inside the bark and bark width were taken at log lengths necessitated by the rule against measuring logs longer than 32 feet. All measurements were recorded to the nearest tenth. The age of

[2] Acknowledgment is made of the assistance of E. G. Mason, of the School of Forestry, Oregon State Agricultural College, N. Leroy Cary, and P. E. Melis, who were in charge of the field party at various times. Acknowledgment is also made to the Pacific Northwest Forest Experiment Station for the site curves for the younger stands and the extension of these curves for older stands, made expressly for this study, and to L. H. Reineke, of the U. S. Forest Service, for valuable assistance in drawing the curves presented in this bulletin.

each tree was determined at stump height, and the few years additional needed to increase this to the age at ground level were read from an age-height curve for seedlings and small saplings.

The entire tree from ground level to tip was included in the computation of volume in cubic feet, the stump being treated as a

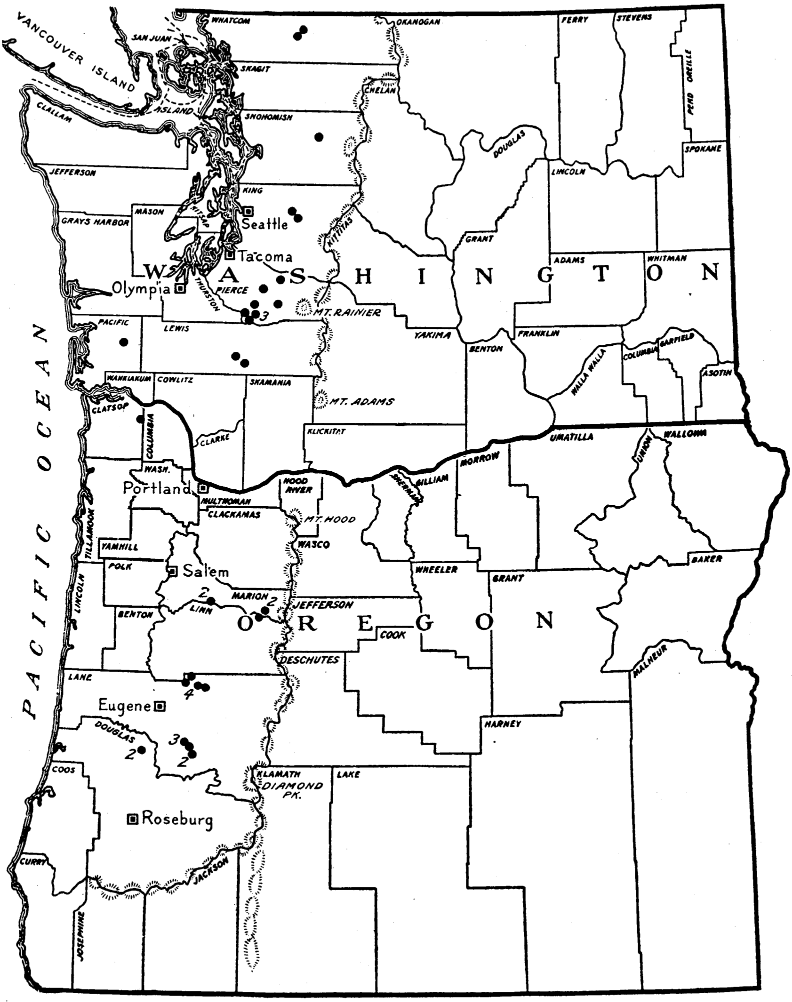


FIGURE 2.—Location of plots in western Oregon and Washington. Each dot represents the approximate location of one or more plots

cylinder, each log as the frustum of a paraboloid and the Smalian formula[3] applied, and the top as a cone. In "stagheaded" trees from which the tops had been broken off previous to felling, the section beyond 8 inches diameter inside the bark was treated as a frustum of a paraboloid instead of as the frustum of a cone, since

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[3] $(B+b)\frac{h}{2}$, in which $B$=basal area of the large end of the log in square feet, $b$=basal area of the small end in square feet, and $h$=length of the log in feet.

it was found that the slight increase in volume given by the first formula was a negligible difference based on the total volume of the tree, and volumes were more quickly computed by the first formula than by the formula for the frustum of a cone. In determining the board-foot volumes of the trees, that portion of the bole lying between stump height and a fixed top-diameter limit of 8 inches inside the bark was considered as merchantable. The logs were measured in board feet by the Scribner Decimal C Rule.

Measurements were made of 2,633 Douglas firs with a volume of 10,146,530 board feet and 1,571,368 cubic feet on 38 plots covering 77.79 acres. The approximate location of these plots is shown in Figure 2. Where several plots were measured in the same locality, a figure with the black circle indicates the number. Basic data are given in Table 1, in which the individual plots are grouped by site classes and then arranged by average age, beginning with the youngest plot in each site class.

TABLE 1.—*Basic data on Douglas firs of merchantable size by plots*

| Plot No. | Area | Site | | Average age | Average diameter breast high | Average height | Gross volume per acre in— | | | | Trees (basis) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Class | Index | | | | Board feet | Percentage of entire stand | Cubic feet | Percentage of entire stand | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | *Acres* | | | *Years* | *Inches* | *Feet* | | | | | *Number* |
| 15 | 3.00 | I | 188 | 204 | 34.8 | 207.6 | 150,990 | 93.5 | 24,078 | 92.4 | 164 |
| 10 | 2.85 | I | 192 | 232 | 42.9 | 217.1 | 192,960 | 87.0 | 29,379 | 86.1 | 125 |
| 18 | 4.63 | I | 190 | 333 | 80.6 | 227.9 | 133,740 | 89.3 | 19,572 | 89.3 | 44 |
| 21 | 2.02 | I | 205 | 340 | 50.0 | 246.6 | 222,760 | 97.2 | 32,801 | 96.4 | 60 |
| 28 | 2.31 | I | 198 | 412 | 74.0 | 254.9 | 294,870 | 94.4 | 43,684 | 93.0 | 52 |
| 11 | 1.34 | II | 178 | 64 | 16.7 | 135.9 | 40,260 | 86.8 | 8,317 | 85.4 | 129 |
| 32 | 2.86 | II | 155 | 94 | 24.5 | 136.7 | 51,030 | 94.4 | 9,625 | 92.8 | 167 |
| 6 | 1.35 | II | 171 | 112 | 31.0 | 170.5 | 92,730 | 94.9 | 15,431 | 93.7 | 71 |
| 33 | 2.06 | II | 176 | 122 | 32.2 | 175.3 | 81,400 | 90.6 | 13,304 | 88.3 | 78 |
| 8 | 2.30 | II | 178 | 158 | 39.7 | 190.0 | 124,820 | 97.6 | 20,287 | 96.7 | 97 |
| 26 | 2.10 | II | 174 | 183 | 44.9 | 190.0 | 120,480 | 99.9 | 19,560 | 99.8 | 72 |
| 14 | .78 | II | 182 | 197 | 33.5 | 208.1 | 177,190 | 99.5 | 27,863 | 99.2 | 52 |
| 7 | 1.24 | II | 175 | 198 | 53.9 | 203.6 | 154,110 | 99.1 | 23,956 | 98.8 | 34 |
| 12 | 2.35 | II | 181 | 237 | 39.6 | 209.3 | 180,350 | 94.1 | 27,502 | 92.1 | 108 |
| 16 | 2.16 | II | 182 | 238 | 40.5 | 212.3 | 109,170 | 99.4 | 17,234 | 99.1 | 65 |
| 27 | .91 | II | 178 | 243 | 40.5 | 207.0 | 165,020 | 99.5 | 25,673 | 99.0 | 44 |
| 25 | 3.66 | II | 182 | 245 | 51.9 | 213.0 | 162,100 | 99.9 | 24,868 | 99.9 | 93 |
| 35 | .59 | II | 168 | 245 | 33.7 | 190.8 | 99,730 | 96.8 | 16,253 | 95.1 | 26 |
| 17 | 1.13 | II | 180 | 245 | 38.0 | 199.6 | 126,110 | 90.8 | 19,694 | 87.8 | 44 |
| 36 | 1.18 | II | 157 | 258 | 42.4 | 172.3 | 125,230 | 96.1 | 19,197 | 94.4 | 38 |
| 30 | 1.16 | II | 174 | 289 | 44.9 | 206.2 | 229,140 | 95.0 | 35,158 | 93.6 | 62 |
| 24 | 1.09 | II | 170 | 309 | 41.9 | 205.3 | 227,110 | 99.6 | 34,567 | 99.5 | 59 |
| 22 | 1.58 | II | 174 | 316 | 47.4 | 211.0 | 127,140 | 94.7 | 19,335 | 92.8 | 36 |
| 38 | 2.38 | II | 180 | 319 | 53.5 | 224.8 | 161,270 | 99.9 | 23,705 | 99.9 | 51 |
| 37 | 2.23 | II | 174 | 322 | 59.0 | 216.5 | 149,150 | 100.0 | 21,790 | 100.0 | 38 |
| 31 | 1.68 | II | 179 | 333 | 47.1 | 221.7 | 231,680 | 94.4 | 35,828 | 93.4 | 79 |
| 13 | 1.15 | II | 183 | 345 | 57.6 | 238.4 | 237,620 | 95.3 | 35,192 | 93.9 | 32 |
| 20 | 2.00 | II | 183 | 349 | 51.5 | 223.3 | 253,400 | 99.7 | 38,161 | 99.6 | 79 |
| 34 | 3.00 | II | 169 | 383 | 63.5 | 211.0 | 85,800 | 92.7 | 13,051 | 89.4 | 28 |
| 23 | 2.33 | II | 174 | 404 | 59.5 | 214.6 | 177,300 | 96.1 | 26,252 | 94.9 | 48 |
| 19 | 1.96 | II | 164 | 559 | 83.5 | 212.5 | 113,610 | 72.7 | 16,879 | 68.4 | 13 |
| 4 | 1.02 | III | 150 | 66 | 18.8 | 119.9 | 17,750 | 58.6 | 3,759 | 58.5 | 37 |
| 1 | 2.86 | III | 144 | 103 | 24.5 | 122.6 | 34,820 | 89.5 | 5,695 | 87.7 | 48 |
| 2 | 2.00 | III | 150 | 114 | 29.6 | 147.0 | 47,390 | 91.8 | 8,477 | 89.8 | 62 |
| 5 | 2.71 | III | 142 | 116 | 25.9 | 134.4 | 36,780 | 82.1 | 7,037 | 80.9 | 117 |
| 29 | 1.00 | III | 143 | 145 | 24.3 | 145.0 | 68,410 | 99.5 | 12,809 | 99.2 | 82 |
| 3 | 3.41 | III | 130 | 149 | 29.1 | 142.6 | 39,980 | 79.9 | 7,024 | 77.1 | 88 |
| 9 | 3.41 | III | 132 | 400 | 36.4 | 168.1 | 78,650 | 97.1 | 12,722 | 95.7 | 111 |
| Total or average | 77.79 | ------ | ------ | 221 | -------- | -------- | -------- | -------- | -------- | -------- | 2,633 |

All computations were carried to two decimal places; but the resulting figures were rounded off to the nearest tenth, unit, or, in the case of board feet, 10, for this and subsequent tables, which explains minor discrepancies that may appear between the actual average or addition of figures cited and the figure for such average or addition recorded in these tables.

Naturally, stands on different areas will have different yields at the same age because of differences in soil, altitude, exposure, temperature, precipitation, and other physical factors, all of which influence productivity. Site class or site quality expresses the relative productive capacity or quality of different areas resulting from the action of the physical factors. The most reliable expression of site quality has been found to be the average total height of the dominant and codominant trees; that is, the largest and usually the tallest trees. In this region five classes of sites are recognized for Douglas fir, designated as excellent, good, fair, poor, and very poor, or for convenience as I, II, III, IV, and V. McArdle (*15*) discusses site for Douglas fir in some detail.

In column 3 of Table 1 the site class of each plot is given. The site curves from which the site qualities were read were accurate for young stands up to 160 years, but beyond that age were extended, based on all the available but nevertheless insufficient data, and consequently the site qualities established for the older plots in this study, while probably correct, can not be considered as absolutely so. Furthermore, in a few of the oldest plots there were scarcely enough dominant and codominant trees without broken tops to make determination of site quality possible. The site index—that is, the average height of the dominant and codominant trees at 100 years of age—is given in column 4. This was determined in order to give an exact basis for comparison between plots on the same site. The plots fall in Sites I, II, and III, which is to be expected, in as much as, according to McArdle (*14*), about 98 per cent of all Douglas fir land in this region comes within these three classes.

The age of individual trees was determined at stump height, and this age was corrected to ground level by the addition of the number of years required for the average tree to grow to stump height, read from an age-height curve for Douglas fir seedlings. The average age of the felled trees in each plot is given in column 5. Previous investigations (*15*, *22*) had shown that young stands of Douglas fir on the whole were even aged, so that it was also assumed that this would hold in mature and overmature stands. The results of this study, which is the first work that has been done on old-growth Douglas fir, show that these stands are not so uniformly even aged as was thought and in extreme cases may even approach the character of an uneven-aged stand. It must be remembered that these plots were measured during four successive years on logging operations scattered throughout the Douglas fir region in the Cascade Mountains; that their selection depended strongly on the location of logging operations; and that therefore they should be a good sample of conditions existing in overmature stands. No adequate explanation of the tendency for stands to become somewhat uneven aged can be offered, since special study has not been made of this. In part, this condition may be explained by the fact that it is usual to find individual trees or groups that have died, scattered through mature and overmature stands. It is reasonable to suppose that the resulting openings are frequently occupied by seedlings, some of which manage to develop under the partial shade; since these openings occur from time to time, the new trees resulting are of different ages. The cause of this dying of Douglas fir, individually or in small groups, has not been determined.

The average height given in column 7 is not based on all the trees in the plot, since those trees with broken tops were necessarily excluded from this calculation. In the younger plots, where few trees had broken tops, the basis of trees for average height is little reduced, but in the older plots, where broken tops were common, the basis is naturally much reduced. However, the figure of average height is seldom used in this study for comparative purposes.

In columns 8 and 10 are given the gross volumes in board and cubic feet of all the Douglas firs of merchantable size measured on the plot, but changed to a per-acre basis to permit direct comparison between plots; while columns 9 and 11 show the percentage relation of these volumes to the gross volume of all the trees of all species on the plot, whether standing or felled. Although every effort was made to select plots of pure Douglas fir where all trees of merchantable size were cut, this was not always possible, so that some of the plots had a small number of trees of other species of merchantable size. Furthermore, trees too small to be merchantable, particularly western hemlock, were common; and since all trees of all species 12 inches in diameter breast high or larger are included in the total volume for each plot, this still further increases the volume of trees other than felled Douglas fir of merchantable size on the plots. Most of these small trees are knocked down and destroyed in logging. There were 3,496 trees of all species 12 inches or larger in diameter breast high on the 38 plots. The heights of standing trees were measured with a Forest Service standard hypsometer. These measurements, together with the diameter breast high, made it possible to compute the board and cubic-foot volume of each tree from taper curves.

The number of trees on each plot is given in column 12 and serves as a basis for computations. This includes only Douglas firs of merchantable size, practically all of which were felled. On some logging operations trees judged to be unmerchantable because of decay are left standing, and it was impossible entirely to avoid such operations in locating plots. The volumes of such trees were obtained from taper curves based on diameter breast high and height; their ages were taken either as the average age of the felled trees on the plot or the average age of several trees of the same size and character immediately surrounding them; the percentages of cull from various causes were considered the same as that found by actual measurement of the felled trees, except decay, which was closely estimated by hypsometer measurements on the heights of conks or swollen knots, as will be explained later. Furthermore, the loss through decay was deducted before allowance was made for losses from other causes. Altogether there were 50 such standing Douglas firs of merchantable size among the 2,633 trees included in this study. They stood on 12 of the plots studied, in numbers varying from 1 to 8 on a plot, and averaging 4 to the plot.

Curves (fig. 3) showing the gross volume per acre in board and cubic feet, according to the age of the trees, were prepared for the plots on Site II, to permit determinations of the volumes per acre at various ages. As is customary with yield data, the gross volumes without deduction for defect of any kind are used. The plots are averaged into 50-year age classes from 51 to 100 years, 101 to 150 years, and so on, a point being plotted for each age class. Owing to the few plots on Sites I and III, curves could not be drawn for them. The lower ends of these curves are shaped in accordance with similar curves [4] based on an adequate number of plots in fully stocked stands but extending only to 160 years. A comparison shows that the curves presented here for Site II are somewhat lower up to 160 years than the curves for fully stocked stands. Since the loca-

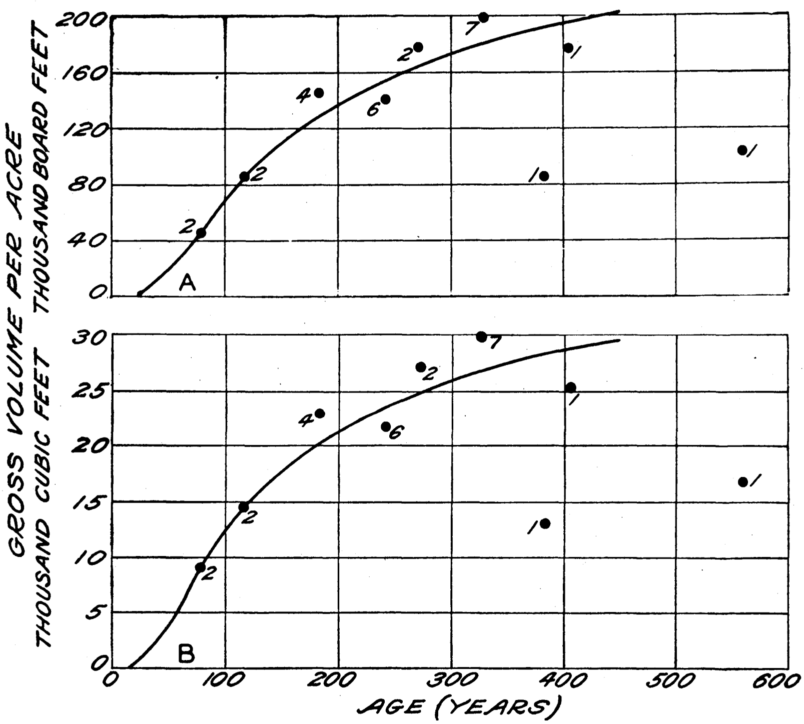



FIGURE 3.—Gross volume per acre of Douglas firs of merchantable size in relation to age on Site II: A, Board feet (Scribner Decimal C rule); B, cubic feet

tion of plots in this study was controlled by the location of logging operations, it was not possible to select all the plots in fully stocked stands, and in some cases it was apparent that the stands were decidedly understocked. This accounts for the lower yield shown by this figure. However, this lower yield accords with existing conditions, because subnormal stocking is the usual condition in the present Douglas fir stands (*19, p. 641*). Beyond 160 years of age there is no basis for comparison, and it is impossible to determine whether the values given in these curves are lower or higher than they would be for fully stocked stands. Although these curves represent the only

[4] Prepared by the Pacific Northwest Forest Experiment Station for a yield study of Douglas fir.

yield data yet available for mature and overmature stands, it must be emphasized that they are applicable only for the purpose of this study, that is, to show the relation between growth and decay, since they are based on a small number of plots and on stands part of which are not fully stocked. Theoretically these curves might decline in the older-age classes because of the well-known tendency of greatly overmature Douglas fir stands to break up and be replaced by western hemlock. However, the usual age at which this breaking up begins is not known and might be beyond the limits of these curves. There need be no further discussion of these curves, as their use will be brought out later.

## CAUSES OF LOSS

Although it is well known that losses in Douglas fir timber are high, particularly in the older stands, no exact figures on these losses have shown the amount or the relative importance of the various causes of cull. Incidental to this study of decay, it was possible, with a little additional field work, to take measurements on other classes of cull. After all, it is not only the loss from decay that must be considered in stands but the total loss from all causes. In Table 2 is shown the cull percentage based on the total board and cubic foot volume of all the plots combined. Decay is by far the most important cause of loss, amounting to 16.99 per cent in board feet. It is followed by breakage in felling, amounting to 9.25 per cent; these two factors alone account for 26.24 per cent in the 27.77 per cent total loss. Shake amounted to 0.93 per cent. Certain losses were individually so unimportant that they were combined with losses from similar causes into a broad classification, called "miscellaneous defect," in order to simplify the presentation of loss figures throughout the remainder of this bulletin.

TABLE 2.—*Percentage of loss in Douglas firs of merchantable size based on gross board and cubic foot volumes*

[Basis: 38 plots, 2,633 trees, 10,146,530 board feet, 1,571,368 cubic feet]

| Causes of loss | Percentage of loss [1] in— Board-foot volume | Percentage of loss [1] in— Cubic-foot volume | Causes of loss | Percentage of loss [1] in— Board-foot volume | Percentage of loss [1] in— Cubic-foot volume |
|---|---|---|---|---|---|
| Shake | 0.93 | 0.55 | Rots: | | |
| Miscellaneous defects: | | | Red ring rot (Trametes pini) | 13.72 | 7.52 |
| Broken top | .02 | .04 | Red-brown butt rot (Polyporus schweinitzii) | 1.06 | .75 |
| Volunteer | Trace. | Trace. | Yellow-brown top rot (Fomes roseus) | .69 | .38 |
| Crook | Trace. | Trace. | Brown trunk rot (Fomes laricis) | 1.46 | .80 |
| Fork | .06 | .07 | Pitted sap rot (Polystictus abietinus) | .02 | .02 |
| Knots | .52 | .62 | Spongy sap rot (Fomes annosus) | .02 | .01 |
| Insects | Trace. | Trace. | Brown cubical rot (Polyporus sulphureus) | 0 | Trace. |
| Fire scar | Trace. | Trace. | Unknown rots | .02 | .01 |
| Check | Trace. | Trace. | Total | 16.99 | 9.50 |
| Total | .60 | .73 | Total loss from all causes | 27.77 | 23.35 |
| Breakage in felling | 9.25 | 12.57 | | | |

[1] Trace means that percentage of loss was less than 0.01.

It will be noticed that the percentage of loss by several causes, notably breakage in felling, is higher in cubic feet than in board feet. This is because of the scaling rules in effect for board-foot measure, which state that a log 66⅔ per cent unmerchantable must be scaled as 100 per cent unmerchantable. Consequently a log with 66⅔ per cent of its gross merchantable board-foot volume lost through decay was considered in this study to be a complete loss. If such a log was also broken it was still classed as completely unmerchantable in board feet because of rot, since this last defect appeared before breakage. In cubic feet, however, the actual volume of decayed wood was charged against decay, while the remainder of the loss was considered breakage in felling. Naturally this would give, in cubic feet, a greater relative loss in breakage in felling. Cubic-foot figures on loss in this study are an exact measure of the actual volume of wood lost from the gross volume of the tree, while board-foot figures express this loss from the gross merchantable volume of the tree according to logging and milling practice, measured by empirical rules. The two sets of figures are not comparable, nor are they convertible.

While Table 2 was based on the gross volume of all the Douglas firs of merchantable size, Table 3 gives the losses by individual plots arranged by ages, beginning with the youngest plot. The average figures at the end of the table are a direct average with each plot given equal weight. In Table 4 the plots have been grouped into 50-year age classes to demonstrate the relation of age to certain defects, a relation which will be brought out later in the discussion.

