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DETERIORATION OF FIRE-KILLED DOUGLAS FIR
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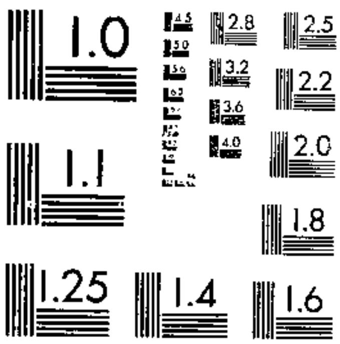

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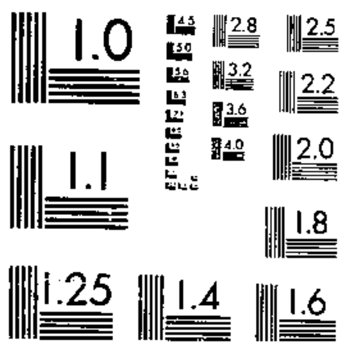

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NATIONAL BUREAU OF STANDARDS-1963-A

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Deterioration of Fire-Killed Douglas-Fir [1]

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INTRODUCTION

In the Douglas-fir region of western Oregon and Washington, mature merchantable timber has been killed by fire on about 800,000 acres [2] during the past decade, or on an average area annually of 80,000 acres. During the same period approximately 30 percent of the original merchantable volume of timber, principally Douglas-fir (*Pseudotsuga taxifolia* (Poir.) Britton), killed by fire has been saved by salvage operations. The rest has been lost through deterioration (see definition, p. 2). On large burns and inaccessible areas loss is greatest. Shepard (*15, p. 66*) [3] estimated that nearly 45 percent of the merchantable timber killed in recent years in western Oregon and Washington, exclusive of timber killed on national forest land and exclusive of large burns such as the Tillamook burn, had been saved through salvage operations.

Any working plan that will eventually lead to sustained yield from the forests of the Douglas-fir region must necessarily include accurate

[1] Submitted for publication September, 1942.
[2] Approximate figures for the years 1929 to 1938, inclusive.
[3] Italic numbers in parentheses refer to Literature Cited, p. 54.

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predictions of losses. Some studies have been made that provide information basic to predictions of loss both in living and dead timber. Losses in living Douglas-fir from decay and other agencies have been investigated by Boyce (*2*, *4*). Studies of losses from deterioration in dead timber, caused by wind throw in the Douglas-fir region, have been reported by Boyce (*3*) and by Buchanan and Englerth (*6*). In 1912 Knapp (*11*) made a study of the strength and usability of fire-killed Douglas-fir and gave some general information on the rate of deterioration and the agents involved in the deteriorating process. In 1935 Beal, Kimmey, and Rapraeger (*1*) published a brief summary of the first year's work on the present study. More recently Furniss (*9*) reported upon the progress of salvage in the Tillamook burn, in Oregon, as affected by insects. Until now, however, no comprehensive study has been made of the rate and progress of deterioration of fire-killed Douglas-fir as a means of anticipating the cumulative losses that develop following a fire.

The object of the present study was to meet the pressing need for detailed information on the causes, character, and rates of deterioration of fire-killed Douglas-fir. Particular emphasis was placed on obtaining basic information on which salvage operations may be efficiently planned. This information has particular application at this time because war demands for lumber far exceed the normal supply and dangers of incendiarism are greatly increased. The investigation was carried on from 1934 to 1939, inclusive, in western Oregon and Washington.

Deterioration Defined

The physical changes that take place in a tree following death by fire are designated as "deterioration" in this bulletin. Although the whole tree is considered, principal emphasis is given to changes of form and color that affect the merchantable value of the wood of the main bole. In this part of the tree two degrees of deterioration are recognized; namely, limited and general. The term "limited deterioration" is applied to changes affecting the original character of the wood but not making it unsuitable for potential use as lumber of low grade. The term "general deterioration" is applied to changes that make the wood actually unsuitable or technically undesirable for most uses as lumber even of low grade.

The Salvage Problem

The percentage of merchantable timber salvaged from a particular fire depends, aside from the rate of deterioration, on several factors, such as the size and character of the burn, accessibility to market, ownership, and log-market conditions. After a fire of catastrophic proportions, such as the Tillamook fire of 1933, which burned over approximately a quarter of a million acres and killed more than 10 billion board feet of Oregon's finest timber,[4] operators are faced with tremendous salvage problems involving progressive deterioration. Such burns, which are not uncommon in the Douglas-fir region (*15*, *p. 115*), fall into a special class in which a salvage even approaching the average

[4] MORRIS, W. G. THE TILLAMOOK BURN—ITS AREA AND TIMBER VOLUME. Pacific Northwest Forest Expt. Sta. Res. Notes 18: 2-4. Illus. 1936. [Processed.]

of 30 percent cannot be expected without adequate knowledge of the probable rate of deterioration. The great size of the area burned and the enormous volume of timber involved constitute a practically insuperable obstacle to immediate salvage. Even if immediate salvage were physically possible, it might be undesirable because of the resultant flooding of log and lumber markets. The volume of timber killed by the 1933 Tillamook fire was about two and one-half times that cut by west coast lumber operators during the same year.

From the market standpoint as well as from the standpoint of allowable cut in sustained-yield management, it would be ideal if the dead timber could be held to be cut as needed. Loss from deterioration, however, necessitates disposal of the dead timber as rapidly as possible. Consequently, a thorough knowledge of the causes, character, and rates of deterioration is essential if the maximum salvage compatible with changing economic conditions and the state of the lumber market is to be obtained.

METHODS AND BASES

Sampling by Forest Types

A special effort was made to obtain a good representation of study areas in the two main subdivisions of the Douglas-fir region, the forests of the Coast Ranges and the forests of the Cascade Range. In the present study the Coast type was considered as comprising the west slope, or fog belt, as well as the east slope of the Coast Ranges. The usual classification of the west slope of the Cascade Range, including the foothills, as Cascade type was followed.

Sampling by Growth Types

Because of fundamental differences inherent in trees of different ages, the data on deterioration were segregated by the three generally recognized growth types of Douglas-fir. These growth types may be defined as follows:

Young Growth.—Includes the so-called second growth, commonly called "red-fir" by most lumbermen and timber operators in the region. This type consists of young, rapidly growing stands of merchantable Douglas-fir between the ages of 60 and 250 years (generally 100 to 200 years) and with a usual d. b. h.[5] range of about 10 to 50 inches. The trees are characterized by wide rings over the entire cross section of the bole, denoting rapid growth throughout the life of the tree. These wide growth rings contain a large proportion of dark summerwood, and the wood has a reddish color; hence, the name "red-fir."

Intermediate Growth.—Commonly called "bastard growth" or "bastard fir" by people of the lumber industry in the region. This type consists of mature stands of merchantable Douglas-fir between the ages of 200 and 400 years (usually 250 to 350 years) and with a usual d. b. h. range of about 30 to 70 inches. On a cross section, trees of this type are characterized by a large proportion of rapidly grown material in the central part of the bole, surrounded by a

[5] The term d. b. h. means the tree diameter, including the bark, at 4.5 feet from the ground (breast height).

narrower band of more slowly grown wood, denoting a retardation of growth for approximately the latter half of the tree's life. Usually this outer band of slowly grown wood, which includes the sapwood, is approximately two to three times the width of the sapwood. There is no definite demarcation between the growth types, and therefore it is often difficult to classify certain stands. Stands that did not fit into either the young-growth or the old-growth types were classified as intermediate-growth type, thus making this intermediate type one of considerable diversity in age, diameter, and stage of maturity.

Old Growth.—Known also as "yellow-fir" among lumbermen of the Northwest. This type consists of overmature stands of Douglas-fir, mostly over the age of 400 years, and with a usual d. b. h. range of about 40 to 100 inches or more. Trees of this type are characterized by a large percentage of wood with narrow growth rings, denoting slow growth for more than half of the tree's life. The narrow growth rings contain a large percentage of spring wood, making the wood soft and light-colored; hence, the name "yellow-fir," in contrast to the "red-fir" of the young-growth type.

Douglas-fir in the Northwest grows in rather even-aged stands. For this reason it was possible to classify the tree growth by study areas rather than by individual trees.

Selection of Sampling Areas

Rate of deterioration was determined by a comparison of the degree of deterioration in burns of various ages, from recent to very old. As a basis for this comparison, representative sampling areas were examined in burns of various ages in each of the three growth types studied. All such areas were limited to burns in which fires of definitely known dates had killed outright a fairly large volume of merchantable Douglas-fir. This limitation was set in order to establish beyond reasonable doubt the time of death of the sampled trees. As has been pointed out, the search for suitable study areas was made throughout the region.

Another primary consideration in sampling was accessibility to fire-killed trees that had recently been felled. This requirement alone excluded many otherwise suitable burns. The greatest number of satisfactory study areas were located where logging salvage operations were in progress. Some sampling areas were in snag-felling operations, right-of-way clearings, and along fire lines constructed through burned timber. A few areas were in wood-cutters' operations and in land-clearing operations in fire-killed forests. In a few cases trees were felled for the specific purpose of determining the amount of deterioration.

In some large burns it was possible to obtain more than one study area, but in such cases only one sample in a given growth type was taken in any one year. Also, in large burns, it was possible by sampling in different years to obtain data on trees that had been dead various lengths of time. For example, in the Tillamook burn two samples were taken each year from 1934 to 1939, one in old growth on the west slope of the Coast Ranges, and another in intermediate growth on the east slope.

The exacting requirements for suitable study areas limited the number of areas available in any one year, especially in the older burns. For this reason it was necessary to carry on the study over a period of 6 years in order to obtain sufficient data on which to base reliable conclusions.

Collection of Data

General information on the following was obtained on each area: Location; date of burning; degree of initial burning; proximity to old burns; exposure; character, age, and size of trees in the original stand; present general progress of deterioration in associated tree species; condition of bark, branches, and tops of standing trees, and trees after felling; and size and density of reproduction and other vegetative regrowth on the area.

Individual tree data were taken on Forest Service Form 558a. Chapman and Demeritt show this form and discuss its use in their forest mensuration text (*7, pp. 72–74*). The full length of each tree, from the ground level to the tip, was plotted to show diameter inside bark, diameter inside sapwood, and diameter inside the limits of deterioration at various points along the bole. The d. b. h. was determined for all trees. Total height was measured in all except a few of the older burns where treetops were rotted out. In such cases height curves were used to determine total height. The age of each tree was determined by adding the estimated age of the tree when it was the height of the stump to the ring count on the stump. Measurements were taken with a steel diameter tape or 4-foot scale stick and a 50-foot steel tape.

Examinations of deterioration were made at the stump, and, in areas on which logging operations were being carried on, at each place where the tree was "bucked" or broken. Above the uppermost buck the tree was chopped into at intervals along the bole as conditions necessitated. On areas where logging was not in progress, the examinations in addition to those at the stump were made at log-length or shorter intervals by chopping into the trees and at breaks caused by felling. At each point of examination data were taken on the following points: Amount of deterioration by all causes; the agents responsible for deterioration; and, so far as possible, the relative importance of each deteriorating agent.

Computations

Sufficient data were taken to give the original shape and volume of each tree when plotted on Form 558a and to determine the extent and volume of the sapwood and the loss through deterioration. From these data the loss was computed and classified for each tree and each log.

Volumes were computed in both board feet and cubic feet. The Scribner Decimal C scale was used to determine the board-foot volume of the merchantable length, from a 4-foot stump to an 8-inch top diameter inside the bark. The merchantable length was divided into 32-foot logs, starting at the stump and allowing 6 inches of trim for each log; thus the top log was usually less than 32 feet long. The Scribner Decimal C scale allows no board-foot volume for a log less than 6 feet long. The total volume, the volume of the sapwood, the volume of loss caused by general deterioration since the fire, and the volume of loss due to each fungus species concerned were determined in board feet for each log. In computing cull in board feet, all logs under 16 inches in diameter inside the bark at the small end were considered total cull when more than 50 percent of their volume was cull, and logs 16 inches or over in diameter were considered total cull when more than 66.7 percent of their volume was cull. All diameter measurements were taken to the nearest inch.

Cubic-foot volumes were determined by measuring with a planimeter the area of the plotted diagrams on Form 558a and applying a factor to convert this value to cubic-foot volume. Cubic-foot volumes were determined for the entire tree, inside the bark from the tip to a 4-foot stump and from the stump to the ground level, by figuring the stump as a cylinder with a diameter equal to that of the top of the stump inside the bark. Total sapwood and total cull volumes were determined in cubic feet for the entire tree. Total sapwood and cull volumes were also determined in cubic feet for each log.

Summary of Basic Samples

Data were taken on 63 areas. Of these, 41 were Coast type and 22 were Cascade type. On 29 of the areas the trees were of old-growth type; on 22 areas, of intermediate-growth type; and on 12 areas, of young-growth type. The locations of these areas are shown on the map in figure 1. The areas included burns from 1 to 62 years old, as shown in table 1.

Table 1.—*Bases of field data*

Growth type and age of burn (years)	Areas	Trees	32-foot logs	Volume	
	Number	*Number*	*Number*	*Cubic feet*	*Board feet*
Young growth:					
1	2	10	41	3,202	17,870
2	2	13	48	3,737	20,700
3	2	20	73	8,899	54,980
4	2	17	33	1,640	7,400
5	2	11	19	1,238	5,170
6-10	2	20	49	3,948	20,600
Total	12	91	263	22,664	126,810
Intermediate growth:					
1	3	10	53	9,050	58,010
2	4	34	105	39,014	258,220
3	3	42	241	40,998	266,750
4	2	29	157	21,865	138,600
5	2	20	104	14,766	94,440
6	2	20	114	18,634	118,610
7	1	10	54	8,787	55,010
8	1	10	30	2,208	11,830
9	1	10	61	9,848	65,650
10	1	10	53	9,155	57,150
11-15	1	10	49	9,148	57,760
16-20	1	10	47	9,320	58,720
Total	22	215	1,158	192,792	1,240,610
Old growth:					
1	2	9	56	15,430	104,480
2	2	18	112	41,582	279,410
3	2	19	101	26,604	169,530
4	2	36	225	57,308	371,700
5	2	18	111	23,115	149,290
6	1	10	65	17,537	117,350
7	1	10	58	14,212	94,050
8	1	10	59	13,662	93,650
9	1	10	45	10,687	70,450

TABLE 1.—*Bases of field data*—Continued

Growth type and age of burn (years)	Areas	Trees	32-foot logs	Volume	
	Number	*Number*	*Number*	*Cubic feet*	*Board feet*
Old growth—Continued.					
10	2	20	120	42,531	202,320
11	2	21	123	33,273	222,360
12	1	10	60	19,554	133,720
13	1	7	48	18,757	126,200
14	1	10	67	25,515	172,620
15	1	10	63	28,145	182,080
16-20	1	13	74	17,780	122,700
21-25	1	20	110	43,384	310,850
26-35	1	10	45	8,905	58,880
36-45	2	24	141	38,107	265,070
46-55	1	3	21	9,663	65,840
56-65	1	8	38	12,572	81,920
Total	29	206	1,757	510,419	3,484,570
Grand total	63	602	3,178	731,875	4,851,990

The number of individual trees used as a basis on each area depended on the degree of variation found in size of trees and amount of deterioration in different trees on the area. Detailed measurements on 10 trees were usually considered sufficient to determine the extent and the nature of deterioration on an area. However, on some of the younger burns where deterioration was slight and uniform, less than 10 trees were used, and in a few of the older burns where deterioration was more variable, as many as 20 or more trees were used.

The ranges in d. b. h. of the trees included in the bases for the various growth types were as follows: Young growth 12 to 60 inches, intermediate growth 22 to 74 inches, and old growth 27 to 104 inches. More trees of the young-growth type were in the 21- to 30-inch d. b. h. class than in any other 10-inch d. b. h. class, more trees of the intermediate-growth type were in the 41- to 50-inch d. b. h. class, and more trees of the old-growth type were in the 51- to 60-inch d. b. h. class.

The basis of logs shown in table 1 includes only full-length 32-foot logs with 0.5-foot trim allowance. In nearly all trees the top log was less than 32 feet long, and although these shorter logs are included in the board-foot volumes in table 1, they are not included in the column headed "32-foot logs."

Deterioration of fire-killed Douglas-fir usually progresses at a rather uniform rate. For this reason a large basis is not necessary for an accurate determination of rate of loss. The basis obtained in this study is considered adequate for determining not only the rate of deterioration for all three growth types but also the importance of the various agents involved in the deteriorating process.

CAUSES OF LOSS AND AGENTS OF DETERIORATION

In the ordinary forest fire in green timber of the Douglas-fir region, the immediate destruction of merchantable timber by combustion is usually very small (see fig. 8, *A*). A burned area is usually considered to have the same merchantable volume of timber immediately following a fire as it had just preceding the fire.

