UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 871

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. PROFESSIONAL PAPER November 10, 1920

THE DRY-ROT OF INCENSE CEDAR

By

J. S. BOYCE, Assistant Pathologist
Office of Investigations in Forest Pathology

CONTENTS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1920

UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 871

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. PROFESSIONAL PAPER November 10, 1920

THE DRY-ROT OF INCENSE CEDAR.

By J. S. Boyce, *Assistant Pathologist, Office of Investigations in Forest Pathology.*

CONTENTS.

IMPORTANCE OF INCENSE CEDAR.

Incense cedar (*Libocedrus decurrens*) is of considerable economic importance on the Pacific coast. The available supply of this species, which never occurs alone but always in mixture, chiefly with yellow pine, Jeffrey pine, sugar pine, Douglas fir, and white fir, averaging about 8 per cent of the stand, although often forming as high as 30 to 50 per cent, is estimated at 11 billion feet, 10 billion of which occurs in California (17, pp. 9–10).[1] That the wood is very valuable for special purposes on account of certain qualities has been clearly pointed out by Mitchell (17, pp. 2–9) recently and was mentioned by Von Schrenk (26, p. 69) 20 years ago. However, in spite of the well-known value of the wood, only about 30 million feet is cut annually in California. The stumpage rate is low and the price for the finished product often little more than pays the cost of logging and manufacture, according to Mitchell (17, p. 6).

The reason for this is obvious. The heartwood of incense cedar is commonly rendered totally worthless by the so-called dry-rot caused by *Polyporus amarus*. An idea of the quantity of timber rendered unmerchantable by this dry-rot may be obtained from Mitchell's statement (17, p. 3) that so common is this defect that it is the usual practice to cut estimates of this species from 30 to 50 per cent on ac-

[1] The serial numbers in parentheses refer to "Literature cited" at the end of the bulletin.

182803°—20—Bull. 871——1

count of it. This leads to a distinct prejudice against the species on the part of both the lumberman and the forester. The lumberman is naturally averse to handling a large quantity of practically worthless material for which there is little or no market in order to secure a small amount of valuable material, when the profit on the more valuable product is not sufficient to carry adequately the entire product. The forester sees a species of very little value, as attested by the low stumpage rate, occupying space which might be given over to surrounding species on which a much higher stumpage rate could be realized.

This prejudice, which has resulted in the classification of incense cedar as an "inferior" species, is not based on any inherent quality of the tree itself, for sound cedar wood, as has already been stated, is quite valuable, finding a ready market; and the tree, on account of its relatively high tolerance of shade, particularly during its earlier life, is a valuable component of the mixed stand in which it occurs.

Incense cedar is a thrifty, aggressive species, quite tolerant of shade, and has a definite, permanent place in the forests of the Pacific coast. Its aggressiveness makes it almost an impossibility to eradicate the species entirely, and such an attempt would be highly inadvisable and might result in unforeseen disastrous consequences resulting from an artificial change in the composition of the stand. Greeley (6, p. 112) and Meinecke (16, pp. 21–22) have specifically advised against this. The lumberman, logging in types with incense cedar represented, faces the necessity of handling a large quantity of almost worthless timber, which if sound would be of high value.

Since incense cedar probably can not be eliminated from the stand, the problem presents itself of the proper treatment of an inferior species which in time will undoubtedly become quite valuable. Foresters and lumbermen are showing more and more interest in the question, fully realizing that this species will always have to be reckoned with. We must have exact, far-reaching studies not only to handle properly and utilize the cedar at present, but to lay the foundations for a rational system of silvicultural management for the future. Production is inevitable; proper treatment must be evolved. Consequently, the study on which this paper is based was undertaken in an attempt to throw light on certain of the phases involved.

TOTAL-LOSS FACTORS.

Throughout American forestry literature dealing with regulation and management are found statements in regard to individual components of mixed stands to the effect that "in virgin forests increment equals decay," or sometimes "deterioration" is used in place of "decay." Chapman (2, p. 317) and Meinecke (16, p. 3–4) have shown this generalization to be of absolutely no value, since the assumption is based on the factors of increment and decay, of which almost nothing is known. When deterioration is used in place of decay, it is an impossibility to reach a conclusion as to just what factors of loss are included in the term.

The term "total loss" has been introduced by Meinecke (16, p. 4–5) to cover all factors which lead to any reduction of increment or actual volume in a stand, and he makes a strong plea for exact studies of all components of the total-loss factor for individual species before any effort is made to determine this for the mixed stand.

To determine the components of the total-loss factor for any given species is merely a matter of simple observation, but to gauge accurately their relative importance is not easy, calling for careful comprehensive work.

In the case of incense cedar the numerical dropping out of individual trees, the mechanical injuries caused by fire, frost, lightning, the breaking of branches, and other causes, a mistletoe, and several fungi play a more or less important part in the total-loss factor. These components may be divided into two broad classes, those reducing the future capital of timber (lessening the increment) and those reducing the present capital of timber (destroying actual merchantable material). It is impossible to draw a sharp line between these two classes, since some components find a place in both.

The unavoidable yearly dropping out of certain trees, varying in size from seedlings to veterans, affects both the increment and merchantable material in a stand. Mechanical injuries, while primarily causing a loss in the merchantable timber, to some extent interfere with the normal growth of the tree, thus reducing the increment.

A mistletoe (*Phoradendron juniperinum libocedri*), the incense-cedar rust (*Gymnosporangium blasdaleanum*) (15, p. 35–37; 11), a leaf-inhabiting fungus (*Stigmatea sequoiae*) (3, p. 87; 4, p. 314), and the black cobweb fungus (*Herpotrichia nigra*) all primarily cause a loss in the future capital of timber by reducing the annual increment of infected trees. The amount of this loss is exceedingly difficult to gauge accurately, but it is so small in relation to the damage caused by the agencies reducing the present capital of timber that the above-mentioned organisms are given no consideration in this paper except incidental mention. Under certain conditions, the mistletoe is responsible for a slight reduction in the merchantable contents of the host tree by causing spindle to barrel shaped swellings on the boles of mature and overmature trees (14, p. 37). The wood of these swellings is rendered valueless for lumber, owing to the presence of the mistletoe "sinkers," or roots, either living or dead. Swellings are rarely, if ever, found on the boles of younger trees.

Most important of all, however, is the loss of the present capital of timber through decay. The organisms causing decay in incense cedar are the pouch fungus (*Polyporus volvatus*), *Polystictus abietinus*, *Polystictus versicolor*, *Lenzites sepiaria*, the red-belt Fomes (*Fomes pinicola*), some unknown fungi, and the incense-cedar dry-rot fungus (*Polyporus amarus*). The first five listed have never been found attacking living incense cedars. There are several forms of decay of trifling importance in living trees, the causes of which have not been determined. *Polyporus schweinitzii* has been found in one case.

Standing out above all the other components of the total-loss factor is *Polyporus amarus*, causing dry-rot in the heartwood of the tree. Since the first utilization of incense cedar, the great destruction wrought by this fungus has been a matter of extreme concern to lumbermen and foresters, as is shown by the constant references to the decay found throughout the literature wherever incense cedar is mentioned.

The importance of dry-rot can not be overestimated, and it is on this point, together with the related mechanical injuries, that a study of the total-loss factor must be concentrated; the other considerations play a distinctly secondary rôle.

METHOD OF COLLECTING DATA.

SELECTION OF AREAS.

The first step in carrying on a study of the total-loss factors in any given species is the selection of proper areas for work. The areas selected, if the results are to serve for any but strictly local application, must be representative of the larger unit or region of which they form a part. It is self-evident then that areas located in the altitudinal or horizontal extremes of the range of the species under investigation must be avoided. The results of a study on such areas, while scientifically interesting, would be absolutely without practical value, since they would only answer for a limited unit on which the stand is abnormal and would fail to answer any questions in regard to the major and more valuable portion of the range of the species.

All indications tend to show that there is a considerable variation in the growth and development of incense cedar in different parts of its range. This has already been hinted at by Mitchell (17, p. 9, 13, 23, 24). The writer distinguishes three distinct ranges based on the development of the tree, and these are termed, for convenience, the optimum, intermediate, and extreme ranges.

The best development is found in the southern Sierras, particularly on the Sierra, Sequoia, and Stanislaus National Forests, and the southern portion of the Eldorado National Forest, where the species is relatively rapid growing and thrifty.

In the intermediate range, comprising the northern Sierras and the Coast Ranges, slower growth is the rule, and in the mixed stand where the cedar always occurs it plays a distinctly secondary part and might almost be classed as an understory tree.

The poorest development is found in the extreme range, which includes stands at the horizontal and altitudinal extremes of the distribution of the species. In such situations the trees are short, scrubby, and relatively of little value.

With the above facts in mind, it was considered essential to choose areas representative of the intermediate and optimum range; the extreme range could be neglected, since it is of no practical importance.

In the uneven-aged stands care had to be observed to select areas on which all age classes were represented, since if there is a relation between any of the total-loss factors and age of the tree, this would fail to appear if even-aged or nearly even-aged trees alone were considered.

Observation and a preliminary study by Meinecke[1] showed conclusively that the total-loss factor of supreme importance in the case of incense cedar is dry-rot caused by *Polyporus amarus*. Above all, then, it was essential to select stands in which dry-rot was common, using discretion not to make the selections where loss from dry-rot was far above or below normal. Other total-loss factors, particularly mechanical injuries, could not be disregarded and were carefully considered.

With a knowledge of the habits and condition of incense cedar throughout its range, several possible areas were tentatively chosen, a careful examination made in each case, and then the most suitable stands were decided upon.

DESCRIPTION OF AREAS.

The area selected to represent the intermediate range is at Sloat, Calif., within the boundaries of the Plumas National Forest, in the northern Sierra Nevada Mountains. In general, the region is one of heavy snowfall, with moderate winter temperatures and a long, dry, warm summer season. Lightning storms are not very frequent.

The tract has a relative altitude of 4,300 to 4,700 feet. The fairly deep soil is a decomposed lava, normally dry and loose.

The virgin uneven-aged stand, with a strong representation of mature and badly overmature trees of all species, is principally composed of western yellow pine (*Pinus ponderosa*), Jeffrey pine (*Pinus jeffreyi*), and Douglas fir (*Pseudotsuga taxifolia*). Where

[1] The writer wishes to acknowledge his indebtedness to Dr. E. P. Meinecke, who first inaugurated a study of incense cedar in 1912, the data obtained being included in this paper, for advice and direction throughout the course of all the later work. The essential methods followed in this study are outlined by him in United States Department of Agriculture Bulletin 275 (16).

Douglas fir predominates, the two pines take second place, and vice versa. Third in order comes incense cedar, while sugar pine (*Pinus lambertiana*) and white fir (*Abies concolor*) are but lightly represented.

In the more dense stand on the lower slopes and in the draws incense cedar forms a distinct understory, overtopped by all the other species; it is in such localities that the cedar shows every indication of slow growth and strong suppression. On the higher slopes and along the ridges, where the stand is more open, the cedar in individual cases often assumes a better position in the stand, and all the trees of this species, with few exceptions, appear to be more thrifty and to have made a more rapid growth. Badly suppressed trees are rare.

The three areas selected to represent the optimum range are on the Stanislaus National Forest in the southern Sierra Nevada Mountains. One of these is at Strawberry, at an altitude of 5,300 to 5,600 feet; a second at Cow Creek, about 5 miles north and east of the first and at about the same elevation; and the third at Crockers Station, about 30 miles to the south and a little east of the Strawberry area and at an altitude of about 4,500 feet. Since the areas are so nearly alike, a composite description will suffice.

The soil is a rather deep, loose, decomposed granite, with many large granite bowlders. It is normally somewhat dry.

The virgin uneven-aged overmature stand is rather open and is composed of sugar pine, western yellow pine, Jeffrey pine, white fir, incense cedar, and Douglas fir. Normally the pines predominate, with white fir or incense cedar next in order, Douglas fir being found sparingly only on the Crocker area. Incense cedar is represented by trees of all ages, and on the whole appears very thrifty. There are many individuals of large size, comparatively young. The cedar here is far from forming such a distinct understory as on the Sloat area, so the stand has made a much more rapid growth.

NOTES ON INDIVIDUAL TREES.

After the general notes were completed on an area, work was commenced on individual trees. Trees of all ages and conditions must be cut for a study of this kind, the primary purpose being to determine the age of the stand at which dry-rot becomes extensive. Observations on logging operations and the results of Meinecke's preliminary study had shown that trees between 100 and 240 years old would yield the essential data on this point, and it was within these age limits that the investigation was concentrated, but the lower and higher ages were not neglected by any means. This resulted in clear cutting within the ages mentioned, except that those trees in which it was plainly apparent an accurate age count could not be made were left standing, while only a portion of the trees in the stand above and below these ages were cut. Thus, since a given tract was not clear cut, the representation of age, diameter breast high, and height classes obtained from the study must not be assumed as an exact expression of the actual conditions.

Each tree was cut as closely as possible to a stump height of 18 inches, then limbed and bucked. The first or butt log was made 7 feet long and the others 14 feet long, the number of cuts depending, of course, on the length of the tree. The last cut was always made well in the top near the upper limit of the heartwood. The reason for bucking in 7 and 14 foot lengths was purely a practical one; any sound heartwood could then be utilized for 7-foot posts. The age count at stump height was taken as the age of the tree instead of adding a few years corresponding to the height of the stump, since the aim is to have all figures taken directly comparable. In this case with a minute constant variation no error can be introduced. Trees with wounds which destroy the center at stump height were avoided when possible, since in such cases an accurate age count could not be obtained; hence, trees of this kind are valueless for all further calculations in which the exact age is a factor. The sap width was obtained from an average of six or eight measurements. Three radii were measured to secure the average diameter. Separate measurements were made for the area covered by decay. The dates of occurrence and closure, when healed, were determined for all wounds present. Each log was split at least once in order to reveal completely all decay and internal wounds. Great care had to be observed in splitting the logs in order to be certain not to miss any decay, since the dry-rot occurs in pockets which may be separated in a linear direction by several feet of sound wood. This habit of "jumping" also made it exceedingly difficult to trace the entrance of the decay in certain cases where the decay might be several feet removed from any possible point of entrance. It often became necessary to split log after log into many small pieces.

In all, 1,075 trees were analyzed, 509 at Sloat, 266 at Strawberry, 100 at Cow Creek, and 200 at Crockers Station.

In all future references in this paper, for the sake of convenience the term "intermediate area" will be used to designate the area at Sloat, since it represents conditions in the intermediate range, and the term "optimum area" to designate the combined areas at Strawberry, Cow Creek, and Crockers Station, since they represent conditions in the optimum range. The results of the field work follow.

SECONDARY ROTS.

Under this heading are grouped all decays the causes of which are unknown. Such decays are of various types and are almost invariably found immediately adjacent to open or healed-over wounds, particularly fire scars. Instances were encountered where the decays were so badly eaten out by insects as to preclude any description of the rot. By reason of this, some light infections of *Polyporus amarus* may have been included under secondary rots, but such cases have undoubtedly been very rare.

Of the 59 infections of secondary rots examined, only 9 resulted in culls of any importance, the highest percentage of unmerchantable timber in relation to the total volume of the tree being 19.5 per cent. In all the remaining 50 trees the infections were negligible. These figures show secondary rots to be of only trivial importance in reducing the merchantable volume; hence, such decays are not further considered in this paper.

THE DRY-ROT.

The dry-rot of incense cedar, termed by eastern workers "peckiness" or "pin-rot," caused by the fungus *Polyporus amarus* Hedgc., was first described and figured by Harkness (7) but no cause was given. Next Von Schrenk (26, 67–77, pl. 2, 4, 5) described and figured the disease without stating the cause, and later (28) he mentions *Polyporus libocedris*, but without giving a description of type specimens. Hedgcock (10) first definitely assigned the cause of the dry-rot to *Polyporus amarus* sp. nov. and described the fungus. Later Meinecke (15, p. 35–37) presented a brief description of the sporophore, accompanied by a photograph of a typical fully developed bell-shaped specimen, with the upper surface partially destroyed by insects. Murrill (24, p. 25) places the fungus in the genus Fomes.