TABLE 3.—*Loss in Douglas firs of merchantable size by plots, based on gross board and cubic foot volumes per acre*

| Plot No. | Average age | Percentage of loss [1] in— | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Board-foot volume | | | | | Cubic-foot volume | | | | |
| | | Rot | Shake | Miscellaneous defect | Breakage in felling | Total | Rot | Shake | Miscellaneous defect | Breakage in felling | Total |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | *Years* | | | | | | | | | | |
| 11 | 64 | Trace. | 0 | 0.2 | 2.7 | 2.9 | Trace. | 0 | 0.1 | 2.9 | 3.0 |
| 4 | 66 | 0 | 0 | .1 | 1.0 | 1.1 | 0 | 0 | .1 | 1.3 | 1.4 |
| 32 | 94 | .9 | .7 | .1 | 2.6 | 4.3 | .6 | .2 | .1 | 2.7 | 3.6 |
| 1 | 103 | 3.2 | 0 | .1 | 9.5 | 12.8 | 1.3 | 0 | .3 | 12.3 | 13.9 |
| 6 | 112 | .2 | .6 | .1 | 6.9 | 7.8 | .2 | .4 | .1 | 8.9 | 9.6 |
| 2 | 114 | 8.7 | Trace. | .6 | 4.5 | 13.8 | 3.8 | Trace. | .8 | 6.4 | 11.0 |
| 5 | 116 | 2.3 | 1.1 | 1.8 | 2.7 | 7.9 | 1.6 | .3 | 2.1 | 3.9 | 7.9 |
| 33 | 122 | 2.9 | .6 | .1 | 6.3 | 9.9 | 1.3 | .4 | .1 | 8.3 | 10.1 |
| 29 | 145 | 6.2 | 2.0 | .1 | 1.8 | 10.1 | 3.4 | 1.5 | .1 | 2.8 | 7.8 |
| 3 | 149 | 5.4 | .2 | 0 | 6.8 | 12.4 | 3.3 | .1 | 0 | 9.4 | 12.8 |
| 8 | 158 | 4.3 | 1.0 | .2 | 7.2 | 12.7 | 2.1 | .6 | .2 | 9.2 | 12.1 |
| 26 | 183 | 14.5 | .8 | 4.8 | 10.1 | 30.2 | 7.3 | .5 | 6.0 | 13.0 | 26.8 |
| 14 | 197 | 4.1 | .3 | 0 | 6.9 | 11.3 | 2.4 | .3 | 0 | 10.0 | 12.7 |
| 7 | 198 | 6.8 | 1.6 | 2.5 | 6.6 | 17.5 | 3.6 | 1.3 | 2.9 | 8.7 | 16.5 |
| 15 | 204 | .2 | .1 | .2 | 7.5 | 8.0 | .1 | Trace. | .1 | 9.5 | 9.7 |
| 10 | 232 | 7.0 | .3 | Trace. | 9.5 | 16.8 | 3.7 | .2 | Trace. | 12.0 | 15.9 |
| 12 | 237 | 17.9 | .3 | 0 | 8.2 | 26.4 | 10.6 | .3 | 0 | 11.5 | 22.4 |
| 16 | 238 | 1.6 | .1 | .1 | 6.4 | 8.2 | 1.0 | .1 | .1 | 8.4 | 9.6 |
| 27 | 243 | 8.0 | .8 | 0 | 7.6 | 16.4 | 4.7 | .5 | 0 | 10.4 | 15.6 |
| 35 | 245 | 3.5 | 1.2 | 0 | 7.4 | 12.1 | 1.9 | .7 | 0 | 9.6 | 12.2 |
| 25 | 245 | 29.8 | .3 | 6.3 | 13.0 | 49.4 | 16.9 | .2 | 7.5 | 16.9 | 41.5 |
| 17 | 245 | .2 | .2 | 0 | 9.7 | 10.1 | .1 | .1 | 0 | 11.8 | 12.0 |

[1] Trace means that percentage of loss was less than 0.01.

TABLE 3.—*Loss in Douglas firs of merchantable size by plots, etc.*—Continued

| Plot No. | Average age | Percentage of loss in— | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Board-foot volume | | | | | Cubic-foot volume | | | | |
| | | Rot | Shake | Miscellaneous defect | Breakage in felling | Total | Rot | Shake | Miscellaneous defect | Breakage in felling | Total |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | *Years* | | | | | | | | | | |
| 36 | 258 | 22.5 | 2.0 | 0 | 5.3 | 29.8 | 11.6 | 0.8 | 0 | 8.8 | 21.2 |
| 30 | 289 | 3.5 | 1.4 | Trace. | 6.4 | 11.3 | 2.3 | .4 | Trace. | 8.5 | 11.2 |
| 24 | 309 | 16.0 | .3 | 0 | 12.2 | 28.5 | 8.5 | .1 | 0 | 17.7 | 26.3 |
| 22 | 316 | 24.0 | 1.2 | Trace. | 11.3 | 36.5 | 13.9 | .4 | Trace. | 17.1 | 31.4 |
| 38 | 319 | 54.8 | 1.3 | Trace. | 5.4 | 61.5 | 32.2 | .6 | .1 | 9.1 | 42.0 |
| 37 | 322 | 45.5 | 1.3 | 0 | 9.4 | 56.2 | 26.8 | .5 | 0 | 15.1 | 42.4 |
| 18 | 333 | 12.2 | 2.3 | .2 | 8.3 | 23.0 | 7.7 | 2.8 | .2 | 10.2 | 20.9 |
| 31 | 333 | 22.3 | 2.9 | Trace. | 7.7 | 32.9 | 13.6 | 1.1 | Trace. | 11.2 | 25.9 |
| 21 | 340 | 29.4 | .9 | 0 | 14.0 | 44.3 | 17.2 | .5 | 0 | 20.2 | 37.9 |
| 13 | 345 | 13.7 | 1.1 | .4 | 13.8 | 29.0 | 8.0 | .8 | .4 | 17.7 | 26.9 |
| 20 | 349 | 12.5 | .5 | Trace. | 16.0 | 29.0 | 7.0 | .2 | Trace. | 19.9 | 27.1 |
| 34 | 383 | 12.0 | 2.0 | .1 | 13.4 | 27.5 | 7.7 | 1.1 | Trace. | 16.5 | 25.3 |
| 9 | 400 | 5.2 | 1.2 | .1 | 7.9 | 14.4 | 3.4 | .6 | .1 | 10.4 | 14.5 |
| 23 | 404 | 30.9 | .3 | Trace. | 13.3 | 44.5 | 17.5 | .2 | Trace. | 20.6 | 38.3 |
| 28 | 412 | 30.0 | 1.2 | 0 | 7.3 | 38.5 | 16.9 | .4 | 0 | 12.8 | 30.1 |
| 19 | 559 | 8.2 | .4 | .1 | 9.4 | 18.1 | 5.1 | .3 | .3 | 11.4 | 17.1 |
| Average | 247 | 12.4 | .9 | .5 | 8.0 | 21.8 | 7.1 | .5 | .6 | 11.0 | 19.1 |

TABLE 4.—*Loss in Douglas firs of merchantable size by plots grouped in 50-year age classes, based on gross board and cubic foot volumes per acre*

| Age class | Average | Percentage of loss[1] in— | | | | | | | | | | Plots (basis) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Board-foot volume | | | | | Cubic-foot volume | | | | | |
| | | Rot | Shake | Miscellaneous defect | Breakage in felling | Total | Rot | Shake | Miscellaneous defect | Breakage in felling | Total | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| | *Years* | | | | | | | | | | | *Number* |
| 51 to 100 | 75 | 0.3 | 0.2 | 0.1 | 2.1 | 2.7 | 0.2 | 0.1 | 0.1 | 2.3 | 2.7 | 3 |
| 101 to 150 | 123 | 4.1 | .6 | .4 | 5.5 | 10.6 | 2.1 | .4 | .5 | 7.4 | 10.4 | 7 |
| 151 to 200 | 184 | 7.4 | .9 | 1.9 | 7.7 | 17.9 | 3.9 | .7 | 2.3 | 10.2 | 17.1 | 4 |
| 201 to 250 | 236 | 8.5 | .4 | .8 | 8.7 | 18.4 | 4.9 | .3 | 1.0 | 11.3 | 17.5 | 8 |
| 251 to 300 | 274 | 13.0 | 1.7 | Trace. | 5.9 | 20.6 | 7.0 | .6 | Trace. | 8.7 | 16.3 | 2 |
| 301 to 350 | 330 | 25.6 | 1.3 | .1 | 10.9 | 37.9 | 15.0 | .8 | .1 | 15.4 | 31.3 | 9 |
| 351 to 400 | 392 | 8.6 | 1.6 | .1 | 10.7 | 21.0 | 5.6 | .9 | .1 | 13.5 | 20.1 | 2 |
| 401 to 450 | 408 | 30.5 | .8 | Trace. | 10.3 | 41.6 | 17.2 | .3 | Trace. | 16.7 | 34.2 | 2 |
| 551 to 600 | 559 | 8.2 | .4 | .1 | 9.4 | 18.1 | 5.1 | .3 | .3 | 11.4 | 17.1 | 1 |

[1] Trace means that percentage of loss was less than 0.01.

## SHAKE

The common shake was ring shake following the annual rings. Star shake or radial shake from the center of the tree toward the outside or from the outside part way to the center, the latter so characteristic of frost cracks, was seldom found. Shake was not confined to the butts of trees but was most frequent there. While shake might be found anywhere in the trees, it was nearly always in the lower half of the trunk and consequently caused more serious losses than the figures indicate, since it is from the lower bole that most of the high-grade logs come. As has been brought out before (*27*), shake is particularly apt to develop at a point of weakness in the wood. It was not uncommon to find shake connected with a lightning ring, that is, an annual ring with a layer of cells changed in both structure and shape from the normal by an electrical discharge which affected the cambium. A lightning ring forms a plane of cleavage in wood.

To determine the loss from shake in board-foot volume, the standard scaling practice of the Forest Service (*30, p. 20, 22*) was followed. In cubic-foot volume in the case of ring shake, the width of the shake was measured at each end of the log and the volume of the shake computed as a hollow cylinder. If the shake appeared on only one end of the log, its lineal extent was estimated.

From Table 2 it can be seen that the complete loss from shake amounted to 0.93 per cent of the gross board-foot volume, a relatively small percentage. In Table 4 shake shows a tendency to increase in amount with the increase in the age of the stand, but this increase is not striking. Shake may appear rather early in the life of the stand, for in plot 32, age 94 years, there is 0.7 per cent loss from this cause (Table 3); and in plot 5, age 116 years, there is 1.1 per cent loss; while the maximum loss is 2.9 per cent in plot 31, age 333 years. Curves showing the percentages of loss in board and cubic feet resulting from shake have been prepared (fig. 4) to bring out more clearly the increase in shake with increasing age of the stand.

## MISCELLANEOUS DEFECTS

Under the classification of miscellaneous defects are grouped a number of defects which individually are of little consequence, but which in the aggregate cause a measurable loss—in this study 0.60 per cent of the total volume in board feet, as shown in Table 2. Of this loss 0.52 per cent is chargeable to knots, in the case of logs with so many limbs that no merchantable lumber could be sawed from them. Such logs are commonly found in the upper bole near the merchantable diameter limit or in " wolf " trees; that is, trees which have grown much faster than their neighbors and consequently have not self-pruned properly. The loss from broken tops amounted to 0.02 per cent. Breaking off of tops by wind or other agencies is common in Douglas fir, particularly in overmature stands, or in a young stand that has suffered from an ice storm. Frequently checking or staining occurs for a few feet down the trunk, even if decay does not enter subsequently. This results in a little cull when the trees are felled. The only other loss of sufficient volume to make a definite figure was " fork "; that is, the volume lost in bucking out the actual fork in forked trees. This amounted to 0.06 per cent.

The loss in volunteers was very small. This was found in broken-topped trees where a limb had replaced the missing top, becoming a volunteer top. At the point where the top joined the main bole there was always a crooked portion unfit for lumber. Douglas fir is naturally a tall, straight tree; hence the cull from crook was negligible. Wood-boring insects and checks were likewise unimportant. There were very few fire scars found in the trees. This is because ground fires are not common in the Douglas fir region. When fire does occur it is usually sufficiently intense to kill the trees outright.

An examination of Table 4 indicates that there is very little relation between miscellaneous defects and age. This is to be expected since some of the factors making up this classification are little affected by age after the trees have passed the small-pole stage. Among these are crook, fork, knots, and fire scars. In fact, short

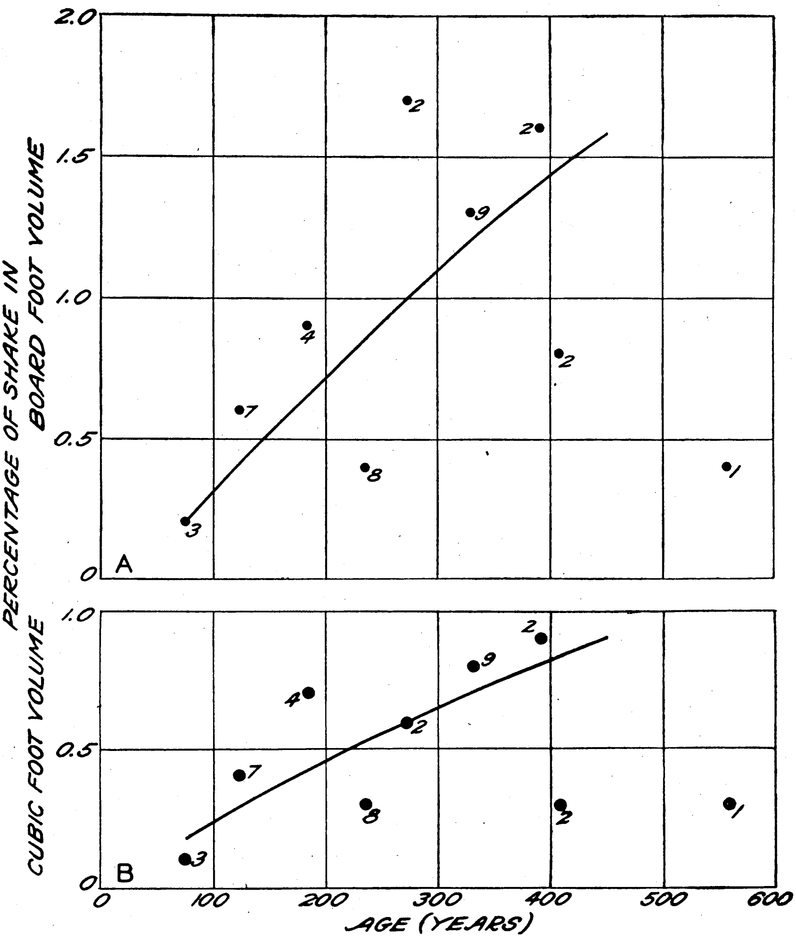



FIGURE 4.—Percentage of shake in relation to age of Douglas firs of merchantable size based on gross volume per acre: A, Board feet (Scribner Decimal C rule); B, cubic feet

crooks which are common in the upper boles of young trees that have suffered broken tops from snow and ice storms tend to straighten out as the trees become older and diameter increases. The greatest loss from miscellaneous defects, 1.9 per cent, occurs in the 151 to 200 year age class and is attributable to two plots, as is shown in Table 3—No. 26 with 4.8 per cent loss, and No. 7 with 2.5 per cent loss—for which the original data show that knots were responsible. In fact, in every plot where miscellaneous defects were more than 0.5

per cent, knots were the principal cause. It may be that the losses from knots in the understocked stands represented by many of these plots, are higher than would be found in fully stocked stands, since there should be a greater development of branches in the more open understocked stands.

## WASTE

On most logging operations there is some waste; that is, timber lost that could have been saved by more careful utilization. Common sources of waste are leaving high stumps, leaving merchantable timber in breaks, tops or cull logs, and overlooking merchantable logs. This loss is affected by general market conditions, accessibility of the individual operation to market, and the policy of the operator. Some operators are naturally wasteful. Because waste is so completely controlled by human factors, it is not considered further in this bulletin.

## BREAKAGE IN FELLING

Next to decay the most serious cause of loss in this region is timber broken in felling. Hanzlik and Fuller (*10*) have presented some data on breakage in Douglas fir, but aside from this there is no published information available on losses from this cause. Wagener (*31, p. 640*) lists the types of breakage that occur in Pacific-coast logging operations. In the present study on Douglas fir it was not possible to determine the amount of breakage caused by yarding and loading—that is, dragging the logs to the railroad and loading on cars—therefore all reference to breakage or broken timber applies only to the damage done in felling and apparent as the trees lie on the ground.

Breakage is an extremely variable loss, since so many factors influence it. The personal element plays a large part. Skillful timber fellers can get trees down with a minimum of breakage, while others will destroy a great deal of timber. The policy of the operator has its influence. In some camps the fellers are expected to break the tops of trees to avoid bucking expense, but in other camps effort is made to save even top logs. Again, the market may influence breakage since there is more tendency toward closer utilization when there is a good market than when there is a poor one.

Aside from the human factors, it is apparent that topography necessarily is extremely important. Breakage naturally is greater on rough ground than on smooth ground. Then, too, the size of the trees must be considered, since the larger trees are more subject to breakage; and since, within broad limits, size is related to age, older stands show more breakage than younger, other factors being equal. Finally, the stand per acre is important—the denser the stand, the greater the difficulties in felling and the higher the rate of breakage. In considering the loss from breakage, it must be remembered that the actual loss is not quite so serious as the figures indicate. Most breakage occurs in the upper part of the boles, where the majority of the knotty, low-grade logs are found.

The cubic-foot volumes of broken sections, irrespective of length, were computed directly by the Smalian formula. The board-foot volumes were scaled directly for the sections 6 feet in length or longer. Sections less than 6 feet long were scaled pro rata on the basis of their length. For example, a 6-foot section 12 inches in diameter inside the bark at the small end contains 30 board feet. A section with the same diameter, but 4 feet long, would contain 20 board feet; one 3 feet long, 15 board feet. In small pieces the board-foot measure was carried to the nearest 5 feet, and not rounded off to the nearest 10 in accordance with the Scribner Decimal C rule until final computations were made on groups of trees or plots. Broken sections less than 6 feet long were not common.

Table 2 shows a loss from breakage in gross board-foot volume of all the Douglas firs of merchantable size amounting to 9.25 per cent. Table 3, in which the various losses are given for individual plots, shows (column 6) that breakage is variable, the lowest figure in board-foot volume being 1 per cent in a 66-year-old plot and the highest 16 per cent in a 349-year-old plot. But young timber does not necessarily have low breakage, since a 103-year-old plot shows a loss of 9.5 per cent and a 412-year-old plot a loss of 7.3 per cent. However, there is a definite tendency for breakage to increase with age up to a certain limit, as is brought out in Table 4, column 6, which tendency is partly interfered with by the other variables.

To determine the influence of topography and density of the stand on breakage, the plots were divided into two classes, those on rough ground and those on smooth ground. Rough ground included areas with steep slopes, cut up by numerous small ravines, or with rock outcrops. These features might be alone or in any combination. Smooth ground included only level areas and those with gentle to moderate slopes, without ravines or rock outcrops. These two groups of plots were then compared as to their gross stand per acre in board feet. The data are presented in Table 5.

TABLE 5.—*Breakage in felling Douglas firs of merchantable size on smooth and rough ground by plots, grouped by gross volume per acre in board feet*

| Gross volume per acre class (M bd. ft.) | Smooth ground | | | | | | |
|---|---|---|---|---|---|---|---|
| | Average diameter breast high | Average height | Average gross volume per acre in— | | Breakage in felling in— | | Plots (basis) |
| | | | Board feet | Cubic feet | Board-foot volume | Cubic-foot volume | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| | *Inches* | *Feet* | | | *Per cent* | *Per cent* | *Number* |
| 1 to 50 | 23.2 | 142 | 43,830 | 8,397 | 3.5 | 4.6 | 2 |
| 51 to 100 | 30 | 162 | 78,110 | 12,045 | 5.3 | 7.1 | 5 |
| 101 to 150 | 57.6 | 205 | 125,950 | 19,160 | 7.7 | 10.5 | 6 |
| 151 to 200 | 45.6 | 212 | 169,030 | 25,910 | 8.7 | 12.1 | 9 |
| 201 to 250 | 47.9 | 218 | 231,390 | 35,186 | 10.1 | 13.8 | 4 |
| 251 to 300 | 74 | 255 | 294,870 | 43,684 | 7.3 | 12.8 | 1 |
| Average or total | 45.1 | 198 | 147,250 | 22,581 | 7.6 | 10.5 | 27 |

TABLE 5.—*Breakage in felling Douglas firs of merchantable size, etc.*—Continued

| Gross volume per acre class (M bd. ft.) | Rough ground | | | | | | |
|---|---|---|---|---|---|---|---|
| | Average diameter breast high | Average height | Average gross volume per acre in— | | Breakage in felling in— | | Plots (basis) |
| | | | Board feet | Cubic feet | Board-foot volume | Cubic-foot volume | |
| 1 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| | *Inches* | *Feet* | | | *Per cent* | *Per cent* | *Number* |
| 1 to 50 | 24. 6 | 132 | 32, 290 | 5, 879 | 5. 5 | 7. 5 | 4 |
| 51 to 100 | 47. 9 | 193 | 83, 600 | 13, 178 | 9. 9 | 12. 4 | 2 |
| 101 to 150 | 43. 4 | 200 | 124, 580 | 19, 530 | 10. 4 | 14 | 3 |
| 201 to 250 | 50 | 247 | 222, 760 | 32, 801 | 14 | 20. 2 | 1 |
| 251 to 300 | 51. 5 | 223 | 253, 400 | 38, 161 | 16 | 19. 9 | 1 |
| Average or total | 38. 7 | 180 | 104, 200 | 16, 311 | 9. 3 | 12. 4 | 11 |

This table shows a definite tendency for the percentage of breakage to increase with the increased density of the stand in both board and cubic foot volume. It is also apparent that breakage on rough

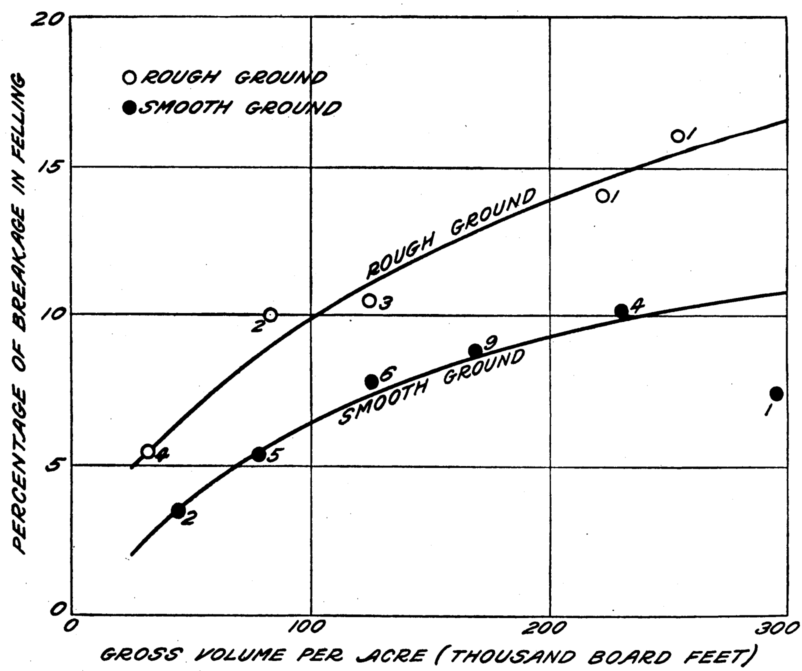



FIGURE 5.—Percentage of breakage in felling in Douglas firs of merchantable size on rough and smooth ground by plots in relation to gross volume per acre in board feet. (Scribner Decimal C rule)

ground amounting to 9.3 per cent in board-foot volume (Table 5, column 13) was greater than that on smooth ground, which amounted to 7.6 per cent. (Table 5, column 6.) This apparent difference is even more marked when it is considered that the stand per acre on rough ground is less than that on smooth ground, 104,200 board feet on the former (column 11) as compared with 147,250 board feet on the latter (column 4), and the trees also are smaller in average diameter breast high and in average height; while it is in the less dense stands with smaller trees that the least breakage should be expected, other conditions being equal.