Soon after a forest fire, deterioration of the fire-killed trees begins and continues until no sound wood remains. The agents causing deterioration of fire-killed Douglas-fir are fungi, insects, and weather;

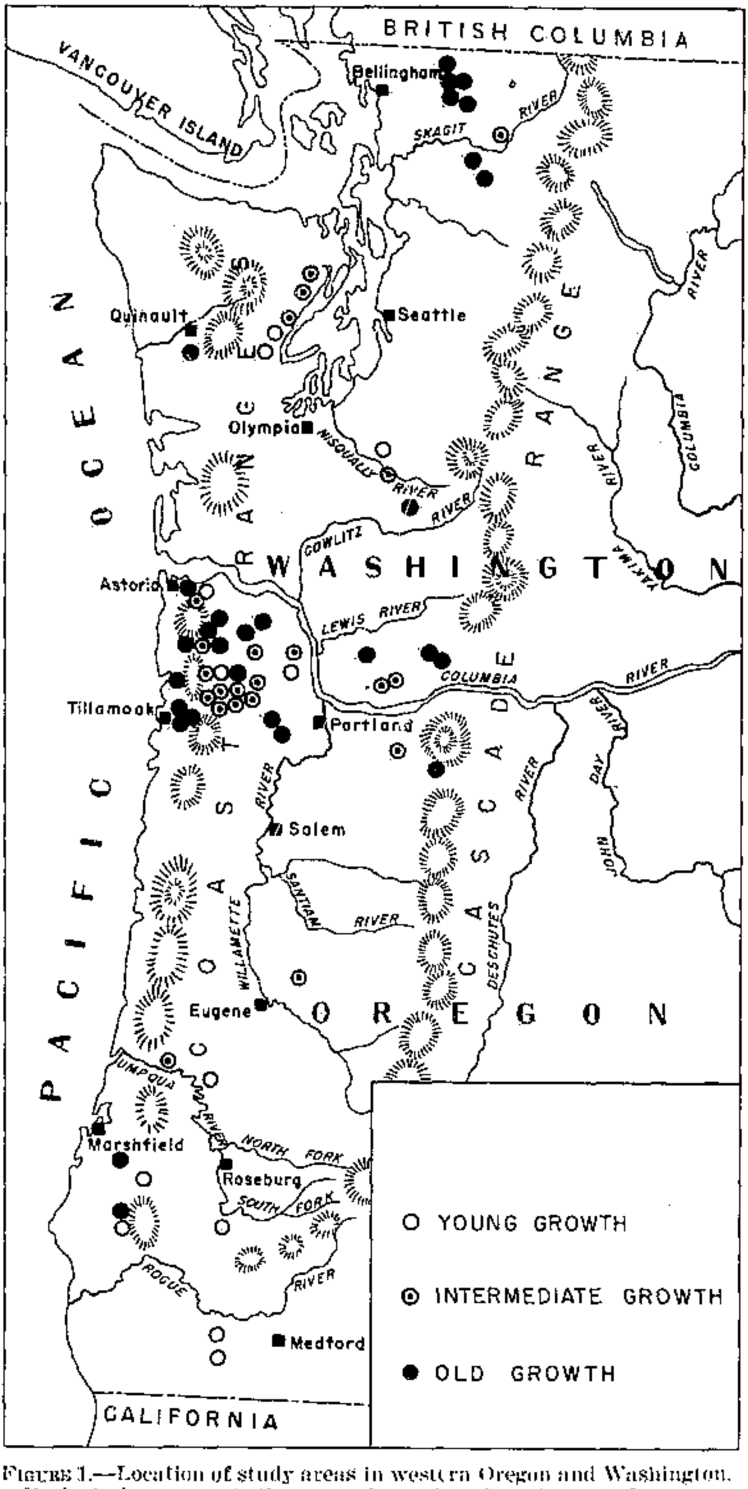

FIGURE 1.—Location of study areas in western Oregon and Washington. Each circle represents the approximate location of one study area.

of these, fungi and insects are of chief importance. Other losses associated with deterioration, such as excessive breakage and consumption of wood by subsequent fires, are of less importance.

On the basis of present information, the parts played by insects and by fungi in the deterioration of fire-killed timber are inseparable. These agents work togeth r, and apparently at generally similar rates. Usually conditions favoring decay also favor insects. In some cases the insects follow the decays; in others the insects precede the decays. The outstanding difference between the work of these two agents is the resulting degree of deterioration. Insects typically cause partial deterioration, as, after their attack, the wood is usually of some potential use, even though it may be degraded to the point where at present it cannot be removed profitably from the woods. In contrast with this, the decays render the wood useless.

Certain fungi, which cause the so-called brown rots or carbonizing decays and attack principally the cellulose in the wood, seem to restrict insect activity in fire-killed trees. The so-called white rots caused by fungi that attack principally the lignin in the wood do not seem to restrict insect activity.

Deterioration by Fungi

FUNGI CAUSING STAIN

The fungi causing wood stain in fire-killed Douglas-fir belong mostly to the genus *Ceratostomella*. The fruiting bodies of this genus consist of microscopic filaments or minute, dark-colored, pear-shaped bodies produced on the surface of the affected wood. Wood-staining fungi attack sapwood almost exclusively. They are of importance during the first 1 to 3 years following fire, before the other deteriorating agents cause much damage. In many salvage operations where Douglas-fir is salvaged within a few years after fire, wood-staining fungi are the most important deteriorating agents.

Unlike the decays, the principal wood-staining fungi do not materially weaken the wood, for they live primarily upon the contents of the cells. Wood stains caused by fungi are generally classified under the heading of "blue stain," and cause degrade of the wood affected. If not otherwise deteriorated, the wood so degraded is as suitable as unstained wood for many uses. This degrade is based largely on color prejudice, although presence of the stain definitely brands the wood as having been exposed to decay fungi. This being the case, the wood may and sometimes does contain the hyphae of wood-decaying fungi in addition to the hyphae of the fungus causing the stain. This fact undoubtedly constitutes one reason for the prejudice against blue-stained wood.

FUNGI CAUSING DECAY

The sporophores of the wood-decaying fungi are familiar to the woodsman. They consist of toadstools or mushrooms on or near the base of the tree, resupinate crusts or plates on the under side of logs, or the more common bracket-shaped or hoof-shaped fruiting bodies attached to the bark of standing and fallen trees and known as conks

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or punks. Most of the fungi causing serious deterioration of fire-killed Douglas-fir have hoof-shaped, crustlike or shelflike sporophores.

The fungi causing decay of fire-killed Douglas-fir may be divided into two general groups: (1) Those confining their activities primarily to the sapwood; (2) those attacking both sapwood and heartwood.

After the death of a tree the first wood to become exposed to infection is the outer sapwood. The principal sapwood-decaying fungi generally spread so rapidly that they soon occupy much of the sapwood. The fungi causing the deeper penetrating decays also gain entrance through the sapwood or through cracks or other openings extending into the heartwood. These latter fungi have the capacity to cause as complete decay of the sapwood as do the purely sapwood-decaying fungi, but usually they do not develop as rapidly and are outnumbered by the sapwood-decaying fungi during the earlier years. Later, after most of the sapwood has been consumed, the heartwood-decaying fungi become increasingly more important.

In addition to the fungi that work primarily on dead trees, there are a number of fungi that cause decays in the heartwood of the living trees. Most such fungi are relatively inactive in dead trees, but some of them continue activity to a degree comparable to that of a scavenger fungus. The ring scale fungus, *Fomes pini* (Fr.) Karst., which is so commonly found causing decay of the heartwood of living trees in old-growth Douglas-fir stands, becomes relatively inactive in fire-killed trees.

FUNGI CAUSING PRINCIPAL DECAYS OF FIRE-KILLED DOUGLAS-FIR

The red-belt fungus, *Fomes pinicola* (Sw. ex Fr.) Cke., is responsible for the greatest proportion of decay. The young sporophores or conks of this fungus appear as round, white corky masses emerging usually from bark crevices, and showing clearly against the blackened bark (fig. 2, *A*). The conks are perennial, adding new layers of growth each year, and the shapes of the older conks range from shelflike to hoof-shaped (fig. 2, *B*). The layers are indicated by the zoned structure of the top, which is smooth and gray to black. The margins during the growing season are nearly white, later usually turning to a shiny red; hence, the name "red belt." The lower surface is white to light cream and contains numerous small regular pores. This fungus grows under a wide range of conditions and attacks both sapwood and heartwood. The decay in fire-killed Douglas-fir first appears in the sapwood, in long streaks as a pale-yellow to light-brown stain during the first to the third year after the fire. The typical or advanced stage of this decay is a brown crumbly rot of charcoal consistency, which breaks up into cubical pieces by the formation of shrinkage cracks, which often become filled with thin white layers of mycelium.

The purple fungus, *Polyporus abietinus* Dicks. ex Fr., is the second most important fungus in the process of deterioration, but probably causes the most loss to owners of old-growth fire-killed Douglas-fir, as it is the principal decay in trees of this growth type for the first 5 to 10 years, and it is at this time that most such timber is salvaged. The conks or sporophores are small, thin, and bracket-shaped (fig. 2, *C*). They are annual and are usually numerous and often crowded together

FIGURE 2.—Fruiting bodies of the two fungi most important in causing deterioration of fire-killed Douglas-fir: *A*, Immature sporophores of *Fomes pinicola* on the bark 4 years after the tree was killed; *B*, mature sporophore of *F. pinicola*; *C*, detail of sporophores of *Polyporus abietinus*; *D*, sporophores of *P. abietinus* on the bark 4 years after the tree was killed.

in an imbricated manner along bark crevices (fig. 2, *D*). The upper surface of the conks is hairy, zoned, and white to gray, becoming dark with age. The name "purple fungus" is derived from the purple lower surface, which contains numerous regularly or irregularly shaped pores. This fungus confines its action to the sapwood and is usually the predominating sapwood destroyer in fire-killed Douglas-fir. On the surface of a log the decay first appears as water-soaked areas under the bark, and in a section of the wood as a yellowish stain during the first or the second year after the fire. The typical decay is a white rot, which in the late stage forms shallow, long pockets, giving the wood a honeycombed appearance. The small pockets are lined with a thin layer of white fibers, which give the decayed wood a white-flecked appearance. In the final stage the pockets become empty and cause the decayed wood to become spongy and very light in weight and to separate easily into layers along the annual rings.

The chalky quinine fungus, *Fomes officinalis* (Vill. ex Fr.) Faull, is of considerable importance in the deterioration problem. The sporophores are large, chalky white to light brown, and range from bracket-shaped to hoof-shaped (fig. 3, *B*). The upper surface is roughened and zoned. The lower surface is nearly white, with small regular pores. The context is soft when young but tough or chalky when old and has a very bitter taste, from which is derived the name "quinine fungus." This fungus not only causes a fairly rapid decay of the sapwood and heartwood of fire-killed trees but also is one of the important destroyers of heartwood in living Douglas-fir (*2*). The decay produced by this fungus is generally similar in appearance to that caused by the red-belt fungus. In the final stage, decay caused by these two fungi is very similar in color when of the same moisture content. In fire-killed trees, however, the quinine fungus usually works in the center of the tree and consequently the rot is drier than that of *F. pinicola*, which works inwardly from the surface of the bole. For this reason the rot of *F. officinalis* usually appears lighter in color when both decays are found in the same tree. The most pronounced difference between the two decays consists of the thicker and tougher layers of white mycelium found in the shrinkage cracks of the decay caused by the quinine fungus. This fungus was most important in burns which were 10 to 15 years or more old.

The slash fungus, *Lenzites saepiaria* Wulf. ex Fr., is one of the species commonly found causing decay. The sporophores are small, annual, and bracket-shaped (fig. 3, *A*). The upper surface is zoned and dark orange to dark brown. The lower surface is nearly brown, becoming gray with age, and contains irregular pores or platelike gills. This fungus causes a rapid decay of sapwood but invades the heartwood slowly. It is more commonly found on drier sites, such as are characteristic of the Cascade type, and is less common in moist situations. About 1 to 2 years after a fire, the decay appears in the sapwood as a light-brown stain in small patches, and in the final stage it is a dark-brown, crumbly rot, occasionally with tan mycelial felts in the shrinkage cracks. The decayed wood is soft and light in weight, and breaks up into small cubes.

The pouch fungus, *Polyporus volvatus* Pk., was not found producing an advanced stage of decay during this study. It is of considerable importance, however, in causing discoloration of the outer sapwood during the first 4 years following the death of the trees. Protruding from insect burrows in the bark, the young annual sporophores are small, globose, and reddish brown, becoming tan to white with age (fig. 3, *D*). The mature globose sporophores may reach a size of 1 to 1.5 inches in diameter (fig. 3, *C*). The brown pore surface is completely covered by a leathery membrane continuous with the upper surface

FIGURE 3.—Typical, mature fruiting bodies of fungi important in the deterioration of fire-killed Douglas-fir: *A*, *Lenzites saepiaria*; *B*, *Fomes officinalis*; *C* and *D*, *Polyporus volvatus*.

except for a small opening, which appears in the membrane at maturity. The discoloration produced by this fungus is typically cream to light tan, varying little from the normal color of the sapwood on cross sections; however, on a radial or tangential section of a log the discoloration is quite evident. Sapwood containing this discoloration is brash, as evidenced by its breaking squarely across the grain in contrast to the splintering of normal sapwood when broken. The discoloration caused by this fungus is evident in fire-killed trees chiefly during the first 4 years following their death. After that, incipient and typical stages of decay caused by other fungi obscure the deterioration caused by this fungus. No advanced stage of decay caused by *P. volvatus* was found during the entire study, although Schmitz (*14*) found in a laboratory study that this fungus caused decay of Douglas-fir wood, as evidenced by an average loss of weight of 2.3 percent in 5 months.

The shelf fungus, *Fomes applanatus* (Pers. ex Fr.) Gill., was occasionally encountered in the base of fire-killed trees, but because of its exacting moisture requirements it is not of great importance. The old sporophores are large and distinctly shelflike (fig. 4, *A*). They are perennial, adding a new layer of pores each year. The upper surface is gray and zoned, and often is covered with the dustlike brown spores produced by the fungus, which give the entire surface a tan color. The under surface is white when fresh, becoming brown when bruised or dried. This fungus, unlike the slash fungus, is found only in moist localities where the wood is not subject to rapid drying. Its action is limited chiefly to the sapwood of the stump and basal log, although the heartwood becomes decayed when sufficient moisture is present. The fungus causes a stringy and moist decay, cream to light brown in color, generally with a white mottle containing numerous small black flecks and bars running longitudinally, and it also frequently forms black zone lines. General observations indicate that this fungus is considerably more important in causing deterioration of fire-killed western hemlock, *Tsuga heterophylla* (Raf.) Sarg., and the balsam firs, *Abies* spp., than it is in the deterioration of fire-killed Douglas-fir.

FUNGI CAUSING LESS IMPORTANT DECAYS OF FIRE-KILLED DOUGLAS-FIR

Several species of fungi commonly found are individually of no great importance; however, these fungi, when considered as a group, become of considerable importance in the deteriorating process.

Of the fungi in this group that confine their activity to the sapwood, probably the most important are several species of *Stereum*. *Stereum rugisporum* (Ell. and Ev.) Burt. was the most commonly encountered species. Another fungus of this group occasionally found is *Polyporus* (*Polystictus*) *versicolor* L. ex Fr. Although these minor sapwood fungi commonly produce sporophores, their decays are usually quite superficial.

Of this group, the more important fungi that destroy the heartwood are *Polyporus fibrillosus* Karst., *Ganoderma oregonense* Murr. (fig. 4, *B*), and several species of *Poria*. The most commonly encountered *Poria* was *P. selecta* Karst. In this group of heartwood fungi are two of the important heartwood-decaying fungi of living Douglas-fir, which, like the quinine fungus, continue their activity and spread in the tree after it is killed. They are *Polyporus schweinitzii* Fr. and *Fomes subroseus* (Weir) Overh. *P. schweinitzii* is of special importance because it works primarily in the valuable butt sections of the trees, and often predisposes the affected snags to wind throw (fig. 4, *C*). This fungus causes a charcoallike disintegration of the wood, known as red-brown butt rot.

A species of fungus usually of minor importance may occasionally be prevalent in individual trees where growth conditions are especially favorable for it. But such a species considered by itself in the whole study of deterioration of fire-killed Douglas-fir in the Douglas-fir

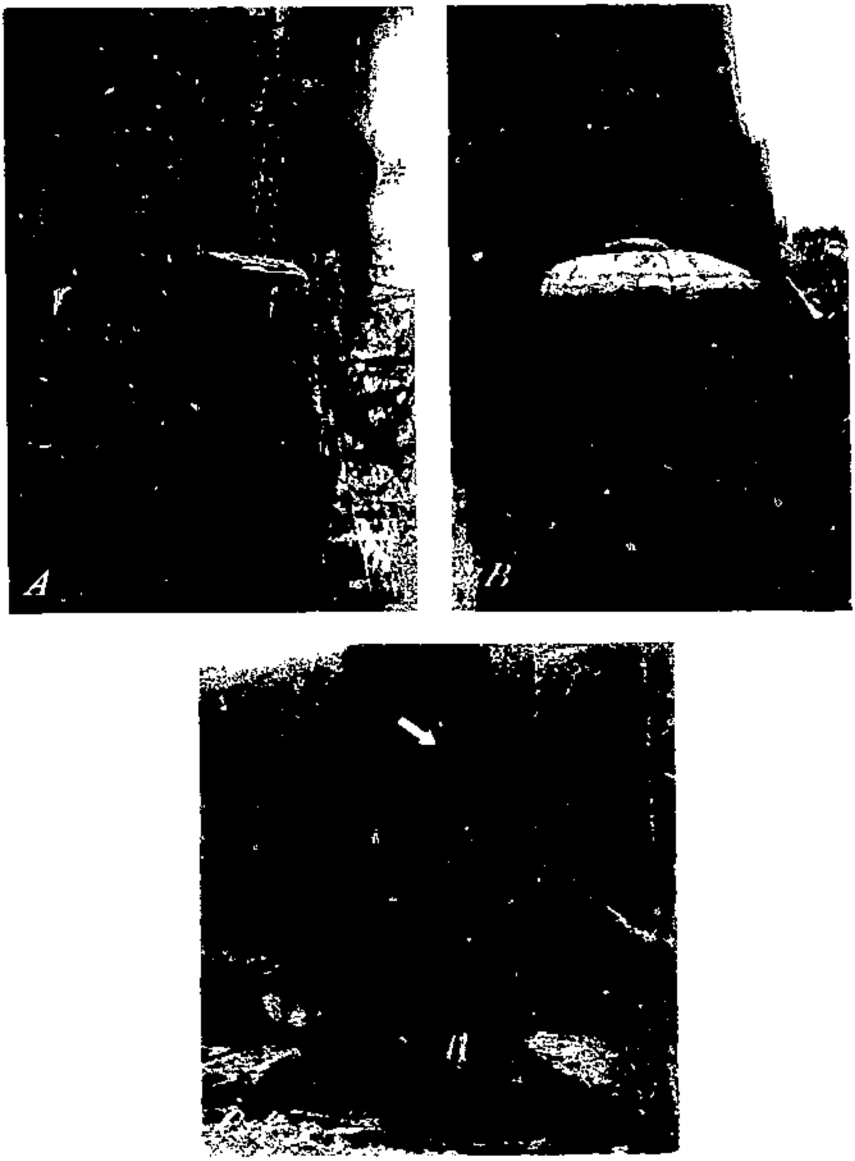

FIGURE 1.—Typical fruiting bodies of fungi that frequently cause wind throw of fire-killed trees: A, *Fomes applanatus*; B, *Ganoderma oregonense*; C, *Polyporus schweinitzii*.

region is of little consequence because of its too exacting requirements for development. Because of the great variety of influencing factors, the more exacting a species may be the less important it is in the problem as a whole.