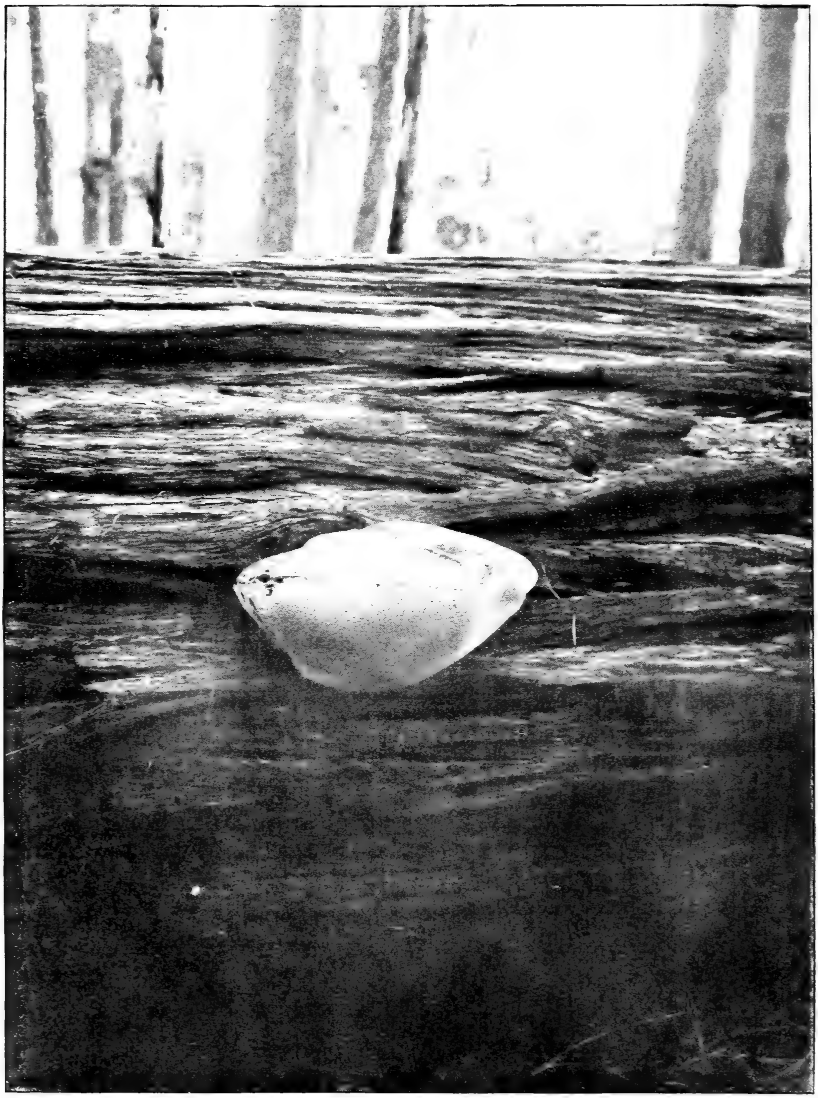
Harkness and Moore, Mayr, and Sargent have attributed the cause of the dry-rot to *Daedalea vorax* Hke., but Von Schrenk (26, p. 67–68) has shown this to be an error. Farlow and Seymour (5, p. 169) and Bryant (1, p. 15) have made the same mistake.

The dry-rot is very widely distributed. It has been found at elevations varying from 650 to 6,480 feet as far north as Oakridge, Lane County, Oreg., west to the west of China Flat, Humboldt County, Calif., east to Shaver, Fresno County, Calif., and south to the north and east of Mentone, San Bernardino County, Calif. In fact, from all indications and hearsay evidence it is quite reasonable to presume that dry-rot is more or less prevalent in incense cedar throughout the range of the host (30, p. 150–152).

THE SPOROPHORE.

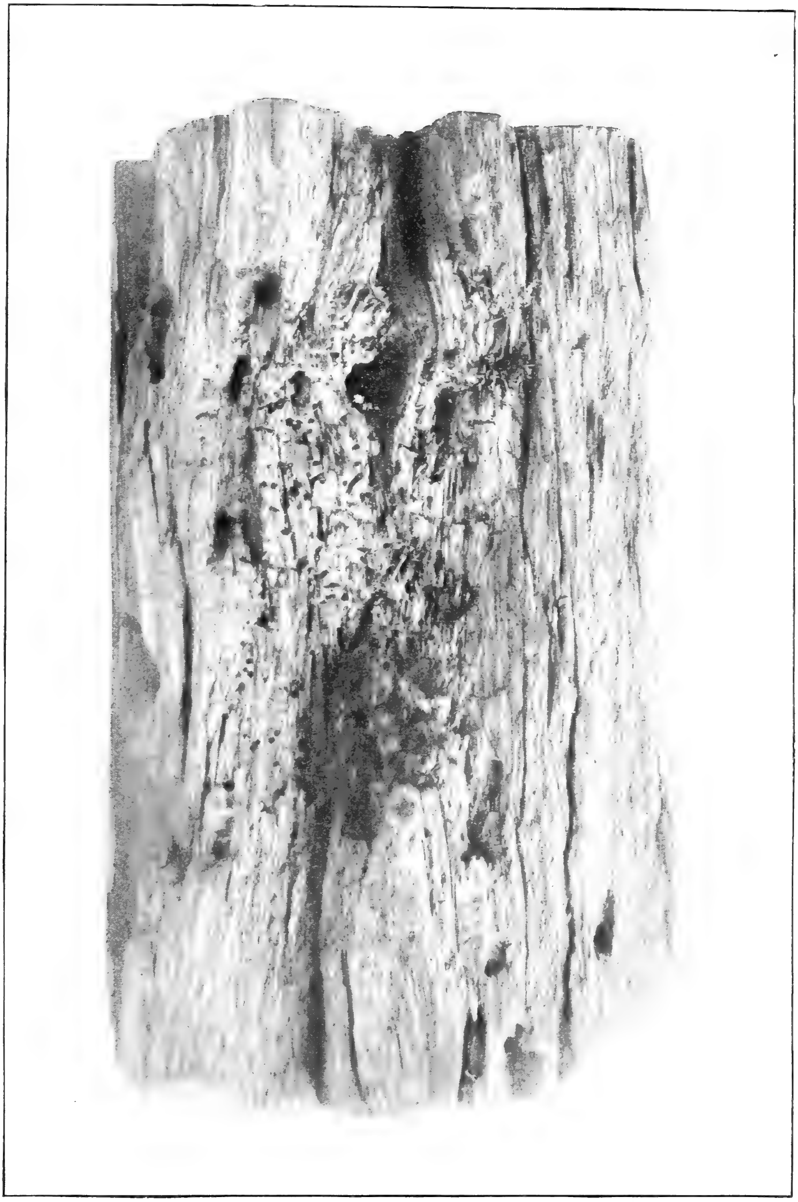
Since Hedgcock's description was published, so many sporophores have been collected that the original description may be supplemented by the following, which is based on the examination of 25 sporophores, both fresh and old:

Polyporus amarus.—Pileus soft and mushy when young, then rather tough and cheesy, finally becoming hard and chalky when old, ungulate, bell shaped or occa-



A FRESH SPOROPHORE OF POLYPORUS AMARUS ON A DOWN TREE.

Photographed by Gravatt.



AN OLD SHOT-HOLE CUP. THE ORIGINAL SPOROPHORE ISSUED FROM THE KNOT HOLE AT THE TOP.

Photographed by Meinecke.

sionally subapplanate, often spuriously stipitate from knot holes, 4 to 15 by 5 to 22 by 5 to 20 cm., commonly 7 to 10 by 11 to 13 by 8 to 13 cm., occasionally abortive without hymenial layer, then assuming irregular shapes; surface pubescent when young, rimose and chalky when old, at first buff, then tan, and often blotched with brown when attacked by insects; margin obtuse, frequently having an outer band of darker brown, often slightly furrowed; context homogeneous,[1] lemon-yellow, later buff to tan, usually darker near the surface when old, slightly bitter to the taste, 4 to 14 cm. thick, commonly 9 to 11 cm., usually friable when dry but occasionally becoming partially horny, hard; tubes not stratified, lemon-yellow within, cylindric 0.2 to 3 cm. in length, shorter next the margin, mouths circular or slightly irregular, 1 to 3 to a millimeter, lemon or sulphur yellow during growth, turning brown when bruised or old, becoming lacerate; under surface of the hymenial layer sometimes exuding clear yellow drops of liquid, sweetish to taste; spores hyaline or slightly tinged with yellowish brown, smooth, ovoid (200) range 3 to 6.5 μ by 4.5 to 9 μ; standard size 3.5 to 4.5 μ by 6.5 to 7 μ, nucleated; cystidia none.

The following table presents detailed measurements of 24 sporophores of *Polyporus amarus:*

TABLE I.—*Sporophore measurements of the incense-cedar dry-rot fungus.*

cm. *cm.* *cm.*	*cm.* *cm.* *cm.*	*cm.* *cm.* *cm.*
3.8 by 4.8 by 8.3	8.0 by 13.0 by 13.0	9.5 by 17.0 by 13.3
4.2 by 5.5 by 5.5	9.0 by 11.5 by 9.9	9.8 by 13.2 by 13.0
6.0 by 7.3 by 8.6	9.0 by 10.0 by 10.0	10.3 by 14.9 by 14.8
6.8 by 11.2 by 12.3	9.0 by 10.5 by 11.0	11.4 by 20.7 by 19.8
7.5 by 11.4 by 9.0	9.0 by 13.3 by 12.0	12.0 by 16.4 by 10.8
7.5 by 17.0 by 8.1	9.1 by 10.7 by 8.5	12.1 by 21.2 by 12.5
7.6 by 11.4 by 9.5	9.1 by 12.4 by 8.9	14.5 by 22.0 by 13.0
8.0 by 12.5 by 10.0	9.5 by 14.7 by 11.0	14.8 by 12.7 by 16.5

The sporophores, which last for one season only even at best, are not at all common, a statement which is supported by the number of years the dry-rot was known before the cause was definitely determined. During certain years sporophores seem to be very rare. They most commonly occur in the summer, and especially in the fall, but occasionally are found at other seasons. Observations record two fresh ones in March in a rather mild climate at an altitude of about 3,000 feet in the Sierra Nevada. Another was found in a different locality in June. No sporophores have been found developing later than October, but occasional fresh ones may be carried over from a previous fall into the winter in a frozen condition. They are then destroyed in the spring.

Typically the sporophores are produced on living trees but are, on occasions, found on dead fallen trees. (Pl. I.) Seven such cases have been observed during the past five years. In five of these it was possible to determine the time which elapsed between the felling of the tree and the appearance of the sporophore. Three of the sporophores were produced 3 years, one 4 years, and one 27 years after the trees had been cut. As to how long the mycelium may

[1] The substance of the sporophore not including the outer layers.

persist in a dead fallen tree it is impossible to state, but the last figure given indicates a rather extended period in some cases. These cases refute the statements of Harkness (7) and Von Schrenk (26, p. 75) that the mycelium does not grow after the death of the tree.

On dead down trees the sporophores were never half bell shaped or ungulate, but were more typically near the subapplanate type.

Since so few cases of sporophores on dead fallen trees have been recorded during a rather extended period, it is safe to assume that infected fallen trunks are of slight importance from the standpoint of forest sanitation in infecting living trees through the production of sporophores.

Although sporophores are rather rare, an accurate indication of the place formerly occupied by a sporophore is supplied by the shot-hole cup (Pl. II), so termed and described by Meinecke (15, p. 23, 46). These shot-hole cups appear as cup-shaped depressions below a knot, the depression being riddled with numerous fine holes. At first they have the color of the freshly opened bark of the tree, but later become weathered and gray with age. They are formed in the following manner: The soft fleshly or cheesy sporophores issuing through knots are usually soon eaten by squirrels and micro-lepidopterous larvæ. Some of these larvæ then bore into the bark of the tree, where they are sought after by woodpeckers, which chop out a cup-shaped depression in the bark, corresponding to the place formerly occupied by the sporophores. This depression is riddled with what appear to be numerous fine shot holes, the burrows of the insect larvæ.

The presence of a shot-hole cup is just as reliable an index of dry-rot in a tree as is a sporophore. However, the same diagnostic values in relation to the age of the fungus plant in the tree, and consequently the extent of the resulting decay, must not be attached alike to sporophores and fresh and old shot-hole cups. An old, gray, weathered shot-hole cup would indicate the most extensive serious decay, while a fresh shot-hole cup, in turn, would indicate more extensive decay than a sporophore, since it is evident that more time must elapse before a shot-hole cup is formed than a sporophore and the longer the fungus plant lives in the heartwood the greater the amount of decay resulting.

The number of sporophores occurring on a standing living tree is typically one. Von Schrenk (27, p. 205) gives the number as usually one, but it must be remembered that at this time no description of *Polyporus amarus* had appeared, so it can not be stated definitely that Von Schrenk was referring to this fungus. However, Meinecke (15, p. 46, pl. 12) gives the number as typically one. Sometimes two have been found. As many as five shot-hole cups have been observed on a single living tree, but an examination of their condition invariably showed that they had been developed successively, or at least not more than two in the same year. But on dead down trees the above rule does not hold. Of the seven known occurrences (see p. 9) several trees had two or more fresh sporophores.

During the course of the actual work of dissecting the trees exact data were secured on three sporophores and 17 shot-hole cups distributed on 15 trees, as follows: Two abortive sporophores on separate trees, one normal sporophore and two shot-hole cups on the same tree, 10 shot-hole cups on separate trees, 2 shot-hole cups on the same tree, and 3 shot-hole cups on the same tree.

That there might be a definite orientation of the sporophores in standing living trees was suggested by the work with *Trametes pini* of Möller (18), in which he found 89.4 per cent of the sporophores on the westerly side of the trees, attributing this to the facts that the prevailing winds were from the west, the trees were most strongly struck by rain on the west side, and therefore the branch stubs (a very common point of infection) were more moist on that side. Furthermore, he states that the sporophores appear at the same spot at which the infection commences. Weir and Hubert (32, p. 30), working with the Indian-paint fungus (*Echinodontium tinctorium*) on western hemlock (*Tsuga heterophylla*), found that most of the sporophores had a northwest to north-northeast orientation. However, the sporophores and shot-hole cups of *Polyporus amarus* are rather equally distributed to all points of the compass, showing no definite relation to any particular direction, and in not a single case was the sporophore developed at the same point at which the infection apparently commenced.

These sporophores and shot-hole cups occurred on trees ranging from 24.2 to 44.2 inches diameter breast high. The youngest tree which bore a shot-hole cup was 193 years old at stump height (1.5 feet), the next youngest was 221 years of age (28 years older), and the oldest, 379 years. Between the ages of 193 and 379 years the trees with sporophores or shot-hole cups were rather equally distributed. These figures are not given for the purpose of establishing a diameter breast high or age range for trees in which *Polyporus amarus* fruits; the number of trees examined forms entirely too meager a basis.

Sporophore formation did not seem to be in any way related to the width of the sapwood, since the sapwood in the trees which had formed sporophores varied from comparatively narrow in some cases to rather wide in others.

The heights at which the sporophores and shot-hole cups were found varied from 9.6 feet to 48.7 feet from the ground level, but thirteen of them occurred between 15 and 30 feet and only two at a greater height than the latter figure. Sporophores or shot-hole cups always indicate that there is well-developed dry-rot in the heartwood. In such infections it is generally possible to distinguish three stages in the affected heartwood, with upper and lower limits. These stages for convenience are termed total extent, unmerchantable extent, and maximum concentration. "Total extent" is expressed by giving the height in feet in relation to the ground level of the lowest and highest point in the bole of the tree invaded by the fungus without regard to radial extent. By "unmerchantable extent" is meant the portion of the bole rendered valueless for lumber by the dry-rot, while "maximum concentration" covers that portion of the bole in which the decay seems to be at its worst. The upper and lower limits of all three of these stages may at times coincide, but especially that of the unmerchantable extent and maximum concentration. It is self-evident that these last two mentioned can never exceed the total extent.

The sporophores and shot-hole cups invariably appeared between the upper and lower limits of the maximum concentration. The lower limits varied from 3 to 25 feet below the sporophores or shot-hole cups, and the upper limits from 4 to 45 feet above them. In every case except one the lower limit of the unmerchantable extent was at 0. In other words the bole of every tree was unmerchantable, at least from the ground level to the sporophore or shot-hole cup. In the one exception the unmerchantable extent did not commence until 8.2 feet from the ground level. This was due to the presence of a large open fire scar extending from 0 to 10.8 feet. The fungus distinctly avoids the dried-out wood around open wounds, which habit will be fully discussed later in this paper. The upper limits of the unmerchantable extent were variable. In the two abortive sporophores the unmerchantable portion extended for 10 and 24 feet, respectively, above the sporophores, while the extent above the shot-hole cups was 23 and 53 feet.

The total extent in every tree with sporophores except one (see above, under unmerchantable extent) reached from the sporophore or shot-hole cup to the ground level, but the upper extent was variable, being for the two sporophores 24 and 25 feet, respectively, and for the shot-hole cups ranging from 24 to 53 feet.

From the figures available it is impossible to make an exact statement as to the range of the total extent, unmerchantable extent, and maximum concentration of the dry-rot in trees with sporophores or shot-hole cups, except that it may be safely assumed not only from the figures at hand but from observations on logging areas that the bole of a tree will always be unmerchantable from the ground level to a variable height above a sporophore or shot-hole cup. But it must be remembered that an old shot-hole cup indicates a greater development for the fungus plant in the tree than does the first appearance of a sporophore or fresh shot-hole cup, and one should be influenced accordingly in judging the condition of a standing tree.

THE DECAY.

The dry-rot, described and pictured by Harkness (7), Von Schrenk (26, p. 68, pl. 2), and Meinecke (15, p. 46, pl. 12), is a very characteristic decay, most closely resembling the so-called peckiness of the eastern cypress (*Taxodium distichum*). Von Schrenk (26, p. 52–53) points to this analogy, even suggesting that the two diseases may be caused by the same fungus, but Long (12) has disproved this theory. The former investigator (29, p. 30) also calls attention to the macroscopical similarity between this dry-rot and the brown-rot of redwood.