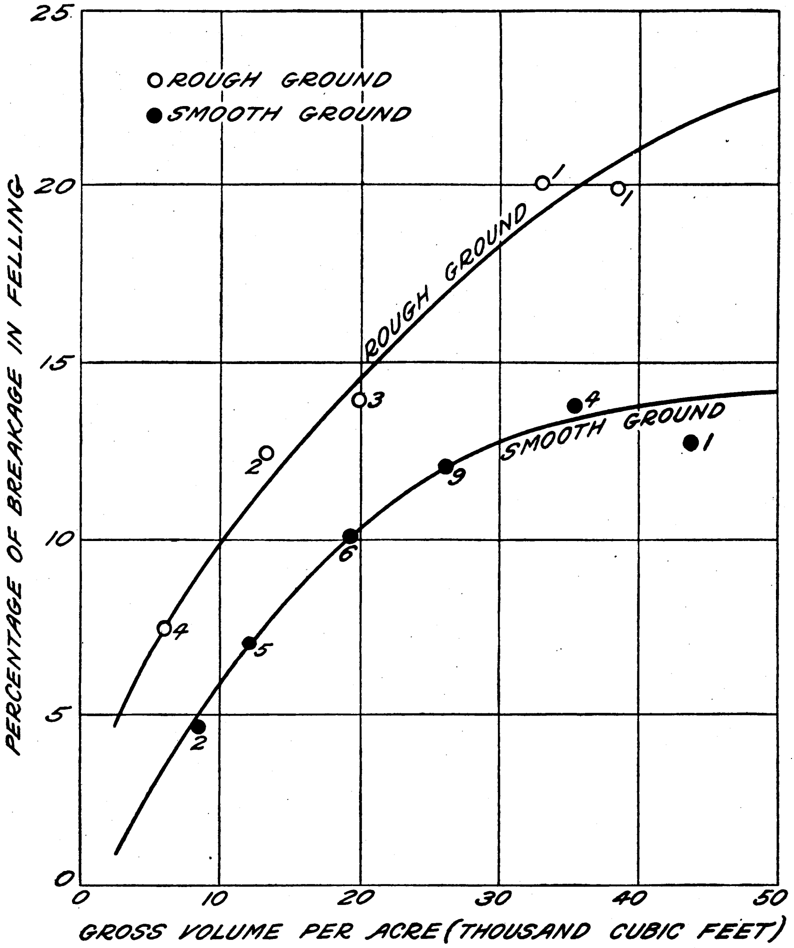



FIGURE 6.—Percentage of breakage in felling in Douglas firs of merchantable size on rough and smooth ground by plots in relation to gross volume per acre in cubic feet

In order to bring out more clearly the increase in breakage with the increased density of the stand and the difference between rough and smooth ground, the data in Table 5 for board and cubic feet are shown in Figures 5 and 6. The curves show a marked difference between the two types of ground, together with increased breakage with increased density of the stand.

The previous consideration of breakage has been on the basis of plots and included trees with a large amount of decay which exerts some influence on breakage. The presence of decay may influence the actual breaking of the tree when it is felled. Then, too, in measuring in board feet, decay often conceals an actual loss in breakage. For example, under the scaling rules a log that is two-thirds or more unmerchantable, owing to decay, is classed as completely unmerchantable, and the loss is charged against rot, even though there might have been some loss caused by breakage in the remaining third of the volume. Table 6, which is based on individual trees selected from the plots on smooth and rough ground and arranged by 8-inch diameter classes, includes only those trees free from decay, or with so little rot or rot so located that it could have no effect on breakage. The table shows more breakage on rough ground than on smooth, and in general an increase in the amount of breakage with the increased diameter breast high. In spite of the fact that the trees on smooth ground average larger than those on rough ground they show still less breakage. Curves showing the percentages of breakage in board and cubic feet with relation to diameter are used in Figure 7 to bring out more clearly the greater loss through breakage on rough ground and the increase in this loss with increasing diameter breast high. It is noticeable that when the greater diameters are reached breakage increases more slowly with the increase in diameter. This may be explained by two facts: After trees attain a certain size they are not so easily broken by other trees falling on them; and as the trees increase in size the volume of the top logs, in which most of the breakage occurs, becomes relatively smaller in proportion to the total volume of the tree.

TABLE 6.—*Breakage in felling Douglas firs of merchantable size on smooth and rough ground by trees grouped in 8-inch diameter classes, based on gross board and cubic-foot volume per average tree*

| Diameter breast-high class (inches) | Smooth ground | | | | | Rough ground | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Average diameter breast high | Average height | Breakage in— Board-foot volume | Breakage in— Cubic-foot volume | Trees (basis) | Average diameter breast high | Average height | Breakage in— Board-foot volume | Breakage in— Cubic-foot volume | Trees (basis) |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| | *Inches* | *Feet* | *Per cent* | *Per cent* | *Number* | *Inches* | *Feet* | *Per cent* | *Per cent* | *Number* |
| 16 | 16. 4 | 130 | 2. 3 | 3. 2 | 179 | 17. 8 | 117 | 6. 8 | 7. 1 | 65 |
| 24 | 24. 3 | 155 | 5. 3 | 7. 1 | 254 | 23. 8 | 137 | 5. 6 | 7. 4 | 140 |
| 32 | 32. 2 | 184 | 7. 5 | 10. 2 | 356 | 31. 8 | 164 | 7. 3 | 9. 9 | 118 |
| 40 | 39. 8 | 204 | 8. 1 | 11. 0 | 324 | 40. 2 | 192 | 10. 5 | 13. 1 | 90 |
| 48 | 48. 0 | 216 | 8. 9 | 12. 5 | 222 | 48. 0 | 213 | 14. 3 | 16. 5 | 66 |
| 56 | 55. 8 | 224 | 10. 2 | 13. 0 | 137 | 55. 4 | 226 | 17. 0 | 18. 7 | 48 |
| 64 | 63. 4 | 232 | 13. 0 | 15. 6 | 46 | 63. 7 | 241 | 13. 2 | 17. 3 | 22 |
| 72 | 72. 7 | 240 | 13. 9 | 16. 8 | 29 | 72. 0 | 244 | 14. 6 | 17. 0 | 13 |
| 80 | 79. 8 | 240 | 12. 5 | 12. 9 | 23 | 76. 7 | 239 | 17. 4 | 19. 2 | 3 |
| 88 | 87. 2 | 213 | 12. 5 | 13. 1 | 8 | 90. 0 | 268 | 42. 1 | 44. 3 | 1 |
| 96 | 95. 5 | 240 | 12. 6 | 13. 7 | 4 | 95. 2 | 252 | 18. 9 | 21. 9 | 1 |
| 104 | 103. 5 | 234 | 9. 7 | 11. 2 | 4 | | | | | |
| 120 | 120. 0 | 225 | 4. 2 | 6. 0 | 1 | | | | | |
| Average or total | 38. 0 | 189 | 7. 5 | 10. 0 | 1, 587 | 36. 0 | 173 | 9. 5 | 11. 6 | 567 |

Although for this study plots of as nearly pure Douglas fir as possible were selected, some of the stands had a light admixture of other species. While in all such plots the Douglas fir greatly outnum-

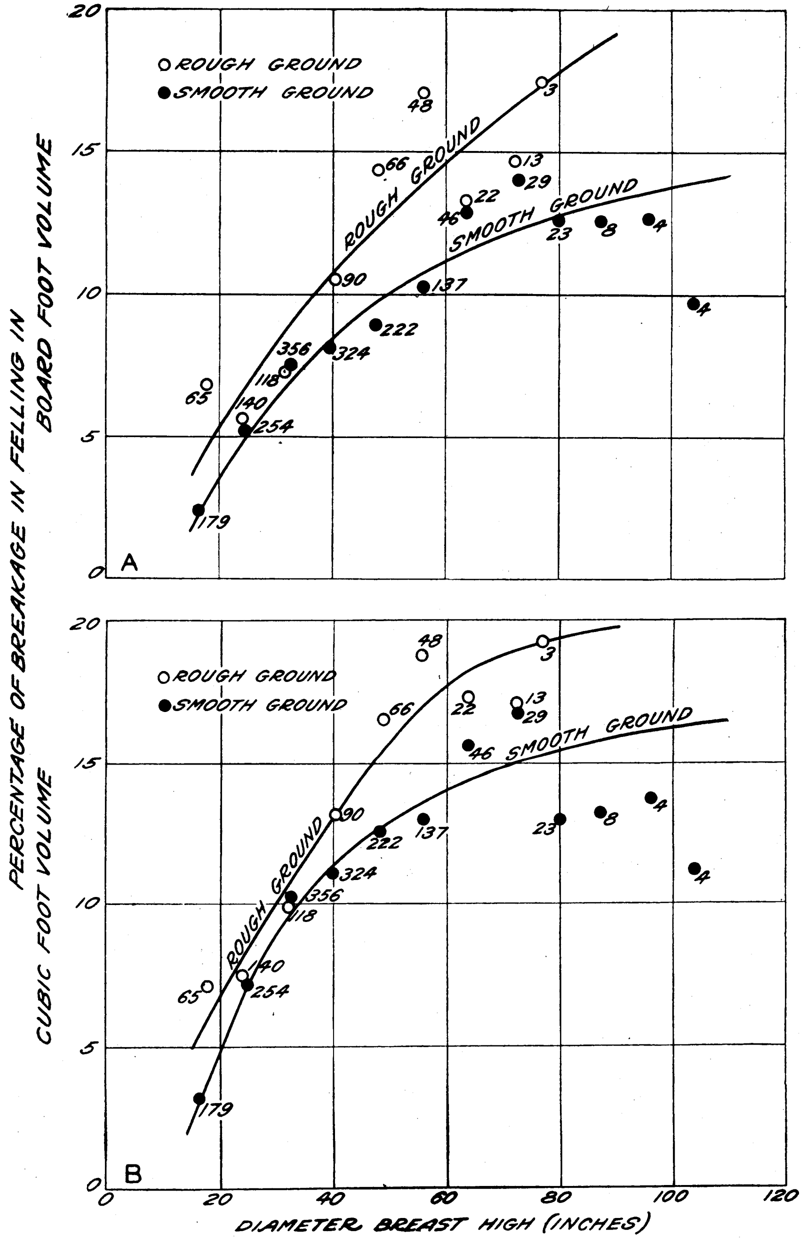



**Figure 7.**—Percentage of breakage in felling of Douglas fir on rough and smooth ground in relation to diameter breast high based on gross volume per average tree: A, Board feet (Scribner Decimal C rule); B, cubic feet

bered the other species, these other species occur in most stands. Therefore it seemed that a comparison of breakage in the different species might be of some value. In Table 7 comparative breakage figures are presented for nine plots. For these breakage figures to be exactly comparable, trees of each species on each plot should have approximately the same average diameter breast high and height. Of course it was impossible to find such ideal conditions, nor were there enough trees of other species measured to make an adequate basis for curves relating percentage of breakage to diameter breast high, thus allowing a direct comparison to be made between species. From this table it can be seen that Douglas fir is less subject to breakage than those species associated with it, the most common of which is western hemlock. Where the breakage in board feet (column 8) is higher in Douglas fir than in the other species, the Douglas fir trees have a greater average diameter breast high and a greater average height.

TABLE 7.—*Comparison of breakage in felling between Douglas fir and associated species*

| Species | Type of ground | Plot No. | Average diameter breast high | Average height | Average gross volume per tree in— | | Breakage in felling in— | | Trees (basis) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Board feet | Cubic feet | Board-foot volume | Cubic-foot volume | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | | | *Inches* | *Feet* | | | *Per cent* | *Per cent* | *Number* |
| Douglas fir | Rough | 3 | 31.0 | 142 | 1,500 | 262 | 6.7 | 10.2 | 85 |
| Incense cedar | | | 37.4 | 128 | 1,340 | 257 | 13.1 | 16.1 | 8 |
| Douglas fir | do | 5 | 25.9 | 134 | 840 | 161 | 2.8 | 4.0 | 111 |
| Incense cedar | | | 43.5 | 138 | 1,650 | 348 | 6.6 | 7.9 | 5 |
| Douglas fir | Smooth | 10 | 42.9 | 217 | 4,400 | 670 | 9.5 | 12.0 | 125 |
| Western hemlock | | | 26.0 | 165 | 1,830 | 292 | 17.2 | 19.6 | 31 |
| Sitka spruce | | | 25.9 | 175 | 1,940 | 322 | 7.5 | 9.8 | 11 |
| Douglas fir | do | 12 | 39.6 | 209 | 3,840 | 587 | 8.4 | 11.8 | 107 |
| Western hemlock | | | 24.5 | 149 | 1,220 | 211 | 10.0 | 12.2 | 19 |
| Douglas fir | do | 15 | 34.8 | 207 | 2,760 | 440 | 7.5 | 9.5 | 164 |
| Western hemlock | | | 27.3 | 157 | 1,620 | 274 | 5.6 | 7.8 | 13 |
| Douglas fir | do | 19 | 83.4 | 212 | 17,130 | 2,544 | 9.4 | 11.4 | 13 |
| Western hemlock | | | 33.7 | 151 | 2,300 | 379 | 4.0 | 6.3 | 7 |
| Douglas fir | do | 28 | 74.0 | 255 | 13,100 | 1,940 | 7.3 | 12.8 | 52 |
| Western hemlock | | | 36.7 | 175 | 2,550 | 445 | 10.4 | 16.6 | 6 |
| Douglas fir | do | 30 | 44.8 | 206 | 4,290 | 658 | 6.4 | 8.5 | 62 |
| Western hemlock | | | 21.4 | 141 | 920 | 163 | 9.0 | 11.1 | 8 |
| Douglas fir | do | 31 | 47.1 | 222 | 4,920 | 761 | 7.7 | 11.2 | 79 |
| Western hemlock | | | 27.0 | 152 | 1,600 | 277 | 10.0 | 11.7 | 11 |

## ROT

In a previous paper (*4*) it was pointed out that practically all decay in Douglas fir was caused by four wood-destroying fungi. As a result of this more extensive study, several other fungi, not previously discussed, have been found to cause occasional loss, and additional information on the four important ones has become available, so that descriptions of all are necessary to an understanding of the detailed discussion of decay which follows.

In the description of rots several terms that need explanation will be used. There are various stages in decay as the wood is changed from being sound to a condition of complete decay. In the earliest stages the wood appears to be hard and firm, the only evidence of infection being a slight color change from the normal that is easily confused with harmless color variations or discolorations. This is known as incipient decay, early decay, or advance rot. In some cases there is not even a variation in color to indicate the presence of decay, which is then known as hidden decay. After the incipient stage is passed, the wood becomes more and more noticeably affected until it is finally changed completely in appearance and structure and can be crumbled between the fingers or easily broken. This stage is known as advanced decay, typical decay, final decay, or late decay. A stage intermediate between incipient decay and advanced decay can sometimes be recognized.

In a decaying trunk all stages of rot are present, ranging up or down the tree from the advanced decay, where the fungus has been at work the longest, through the incipient decay to sound wood. The same progression may be seen on a cross section passing from the center of the decayed portion of the heartwood to the sapwood. Vertically, incipient decay may extend from a few inches to many feet beyond the area of advanced decay, varying with the individual tree and the kind of rot.

After rot has been present for a time, the fruiting bodies—sporophores, or conks—develop. These are usually quite large and may appear on the trunk, or occasionally on the branches, in the form of flat or hoof-shaped brackets, or they may appear on the ground near by, coming up from a decayed root and somewhat resembling large, dark-colored toadstools except that they have short thick stalks, and porous undersides. Their appearance invariably indicates decay in the tree. The microscopically small spores, released from the pores on the underside of the conks, are carried away by the wind. Finding a suitable place, they germinate and decay of the wood begins. The tiny fungous thread developing from the spore can not penetrate bark or living sapwood; consequently, for decay to result, a spore must alight on exposed deadwood directly connected with the heartwood. Dead branch stubs, broken tops, and open wounds offer an abundance of infection points.

## DESCRIPTION OF ROTS

### RED RING ROT

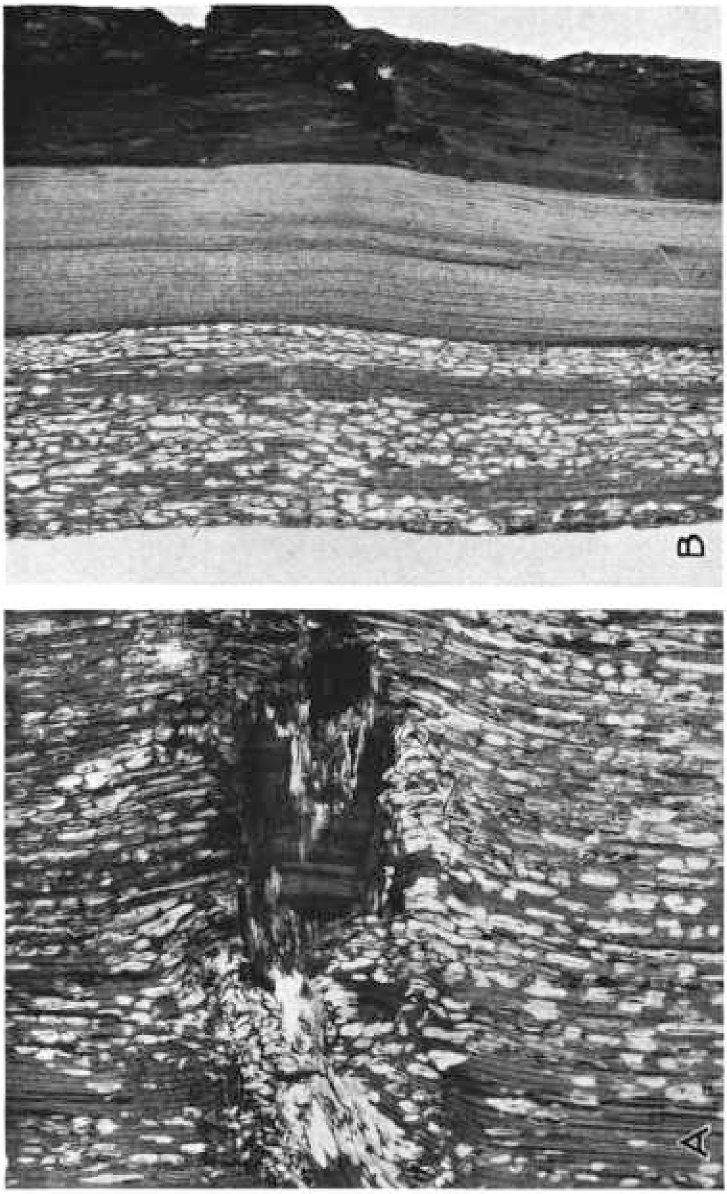
Red ring rot, which is commonly known as conk rot in the Douglas fir region and elsewhere as red ring rot, ring scale rot, honeycomb rot, or pecky wood rot, is caused by the ring-scale fungus, *Trametes pini* (Thore) Fr. The incipient decay is very striking, as shown in Figure 8. It appears as a pronounced reddish purple or olive-purple color against the red or yellow heartwood, and occasionally the color may be so deep as to appear brownish. Gradually the color fades as the distance from the advanced decay increases, until it is lost entirely. The color is often most pronounced in the outermost heartwood just where it joins the sapwood. The discolorations described are sometimes bounded by a narrow zone of pronounced red. As wood is little if at all weakened by the incipient rot, it is used in the lower grades of lumber. The discoloration may extend vertically 10 to 20 feet, rarely more, in advance of the cellulose pits, although 3.5 feet was found to be average. Radially the discoloration is limited to 2 or 3 inches. The red heartwood of "red" fir, which is only the normal-colored heartwood of young trees, is frequently mistaken by graders and scalers for the incipient stage of red ring rot, with the result that sound wood is culled or degraded.

In the advanced stage of rot the wood has a color the same or deeper than in the incipient stage, but is more or less riddled with spindle-shaped, slightly pointed white cavities or pockets running

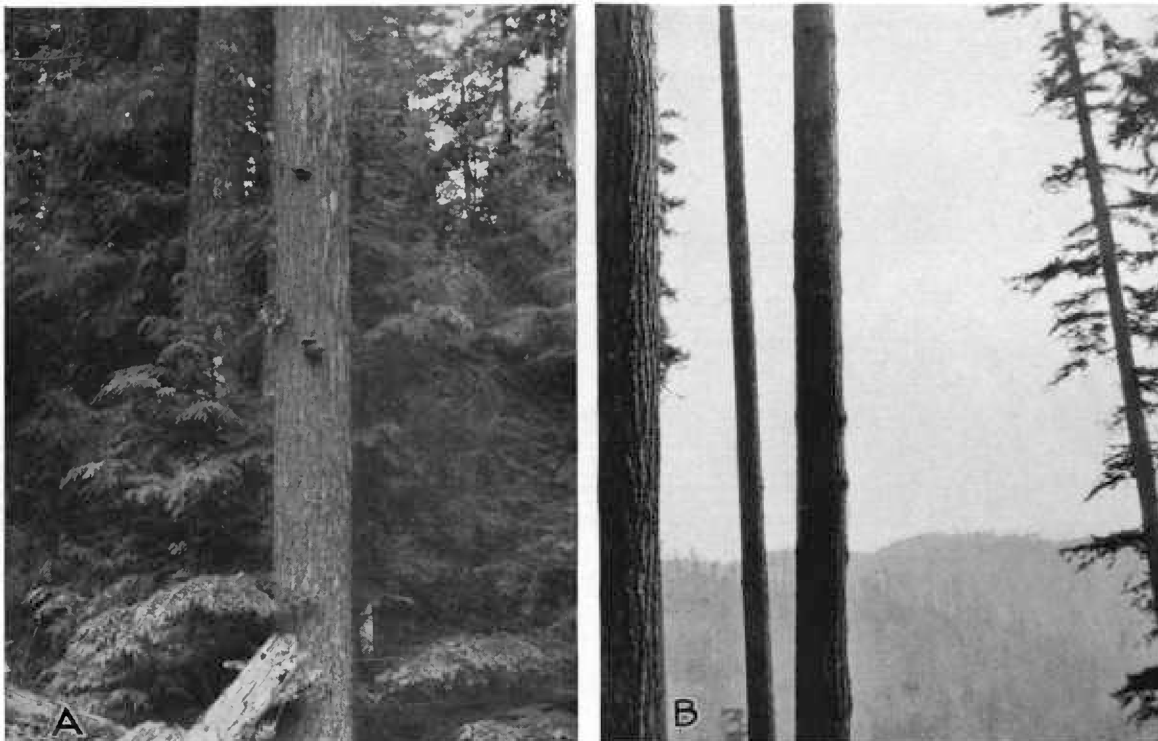
FIGURE 8.—End of a log with red ring rot caused by the ring-scale fungus, *Trametes pini*. The upper dark-colored portion of the log indicates the reddish purple stain characteristic of the incipient stage, and the lower portion shows the white cellulose pockets and the ring-scale character. (Photographed by A. H. Hodgson)

parallel to the grain and separated by firm wood, which are illustrated in Plate 1. In these pockets the wood has been reduced to a white, soft, fibrous mass of cellulose.