RELATIVE IMPORTANCE OF FUNGI CAUSING DETERIORATION

The relative amount of decay caused by each species of fungus is different each succeeding year after death of the tree. Usually the sapwood decays predominate for the first 5 to 10 years, after which the heartwood decays become more prevalent. Table 2 shows the relative importance of the different fungi in the total fungus-induced deterioration in the three growth types in burns of various ages. The percentage of the total deterioration caused by each fungus was computed on a total volume basis for all areas in the individual age classes within each growth type. For example, in 1-year burns of the young-growth type the volume of deterioration caused by *Fomes pinicola* was 25 percent of the total volume of deterioration found in the two young-growth type areas that were studied 1 year after the death of the trees.

In table 2 the percentages of deterioration caused by the various fungi are shown to the nearest 1 percent, and any observed percentage less than 0.5 is shown as "trace." In actuality, the data were computed much more accurately than this, since in taking field data the estimates of percentage of deterioration caused by the various fungi were usually made to the nearest 5-percent at each point of examination. The percentage of deterioration caused by one of the less common fungi was sometimes fairly high at a few points of examination, or even throughout a tree or over an entire area, but when the percentage of deterioration caused by this fungus was computed on a basis of the total deterioration for a large number of samples it was very small or even negligible. For this reason some species of fungi are not shown in the table, although they may have been found producing sporophores and causing a small amount of deterioration.

From table 2 it may be noted that the blue-staining and the more or less superficial sapwood-decaying fungi are important only in the first few years following a fire, later becoming obscured by other fungi. The heartwood of fire-killed stands of Douglas-fir is decayed largely by *Fomes pinicola*, which in some areas is the only fungus found decaying the heartwood. This fungus also causes a large percentage of the sapwood decay, especially in the younger growth types. It was found that trees of rapid growth usually contain a larger percentage of *F. pinicola* decay than trees of slower growth; this is often true in the sapwood as well as the heartwood. Sapwood of trees of slow growth usually is decayed principally by *Polyporus abietinus*, particularly on areas of the older growth types. Occasionally, on the drier sites, areas are found in which *Lenzites saepiaria* is the predominating sapwood destroyer in many of the trees.

Although *Fomes pinicola* was always found to be the principal heartwood destroyer, *F. officinalis* is often found causing extensive heartwood decay in trees that have been dead more than 15 years. The data show that this latter fungus causes about one-fourth as much decay as *F. pinicola* on burns over 15 years old.

TABLE 2.—*Relative amounts of deterioration caused by different fungi in fire-killed Douglas-fir of different growth types on burns of various ages*

Growth type and age of burn (years)	Percentage of total cubic volume deteriorated by fungi	Percentage of total fungus-induced deterioration caused by—										
		Fomes pinicola	*Polyporus abietinus*	*Fomes officinalis*	*Lenzites saepiaria*	Blue-staining fungi	*Polyporus volvatus*	*Stereum* spp.	*Fomes applanatus*	*Polyporus schweinitzii*	*Polyporus fibrillosus*	*Polyporus versicolor*
Young growth:												
1	19.2	25	30	0	0	0	0	45	0	0	0	0
2	26.5	71	18	0	0	7	4	0	0	0	0	0
3	50.7	40	48	0	0	5	5	1	0	0	0	0
4	59.9	66	20	0	11	0	2	1	0	0	0	Trace
5	62.4	55	19	0	24	0	0	0	0	0	0	2
8	52.7	57	43	0	0	0	0	0	0	0	0	0
9	78.7	58	42	0	0	0	0	0	0	0	0	0
Total [1]	.....	55	33	0	4	2	2	4	0	0	0	Trace
Intermediate growth:												
1	6.8	41	34	0	0	3	18	4	0	0	0	0
2	10.5	11	30	0	0	46	4	0	0	0	0	0
3	17.8	38	39	0	2	16	3	2	0	0	0	0
4	20.3	70	27	0	0	0	2	Trace	0	0	Trace	0
5	20.2	43	48	0	6	0	Trace	2	0	0	0	0
6	20.8	45	55	0	0	0	0	0	0	0	0	0
7	31.9	39	59	2	1	0	0	0	0	0	0	0
8	39.4	35	55	0	10	0	0	0	0	0	0	0
9	40.2	48	48	0	0	0	0	0	0	3	0	0
10	34.9	84	16	0	0	0	0	0	0	0	0	0
12	36.9	32	66	0	2	0	0	0	0	0	0	0
16	36.4	65	35	0	0	0	0	0	0	0	0	0
Total [1]	...	46	42	Trace	1	8	1	Trace	0	Trace	Trace	0
Old growth:												
1	1.6	0	0	0	0	64	8	28	0	0	0	0
2	1.9	4	10	0	0	80	3	3	0	0	0	0
3	12.9	27	53	0	5	12	2	1	0	0	0	0
4	16.2	38	60	0	Trace	0	1	1	0	0	0	0
5	25.5	49	50	Trace	0	0	0	1	0	0	0	0
6	19.5	38	59	0	0	0	0	0	3	0	0	0
7	22.3	43	54	2	0	0	0	0	1	0	0	0
8	28.9	45	55	0	0	0	0	0	0	0	0	0
9	28.0	45	48	0	7	0	0	0	0	0	0	0
10	31.8	46	48	0	5	0	0	0	0	0	0	0
11	23.6	46	51	0	3	0	0	0	0	0	0	0
12	40.9	67	33	0	0	0	0	0	0	0	0	0
13	20.8	42	56	Trace	0	0	0	0	1	0	0	0
14	18.7	49	49	0	1	0	0	0	0	0	0	0
15	32.0	62	38	0	0	0	0	0	0	0	0	0
16	43.5	50	20	20	10	0	0	0	0	0	0	0
22	61.5	83	3	11	2	0	0	0	0	0	0	0
32	98.7	75	5	20	0	0	0	0	0	0	0	0
38	68.4	76	20	0	4	0	0	0	0	0	0	0
43	95.6	58	6	35	0	0	0	0	0	0	0	0
45	61.6	87	10	3	0	0	0	0	0	0	0	0
62	74.1	96	4	0	0	0	0	0	0	0	0	0
Total [1]	...	62	28	7	2	1	Trace	Trace	Trace	0	0	0
Grand total [1]	...	59	30	5	2	2	Trace	Trace	Trace	Trace	Trace	Trace

[1] Percentage of deterioration in all the areas studied.

The "total" values in table 2 show the percentage of deterioration caused by each fungus species in all the areas studied within the various growth types. While these values are of considerable interest, they do not necessarily indicate the relative importance of the various fungi in the deteriorating process, because the basis was considerably greater in the younger age classes of burns. The high percentage shown for *Polyporus abietinus* demonstrates this, especially the high percentage for this species in the intermediate-growth type, since areas in this type were studied only to 16 years following fire. Sixteen years after a fire, trees of this type may often be not more than 50-percent decayed.

DISCOLORATION BEYOND THE TYPICAL DECAY

The fungus mycelia penetrate the wood for some distance in advance of the portions distinctly decayed. This advance zone of decay is in most cases marked by some sort of discoloration of the wood, depending on the species of fungus responsible for the decay, and is usually accompanied by a slight softening of the wood. The discolored wood containing the incipient stages of decay in fire-killed timber is decidedly a loss to lumbermen. The strength of the wood may sometimes not be greatly impaired, and the action of the fungi may be stopped by kiln-drying the lumber. However, since kiln-dried wood is used mostly as finishing material, it is degraded by discoloration, and for this reason wood with incipient decay is seldom kiln-dried. If the lumber is not kiln-dried or otherwise treated to kill the mycelia within it, the fungi remain as potential wood destroyers, which will resume growth and continue disintegration as soon as conditions are again favorable (*10*). This defect was considered as part of the general deterioration throughout the study.

The discoloration accompanying incipient decay should not be confused with the blue stain caused by *Ceratostomella* spp., with superficial growth of molds, with the stains often caused in the sapwood by the leaching of pigments from the bark, or with other stains of nonpathogenic origin. Such stains are not potential wood destroyers and in most cases do not cause appreciable loss; therefore, except for blue stain, they were not included in the losses estimated in this study. However, since some of the wood thus stained may also contain the hyphae of wood-destroying fungi, the propriety of excluding it from the loss column is open to question.

The discoloration, beyond that of the typical decay, caused by incipient decay in fire-killed Douglas-fir is as follows for the principal fungus species found:

Fomes pinicola.—Faint yellow to red or reddish brown.
Polyporus abietinus.—Light yellow to tan.
Fomes officinalis.—Yellow or pink to light reddish brown, or sometimes purple.
Lenzites saepiaria.—Pale tan to brown.
Fomes applanatus.—Tan to brown, sometimes purplish brown to violet.

PENETRATION OF MYCELIA BEYOND DISCOLORED ZONE

A few hyphae of decay fungi are present for some distance beyond the discolored zone, but wood containing such hyphae is probably not appreciably weakened mechanically. It is not recommended, however, for use in places where moisture conditions are favorable to decay, because the hyphae of many fungi possess for a long time the power to resume activity and continue the spread of decay under favorable conditions. Cases are known in which these latent hyphae have resumed activity in wood that had been kept air-dry for periods ranging up to 7 years (*10*). However, if the wood is properly kiln-dried or otherwise treated to destroy the hyphae and if the wood is not actually weakened, it is as durable as if cut from a sound tree

(*10*). For this reason the hidden stage of decay was not considered in the estimates of deterioration made in this study.

In connection with the study of the deterioration of fire-killed Douglas-fir, a special study was made of the depth of radial penetration of the fungus mycelia into the wood beyond the discoloration areas of the decay. Three of the principal species of fungi were studied in a total of 75 special wood-block samples collected on 9 different areas. The distance of radial penetration into the apparently sound wood was determined by 2 general methods: (1) Cultures were made from the specimens at different distances from the margin of discoloration, and (2) sections cut from the specimens at various distances from the discoloration were examined under the microscope. The 2 methods of determining the radial penetration of the mycelia beyond the discoloration gave practically the same results, which are summarized in table 3. While in a number of cases the penetration amounted to over an inch, the average was about three-fourths of an inch. Consequently, if a deduction in scale is to be made for this defect, it would be equitable to both buyer and seller to deduct 2 inches from the diameter of the log inside all visible decay or discoloration.

This defect was not included when figuring the losses from deterioration in this study, because these few hyphae do not materially weaken the wood or cause a degrade in lumber because of objectionable color. However, this invisible penetration is as potentially dangerous as that in the discolored wood if the wood is not treated to kill the hyphae. If lumber containing this invisible early stage of decay is kiln-dried at temperatures high enough to kill the fungus hyphae, there is no loss.

TABLE 3.—*Depth of radial penetration of fungus mycelia beyond discolored area of decay in fire-killed Douglas-fir*

Fungus species	Depth of radial penetration beyond discoloration		
	Minimum	Maximum	Average
	Sixteenths of an inch	*Sixteenths of an inch*	*Sixteenths of an inch*
Fomes pinicola	2	25	15
Polyporus abietinus	4	23	10
Lenzites saepiaria	2	15	9

DETERIORATION BY INSECTS

Almost immediately after Douglas-fir trees are killed by fire they are attacked by many kinds of insects (*1, 9*). These insects and others that attack later help to deteriorate the wood so that in time it cannot be utilized as lumber. In addition to the primary damage caused by insect galleries, some insects cause indirect damage by introducing wood-staining fungi (*5, 16*). It is suspected that wood-decaying fungi may gain access to the wood through holes made through the bark by insects. The galleries of certain borers, by increasing the exposed wood surface, seem to provide a means of more rapid penetration by wood-decaying fungi (*12*). Insects causing deterioration of fire-killed

Douglas-fir may be divided into three groups, characterized by the portion of the bole they attack, as follows: (1) Those attacking the phloem region (bark and cambium); (2) those attacking the sapwood; (3) those attacking the heartwood. In general, this grouping also denotes the chronological order of insect attacks. Although the groups are fairly well defined, there is some overlapping. For example, some insects first are phloem feeders and later enter the sapwood and even the heartwood. Likewise, the relative order of attacks is not in all cases indicated by the part of the tree that is attacked.

INSECTS INFESTING PHLOEM REGION

Insects infesting the phloem region feed primarily in the region comprising the inner bark and the outer layers of sapwood. As a group, they are the first to attack. Their initial concerted attack usually occurs during the spring following fire, as most fires in the Douglas-fir region occur in late summer or early fall after the egg-laying period of the insects is past. Maximum abundance of the various species is attained during the first to the third year following fire. Their most characteristic role is as bark looseners. A few of them are known to introduce wood-staining fungi (*5, 16*). Some phloem-infesting insects later become important in the deterioration of the sapwood and the heartwood.

The Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopk., is the most important as well as the most abundant of the phloem feeders. The adult is a reddish-brown beetle averaging slightly less than one-fourth of an inch in length. Eggs are laid in the spring. The full-grown larvae are curved, pearly white, and approximately one-fourth of an inch long. The adult progeny emerge the next spring following the egg-laying, thus completing one annual generation. Attacks by *D. pseudotsugae* often occur from the base nearly to the tip of a tree but are most abundant along the midbole. Many years after a tree is abandoned by the beetles, the characteristic galleries on the inner bark (fig. 5, *A*) remain as evidence of attack by this species.

In the Northwest the Douglas-fir beetle normally attacks only injured, weakened, and recently killed trees and appears to be few in numbers and of little economic importance. Yet after a fire, even such a large one as the Tillamook fire, practically all fire-killed trees are attacked by this beetle. The problem of where such large numbers of beetles come from so suddenly has not been solved, but it is certain that they find favorable conditions for attack and rapid increase in the burned trees. Usually by the second year following fire the attacked trees are no longer attractive to the beetles. By then, however, a large beetle population may be present, and, being without preferred host material, may attack healthy green timber in the surrounding area. In such cases much additional timber is killed and the magnitude of the original salvage problem is considerably increased (*8*).

In burned timber the Douglas-fir beetle is of importance in two respects. As a bark loosener, it is one of the chief factors in opening the bole to other agents of deterioration and may thus accelerate the establishment of fungi. In this connection it is pertinent that where Douglas-fir beetle galleries are very numerous they tend to retard deterioration by other insects to some extent by making conditions

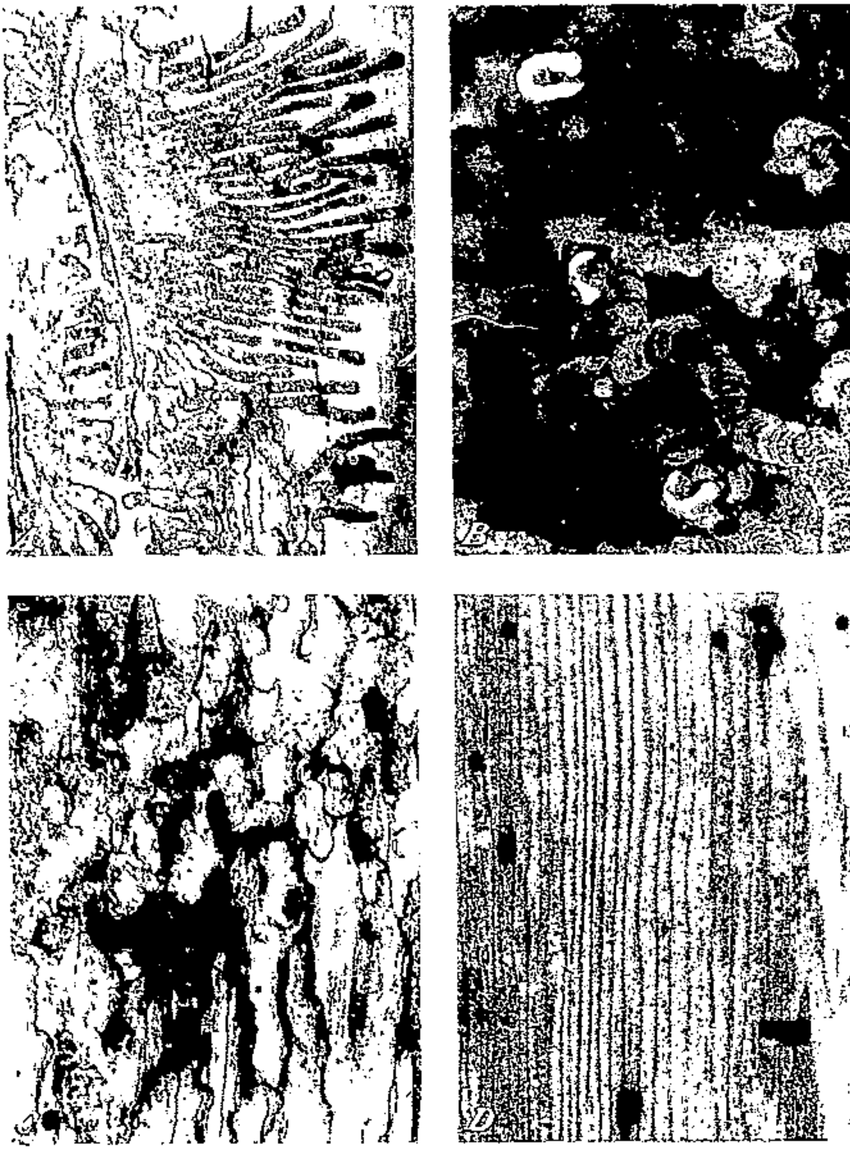

FIGURE [illegible].—Characteristic work of the more important insects that mine beneath the bark and in the sapwood of fire-killed Douglas fir in the early years following fire: *A*, Egg galleries and larval mines of *Dendroctonus pseudotsugae* on inner bark surface; *B*, larvae and larval mines of *Melanophila drummondi* on inner bark surface; *C*, mines of *Asemum atrum* showing on the surface of the sapwood; *D*, section through galleries of *Trypodendron bivittatum* in sapwood. Similar damage is caused by two other common ambrosia beetles, *Gnathotrichus sulcatus* and *G. retusus*.

less favorable for borer development. As an established carrier of the sapwood-staining fungus, *Ceratostomella pseudotsugae* Rumbold (*13*), the Douglas-fir beetle is one of the factors influencing the early stages of deterioration in the sapwood.