Typically, the decay consists of vertically elongated pockets, varying in length from one-half inch to about a foot, which are filled with a brown friable mass, and the line of demarcation between the sound and decayed wood is very sharp. In some of these pockets small cobweblike or feltlike masses of white mycelium occur. The pockets are separated from each other by what appears to be sound wood, although in some cases streaks of straw-colored or brownish wood may extend vertically between two pockets. This is especially noticeable between young pockets. When immature the decay is faintly yellowish brown, soft and somewhat moist, and not broken up in the pockets. At times the mature pockets may be several feet long and rather broad; this type always occurs in connection with healed-over wounds, particularly healed fire scars in the butt of the tree. The decay has never been found in living sapwood and is usually confined to the heartwood of the trunk, but in very badly decayed trees the dry-rot sometimes extends into the heartwood of the larger limbs.

In the aggregate, the immature decay or advance rot extends but a short distance vertically in advance of the typical decay, and a distance of 2 feet beyond the last visible evidence of decay to the average eye will usually exclude all immature decay. This immature decay is very difficult to detect, occurring as it does in pockets, with the color in the very earliest stages differing but slightly, if at all, from the normal wood.

An occasional pocket may occur several feet in advance of the main body of decay, and while the wood of the pocket itself is of course greatly weakened, the intervening wood is probably very little affected, since the fungus hyphæ are very sparingly found between pockets of decay. In all, 566 trees containing typical dry-rot were dissected.

Typical dry-rot with small masses of white mycelium in some of the pockets is shown in Plate III.

STRUCTURE OF THE DISEASED WOOD.

The structure of the decayed wood in mature pockets was found to be practically as described by Von Schrenk (26, p. 70–71). In the very early stages of decay (immature pockets), cracks in the cell walls such as he describes for old pockets, which were most common in the pits, were rather rare. It was also found that cracks often started from the holes in the cell walls made by the hyphæ of the fungus. The color of the decayed wood varies from light to dark brown, depending on the state of decay.

In some of the decayed wood examined the bordered pits gave much the same appearance as is often presented by starch grains in a plant cell which have been partially corroded by diastase. Further examinations showed this condition of the bordered pits to exist in badly decayed wood, in slightly decayed wood, in the straw-colored wood between the pockets, and in sound wood. Immediately upon treatment with xylol, and more slowly with oil of turpentine, the pits resumed their normal smooth appearance; consequently, the condition is the result of a deposit on the membrane of the pits, but as to the nature of the substance deposited or the cause of its deposition the writer is unable to give any information. At least, the fact that the deposit was found on the pits in sound wood proves that it is in no way a result of the action of the fungus.

Badly decayed wood, slightly decayed wood, straw-colored and brownish colored wood between the pockets, and sound wood were treated with various reagents, the results in each case being practically identical. Anilin sulphate colored the cell walls a brilliant yellow. A cherry to violet-red stain was produced by treatment with phloroglucin and hydrochloric acid. Chloriodid of zinc and alcoholic iodin with sulphuric acid both stained the walls a yellowish brown color. After treatment for 12 hours with Javelle water, the wood turned a yellowish brown upon the application of chloriodid of zinc, and a brilliant yellow with the addition of anilin sulphate. The above tests demonstrate that the lignin compounds in the cell walls are not changed, in so far as our present knowledge of the nature of so-called lignin enables us to judge. Therefore, it seems probable that the fungus extracts from the cell walls either the cellulose or some other compound yet unknown.

THE MYCELIUM.

Hyphæ were very rare in the pockets of badly decayed wood or in the apparently sound wood immediately surrounding these. Proof of their having been quite commonly present, however, was afforded by the tiny holes in the cell walls of the decayed wood through which the hyphæ had passed. In the slightly decayed wood and the wood immediately surrounding it hyphæ were found abundantly. They bore through the cell walls in all directions, showing no preference for the bordered pits and apparently making no distinction between spring and summer wood. They were rarely found in the medullary rays.

Harkness (7) states that "the mycelium does not leave behind the slightest microscopical trace of its presence in the sound wood when passing from pocket to pocket." In some of the brownish and straw-colored streaks of wood which extended vertically from pocket to pocket of immature decay, hyphæ were found sparingly. These usually followed the lumen of a tracheid, but sometimes passed through the wall into the lumen of the adjacent tracheid. The writer was unable to follow the entire course of the hyphæ in any case from pocket to pocket and therefore could not verify Von Schrenk's statement (26, p. 73) that "between the rotted areas the hyphæ usually extend directly from hole to hole." In some cases no hyphæ were encountered in the discolored streaks between the young pockets, but this was probably due to the failure to make sections at the proper place. Hyphæ were commonly present in the apparently sound wood surrounding young pockets to a distance of 4 mm. (0.157 inch), and sparingly from that point to 8 mm. (0.314 inch) in a horizontal direction. Owing to lack of proper material it was possible to make only a limited study of the vertical distribution of the hyphæ. In the case of the last (highest) pocket in a diseased tree the hyphæ were abundant to a distance of 1.5 cm. (0.6 inch) above the pocket, and sparingly from that point on to 7.8 cm. (3.07 inch), where they ended.

Observation leads to the inference that the hyphæ are able to pass for some distance through the sound wood without causing the slightest microscopical change in the color or structure other than an occasional hole in a cell wall as the hypha passes from the lumen of one tracheid to that of another. In certain cases isolated pockets of decay have been found at a maximum distance of approximately 4.3 meters (14.3 feet) from the nearest pocket of decay, yet a very careful analysis showed that there was only one possible means of entrance for the fungus into the tree, and consequently the hyphæ must have traversed this distance through the sound wood before causing another pocket of decay.

As to why the fungus decays only the wood in localized pockets which are separated by areas of practically sound wood it is impossible to state, since nothing is known of the influence of a possible variation of the chemical and physical properties of the wood on the fungus. Or it may be that the answer to the question lies in another direction; that is, the hyphæ in their work of destruction after a certain time produce conditions unfavorable for their further development and are forced to seek another field.

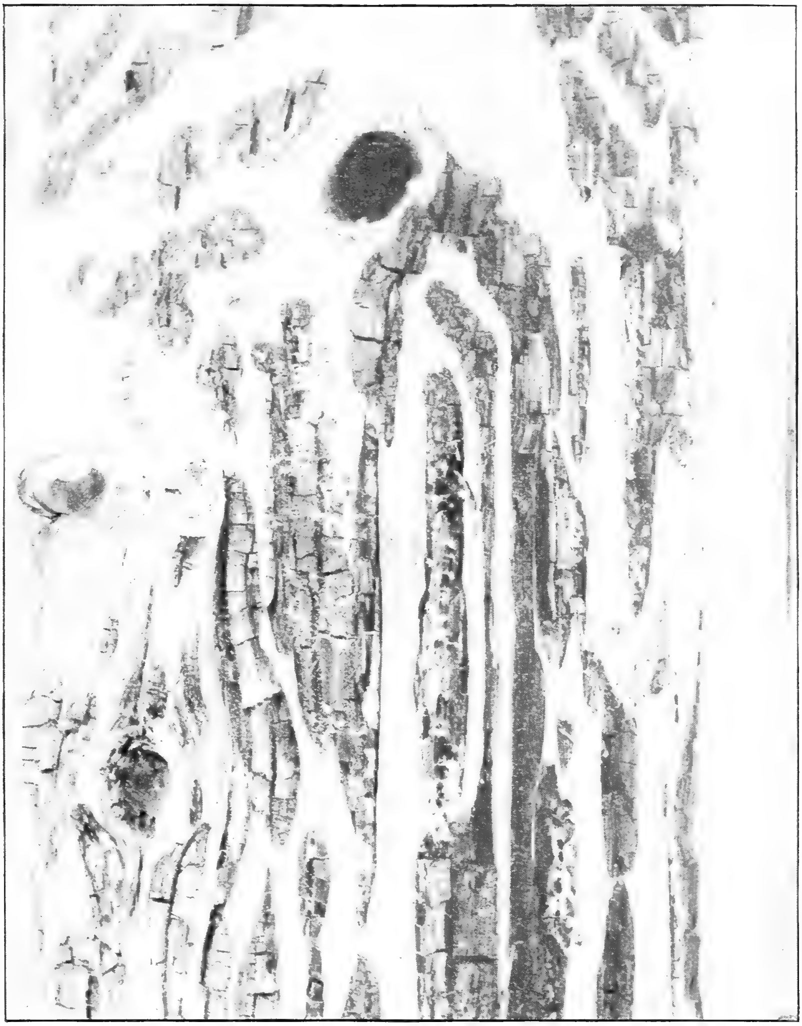
In the wood the hyphæ are hyaline, varying in diameter from 0.8 to 3.3 μ but being most commonly 0.8 to 1.7 μ, branching and rebranching into the finest threads, anastomosing, sparsely septate, rarely constricted at the septa, and sometimes having clamp connections. They never become so abundant as to fill the tracheids completely. Usually the hyphæ pass from the lumen of one tracheid into that of an adjoining tracheid and then extend up or down the lumen, but occasionally a single hypha may cross several tracheids in a radial or tangential direction without extending up or down their lumens or giving off any branches. The holes in the walls of the tracheids made by the hyphæ are very small, particularly so since the hyphæ are often sharply constricted when passing through the walls. Rarely the hyphæ are irregular in shape.

The hyphæ composing the cobweblike and feltlike masses of mycelium in the badly decayed wood (see p. 13) are usually hyaline, but sometimes have granular contents. They vary in diameter from 0.8 to 40 μ, are richly branched, more commonly septate than the hyphæ found in the wood cells, and sometimes constricted at the septa. No clamp connections were found. They frequently anastomose. They were often very irregular in shape, and globose or spindle-shaped swellings were frequent.

OTHER FORMS OF DECAY.

Besides the typical decay already described, two other very characteristic forms were found. One of these is characterized by small spots or pockets of brown decayed wood varying in width from 0.5 to 2 mm. (0.02 to 0.08 inch) and in length from 1 to 4 mm. (0.04 to 0.16 inch), with the long axis running vertically in the wood. In some cases larger decayed spots are formed by the joining of two or more smaller ones. The tiny decayed spots are separated by apparently sound wood. As for the structure of the decayed wood and its reactions with various reagents, these agree exactly with the typical form of dry-rot (see p. 14), and this decay is very probably an abnormal form of the typical decay caused by *Polyporus amarus*.

The other form of decay consists of very small white spots (measurements as given above) in which the wood has been reduced to cellulose, separated by apparently sound wood. The structure of the decayed wood is practically as described by Hartig (8, p. 53–54; 9, p. 36–37) for decay caused by the ring-scale fungus (*Trametes pini*), and the rot under consideration is undoubtedly caused by this fungus, since, through the courtesy of Dr. James R. Weir, the writer has been privileged to examine sporophores of *Trametes pini* with the typical



TYPICAL DRY-ROT IN INCENSE CEDAR CAUSED BY POLYPORUS AMARUS.

Photographed by Meinecke.

decay collected on incense cedar in Oregon. As far as the writer can ascertain, this is the only collection of its kind now known. Neither of these two decays affects the living sapwood.

The mycelium of both is the same and differs from the mycelium of typical dry-rot. Studies were made where these two decays were distinct, where they graded into one another, and where they graded into the typical dry-rot. The hyphæ vary from hyaline to dark brown in color, with a diameter ranging from 0.8 to 6.7 μ but most commonly 3 μ. The heavier brown hyphæ often branch profusely, the branches becoming smaller and lighter in color. The smallest ones are usually hyaline, and so are some of the larger hyphæ. In some instances the smaller hyphæ are merely continuations of the heavier strands. The hyphæ are sparsely septate, often constricted at the septa and without clamp connections. They bore through the cell walls in all directions, but seemingly more often through the tangential walls. No preference is shown for the bordered pits. They are characteristically sharply constricted when passing through the walls of the tracheids and have marked attachment organs. The hyphæ did not enlarge in the secondary lamellæ when boring through the wall, as is shown by Hartig (8, 9) for *Trametes pini*. Quite typically, a single strand may pass tangentially through as many as 20 or 30 tracheids, often completely traversing an annual ring, without sending any side branches into the lumens. This mycelium appears to agree closely with that described and figured by Von Schrenk (26, pp. 73–74, pls. 4–5), but which he assumed to be secondary and in no way connected with the dry-rot. Often the hyphæ seem to pierce a cell wall without developing in the lumen of the tracheid entered, a condition recorded by Hartig (8, p. 46) for *Trametes pini*. However, in so many cases unattached fragments of hyphæ were found in tracheids through the walls of which the hyphæ had penetrated without developing in the lumen that most probably the hyphæ did develop but were broken off in sectioning.

In all, 80 trees which contained one or both of these decays were dissected. The *Trametes pini* decay occurred alone in 61 of these, the dry-rot in small pockets in 11, and both forms in 8 trees. In 28 of the 61 trees having the *Trametes pini* decay, this was either intermingled, graded into, or very close to pockets of typical decay without there being any line of demarcation between the two. In certain cases the two decays could be absolutely traced to the same source of infection. Tree No. 40 on the intermediate area forms an excellent example. This tree had two small open fire scars in the butt just at ground level. There was a light infection of typical pockets of dry-rot extending from ground level to a height of 7.3 feet. At this point *Trametes pini* decay appeared without any line of demarcation and extended to 29.4 feet, and then the typical pockets of dry-rot reappeared, which ultimately ended at a height of 41.4 feet. The only possible means of entrance for the two forms of decay were the small open fire scars at the ground level. A similar condition is presented in tree No. 7 on the intermediate area. This tree had a large open fire scar extending from the ground level to a height of 8 feet. Typical dry-rot entering through this open wound began at 6 feet, extending to 9.7 feet, where it merged into *Trametes pini* decay, which then gave place to the typical dry-rot at 14.7 feet, and the latter finally ended at a height of 20.7 feet. No line of demarcation could be distinguished between the two decays, and the point of entrance of the infection was at the open fire scar. Other examples could be cited, but these seem sufficient.

In the eleven trees in which the dry-rot in small pockets occurred it was either very close to or intermingled with typical dry-rot in six, and in four of these six trees both forms of decay could be exactly traced to a common point of entrance. There were no apparent lines of demarcation in any instance between the two forms of decay. In tree No. 392 in the intermediate range typical pockets of dry-rot extended from ground level to 28.7 feet. At this point the typical decay changed to the small pockets, and this form occupied the heartwood to 36.9 feet, where the decay stopped altogether.

Finally let us consider the eight trees in which both the dry-rot in small pockets and the *Trametes pini* decay were found. In two of the trees the two decays occurred in different parts of the bole. In two trees the decays were very close together, while in four trees the two were accompanied by pockets of typical dry-rot. Tree No. 296 on the intermediate area offers an excellent illustration of this last condition. In this tree the dry-rot in small pockets, the *Trametes pini* decay, and typical pockets of dry-rot were intermingled, and transition stages between the three forms were apparent from ground level to a height of 30.3 feet. In four of the eight infected trees it was possible to trace the entrance of both decays to the same point, healed fire scars. There were no lines of demarcation separating the various decays.

The interesting point in connection with the two forms of dry-rot and the decay caused by *Trametes pini* is that they occurred in the same substrata, either merging into one another or actually intermingling without any well-defined lines between them. That such lines of demarcation between different decays are the general rule has long been accepted and has been most recently expressed again by Weir (31). Hence, it is particularly interesting to find two exactly opposite types of decay intermingling so freely. It is quite probable, however, that such occurrences in the future will come to be recognized as quite common. The writer has already found decays caused by *Trametes pini* and by *Fomes laricis* (the chalky quinine fungus) intermingled in the wood of living Douglas firs on several occasions, while down logs in the woods are often mycological gardens of wood-destroying fungi with the decays completely intermingled.

Both the dry-rot in small pockets and the *Trametes pini* decay are nearly always found around decayed knots or following along healed wounds, mainly those caused by fire. Where the infections occur around knots the decay is almost invariably confined to the immediate neighborhood of the knot, resulting in little or no loss in the merchantable contents of the tree. Where any appreciable quantity of wood was rendered unmerchantable, the decays were almost invariably in intimate connection with healed-over wounds caused by fire, frost, or lightning, particularly the first, throughout their extent. Exceptions to this rule did occur. In one tree, for example, the *Trametes pini* decay extended for a distance of 23.5 feet in the center of the tree above an open fire scar without being in connection with any other wound. But the fire scar was very large, extending deeply into the tree and undoubtedly had a far-reaching influence on conditions in the heartwood. In another tree (tree No. 40 on the intermediate area; see p. 17) this same decay extended for 22.1 feet in between two areas of typical dry-rot without following along any wound. The dry-rot in small pockets was found in one instance to extend for a distance of 8.2 feet, not in connection with a wound but merely as an extension of typical dry-rot. This case has already been cited (tree No. 392 on the intermediate area; see p. 18).

The above fact suggests that the dry-rot in small pockets may be the result of the influence on the dry-rot fungus of changed conditions in the heartwood, either physical, chemical, or both, induced by the presence of wounds or knots.