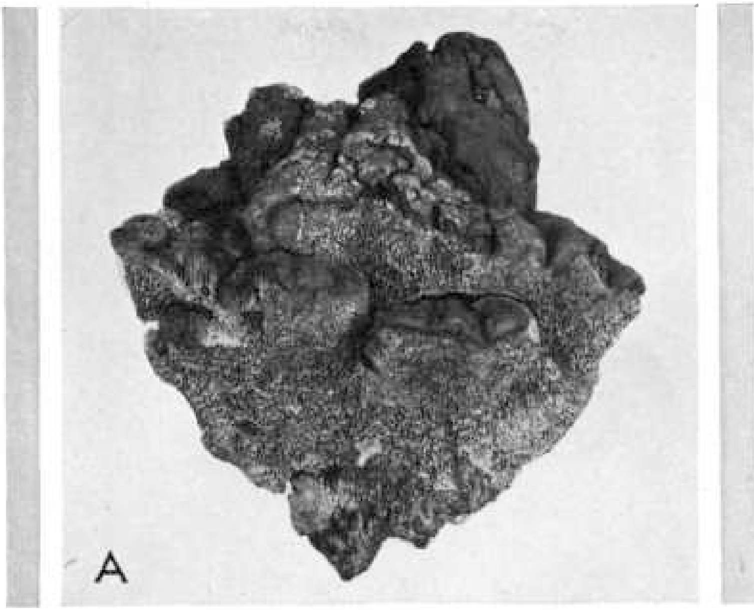
A number of pockets may merge, forming an irregularly shaped area of rotted wood. In some cases the pocket may contain no cellulose fibers. When seen on the cross section at the end of a log, they may be scattered rather uniformly throughout the affected wood or may be in the form of ring scale, which quite commonly results from the rot being confined to more or less definite groups of annual rings, as shown in Figure 8.



A, Radial view of the advanced stage of red ring rot caused by the ring-scale fungus, *Trametes pini*, showing a partially decayed knot; B, radial view of a decayed trunk showing the advanced stage of red ring rot (on the left), sound heartwood, sapwood, and bark

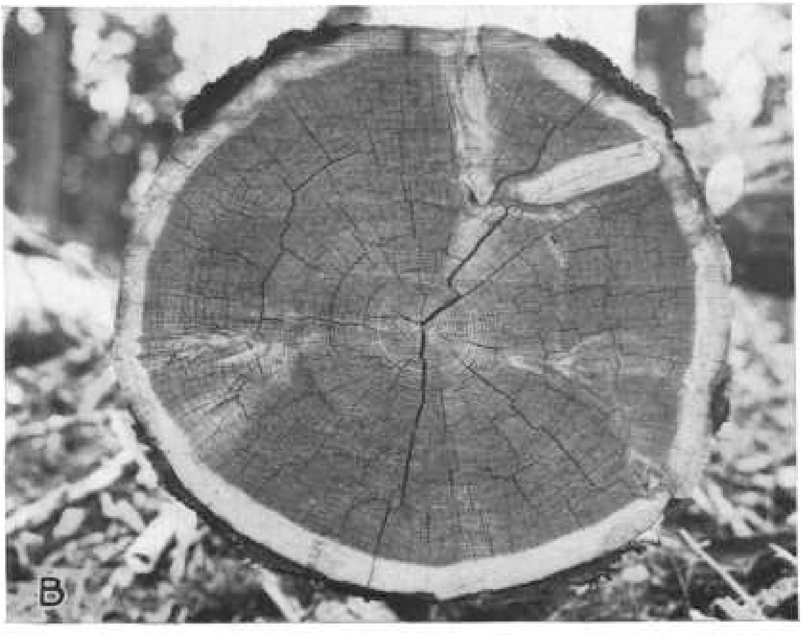



A, Conks of the ring-scale fungus, *Trametes pini*, on a Douglas fir. These conks indicate red ring rot in the heartwood. (Photograph by the writer and R. E. McArdle); B, swollen knots on a living tree indicating red ring rot caused by the ring-scale fungus in the heartwood

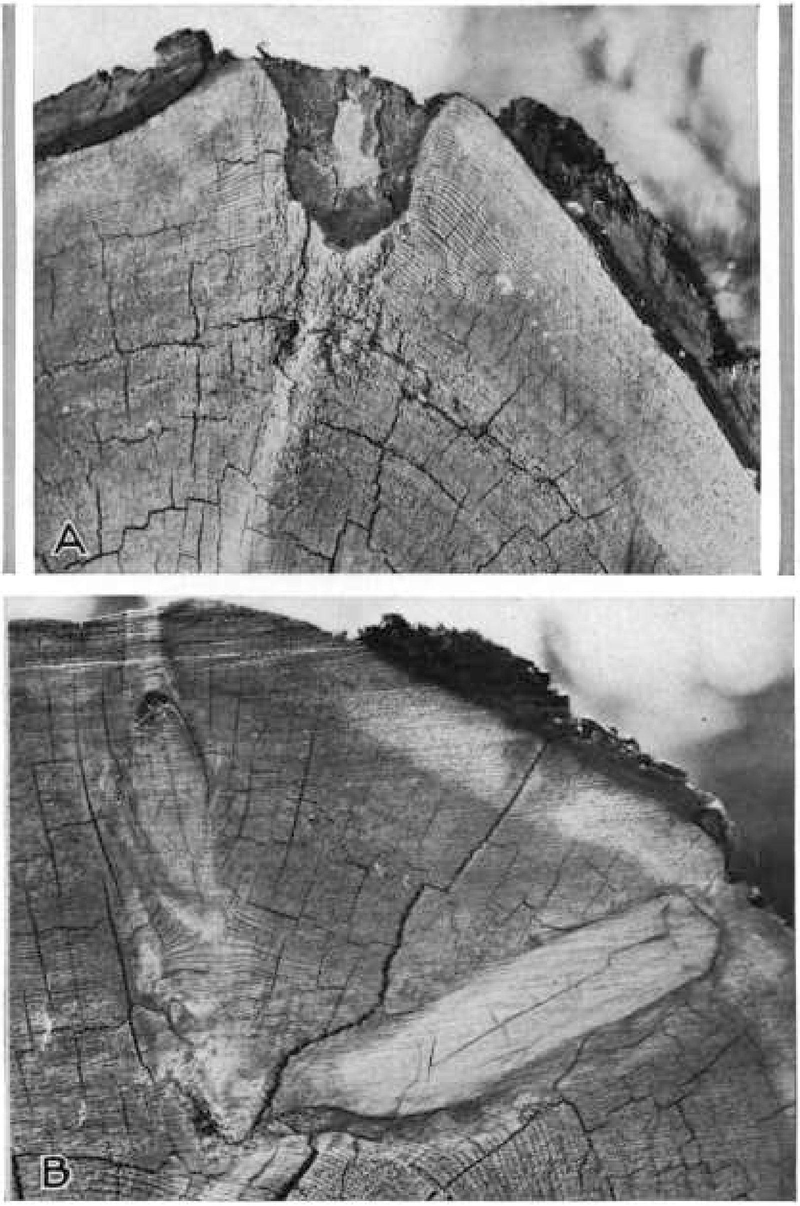




A, Conk, or sporophore, of the ring-scale fungus, *Trametes pini*, showing the rough upper surface and the irregular pores on the under surface. This fungus causes red ring rot; B, side view of swollen knots on a log from which the hark has heen removed. (Photographs hy the writer and R. E. McArdle)



A, Cross section through a Douglas fir log with red ring rot caused by the ring-scale fungus, *Trametes pini*, showing a swollen knot; B, cross section through a sound Douglas fir log showing normal knots. (Photographs by the writer and R. E. McArdle)




A, Cross section through a swollen knot. This is a detailed view of the swollen knot shown in Plate 4, A; B, cross section through sound knots. This is a detailed view of the sound knots shown in Plate 4, B. (Photographs by the writer and R. E. McArdle)

The heartwood in the butt of this Douglas fir has been completely destroyed by red-brown butt rot caused by the velvet top fungus, *Polyporus schweinitzii*. (Photograph by G. G. Hedgcock)

While red ring rot is not limited to any definite portion of the trunk, it is not frequent in the butt of the tree, seeming to find conditions there less favorable for its development. In completely decayed trees, although the rot may include nearly the entire heartwood at the top of the first 16 or 32 foot log, it is quite usual for the rotted area on the stump to be small or completely absent. The stumps usually vary from 2 to 4 feet in height.

Sawyers often observe (*1*) that many butt logs of Douglas fir are very tough and hard to saw. This may indicate that there is a greater relative amount of compression wood, with its thick cell walls, in the butt of the tree than in the upper portions. It would be more difficult for a wood-destroying fungus to decay such wood than wood of normal density. Again, the resin content or the moisture content may be higher in the butt, and either condition might have a retarding effect on rot.

Sporophores, or conks, are very common in overmature stands. (Pl. 2, A.) These perennial fruiting bodies issue from the tree through knots. They vary in size and may be bracketlike or hooflike in shape. The upper side is a dull grayish or brownish black, rough, and with approximately concentric furrows parallel to the lighter brown margin. The underside is a grayish brown or rich brown color with large irregular pores. (Pl. 3, A.) When the conk is actively growing, the margin is velvety and light golden brown in color. Its substance is corky or punky.

Besides the conks, swollen knots are developed as shown in Plate 2, B. These are merely the initial stages of sporophores, in which the substance forming the conks is growing out through the knots, and consequently is just as good an indication of the presence of decay as are sporophores. Often the sporophore never develops beyond this stage. Chopping into one of these swollen knots reveals a brown punky substance, the same as in a fully developed sporophore. In some cases the sapwood and new bark grow over the swollen knot, hence it is necessary to chop through solid wood before the punky knot is reached. These are called blind conks. The swellings are caused by the living-wood tissue trying to grow over the knot where the conk is being formed, as shown in Plate 4, A, Plate 5, A, and Plate 3, B; and in many cases the appearance is accentuated by the growing conks actually pushing out the thick dead bark in a characteristic manner. The swelling resulting from the attempt to heal over a decayed knot is very marked when contrasted with the appearance of a normal sound knot grown over, as illustrated by Plates 4, B, and 5, B.

As the development of conks and swollen knots follows very closely the progress of decay in the heartwood, it is possible to pick out rather accurately the trees affected by red ring rot. It is extremely rare for a tree without conks or swollen knots to have red ring rot. No study has been made of the time required for the development of conks after infection, or of the rate of progress of decay in individual trees. Suri (*29, p. 328*) states that in deodar, *Cedrus deodara* Loud., infected with red ring rot, sporophores develop about 5 to 15 years after actual infection. An exact analysis of 170 Douglas fir trees with a total volume of 203,920 board feet and 38.4 per cent of loss from red ring rot showed that loss from infections without conks or swollen knots comprised only 0.04 per cent, or an average loss of 3 board feet per infection (*4, p. 13*). When high up in a tree among the branches, swollen knots or conks are not readily seen with the naked eye, but if occurring there they do not make much difference in the accuracy of an estimate, since the scale of the top logs is insignificant in the total.

It is not only possible to pick out the decayed trees, but it is also feasible to judge with some accuracy the normal extent of red ring rot. Through careful study of a number of decayed trees it was found that the rot extended approximately 20 feet above or below the highest or lowest conk and approximately 9.5 feet (*4, p. 14*) above or below the highest or lowest swollen knot. These distances include the incipient decay and are close approximations. Naturally, individual examples varied considerably from the distances given, but these figures have been found to be a good average. They should be used only when there are several sporophores or swollen knots separated by a few feet. If there is a single conk or swollen knot or one compact group, only one 16-foot log, or 8 feet in each direction, should be culled. By studying felled trees and then watching infected logs through the mill, these limits can be set to fit any local conditions. Of course, when timber is felled and bucked it is possible to judge the extent of red ring rot much more exactly, since the ends of the logs can be examined for rot and the sides for swollen knots or conks.

It is difficult to estimate decay in fire-killed timber, but even there red ring rot can be detected. The dry, punky substance of the conks or swollen knots extending into the tree burns readily, while the surrounding bark is merely scorched and blackened, resulting in circular holes reaching 2 to 3 inches into the trunk—thoroughly reliable indications when their significance is understood. Of course it is impossible to tell whether the hole was formerly occupied by a swollen knot or by a conk.

Scars of any kind are rarely responsible for infections of red ring rot. The fungus almost invariably enters the tree through knots or branch stubs (*4, p. 7, 8*).

#### RED-BROWN BUTT ROT

Red-brown butt rot, which also decays the roots, is caused by the velvet-top fungus, *Polyporus schweinitzii* Fr. The decay makes infected trees liable to wind throw, and it is not uncommon in the spring after the winter storms to see large Douglas firs broken off near the ground with the heartwood completely destroyed by this rot.

The incipient stage of red-brown butt rot is first evident as a faint yellowing or browning of the normal wood. This color intensifies, and the wood becomes soft. A hidden stage occurs for some distance beyond the incipient stage. While the incipient stage may extend over 8 feet beyond the advanced stage, the average is about 2 feet. In the advanced stage the wood is a pronounced red brown in color, completely broken down, as is shown in Plate 6, and crushes to a smooth powder between the fingers. In the shrinkage cracks are formed thin, crustlike layers of mycelium, which are easily mistaken for resin deposits. The rot is typically confined to the roots and butt, commonly not extending beyond the first 16-foot log, although occasionally it may extend 40 feet up the trunk. Rarely it may be found higher, localized around the stub of a dead branch and not connected with the butt. On the end of a log the decay is approximately circular in outline, and the rot column as seen longitudinally is roughly cone shaped, tapering from the butt.

The following empirical rule for judging the longitudinal extent of the rot column in the butt log has been evolved from the dissection of a number of infected trees 200 years old and older. If the average diameter of the rot area on the butt of the log does not exceed 4 inches, the rot will extend up the log 1 foot for each inch in the diameter of the rot area. If the average diameter of the rot is from 5 to 10 inches, deduct 1 inch from that diameter and apply the same rule. If the diameter of the rot is more than 10 inches, deduct 1 inch for each additional 10 inches of that diameter. For example, in a log with a rot area 8 inches in diameter, the rot column should be figured as 7 feet long; if the average diameter is from 11 to 20 inches, deduct 2 inches; from 21 to 30 inches, deduct 3 inches; and 31 inches or over deduct 4 inches. It must be emphasized that there will be many exceptions to this rule, that it is not exact for individual logs, and can only be applied in scaling a number of defective logs.

The annual conks which develop most abundantly just after the fall rains begin are to be found issuing from an old wound on the butt of an infected tree or more commonly on the ground near by coming up from a decayed root. (Pl. 7.) On the tree the conk is a thin bracket, and frequently two or more brackets grow one above the other. On the ground, when viewed from above, the conk is circular in shape, sunken in the center, and tapering to a short, thick stalk. When fresh the upper surface is velvety, concentrically zoned, and reddish brown, with a light yellow-brown margin. The undersurface is dirty green and turns red brown when bruised. The conspicuous pores on the undersurface are irregular in shape. The substance of the conk is moist and cheesy. When old and dried, the conks become corky and have a deep red-brown or blackish brown color. Swollen and punky knots are not developed.

While the conks are a positive indication of red-brown butt rot, they are to be found only on a small minority of the infected trees. The next best clue to the presence of this decay is fire scars. The majority of fire-scarred trees become infected through the scar; therefore it is possible to judge the relative amount of decay by the number of such trees in the stand after the presence of conks has revealed the existence of this rot in the locality. Each fire-scarred tree can be considered as infected. Even though a scar has been healed over for a long time, it can often be detected by the difference in the appearance of the bark over the healed wound, which is hard to describe but not difficult to distinguish after a little experience. Swollen or churn butts usually indicate a fire scar or other wound long since healed. In cruising timber, culling 8 feet of the butt log usually is a sufficient allowance for this defect. If a butt scar is plainly visible, the rot can be considered as extending about 2 feet higher than the scar and the entire trunk culled from ground level to that height.

### YELLOW-BROWN TOP ROT

Yellow-brown top rot, also known as brown pocket rot, caused by the rose-colored conk, *Fomes roseus* (Alb. and Schw.) Cke., occurs much more frequently on down, dead trees than it does on living ones. The first indication of the rot is a faint brownish or yellowish brown color, the outer limit of which is sometimes marked by a zone of greenish brown discoloration. The yellowish brown color deepens and the wood becomes soft. The incipient decay extends on an average about 3 feet beyond the advanced decay, but in exceptional cases it may extend 25 feet. The advanced decay is a yellow-brown crumbly rot with mycelium felts much less conspicuous than those of brown trunk rot. (Pl. 8, A.)

Normally the rot occurs in the upper part of the trunk or in the top beyond the merchantable limit; consequently, it is not economically so important as the others thus far discussed, for when it does destroy merchantable volume the lower quality top logs are the ones that suffer most. The rot column is roughly cylindrical, following the shape of the heartwood, and tapers conelike at the ends. Seen as a cross section at the ends of logs, the rot is circular in area.

The perennial, bracketlike conks, ranging up to 6 inches or so in width, are readily recognized by the delicate rose color and small regular pores of the undersurface. The upper surface is hard, rough, zoned, and black, as illustrated in Plate 8, A. No swollen or punk knots are associated with this decay.

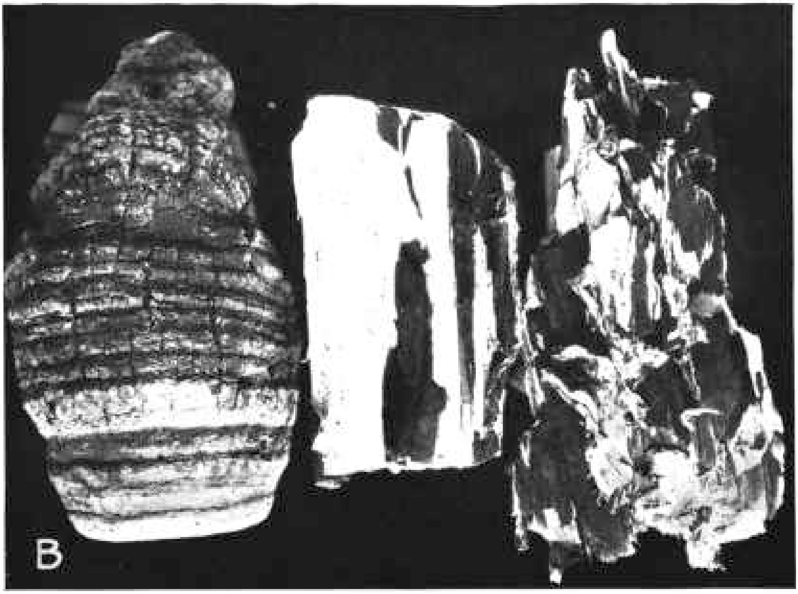
Yellow-brown top rot is very difficult to detect in standing timber. Although conks are not uncommon, they are so high up in the trees as to be easily overlooked, and are often completely hidden by the branches. The decay enters through the stubs of dead branches, dead tops, and wounds. Consequently, spike-topped trees are often infected.

### BROWN TRUNK ROT

Brown trunk rot, also known as reddish brown rot and brown heartwood rot, is caused by the quinine fungus, *Fomes laricis* (Jacq.) Murr. The incipient rot is difficult to detect, since it first appears as an extremely faint, barely discernible brownish discoloration, scarcely contrasting with the normal reddish or orange-reddish color of the heartwood. It is preceded by a hidden stage which extends for several inches beyond the last visible discoloration. As the discoloration becomes more pronounced the wood becomes softer. Rarely the incipient stage appears to be indicated by a brilliant and intense purplish discoloration. It was found that incipient rot might extend 8.5 feet beyond the advanced decay, but the average was 3.6 feet. The wood is seriously weakened, even in the hidden stage of the rot.

In the advanced stage the wood is a brown mass, easily crumbled between the fingers. In shrinking it is more or less separated by cracks into irregular cubes. The cracks may be occupied by the conspicuous white mycelium felts. (Pl. 8, B.) These felts may completely fill large cracks or old wind-shakes, becoming a quarter of an inch thick, a foot or more wide, and several feet long. The decay is not confined to any particular portion of the bole. Where it runs out, the rot column is roughly conical, elsewhere it is more

Conks of the velvet-top fungus, *Polyporus schweinitzii*, causing red-brown butt rot, on the ground near the base of an infected Douglas fir. Conks of this type vary from a few inches to a foot or more in diameter. (Photograph by Henry J. Rust)



A, Cross section of the decayed top from a living tree showing yellow-brown top rot caused by rose-colored conk, *Fomes roseus*, and the upper surface of a conk. Diameter inside bark of the section is 3.5 inches; B, decayed wood showing the white mycelium felts and an old chalky conk of brown trunk rot caused by the quinine fungus, *F. laricis*. (Photograph by E. E. Hubert)

Conks of brown cubical rot caused by the sulphur fungus, *Polyporus sulphureus*, on the butt of a dead white fir. (Photograph by Henry J. Rust)


A, Cull logs left in the woods. (Photograph by A. H. Hodgson); B, a greatly overmature, highly defective stand in the Douglas fir type. (Photograph by G. A. Bright.) Most of the defect in both cases is red ring rot caused by the ring-scale fungus, *Trametes pini*

Douglas firs left standing on a logging operation because presumably decayed. Later when a railroad right of way was cut through this stand a large percentage of merchantable volume was found or less cylindrical. Seen on the ends of logs, the rot is usually somewhat circular in outline. In the advanced stage, shrinkage cracks are common along the annual rings and at right angles to them. Often these cracks are filled with the conspicuous mycelium felts.

The quinine fungus has large, whitish, perennial conks not common on living trees. They are either roughly hoof shaped or long and narrow. The substance of the conk is white, soft, and cheesy when young, and rather crumbly and chalky when old and dry. An old conk is depicted in Plate 8, B. The upper surface is chalky white or brownish, rough, and zoned, while the undersurface is white and has small pores. The conks issue through knots or old wounds. This decay forms no swollen or punky knots.