The fir flatheaded borer, *Melanophila drummondi* (Kby.), is somewhat less abundant and causes considerably less deterioration than the Douglas-fir beetle. The adult, which is approximately three-eighths of an inch long, is a flattened black beetle with a variable metallic luster and with or without yellowish spots on the wing covers. The full-grown larvae are creamy white and somewhat resemble the shape of a bent horseshoe nail (fig. 5, *B*). Characteristic larval mines are formed in the inner bark (fig. 5, *B*). One generation a year, with attacks occurring in the early summer following fire, appears to be typical. In some trees in which the inner bark has dried out more slowly than usual, attacks may be made the second year following fire. Infestation may extend practically throughout the length of the bole, but it most frequently occurs above the basal 30 to 40 feet and is heaviest toward the top.

In addition to its role as a bark loosener, the fir flatheaded borer is an important factor affecting salvage by killing scorched and exposed trees adjacent to burns. As a killer of green trees, however, it is of much less importance than the Douglas-fir beetle.

A number of other phloem-feeding insects of lesser importance attack fire-killed Douglas-fir during the first few years following fire. Of these the more common are the roundheaded borers *Tetropium velutinum* Lec. and *Stenocorus lineatum* (Oliv.).

INSECTS INFESTING SAPWOOD

The sapwood of fire-killed trees is commonly infested by many species of borers. Few of these are of importance in the salvage problem, for they seldom become abundant enough to cause cull of the wood before fungi have rendered it useless for lumber. A few do cause degrade. Some borers that mine in the sapwood later bore into the heartwood, where they sometimes cause considerable damage. This latter group of insects is discussed in the following section headed "Insects Infesting Heartwood."

The ambrosia beetles, or pinhole borers, of which *Trypodendron bivittatum* (Kby.), *Gnathotrichus retusus* (Lec.), and *G. sulcatus* (Lec.), are the principal species, are the first insects to attack the sapwood and are frequently the first insects to attack burned trees. They are the only sapwood-infesting insects causing appreciable deterioration. The adults are cylindrical, dark-brown, shiny beetles approximately one-eighth of an inch in length. They make small branching galleries that soon become heavily stained by certain fungi that are specifically associated with them. One or more generations, depending upon the species, are produced annually. Attacks are made throughout the growing season, but the heaviest attack is made in the spring and a somewhat lighter concentration occurs in the fall. On individual trees, attacks are usually heaviest in the lower bole although they may extend high into the crown. Most attacks are made in the first and second years following fire, but both species of *Gnathotrichus* have been reared from trees that had been dead many years.

As is the case with the Douglas-fir beetle, the ambrosia beetles attack nearly all fire-killed Douglas-firs irrespective of the size of the burn. Their galleries cause a defect known as "pinholes," which, together with the accompanying blue stain, causes degrade of lumber cut from infested trees (fig. 5, *D*).

Other sapwood-infesting insects commonly found during the first few years after fire are as follows: The horntails, of which *Xeris caudata* Cress. is an example; the buprestids, *Buprestis aurulenta* L., *B. langi* (Mann.), *B. rusticorum* (Kby.), *Dicerca sexualis* Cr., and *Chalcophora angulicollis* (Lec.); and the cerambycids, *Xylotrechus undulatus* (Say) and *Neoclytus muricatulus* (Kby.). These insects are most abundant from the midbole to the top. *Buprestis aurulenta* and *B. langi* also bore into the heartwood, but penetrate so slowly that other deteriorating agents usually precede them.

INSECTS INFESTING HEARTWOOD

The relatively few insects that attack sound heartwood are the most important ones in determining limits of salvability. Although their galleries usually cause only degrade, this is frequently sufficient to so reduce the sound volume of a tree that it is unprofitable to remove it from the woods. The destructiveness of the heartwood borers is accentuated by the fact that they mine chiefly in the portion of a tree where the lumber values are normally greatest.

A very large roundheaded borer, *Ergates spiculatus* Lec., is known to loggers as the "timber worm." The adult (fig. 6, *A*), a large dark-brown beetle from 2 to 2½ inches long, is seldom seen except when an occasional one is attracted to light during the flight period in late summer. In contrast, the larvae (fig. 6, *B*), which attain a length of 3 inches, are well known to woods workers and others who have occasion to cut into old Douglas-fir snags. Fortunately, the large larvae of this borer never become abundant in fire-killed trees before the fifth or sixth year following fire, and often not until some years later, or in some areas not at all. Attacks are repeatedly made as long as sound wood remains. The galleries may be present from the base far into the top, but their occurrence is characteristically patchy, so that it is difficult to make deductions for this type of damage. *E. spiculatus* extends its large galleries (fig. 7, *C*) farther ahead of general deterioration than any other insect. The presence of these galleries is quite likely to be the factor determining the ultimate limit of practical salvage in a given area.

Another roundheaded borer, *Criocephalus productus* Lec., may at times cause much damage to the heartwood and has limited salvage operations in a number of cases. The adults are black and attain a length of 1 to 1¼ inches (fig. 6, *C*). The larvae (fig. 6, *D*) at maturity are approximately 1½ inches in length. Attacks presumably occur in the summer of the first year following fire. Closely related species have been observed to be attracted to burned trees that were still smoldering. The life cycle of *C. productus* was not definitely established, but circumstantial evidence indicated that several years are required to reach maturity. This beetle was not found to reattack fire-killed trees. The larva first mines beneath the bark, later it penetrates the sapwood, and finally it makes a large open pupal cell that

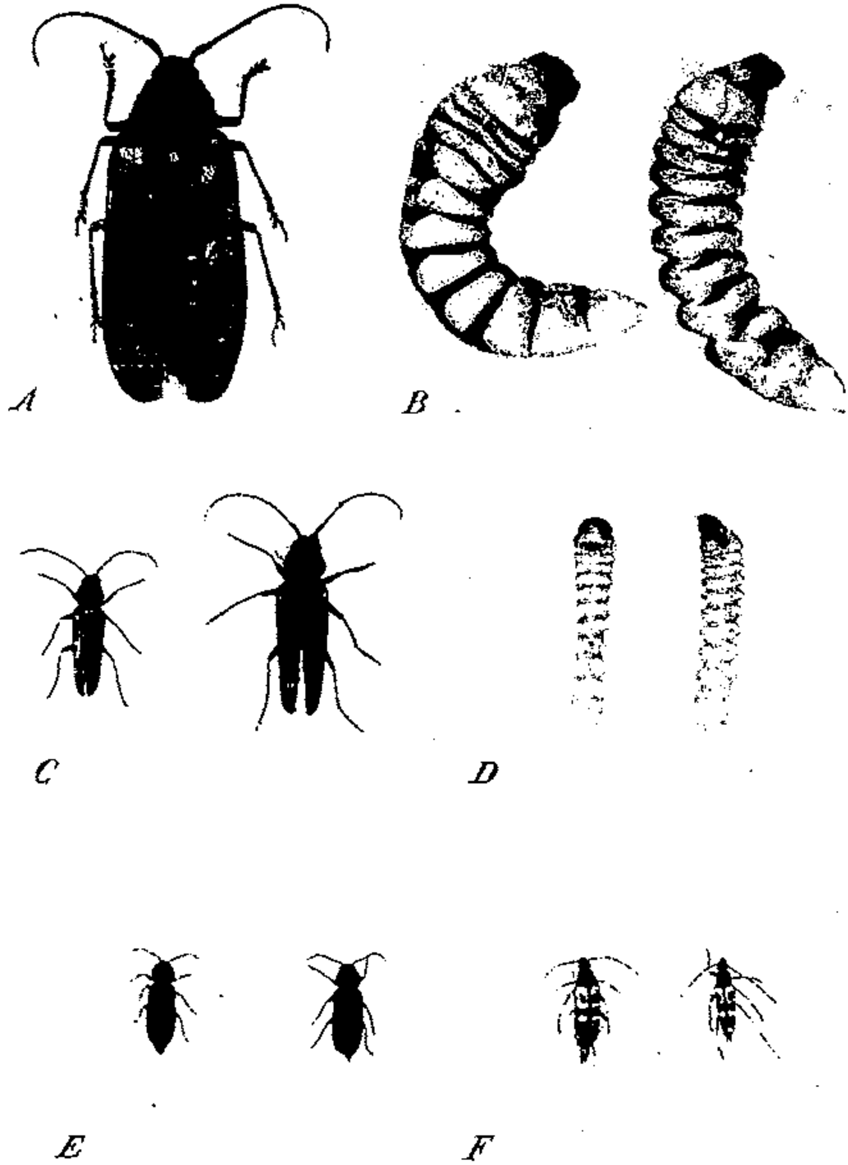

FIGURE 6.—Principal insects causing damage to the heartwood of fire-killed Douglas-fir: *A*, *Ergates spiculatus*, adult; *B*, *E. spiculatus*, larvae; *C*, *Criocephalus productus*, adults; *D*, *C. productus*, larvae; *E*, *Asemum atrum*, adults; *F*, *Leptura obliterata*, adults.

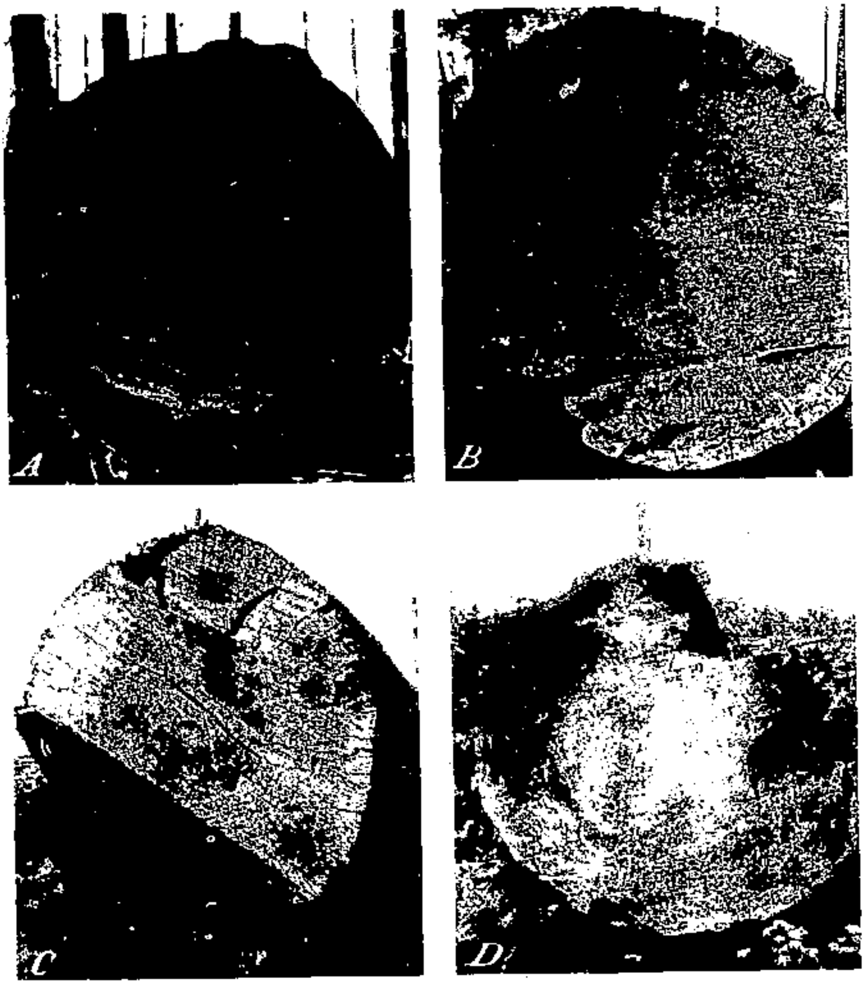

FIGURE 7.—Cross sections of old growth Douglas-fir showing certain phases in the deterioration of fire-killed trees: *A*, tree 5 years after being killed by fire, showing general deterioration just starting into the heartwood; *B*, similar tree in another 5-year area, showing galleries of *Criocephalus productus* penetrating the otherwise sound heartwood several inches in advance of the general deterioration; *C*, tree in a 16-year-old burn, showing galleries of *Ergates* in the heartwood (sapwood mostly gone) in advance of general deterioration; *D*, tree in a 32-year-old burn showing general deterioration practically complete, with decay and insect galleries extending practically to the center. Note case-hardened shell of outer heartwood; sapwood is all gone.

usually extends several inches into the heartwood (fig. 7, *B*). Construction of the pupal cells takes place from 3 to 6 years following fire and causes the principal damage by this insect. The oldest burn in which *C. productus* was found was one in which the trees had been dead 10 years. Attacks characteristically occur in the upper portion of the bole but may also be present near the base.

A third roundheaded borer, *Asemum atrum* Esch., is the most abundant species that bores in the heartwood in the early years following fire, but it causes less damage than *Criocephalus productus*, of which it is a near relative. The adult of *A. atrum* is a black beetle approximately one-half of an inch long (fig. 6, *E*). The mature larva is approximately 1 inch long, and, aside from its size, so closely resembles that of *C. productus* that these two species in the larval stage can be separated with certainty only by microscopic examination. The length of the life cycle of *A. atrum* in fire-killed Douglas-fir was not determined, but attacks were noted the first year following fire and adults emerged the third year following fire. Reattacks occur in the spring, year after year, long after the trees are dead. At first the larvae work between the bark and wood (fig. 5, *C*) and later mine extensively in the sapwood. Within 3 years in young trees and within about 5 years in old trees they begin to extend their galleries into the heartwood. At the end of 12 years they have been found abundantly 6 to 8 inches in the heartwood. Although *A. atrum* attacks the tree throughout its length, it is far more common in the basal 20 to 30 feet. Often the galleries show deep in the heartwood at the stump cut and hardly at all at the top end of the basal 32-foot log.

Several Lepturini, a group of roundheaded borers, are very abundant during the later stages of deterioration and cause some damage to the heartwood. *Leptura obliterata* Hald. is typical and is perhaps the most abundant of these borers. The adult is dark brown to black, with various yellowish markings, and is one-half to three-fourths of an inch in length (fig. 6, *F*). The eggs are laid during the spring and summer. The larva is creamy white with a light-brown head and is approximately 1 inch long when full-grown. Beginning about the third year following fire and continuing until the wood is completely deteriorated, the larvae are very abundant. As small larvae they may at first be found under the bark, but they soon enter the sapwood, which is mined and remined by successive generations of the borers until it is riddled. In the heartwood the larvae progress with the general deterioration but may extend their galleries approximately an inch and occasionally somewhat farther into the sound wood. Although attacks are present from the base to the top, they are more common from the midbole to the base, especially as deterioration progresses and the top dries out.

One of the ambrosia beetles, *Platypus wilsoni* Sw., has been observed to extend galleries into the heartwood of intermediate- and old-growth fire-killed Douglas-fir during the third and fourth years following fire. Such attacks cause only a minor amount of degrade and seem to be unusual and nonproductive of brood. In the first year or two following fire, *P. wilsoni* heavily attacks western hemlock and contributes considerably to the rapid deterioration of this species. By the third and fourth years following fire, hemlock becomes quite dry and considerably rotten, a condition that seems to be unfavorable for *P. wilsoni.* This insect may then attack Douglas-fir because of its more moist condition.

Deterioration by Weather

There is very little loss attributable directly to weathering or checking. In very old burns in which the sapwood has sloughed from the trees and the outer layers of heartwood have become case-hardened, there is often severe cracking or checking of the case-hardened shell of heartwood; however, this checking usually does not extend deeper than the discolored wood bearing incipient decay and the hyphae of wood-decaying fungi. When fire-killed Douglas-fir trees are felled and "bucked" and are then left in the woods for a considerable time, they will usually end-check more extensively than green logs left for the same length of time.

Because of the exceptionally high atmospheric temperatures on hot, dry slopes of the Siskiyou Mountains in southwestern Oregon, the thin-barked tops of small fire-killed trees of the young-growth type were found to check practically to the center after being dead 4 or 5 years. This checking was confined to the upper bole well above the upper merchantable diameter limit of 8 inches. In the tops of these small trees the bark was so thin that it loosened and began sloughing off about the second year following the fire. The sapwood as well as the heartwood became so dry before decay reached the typical stage that further progress of decay was checked.

The weather undoubtedly has an indirect effect on deterioration by its influence on growing conditions for the deteriorating agents, in some cases limiting the number of species of fungi and insects that cause deterioration.

Other Causes of Loss

BREAKAGE IN FELLING

There is more breakage in felling fire-killed trees than in felling green trees of the same size under similar topographic conditions. It has been found (*1*) that breakage in fire-killed Douglas-fir trees that had been dead from 1 to 3 years averaged 18 percent when the trees were felled on slopes up to 30 percent, as compared with 8 percent breakage in green Douglas-fir trees on similar slopes. This increase in breakage is attributed to several factors, including brittleness of the branches, lack of foliage, lack of undergrowth, and weakening of the sapwood by deteriorating agents.

The increased susceptibility of fire-killed Douglas-fir trees to breakage in felling is not a factor in the general deterioration of the wood in standing trees as defined in this bulletin, and therefore was not included in the computations of deterioration as herein presented.