In further support of this hypothesis, it is almost invariably the rule wherever typical dry-rot is found along healed fire scars in the butt of a tree that instead of the pockets of normal size, one or more long continuous pockets of the dry-rot follow immediately along the scar throughout its length and invariably run out close to the end of the scar. A maximum length of 10 feet has been attained. Such pockets have never been found except in connection with wounds. This seems to prove that variations in the typical form of dry-rot may be induced by certain types of wounds in the tree.

The fact that the *Trametes pini* decay is usually found in the immediate vicinity of knots or healed-over wounds may be taken to indicate that incense cedar is an unsuitable host for *Trametes pini* and that the organism can rarely progress much beyond the point of infection. This would also explain the rare production of sporophores and the fact that in the only known collection, to cite Weir's words in a letter to the writer, "The sporophores are of the small depauperate type which I find occasionally on trees at high elevations or on old punk knots from which the original sporophores have fallen and are reviving."

However, for the purposes of this paper these decays may all be treated as one and the same, since the dry-rot in small pockets and the *Trametes pini* decay are of negligible importance both in the number of infections and amount of cull resulting. Hence, except in the data on the rate of spread of the dry-rot, they are included in all subsequent pages with the typical decay of *Polyporus amarus*.

No relation was found between the width of the sapwood and the extent of decay; trees with wide and narrow sapwood seem to be equally affected with the dry-rot.

RAPIDITY OF SPREAD OF THE DRY-ROT.

Although the rapidity of the spread of decay caused by heartwood-inhabiting fungi in standing trees has always been of interest, very little work has been done on this line. Hartig (9, p. 115–116), mentions this briefly in relation to the rot caused by *Polyporus* (*Fomes*) *igniarius* in oak. More recently Münch (23) has published some interesting results from studies of the same fungus and host, showing a wide variation of 3.8 to 37.5 cm. (0.12 to 1.23 feet) in the yearly vertical progress of the decay, with an average of 5 to 9 cm. (0.16 to 0.30 of a foot). No tangible difference was found between the upward and downward rate of spread from the point of infection. Münch's results are based on an analysis of only 15 cases, and their value is further reduced by the fact that in determining the age of the infection which entered a tree through an open wound, he assumed that infection must have occurred the year the wound was made, or at least a very few years subsequently, even though the wound was still open at the time of analysis. True enough, as shown by Münch (23), *Fomes igniarius* attacks not only the heartwood but the sapwood of many trees and kills the cambium, causing cankers with subsequent callusing, and by counting the number of annual rings in the callus at the point of infection the age of the decay can be determined, provided a canker was formed the year of infection; but this is not uniformly the case, to judge from Münch's (23, p. 519) own statement that "*Fomes igniarius* produces exceedingly variable cankers. Sometimes small points of infection which are scarcely noticeable and are soon healed perfectly . . ."

In securing the figures on the yearly rate of spread of the dry-rot, only those infections were considered the entrance of which could be absolutely traced, without any other possibilities, to a healed scar for which it was possible to determine the exact dates of occurrence and closure. For example, an infection is found in a tree which was cut in 1915. The fungus entered through a healed fire scar which occurred in 1781 and was completely closed by callusing in 1816. By subtracting 1781 and then 1816 from 1915 it is seen that the fungus has been in the heartwood a minimum of 99 and a maximum of 134 years. During this period resulting decay has progressed a vertical distance of 34.2 feet in the bole, or a yearly average of 0.25 to 0.34 of a foot. The radial extent of the decay is disregarded, since this is of little importance from a practical viewpoint. Any serious infection usually extends more or less throughout the heartwood in a radial direction. Of course, the above method does not give a single figure for the yearly average progress of the dry-rot, but it does give the exact minimum and maximum limits between which the true figure lies.

In all 99 infections were possible of analysis by this method. The great majority of these commenced at ground level, entering through fire scars and extending up the bole. Ten of the infections were traced to wounds high enough up on the trunk, however, to make possible a comparison of the upward and downward progress of the dry-rot. This meager basis indicated that the dry-rot, in the main, progresses more rapidly downward than upward, although in individual cases this relation may be reversed.

The yearly progress of the decay is exceedingly variable. At one extreme there is a tree in which the fungus had been vegetating between 124 and 135 years, but the resulting dry-rot had only attained a length of 0.4 of a foot, or a minimum average yearly progress of 0.002 and a maximum of 0.003 of a foot. The tree was 147 years old. At the other extreme, the fungus in from 10 to 58 years caused decay extending over 30.9 feet of the bole of another tree, that is, a minimum average progress of 0.53 of a foot a year and a maximum of 3.09 feet. This tree was 240 years old. Again, in a 107-year-old tree the fungus caused a decay with a minimum average progress of 0.87 of a foot and a maximum of 1.90 feet a year, extending a total of 40 feet vertically. In the main, however, the minimum progress of the dry-rot varied from 0.01 to 0.20 of a foot a year, while the maximum ranged from 0.01 to 0.35 of a foot. Higher yearly rates than the upper limits stated were not uncommon, but lower rates than 0.01 of a foot were rare.

These figures clearly demonstrate the slow progress of the dry-rot fungus in causing decay. Generally it required from 50 to 300 years to bring about any far-reaching dry-rot. In the heartwood of certain individuals the fungus had vegetated for decades, the resulting decay only extending 1 or 2 feet from the point of infection. A similar condition was found by Münch (loc. cit.) for *Polyporus* (*Fomes*) *igniarius* attacking oak. As to why the development of the dry-rot fungus in certain cases is so inhibited the writer is unable to present any definite information, but certainly the chemical and physical condition of the substratum must have a strong bearing on this phenomenon. Hartig (9, pp. 115–116) believes in the case of *Polyporus* (*Fomes*) *igniarius* that the width of the annual rings of the wood is not without influence on the rapidity of decay. Münch (20, p. 156) states that the more rapidly grown coniferous wood, consequently that with the broader annual rings, is more speedily decayed by *Fomes annosus* than slower grown wood with narrower rings, even extending this to broad and narrow rings in the same individual. Later (22, p. 403–406), he shows that suppressed individuals of beech artificially infected with *Stereum purpureum*, *S. rugosum*, *Polyporus* (*Fomes*) *igniarius*, and *P.* (*F.*) *fomentarius* were more seriously decayed than dominant thrifty trees, yet it is just such suppressed trees which must have the narrowest annual rings. Finally (23, p. 521), the same investigator finds no relation whatsoever between the breadth of the annual rings and the rapidity of decay in the wood of oak attacked by *Polyporus* (*Fomes*) *igniarius*.

PURPLE COLORATION.

Accompanying the dry-rot is a purplish coloration of the heartwood which is very characteristic. The writer does not find this mentioned in any description of the dry-rot so far available, but it is well known to the lumberman. This color varies from a light salmon-red or pink to a pronounced purplish red in trees with heavy decay, where it may stand out strongly in cross section as a ring surrounding the decayed area or present a mottled appearance over the entire heartwood. Where the coloration is faint it is sometimes impossible to detect it in cross section, but if the tree is split longitudinally the color is readily apparent, although it often fades out entirely after several days' exposure to light and air. It usually commences at ground level and extends upward, but may start at varying heights.

Microscopical studies of this colored wood did not show any deviation from sound wood. No hyphæ were found except at points immediately adjacent to pockets of dry-rot. No chemical or physical examination was possible.

In all, 634 trees were dissected in which the purple coloration was present. The notes from Cow Creek did not include data on this coloration. The youngest tree in which the coloration was present had an age of 72 years, while the youngest tree cut was 52 years old. No attempt can be made to set a minimum age limit for trees with purple coloration, since not many trees were cut below the age of 70 years.

Of the 634 trees under consideration, the purple was present in 84 in which no dry-rot was found. In these the coloration, varying through all shades from a very faint salmon pink to pronounced reddish purple, usually began at the ground level, extending up the heartwood to a minimum height of 2.6 feet and a maximum height of 31.4 feet. Of these trees 39 had open or healed-over wounds, mainly caused by fire, offering or having offered a means of access for the dry-rot, but the remaining 45 were without indications of wounds, the only possible mode of entrance for the decay being through branch stubs. It would be highly improbable that all of these trees could be infected by the dry-rot fungus without showing any indications of decay, so the conclusion is obvious that purple coloration may exist unaccompanied by *Polyporus amarus*.

In all, 510 trees with typical dry-rot alone or in conjunction with secondary decay were worked up at Sloat, Strawberry, and Crockers Station. Notes on 25 of these were incomplete so far as purple coloration is concerned, so they drop out of consideration. All but 17 of the remaining 485 had purple coloration accompanying the decay. In certain cases the coloration did not extend over the entire decayed area, running out before the decay ended, or else isolated pockets of dry-rot were found outside the area of coloration. In the 17 cases of dry-rot unaccompanied by any coloration, the decay as a rule was negligible. In four of these trees, however, there was a loss in volume caused by the dry-rot of 7.1, 21.3, 39, and 67 per cent, respectively, without any coloration being visible, indicating that serious decay can exist apart from the purple coloration.

Of the 59 infections of the *Trametes pini* decay, 4 became impossible of consideration because of incomplete notes. Of the remaining 55, 12 were unaccompanied by purple coloration, but all of these except two were very superficial infections. Even in these two the amount of cull was very small. This decay had already been shown almost invariably to follow wounds in the trees; hence, it becomes quite reasonable to presume that the absence of purple coloration was brought about in most instances by the change in the physical or chemical condition of the heartwood induced by the influence of the wounds.

Where the typical decay and the *Trametes pini* decay were intermingled the coloration was almost invariably present, although not always throughout the entire infected wood. This was also the case with the brown dotlike pockets. However, these data should not be judged as more valuable than indications, since the number of cases available was relatively few.

Secondary rots comprised 43 infections; only 12 of these were in conjunction with purple coloration. The 31 without coloration only yielded one cull case; the amount of unmerchantable volume was very small, and furthermore these secondary rots were almost invariably in connection with healed or open wounds.

Hence, on account of the failure to find any microscopical evidence of fungous action in purple wood, the presence of dry-rot outside the area of purple coloration in certain trees, the frequent occurrence of extensive coloration in trees free from dry-rot, combined with the usual presence of the purple coloration in wood badly enough decayed by *Polyporus amarus* to cause a noticeable reduction in the merchantable contents of the individual tree, while it may be more often absent in light infections, the conclusion appears obvious that purple coloration is not a result of the action of the fungus, but, on the contrary, if it bears any relation whatever to the dry-rot, is merely a condition of the heartwood inducing favorable development of the vegetating hyphæ. The fact that the *Trametes pini* decay is more often unaccompanied by the coloration is offset by such infections usually being superficial and following wounds which probably exert a profound influence on the heartwood. No relation was found between the purple coloration and the width of the sapwood. Trees with sapwood varying from very narrow to very broad alike had the coloration in the heartwood.

RELATION OF DRY-ROT TO AGE AND CONDITION OF THE TREE.

From previous hints in the literature (22, p. 403-406; 23, p. 520; 16, p. 18–19, footnotes), Meinecke's preliminary study on incense cedar and his later work on white fir (16), it was reasonable to assume that some relation should exist between dry-rot and the age and condition of the tree; i. e., the degree of dominance and suppression.

Münch (22, p. 405), working with artificially infected red beech, found suppressed trees more susceptible to decay by *Polyporus (Fomes) igniarius*, *P. (F.) fomentarius*, *Stereum rugosum*, and *S. purpureum* than thrifty, dominant ones and explains this by the theory that the wood of suppressed trees contains a greater amount of air, consequently more oxygen, than thrifty dominants. In previous experiments the same investigator (19, 20, 21) had brought out the strongly favorable influence of oxygen in the host tissues on the development of wood-inhabiting fungi. Meinecke (16, p. 48) recognizes three periods in the life of white fir in its relation to the stringy brown-rot caused by the Indian-paint fungus (*Echinodontium tinctorium*): (1) The age of infection, at which "the infection rarely leads to more than negligible decay unless the tree is handicapped by quite unusually severe conditions, such as very large old wounds;" (2) the critical age, which "marks the point after which a combination of pronounced suppression and heavy wounding generally results in distinct decay;" and (3) the age of decline, "when even dominant (that is, thrifty) trees become subject to extensive and intensive decay." The relation between decay and suppression is brought out.

The crown class, as determined by observation of the standing tree, expresses the past history, more or less strongly modified by conditions prevailing through a varying number of years previous to the time of observation; it may not give the real past history of the tree. "Dominance" and "suppression" are really incorrect terms, used for lack of better ones. They are based on the relation of the height of one tree species to others in the same stand. In this case height alone would be misleading. For example, consider a more or less second-story species in a mixed stand, in which category incense cedar falls. Practically all the trees would be included in the intermediate or suppressed classes when related to other species in the stand, thus entirely obscuring the true relation of the individuals within the second-story species. On the other hand, it is an exceedingly difficult undertaking, often leading to grave error, to attempt classification by the observation of individuals in a mixed stand with relation to other individuals of the same species.

For our purposes we can not consider other tree species, but must compare individual trees with others of the same species. But here, also, height alone is not the deciding factor. Instead of giving dominance and suppression in the current meaning, these terms are expressed by the relation of the actual volume of the tree to the average volume of trees of the same age. Therefore, it was necessary to "curve" data collected on a number of trees to secure average volumes by age. Only trees of normal form with exact ages and free from severe wounds, malformations, and other seriously injurious factors which would interfere with the correct computation of the volume were used. Curves were constructed for the intermediate area and for the optimum area, since it was apparent that the volumes by ages would be much higher for the last-named areas than for the first, which fact was strongly brought out by the resulting curves. These curves are presented in figure 1, the higher curve based on 461 trees representing the optimum area and the lower based on 340 trees, the intermediate area. The National Forests on which these areas were located are also indicated. Thence, the trees for the intermediate area and for the optimum area were rated in regard to their respective curves, those with a volume higher than the average given by the curve for the same age being classed as dominant and those with a lower volume as suppressed. At first, an intermediate group was selected by designating an arbitrary volume above and below the average volume, trees between these limits being classed as intermediate. However, it was found that such trees inclined either toward the dominant or the suppressed in their characteristics, depending on whether they were above or below the average in volume for the same age. Furthermore, it was exceedingly difficult

182803°—20—Bull. 871——4

to determine just what the limits of the intermediate class should be, so in order to preclude any error in judgment the procedure as first stated of establishing just two classes, dominant and suppressed, to include all the trees, is followed throughout.

The method of obtaining the volume of the tree in cubic feet requires a little explanation. Each tree was considered as a perfect cone over the stump, at which the age count had been taken, in order to obtain directly comparable figures for the different ages. Figures from normal trees showing the relation of the diameter breast high to diameter of butt at stump height (1.5 feet) were plotted and curved, the strongest portion of this curve lying between 10 and 50 inches diameter breast high. From this curve a table expressing

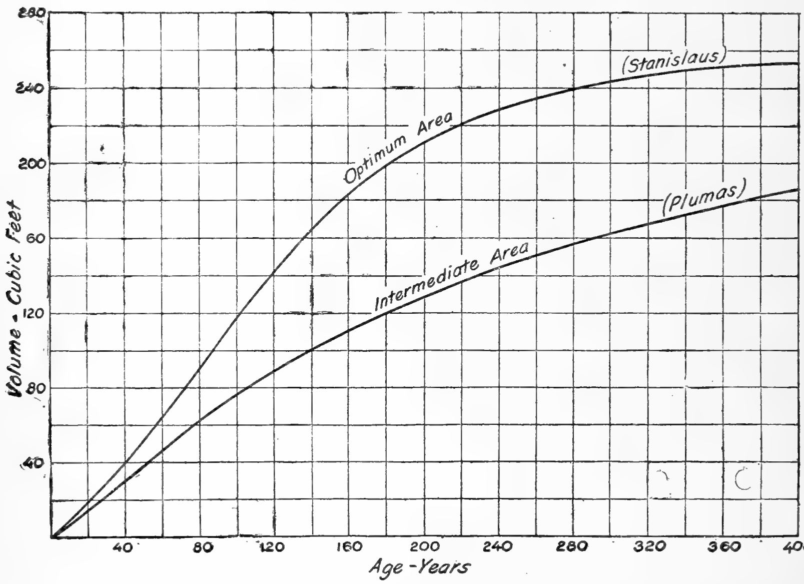


FIG. 1.—Comparison of average volumes of incense cedar on the optimum and intermediate areas.

the relation of the diameter breast high to diameter of butt at stump height for each inch class was read. It was then a simple matter to secure the diameter outside the bark at stump height for any tree, no matter how irregular the stump might be, due to wounds or other factors, and combining this with the height to work out the total cubic contents. Loss of volume caused by wounds or other factors was disregarded. In other words, each tree was treated as if it was absolutely normal. Let it be emphasized again that the volumes obtained were not meant to be an exact expression of the actual volume of each tree to the last cubic foot but merely had to be directly comparable to each other for the various ages.

In considering the trees with decay, each separate focus of dry-rot is termed an infection, and there may be two or more infections in the same tree, each one, however, the result of a separate and distinct inoculation. As soon as an infection causes a measurable amount of cull it becomes a cull case and is so termed. Hence, every infection is not a cull case, but every cull case is an infection. Only loss of merchantable timber through dry-rot is considered; cull from wounds, knots, limbs, insect borings, or crook is disregarded, since these have no bearing on the loss from dry-rot except when the decay is directly traceable to a wound. In such cases loss from the wound is included with the volume of rot.