On the whole, it is not easy to judge brown trunk rot in standing timber. Since conks are developed only occasionally and only after decay has become extensive, a tree with a single conk must be considered unmerchantable. Broken tops are a common point of entrance for this decay; consequently, in a stand where the presence of conks has shown the decay to occur, broken-topped trees are probably infected. The trunks must be closely scanned for large broken-off branches in which the decay can be seen, for a branch with decayed heartwood indicates extensive rot in the trunk. Stands so much overmature that they are being replaced by hemlock are particularly subject to brown trunk rot. It seldom causes loss of consequence in other than very overmature timber.

### BROWN CUBICAL ROT

The sulphur fungus, *Polyporus sulphureus* (Bull.) Fr., causes brown cubical rot, also called brown-checked wood rot. It is very difficult or impossible to distinguish this decay from brown trunk rot, although it usually starts in the butt of the tree, entering through an old wound, and normally does not extend above the lower half of the trunk. The conks, shown in Plate 9, are annual, mostly appearing in the summer or fall after a rain, and develop in clusters of large, flat shelves. They are soft, juicy, and cheesy, without any bitter taste. The upper surface is orange yellow and smooth; the smooth underside is a brilliant sulphur yellow. The pores are small. The conks are often partly eaten by rodents. When the conks dry up they commonly turn chalky white, or occasionally dirty yellow, and become brittle. No swollen or punky knots have been associated with this fungus.

### PITTED SAP ROT

Pitted sap rot, which is very common in the sapwood of dead timber, occasionally occurs on the dead sapwood of basal wounds, particularly fire scars, on living trees. It is caused by the purple fungus, *Polystictus abietinus* (Dicks.) Fr. The rot first appears as a faint yellowish tan color and is accompanied by a softening of the wood. Next, the outlines of small white pockets become visible. In the advanced stage these pockets, which are elongated parallel to the grain, are at first filled with whitish fibers, but later become empty. They are separated by strips of apparently sound wood. The pitted sap rot is confined to the dead sapwood around scars, usually fire scars, on the butts of trees. It causes little loss, since most of the affected sapwood forms part of the butt swell and slabs out in sawing.

The thin, bracket-shaped annual conks are small, with a grayish white, hairy, zoned upper surface, becoming dirty white with age. The purplish lower surface has conspicuous, irregular pores which sometimes become broken up so that the lower surface appears toothed. Aside from the conks, there are no reliable indications of this rot except the presence of fire scars. It is not found so often on mature or overmature trees as on trees in second-growth stands swept by ground fires.

### SPONGY SAP ROT

The conifer root fungus, *Fomes annosus* (Fr.) Cke., causes spongy sap rot. The incipient rot is indicated by a reddish or violet color of the affected wood. The advanced decay is characterized by small white cellulose pockets following the grain of the wood and similar to the pockets of red ring rot. These pockets frequently run together, resulting in masses of moist, spongy, white fibers. Throughout the spongy masses, or in the pockets, occasional black flecks can be seen. The rot is confined to the roots and butt of the tree, rarely extending more than 2 to 4 feet high. It may occur in either heartwood or sapwood.

The perennial conks vary from bracketlike to almost crustlike form. The upper surface is zoned and of a gray-brown color. The undersurface is yellowish white and has numerous small pores. The conks are found in the root crotches or on exposed roots, often partially covered by duff; hence they are easily overlooked.

### ENTRANCE OF ROT

In a previous study (*4, p. 7–10*) it was shown that knots or branch stubs were the means of entrance for 89.2 per cent of the decay by board-foot volume, while dead tops and scars of various kinds accounted for most of the remainder. Among the scars, those caused by fire were responsible for 4.2 per cent of the total rot, and are the only type of scar that can be prevented to some degree. This can be done by more efficient fire protection. It was concluded that reducing the scars caused by controllable mechanical injuries could cause little reduction in the amount of rot.

The present study, in which it was not possible to dissect the trees, largely corroborated the previous conclusions. However, it becomes increasingly apparent that fire scars, which can be controlled to some extent, are of more importance than is indicated by the actual volume of decay for which they are responsible, for the decay is largely butt rot, destroying part of the valuable butt log, which becomes relatively more valuable as the size of the timber decreases. Butt rot also predisposes trees to windfall, particularly if it affects their roots.

### IMPORTANCE OF ROTS

The loss through decay amounted to 16.99 per cent of the board feet measured, while the loss from all other causes combined was only 10.78 per cent, as can be seen from Table 2. Red ring rot is by far the most important of the various decays; this is shown more clearly by Table 8, in which the total percentage of rot in board and cubic feet in Table 2 is taken as 100 per cent. This shows that red ring rot comprised 80.8 per cent of all the decay in board feet, brown trunk rot coming next with only 8.6 per cent, closely followed by red-brown butt rot with 6.2 per cent and yellow-brown top rot with 4.1 per cent, while pitted sap rot, spongy sap rot, brown cubical rot, and unknown rots were practically negligible, so that subsequently in this bulletin they will be combined and listed as "other rots."

TABLE 8.—*Relative importance of the different rots in Douglas fir*

| Type of rot | Total rot in— | |
|---|---|---|
| | Board-foot volume | Cubic-foot volume |
| | *Per cent* | *Per cent* |
| Red ring rot (Trametes pini) | 80.8 | 79.2 |
| Brown trunk rot (Fomes laricis) | 8.6 | 8.4 |
| Red-brown butt rot (Polyporus schweinitzii) | 6.2 | 7.9 |
| Yellow-brown top rot (Fomes roseus) | 4.1 | 4.0 |
| Pitted sap rot (Polystictus abietinus) | .1 | .2 |
| Spongy sap rot (Fomes annosus) | .1 | .1 |
| Brown cubical rot (Polyporus sulphureus) | 0 | Trace.[1] |
| Unknown rots | .1 | .1 |

[1] Trace means that percentage of rot was less than 0.01.

In scaling out decay in board feet, the Forest Service regulations for this region were followed. All logs decayed 66⅔ per cent or more were classed as totally unmerchantable. On the other hand, the actual cubic-foot volume of rot was figured, and the remaining volume in the section, no matter how small, was considered sound, which accounts for the much higher percentage of decay in board-foot volume than in cubic-foot volume. In other words, the cubic-foot figure is an exact measure of the actual volume of decayed wood, but the board-foot figure is a measure of the volume rendered unmerchantable by decay, according to present Forest Service scaling practice. In neither board-foot nor cubic-foot measurement was the incipient decay of red ring rot included with the volume of decay, because wood so affected is quite satisfactory for lower grades of lumber. Although there is an appreciable loss in quality by degrading because of incipient red ring rot, no study has been made of the amount of this loss. For the other rots, wood in the incipient stage of decay was included in the volume of decayed wood.

The distribution of the four important rots in the different plots is given in Table 9, in which the plots have been grouped by sites and arranged chronologically by ages. The greatest loss through decay amounted to 54.8 per cent of the board-feet volume on plot 38, an enormous loss when it is remembered that this plot represents a stand covering hundreds of acres. Plate 10, A, which while not a photograph taken on plot 38, was taken on another portion of the same logging operation and in a stand of the same character, illustrates the large number of cull logs in such a highly defective stand. Plate 10, B, represents this type of stand before logging. The highest loss through red ring rot was 50.7 per cent in the same plot; through butt rot, 4.1 per cent, in plot 9; through top rot, 6 per cent, in plot 36; and through trunk rot, 9.7 per cent, in plot 37. The loss caused by all other rots combined was appreciable in only two plots, Nos. 24 and 5, being 0.7 per cent in each case. In plot 5, supporting a stand which had suffered from a ground fire which had fire-scarred many trees, pitted sap rot was responsible. In plot 24, spongy rot was the cause. Seldom did loss from any of the other decays exceed that from red ring rot.

**Table 9.**—*Rot in Douglas firs of merchantable size by plots on Sites I, II, and III, based on gross board-foot and cubic-foot volumes per acre*

| Plot No. | Average age | Percentage of rot[1] in— Board-foot volume: Red ring rot | Butt rot | Top rot | Trunk rot | Other rot | Total rot | Cubic-foot volume: Red ring rot | Butt rot | Top rot | Trunk rot | Other rot | Total rot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| **SITE I** | | | | | | | | | | | | | |
| | *Years* | | | | | | | | | | | | |
| 15 | 204 | 0 | 0.1 | Tr. | Tr. | 0 | 0.2 | 0 | 0.1 | Tr. | Tr. | 0 | 0.1 |
| 10 | 232 | 6.6 | .1 | 0 | 0.3 | 0 | 7.0 | 3.5 | .1 | 0 | 0.1 | 0 | 3.7 |
| 18 | 333 | 7.2 | .9 | 1.2 | 2.9 | 0 | 12.2 | 4.6 | .7 | .7 | 1.7 | 0 | 7.7 |
| 21 | 340 | 27.6 | .6 | 0 | 1.1 | .1 | 29.4 | 15.8 | .6 | 0 | .6 | .2 | 17.2 |
| 28 | 412 | 24.0 | 3.0 | 1.2 | 1.8 | Tr. | 30.0 | 12.4 | 2.6 | .8 | 1.1 | Tr. | 16.9 |
| Total or average | 304 | 13.1 | .9 | .5 | 1.2 | Tr. | 15.7 | 7.3 | .8 | .3 | .7 | .04 | 9.1 |
| **SITE II** | | | | | | | | | | | | | |
| 11 | 64 | 0 | 0 | 0 | 0 | Tr. | Tr. | 0 | Tr. | 0 | 0 | Tr. | Tr. |
| 32 | 94 | .4 | .5 | Tr. | 0 | 0 | 0.9 | .3 | 0.3 | Tr. | 0 | 0 | 0.6 |
| 6 | 112 | .1 | .1 | Tr. | 0 | 0 | .2 | .1 | .1 | Tr. | 0 | 0 | .2 |
| 33 | 122 | 1.7 | .3 | .9 | 0 | 0 | 2.9 | .7 | .2 | .4 | 0 | 0 | 1.3 |
| 8 | 158 | 3.5 | .1 | .1 | .6 | Tr. | 4.3 | 1.5 | .1 | .1 | .4 | Tr. | 2.1 |
| 26 | 183 | 10.7 | .6 | .1 | 3.1 | Tr. | 14.5 | 5.7 | .4 | Tr. | 1.2 | Tr. | 7.3 |
| 14 | 197 | 4.1 | Tr. | 0 | 0 | 0 | 4.1 | 2.4 | Tr. | 0 | 0 | 0 | 2.4 |
| 7 | 198 | 5.3 | Tr. | .6 | .9 | 0 | 6.8 | 3.0 | Tr. | .2 | .4 | 0 | 3.6 |
| 12 | 237 | 16.5 | .6 | .2 | .4 | .2 | 17.9 | 9.6 | .5 | .1 | .2 | .2 | 10.6 |
| 16 | 238 | 0 | 1.2 | .1 | .3 | 0 | 1.6 | 0 | .7 | .1 | .2 | 0 | 1.0 |
| 27 | 243 | 7.6 | .3 | Tr. | .1 | 0 | 8.0 | 4.4 | .2 | Tr. | .1 | 0 | 4.7 |
| 35 | 245 | 3.4 | 0 | .1 | 0 | 0 | 3.5 | 1.8 | 0 | .1 | 0 | 0 | 1.9 |
| 25 | 245 | 27.5 | .5 | .2 | 1.6 | 0 | 29.8 | 15.7 | .3 | .1 | .8 | 0 | 16.9 |
| 17 | 245 | 0 | .1 | 0 | .1 | 0 | .2 | 0 | .1 | 0 | Tr. | 0 | .1 |
| 36 | 258 | 13.1 | .6 | 6.0 | 2.6 | .2 | 22.5 | 6.2 | .5 | 3.5 | 1.3 | .1 | 11.6 |
| 30 | 289 | 1.9 | 1.1 | .5 | 0 | 0 | 3.5 | 1.2 | .7 | .4 | 0 | 0 | 2.3 |
| 24 | 309 | 13.2 | .7 | 0 | 1.4 | .7 | 16.0 | 7.0 | .5 | 0 | .7 | .3 | 8.5 |
| 22 | 316 | 23.7 | .1 | .1 | Tr. | .1 | 24.0 | 13.8 | .1 | Tr. | Tr. | Tr. | 13.9 |
| 38 | 319 | 50.7 | .5 | 2.5 | 1.1 | 0 | 54.8 | 29.9 | .3 | 1.3 | .7 | 0 | 32.2 |
| 37 | 322 | 33.4 | 1.6 | .8 | 9.7 | Tr. | 45.5 | 18.9 | 1.7 | .5 | 5.6 | .1 | 26.8 |
| 31 | 333 | 21.7 | .3 | .1 | .2 | 0 | 22.3 | 13.2 | .2 | .1 | .1 | 0 | 13.6 |
| 13 | 345 | 6.6 | 1.4 | Tr. | 5.7 | 0 | 13.7 | 3.7 | 1.1 | Tr. | 3.3 | 0 | 8.1 |
| 20 | 349 | 9.5 | 2.1 | .6 | .3 | 0 | 12.5 | 5.2 | 1.3 | .3 | .2 | 0 | 7.0 |
| 34 | 383 | 4.7 | 1.5 | 3.9 | 1.9 | 0 | 12.0 | 3.1 | 1.2 | 2.1 | 1.3 | 0 | 7.7 |
| 23 | 404 | 25.2 | 1.7 | 1.1 | 2.9 | 0 | 30.9 | 13.9 | 1.1 | .6 | 1.8 | .1 | 17.5 |
| 19 | 559 | .8 | 3.1 | 3.2 | 1.1 | 0 | 8.2 | .4 | 2.1 | 2.0 | .6 | 0 | 5.1 |
| Total or average | 260 | 11.0 | .7 | .8 | 1.3 | Tr. | 13.8 | 6.2 | .5 | .5 | .7 | Tr. | 7.9 |
| **SITE III** | | | | | | | | | | | | | |
| 4 | 66 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 103 | 0 | 1.8 | .1 | 1.2 | .1 | 3.2 | 0 | .9 | Tr. | .4 | Tr. | 1.3 |
| 2 | 114 | 4.0 | 2.1 | .1 | 2.5 | 0 | 8.7 | 2.0 | .8 | Tr. | 1.0 | 0 | 3.8 |
| 5 | 116 | .5 | .7 | .2 | .2 | .7 | 2.3 | .3 | .4 | .1 | .1 | .7 | 1.6 |
| 29 | 145 | 5.6 | .6 | 0 | 0 | 0 | 6.2 | 3.0 | .4 | Tr. | 0 | Tr. | 3.4 |
| 3 | 149 | 3.6 | 1.2 | Tr. | .5 | .1 | 5.4 | 2.4 | .6 | Tr. | .2 | .1 | 3.3 |
| 9 | 400 | .6 | 4.1 | .2 | .2 | .1 | 5.2 | .4 | 2.7 | .1 | .1 | .1 | 3.4 |
| Total or average | 156 | 2.0 | 1.5 | .1 | .7 | .1 | 4.4 | 1.1 | .8 | Tr. | .3 | .1 | 2.3 |

[1] Trace (Tr.) means that percentage of rot was less than 0.01.

## AGE AT WHICH INFECTION OCCURS

In this study it was, of course, impossible to determine the earliest age at which Douglas fir became infected with any decay, since for this purpose it would have been necessary not only to fell but to split open a large number of young trees. Where the trees are cut into log lengths but not opened up farther, it is not possible to find very small infections. Table 10 shows the youngest tree with measurable loss caused by each type of rot. From this it can be seen that decay may appear in individual trees rather early in the life of the stand. The first measurable loss was caused by butt rot in a tree 73 years old, and the original data showed that butt rot was first found in a 63-year-old tree, though in negligible quantity. Top rot and red ring rot both appeared in trees less than 100 years old, but trunk rot caused loss first in a 146-year-old tree. It was apparent throughout the study that trunk rot did not appear until later in the life of the stand than the other three decays.

TABLE 10.—*Youngest trees on the plots with actual loss in board-foot volume caused by the important rots*

| Age (years) | Diameter breast high | Height | Gross volume of tree in— | | Rot in— | | Type of rot |
|---|---|---|---|---|---|---|---|
| | | | Board feet | Cubic feet | Board-foot volume | Cubic-foot volume | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| | *Inches* | *Feet* | | | *Per cent* | *Per cent* | |
| 73 | 20.0 | 120.1 | 370 | 87 | 5.4 | 3.2 | Butt rot. |
| 76 | 21.2 | 137.3 | 670 | 126 | 1.5 | .4 | Top rot. |
| 91 | 8.0 | 61.1 | 20 | 5 | 100.0 | 61.4 | Red ring rot. |
| 146 | 35.4 | 150.2 | 1,250 | 240 | 12.8 | 4.3 | Trunk rot. |

Red ring rot may appear in individual trees much younger than those found infected on these plots. Near Salem, Oreg., extensive decay from this cause was found in a small suppressed Douglas fir [5] 4 inches in diameter at breast height and 24 years old at stump height, 1 foot above the ground, or 27 years old at ground level, as calculated by means of a seedling height curve. The tree had died from the effects of suppression not more than two years prior to its inspection. The heartwood was decayed throughout its length. Four small sporophores or conks occurred along the bole. Since decay had progressed so far before the tree died at an age of 27 years, infection must have occurred some years previously.

## RELATION OF ROT TO AGE AND SITE

From the practical standpoint the age at which decay begins in individual trees is of little consequence, but the age at which the stand becomes appreciably affected by decay, and the rate at which loss by decay increases during the life of the stand are of paramount

[5] Data on this tree furnished by T. W. Childs.

importance to proper management. It is well known that young stands are practically free from decay and that old stands may be heavily infected, but beyond this vague generality no exact information has been available. Furthermore, nothing has been known concerning the influence of site on decay. Theoretically, the most defective timber would be expected to occur on the poorest site, where growth is slowest, since Meinecke (*17, p. 47*) has shown that suppressed trees of white fir, *Abies concolor* (Gord.) A. Murray, are subject to decay at an earlier age than dominants; and it has been found in the case of incense cedar, *Libocedrus decurrens* Torr., that the slower growing trees outside the optimum range suffer more from decay than the faster growing trees within the optimum (*2, p. 28*).

Decay is shown in Table 9 for the plots arranged chronologically by ages for Sites I, II, and III. On Site I it can be seen that the percentage of decay increases very definitely with increasing age. This is also true for Site II, but is not so apparent, because of the great variation in individual plots. It is quite evident that stands may attain a considerable age with little or no loss from decay—for example, plot 16, age 238 years, with 1.6 per cent of rot in the board-foot volume; plot 17, age 245 years, with 0.2 per cent of rot; and plot 30, age 289 years, with 3.5 per cent. On the other hand, loss at the same ages may be heavy, as is shown by plot 25, age 245 years, with 29.8 per cent of rot in the board-foot volume. There is no explanation of why certain stands may attain old age with little rot. All stands have ample opportunity for infection, since red ring rot, which produces conks so abundantly, is present everywhere. Plot 9, age 400 years, is a good example. It had a loss of only 5.2 per cent from decay, 4.1 per cent of the loss being caused by butt rot and only 0.6 per cent by red ring rot. Nevertheless this stand was in a locality where heavy losses from red ring rot were the rule, and it was situated close to highly defective stands. Of two old trees standing side by side with apparently equal chances to become infected, one may be sound and the other badly decayed. Whether the difference is due to mere chance, or to one tree possessing some inherent resistance to wood-destroying fungi, is problematical. When this speculation is carried on to consideration of whole stands the question becomes even more complex.

In order to bring out more clearly the relation of decay to age on Site II the plots are grouped in 50-year age classes in Table 11. This demonstrates the decided increase in the amount of decay up to and including the 301 to 350 year age class. Beyond that age class the data become irregular, owing to the fact that each class is based on only one plot; and, as has been pointed out before, occasional stands may reach old age with very little loss from rot. Probably there is some further explanation for the low figure of 8.2 per cent of decay in board-foot volume in the 559-year-old plot representing the last age class. It is known that if a Douglas fir stand is allowed to round out its life undisturbed by fire, lumbering, or any other destructive force, as the older trees die their places are taken mostly by western hemlock, *Tsuga heterophylla*, so that ultimately the final stand becomes predominantly hemlock. This breaking up may begin as early as after 350 years, and a Douglas fir stand more than 600 years old which has not broken up completely is rare. It is reasonable to believe that the majority of the first trees to go would be badly decayed individuals, which, if nothing else, are more subject to wind throw than are sound trees. Thus, when a stand is breaking up there is a strong possibility that the percentage of decay in the Douglas firs might actually decrease, since the dropping out of the decadent individuals might more than offset the increase in decay among the survivors. This 559-year-old plot represented such a stand, and by referring to Table 1 it is seen that Douglas fir of merchantable size comprised only 72.7 per cent of the entire stand measured in board feet, and the remainder was young western hemlock. It was not feasible, however, to study any more plots representative of such stands and to determine whether the percentage of decay actually does decrease with extreme age in the Douglas fir.

TABLE 11.—*Rot in Douglas firs of merchantable size by plots on Site II, grouped in 50-year age classes, based on gross board-foot and cubic-foot volumes per acre*

| Age class (years) | Average age | Percentage of rot [1] in— | | | | | | | | | | | | Plots (basis) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Board-foot volume | | | | | | Cubic-foot volume | | | | | | |
| | | Red ring rot | Butt rot | Top rot | Trunk rot | Other rot | Total rot | Red ring rot | Butt rot | Top rot | Trunk rot | Other rot | Total rot | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| | *Years* | | | | | | | | | | | | | *Number* |
| 51 to 100 | 79 | 0.2 | 0.3 | Tr. | 0 | Tr. | 0.5 | 0.2 | 0.2 | Tr. | 0 | Tr. | 0.4 | 2 |
| 101 to 150 | 117 | .9 | .2 | 0.5 | 0 | 0 | 1.6 | .4 | .2 | 0.2 | 0 | 0 | .8 | 2 |
| 151 to 200 | 184 | 5.9 | .2 | .2 | 1.2 | Tr. | 7.5 | 3.2 | .1 | .1 | 0.5 | Tr. | 3.9 | 4 |
| 201 to 250 | 242 | 9.2 | .5 | .1 | .4 | Tr. | 10.2 | 5.3 | .3 | .1 | .2 | Tr. | 5.9 | 6 |
| 251 to 300 | 274 | 7.5 | .9 | 3.3 | 1.3 | .1 | 13.1 | 3.7 | .6 | 2 | .7 | Tr. | 7 | 2 |
| 301 to 350 | 328 | 22.7 | 1 | .6 | 2.3 | .1 | 26.7 | 13.1 | .7 | .3 | 1.5 | 0.1 | 15.7 | 7 |
| 351 to 400 | 383 | 4.7 | 1.5 | 3.9 | 1.9 | 0 | 12 | 3.1 | 1.2 | 2.1 | 1.3 | 0 | 7.7 | 1 |
| 401 to 450 | 404 | 25.2 | 1.7 | 1.1 | 2.9 | 0 | 30.9 | 13.9 | 1.1 | .6 | 1.8 | .1 | 17.5 | 1 |
| 551 to 600 | 559 | .8 | 3.1 | 3.2 | 1.1 | 0 | 8.2 | .4 | 2.1 | 2 | .6 | 0 | 5.1 | 1 |
| Total or average. | 260 | 11 | .7 | .8 | 1.3 | Tr. | 13.8 | 6.2 | .5 | .5 | .7 | Tr. | 7.9 | 26 |

[1] Trace (Tr.) means that percentage of rot was less than 0.01.