FIRE

While fires may, and often do, kill large quantities of merchantable timber, in the ordinary fire of the Douglas-fir region the immediate destruction of green timber is usually very small (fig. 8, *A*). The burning of wood usually is confined to dead trees, either standing or fallen, and to previously fire-scarred or decayed portions of them that were partially unmerchantable before the fire. In exceptionally hot crown fires some of the broken or dead and decayed tops are consumed; however, this burning is usually in tree tops where the diameter is less than the 8-inch merchantable limit or in previously unmerchantable material. It is estimated that not over 3 percent of

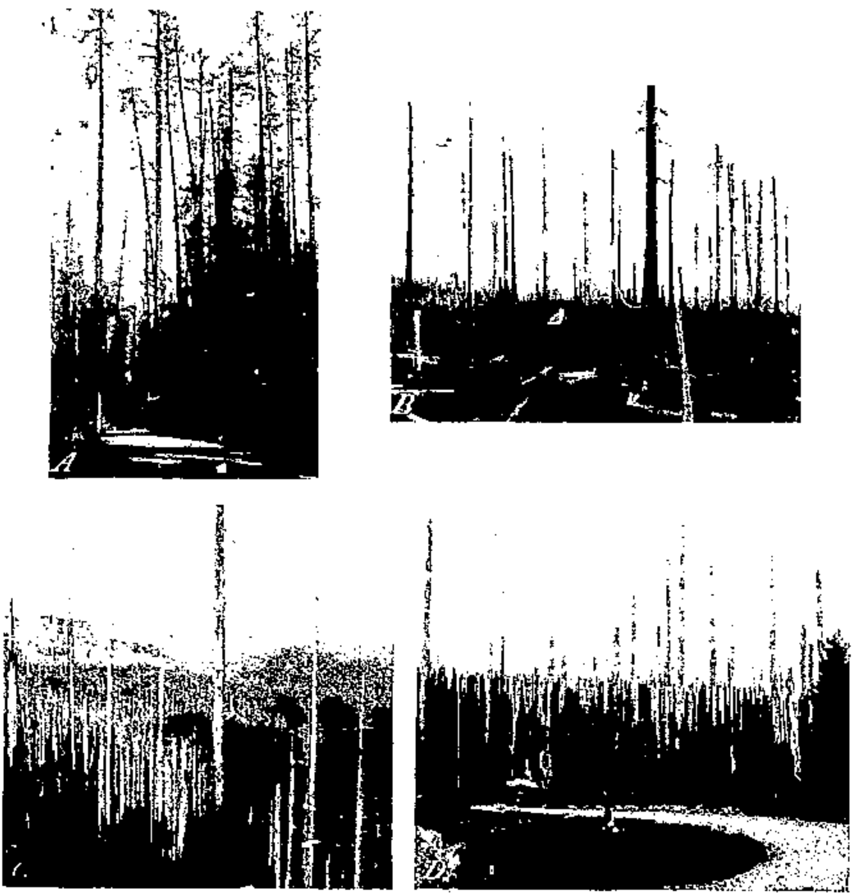

FIGURE 8.—Stages in the break-down of stands of fire-killed Douglas-fir. *A*, Stand killed by fire but otherwise little damaged by initial fire; twigs and small branches intact 1 year after death. *B*, Partially logged stand dead 12 years; bark beginning to slough; smaller branches gone. *C*, A well-preserved stand 22 years after death by fire; bark all off; many large limbs fallen. *D*, Remnant of an old-growth stand dead 62 years; only scattered limbless snags remaining; reproduction established.

all merchantable material in an ordinary mature Douglas-fir stand is consumed by a hot forest fire. In younger stands the percentage of loss is less. Under present-day utilization practices in the mature stands of old growth there would be no loss of merchantable green material in an ordinary forest fire.

Although no detailed data were taken on areas in which more than one fire had occurred, general observations on such areas indicate that subsequent fires consume a very small amount of standing merchantable material when they occur in stands that have been dead less than 5 years. However, severe fires occurring in old burns, in which the standing trees have lost their bark, often cause some loss by burning through the disintegrated and dried sapwood and into the otherwise merchantable heartwood. Such loss usually is not so uniform in the different trees of an area, or even in the different parts of an individual tree, as loss from decay and insects. The burning of a snag often is confined to the base or to one side, and in the case of trees with decayed or hollow butts the burning usually occurs inside the tree, often causing the snag to fall.

DETERIORATION AND RATE OF LOSS

General Progress of Deterioration

It is difficult to express the rate of loss through deterioration in fire-killed trees without considerable detailed discussion and a number of graphs and tables. For the sake of conciseness the extent of the average deterioration in different years after the fire is shown diagrammatically in generalized sketches representing cross sections of Douglas-fir logs. Deterioration for young growth, intermediate growth, and old growth is shown in figures 9, 10, and 11, respectively.

Two types of deterioration, namely, limited and general, are shown in the diagrams. Wood with limited deterioration is suitable for low-grade lumber, whereas wood with general deterioration is unsuitable or undesirable for most uses as lumber even of low grade. Limited deterioration may not always occur, especially in the heartwood.

The bases for these diagrams (figs. 9, 10, and 11) are data from all areas and for all trees used in the entire study (tables 1 and 8). The state of deterioration depicted for any one year was determined by averaging the data from the several areas of that age. Since each area represented a particular set of conditions, it was considered desirable to keep the computations on an area basis. This method gave the same value to an area with a small number of trees as a basis as it did to an area on which a large number of trees were examined.

As indicated by the diagrams, the first deterioration that becomes apparent is caused by blue-stain fungi and ambrosia beetles working simultaneously. Although exceptions are common in individual trees and occasionally in entire areas, deterioration of this kind occurs in all growth types during the first year after fire. Deterioration caused by blue-stain fungi and ambrosia beetles is totally obscured by that of other agents by the beginning of the second year in young growth and by the beginning of the fourth year in old growth. Throughout the study the presence of ambrosia beetle galleries and blue stain without decay was considered limited deterioration.

Some incipient decay and insect borings usually are noticeable in the sapwood the first year following the death of trees in the young- and intermediate-growth types, and by the second year in the old-growth type. Within a year or two following attack by these agents the entire sapwood is deteriorated by insect galleries, the typical stage of decay, discoloration by incipient decay, and weathering checks (fig. 7, *A*). In this study such wood is considered generally deteriorated.

Upon reaching the heartwood, the progress of the deteriorating agents is considerably slowed in old-growth trees but not noticeably so in young-growth trees. In the heartwood general deterioration progresses at a fairly uniform rate, which gradually accelerates as the center of the tree is approached. In some areas galleries of certain

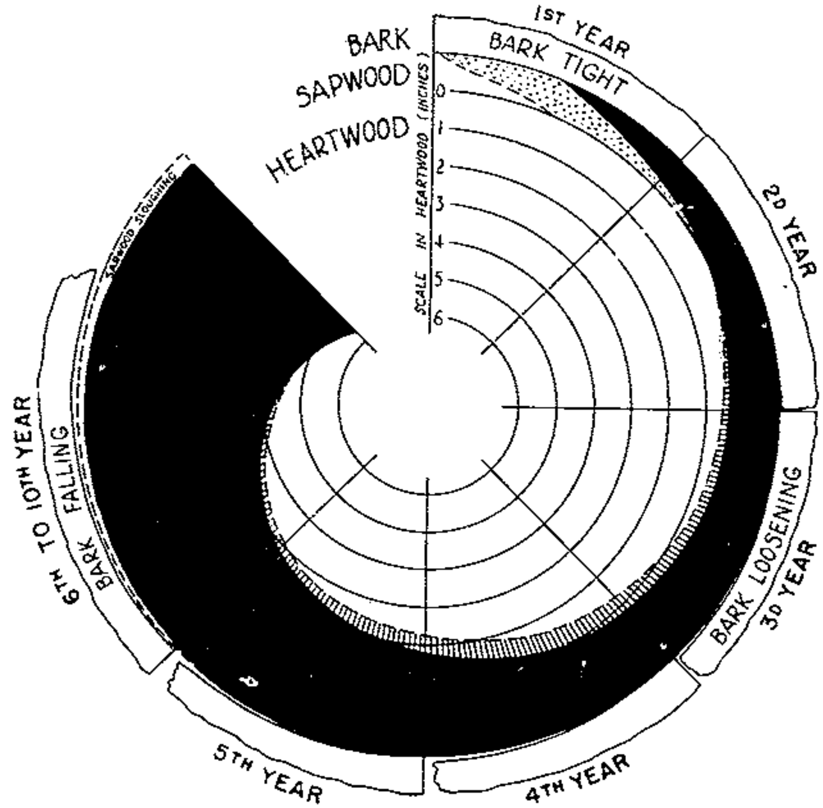

FIGURE 9.—Progress of deterioration in the trunk of an average young-growth fire-killed Douglas-fir tree. The stippling represents limited deterioration by blue-staining fungi and ambrosia beetles in the sapwood. The black area represents general deterioration by all causes. The cross hatching represents limited deterioration by borers in the heartwood.

borers extend into the heartwood beyond the region of general deterioration (fig. 7, *B* and *C*); however, wood thus mined is still potentially usable for lumber of low grade and therefore is shown in the diagrams as limited deterioration. The extent of this partial deterioration is considerably influenced by the galleries of *Criocephalus* borers, which are most active from 3 to about 6 years following fire (fig. 7, *B*), and by *Ergates* borers, which may be present to a variable degree from the fifth or sixth year until all the sound wood is gone (fig. 7, *C*). Factors affecting the occurrence of these borers are discussed later under the heading "Environmental Factors." General deterioration becomes complete at the time discoloration by incipient decay reaches the center of the tree (fig. 7, *D*).

The condition of the bark on trees of each growth type is illustrated in the diagrams (figs. 9, 10, and 11) for different years after the death of the trees. In general, the thinner the bark of a tree the sooner it loosens and falls. Bark ordinarily loosens first in the top of a tree; however, the branches usually hold the bark and keep most of it from

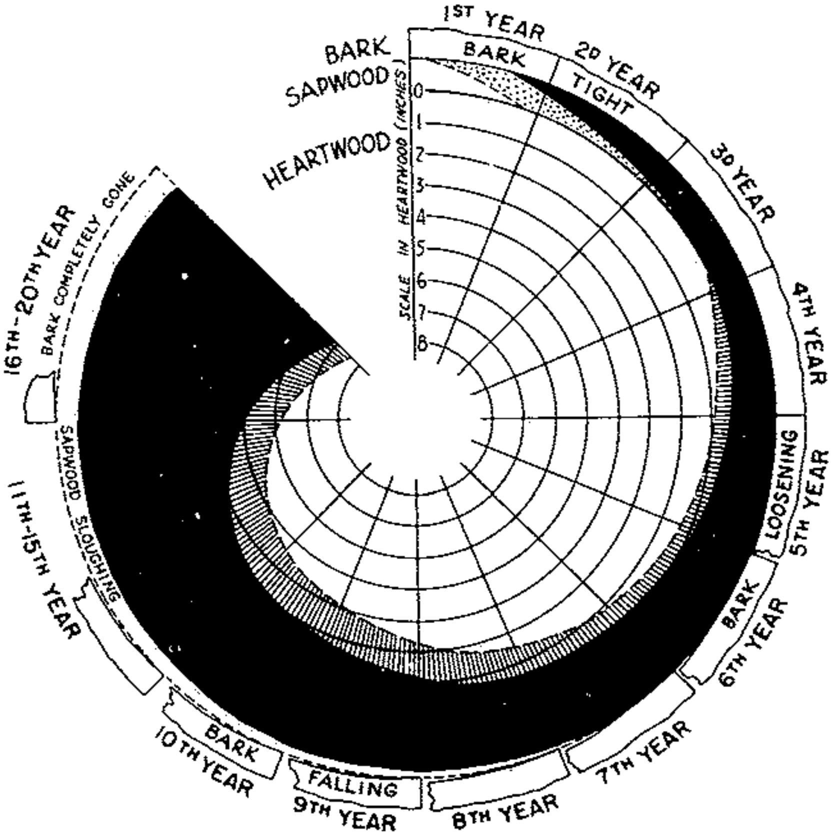

FIGURE 10.—Progress of deterioration in the trunk of an average intermediate-growth fire-killed Douglas-fir tree. The stippling represents limited deterioration by blue-staining fungi and ambrosia beetles in the sapwood. The black area represents general deterioration by all causes. The cross hatching represents limited deterioration by borers in the heartwood.

falling for some time after it is loosened. The bark on the upper part of the clear part of the bole usually is the first to fall, although it normally is not loosened until after the bark is loosened in the top of the tree (fig. 8, *B*). The bark remains longest on the butt of the tree, the last to fall being that adjoining the ground.

Sapwood ordinarily begins to slough from the bole of a fire-killed Douglas-fir tree at about the same time the bark starts to fall to the ground. However, some sapwood may generally be found on a tree for a number of years after all the bark has fallen. Figures 9 to 11 indicate the time and rate of sapwood sloughing for trees of the various growth types.

After the sapwood is sloughed from fire-killed trees the decayed heartwood often begins to slough off. In some areas the outer layers of heartwood become case-hardened and remain intact, although decay usually proceeds inside the case-hardened outer shell. The case-hardened outer layers of heartwood are almost always discolored by

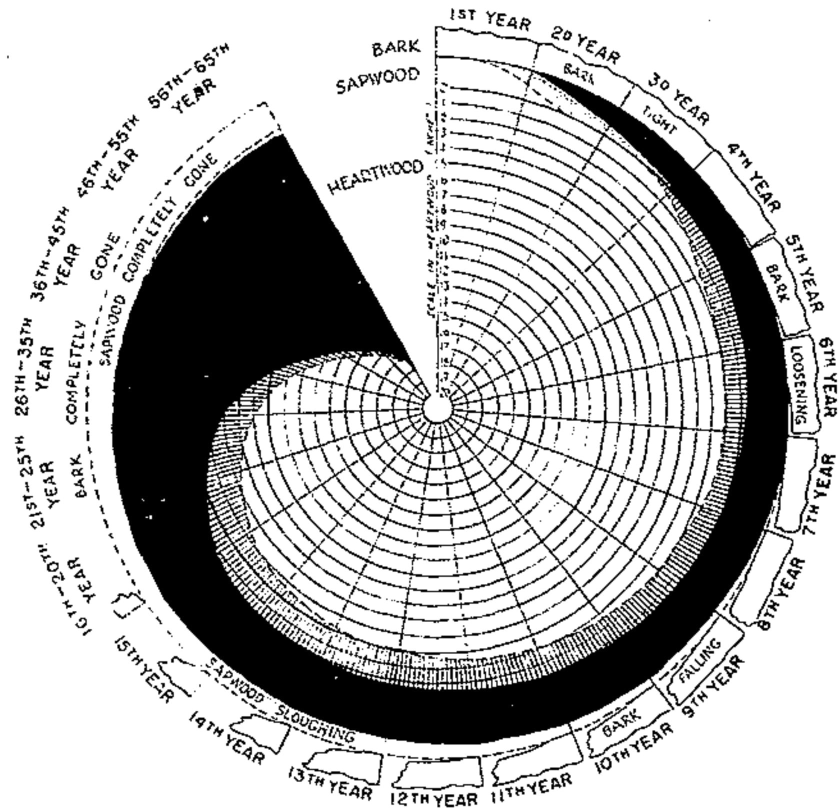

FIGURE 11.—Progress of deterioration in the trunk of an average old-growth fire-killed Douglas-fir tree. The stippling represents limited deterioration by blue-staining fungi and ambrosia beetles in the sapwood. The black area represents general deterioration by all causes. The cross hatching represents limited deterioration by borers in the heartwood.

incipient decay. This case-hardened shell becomes so badly cracked and checked that fungi find easy access to the inner heartwood, and decay usually progresses to the center of the tree (fig. 7, *D*).

The limbs of fire-killed Douglas-fir trees gradually become shorter (fig. 8), the small twigs and ends of branches starting to fall about 2 or 3 years following their death. The larger limbs usually start falling about the tenth year. At about this same time the tops start to break out and the trees gradually become shorter until, about 40 to 50 years after the death of the trees, only limbless snags remain (fig.

8, *D*). At high elevations in the Cascade Range the tops of many trees, especially the thin-barked species, become so dry that deterioration is greatly retarded; in such cases some of the trees rot off near the ground and the whole tree drops at one time (fig. 8, *C*). The falling of bark, large limbs, and treetops may be a serious hazard to woodsmen in certain areas.

Depth of Deterioration

The best index to the reduction of merchantable volume is the average depth of general deterioration. The depth of general deterioration for the three growth types on burns of different ages is shown in figure 12. In the construction of the curves in figure 12 all trees in all areas studied were used. The depth of general deterioration as shown is the average depth for the whole tree and is not necessarily applicable to any one part of the tree. The depth to which the wood had deteriorated in the different logs varied with the position of the log in the tree. Generally the top log of a tree had the deepest penetration and the basal log had the shallowest.

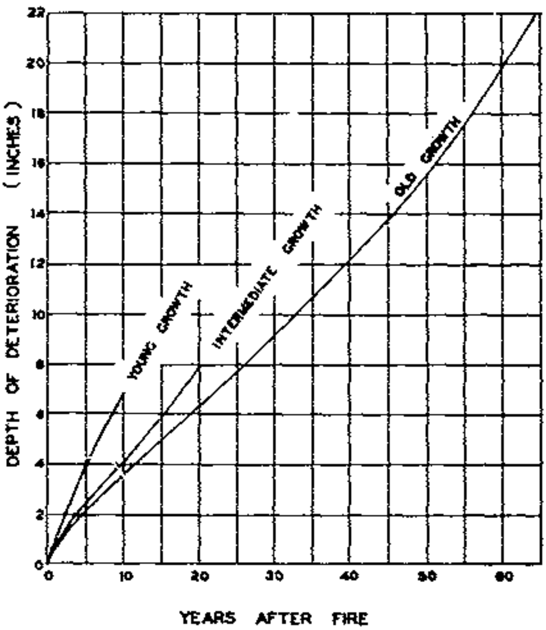

FIGURE 12.—Average depth of the radial penetration of general deterioration in trees of the three growth types of fire-killed Douglas-fir.

From the curves in figure 12 it can be seen that after the rapid deterioration of the sapwood in the first 3 to 5 years the rate of penetration was retarded as deterioration started into the heartwood. The rate of penetration in the heartwood, however, was accelerated as the depth of deterioration became greater. Probable causes for this acceleration are presented later under the discussion of the factors influencing the rate of deterioration. The basic figures used in the construction of the curves in figure 12 are given in the Appendix (see table 8).