For figuring from the field notes and measurements the cull caused by dry-rot, the amount and degree of damage with relation to the resulting loss in merchantable lumber was carefully taken into account, just as it is in scaling. For example, a cull case might have considerable linear extent but consist only of a few scattered pockets in a straight line, resulting in little or no loss in merchantable volume. The same number of dry-rot pockets, shorter in linear extent but radially scattered throughout the heartwood, probably would cause considerable cull. Again, a number of pockets close to the sapwood, mostly slabbing out when the log is sawed, would have far less weight than the same pockets in the center heartwood. Meinecke's method (16, p. 37) of considering the entire bole of the tree over the linear extent of decay as cull, while justifiable with the commercially inferior white fir, could not be applied to the distinctly more valuable incense cedar. Here the lateral extent of the decay also had to be taken into account. This could be readily determined from the field notes and diagrams. For example, if the decay occupied one-fourth of the area as seen on cross sections and had a linear extent of 10 feet, the volume outside the bark of this 10-foot frustum (the tree being considered as a cone, see p. 26) was first secured and then one-fourth of it was considered as the volume of the decayed portion of the tree. Below one-fourth the decay was usually treated as negligible except when it had a linear extent of several feet. The volume was then computed as before.

Separate tables containing the above figures were worked up for the four areas, the trees being arranged progressively by ages, beginning with the youngest. It does not seem necessary to present these tables, since they were merely preliminary.

In considering the trees on the intermediate area it was found that the first infection which resulted in cull occurred in a tree 98 years old. However, infection can take place at a much earlier age than this. For example, in a tree 104 years old there was a light cull case traced to a healed lightning wound. The tree was injured at the age of 50 years and the wound completely healed when the tree was 63 years old; hence, the tree could not have been older than 63 years at the time of infection. Again, in a tree 146 years old there was a serious cull case traced to a healed fire scar. This wound healed when the tree was 38 years old; hence infection could not have occurred subsequent to that age, since the field notes seem to exclude any possibility of an entrance of the dry-rot through a knot. Numerous other examples might be cited, but none of them reduces the minimum age of possible infection below 38 years.

An analysis of infections definitely traced to healed wounds in trees on the optimum area places the earliest age at which trees may be infected at 34 years, and this may be accepted as the age of infection for all the areas, since there is no apparent reason other than chance as to why the various areas should differ in this respect. Infections were very common between the ages of 45 and 80 years. No tendency was apparent toward an earlier age of infection in suppressed than in dominant trees, or vice versa. The foregoing figures are based on an analysis of 99 infections. Of course, this age may be even lower than here indicated, but it is evident that the earliest age of infection can not be lower than the age at which heartwood formation takes place in incense cedar. Just when this occurs is not definitely established, but observation seems to place it somewhere around 20 to 30 years. To be sure, there is a possibility of infection taking place in pathological heartwood resulting from an injury before the true heartwood is formed, the fungus mycelium vegetating in this type of heartwood until such time as true heartwood develops and then attacking it. While absolute proof of this course of procedure is lacking, observations have all tended toward substantiating the theory.

Furthermore, this age agrees approximately with that found by other workers with different species. Meinecke (16, p. 47) finds that for white fir (*Abies concolor*) decay caused by the Indian-paint fungus (*Echinodontium tinctorium*) "may show in trees 60 years old or perhaps younger," while Weir and Hubert (32, pp. 17–18), working with the same fungus in western hemlock (*Tsuga heterophylla*), set the average infection age for one type at 44.5 years and for another at 57.3 years. The figures are obtained by the use of a formula applied to the younger age classes. These same workers (33, pp. 11–12) place the "age of earliest infection" at about 50 years for western white pine (*Pinus monticola*) attacked by several common wood-destroying fungi.

Interesting as the determination of the age of infection or the age of earliest infection may be from an academic viewpoint, it is of little practical importance in this region. The questions of real import in this as in other species are the age at which decay begins to result in cull of economic importance and whether there is any relation between this and dominant and suppressed trees. The trees on the intermediate area and on the optimum area were first arranged by 40-year age classes, grouping dominant and suppressed trees separately, and the percentage of dry-rot was determined for each age class. This was done by relating the total volume of dry-rot in each age class to the total volume in cubic feet of the trees in that age class. From these tables it was apparent that while there was no tangible difference between the amount of decay in the dominant and suppressed trees on the intermediate area, on the optimum area there was a decided difference, most strongly shown in the younger age classes, the dominant group having a lower percentage of decay than the suppressed trees.

That the trees in the intermediate area fail to bear out the relationship between suppression and decay indicated by the results of other workers on different species is after all logical. The reason for this is not hard to find. These trees are in the intermediate range for incense cedar, where the growth on the whole is relatively slow, and while they may be placed in dominant and suppressed groups within themselves, yet in relation to the trees in the optimum range they are slow growing, practically all being included under suppressed, with a few dominants. In other words, most of these trees are under the influence of regional suppression. Another glance at figure 1, which shows the great disparity between the volume-age curves for the two regions, brings this out more clearly. The term "regional suppression" is a new one. However, the concept which it embraces has long been advanced in ecology and silviculture. That there is a marked decrease in vigor and a decline in the rate of growth for each tree species outside its optimum, becoming greater as the distance from the region of best development increases, until finally the species becomes completely suppressed by other species either in or closer to their own optimum, has been pointed out by Mayr (13, pp. 73–79). This is exactly what has happened to incense cedar in the intermediate range. At best a second-story tree, in this region, away from its optimum, it has become, except for a few scattered individuals, badly suppressed by Douglas fir, Jeffrey pine, and yellow pine, which, while not in their own optimum, are yet closer to such a condition than the incense cedar. Mitchell (17, p. 33) recognizes how far this may go in suggesting that it may be advisable to eliminate the species entirely on the sites less adapted to it.

An analysis of the field notes reveals that this regional suppression is not due to a pathological condition, which might be suspected from the presence of the mistletoe (*Phoradendron juniperinum libocedri*) or of the needle and twig parasite (*Gymnosporangium blasdaleanum*).

A comparison of the trees on the intermediate area with the volume-growth curve for the optimum area resulted in the classification of only 38 out of the total of 495 trees as dominant. In other words, 457 of the trees on the intermediate area are actually suppressed when compared to the average for the optimum area.

It is not to be expected that the growth habits of the dry-rot fungus would vary to any extent in regions so closely related climatically as the intermediate and optimum ranges of incense cedar; therefore, it is reasonable to believe that no matter what the classification of the trees on the intermediate area may be in respect to dominance and suppression when compared with the volume-growth curve for that area, to find the true relation of the dry-rot fungus to dominant and suppressed trees it will be necessary to determine the classification of each tree by comparison with the volume-growth curve for the optimum area.

This is brought out in Table II, in which the trees from all the areas are combined, the dominance or suppression of all the trees being determined by comparison with the volume-growth curve for the optimum area. Only trees in which the progress of the decay or a fire scar did not make it impossible to determine the age at stump height are included in this table. This explains the slight discrepancy between the total number of trees dissected and the total number included in this and subsequent tables.

TABLE II.—*Cull caused by dry-rot found in incense cedars of the combined areas.*

Age class.	Number of trees (basis).		Average age.		Cull caused by dry-rot (percentage of the total volume).	
	Dominant.	Suppressed.	Dominant.	Suppressed.	Dominant.	Suppressed.
0 to 40 years	0	1	....	40	....	0
41 to 80 years	8	43	74	57	0	1
81 to 120 years	60	125	105	105	4	2
121 to 160 years	66	218	142	140	4	4
161 to 200 years	42	191	180	179	7	12
201 to 240 years	34	84	223	222	19	26
241 to 280 years	15	79	265	258	52	40
281 to 320 years	7	42	301	294	68	60
321 to 360 years	3	16	341	332	68	66
361 to 400 years	2	2	372	368	83	68
401 to 440 years	0	2	....	436	....	5
Combined	237	803	166	173	16	20

In Table II the dry-rot percentage in the age class 161 to 200 years, for example, is figured on the total volume of all the dominant trees both sound and decayed in that age class and not on the total volume of both dominant and suppressed trees. This is the method used throughout the table.

It will be noticed that the number of trees (basis) in the suppressed class far exceeds the dominant, this being a direct result of the influence of regional suppression on the trees of the intermediate area.

The columns of greatest interest are the last two, in which the dry-rot percentages of the dominant and suppressed trees in the different age classes are directly comparable. By dry-rot percentage is meant the percentage of cull caused by the decay resulting from the work of the dry-rot fungus. The reader should remember that the percentage of cull based on the merchantable volume of the trees would be higher than the percentages here given, since these are based on the total volume of the trees outside bark and including the entire top. In the younger age classes up to 160 years the percentage of cull is small and variable, in one class higher in the suppressed, in another higher in the dominant, and in a third equal. But in the age class of 161 to 200 years a decided jump in the percentage of cull occurs, particularly in the suppressed trees. While the increase in the case of the dominants is only 3 per cent, in the suppressed trees it amounts to 8 per cent, bringing the cull percentage to 12. In the next age class a still further change is apparent. Here the cull percentage in the dominant trees increases strongly, as does also the percentage in the suppressed trees, the latter still remaining considerably higher than the former. But in those subsequent classes which have a sufficient numbers of trees to make the data of value, the cull is higher in the dominant than in the suppressed trees. When the age classes are combined, the total cull is 4 per cent more in the suppressed than in the dominant trees.

The salient features shown by Table II are the low percentage of cull in the younger age classes, the sudden increase earlier in the suppressed than in the dominant trees, which after it once begins goes steadily on with advancing age, and the higher percentage of cull in the suppressed trees as compared with the dominant trees in the two age classes which show the first sudden increase in this percentage.

However, the percentage of cull caused by dry-rot is not the only figure of interest, since it is prerequisite that the trees first be infected and that these infections develop sufficiently to cause measurable cull. Table III gives the figures on percentage of infection and cull cases. The number of trees used as the basis and the average age are the same as in Table II.

TABLE III.—*Infections and cull cases found in incense cedars of the combined areas.*

Age class.	Infections (percentage of total number of trees).		Infections causing measurable decay (percentage of total cull cases).	
	Dominant.	Suppressed.	Dominant.	Suppressed.
0 to 40 years	....	0	....	0
41 to 80 years	12	5	0	5
81 to 120 years	50	33	28	15
121 to 160 years	62	42	35	28
161 to 200 years	57	62	36	44
201 to 240 years	71	74	56	63
241 to 280 years	87	82	80	78
281 to 320 years	100	90	86	88
321 to 360 years	100	87	100	87
361 to 400 years	100	100	100	100
401 to 440 years	....	100	....	100
Combined	61	54	41	42

Table III shows that the percentage of infections is not in exact relation to the percentage of cull caused by dry-rot as given in Table II. In the age class of 41 to 80 years, while the percentage of infections is higher in the dominant trees the percentage of cull is slightly lower. In the age class of 81 to 120 years these percentages bear the same relation to each other as they do in all other classes except the classes of 121 to 160 years and 361 to 400 years. In the former there is a much higher percentage of infections in the dominant trees, while the percentage of cull is equal, and in the latter the percentage of infections is the same in both dominant and suppressed trees, while the percentage of cull is higher in the former. For all the age classes combined the percentage of infections is markedly higher in the dominant than in the suppressed trees.

Now, considering the columns relating to the total trees with cull cases, that is, where infections cause a measurable amount of decay, it is found that in the age class of 41 to 80 years none of the infections in the dominant trees result in cull cases, while all of the infections in the suppressed trees do, thus accounting for the higher percentage of cull in the suppressed trees in that class. In the next age class (81 to 120 years) the dominant trees have almost twice as many cull cases as the suppressed, and the percentage of cull is just twice as great in the former. But in the age class of 121 to 160 years, while the cull cases are in a higher percentage in the dominant trees the percentage of cull is equal in the two classes, showing that there is more loss per cull case in the suppressed than in the dominant trees. In the subsequent age classes the cull cases and the percentage of cull are in the same general relation except in the age class of 361 to 400 years, where the difference is the same as explained for the infections. The total cull cases for the suppressed trees is only 1 per cent higher than for the dominant trees.

The idea might have been advanced that since inoculation by spores of any wood-destroying fungus is to a certain extent a matter of chance, the greater percentage of cull in the suppressed trees might have been due to a greater number of infections in these trees. But Table III shows more infections in the dominant trees, while the cull cases are about equal in both. Therefore the cull cases must be more severe in the suppressed trees.

The infections, or even the cull cases, do not show the same progression through the age classes from the youngest to the oldest as is shown by the cull percentage. In the former the sudden, sharp increase in the age class of 161 to 200 years for the suppressed and in the class of 201 to 240 years for the dominant trees is not apparent. The increase is more regular throughout, thus indicating that there is an influence other than merely the number of infections which has a strong bearing on the development of cull cases and the percentage of cull.

Since neither the total number of infections nor cull cases follows the same law as the percentage of cull, it is self-evident that there must be an exact relation between this last and the more extensive or severe cull cases. Accordingly, in Table IV the severe cull cases, that is, those cases in which one-third or more of the total volume of the tree is a loss through dry-rot, are considered separately. The same basis is used as in Tables II and III and the percentages are based on the number of trees in the dominant and suppressed groups considered separately in each age class.

TABLE IV.—*Relation between dominant and suppressed trees in severe cull cases found in incense cedars of the combined areas.*

Age class.	Severe cull cases (per cent).		Age class.	Severe cull cases (per cent).	
	Dominant.	Suppressed.		Dominant.	Suppressed.
0 to 40 years		0	281 to 320 years	71	66
41 to 80 years	0	0	321 to 360 years	67	81
81 to 120 years	3	2	361 to 400 years	100	50
121 to 160 years	2	2	401 to 440 years		100
161 to 200 years	5	14			
201 to 240 years	26	31	Combined	14	17
241 to 280 years	73	48			

In Table IV is seen the same form of progression for the severe cull cases as was shown for the amount of cull in Table II. Low percentages in both groups up to an age of 160 years, with a sudden increase in the percentage of severe cull cases in the age class of 161 to 200 years for the suppressed group are followed by a like increase in the class of 201 to 240 years for the dominant trees. After 240 years is passed there is a higher percentage of severe cull cases for the subsequent age classes in the dominant group, just as is the case for the percentage of cull. The only exception to this is found in the class of 321 to 360 years, where the relation is reversed.

The outstanding fact shown by Tables II, III, and IV is that incense cedar during the earlier stages of its life, even though heavily infected, is able to retard the progress of the dry-rot fungus in causing decay. Then comes a period, earlier in the case of suppressed than of dominant trees, at which the progress of the fungus can no longer be held in check and the trees become subject to severe decay, with the accompanying high percentage of cull. In other words, the decay becomes extensive. This period occurs in the age class of 161 to 200 years in the suppressed group and in the age class of 201 to 240 years in the dominant group. An analysis of the individual trees, in a table which is too long to present here, reveals the fact that this change begins at 167 years in the suppressed and at 214 years in the dominant trees, At these ages extensive decay, as represented by severe cull cases, becomes common in the individuals of the respective groups. These ages, using Meinecke's nomenclature, may be termed the "critical age" and "age of decline" for incense cedar—that is, the ages at which suppressed trees and dominant trees, respectively, become subject to extensive decay. Meinecke found a combination of severe wounding and pronounced suppression both contributing to the critical age in white fir, but in incense cedar wounding is not necessarily a factor. This will be brought out later when mechanical injuries are considered.

After the age of decline is passed, as shown by the percentage of cull in the classes older than 240 years, the dry-rot is more extensive in the dominant than in the suppressed trees. This means that while the dominant trees are able to ward off the extensive development of the dry-rot fungus for a longer period than the suppressed trees, after the age of decline is once passed dominance ceases to be a factor in resisting decay and, in reality, seems to favor it. This may be due to the fact that in the old, overmature dominant trees there is a higher percentage of food material (i. e., heartwood) for the fungus to work on in relation to the total volume than in the case of the suppressed trees. The fungus does not attack sapwood.

Let us consider what the foregoing paragraphs mean from a practical standpoint. Roughly, we may place the critical age at 165 years and the age of decline at 210 years. This does not mean that there is no loss from decay previous to these ages, or even that there are no severe cull cases; but the latter are so rare, as shown by Table IV, that they may well be regarded as exceptions. Since all but a very few of the trees on the intermediate area are suppressed, taking this area as representative for the intermediate range we can not expect trees within this range to remain free from extensive dry-rot after they have attained the age of 165 years. In the optimum range this same age may be set for suppressed trees, while dominants will remain relatively sound until the age of 210 years is reached. On the optimum areas dominant individuals comprised 36.5 per cent of the total, but on the intermediate area only 7.6 per cent.

No relation was found between diameter breast high and dry-rot. This could hardly be expected, considering that incense cedar is a tolerant species in an uneven-aged mixed stand.

In Tables II, III, and IV the comparison of the dominant and suppressed trees in their relation to the percentage of cull due to dry-rot has been emphasized to the neglect of other considerations in which the same relation might be found in both groups. In Table V many of the data given previously but separately for the dominant and suppressed groups are combined.