In order to provide an adequate means of determining the relation between age and decay, and to evaluate properly the relation between site and decay, the data for Site II in Table 11 are shown for both board and cubic feet in Figure 9. The numbers of plots on Sites I and III were not sufficient to warrant the presentation of curves for these sites. The reason for the small numbers of plots on Sites I and III is obvious. Site I, representing the best and usually the most accessible stands of Douglas fir, had been largely cut off, even on private holdings, at the time this study was made, while the poorer stands on Site III had not been reached to any extent, so that most of the logging was under way on Site II.

In addition to knowing the average conditions of decay on a site, it is also essential to know the worst conditions that may be encountered. For this reason a curve of maximum decay was drawn, based on the most highly defective plots, all of which were on Site II; that is, plot 26 with 14.5 per cent of decay in board-foot volume at 183 years, plot 25 with 29.8 per cent at 245 years, and plot 38 with 54.8 per cent at 319 years. This is the curve marked maximum.

The curves for percentage of average decay in board and cubic foot volumes in Figure 9 have been carried to 450 years, but the curves for maximum decay have been extended only 350 years, since there is no guide for them in the older ages. The average age of the

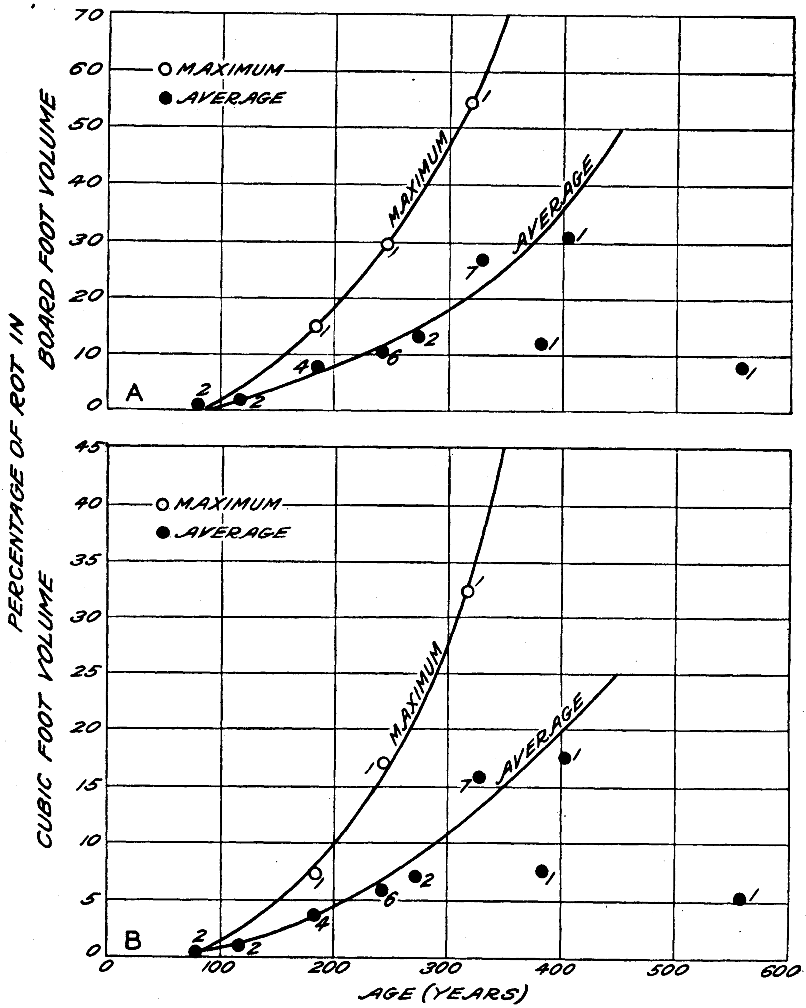



FIGURE 9.—Percentage of rot in relation to age of Douglas firs of merchantable size on Site II based on gross volume per acre: A, Board feet (Scribner Decimal C rule); B, cubic feet

oldest plot is 559 years, but there are no plots between 404 and 559 years. Furthermore, as was pointed out, the Douglas fir stand as represented by this 559-year-old plot on Site II had already broken up to a considerable extent, which fact might result in lowering the percentage of decay, but no other stands of this character were studied in detail, so it was impossible to consider the influence of this one plot on the curve. Comparing the curves for the average percentage of rot on Site II with the data given in Table 9 for the percentage of rot for the plots on Site I, it is seen that stands of which the three youngest plots are representative have less decay than average stands on Site II at the same age. Unfortunately the youngest plot on Site I was 204 years old, so that no comparison can be made for younger ages. Comparing in the same way the percentage of rot for the plots on Site III, it shows that these plots have more decay than average stands of the same age on Site II up to 150 years. It is the cubic-foot figures that are most important, since they are an exact, not a relative, measure of the volume of decayed wood. There is only one plot on Site III older than 150 years, and it has a low percentage of rot. These fragmentary data are not sufficient to permit of a definite conclusion as to the incidence of decay in relation to site, although they seem to indicate that in younger ages rot is of least consequence on Site I and is more serious on Site III than on Site II. For reasons previously given there are no plots on Sites IV and V. It is significant that the youngest trees with actual loss in board-foot volume from the four principal rots, as shown in Table 10, were all on Site III. Möller (*20, p. 200*), who has extensively investigated red ring rot in stands of Scotch pine, *Pinus sylvestris* L., in Germany, concludes that there is no significant difference in the amount of decay on the five sites.

From these curves the correlation of the increase in decay and the increase in age stands forth clearly; but while this in itself is important, the relation between the increment in gross volume and the increment in decay is more significant. In other words, at what age does the stand decay as fast as it grows? The answer to this has been worked out in Tables 12 and 13 for Site II in board and cubic feet by 50-year periods. A word of explanation as to the derivation of these tables should be given. In Table 12, for example, the gross volume per acre in board feet at 50-year intervals is read from the volume curve in Figure 3. The gross increment per acre in column 4 is obtained by subtraction of the gross volume in column 2 by 50-year periods. The percentage of rot in column 6 is read from the curve of average rot percentage for Site II in Figure 9. The volume of rot per acre in column 3 is secured by multiplying the gross volume per acre in column 2 by the corresponding percentage of rot in column 6. The rot increment per acre is again a simple subtraction. Now, by comparing gross increment per acre with rot increment, it is seen that the former keeps well ahead of the latter until somewhere between 300 and 350 years, when decay increment equals gross increment, and from then on exceeds it. That is, from that time on the Douglas fir stand decays faster than it grows. Curves showing rot increment and gross increment with relation to age demonstrate that rot increment equals gross increment at approximately 300 years, as stated in footnote 1 of Table 12. For the sake of brevity these curves are omitted.

TABLE 12.—*Periodic increment in average gross volume and average rot volume per acre for Douglas fir on Site II*

BOARD FEET [1]

| Age (years) | Gross volume | Rot volume | Gross increment | Rot increment | Percentage of rot |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| 50 | 20,000 | 0 | 20,000 | 0 | 0 |
| 100 | 69,000 | 690 | 49,000 | 690 | 1 |
| 150 | 110,000 | 4,400 | 41,000 | 3,710 | 4 |
| 200 | 136,000 | 10,470 | 26,000 | 6,070 | 7.7 |
| 250 | 158,000 | 19,120 | 22,000 | 8,650 | 12.1 |
| 300 | 174,000 | 31,500 | 16,000 | 12,380 | 18.1 |
| 350 | 186,000 | 47,620 | 12,000 | 16,120 | 25.6 |
| 400 | 196,000 | 69,970 | 10,000 | 22,350 | 35.7 |
| 450 | 203,000 | 101,500 | 7,000 | 31,530 | 50.0 |
| **CUBIC FEET [2]** | | | | | |
| 50 | 3,900 | 0 | 3,900 | 0 | 0 |
| 100 | 12,200 | 70 | 8,300 | 70 | .6 |
| 150 | 17,500 | 380 | 5,300 | 310 | 2.2 |
| 200 | 21,100 | 930 | 3,600 | 550 | 4.4 |
| 250 | 23,850 | 1,760 | 2,750 | 830 | 7.4 |
| 300 | 26,000 | 2,830 | 2,150 | 1,070 | 10.9 |
| 350 | 27,700 | 4,160 | 1,700 | 1,330 | 15.0 |
| 400 | 28,900 | 5,690 | 1,200 | 1,530 | 19.7 |
| 450 | 29,600 | 7,400 | 700 | 1,710 | 25.0 |

[1] Rot increment equals gross increment at approximately 300 years.
[2] Rot increment equals gross increment at approximately 345 years.

TABLE 13.—*Periodic increment in average gross volume and maximum rot volume per acre for Douglas fir on Site II*

BOARD FEET [1]

| Age (years) | Gross volume | Rot volume | Gross increment | Rot increment | Percentage of rot |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| 50 | 20,000 | 0 | 20,000 | 0 | 0 |
| 100 | 69,000 | 1,100 | 49,000 | 1,100 | 1.6 |
| 150 | 110,000 | 9,460 | 41,000 | 8,360 | 8.6 |
| 200 | 136,000 | 24,620 | 26,000 | 15,160 | 18.1 |
| 250 | 158,000 | 48,510 | 22,000 | 23,890 | 30.7 |
| 300 | 174,000 | 81,610 | 16,000 | 33,100 | 46.9 |
| 350 | 186,000 | 130,200 | 12,000 | 48,590 | 70.0 |
| **CUBIC FEET [2]** | | | | | |
| 50 | 3,900 | 0 | 3,900 | 0 | 0 |
| 100 | 12,200 | 150 | 8,300 | 150 | 1.2 |
| 150 | 17,500 | 820 | 5,300 | 670 | 4.7 |
| 200 | 21,100 | 2,070 | 3,600 | 1,250 | 9.8 |
| 250 | 23,850 | 3,940 | 2,750 | 1,870 | 16.5 |
| 300 | 26,000 | 6,990 | 2,150 | 3,050 | 26.9 |
| 350 | 27,700 | 12,460 | 1,700 | 5,470 | 45.0 |

[1] Rot increment equals gross increment at approximately 215 years.
[2] Rot increment equals gross increment at approximately 250 years.

From Tables 12 and 13 it is evident that under the very worst conditions, as shown by Table 13, which is based on the maximum increase in decay found on Site II, Douglas fir stands on Site II will not decay faster than they grow in board feet until the age of about 215 years is reached, and under average conditions until they are about 300 years of age. Of course, when measuring volumes in cubic feet this point is attained considerably later in the life of the stand. This means that in the future Douglas fir can be grown on Site II with little resultant loss from decay, since it is not likely that the rotation will exceed 110 years on the national forests, except for occasional stands, and it probably will fall several decades lower on private lands as a rule. At 110 years the maximum loss shown in Figure 9 is 2.8 per cent, based on gross board-foot volume per acre. The large amount of decay in Douglas fir at present is confined to badly overmature stands, an example of which is pictured in Plate 10, B, and is the accumulated result of centuries of unregulated growth.

The idea that decay in Douglas fir works very rapidly is prevalent throughout this region. In fact, it has been suggested that the loss might mount as high as 5 per cent a year, and 2 or 3 per cent is not an uncommon estimate (*26*). Tables 12 and 13 give no support to such estimates. For Site II with maximum rot the most rapid increase in decay amounts to 23.1 per cent of the gross volume in board feet between 300 and 350 years, or 0.46 per cent a year. And for Site II with average rot it is only 0.29 per cent a year between 400 and 450 years. Of course, when a stand reaches the age at which it breaks up, the rate of loss is undoubtedly more rapid than anything shown by these figures, but under such conditions sound or relatively sound trees drop out, along with the highly defective, so that the loss can not all be charged against decay. It was not possible to study enough stands in the process of breaking up to determine the rate of loss in volume of the Douglas fir during such a period.

In forestry literature dealing with regulation and yield, there is found the statement—it might almost be termed an axiom—that in virgin mature and overmature stands decay (or deterioration may be the term used) is balanced by growth. This aphorism has never been supported by exact data. To anyone familiar with the Douglas fir stands of the Pacific Northwest, observation would indicate that in many overmature stands decay alone, to say nothing of the continual dropping out of large individual trees, would result in a net loss in increment for a considerable period. In the case of Douglas fir stands, not only the Douglas firs but also the associated species must be included in calculations of increment.

Accordingly, in Table 14 the gross volume per acre of trees of all species 12 inches and larger in diameter breast high for the Site II plots has been computed in board and cubic feet and averaged by 50-year age classes. The percentage of rot in board and cubic feet is also given. The average age for each plot was necessarily taken as the average age of the felled Douglas firs. The volumes per acre in board and cubic feet were then curved on age in Figure 10, and the percentages of rot were curved in the same way in Figure 11. From these curves, Table 15 was constructed, which shows the gross increment and rot increment by 50-year periods.

TABLE 14.—*Gross volume per acre in board and cubic feet and percentage of rot for trees of all species 12 inches and larger in diameter breast high, by plots on Site II, grouped in 50-year age classes*

| Age class (years) | Average age | Gross volume in— | | Rot in— | | Plots (basis) |
|---|---|---|---|---|---|---|
| | | Board feet | Cubic feet | Board-foot volume | Cubic-foot volume | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| | *Years* | | | *Per cent* | *Per cent* | *Number* |
| 51 to 100 | 79 | 50, 210 | 10, 051 | 0. 4 | 0. 3 | 2 |
| 101 to 150 | 117 | 93, 750 | 15, 808 | 1. 4 | . 6 | 2 |
| 151 to 200 | 184 | 145, 530 | 23, 226 | 7. 4 | 3. 8 | 4 |
| 201 to 250 | 242 | 145, 470 | 22, 931 | 10. 0 | 5. 7 | 6 |
| 251 to 300 | 273 | 185, 720 | 28, 956 | 12. 6 | 6. 7 | 2 |
| 301 to 350 | 328 | 203, 140 | 30, 756 | 26. 6 | 15. 4 | 7 |
| 351 to 400 | 383 | 92, 530 | 14, 606 | 11. 2 | 6. 8 | 1 |
| 401 to 450 | 404 | 184, 570 | 27, 664 | 29. 7 | 16. 6 | 1 |
| 551 to 600 | 559 | 156, 250 | 24, 662 | 5. 9 | 3. 5 | 1 |

TABLE 15.—*Periodic increment in average gross volume and average rot volume per acre for trees of all species, 12 inches and larger in diameter breast high, on Site II*

BOARD FEET [1]

| Age (years) | Gross volume | Rot volume | Gross increment | Rot increment | Percentage of rot |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| 50 | 21, 500 | 0 | 21, 500 | 0 | 0 |
| 100 | 73, 000 | 730 | 51, 500 | 730 | 1. 0 |
| 150 | 113, 500 | 3, 630 | 40, 500 | 2, 900 | 3. 2 |
| 200 | 140, 500 | 9, 980 | 27, 000 | 6, 350 | 7. 1 |
| 250 | 161, 500 | 18, 730 | 21, 000 | 8, 750 | 11. 6 |
| 300 | 177, 000 | 31, 000 | 15, 500 | 12, 270 | 17. 5 |
| 350 | 190, 000 | 46, 930 | 13, 000 | 15, 930 | 24. 7 |
| 400 | 200, 000 | 67, 600 | 10, 000 | 20, 670 | 33. 8 |
| 450 | 208, 000 | 92, 770 | 8, 000 | 25, 170 | 44. 6 |

CUBIC FEET [2]

| Age (years) | Gross volume | Rot volume | Gross increment | Rot increment | Percentage of rot |
|---|---|---|---|---|---|
| 50 | 4, 000 | 0 | 4, 000 | 0 | 0 |
| 100 | 12, 800 | 50 | 8, 800 | 50 | . 4 |
| 150 | 18, 000 | 340 | 5, 200 | 290 | 1. 9 |
| 200 | 21, 900 | 880 | 3, 900 | 540 | 4. 0 |
| 250 | 25, 100 | 1, 710 | 3, 200 | 830 | 6. 8 |
| 300 | 27, 500 | 2, 780 | 2, 400 | 1, 070 | 10. 1 |
| 350 | 29, 300 | 4, 160 | 1, 800 | 1, 380 | 14. 2 |
| 400 | 30, 700 | 5, 650 | 1, 400 | 1, 490 | 18. 4 |
| 450 | 31, 600 | 7, 170 | 900 | 1, 520 | 22. 7 |

[1] Rot increment equals gross increment at approximately 300 years.
[2] Rot increment equals gross increment at approximately 360 years.

Comparing columns 4 and 5 based on board-foot volume in Table 15, it is seen that periodic rot increment is less than periodic gross increment up to and including 300 years, but at 350 years periodic rot increment exceeds periodic gross increment, which means that rot increment equals gross increment at some time in the 300 to 350 year period. The curves for rot increment and gross increment over age as explained on page 37 show that the change occurs at 300 years. For cubic feet (Table 15) the change takes place at 360 years. From 300 years on in board-foot volume and from 360 years on in cubic-foot volume the stand shows a net loss in increment owing to rot. There were not enough plots in the age classes from 400 to 600 years to show the marked decline in gross increment which must occur because of the breaking up of the Douglas fir stand, although the tendency to flatten out, shown at the upper ends of the board and cubic-foot volume curves, indicate this. Data on the older age classes would undoubtedly reveal that for a period of 100 to 200 years or more there would be a heavy loss in net increment. The data show such a loss from decay, which would be supplemented by the dropping out of large trees as the stand breaks up. Finally, the

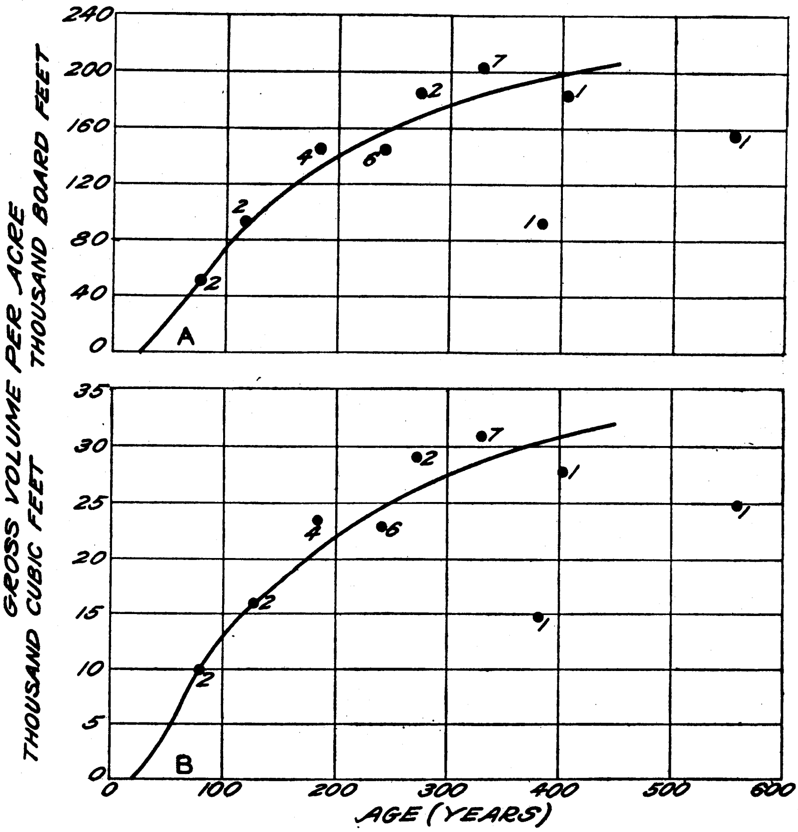



FIGURE 10.—Gross volume per acre of trees of all species, 12 inches and larger in diameter breast high, in relation to age on Site II; A, Board feet (Scribner Decimal C rule); B, cubic feet

net loss in increment would again disappear, and there would be a net gain as the younger trees of western hemlock, Douglas fir, and associated species acting as replacements attained sufficient size. During the period of net loss in increment from decay, as shown by Table 15, this loss is actually more serious than it appears. While rot is largely destroying high-quality wood in the large trees, the volume partly replacing this loss is mostly in young trees, which because of their many limbs for a long period produce only low-quality wood. Logs of grades Nos. 1 and 2 are being replaced by logs of grade No. 3, which during 1929 in the Columbia River region had an average value of $12 per thousand board feet, $3.50 less per thousand than No. 2 logs and $10 less than No. 1. Furthermore, the data in Table 15 are based on all trees 12 inches and larger in diameter breast high, but it is very rare that cutting to such a low diameter limit is carried on anywhere in the Douglas fir region; and in fact on most logging operations in large mature and overmature timber, no trees less than 20 inches in diameter breast high are felled. Those occasional operations with a market for pulpwood do cut small western hemlocks. On the whole, however, the loss in net increment because of rot is actually more serious than the figures presented here show. There is no doubt that for virgin

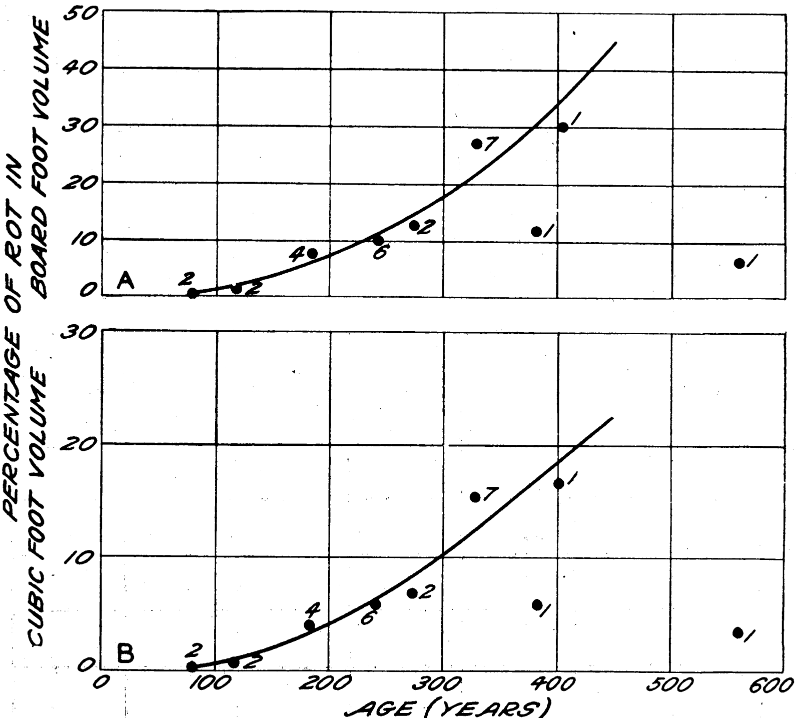



FIGURE 11.—Percentage of rot in relation to age of trees of all species 12 inches and larger in diameter breast high on Site II based on gross volume per acre: A, Board feet (Scribner Decimal C rule); B, cubic feet

overmature Douglas fir stands in the majority of cases the statement that growth increment balances decay increment—however comforting to owners of overmature defective timber—is untenable. Exceptional stands may remain relatively sound throughout their life.