Arbitrary Influence of Tree Diameter on Volume of Loss

Deterioration caused by fungi and insects in a fire-killed Douglas-fir tree starts at the periphery, or just under the bark, and rather uniformly penetrates the bole toward the pith, or center of the heartwood, thereby progressively lessening the diameter of the cylinder of sound wood in the tree. The percentage of volume lost from deterioration thus depends upon two primary factors: (1) The depth to which deteriorating agents have penetrated into the bole and rendered the wood unmerchantable and (2) the diameter of the tree bole. To illustrate this arbitrary influence of tree size upon percentage of volume lost through deterioration, a comparison of the volumes of cylinders of equal length but of different diameters can be made. Or, to draw a closer parallel with the effect of penetration of deterioration into a tree bole, a comparison can be made of percentage of volume reduction of cylinders of various diameters when the radii are decreased by any given amount, as in table 4. From table 4 it can be seen that in comparing cylinders of unequal size the percentage of volume lost through a reduction of the radii is in inverse relationship to the original diameters. The basis for this may be expressed by the formula, $PL=\frac{R^2-(R-D)^2}{R^2}100$, when PL=percentage of volume lost, R= original radius, and D=decrease of radius.

TABLE 4.—*Percentage of volume lost in cylinders of indicated diameters as radius is decreased by given amounts*

Amount of decrease of radius (inches)	Percentage of volume lost in cylinders of indicated diameter (inches)														
	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
1	19	15	13	11	10	9	8	7	7	6	6	5	5	4	4
2	36	29	25	22	19	17	15	14	13	12	11	10	10	9	9
3	51	42	36	31	28	25	22	12	19	18	17	16	15	14	13
4	64	51	46	40	36	33	30	27	25	23	22	20	19	18	17
5	75	62	56	49	44	40	36	33	31	28	27	25	23	22	21
6	84	73	64	57	51	46	42	39	36	33	31	29	28	26	25
7	91	81	72	64	58	53	48	44	41	38	36	34	32	30	29
8	96	87	78	70	64	59	54	50	46	43	40	38	36	34	32
9	99	92	84	76	70	64	59	55	51	47	45	42	40	38	36
10	100	96	89	82	75	69	64	60	56	52	49	46	44	42	39

From the foregoing it is obvious that the greater the diameter of a tree the smaller is the percentage of the volume lost for any given depth to which the wood is deteriorated. Therefore the extent of deterioration in trees of different sizes cannot be compared by volume-loss percentages without allowing for the influence of the diameter upon these values.

LOSS BY GROWTH TYPES

In order to readily compare graphically the percentage of volume lost in trees of each growth type for different years following death, the modal-diameter class was used as being the one diameter class most representative of each growth type. All trees used in each growth type were classified into 10-inch d. b. h. classes. The modal 10-inch d. b. h. class of the young-growth type was 21 to 30 inches; of the intermediate-growth type, 41 to 50 inches; and of the old-growth type, 51 to 60 inches. By using all trees in each growth type that fell within their respective modal diameter classes, the curves in figure 13 were constructed. The basic data used in constructing these curves are given in the Appendix (see table 9). These curves fairly well represent an average for each of the growth types.

The curves in figure 13 illustrating the percentage of cubic-foot volume lost are based on the original total cubic-foot volume of the tree from the ground to the tip, exclusive of the taper in the stump. The board-foot curves are based on the gross merchantable board-foot volume. The curves for the intermediate- and old-growth types show a sudden decrease in rate of loss after the second to fourth year following the fire. This is accounted for by the slower penetration of the deterioration in the heartwood after the sapwood has been deteriorated. This tendency for the rate of loss to be retarded is less evident in the curves for the young growth.

The tendency of the curves to level off after reaching 80 or 90 percent of volume lost is explained by the usually slow rate of deterioration in the basal log of a tree. There are several factors that may account for the slowing down of the deterioration in the base of a standing dead tree. Boyce (*4, p. 25*) suggested that perhaps the greater relative amount of compression wood, with its thick cell walls, in the butts of Douglas-fir trees made it more difficult for wood-destroying fungi to cause decay there. Probably one of the principal factors is the higher moisture content in that part of the dead tree; this is often high enough to greatly retard deterioration, especially in the older burns where the new forest growth is dense enough to prevent rapid drying of the tree butts.

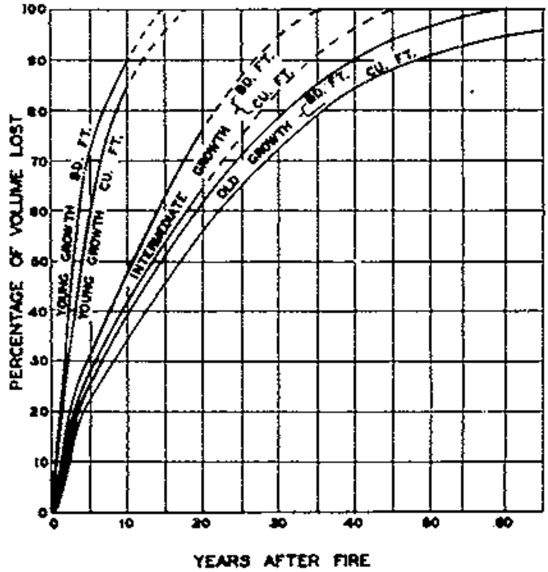

FIGURE 13.—Average rate of volume loss through general deterioration in the modal d. b. h. class of each of the growth types of fire-killed Douglas-fir (young growth 21 to 30 inches, intermediate growth 41 to 50 inches, and old growth 51 to 60 inches). Broken lines indicate estimated extension of curves beyond the age of burns studied for young and intermediate growth.

The curves in figure 13 represent only an average for each growth type. The deterioration in trees of smaller diameter than those represented by the curves in each growth type was more rapid, whereas that in the trees of larger diameter was slower.

Loss by Size Classes

Within a growth type the rate of volume loss from deterioration is generally slower in the larger sizes, as would be expected from the influence of size alone, as shown in table 4. However, because of the influence of other factors, as will be shown later, the rate of loss

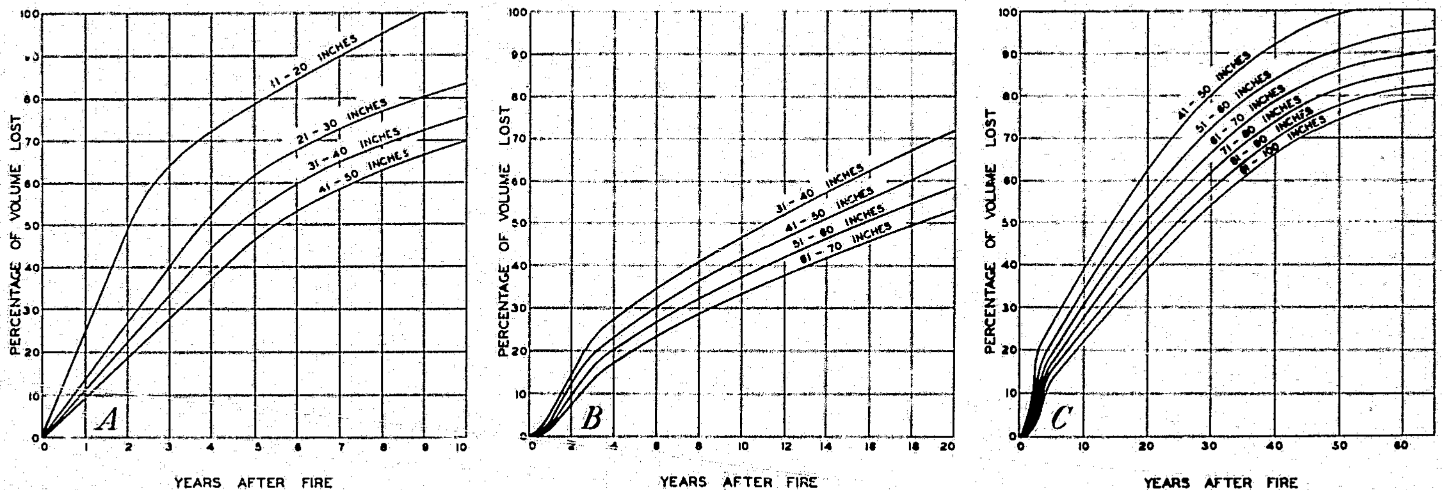

FIGURE 14.—Average rate of loss from general deterioration of the original total cubic-foot volume in trees of the different d. b. h. classes of each of the three growth types of fire-killed Douglas-fir: *A*, Young growth; *B*, intermediate growth; *C*, old growth.

in the larger sizes is not so much slower as might be expected. To show the rate of volume loss in the various-sized trees of the three growth types, all trees in each growth type were grouped into 10-inch d. b. h. classes. The average rate of loss in each of the various d. b. h. classes was determined both in cubic feet and in board feet within each growth type. The three sets of smooth curves in figure 14 show the average rate of volume loss in cubic feet, and those in figure 15 in board feet, for the different d. b. h. classes in each growth type.

The bases for the curves in some of the size classes were comparatively weak. In such cases the curves were drawn to conform to the shape of the smoothed curves representing the size classes with strong bases. The basic data used in the construction of the curves in figures 14 and 15 are given in the Appendix (see table 9).

Loss by Logs

In general, deterioration in a standing fire-killed Douglas-fir tree is slowest at the base and progressively more rapid with increasing distance from the ground. To demonstrate this, the average rate of volume loss was figured in each 32-foot log in a representative tree-diameter class in each growth type. Figure 16 shows graphically, by smoothed curves, the rate of cubic-foot volume loss in each log for the various growth types, and figure 17 shows similarly the rate of board-foot volume loss in these same logs. Log 1 is the basal 32-foot log; log 2, the adjoining 32-foot log; etc.

In figures 16 and 17 the rate of loss in the first three logs is shown for young growth. In the Coast-type forests, young-growth trees in the 21- to 30-inch d. b. h. class usually have three full-length logs, but some trees have four, or occasionally even five. Some young-growth trees in this diameter class in the Cascade-type forests have only two logs and occasionally only one. Figures 16 and 17 show the rate of loss from general deterioration in the first five logs in trees of the 41- to 50-inch d. b. h. class of the intermediate-growth type. Five is the most common number of logs found in intermediate-growth trees of this diameter. However, larger trees and trees in the Coast-type forests often have six and occasionally seven full-length logs, while trees of this diameter in the Cascade-type forests sometimes have less than five logs (see bases of 32-foot logs, table 1). Old-growth trees have, on an average, six logs; accordingly, in figures 16 and 17 the rate of deterioration is shown for the first six logs of trees in the 51- to 60-inch d. b. h. class. The trees in all growth types in the Cascade-type forests are on the average somewhat shorter than trees of similar diameter in the Coast-type forests.

The curves in figures 16 and 17 show the rate of volume loss through general deterioration in each log, expressed in percentage of the original volume. These curves should be helpful to an operator who is salvaging timber in a large burned area, such as the Tillamook burn, since they facilitate determination of marginal logs. The percentage of volume lost in each log increases rapidly from the bottom to the top log, so that in the top log the volume lost reaches 100 percent a few years after the sapwood has deteriorated. Prior to complete deterioration of the tree, log 1 always contains a smaller percentage of loss than any of the other logs.

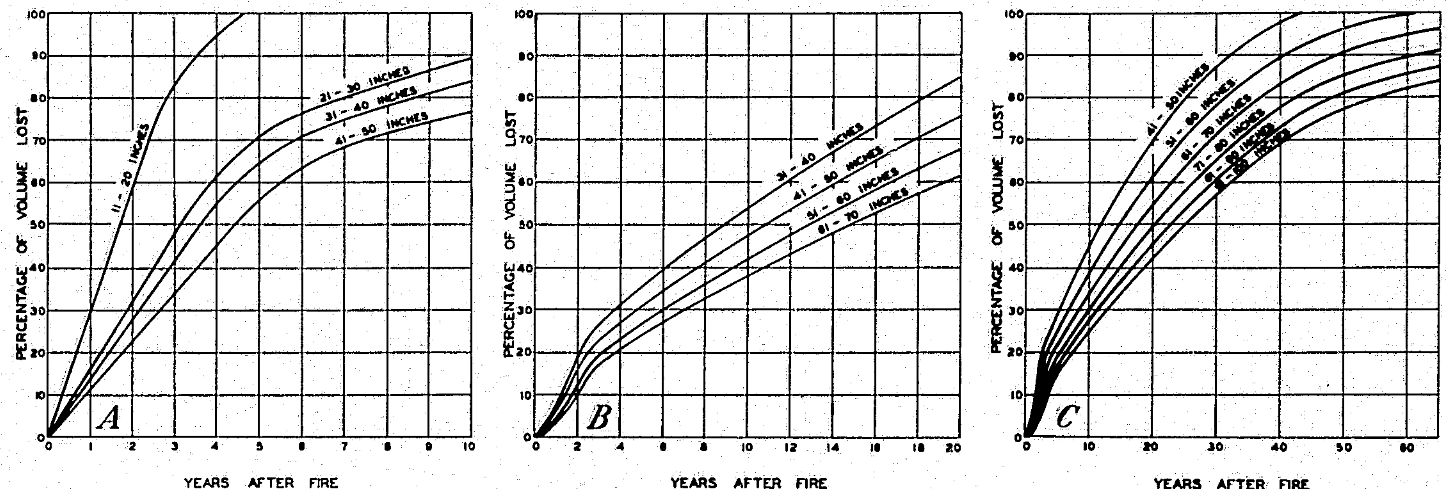

FIGURE 15.—Average rate of loss from general deterioration of the gross board-foot volume in trees of the different d. b. h. classes of each of the three growth types of fire-killed Douglas-fir: *A*, Young growth; *B*, intermediate growth; *C*, old growth.

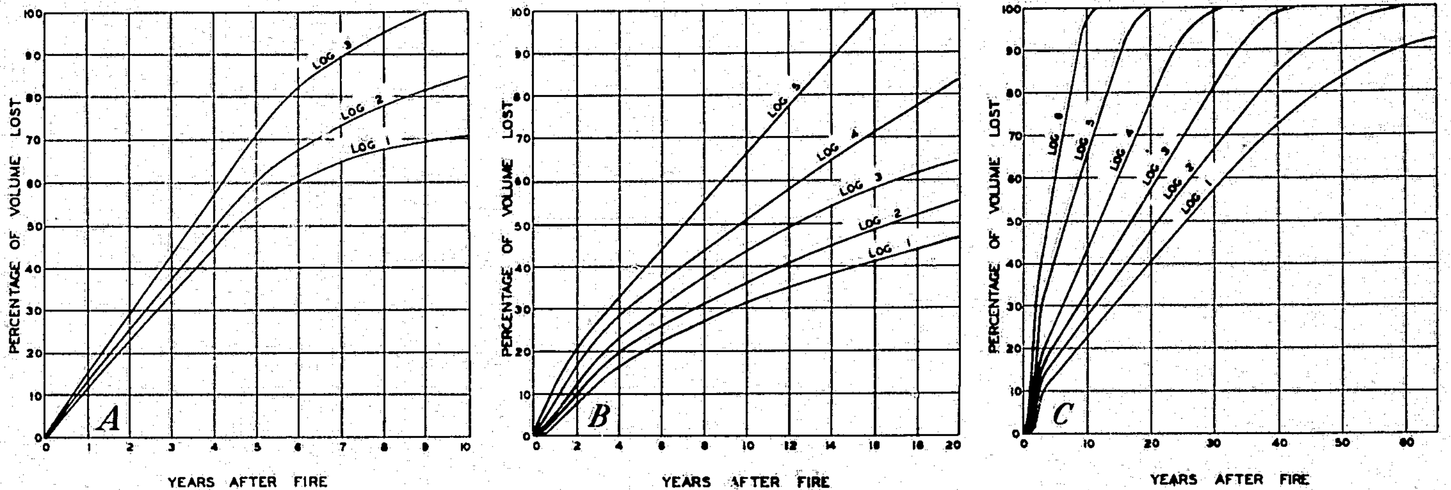

FIGURE 16.—Average rate of cubic-foot volume loss from general deterioration in each 32-foot log in trees of fire-killed Douglas-fir: *A*, First three logs of young-growth trees of the 21- to 30-inch d. b. h. class; *B*, first five logs of intermediate-growth trees of the 41- to 50-inch d. b. h. class; *C*, first six logs of old-growth trees of the 51- to 60-inch d. b. h. class. Log 1 is the basal log, adjoining the stump; log 2 is the next log above, adjoining log 1; log 3 adjoins log 2; etc.

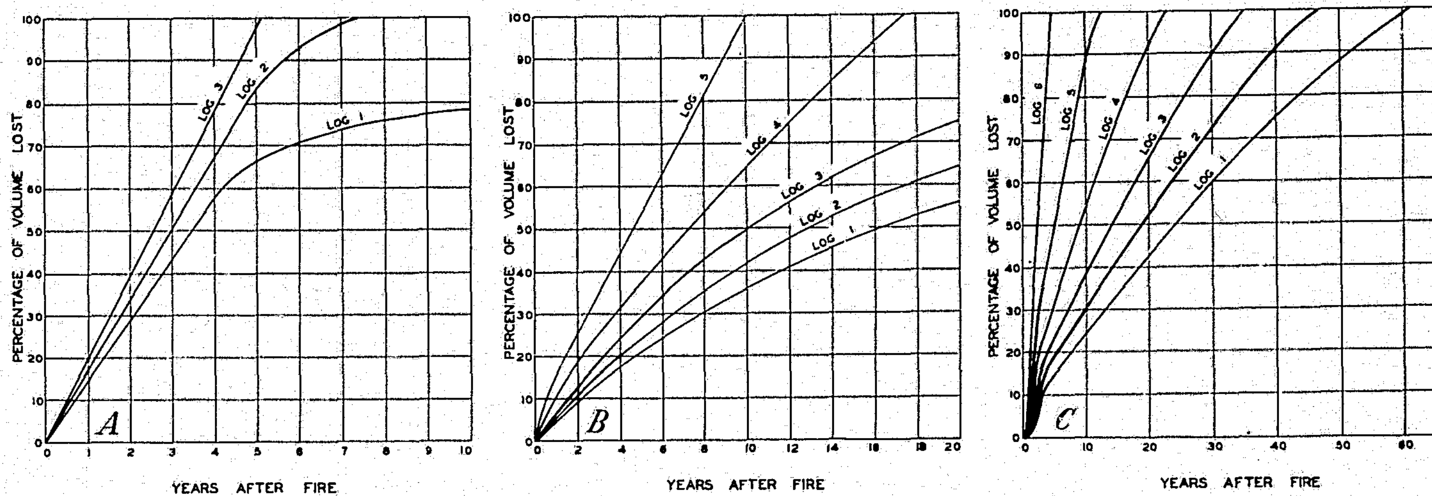

FIGURE 17.—Average rate of board-foot volume loss from general deterioration in each 32-foot log in trees of fire-killed Douglas-fir: *A*, First three logs of young growth trees of the 21- to 30-inch d. b. h. class; *B*, first five logs of intermediate-growth trees of the 41- to 50-inch d. b. h. class; *C*, first six logs of old-growth trees of the 51- to 60-inch d. b. h. class. Log 1 is the basal log, adjoining the stump; log 2 is the next log above, adjoining log 1; log 3 adjoins log 2; etc.