TABLE V.—*Combined data relating to dry-rot found in incense cedars of the combined areas.*

Age class.	Average age (years).	Number of trees (basis).	Percentage of— Dry-rot volume.	Severe cull cases.	Cull cases.	Infections.
0 to 40 years	40	1	0	0	0	0
41 to 80 years	60	51	1	0	4	6
81 to 120 years	105	185	3	3	20	38
121 to 160 years	141	284	4	2	29	46
161 to 200 years	180	233	10	12	42	61
201 to 240 years	223	118	22	30	61	73
241 to 280 years	259	94	44	52	79	83
281 to 320 years	296	49	62	67	88	92
321 to 360 years	334	19	67	79	90	90
361 to 400 years	370	4	82	75	100	100
401 to 440 years	436	2	5	0	100	100
Combined	171	1,040	18	17	42	56

Table V strikingly demonstrates the cumulative risk to incense cedar from dry-rot with advancing age. Starting at 1 per cent of cull in the age class of 41 to 80 years it mounts to 67 per cent in the class of 321 to 360 years. With a very gradual increase up to 160 years it then becomes rapid. The figure of 82 per cent in the class of 361 to 400 years, even though on an insignificant basis, is not without significance when considered in relation to the general previous progression. That this figure should drop to 5 per cent in the last age class need not cause concern, since the basis is only two trees. Even though infected, a tree may escape extensive decay throughout its life. This is a rare occurrence, however. The percentage of severe cull cases closely follows the percentage of cull throughout until the last two age classes with their small bases are reached. These two sets of figures show beyond doubt the high percentage of loss through dry-rot that may be expected in overmature cedars and clearly prove that the presence of such trees in our stands of the present and the future can be nothing but an economic loss.

That the percentages of cull cases and of infections do not follow the same form as the two others just discussed was shown in previous tables, but is more clearly brought out here. The reasons for this have been touched upon. However, these two figures are of interest when compared. It is seen that with advancing age the percentage of cull cases becomes increasingly higher at a more rapid rate than does the percentage of infections, until finally in the class of 321 to 360 years the two coincide. To be more explicit, the infections gradually begin to cause more and more measurable decay, until finally every infection has resulted in a cull case, no matter how slight. In the last two age classes both cull cases and infections have reached 100 per cent; but again we are confronted by the small basis and this figure can not be accepted. There is no doubt that a tree by rare chance may escape infection throughout its life, but there is hardly any possibility that when once infected sooner or later some cull will not result.

To make the relation just discussed even more apparent the four sets of data have been plotted in figure 2. From this, it can be seen that the form of the curves for severe cull cases and cull are the same, but differ quite markedly from the curve for infections. This shows clearly that infections alone are not the sole influence on the development of the dry-rot fungus, for if so the curves would have the same form. The slow progress of the dry-rot in the younger trees is very apparent.

The curve for the cull cases is somewhat intermediate, at first inclining toward the severe cull cases and later coinciding with the infections. The younger trees are able to retard the fungus suffi-

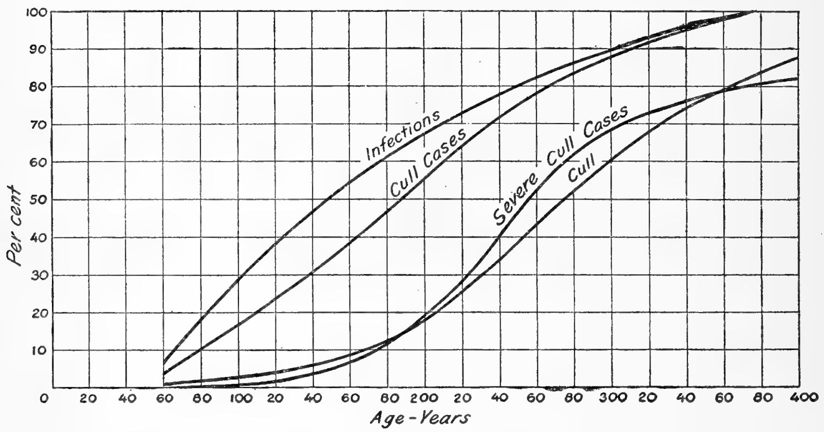


FIG. 2.—Relation of the age of incense cedar trees to infections, cull cases, severe cull cases, and cull.

ciently to prevent many of the infections from developing into cull cases, but later this characteristic is obscured.

The relative percentages of cull due to dry-rot on the various areas is not of importance from the standpoint of the present investigation. That this will vary widely even within the optimum and intermediate ranges is self-evident to anyone who has been on logging operations where incense cedar is being cut. At times the variation, even in localities quite close to each other, is surprising. On the intermediate area the cull for all the trees amounted to 20.5 per cent, while for the optimum area the figure was 16.8 per cent. These figures must not be taken as absolute, since it must be remembered that the areas were not clear cut. Practically every tree between the ages of 100 and 240 years was cut except those in which it was apparent that the age could not be accurately determined. Not all the trees below 100 years or over 240 years were cut, however, since this would have meant an enormously increased cost without adding much to the investigation, the chief aim of which was to determine the age at which dry-rot became extensive and far-reaching. However, the relative representation of trees in the older age classes was maintained as far as possible, neglecting entirely, of course, the few very old veterans always found scattered through a virgin stand.

The cull percentages given are indicative of the relative conditions that will exist in the intermediate and optimum ranges, although stands in the latter will on the whole be relatively more free from dry-rot than our figures indicate. However, the Office of Forest Pathology is now collecting figures for cull percentage by a less intensive method over various localities, and these will include not only cull due to dry-rot but to all other causes as well.

Before drawing final conclusions there is one other factor which must be considered in relation to dry-rot, namely, wounds or mechanical injuries.

MECHANICAL INJURIES.

The mechanical injuries which must be reckoned with are those caused by fire, frost, lightning, and the breaking off of branches as well as such miscellaneous factors as snow, falling trees, mammals, and wind. These injuries are important from three standpoints. First, they often afford an entrance to the heartwood of the tree for spores of wood-destroying fungi; next, the growth processes of a tree may be somewhat interfered with, resulting in a lessening of increment and a consequent tendency to suppression; and, last and least important, an actual loss in merchantable volume may result from the mere presence of the injury.

Spores of the dry-rot fungus (*Polyporus amarus*) must have an entrance to the heartwood before they can germinate and develop. As long as the tree is protected by a layer of bark and sapwood it is immune from the ravages of dry-rot or any other heartwood destroyer. Small superficial wounds are quickly protected by resin exudation from the bark, which forms an antiseptic dressing on the wound, safeguarding it from fungous spores until the wound is finally healed or callused over. But incense cedar is poorly supplied with resin. Normally it is found in a limited quantity in the bark only, active in the inner bark, dry and hard in the outer bark. Large superficial wounds may often prove to be serious. If the bark is torn off over a large surface there is not enough resin available to form a dressing, the sapwood dries out and cracks into the heartwood, and these cracks offer an entrance for fungous spores. The most serious type of wounds, of course, are those extending deep into the heartwood, for then the heartwood is directly exposed to infection by wood-destroying fungi for the entire period of time from the occurrence of the injury until it is completely healed over, and such injuries heal slowly. Wounds heal much more rapidly in young than in mature or overmature trees.

The causes of wounds are taken up in the order of their importance.

FIRE.

The most serious wounds, both numerically and in regard to the type of injury, result from fire. It is almost impossible to find a stand of timber anywhere in the Sierra Nevada or Coast Ranges which has not been visited by repeated fires. While the thick bark characteristic of incense cedar combined with the lack of resin in the wood makes it somewhat fire resistant, yet broad fire wounds commencing at ground level, reaching some distance up the trunk, and extending deeply into the heartwood are very frequent. These wounds are usually roughly triangular in shape, the base being at ground level and the apex at the top of the extent of the scar on the tree trunk. Considerable loss in merchantable timber results from the actual destruction of the wood, and there must be an appreciable decrease in increment until the tree readjusts itself to the loss in conducting tissue caused by the partial destruction of the sapwood and inner bark, which interferes with the conduction of water and soluble salts from the roots to the foliage and the return of elaborated food from the foliage to the roots. This loss is exceedingly difficult to gauge. Total loss in the merchantable timber occurs when a tree is completely girdled and killed or when the supporting tissue is so weakened by the wound that the tree is blown down.

Large fire scars or "catfaces" are rarely caused by only one fire, but usually by successive fires, each one hollowing out the heartwood a little more. As many as 10 distinct fires have been found contributing to the formation of one catface. As long as the wood is completely covered by a charred surface the danger of inoculation by fungous spores is reduced to the minimum, but the wood dries out and checks, forming cracks extending into the unburned wood. In time, the charred surface is weathered away, and finally the heartwood is exposed over the greater surface of the catface. Here is offered an excellent place for the entrance of a heartwood-destroying fungus.

Wounded trees make strong efforts to callus over the injury, and this is often accomplished in course of time if the wound is not too large. Very large catfaces, particularly on mature or overmature trees, are rarely healed over. The prevalence of wounds caused by fire may be seen from Table VI.

Table VI clearly shows that fire injury was much more serious on the intermediate area than on the optimum area. The columns of greatest interest are the third and last. The third column (percentage with open fire scars) shows that of the total number of trees analyzed on the intermediate area, 38.3 per cent had open fire scars, while on the optimum area the percentage is only 23.5. In other words, these percentages of the total number of trees cut on the areas under consideration were still exposed to infection by wood-destroying fungi through fire scars alone. The last column indicates that 72.2 per cent of the trees on the intermediate area and 49.3 per cent of those on the optimum area have had open fire scars at some period of their life history, thus exposing them to inoculation by fungous spores.

Table VI.—*Incense-cedar trees found in the combined areas having fire scars.*

Locality.	Number of trees (basis).	Trees with fire scars (per cent).			
		Open.	Internal.	Miscellaneous.[1]	Total.
Intermediate area	509	38.3	33.2	0.8	72.2
Optimum area	566	23.5	25.4	.4	49.3
Combined	1,075	30.5	29.1	.5	60.1

[1] Includes wounds probably but not certainly caused by fire.

The internal scars on the intermediate area exceeded those on the optimum area by less than 8 per cent, but there were 15 per cent more open scars. This points to the fact that the intermediate area has been visited by more serious fires than the other, since, as has already been pointed out, large catfaces are normally the result of repeated fires.

The combined figures for all the areas show that a total of 30.5 per cent of the trees had open fire scars, while 60 per cent suffered fire injury at some time. The column headed "Miscellaneous" includes trees with scars not identified beyond all doubt as having been caused by fire. These are so few that they need not enter into the interpretation of the figures.

FROST.

Frost causes some injury in incense cedar but is not nearly as serious in this respect as fire. Frost cracks as a rule extend for some distance up the tree and go deeply into the heartwood. A common place for the cracks to commence is just at the apex of an open fire scar, apparently a point of weakness in the tissues of the wood. Often they are somewhat spirally twisted around the trunk, distinctly reminding one of typical lightning scars. While frost cracks present only a very narrow opening for the entrance of fungous spores, yet in length those cracks or clefts are often quite extensive. In many cases the wood around a frost crack is badly discolored, causing considerable loss in the merchantable contents of the tree.

Typical frost cracks are rarely found except on large trees. Table VII shows the percentage of frost cracks on the trees analyzed.

TABLE VII.—*Incense-cedar trees found in the combined areas having frost cracks.*

Locality.	Number of trees (basis).	Trees with frost cracks (per cent).		
		Open.	Internal.	Total.
Intermediate area	509	4.12	3.14	7.26
Optimum area	566	1.41	.53	1.94
Combined	1,075	2.70	1.77	4.47

Here again, as in the case of fire, the wounding is worse on the intermediate than on the optimum area. The percentage of trees exposed now or in the past to inoculation by fungous spores through the medium of frost cracks is rather low and not of great importance on any of the areas. Frost cracks in incense cedar are not nearly so prevalent as Meinecke (16, p. 31) found for white fir.

LIGHTNING.

Incense cedar suffers only slightly from injury by lightning. This is to be expected, since the dominant species in a stand and as such the taller trees (25, p. 36) are most subject to lightning stroke, while incense cedar rarely attains this position in the mixed stand in which it is found. Plummer (25, p. 33) also shows that incense-cedar wood is a poor conductor of electricity.

An incense-cedar tree in the forest badly shattered by lightning is an exceedingly rare sight and immediately provokes comment. However, trees with slight lightning injuries are more common. Such injuries show as superficial wounds on the trunk. Often the wood is not scarred, but the bark and cambium are killed. The bark then drops away, exposing the sapwood, which in turn dries out and checks, offering fungous spores access to the heartwood. Long wounds extending spirally around the tree, so common in white and red fir in this region, are an unusual occurrence on incense cedar.

Table VIII indicates the prevalence of lightning scars.

TABLE VIII.—*Incense-cedar trees found on the combined areas having lightning scars.*

Locality.	Number of trees (basis).	Trees with lightning scars (per cent).		
		Open.	Internal.	Total.
Intermediate area	509	1.76	2.53	4.31
Optimum area	566	3.54	1.06	4.60
Combined	1,075	2.70	1.77	4.47

Besides the trees shown in Table VIII, there were seven on the intermediate area and five on the optimum area with slight wounds which appeared to have resulted from lightning; but an absolute determination was impossible. The meager basis in this table shows practically an equal number of lightning-scarred trees in the two localities.

BREAKING BRANCHES.

Incense cedar does not prune itself easily even when growing in a dense stand, a fact attested by the persistence of the lower limbs. In time, however, some of the lower branches die and break off. The dead stubs then offer a point of entrance for heartwood-destroying fungi; the spores lodging in the dead wood may germinate, develop, and the fungous hyphæ pass through the bark and sapwood of the tree into the heartwood by way of the pin knot. The pin knot in this case plays exactly the same rôle as an open wound, but it must be remembered that the area for lodgment of a fungous spore on a pin knot that is not healed over is exceedingly small in comparison with other types of wounds. On the other hand, there are normally from several to many open pin knots on each tree, and every tree, throughout all but the earliest years of its life, is thus exposed to inoculation by fungous spores through these open pin knots. Many of course heal over, but others take their places.

OTHER CAUSES.

Besides the causes of wounds already discussed, there are a few others of minor importance.

Strong winds will occasionally break off branches or tops, or overthrow entire trees, particularly those weakened by a bad open fire scar in the butt. The thick foliage of incense cedar collects a very heavy weight of wet snow, often causing the tops and branches of young trees especially to break off. Sometimes a falling tree will rake off the limbs and part of the bark of a neighbor. Such injuries are usually superficial unless very large branches have been broken off or the bark has been torn away from the trunk over a considerable area.

Man is at times directly responsible for certain wounds. It is quite a common sight along a newly constructed road to see bark torn off, often rather high on the trunk, where the tree has been struck by a flying rock from a powder blast. Some wounds result from blazing trees to mark a boundary line or trail, but they are usually small and rapidly heal over.

Broken or dead tops, the cause of which is often impossible to determine, are not at all rare. Trees with these injuries comprised 6.9 per cent of the total number on the intermediate area and 7.1 per cent on the optimum area.

PREVALENCE OF INJURIES.

Most incense cedars do not attain any great age or size without suffering some injury. Many old trees, and more rarely young ones, show numerous injuries, often fire, frost, and lightning having combined in the wounding of a single tree. Of the 509 trees on the intermediate area only 116, or 22.8 per cent, escaped without injury, while on the optimum area 38.9 per cent, or 220 of the total 566, were free from wounds. This difference is explained by the fact that the risk from injury has been greater on the intermediate area than on the optimum area, while a greater number of young trees were cut on the last-named area than on the first. The risk of injury is cumulative, increasing with the age of the tree.

This cumulative risk of wounding is shown clearly in Table IX, in which the trees from all areas are combined and arranged by 40-year age classes. Only those trees the ages of which it was possible to determine exactly are included in this table, while the data on wounds previously presented include all the trees. This accounts for the apparent slight discrepancy between the figures on the total number of trees involved.

TABLE IX.—*Incense-cedar trees showing cumulative wounding in the combined areas.*

Age class.	Number of trees (basis).	Total with wounds (per cent).	Trees with severe wounds (percentage of total wounds).	Age class.	Number of trees (basis).	Total with wounds (per cent).	Trees with severe wounds (percentage of total wounds).
1	2	3	4	1	2	3	4
0 to 40 years	1	0	0	281 to 320 years	49	98	62.5
41 to 80 years	51	29.4	6.7	321 to 360 years	19	100	68.5
81 to 120 years	185	48.6	14.4	361 to 400 years	4	100	100
121 to 160 years	284	59.2	28.6	401 to 440 years	2	100	50
161 to 200 years	233	74.3	35.2				
201 to 240 years	118	82.2	44.4	Combined	1,040	67.6	36.3
241 to 280 years	94	92.6	43.6				

In considering the figures in Table IX the reader should keep in mind the fact that since branch stubs are not treated as wounds, wounded trees practically mean fire-scarred trees, as the number of wounds from causes other than fire have been shown to be insignificant.

Considering column 3, which expresses the ratio of the wounded trees to the total trees, it is seen that the trees are subject to considerable wounding at a very early age and that this percentage increases very rapidly, until in the older age classes every tree has been wounded and consequently at some time exposed to infection.