## RELATION OF ROT TO VIGOR OF TREES

Studies on incense cedar (*2, p. 28*) have shown that in the younger age classes, slow-growing trees are more subject to rot than fast-growing ones. Meinecke (*17, p. 47; 18, p. 18*) points out that decay of consequence begins at an earlier age in suppressed trees than it does in dominant trees of white fir affected by the Indian-paint fungus, *Echinodontium tinctorium* Ell. and Ev., and of aspen, *Populus tremuloides* Michx., in Utah principally affected by the false tinder fungus, *Fomes igniarius* (L.) Gill. Schmitz and Jackson (*28, p. 24*) found no relation between crown class and the percentage of heart rot in aspen in Minnesota. Eklund and Wenmark (*9*) studying aspen, *P. tremula* L., in Sweden found that rapidly growing stands were least affected by decay. For balsam fir, *Abies balsamea* (L.) Mill., McCallum (*16, p. 13, 17*) found more decay in the faster growing trees than in the slower growing ones. Younitzky (*32, p. 117*), in a study of decay in Scotch pine in one Province in Russia, states that the dominant trees in the mature plantations are chiefly decayed by the ring-scale fungus. Koneff (*13*), in another locality in the same country, found exactly opposite conditions for the same fungus and presumably the same tree species, in that the volume of decayed wood was proportionately greater in the suppressed trees than in the more vigorous dominant ones. Dravert (*8*), in still a third locality in Russia, but again with the same wood-destroying fungus and tree species involved, found that trees in the II and III classes of suppression, according to Kraft's classification (*7, p. 447*), were relatively more heavily infected than those in the I, IV, and V classes. Münch (*21, p. 405*) determined that suppressed trees of red beech artificially infected were more susceptible to decay than thrifty, dominant ones, and explains the difference by the theory that the wood of suppressed trees has more air and hence more oxygen than the wood of dominant trees.

From all this it is apparent that the evidence on the relation of the rate of growth to degree of decay is decidedly contradictory, except that for three very different tree species decay has been found beginning earlier in the slow-growing trees than in the fast-growing ones.

The present study, with by far the largest number of trees that has ever been obtained as a basis for any exact study of decay, seemed to afford an excellent chance to investigate this point still further. Considering that vigor would be best expressed by the relation of age to volume growth, average-volume curves, which it is not necessary to present here, of volume in cubic feet over age were constructed for all the trees on each site. The trees were grouped into 50-year age classes, and the age and volume of the average tree determined for each age class to establish the points for the average-volume curve for each site. Then, according to this curve, the trees were grouped into two broad classes—those growing more rapidly than average and those growing less rapidly; and for lack of more suitable terms the words dominant and suppressed have been applied to these classes in the following tables and figures. The dominant and suppressed trees in each site were then grouped by 50-year age classes, and the age, volume in cubic feet, and percentage of decay were worked out for the average tree. These data are presented in Table 16. The comparison of dominant and suppressed trees is based on cubic-foot volume only, because board-foot volume is not an exact measure of the actual amount of wood in a tree and is far less an exact measure of the amount destroyed by decay, but is merely an approximate measure for commercial use. For the purpose of this comparison only the more exact measure would serve. For all three sites the percentage of decay in the dominant trees is greater than in the suppressed, although on Site I there is very little difference. Of course, general averages of this kind are likely to be misleading unless the age factor is considered. For example, on Site I there is slightly more decay in the dominant trees than in the suppressed, but the former are also older, which may be the explanation. This same condition exists on Site III. However, on Site II the dominant trees which have the youngest average age have more decay than the suppressed.

TABLE 16.—*Gross volume in cubic feet and percentage of rot per average tree for dominant and suppressed Douglas firs on Sites I, II, and III grouped in 50-year age classes*

SITE I

| Age class (years) | Dominant | | | | Suppressed | | | |
|---|---|---|---|---|---|---|---|---|
| | Average age | Average volume | Rot | Trees (basis) | Average age | Average volume | Rot | Trees (basis) |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| | *Years* | *Cubic feet* | *Per cent* | *Number* | *Years* | *Cubic feet* | *Per cent* | *Number* |
| 156 to 205 | 200 | 634 | 0 | 27 | 198 | 265 | 0.2 | 64 |
| 206 to 255 | 227 | 892 | 2.9 | 69 | 219 | 426 | 1.9 | 119 |
| 256 to 305 | 293 | 1,713 | 1.1 | 16 | 269 | 640 | 4.4 | 11 |
| 306 to 355 | 344 | 2,263 | 11.9 | 19 | 340 | 939 | 11.8 | 48 |
| 356 to 405 | 372 | 2,737 | 14.1 | 15 | 384 | 1,195 | 18.3 | 12 |
| 406 to 455 | 419 | 2,692 | 16.0 | 18 | 419 | 1,539 | 14.7 | 21 |
| Total or average | 277 | 1,415 | 8.8 | 164 | 260 | 605 | 8.4 | 275 |

SITE II

| Age class (years) | Average age | Average volume | Rot | Trees (basis) | Average age | Average volume | Rot | Trees (basis) |
|---|---|---|---|---|---|---|---|---|
| 56 to 105 | 72 | 136 | 0.3 | 194 | 87 | 96 | 0.7 | 84 |
| 106 to 155 | 124 | 454 | .9 | 89 | 125 | 213 | 1.0 | 124 |
| 156 to 205 | 177 | 741 | 3.8 | 91 | 184 | 338 | 3.1 | 93 |
| 206 to 255 | 234 | 896 | 7.3 | 149 | 236 | 366 | 4.1 | 215 |
| 256 to 305 | 278 | 1,066 | 13.2 | 84 | 280 | 439 | 9.3 | 86 |
| 306 to 355 | 331 | 1,339 | 18.8 | 111 | 332 | 621 | 12.3 | 150 |
| 356 to 405 | 372 | 1,637 | 13.4 | 45 | 373 | 925 | 7.9 | 52 |
| 406 to 455 | 428 | 1,923 | 14.5 | 23 | 428 | 1,030 | 18.4 | 19 |
| 456 to 505 | 478 | 2,294 | 18.9 | 2 | ---- | ---- | ---- | ---- |
| 556 to 605 | 604 | 2,784 | ---- | 2 | 600 | 2,200 | 0 | 1 |
| 606 to 655 | 609 | 3,353 | 8.9 | 3 | 618 | 2,492 | 6.3 | 4 |
| 656 to 705 | ---- | ---- | ---- | ---- | 705 | 2,138 | .5 | 1 |
| Total or average | 210 | 812 | 10.6 | 793 | 236 | 431 | 7.8 | 829 |

SITE III

| Age class (years) | Average age | Average volume | Rot | Trees (basis) | Average age | Average volume | Rot | Trees (basis) |
|---|---|---|---|---|---|---|---|---|
| 56 to 105 | 78 | 164 | 0.9 | 50 | 80 | 82 | 0.8 | 46 |
| 106 to 155 | 130 | 304 | 2.1 | 68 | 128 | 127 | 2.2 | 190 |
| 156 to 205 | 173 | 378 | 10.5 | 11 | 172 | 176 | 1.0 | 18 |
| 206 to 255 | 220 | 537 | 7.0 | 13 | 213 | 184 | .7 | 3 |
| 256 to 305 | ---- | ---- | ---- | ---- | 301 | 142 | 0 | 1 |
| 306 to 355 | 339 | 732 | 10.0 | 8 | 335 | 179 | 2.8 | 12 |
| 356 to 405 | 381 | 543 | 6.4 | 17 | 381 | 271 | 3.7 | 21 |
| 406 to 455 | 417 | 570 | 4.5 | 31 | 418 | 294 | 5.8 | 24 |
| 456 to 505 | 487 | 622 | .8 | 3 | 467 | 436 | 0 | 1 |
| 506 to 555 | 511 | 1,394 | 16.7 | 2 | 522 | 448 | 19.7 | 2 |
| 556 to 605 | ---- | ---- | ---- | ---- | 567 | 635 | 0 | 1 |
| 606 to 655 | 612 | 829 | 1.0 | 1 | ---- | ---- | ---- | ---- |
| Total or average | 211 | 382 | 5.0 | 204 | 182 | 152 | 3.0 | 319 |

Accordingly, to illustrate more exactly the difference between the two classes of trees, the data in the tables are shown in Figure 12. On Site I, it appears that the suppressed trees have slightly more decay than the dominants throughout, although there were no trees

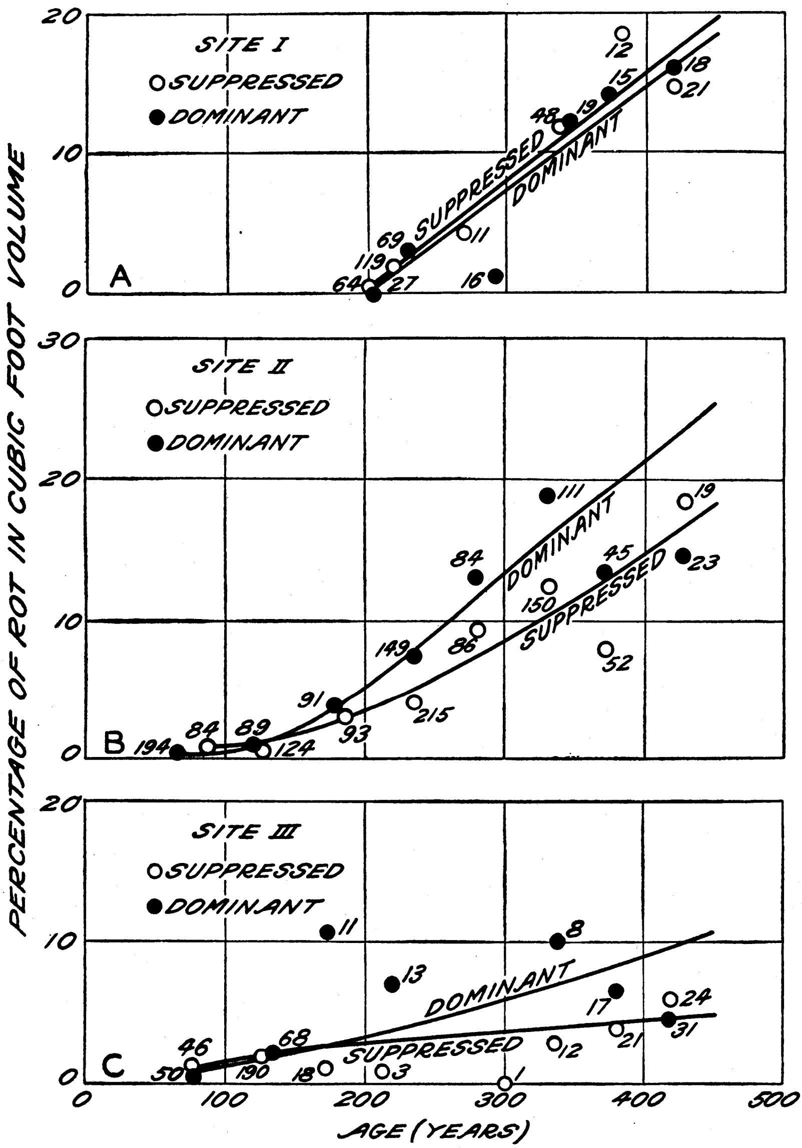



FIGURE 12.—Percentage of rot in gross volume in cubic feet per average tree in relation to age for dominant and suppressed Douglas firs: A, Site I; B, Site II; C, Site III

in the younger ages on this site. But on Sites II and III, the suppressed trees are slightly more subject to rot in their earlier years than the dominants and less as they grow older, the curves crossing at approximately 125 years for Site II and 165 years for Site III. In the older age classes there is much less rot in the suppressed trees than in the dominants. If there is justification for formulating any ideas at all from this somewhat contradictory evidence it might be considered that on Sites II and III suppression tended to increase decay in the younger ages, but as the trees grew older and more subject to rot this influence disappeared. Unfortunately, the younger ages were not represented on Site I. This tendency for decay of consequence to begin at an earlier age accords with the findings for incense cedar, white fir, and aspen in Utah. As to why the older dominant trees were more decayed than the older suppressed trees, no reasonable explanation suggests itself, although it may be that after Douglas fir attains a certain age, which varies with site, vigor has no relation to decay.

### RELATION OF ROT TO LOCALITY

Many ideas have been advanced in regard to the relation between soil quality, depth, and moisture, degree of slope, exposure, altitude, and general locality and the amount of rot in Douglas fir, but these ideas are found to be very contradictory. Some hold that decay is more prevalent on north slopes, others on south; some claim that it is worse on ridge tops, others in valley bottoms; or steep slopes may be opposed to gentle, deep soil to shallow, moist soil to dry, or gravelly soil to loam. But most of these ideas have been based on limited observation, usually over relatively small areas, and never on a detailed study over the Douglas fir region as a whole. Consideration of the factors mentioned showed no tangible relation between rot and any one of them on the 38 plots in this study, except that, as brought out previously, the indications were that Site I had the least decay, and it is this site, of course, that has the best soil. A study of a great number of plots would be necessary to determine the influence of these various factors. Havelik (*11*, *p. 354*), from his observations of red ring rot in Norway spruce, *Picea abies* (L.) Karst. (*P. excelsa* Link), in middle Europe and Sweden, concluded that trees on poor soils and unusually rich soils were much more subject to attack than those on optimum soils, because low-quality wood which decayed easily was developed on the first two soils. Möller (*20*, *p. 201*), after his extensive investigation of red ring rot in Scotch pine in Germany, decided there was no relation between quality of the wood and rot. With equal facility the decay attacked wood with narrow or wide annual rings.

However, it has been the consensus of opinion among those thoroughly acquainted with the entire Douglas fir region that Douglas fir in the northern section of the Cascade Mountains, beginning approximately with the Cowlitz River watershed in Washington and extending north, was on the whole much less decayed than that to the south of this watershed, particularly in Oregon, although occasional individual stands to the north were just as defective as any to the south. It seemed the explanation might be the fact that the timber to the south was on the average older than the stands to the north or that in general it occupied poorer sites.

Accordingly, a comparison was made between the northern and southern Site II plots in Table 17. This could not be done for Site I or Site III, since of the five plots in the former four were in the north, and of the seven plots in the latter six were in the south. From Table 17 it can be seen by following columns 4 and 5, which give the percentage classes, that the loss from decay is generally much higher in the southern plots than in the northern; in fact, the average of all southern plots is 19.5 per cent and for the northern, only 7.3 per cent. To be sure, the 14 plots in the south average 51 years older than the 12 plots in the north, but this does not serve to explain the difference as brought out by Figure 13, in which the data in Table 17 are shown. These curves show that except in the youngest age classes the percentage of decay is much higher through-

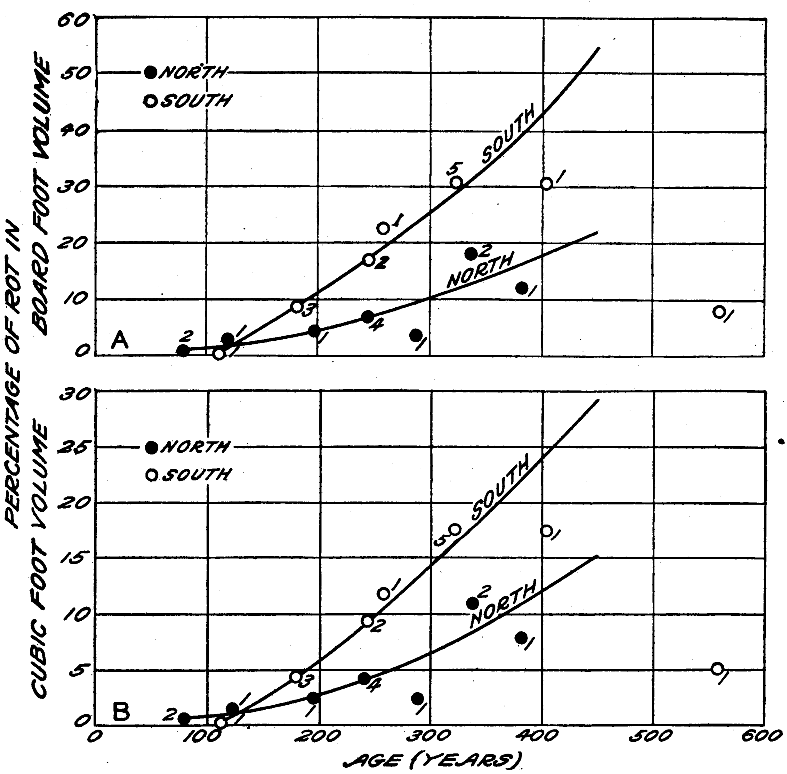



FIGURE 13.—Percentage of rot in relation to age of Douglas firs of merchantable size on Site II in the northern and southern sections of the region, based on gross volume per acre: A, Board feet (Scribner Decimal C rule); B, cubic feet

out in the southern plots than in the northern. The fact that this relation does not hold in the younger classes may be owing to experimental error, since there are three northern plots between 51 and 150 years and only one southern. The difference can not be explained by a variation in site between the two groups, even though they fall in the same site; that is, the northern group being good, Site II and the southern group poor, since the average site index is 176 for the northern plots and 173 for the southern. Furthermore, the difference can not be owing to relative chances of infection, for decay is so prevalent throughout the Douglas fir region that there is abundant opportunity for every stand to be infected.

TABLE 17.—*Comparison of percentage of rot for the northern and southern sections of the region in Douglas firs of merchantable size by plots on Site II grouped in 50-year age classes, based on gross board-foot and cubic-foot volumes per acre*

| Age class (years) | Average age | | Rot in— Board-foot volume | | Rot in— Cubic-foot volume | | Plots (basis) | |
|---|---|---|---|---|---|---|---|---|
| | North | South | North | South | North | South | North | South |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| | *Years* | *Years* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Number* | *Number* |
| 50 to 100 | 79 | | 0.5 | | 0.3 | | 2 | |
| 101 to 150 | 122 | 112 | 2.9 | 0.2 | 1.3 | 0.1 | 1 | 1 |
| 151 to 200 | 197 | 180 | 4.2 | 8.5 | 2.4 | 4.3 | 1 | 3 |
| 201 to 250 | 241 | 245 | 6.9 | 16.7 | 4.1 | 9.3 | 4 | 2 |
| 251 to 300 | 289 | 258 | 3.5 | 22.5 | 2.2 | 11.6 | 1 | 1 |
| 301 to 350 | 339 | 323 | 18.1 | 30.6 | 10.8 | 17.6 | 2 | 5 |
| 351 to 400 | 383 | | 12.0 | | 7.7 | | 1 | |
| 401 to 450 | | 404 | | 30.9 | | 17.5 | | 1 |
| 551 to 600 | | 559 | | 8.2 | | 5.1 | | 1 |
| Average or total | 233 | 284 | 7.3 | 19.5 | 4.4 | 11.0 | 12 | 14 |

Of course, because of the small number of plots available for this comparison it is not positively proved that the difference exists between the two regions as a whole. However, these data tend to support previous observations.

The writer is unable to offer any satisfactory reason for this marked difference in decay in the northern and southern sections of the Cascade Mountains. However, one explanation that has been advanced deserves consideration: It is that summer temperatures seem generally lower and probably relative humidity is higher in the northern Cascades than in the southern, and the probable warmer growing season in the south is more favorable to the development of wood-destroying fungi. Unfortunately, there are no weather records available from properly located stations to permit more than surmise on this. However, it may not be without significance that decay appears much less in the Douglas fir stands of the Coast Range, which is under the influence of the cool, moist breeze off the Pacific Ocean in summer, than in stands at equal latitudes in the Cascade Mountains farther removed from the influence of the sea.

## TOTAL LOSS

Although each individual loss caused by one of the various factors which have been discussed has its own degree of importance, the true picture of the total loss in Douglas fir timber which has been felled can be obtained only by considering these losses in the aggregate. Table 3 shows that 15 of the 38 plots suffered total losses of 25 per cent or more, measured in board feet, and that few plots more than 100 years old escaped with losses of less than 10 per cent. The largest total loss, 61.5 per cent, occurred on plot 38. Adding to this figure the additional loss through damage in logging and through hidden defects revealed only by sawing, it is apparent that an extremely small amount of finished lumber will be obtained from such a defective stand. There is the further indirect loss in the increased cost of logging, for it costs just as much to construct a logging railroad and set up equipment on an area with a total output of only 75,000 board feet per acre, net, as on an area with an output of 150,000 board feet. Neff (*25, p. 593*) considers that in the northern Rocky Mountain region defect increases the cost of production in nearly the same ratio as the occurrence of the defect itself. The number of cull logs left from a stand with a high total loss is shown in Plate 10, A. The photograph was taken on the general area on which plot 38 was located.

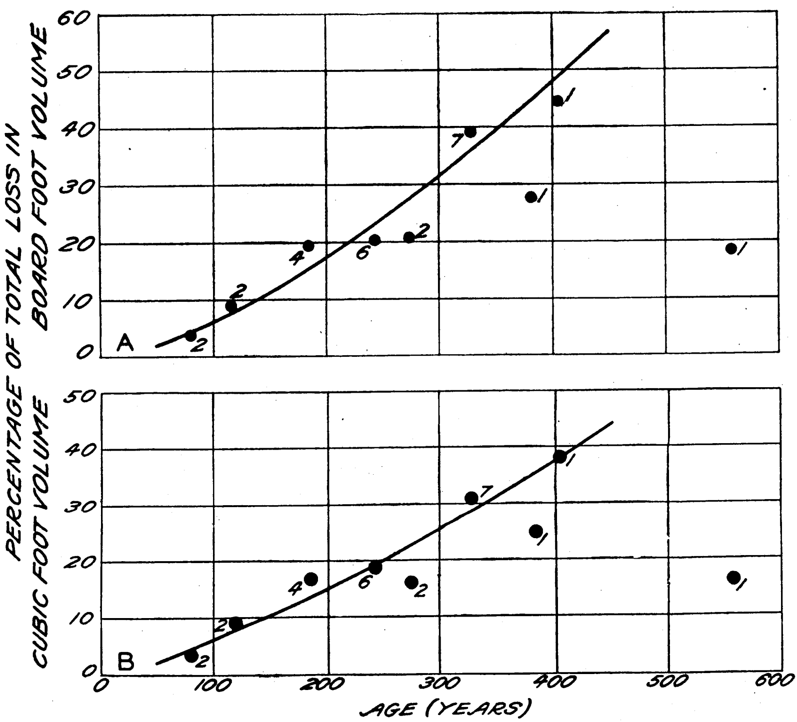



FIGURE 14.—Percentage of total loss in relation to age of Douglas firs of merchantable size on Site II based on gross volume: A, Board feet (Scribner Decimal C rule); B, cubic feet

The general tendency for loss to increase as the stand grows older reveals itself in Table 4. This is to be expected, since rot causes such a large part of the entire loss, while breakage in felling increases with the volume per acre of the stand, and this volume, up to a certain limit, also increases with the age of the stand. In Table 18, the percentage of total loss, measured in board feet and in cubic feet, is given for Site II plots grouped in 50-year age classes. From these percentages, curves showing the relation of total loss to age were constructed for Figure 14. From these curves and those for volume per acre (fig. 3), Table 19 was constructed in the manner described on page 37 to show the relation of increment in gross volume to the increment in total-loss volume. This table shows that on Site II the total-loss increment does not equal gross increment in board-foot volume until 270 years at the earliest, and this age is well beyond any probable future rotation for Douglas fir. Of course, for some time previous to the age at which total-loss increment equals gross increment in a stand, the net increment of sound wood will not be sufficient to offset carrying charges, so that actual financial loss will begin earlier than the loss in volume.