To avoid confusion, the numerous points used in plotting these curves are not shown in figures 16 and 17. The data used in the construction of the curves are presented in the Appendix (see table 10).

Distribution of Loss in the Tree

Most operators who log fire-killed Douglas-fir take out only that part of a tree that they estimate will yield them a profit. As a burned area becomes older they take out less of the original merchantable volume until, about 10 years after a fire, probably only the first two logs of old-growth trees are removed from the forest. As an aid to such operators, the percentage of the tree's original total volume represented in the sound volume of each log has been computed for different periods after fire. Figures 18 and 19 show graphically, in both cubic feet and board feet, the percentage of the tree's original merchantable volume that is salvable at different times following the fire. These curves are based on the data used in constructing the curves in figures 16 and 17 (see table 10, Appendix). The point of origin of each curve represents the proportion of the tree's total original merchantable volume contained in the entire log.

These curves are fairly representative of the usual conditions within their respective growth types, but, since they are based on averages of data taken over a wide range of conditions, they should not be expected to apply perfectly to any one area.

Comparison With Deterioration of Associated Tree Species

In addition to the data taken on Douglas-fir, some general notes were taken on the deterioration of associated tree species on the areas studied. Western hemlock and species of balsam fir (*Abies* spp.) were found to deteriorate much more rapidly than Douglas-fir (fig. 20, *D*). No difference in rate of deterioration between sapwood and heartwood was noted. Fire-killed hemlock and balsam firs were usually found to be unsalvable 5 years after death, except for the lower logs of extremely large trees.

Most of the heartwood of western redcedar, *Thuja plicata* Lamb., remained sound after Douglas-fir and other associated species had completely deteriorated. Nearly all of the heartwood was still sound in standing cedar trees that had been dead for 65 years.

The observations made on rate of deterioration of these tree species associated with Douglas-fir agree with those made by the United States Forest Service in 1911.[6]

FACTORS INFLUENCING DETERIORATION AND RATE OF LOSS

Estimates ranging from 6 to 20 years have been made by experienced timbermen regarding the length of time that fire-killed Douglas-fir can be profitably salvaged. There is no single rate of deterioration applicable to all areas, and as there are many variables these estimates may all be correct for the particular areas to which they refer. Aside from the arbitrary influence of tree size, which affects the percentage of volume deteriorated, there are several factors that seem to play an important part in the rate of deterioration.

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[6] United States Department of Agriculture, Forest Service. Rate of deterioration and usability of fire-killed timber in district 6. *Progress Rpt. District 6, Office of Products.* 51 pp. 1911. [Typewritten.]

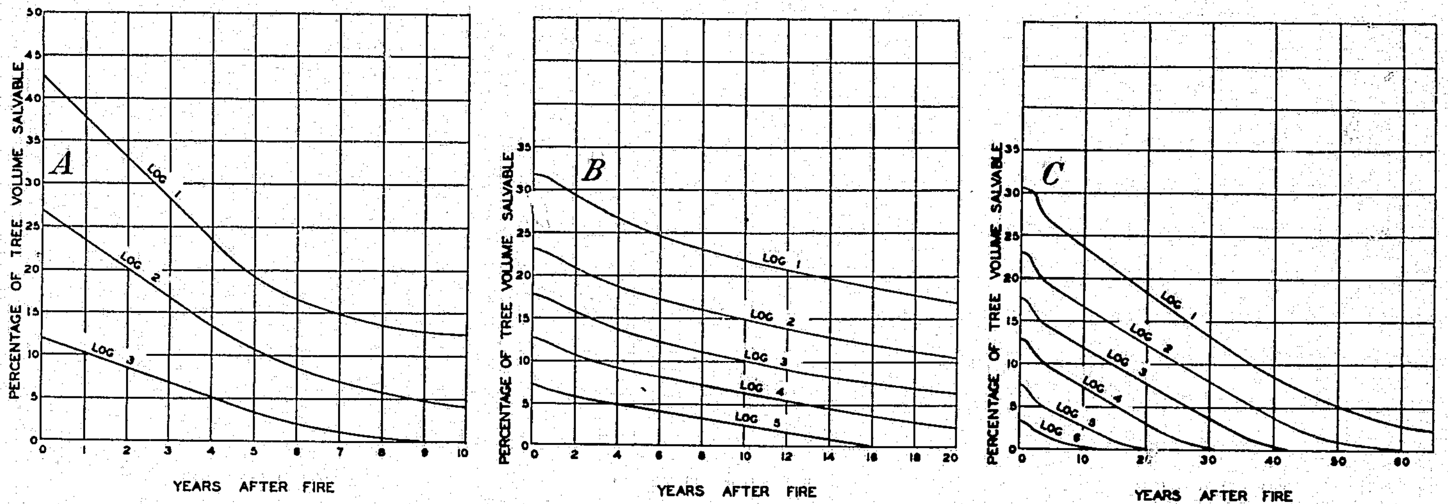

FIGURE 18.—Average percentage of the original total cubic-foot volume of fire-killed Douglas-fir trees salvable in each 32-foot log: *A*, In the first three logs of young-growth trees in the 21- to 30-inch d. b. h. class; *B*, in the first five logs of intermediate-growth trees in the 41- to 50-inch d. b. h. class; *C*, in the first six logs of old-growth trees in the 51- to 60-inch d. b. h. class. Log 1 is the basal log, adjoining the stump; log 2 is the next log above, adjoining log 1; log 3 adjoins log 2; etc.

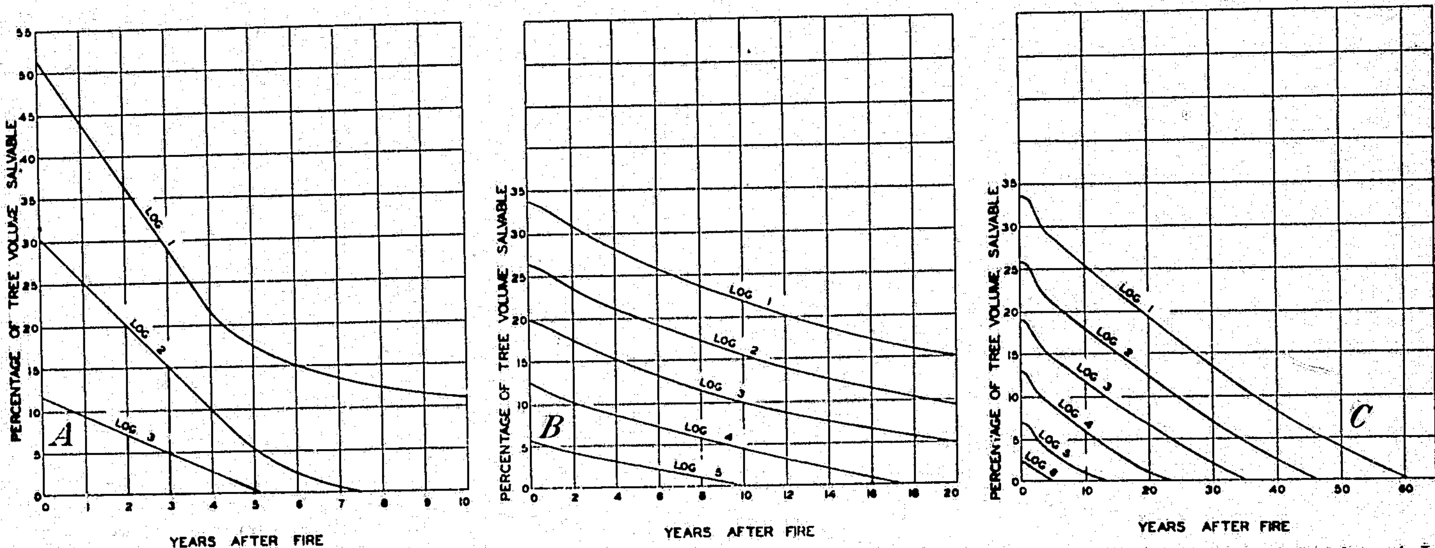

FIGURE 19.—Average percentage of the original gross board-foot volume of fire-killed Douglas-fir trees salvable in each 32-foot log; *A*, In the first three logs of young-growth trees in the 21- to 30inch d. b. h. class; *B*, in the first five logs of intermediate-growth trees in the 41- to 50-inch d. b. h. class; *C*, in the first six logs of old-growth trees in the 51- to 60-inch d. b. h. class. **Log 1 is the basal log, adjoining the stump; log 2 is the next log above, adjoining log 1; log 3 adjoins log 2; etc.**

CHARACTER OF WOOD

The character of the wood (whether sapwood or heartwood) is perhaps of first importance in influencing the rate of deterioration. Sapwood deteriorates rapidly, whereas heartwood is comparatively

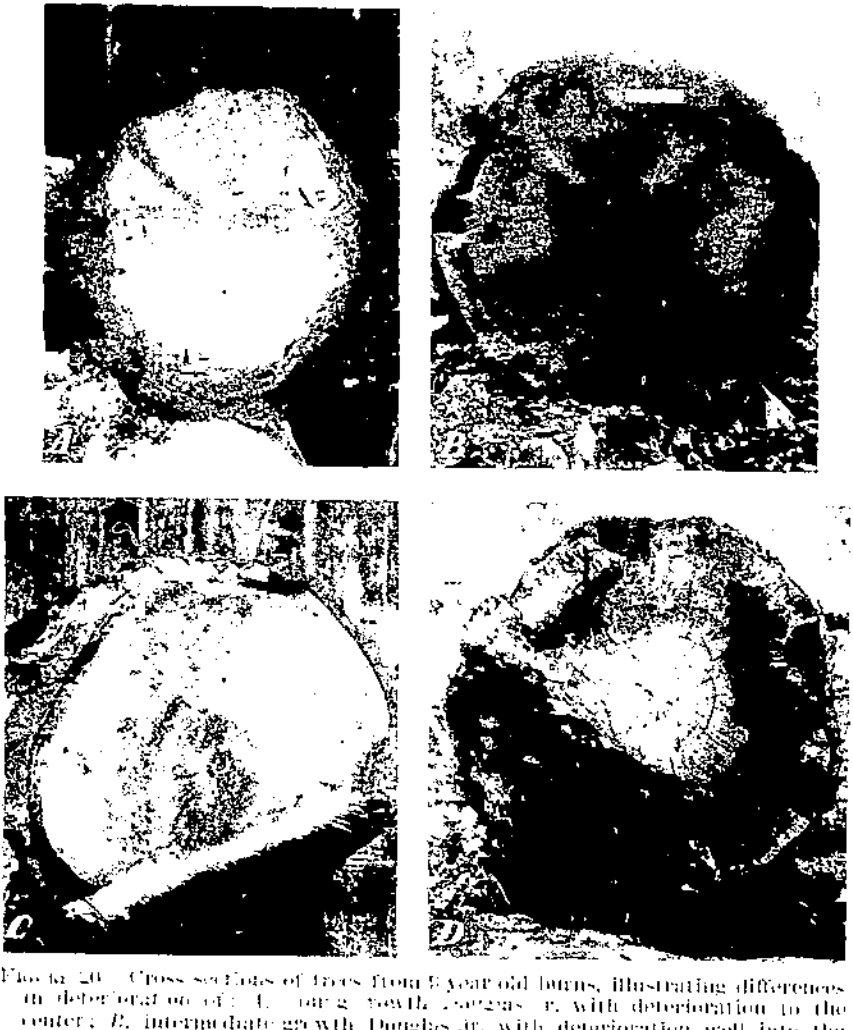

FIGURE 20.—Cross sections of trees from 5-year-old burns, illustrating differences in deterioration of: *A*, young-growth Douglas fir, with deterioration to the center; *B*, intermediate-growth Douglas fir, with deterioration well into the heartwood; *C*, old-growth Douglas fir, with deterioration confined mostly to the sapwood; *D*, a large old-growth western hemlock showing deterioration to the center.

resistant. Very little sapwood can be salvaged 3 years or more after a fire, and sometimes its value is seriously impaired during the first and second years. Sapwood 3 inches thick or more may become badly deteriorated within 3 years or less. After the sapwood has deteriorated on a tree, the rate of deterioration is usually retarded considerably, since heartwood deteriorates more slowly. However, there is sometimes a notable difference in the rate of deterioration of heartwood in different trees.

Width of Growth Rings

The width of the growth rings in heartwood of Douglas-fir probably has an important effect upon the rate of deterioration of a tree after it has been killed by fire. The heartwood of trees of rapid growth, such as those of the young-growth type, is much less resistant to deterioration than is the close-grained heartwood of trees of slow growth as in the old-growth type. Throughout the study, evidence was found that the width of annual growth rings has considerable influence on the rate of heartwood deterioration.

The correlation between the width of growth rings and the rate of heartwood deterioration was shown most clearly by comparing these two factors in trees of one growth type. It was found that ordinarily, other things being equal, the more annual growth rings per inch a tree contained the slower was its rate of deterioration. As an illustration, table 5 lists the average number of annual growth rings per inch, the average depth of deterioration, and the percentage of loss in each of 10 trees used as samples in an old-growth area 38 years after being killed by fire. All these trees were of approximately the same age.

Table 5.—*Width of growth rings, depth of deterioration, and percentage of volume lost in 10 trees used as samples on an area of old-growth fire-killed Douglas-fir 38 years after the fire*

Growth rings per inch (number)	Average depth of deterioration	Volume lost	Growth rings per inch (number)	Average depth of deterioration	Volume lost
	Inches	*Percent*		*Inches*	*Percent*
13.8	[1] 29.0	100.0	20.4	6.6	45.0
14.0	[1] 30.0	100.0	22.9	5.0	40.7
16.1	[1] 20.5	100.0	23.2	4.8	30.2
16.4	21.0	96.1	23.6	3.8	27.2
18.4	9.2	52.0	28.6	2.0	15.4

[1] Deterioration to the center of the bole. This figure is the radius of the bole at 4.5 feet from the ground

The width of annual rings differs in different parts of an individual tree. In general, the growth rings near the center of the bole of the tree are widest and those near the cambium are narrowest. The rate of deterioration may not depend so much on the average number of rings per inch for the entire bole as it does on the average number in the outer heartwood. This would be especially true in burns of younger ages. The probable influence of the width of the growth rings upon the rate of deterioration would explain why the rate of penetration in the heartwood accelerates as deterioration progresses toward the center of the bole, as demonstrated in figure 12. By comparing the acceleration of penetration in the heartwood of old growth with that of intermediate growth in figure 12, it may be noted that the acceleration becomes greater in the old growth after the deterioration has penetrated about 14 inches. This would indicate the time when the deterioration had worked through the thick band of narrow rings and into the inner cylinder of wide rings. In the intermediate growth, this outer band of narrow rings is much thinner, and the acceleration becomes greater when the depth of deterioration is about 5 inches. There is very little difference in acceleration between these two growth types during the first 10 years.

Size and Age of Trees

The size and age of trees in a fire-killed stand of Douglas-fir fairly well indicate the rate of deterioration. Large and old trees indicate a slow rate of deterioration, whereas small and young trees indicate a fast rate of deterioration. Probably the reason these two factors are good indicators of rate of deterioration is because they also indicate the rate of growth and character of wood. That is, large trees usually are old, and old trees usually have a comparatively thin sapwood and a wide band of wood of slow growth; therefore, the rate of penetration is less than in small, young trees of fast growth.

Table 6 shows the percentage of volume lost in each of the trees used as samples on three areas in three different 9-year-old burns. Each area was in a different growth type, and 10 trees were used as samples on each area. Because it was necessary to use burns of the same age, in which there was appreciable deterioration in the heartwood, and because there is not sufficient deterioration in the heartwood of old-growth trees until about 9 years after the fire and the oldest burn of young growth studied was 9 years old, these three areas were chosen for comparison of the different growth types. The average diameter, the average age, and average number of growth rings per inch are shown for each area. The average percentage of volume lost through deterioration and average depth of deterioration are also shown for each area. A cross section of a log from each of the areas represented in table 6 is shown in figure 20, *A*, *B*, and *C*.

TABLE 6.—*Percentage of cubic volume lost, depth of deterioration, and width of growth rings in young-growth, intermediate-growth, and old-growth Douglas-fir 9 years after being killed by fire*

Growth type	Average diameter [1]	Average age	Percentage of cubic volume lost by individual trees										Average loss	Average depth of deterioration	Average rings per inch [2]
	In.	*Yrs.*											*Pct.*	*In.*	*No.*
Young growth	21	150	100.0	100.0	100.0	100.0	100.0	100.0	86.0	60.1	56.9	49.1	78.7	5.8	14.3
Intermediate growth	49	375	46.8	46.6	44.7	44.1	42.1	42.0	39.2	37.6	33.0	31.2	40.2	3.3	15.3
Old growth	52	500	36.1	34.3	31.0	27.0	27.0	26.7	26.2	23.1	21.7	20.5	28.0	2.4	10.2

[1] Diameter inside bark at 4.5 feet from the ground.
[2] Average age divided by average radius at 4.5 feet from the ground.

As previously shown, size alone makes a great difference in the percentage of volume lost when the rate of radial penetration is the same. When the rate of radial penetration is greater in smaller trees, this difference becomes even more pronounced. In many cases, however, the effect of some factor or factors associated with differences in ring width counteracted the influence of tree size to a great extent, when the trees were of the same age. When a tree is larger than another because it grew faster, the influence of size on rate of volume loss is frequently counteracted by the more rapid penetration in the larger tree. Therefore, it may be said that, in general, large trees deteriorate more slowly than small trees only when the difference in size is a result of a difference in age.