Not only does the total number of wounds increase with age in a stand, but the number of severe wounds becomes proportionately greater. Each tree was given a wound rating (x), x, xx, or xxx, the first symbol indicating very slight wounding and the last very severe. In Table IX trees with a rating of xx or xxx are considered as severely wounded. In all cases the character as well as the extent of the wounding and its relation to inoculation by spores of the dry-rot fungus was carefully taken into account in applying the rating.

In column 4 of Table IX it is seen that while in the age class of 41 to 80 years only 6.7 per cent of the wounded trees are severely wounded, an almost steady increase brings this figure to 68.5 per cent in the class of 321 to 360 years. This is to be expected, especially since fire scars predominate, because large scars of this type are almost invariably the result of recurring fires, and in the past virgin stands in California have been fire swept time and again. The two oldest age classes can not be given much weight, owing to an insignificant basis.

The above figures demonstrate the rather slight chance an incense cedar has of rounding out its life without a reduction in its normal increment through an injury interfering with the growth processes or a reduction in its actual content of merchantable timber, either directly from a wound or by a wound affording an entrance for a heartwood-destroying fungus, in this instance most probably the dry-rot fungus (*Polyporus amarus*).

RELATION OF DRY-ROT TO MECHANICAL INJURIES.

The intimate connection of various kinds of wounding, especially fire, with infection by the dry-rot are shown in Table X. The infections are grouped under their respective causes and percentages for each cause, figured on the basis of the total number of infections. Trees of uncertain ages are included in these figures, since it makes no difference in this table whether or not the absolute age of the tree is known.

TABLE X.—*Mode of entrance of dry-rot infections of incense-cedar trees.*

Locality.	Number of infections (basis).	Means of entrance of infections (per cent).						
		Fire scars.	Knots.	Wounds, cause unknown.	Lightning scars.	Unknown causes.	Frost cracks.	Broken or dead tops.
Intermediate area	322	75.8	19.3	0.6	2.5	0.9	0.6	0.3
Optimum area	334	58.7	31.1	5.1	1.5	2.4	.9	.3
Combined	656	67.1	25.3	2.9	2.0	1.7	.8	.3

Table X shows that on the intermediate area nearly 76 per cent of all the infections entered through fire wounds; this means of entrance for the optimum area is approximately 59 per cent, while for all the areas combined it is almost 70 per cent. Since fire scars are almost invariably found in the base of the tree, commencing at ground level, these figures are at variance with Von Schrenk's (26, p. 69) idea that "the decay begins somewhere in the upper part of a tree."

Besides fire wounds being responsible for such a high percentage of the infections, inoculations through wounds of this character quite commonly lead to very serious and damaging dry-rot, even in some of the younger trees. In many cases, even in old trees, a long continuous pocket of dry-rot, sometimes having a linear extent of 10 feet, will follow a healed fire scar, running out at the end of the wound, with no further decay extending up the tree. Such infections do not appear especially serious, but it must be remembered that the most valuable portion of the trees, the heartwood in the butt log, is damaged. On the other hand, the fungus evidently finds conditions highly unsuitable in the wood back of a large open fire scar. Almost every tree with this type of wound appeared sound on the stump when felled, but serious dry-rot appeared at the first cut above the open fire scar. When such logs were split, it was found that the pockets of dry-rot commenced just at or a little above the top of the open fire scar, but rarely lower down. The avoidance of the dried-out wood around an open fire scar by the mycelium of this fungus is not at all in keeping with the results of experiments of Münch (19, 20, 21), which emphasized the highly favorable influence of an increase in oxygen coupled with a decrease in moisture in the host tissues on the development of various wood-inhabiting fungi. There should certainly be a big increase in the oxygen content of heartwood directly exposed to the air over that protected by a heavy layer of bark and sapwood, thus, according to Münch's theory, causing very serious dry-rot in the wood around open fire scars. The exact reverse of this is the condition actually existing. However, every wood-inhabiting fungus must have certain minimum physical requirements for its growth and development. Possibly the dried-out wood in this case falls below the minimum water requirement of *Polyporus amarus*, or it may be that certain chemical changes in the wood brought about by more or less exposure to the air inhibit the growth of the fungus mycelium.

Not every fire scar is inoculated, but the chances for inoculation with subsequent infection are rather high, owing to the relatively large area of heartwood exposed offering a broad surface for the lodgment of spores of the dry-rot fungus. On the optimum area, 70 per cent of the trees wounded by fire subsequently became infected, on the intermediate area 64 per cent, and on the combined areas 67 per cent. The percentage of risk of a tree with a fire scar becoming infected is very high.

Next in importance to fire scars as a means of entrance for dry-rot come knots. Of the infections on the intermediate area 19 per cent entered in this way and 31 per cent on the optimum area, while for the areas combined the figure is 25 per cent, a little more than one-third as many as were traced to fire scars. The greater part of such infections, because they rarely extend beyond the wood of the knot itself, are of little or no importance as compared with fire scars in promoting serious cull. Of the total infections entering through knots only 48 per cent resulted in cull cases and 12 per cent in severe cull cases, while in infections through fire scars, 80 per cent of the total became cull cases and 38 per cent severe cull cases. The above data were at first tabulated by 40-year age classes, but this brought out nothing of importance. In the case of infections through fire scars most of them developed into cull cases in every age class; while for infections through knots up to 200 years less than half developed into cull cases, but beyond that age the cull cases became more numerous.

Considering all the severe cull cases as 100 per cent, it is found that fire is responsible for 84 per cent, knots for 10 per cent, and all other causes for the remaining 6 per cent. Furthermore, 81 per cent of the total volume of cull caused by dry-rot resulted from infections entering through fire scars. This demonstrates the serious rôle played by fire in connection with dry-rot. Fire scars are responsible for by far the greater number of infections, and a high percentage of these infections results in severe cull cases.

Knots are of some importance, though, in promoting severe cull cases throughout the life of the trees, even in the younger age classes. For example, of the fourteen severe cull cases occurring in all the trees up to 165 years of age, four entered through knots.

Of course, every tree is exposed to infection in this way throughout all except the very earliest years of its life, not only at one but at several points, since each tree usually has from several to many open knots or branch stubs, whose dead wood offers a bridge for the fungus from the outside through the bark and living sapwood into the heartwood. However, each knot presents only a very small surface for the lodgment of spores of heartwood-destroying fungi. Out of the total number of trees open to inoculation through knots on the optimum area only 18.2 per cent became infected in this way, on the intermediate area only 11.4 per cent, and for all combined just 15 per cent. In other words, in the trees studied the chances for a tree becoming infected with dry-rot through branch stubs were merely 15 out of 100.

An examination of knots on the outside of a log or tree usually does not give any reliable indication of the condition of the heartwood with respect to its degree of soundness. In this respect dry-rot differs markedly from the stringy brown-rot (*Echinodontium tinctorium*) in white fir and the ring scale or red-rot (*Trametes pini*) in Douglas fir.

Fire and knots are responsible for over 90 per cent of the infections and severe cull cases; other factors are of minor importance.

About 3 per cent of the infections on the combined areas entered through wounds the causes of which it was impossible to exactly determine. Some of these may have been fire wounds, others lightning. Of all such wounds 23 per cent subsequently became infected.

Lightning is of little importance as a means of entrance for dry-rot. On the intermediate area only 2.5 per cent of the infections are traced to this source, on the optimum area 1.5 per cent, and for the combined areas 2 per cent. As a rule, lightning causes small superficial scars offering little opportunity for inoculation, but at times large areas of the cambium and bark are killed. This dead bark then drops off, exposing the sapwood, which dries out. Cracks opening up into the heartwood are formed, and such large areas offer a good chance for the lodgment of fungous spores. This condition is reflected in the percentage of risk of inoculation when it is found that 19.2 per cent of the lightning-struck trees on the optimum area, 31.8 per cent on the intermediate area, and 25 per cent for the combined areas were infected by dry-rot through lightning wounds. This figure is higher than that for all other factors except fire. The chief reason, then, that lightning wounds are of so little importance in relation to decay is not that the character of wounding on the whole is such as to offer little opportunity for inoculation, but rather that this type of wounding is rare.

As an actual means of entrance of decay, frost cracks are even less important than lightning wounds. These cracks, while often of considerable length, even then present only a very narrow opening exposed to the air, the chances of fungous spores lodging in such a small opening being exceedingly small. Not quite 1 per cent of the infections for the combined areas entered through frost cracks, while the risk of infection is only 10.4 per cent lower than for all others except broken and dead tops. But though a rare source of infection, frost cracks sometimes carry an infection, entering through some other type of wound, over a greater linear extent in the heartwood than might normally be expected, thus resulting in a large proportion of cull. The pockets of dry-rot do not occur in the wood immediately adjacent to the cleft or crack, but are usually found some distance removed, leaving the wood around the crack sound.

This is because of the avoidance by the fungus mycelium of the wood around open fire scars.

Infections through broken or dead tops may be absolutely disregarded, both numerically and in respect to the resulting decay. Out of the 75 trees with these injuries only one infection occurred, and this resulted in a negligible amount of decay.

However, the true relation of these various types of mechanical injuries to one another in respect to their importance as a means for the entrance and development of dry-rot on the areas studied is not expressed by the percentage of the total infections for which each type of injury is responsible, but must be shown by the relation of the number of trees infected through each type of wound to the total number of trees both sound and infected. The figures in Table XI express this relation, which might be termed "percentage of risk of infection." In one set of figures is expressed, then, for the trees actually studied the numerical relation of the various types of injuries combined with the relative chances for inoculation offered by each. All the areas are combined.

TABLE XI.—*Risk of infection of incense-cedar trees with dry-rot entering through wounds of the various types.*

Cause of wounding.	Risk of infection (per cent).	Cause of wounding.	Risk of infection (per cent).
Fire	40.0	Lightning	1.2
Knots	15.8	Frost	.5
Unknown	1.6	Broken or dead tops	.1

The figure 40 for fire expresses the fact that of all the trees analyzed each tree had 40 chances out of 100 of being wounded by fire and subsequently becoming infected with dry-rot through this wound, and so on for the other types of injury.

The far greater importance of fire wounds as a means of entrance for dry-rot as compared with all other injuries is strikingly brought out. Knots, the nearest competitor, are far less important, while all the others practically can be neglected.

The close relation of wounds and infections is shown even better in figure 3. The curve for wounds is plotted from Table IX, knots, of course, not being included, for had this been done the wound curve would have followed the 100 per cent ordinate throughout all the ages. The curves for infections and cull are the same as those given in figure 2.

These curves show that infections are practically a function of wounds, the two curves having almost the same form, but of course the infection curve being lower throughout until both have attained 100 per cent. The curve for the percentage of cull is included in order to emphasize the fact that while the increase in the number of wounds is closely followed by an increase in infections, the increase in the amount of cull due to decay is not a direct function of the increase in infections, but is also dependent upon the factor of age and thrift, as previously explained.

Meinecke (16, pp. 47–48) found in white fir that a combination of suppression and severe wounding was a prerequisite for serious decay in trees up to the age of 150 years. This does not hold for incense cedar. Of the ten severe cull cases in suppressed trees up to the age of 165 years, five occurred in trees slightly wounded, one in an entirely unwounded individual, and only four on severely wounded trees. Of the four dominant trees below the same age with severe cull cases, two are severely wounded and two slightly

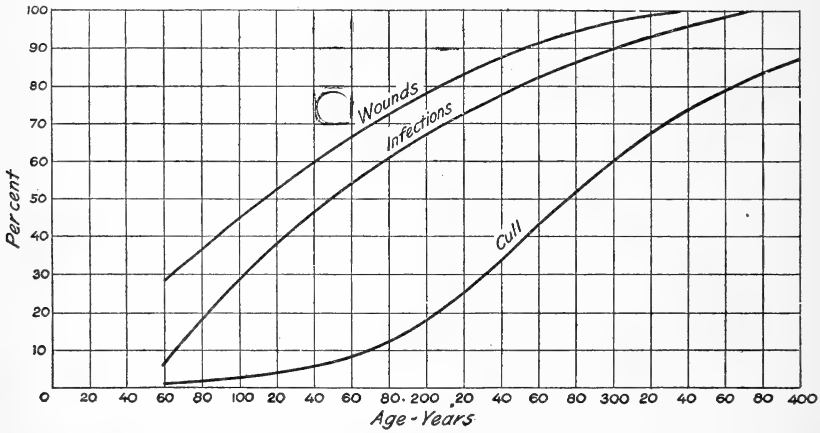


FIG. 3.—Relation of the age of incense-cedar trees to wounds, infections, and cull.

wounded. And, in fact, throughout all the age classes occur trees slightly wounded but with severe cull cases.

The foregoing considerations lead to the following conclusions: (1) Fire is responsible for by far the greatest number of dry-rot infections, commonly leading to serious decay, resulting in heavy cull. Fire is three times as important as its closest competitor, knots. (2) Knots are responsible for some far-reaching decay, but most of the infections through knots are confined to the immediate vicinity of the knot. (3) Aside from fire and knots all other means of entrance for decay are of little import. Lightning would be serious except that wounding from this source is rare. Frost is of no importance in promoting inoculation, since the wounded surface presented is small and frost cracks are relatively few. However, frost cracks often assist in carrying the dry-rot over a greater length of the bole than would be normal. Damage from unknown causes leads to some infection, but it is not of much importance. Infections through dead or broken tops are so insignificant that they may be entirely disregarded. (4) Severe wounding is not a prerequisite for severe cull cases or extensive decay at any stage in the life of incense cedar.

APPLICATION OF RESULTS.

RELATIVE IMPORTANCE OF DRY-ROT.

In the foregoing discussion the one big factor which stands out almost to the exclusion of all others is the dry-rot. Mechanical injuries of certain types play some rôle, not only in destroying merchantable timber values but in lessening the annual increment. However, it is chiefly the fact that wounds are the means for the entrance of dry-rot which makes them of any but insignificant importance.

Factors reducing the annual increment of the host, namely, *Gymnosporangium blasdaleanum*, *Phoradendron juniperinum libocedri*, *Stigmatea sequoiae*, and *Herpotrichia nigra* are of minor importance. In fact, only the first two named, being decidedly ubiquitous, are worthy of the least consideration; but the resulting loss is so slight and intangible that under present conditions it may well be disregarded except incidentally. The rare trifling loss in merchantable timber from burls of the mistletoe can not be of consequence.

Fungi such as *Polystictus abietinus*, *P. versicolor*, *Polyporus volvatus*, and others (see p. 4), only attacking dead wood and never found on living trees, are to be regarded as beneficial, since they hasten the decomposition of ground litter, thus increasing the humus in the soil and removing a serious fire menace.

Loss resulting in the heartwood of living trees from the so-called secondary rots is very slight in the aggregate. It is rare that such decays are at all far-reaching, and, furthermore, it is possible that certain of them may be abnormal forms of the dry-rot.

To repeat, then, the one big consideration from a pathological viewpoint which must hold above all in the silvicultural treatment and utilization of incense cedar is the dry-rot, together with the interrelated mechanical injuries.

CONTROL OF DRY-ROT.

Very little can be hoped for in the line of any serious consideration or attempt at direct control of dry-rot on private holdings for years to come. The private owner is averse to any increase in expenditures which does not show prospects of immediate gain. On certain private holdings where the incense cedar was heavily affected by dry-rot, all the trees have been left standing, only the more valuable species being removed, leaving the diseased individuals to continue spreading the decay to uninfected members of the present and future generations.

On the National Forests a great deal can be accomplished in the way of control of mechanical injuries resulting in wounds through which the dry-rot fungus can enter. As has been shown, fire is by far the most important factor in promoting dry-rot, with knots, the nearest competitor, of relatively far less importance both in regard to the number and seriousness of resulting infections.

Fire can be, in a great measure, directly controlled. The ever-increasing efficiency of the fire-protection methods on the National Forests, with the continual reduction in the number of damaging fires, speaks for itself. Certain private holdings are also protected from fire, either incidentally by falling within the boundaries of a National Forest or through a protection system handled on a cooperative basis by the United States Forest Service. Knots, of course, can not be controlled. Natural pruning, with the continual production of dead branches, which later break off, is inevitable in any forest. However, it may be expected that infections through this source will become increasingly fewer as time goes on, in proportion to the reduction in the number of fire-wounded trees. All other factors, whether controllable or uncontrollable, and this includes frost and lightning, are of so little importance that they may be neglected in any consideration of mechanical injuries in the future stand.

But fire protection works for the future welfare of the stand alone. It can not affect the huge number of individuals in the forest with healed or open wounds through which dry-rot has already entered or those uninfected individuals with open wounds still exposing them to attack by heartwood-destroying fungi; nor can it have any influence on all the other injured, diseased, or distorted members of the forest community. These have no place in the stand, are in most cases a direct menace to the sound trees, and should be removed as soon as possible. Unfortunately, we have not been able to attain the highly desirable intensive practice of eradicating such undesirable individuals by means of improvement thinnings applied at will wherever needed in the forest.

Under present conditions this can only be done in the main through timber sales, with free-use permits playing a limited part. But the Government is far from able to sell the timber where cutting is most needed from a silvicultural point of view. Economic factors, especially transportation, and in some cases the degree of soundness of the stand play the chief rôle in determining the exact location of a sale area. In fact, a mature or overmature stand badly in need of cutting may have to be left untouched, owing to the refusal of prospective purchasers to handle the high representation of inferior species.