These figures on total loss, since they include the percentage of breakage without regard to the topography, show only the trend of total loss and should not be applied directly to other stands.

TABLE 18.—*Total loss in Douglas firs of merchantable size by plots on Site II grouped in 50-year age classes, based on gross board and cubic foot volumes per acre*

| Age class (years) | Average age | Total loss in— Board-foot volume | Total loss in— Cubic-foot volume | Plots (basis) | Age class (years) | Average age | Total loss in— Board-foot volume | Total loss in— Cubic-foot volume | Plots (basis) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| | *Years* | *Per cent* | *Per cent* | *Number* | | *Years* | *Per cent* | *Per cent* | *Number* |
| 51 to 100 | 79 | 3.6 | 3.3 | 2 | 301 to 350 | 328 | 39.1 | 31.7 | 7 |
| 101 to 150 | 117 | 8.8 | 9.8 | 2 | 351 to 400 | 383 | 27.5 | 25.3 | 1 |
| 151 to 200 | 184 | 19.2 | 17.0 | 4 | 401 to 450 | 404 | 44.5 | 38.3 | 1 |
| 201 to 250 | 242 | 20.4 | 18.9 | 6 | 551 to 600 | 559 | 18.1 | 17.1 | 1 |
| 251 to 300 | 273 | 20.5 | 16.2 | 2 | | | | | |

TABLE 19.—*Periodic increment in average gross volume and average total loss volume per acre for Douglas fir on Site II*

BOARD FEET [1]

| Age (years) | Gross volume | Total loss volume | Gross increment | Total loss increment | Percentage of total loss |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| 50 | 20,000 | 300 | 20,000 | 300 | 1.5 |
| 100 | 69,000 | 3,930 | 49,000 | 3,630 | 5.7 |
| 150 | 110,000 | 11,100 | 41,000 | 7,170 | 11.0 |
| 200 | 136,000 | 23,260 | 26,000 | 12,160 | 17.1 |
| 250 | 158,000 | 37,760 | 22,000 | 14,500 | 23.9 |
| 300 | 174,000 | 54,640 | 16,000 | 16,880 | 31.4 |
| 350 | 186,000 | 72,910 | 12,000 | 18,270 | 39.2 |
| 400 | 196,000 | 93,490 | 10,000 | 20,580 | 47.7 |
| 450 | 203,000 | 114,700 | 7,000 | 21,210 | 56.5 |

CUBIC FEET [2]

| Age (years) | Gross volume | Total loss volume | Gross increment | Total loss increment | Percentage of total loss |
|---|---|---|---|---|---|
| 50 | 3,900 | 78 | 3,900 | 78 | 2.0 |
| 100 | 12,200 | 744 | 8,300 | 666 | 6.1 |
| 150 | 17,500 | 1,820 | 5,300 | 1,076 | 10.4 |
| 200 | 21,100 | 3,228 | 3,600 | 1,408 | 15.3 |
| 250 | 23,850 | 4,913 | 2,750 | 1,685 | 20.6 |
| 300 | 26,000 | 6,812 | 2,150 | 1,899 | 26.2 |
| 350 | 27,700 | 8,892 | 1,700 | 2,080 | 32.1 |
| 400 | 28,900 | 11,040 | 1,200 | 2,148 | 38.2 |
| 450 | 29,600 | 13,231 | 700 | 2,191 | 44.7 |

[1] Total loss increment equals gross increment at approximately 270 years.
[2] Total loss increment equals gross increment at approximately 295 years.

## APPLICATION OF RESULTS

A knowledge of the indications of decay in logs and standing trees is an absolute prerequisite to relatively exact scaling and cruising. The importance of accurate scaling and cruising is evident, since the entire lumber industry is largely dependent on them. Logs are bought and sold on board-foot scale alone, timberland changes hands, and logging operations are based on the amount of timber that can be obtained from a given unit of area as determined by cruising. Consequently, exact cruising and scaling reduce the financial risk in the lumber industry, particularly in exploiting a species such as Douglas fir with a large amount of defect. When logs are purchased which actually cut out considerably less than scaled, there is a serious loss; but even more serious is the loss when a mill and railroad are constructed and logging equipment set up only to find that because of decay the amount of timber obtained from the area tributary to the mill is so much less than estimated that it is not possible to make a profit throughout the life of the operation. The financial difficulties of more than one lumber company cutting overmature Douglas fir can be attributed to underestimating the amount of decay when cruising the stand.

The indications by which the presence and approximate extent of the various decays may be determined have been given on pages 23 to 30 and in previous papers (*3*, *4*, *5*). In addition, the average losses that can be expected from other causes, such as shake, miscellaneous defect, and breakage in felling, on which heretofore there have been no exact data, are discussed on pages 11 to 22. It is essential to understand the significance of various other abnormalities such as burls, branch fans, and dead limbs, which are often mistakenly considered signs of decay. These have been discussed in detail (*4*, *p. 11*) in a previous paper. With this information the scaler or cruiser can work in Douglas fir with relative accuracy. The scaler has a simpler problem than the cruiser, because he can examine the logs at close range and observe not only the conks or swollen knots on the sides but also the presence in the ends of the logs of rot indicated by decomposed or discolored wood. The cruiser, on the other hand, must examine standing trees, which is not an easy task, since mature Douglas firs 250 feet high are not uncommon. In fact, field glasses or binoculars are necessary in order to pick out the conks and swollen knots in the upper part of the trunk with any accuracy. The cruiser should use a volume table based on diameter breast high and number of 32-foot logs, but giving the volume in each log. Only in this way is it possible to evaluate properly the loss through decay, since quite commonly, in Douglas fir, decay does not extend throughout the length of the trunk, but includes only one or more logs or parts of logs.

The information on the amount of defect other than decay in Douglas fir is not so difficult to apply. For example, a stand of timber approximately 300 years old, as determined from several windfalls or adjacent cutting operations, has been cruised and found to average 150,000 board feet per acre gross, with an estimated loss from decay of 15 per cent. In a stand of 150,000 board feet per acre on smooth ground a loss of 8 per cent from breakage in felling may be expected (fig. 5) and the loss through shake in a 300-year-old stand averages 1.1 per cent. (Fig. 4.) Miscellaneous defect averages 0.6 per cent, as stated on page 14. Combining these makes a total loss of 24.7 per cent, with a resulting stand of 112,950 board feet per acre.

Still another use can be made of the indications of decay, and that is identification of trees which, because of decay, contain no merchantable volume or so little they are not worth felling. Felling and bucking charges can be avoided by leaving such trees standing. The trees which are felled should be carefully marked for bucking so as to get the maximum of merchantable wood and exclude the unmerchantable. Cull sections of the trees should be designated to be left in the woods. The aim should be to spend as little money as possible on unmerchantable timber, for it must be remembered that it costs just as much to fell, buck, transport, and mill an unmerchantable log as a sound one. In fact, on an operation in defective timber it should be the work of one trained man to select defective trees to be left standing and mark felled trees for bucking to exclude unmerchantable logs. There can be no question that this would be profitable, because the values involved in the proper utilization of a badly defective stand are high.

This work must not be left to untrained judgment; it must be done skillfully, otherwise heavy losses will result. Plate 11 shows trees left uncut on a logging operation because they were considered unmerchantable, owing largely to red ring rot. Later a railroad right of way was cut through this timber, and many of these trees were found to be partially or completely merchantable. Some years ago an operator logged a half section, leaving a large number of trees standing as decayed in the judgment of the fellers. Shortly after there was a change in woods management, and it was decided to log the remaining trees on the same area. The log scale obtained from the supposedly decayed trees was only approximately 4 per cent less than that from the presumably sound ones first cut.

Leaving decayed trees standing not only reduces logging costs, but these trees will serve as seed trees to aid in restocking the cut-over area. It has been pointed out by the writer in a previous paper (*6*) that the usual objections that such trees will spread decay to the future stand and will produce poorer seed resulting in poorer seedlings are not important, because the future even-aged stands of second-growth Douglas fir managed on a clear-cutting system will be cut before the trees attain the age at which they become subject to extensive decay, and because there seems to be no sound biological reason for decay, which attacks the dead heartwood only, to so affect the vital functions of the tree that the quality of the seed is reduced. Furthermore, much of the reproduction on cut-over land must come from seed dropped by the trees just previous to logging or by seeding in from the adjacent stand, so that if the original stand contains decayed trees, seedlings from this seed source can not be prevented from forming a proportionate part of the future stand. Then, too, cones on sound seed trees will be cross-fertilized to some extent by pollen from decayed trees in the immediate or in the adjacent stand. Furthermore, experience has shown that of the seed trees left, some will be killed by the subsequent slash burning and others will die from the shock of sudden exposure and change in site conditions incident to clear cutting, so that investment in sound seed trees would be a relatively heavy one. Of course, many operators are not interested in restocking their land, but all are certainly interested in reducing costs; and it should be remembered that most companies must hold their cut-over land for some time in order to give adequate fire protection to their equipment, so that it is certainly desirable to have this land become an increasingly valuable asset by restocking with young trees rather than remain continuously nonproductive or less productive, particularly when the restocking can be accomplished at no additional expense.

At present clear cutting is practically universal in the Douglas fir region. On the national forests scattered seed trees are left as an insurance for future reproduction, and on some private operations completely defective trees are left. Where small trees—that is, 16 inches in diameter breast high or less—occur among larger trees they are usually left standing, but are mostly so badly broken up by felling and logging the larger ones that they are of little or no value to the succeeding stand. Those that do escape logging injury are usually damaged or killed by slash burning. The best method for reproducing the future stands when the forests of the region are brought under regulation has not yet been determined. It may be that in regulated stands repeated clear cutting with scattered seed trees on a relatively short rotation, even if not followed by broadcast slash burning, may be so deleterious to the soil that some other method will have to be used. Whether the shelter-wood method, or a modification of it, will replace the present method is problematical. If the shelter-wood method is sometimes practiced, it will be possible to remove by the first cutting the occasional infected trees that will appear in the second-growth stands. But it seems certain, as stated by Munger (*24, p. 35*), that clear cutting will be the practice for 20 to 30 years more.

Any attempt to remove the decayed trees from the present mature and overmature stands in advance of final logging seems ill-advised unless the material removed will pay the cost of the operation. Their removal is not necessary as a protection to the future stands, and its effectiveness in lessening the increase in decay through reducing new infections in present stands would be very problematical unless the work were carried on over extensive areas, comprising natural topographical units such as entire watersheds.

In many tree species subject to decay there is a very definite relation between the amount of decay and the character and degree of wounding, particularly scars caused by fire, so that a reduction in mechanical injuries will be followed by a reduction in loss from rot. Consequently, adequate fire protection is, in addition to its primary usefulness, an effective control measure against decay. In Douglas fir, red-brown butt rot is commonly associated with fire scars, so that some control can be accomplished by lessening fires. However, red ring rot, which causes 80 per cent of the loss, rarely enters the tree through open wounds, but almost invariably infects through dead-branch stubs; consequently in Douglas fir less reduction in decay losses can be accomplished by protecting stands from mechanical injuries than in other species on which exact information has been gathered. It may be that in the managed forests of the future, when understocking is not so common, the loss from red ring rot will be somewhat lessened, since the development of branches should decrease with increase in density of the stand, giving fewer points of entrance for this rot.

According to McArdle (*15, p. 41*), the greatest average yearly production of wood volume measured in board feet (Scribner Decimal C rule) on Sites I, II, and III is reached before the stand attains the age of 110 years; therefore, it is unlikely that in the managed forests of the future the cutting age will extend much beyond this time. For the national forests, a rotation of 110 years is planned. According to Figure 9, the average loss from decay at this age on Site II is 1.4 per cent, and the worst loss to be expected on Site II is 2.8 per cent. These figures show that in the managed and naturally reproduced stands of the future the loss from decay on Site II will be small by the time cutting age is reached. The same relation will probably hold for Sites I and III.

Although the loss from decay in young timber is of minor importance, there are now and will be for some time in the future mature and overmature stands in which the rate of decay or total loss is important, since it will determine whether the stand can be held or must be utilized promptly. Table 12 shows that on Site II under average conditions, loss through decay measured in board-foot volume equals increment at 300 years, and from then on exceeds it; and Table 19 shows that for total loss the same thing occurs at 270 years. Even before loss equals increment, however, there may be a financial loss, because the net growth of sound wood will not offset the carrying charges, such as taxes, interest on the investment, protection costs, and overhead. On the other hand, the appreciation in the value of stumpage and the development of methods of closer utilization may offset this financial loss and even the net loss in volume for some years after such volume loss begins. Then, too, if rot is largely confined to the center heartwood, the grade of lumber sawed may actually be higher than the average, since the low-grade, knotty lumber comes largely from the center of the tree. When decayed, this portion changes from low grade to unmerchantable. But, finally, there will come a time when financial loss can not be further postponed; if this time does not come sooner, it will certainly begin when the stand starts to break up with the continual dropping out of large trees of high value. Even then cutting may have to be postponed for a time to avoid the even greater loss of selling lumber on a low market.

From the foregoing it is evident that no definite rule can be given by which to determine exactly when Douglas fir timber should be cut, since, besides the rate of decay and other losses, so many factors are present that each stand demands separate consideration. The first essential for each working circle is a complete stock taking, including for the stands composing it the average age, volume per acre and percentage of rot as determined by cruising, site, and topography. With these data it will be possible to determine one point relating percentage of decay to age, and to draw a curve similar in form to one of those in Figure 9. By such a curve the rate of decay for the future can be approximately predicted. To this can be added the loss through shake, predicted on the basis of the age of the stand; the average loss from miscellaneous defect and the probable loss from breakage, calculated with reference to the density of the stand and the character of the ground. These data can then be applied to gross-yield figures as determined from yield tables, and the net yield can be predicted, together with the time at which loss equals growth and net loss succeeds net yield for an extended period. It must be remembered that this method of predicting loss is an approximation and that absolute exactness can never be obtained by further refinement—that is, by using more plots as a basis for the curves—or by any other method; and that up to now no method of estimating future loss in stands has existed, other than that of individual judgment, which is very uncertain at best.

In the application of yield tables, a knowledge of prospective loss is essential. Yield tables are based on normal—that is, fully stocked—stands and gross yield. But the net yield and not the gross yield is important, since the former determines the monetary return when the stand is cut; so that a yield study in any timber type subject to defect is not complete unless accompanied by a study of loss.

For example, McArdle (*15, Table 4*) shows that on Site II with a site index of 170 the gross yield in a normal stand of Douglas fir 150 years old will be 121,200 board feet per acre by the Scribner Decimal C rule. Figure 9 shows that the average loss from decay on Site II at this age is 4 per cent. From Figure 4 it is seen that the loss from shake is 0.5 per cent (reading to the nearest tenth), and that the usual loss from miscellaneous defect is 0.6 per cent (page 14). For a stand of 121,200 board feet per acre the average breakage in felling on smooth ground is 7.2 per cent and on rough ground 10.8 per cent. (Fig. 5.) The total of all these loss factors will be 12.3 per cent or 15.9 per cent, according to whether the ground is smooth or rough. The gross stand of 121,200 board feet per acre must therefore be reduced by 12.3 or 15.9 per cent, depending on the character of the ground. In addition the net yield will be still further reduced by understocking. From Figure 3 it can be seen that at 150 years the average gross yield of the plots studied was 110,000 board feet, or 9.2 per cent less than the yield of a fully stocked stand as determined by McArdle. For years to come, varying degrees of understocking will be the rule rather than the exception in the naturally stocked second-growth stands throughout the Douglas fir region. Meyer (*19, p. 641*) has found that the average stand of immature Douglas fir has from 82 to 83 per cent of the normal board-foot volume. Fully stocked stands will occur over restricted areas only.

## SUMMARY

Douglas fir is the most important timber tree of the Pacific Northwest and comprises about one-fourth of the remaining saw timber in the United States. Since the species is necessary to the economic future of the region in which it attains optimum development—western Oregon and Washington west of the summit of the Cascade Mountains and north of the Umpqua-Rogue River divide—a series of investigations of which this is one has been made on the life

history and habits of the tree, to provide a sound basis for its management.

In the region in question Douglas fir is very little affected by insects, fungi (except heartwood destroyers), or mistletoe. The Douglas fir bark beetle, *Dendroctonus pseudotsugae* Hopk., is abundant in felled trees, but has caused no great losses in living timber. A woolly aphid, *Chermes cooleyi* Gill., is common but relatively harmless. Periodically the western hemlock looper, *Ellopia fervidaria* Hbn., destroys considerable merchantable timber in some localities. The needle-cast fungus, *Rhabdocline pseudotsugae* Syd., causes considerable defoliation on young trees over limited areas. The relatively harmless needle-rust fungus, *Melampsora albertensis*, Arth., has not been found in the region. Seedlings and saplings are occasionally killed by the honey fungus, *Armillaria mellea* (Vahl) Fr. The conifer root fungus, *Fomes annosus* (Fr.) Cke., has not been found as a parasite. Douglas fir dwarf mistletoe, *Razoumofskya douglasii* (Engelm.) Kuntze, is unknown. A form of winter injury known as parch blight reddens the needles on trees in the winter, but the affected trees are rarely injured severely. Young stands are sometimes seriously damaged by ice storms, known locally as "silver thaws," or by wet-snow storms. However, the losses caused by the foregoing are small compared with the enormous losses through decay caused by wood-destroying fungi.

A detailed study of loss in Douglas fir was made on 38 plots covering 77.79 acres and containing 2,633 trees with a total volume of over 10,146,000 board feet or 1,571,000 cubic feet. The loss caused by rot amounted to 16.99 per cent in board-foot volume and 9.50 per cent in cubic-foot volume; 9.25 per cent of the volume in board feet and 12.57 per cent of the volume in cubic feet was broken in felling; shake accounted for a loss of 0.93 per cent in board-foot volume and 0.55 per cent in cubic-foot volume; and miscellaneous defects, such as broken top, volunteer, crook, fork, knots, insects, fire scar, and check, were responsible for a reduction of 0.60 per cent in the board-foot volume and 0.73 per cent in the cubic-foot volume, making a total loss of 27.77 per cent in board-foot volume and 23.35 per cent in cubic-foot volume.

The loss through shake increased with the age of the stand. There was no relation between miscellaneous defect and the age of the stand. Breakage in felling was influenced by topography, density of the stand, and size of the trees—the greater losses occurring on the rougher ground, in the denser stands, and among the larger trees.

Of the loss by decay, red ring rot caused by the ring scale fungus, *Trametes pini* (Thore) Fr., was responsible for 80.8 per cent in board-foot volume; brown trunk rot caused by the quinine fungus, *Fomes laricis* (Jacq.) Murr., for 8.6 per cent; red-brown butt rot caused by the velvet-top fungus, *Polyporus schweinitzii* Fr., for 6.2 per cent; yellow-brown top rot caused by the rose-colored conk, *F. roseus* (Alb. and Schw.) Cke., for 4.1 per cent; pitted sap rot caused by the purple fungus, *Polystictus abietinus* (Dicks.) Fr., for 0.1 per cent; spongy sap rot caused by the conifer root fungus, *F. annosus* (Fr.) Cke., for 0.1 per cent; and unknown rots for 0.1 per cent. In cubic-foot volume measurements these figures were:

Red ring rot 79.2 per cent, brown trunk rot 8.4 per cent, red-brown butt rot 7.9 per cent, yellow-brown top rot 4.0 per cent, pitted sap rot 0.2 per cent, spongy sap rot 0.1 per cent, brown cubical rot caused by the sulphur fungus, *Polyporus sulphureus* (Bull.) Fr., trace, and unknown rots 0.1 per cent. There are definite indications on the trunks of living trees of the presence of the more important of these rots in the heartwood; red ring rot in particular being easily detected by swollen knots and conks, and red-brown butt rot by fire scars, churn butts, and conks. The greatest loss in any one plot amounted to 54.8 per cent in board-foot volume and 32.2 per cent in cubic-foot volume, nearly all of which was caused by red ring rot.

Scars are of minor importance as a means of entrance for decay, because red ring rot almost invariably enters through dead-branch stubs or knots. Of the scars, those caused by fire are of most importance, because red-brown butt rot commonly enters through fire scars, and this decay not only attacks the heartwood of the valuable butt log but also predisposes trees to windfall.

Actual loss through decay may appear in individual trees rather early in the life of a stand. Red ring rot was found causing loss in a tree 27 years old, red-brown butt rot in one 73 years old, yellow-brown top rot in one 76 years old, and brown trunk rot in one 146 years old. It was apparent that this latter decay appeared later in the life of a stand than the other three.

Although occasional stands remained relatively free from decay throughout their life, as a rule the amount of decay increased rapidly in mature and overmature stands. The data were not sufficiently comprehensive to determine definitely if there was any relation between site and decay, but they seemed to indicate that in the younger ages rot is of least consequence on Site I and is more serious on Site III than on Site II. There were only five plots on Site I, seven on Site III, and none on Sites IV and V. On Site II, in board-foot volume, rot increment equaled gross increment at 300 years, and in cubic-foot volume at 345 years. In other words, from those periods on, the stands were not making a net growth but were actually losing in volume. The most rapid rate of increase in decay in the most highly defective stands was 23.1 per cent of the gross board-foot volume for a 50-year period from 300 to 350 years, or an average of 0.46 per cent a year. For the average stands on Site II, the most rapid increase in decay averaged 0.29 per cent a year from 400 to 450 years.

Although no definite relation was found between vigor of the trees and decay, there were indications that on Sites II and III suppression tended to increase decay in the younger trees up to 125 and 165 years, respectively, but beyond these ages this influence disappeared, and the dominant ones had most decay. Trees in the younger age classes were not represented on Site I.

In the northern portion of the region covered by this study the loss through decay was less than that in the southern portion for stands of the same age and site index, although the number of plots studied was not sufficient to settle the point conclusively. The data support general observations made previously.

Total loss, which included decay, shake, miscellaneous defect, and breakage in felling, but not waste, also increased with the increasing age of stands. On Site II in board-foot volume, total-loss increment equaled gross increment at 270 years. The same period in cubic-foot volume was reached at 295 years.

Ability to recognize and interpret indications of decay in standing trees and logs, together with the information on the average losses that may be expected from other causes, will make possible more exact cruising and scaling. Trees which because of decay contain no merchantable volume, or so little that they are not worth felling, can be identified in advance of logging and left standing, so that felling charges are saved; further, such trees will serve as seed trees. After the stand is felled the partially decayed trees can be carefully marked for bucking in order to get the maximum of merchantable volume and leave the unmerchantable material on the ground, thus saving logging and milling costs.

In the future Douglas fir stands will ordinarily be cut before they attain the age of 110 years, and at this age the loss through decay is small on Sites I, II, and III. However, large areas are still occupied by mature and overmature stands, and figures on the rate of decay and other losses can be applied to these stands to determine whether they can be held or should be utilized as promptly as possible. Furthermore, yield tables which deal only with gross volume are incomplete without loss tables, which make it possible to predict net volume. This study has partially supplied such loss tables to supplement the yield tables previously completed.

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