In the case of incense cedar, this prejudice on the part of the lumberman does not arise from any inherent qualities or characteristics of the timber itself, but from the heavy infection of dry-rot in the mature and overmature trees, with the resulting high percentage of cull. Sound incense cedar is distinctly of high value and much sought after for special purposes, such as pencil slats, and in a lesser degree for cabinet material and interior finish. Wood not too badly decayed is of some value for posts and low-grade railroad ties. But the lumberman is naturally averse to handling a large quantity of unmerchantable material in order to secure a small percentage of a really valuable product.

The first step in overcoming this objection must be the application of a careful scaling policy.

SCALING.

In order to handle incense cedar properly on a timber sale the outward indications of hidden defect should be thoroughly understood. A valuable index to the condition of the timber will be found in the presence of sporophores or shot-hole cups on the trees. When found, their apparent age should be carefully taken into account in determining the degree and extent of the dry-rot (see p. 10). Excellent clues as to how a decayed tree should best be bucked are contained in the occurrence of shot-hole cups or sporophores. Since heavy dry-rot almost invariably extends from the ground level to a varying height above the highest sporophore or shot-hole cup it would, of course, be a waste of labor to buck the tree again at any place between the stump height and the last-named point.

The scaler should keep in mind the relation of wounds, particularly those caused by fire, to dry-rot in the tree. A large pocket of dry-rot occurring close to a healed wound, especially fire scars in the butt of the tree, usually diminishes in area as the height increases and ends in a point immediately above the termination of the healed fire scar it is following. For example, in case a butt log shows a large pocket of decay adjacent to a healed fire scar on its basal cross section, while the top cross section is absolutely sound, it is safe to assume that the decay will end about 6 feet from the base of the log, or in exceptional cases a length of 10 feet may be attained (see p. 44).

Particular care should be used in scaling butt logs with an open fire scar at the base. As has been shown (see p. 44), dry-rot of any seriousness is rarely found in the dried-out wood around an open fire scar. The base of such a log is nearly always absolutely sound; the top may show the entire heartwood unmerchantable. It is quite possible, then, for the scaler to judge the decay as extending half way down the log from the top, giving the lower half full scale and judging the upper half unmerchantable. This procedure is particularly likely to be followed on double-length logs (20, 24, 28 feet, etc.). But invariably the dry-rot will commence just at the top of the fire scar and almost immediately spreads out over the entire radius of the heartwood. In other words, in a log with an open fire scar showing on the base but otherwise sound and with pockets of dry-rot in the top end, the decay should be considered as beginning at about the top of the fire scar and extending from there to the upper end of the log in practically the same degree and radial extent with relation to the heartwood as is shown on the top end.

Advance rot (see p. 13) should be treated just the same as mature dry-rot.

In the case of a large swelling on the bole caused by mistletoe it is best to have the tree bucked in such a manner as to exclude the swelling rather than have such a defect reach the landing as part of an otherwise sound log and then be scaled out.

MARKING.

Timber sales at present offer the only extensive means of practicing intensive silviculture on our National Forests, and the entire results are absolutely based on correct marking. Fundamentally, the object of marking is to leave the stand in the optimum condition for its future welfare and development. This goal should never be lost sight of, no matter how clouded the issue may be by a complexity of immediate and often pressing considerations. To attain this end requires a high degree of skill, grounded on a thorough understanding of all the factors involved, not the least of which are those making for total loss in the species under consideration.

The fundamental object of marking has been far from completely attained if, after cutting, diseased individuals are left standing to carry infection to otherwise sound trees of merchantable size, besides menacing the future of the advance growth and reproduction. Obviously, then, trees with sporophores or shot-hole cups should invariably be marked for cutting, for these are positive proofs of damaging dry-rot. Such trees are as a rule not only a total loss, being unmerchantable from the butt to varying distances of 10 to 50 feet above the highest sporophore or shot-hole cup, but are the most potent factors in spreading infection to other trees, since infection can only be brought about by spores coming from sporophores on diseased trees. True enough, shot-hole cups in themselves do not menace surrounding trees with possible infection, but they do indicate that the fungus has reached fruiting maturity and is very likely to develop more sporophores, as is attested by the not uncommon occurrence of two or more shot-hole cups of varying ages on the same tree. Furthermore, the fungus mycelium in any infected tree possesses the potential capacity of sooner or later producing sporophores.

Remembering the great percentage of dry-rot infections entering through wounds, trees with injuries must be treated accordingly. Trees with healed wounds are of less concern than those with open wounds, since the former, if not already infected, are immune except for the inevitable, though fortunately not frequent, attack through branch stubs, while the latter are still open to infection. Then, too, the area of heartwood exposed by the injury is of grave consequence; the larger the area the greater the opportunity for infection. We already know the high percentage of infections through fire scars which so commonly expose large areas of heartwood; therefore fire-scarred trees, above all, should be marked as heavily as possible. Large lightning wounds are a serious danger, but small superficial injuries, especially if high up on the bole, can be almost disregarded. Frost cracks, though by virtue of the exceedingly small amount of heartwood they expose offering slight chance for infection, often aid in spreading infection established through some other agency, and trees with such wounds should be marked for cutting whenever possible. From the pathological viewpoint spiketops or stagheads may be almost disregarded except for their suppressing influence on the injured individual, but sound silviculture demands the removal of such trees from the stand.

Even if the Utopian dream of a forest community without injured individuals could be attained, this in itself would not result in completely controlling the destruction wrought by the dry-rot fungus, but only in minimizing it in a great measure. There would still be some loss from infections entering through knots. Then, too, no matter to what degree of intensive management a forest in this region may be brought in the future, some injuries will always occur, even from fire, while frost and lightning wounds are inevitable. The unavoidable injuries to a certain number of the seed trees during logging on any sales area must not be overlooked.

Therefore, all wounded trees must not only be eliminated on sales areas, but trees, even though unwounded and thrifty, must not be left with the expectation that they will be sound at the next cutting if by the time the cutting takes place they will have attained or passed beyond the age at which loss from dry-rot becomes of serious economic importance. It has been shown that the critical age occurs at 165 years and the age of decline at 210 years. Beyond the age of 165 years suppressed trees become subject to extensive decay, while up to that age they may be expected, with rare exceptions, to remain relatively sound, the same being true for the dominant trees at an age of 210 years.

Since in the intermediate range all but an insignificant percentage of the trees are suppressed in a greater or less degree, it becomes obvious that in this region incense cedar should be cut by the time it reaches 165 years, the critical age.

In the optimum range, suppressed trees must not be allowed to pass 165 years and dominant individuals 210 years (the age of decline) before felling.

Even in the distant future, when the risk of wounding in the forests is reduced to a minimum, it is highly problematical whether a new age of decline can be established at a higher age, on account of the entrance of decay through knots. Damaging dry-rot has entered trees through knots beginning at 105 years, and while such cases are rare in the years below the critical age and age of decline, yet they are sufficient to indicate that this condition will always have to be reckoned with. Furthermore, as time goes on, the increasing value of timber will result in noticeably lowering figures as to what constitutes an allowable percentage of cull in any species.

From a pathological viewpoint the critical age must limit the rotation of incense cedar in the intermediate range. It is doubtful whether even in the managed stands of the future the incense cedars in this range will be other than suppressed in most cases, since the present widespread suppression does not seem to be the result of any influence that could be removed by a system of forest management, arising apparently from the fact that the cedar is removed from the region of its optimum development.

In the optimum range the rotation must be limited by the age of decline. The critical age is not so important except during the period of transition, for suppressed trees, while common enough in the virgin stands of to-day in this range, will have little place in the managed stands of the future. Here, the species being in its optimum, nothing but thrifty, dominant individuals should be produced under a rational system of management.

The influence of decay on harvesting a timber crop was hinted at years ago by Von Schrenk (27, p. 203) and clearly pointed out by Meinecke (16, p. 61) for white fir. Mitchell (17, p. 32) took this so-called pathological rotation carefully into account, recommending a rotation of 150 years, at which time the species attains a good merchantable size. The rotation recommended by Mitchell is based on Meinecke's preliminary study of dry-rot.

As a result of the present study, the pathological rotation for incense cedar must be placed at 165 years in the intermediate and 210 years in the optimum range. During the transition period, while suppressed trees are still a factor in the optimum range, these should be cut when not older than 165 years. This does not mean that in the two regions under consideration cedar can best be cut at regular intervals of 165 and 210 years, respectively, but simply that if it is left to a greater age there is a full realization of the resulting enormously increased loss through dry-rot. The pathological rotation becomes a maximum limiting factor for the actual rotation, which may be financial, silvicultural, or one of maximum volume, depending on conditions in the future. From present indications it is highly probable that all other rotations for incense cedar will fall below the pathological rotation in both regions; the difference will be quite marked in the optimum range. It is possible in the optimum range that during the transition period, if necessary to leave suppressed trees standing after cutting, the increased vigor of such individuals which may follow the opening up of the stand might raise the critical age somewhat, but in the present state of our knowledge not only regarding the influence of thinning on the development of wood-destroying fungi in standing trees, but in the case of incense cedar regarding the actual response of the trees themselves, this consideration is entirely too hypothetical to influence our present conclusions.

SUMMARY.

The results of this study point to the following main conclusions:

(1) Incense cedar is classed as an inferior species because of a uniformly heavy percentage of cull caused by the dry-rot fungus (*Polyporus amarus*). Judicious scaling and instruction in the proper methods of bucking will ultimately aid materially in changing this view.

(2) Dry-rot can be eliminated in a large measure from future stands by intensive fire protection, but it can not be entirely controlled in this way, owing to the continued occurrence of unavoidable mechanical injuries caused by pruning, lightning, and frost.

(3) The following directions should apply to marking on timber sales:

(*a*) Trees with sporophores and shot-hole cups must be marked for cutting.

(*b*) Seriously wounded trees, especially those with fire scars, should be marked to be cut.

(*c*) In the intermediate range all but a very small percentage of the trees are suppressed. Since suppressed trees are subject to severe dry-rot after they pass the critical age of 165 years, trees left standing should be of such an age that they will not pass that age before the next cutting occurs. Dominant trees, being so few, may be classed with suppressed trees, but in reserving seed trees only the most thrifty individuals should be considered. By this practice some dominants will be among the trees left, and these will be safe until the age of 210 years is reached.

(*d*) In the optimum range, suppressed trees are subject to damaging dry-rot after they pass the age of 165 years (the critical age), while dominant trees are safe until 210 years (the age of decline) is reached. Therefore, suppressed trees left standing must be of such an age that they will not pass the critical age (165 years) before the next cutting occurs, and dominant trees left should not pass the age of decline (210 years) before the next cutting. Suppressed trees, however, should be heavily marked for cutting and only left unmarked if unavoidable.

(4) The rotation for incense cedar must not exceed 165 years in the intermediate and 210 years in the optimum range.

If for any reason the pathological rotations, as determined in this paper, must be exceeded in future operations on cut-over lands, the forester in making the decision will have a full realization of the enormous loss in merchantable timber to be faced through cumulative risk of cull due to dry-rot in the stands so handled.

LITERATURE CITED.

(1) BRYANT, R. C.
1913. Logging . . . ed. 1, 590 p., 132 fig. New York, London.

(2) CHAPMAN, H. H.
1913. Coördination of growth studies, reconnaissance, and regulation of yield on national forests. *In* Proc. Soc. Amer. Foresters, v. 8, no. 3, p. 317–326.

(3) COOKE, M. C., and HARKNESS, W. H.
1881. Californian fungi. *In* Grevillea, v. 9, no. 51, p. 81–87, 1881. (Continued article.)

(4) ELLIS, J. B., and EVERHART, B. M.
1892. The North American Pyrenomycetes . . . 793 p., 41 pl. Newfield, N. J.

(5) FARLOW, W. G., and SEYMOUR, A. B.
1888–91. Provisional host-index of the fungi of the United States. 3 v. in 1. Cambridge.

(6) GREELEY, W. B.
1907. A rough system of management for forest lands in the western Sierras. *In* Proc. Soc. Amer. Foresters, v. 2 no. 1, p. 103–114.

(7) HARKNESS, H. W.
1879. A foe to the lumberman. *In* Pacific Rural Press, v. 17, no. 4, p. 49, 1 fig.

HARTIG, ROBERT.
(8) 1874. Wichtige Krankheiten der Waldbäume . . . 127 p., 6 pl. Berlin.
(9) 1878. Zersetsungserscheinungen des Holzes der Nadelholzbäume und der Eiche in forstlicher, botanische und chemischer Richtung. . . 151 p., 21 pl. (15 col.). Berlin.

(10) HEDGCOCK, G. G.
1910. A new polypore on incense cedar. *In* Mycologia, v. 2, no. 3, p. 155–156.

(11) JACKSON, H. S.
1914. A new pomaceous rust of economic importance, Gymnosporangium blasdaleanum. *In* Phytopathology, v. 4, no. 4, p. 261–270, 1 fig., pl. 12–13. Bibliography, p. 268–269.

(12) LONG, W. H.
1914. Preliminary note on the cause of "pecky" cypress. (Abstract.) *In* Phytopathology, v. 4, no. 1, p. 39.

(13) MAYR, HEINRICH.
1909. Waldbau auf naturgesetzlicher Grundlage. . . 568 p., 27 fig., 3 pl.

MEINECKE, E. P
(14) 1912. Parasitism of Phoradendron juniperinum libocedri Engelm. *In* Proc. Soc. Amer. Foresters, v. 7, no. 1, p. 35–41, 2 pl.
(15) 1914. Forest tree diseases common in California and Nevada. . . A manual for field use. 67 p., 24 pl. Washington, D. C. Published by the U. S. Dept. Agr. Forest Serv.
(16) 1916. Forest pathology in forest regulation. U. S. Dept. Agr. Bul. 275, 62 p.

(17) MITCHELL, J. A.
1918. Incense cedar. U. S. Dept. Agr. Bul. 604, 40 p., 3 fig., 5 pl., 1 fold. map.

(18) Möller, A.
1904. Über die Notwendigkeit und Möglichkeit wirksamer Bekämpfung des Kiefernbaumschwammes Trametes Pini (Thore) Fries. *In* Ztschr. Forst u. Jagdw., Jahrg. 36, Heft 11, p. 677–715, pl. 4–5.

Münch, Ernst.
(19) 1907–8. Die Blaufäule des Nadelholzes. *In* Naturw. Ztschr. Land u. Forstw., Jahrg. 5, Heft 11, p. 531–573, fig. 1–28, 1907; Jahrg. 6, Heft 1, p. 32–47, fig. 29–31; Heft 6, p. 297–323, 1908.

(20) 1909. Untersuchungen über Immunität und Krankheitsempfänglichkeit der Holzpflanzen. *In* Naturw. Ztschr. Forst u. Landw., Jahrg. 7, Heft 1, p. 54–75, fig. 1; Heft 2, p. 87–114, fig. 2–5; Heft 3, p. 129–160.

(21) 1910. Über Krankhafte Kernbildung. *In* Naturw. Ztschr. Forst u. Landw., Jahrg. 8, Heft 11, p. 533–547, illus.; Heft 12, p. 553–569, 2 fig.

(22) 1910. Versuche über Baumkrankheiten. *In* Naturw. Ztschr. Forst u. Landw., Jahrg. 8, Heft 8, p. 389–408, 3 pl.; Heft 9, p. 425–447, fig. 18.

(23) 1915. Untersuchungen über Eichenkrankheiten. *In* Naturw. Ztschr. Forst u. Landw., Jahrg. 13, Heft 11/12, p. 509–522, 6 fig.

(24) Murrill, W. A.
1915. Western Polypores. 36 p.

(25) Plummer, F. G.
1912. Lightning in relation to forest fires. U. S. Dept. Agr. Forest Serv. Bul. 111, 39 p., 16 fig.

Schrenk, Hermann von.
(26) 1900. A disease of Taxodium known as peckiness, also a similar disease of Libocedrus decurrens. *In* Mo. Bot. Gard. 11th Ann. Rpt., p. 23–77, 6 pl. (partly col.).

(27) 1901. Fungous diseases of forest trees. *In* U. S. Dept. Agr. Yearbook, 1900, p. 199–210, pl. 21–25.

(28) 1902. Notes on diseases of western conifers. *In* Science, n. s., v. 16, no. 395, p. 138.

(29) 1903. The brown-rot disease of the redwood. *In* U. S. Dept. Agr., Bur. Forestry Bul. 38, p. 29–31.

(30) Sudworth, G. B.
1908. Forest trees of the Pacific slope. 441 p., illus., 15 fold. pl., maps. Published by the U. S. Dept. Agr. Forest Serv.

Weir, J. R.
(31) 1915. Some observations on abortive sporophores of wood-destroying fungi. *In* Phytopathology, v. 5, no. 1, p. 48–50.

—— and Hubert, E. E.
(32) 1918. A study of heart-rot in western hemlock. U. S. Dept. Agr. Bul. 722, 39 p., 13 fig.

(33) 1919. A study of the rots of western white pine. U. S. Dept. Agr. Bul. 799, 24 pp.