Thickness of Sapwood

Trees with thick sapwood appear to deteriorate more rapidly than those with thin sapwood. Beneath thick sapwood both fungi and insects penetrate the heartwood more rapidly than beneath thin sapwood. There are several factors associated with thick sapwood that undoubtedly account to a great extent for this difference in rate of deterioration. Thick sapwood holds moisture well and provides very favorable environment for the establishment of fungi and insects, whereas thin sapwood dries out rapidly and offers less suitable conditions for the deteriorating agents. Thick sapwood is usually associated with trees of rapid growth, whereas thin sapwood usually occurs on the trees of slow growth. This fact indicates that the ring width in the heartwood may be more important than sapwood thickness in influencing the rate of deterioration.

Since sapwood deteriorates at such a rapid rate as compared with heartwood, it is evident that during the first few years a tree with thick sapwood will lose merchantable volume more rapidly than a similar tree with thin sapwood.

From the data collected in this study it appears that the thickness of sapwood remains fairly constant throughout the life of a Douglas-fir tree. The average sapwood thickness for all trees examined in the young-growth type was 1.5 inches; that for trees in the intermediate-growth type, 1.6 inches; and that for trees of the old-growth type, 1.7 inches (see table 8, Appendix). However, variations in sapwood thickness from less than 1 inch to more than 3 inches were found in all three growth types.

Subsequent Fires

The effect of subsequent fires upon rate of deterioration was investigated only in a general way during this study. Such fires have already been recognized as contributing to the general deterioration in that they consume some wood that would otherwise be salvable. The effect of fire upon the progress of other deteriorating agents is perhaps of more importance than its direct effects.

In some cases subsequent fires seem to accelerate deterioration by keeping the dead trees in a favorable condition for fungus and insect activity, whereas in other cases the opposite seems to be true. (See section headed "Forest Cover," p. 49.) Fires that reburn an area after the first year kill some insects, but such reduction of insect population is of little importance and cannot be considered as a practical means of reducing deterioration caused by insects. Subsequent fires also tend to reduce insect-caused deterioration by making the burned trees less suitable for attack and by consuming, in old burns, some of the outer wood that is the main feeding ground for the small larvae of the more important borers.

ENVIRONMENTAL FACTORS

ABUNDANCE OF FUNGI AND INSECTS

Even in the largest burns there seems to be an unlimited source of infection by fungi. In contrast with this, size of the available insect population determines to a large degree the amount of insect-caused deterioration that will result following fire. This is especially true of those species that attack only during a limited period when the trees are in a suitable condition.

In the undisturbed forest many of the insects that cause deterioration of fire-killed trees are relatively uncommon. Timber killed by fires in such areas is much less likely to be heavily attacked by insects than are trees in areas where insects are more plentiful, as near blow-downs or old burns. During the study, nearness to old burns was observed to be correlated with amount of borer damage (table 7).

In individual trees it may be that the accelerated deterioration near the center is due in part to the build-up of borer population within the tree. As penetration advances the volume of wood available for attack diminishes, perhaps forcing the borers to extend their galleries into the wood more rapidly. Accelerated deterioration near the center of a tree by decay fungi may similarly be influenced by the decreasing amount of wood available for attack.

TABLE 7.—*Borer penetration of heartwood of fire-killed Douglas-fir trees in the 1933 Tillamook burn, shown in relationship to proximity to older burns*

[Data taken in 1938]

Area No.	Exposure	Average age of trees	Average d. b. h. of trees	Distance between area and old burns (1919 or older)	Average penetration of heartwood	Maximum penetration of heartwood	Relative abundance of insects (chiefly *Criocephalus*) in heartwood[1]
		Years	*Inches*	*Mile*	*Inches*	*Inches*	
1	South	420	56	1	0	0	None.
2	West	300	52	1	0	0	Do.
3	North	275	43	1	0	0	Do.
4	do	380	51	1	0	½	Very few.
5	Northeast	400	53	1	0	1	Do.
6	Valley bottom	280	46	1	½	0-1	Few.
7	do	275	41	1	1	1-2	Do.
8	do	390	55	⅛	1	1-3	Common.
9	South	420	52	¼	1	1-3	Do.
10	North	410	66	¼	1	1-3	Do.
11	Southeast	410	55	¼	2	1-3	Abundant.
12	Valley bottom	275	39	⅛	2	1-5	Do.
13	South	420	44	[2] 0	2	1-5	Very abundant.
14	do	410	53	[2] 0	4	1-6	Do.

[1] Insects did not limit salvage in areas where few were found. In areas where insects were common to abundant, some logs were left in the woods. In areas where insects were very abundant, salvage was impractical because of excessive cull.
[2] Adjacent.

FOREST TYPES

Of the 63 areas studied, 41 were in the Coast-type forests and 22 were in the Cascade-type forests (fig. 1). In the course of the field work no consistent difference in rate of deterioration between the Coast-type Douglas-fir areas and Cascade-type areas was perceived.

In an effort to determine whether there is a consistent difference in the rate of deterioration in trees of these 2 forest types the data were analyzed in several ways. Using each area as a unit, the total percentage lost on each old-growth Cascade-type area was plotted on a "time-since-the-fire" basis and a curve was drawn. This was done also with the data for the old-growth Coast-type areas, and the 2 curves were compared. The 2 curves were so similar that it could not be said that either type showed a more rapid rate of deterioration. Then, using each tree as a unit, 2 more curves were constructed, and again the curves were similar for the 2 forest types. To eliminate the factor of tree size, 1 old-growth size class (51- to 60-inch d. b. h.) was used and, with the individual trees as units, curves were drawn. Still the curves for the 2 forest types were similar. In order to eliminate the factor of tree shape, the basal 32-foot log in each tree of this 1 size class was used as a unit but, as before, the 2 sets of curves were so similar that only one conclusion could be drawn, namely, that in general the rate of deterioration of fire-killed Douglas-fir is similar in the 2 forest types.

FOREST COVER

It is generally known that where Douglas-fir trees have fallen in the forest in this region they sometimes remain sound over exceedingly long periods. In logging operations in green timber, sound logs are occasionally salvaged from wind-thrown trees that have been on the ground for a hundred or more years. The explanation for the lasting qualities of down trees in the forest probably lies in the nature of their immediate environment. They are heavily shaded and therefore remain excessively wet and cold and are not attractive to wood-deteriorating fungi and insects.

In connection with the present project, the deterioration of trees that had been felled immediately following a fire was studied in an effort to determine whether or not such down trees deteriorated more slowly than similar standing trees. On areas burned within 10 years no material difference was noted between the rates of deterioration in the two types of fire-killed trees. Data of this type were not obtained from areas on which the trees had been dead more than 10 years. Deterioration by fungi and insects occurred in both standing and felled trees, and the data collected do not indicate that felled trees in an open burn are more resistant to deterioration than are similar standing trees. In the first 10 years after a fire, there is very little shading of down trees by new vegetative growth. The similarity of rates of deterioration in the felled and standing fire-killed trees was probably due to the similarity of exposure. Both types of trees were in the open, fully exposed to rapid changes in weather and, therefore, subject to alternate wetting and drying, a condition favorable for the development of deteriorating agents.

In some of the older burns, especially those near the coast, the butts of fire-killed trees that have become shaded by new vegetative growth show, to some extent, the same resistance to the agents causing deterioration as that evidenced by down trees under heavy forest cover. Because of the great amount of moisture due to heavy fogs and rains along the coast, the bases of snags that are protected by the cover of the green forest often become so wet that deterioration by fungi and insects is retarded. Observations made during this study indicate that subsequent fires in fire-killed Douglas-fir stands on such areas tend to accelerate the normal deterioration by keeping down the reproduction and other growth, so that the dead trees are left exposed to the sun, wind, and rain instead of being sheltered and shaded at their bases by the new growth. In contrast with this, it was observed that in a forest, where moisture is not excessive, subsequent fires tend to retard deterioration by keeping down the new forest growth and allowing the trees to become too dry for the optimum development of insects and fungi.

OTHER ENVIRONMENTAL FACTORS

Numerous other factors also influence the rate of deterioration of fire-killed Douglas-fir. Probably no two burned areas have the same set of influencing conditions. The most important and most influential factors are those that affect moisture and temperature conditions. Among these are rainfall, slope, exposure, soil, and elevation, which have a direct or indirect influence. It would probably be impossible to find any one factor that would invariably denote rapid deterioration or slow deterioration, because so many factors are involved that a different combination occurs on each area. Conditions found on a north slope in the Cascade type may cause a rate of deterioration comparable with that caused by a different combination of factors found on a south slope in the Coast type. It is the general opinion among timbermen that burned trees will deteriorate more rapidly on a south slope than on a north slope. While this would be generally true if applied to a relatively small area, where most of the other factors have an equal influence, it would not be true if applied to the Douglas-fir region as a whole. At high elevations in the Cascade type it was found that burned timber on a south slope soon became case-hardened and dry and remained preserved much longer than on the north slopes. Figure 8, *C*, shows a stand of trees that had been dead for 32 years on a south slope at a high elevation in the Cascade Range. Many of these trees were still full-length and contained much sound wood, which was dry and surrounded by a case-hardened shell. The rate of deterioration in such an area is abnormally slow and takes place principally near the ground level, where the most moisture occurs. This is in contrast with the normally more rapid deterioration found at lower elevations and on north slopes, where deterioration occurs most rapidly in the tops of the trees.

Fungi and insects being the principal agents, the most rapid deterioration occurs where the combination of all factors involved forms an optimum condition for the growth of wood-decaying fungi and the development of wood-inhabiting insects.

APPLICATION TO SALVAGE OPERATIONS

The timber owner who is confronted with a tract of burned Douglas-fir to be salvaged may want to know how the data in this bulletin can best be applied to his particular area. No hard and fast rule can be made with regard to this, for each case of salvage is marked by certain peculiarities that distinguish it from all others. In addition to the factor of progressive deterioration of the burned timber, there are many physical factors and economic considerations that, although not investigated in this study, must be taken into account. Among the more important of these are the following: Size and accessibility of the burned area, size and type of the timber, volume of the stand, time required to get to and cut over the entire area, type and size of the operation to be used, and the existing log- and lumber-market conditions.

The following example of how the limits of salvability are influenced by such factors will illustrate the importance of economic considerations: A logger who sells burned timber on the open log market may be confronted with a total loss of the sapwood when it is merely blue-stained, or he may face considerable loss of the heartwood when the wood affected is merely degraded, or is suspected of being degraded, by borer holes. In contrast with this, the operator who cuts burned timber for his own mill merely takes the actual loss caused by deterioration. In fact, such an operator may even be able to saw a limited amount of merchantable lumber from the type of wood that in this study has been considered a total loss. Obviously the mill operator may carry on salvage operations after it is no longer profitable for the logger.

So far as the progressive deterioration of burned trees is concerned, it should be recognized that the limits of potential salvability, brought out in the various graphs, are maximum and that the limits of practical salvability depend upon existing utilization practices. Under present utilization practices much usable wood remains after salvage is no longer profitable. In recent years large-scale salvage for lumber has been carried on for approximately 1 to 2 years in young-growth stands, 4 to 7 years in intermediate-growth stands, and 5 to 10 years or more in old-growth stands. From this it is evident that growth type is one of the more important factors to consider in estimating the duration of a salvage operation. For a more accurate forecast of the period of salvability, it is desirable to have information on average tree size and age in the various growth types. A factor that should also be considered is the possibility of excessive borer damage that may result from proximity to old burns that contain large beetle populations. As salvage progresses, it is often possible, by sampling in advance of the operation, to avoid costly development of local areas where borer damage is excessive.

From this discussion it can be seen that the potentially salvable wood in fire-killed Douglas-fir that can actually be salvaged will be determined by existing conditions. Nevertheless, the average figures on deterioration brought out in this bulletin, considered in relation to a particular stand and a particular economic set-up, should provide a good basis in planning for the profitable removal of the maximum volume of timber.

SUMMARY AND CONCLUSIONS

A study was made of deterioration in fire-killed Douglas-fir, *Pseudotsuga taxifolia* (Poir.) Britton, with the object of obtaining information essential to making comprehensive plans for the salvage of this type of timber. During 6 years (1934–39), detailed data were taken on 602 trees in 63 representative areas of the Douglas-fir region of western Oregon and Washington. Information was obtained on the various agents causing deterioration; fungi and insects were found to be the principal ones. These two factors were usually intimately associated and frequently interdependent. Therefore their effects were considered in combination rather than separately.

The rate of deterioration and the relative importance of the various species of fungi and insects involved were determined for young-growth, intermediate-growth, and old-growth types of timber.

Wood stain, caused principally by fungi belonging to the genus *Ceratostomella*, was of considerable importance in causing loss in the sapwood, but only during the first 3 years following fire.

Wood-decaying fungi were of two distinct types: Those causing decay only in the sapwood and those causing decay in both the sapwood and the heartwood. Of the first type, *Polyporus abietinus* Dicks. ex Fr. was the most important species, causing more than 50 percent of the decay in the sapwood. Of the fungi causing decay in the sapwood and the heartwood, *Fomes pinicola* (Sw. ex Fr.) Cke., was the most important species. This fungus caused nearly as much decay in the sapwood as *Polyporus abietinus*, and more than 75 percent of the decay in the heartwood. Two other species that caused considerable decay in both the sapwood and the heartwood in some areas were *Fomes officinalis* (Vill. ex Fr.) Faull and *Lenzites saepiaria* Wulf. ex Fr., while *Polyporus volvatus* Pk. and *Stereum* spp. were important deteriorators confined to the sapwood. There were several other species that caused some decay, but they were less important.

The discoloration caused by the incipient stage of decay was considered deterioration and was included in the loss estimates. However, a special microscopical and cultural study showed that viable fungus hyphae extended about 1 inch radially beyond all visible decay discoloration. This potential deterioration was not included in the loss estimates, because lumber containing this mycelium is not a loss if it is properly kiln-dried to kill the fungi.

Insects attacking fire-killed Douglas-fir characteristically cause only partial deterioration, as the affected wood is potentially usable as low-grade lumber unless otherwise degraded. Insects causing deterioration are of three types: Those infesting the phloem region, those infesting the sapwood, and those infesting the heartwood. This grouping, however, is not hard and fast, for some species attack in more than one region.

The Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopk., is the most important of the true phloem feeders. It aids in loosening the bark, introduces blue-stain fungi, and is a threat to green timber. The fir flatheaded borer, *Melanophila drummondi* (Kby.), is a somewhat less important phloem feeder.

Three species of ambrosia beetles, *Trypodendron bivittatum* (Kby.), *Gnathotrichus retusus* (Lec.), and *G. sulcatus* (Lec.), cause degrade of the sapwood by making "pinholes" and by introducing blue-stain fungi. A number of other wood borers that mine principally in the sapwood cause some deterioration, but most of them enter too late to be of much importance. Certain horntails, buprestids, and cerambycids are of the latter type.

Relatively few insects cause damage to the heartwood in advance of general deterioration. Several roundheaded borers, of which *Er-*

gates spiculatus Lec., *Criocephalus productus* Lec., *Asemum atrum* Esch., and *Leptura obliterata* Hald. are the most important, cause considerable damage to otherwise sound heartwood. Both *E. spiculatus* and *C. productus* may determine the practical limits of salvage under existing economic conditions. An ambrosia beetle, *Platypus wilsoni* Sw., occasionally causes "pinholes" in the heartwood but is not of much economic importance.

Additional deterioration by weathering or checking of the wood. breakage in felling, and burning of merchantable wood in the initial fire and subsequent fires were other forms of loss. However, the amount of loss attributable to these causes was of minor importance compared with the loss through deterioration by fungi and insects.

Deterioration caused by fungi and insects in fire-killed Douglas-fir starts just under the bark and progresses rather uniformly from the periphery toward the center of the bole. The percentage of volume lost from deterioration depends upon two primary factors: The depth to which the deteriorating agents have penetrated the bole, rendering the wood unmerchantable; and the diameter of the tree. The sapwood deteriorates so rapidly that it usually is unmerchantable 3 years after a fire. Deterioration in the heartwood progresses at a slower rate. The most rapid deterioration occurs in the trees of the young-growth type and the slowest in trees of the old-growth type. Within the growth types, deterioration is generally most rapid in the smallest trees and slowest in the largest trees. The rate of loss is slowest in the butt of a tree and increases with the distance from the ground. Trees of the three growth types average about 50 percent deteriorated in the following periods: Young growth in 3 to 4 years, intermediate growth in 10 to 15 years, and old growth in 15 to 20 years. It was found that old-growth trees of average size usually did not become completely deteriorated until 60 years or more after their death.

The following factors influenced the rate of deterioration: Character of wood, width of growth rings in the trees, size and age of the trees, sapwood thickness, subsequent fires, and environmental factors, such as abundance of fungi and insects, forest cover, etc. Although the sapwood of all trees deteriorates at a rapid rate, the rate of deterioration in the heartwood appears to be influenced by the rate of growth. The rate of deterioration is greater in trees with wide growth rings than in those with comparatively narrow growth rings. Large, old trees deteriorate at a slower rate than small, young trees. However, when the larger size of the trees is the result of more rapid growth rather than of greater age, the influence of size on rate of volume loss is largely counteracted by deeper penetration in the larger trees. There is evidence that the deeper penetration is associated with the wider growth rings. The radial loss in the heartwood progresses at an accelerated rate. The factor causing this acceleration may be the width of the growth rings, as normally there is a gradation in the width of growth rings from the tree's periphery to the center of the heartwood. Trees with thick sapwood deteriorate more rapidly than do similar trees with thin sapwood. From the results of this study it appears that size of insect population is one of the factors affecting rate of deterioration, for borer damage in recent burns was found to be greatest near older burns that provided a large source of infestation.

It appears that the rates of deterioration are generally similar in fire-killed Douglas-fir of the Coast and Cascade forest types. Felled fire-killed trees in open burns were found to deteriorate at approximately the same rate as standing fire-killed trees. Factors such as rainfall, slope, exposure, and elevation undoubtedly have an effect on the rate of deterioration, but they were so obscured by the influence of the character of wood, width of growth rings, and other factors that their individual importance could not be determined from this study. Deterioration is most rapid where conditions are optimum for the development of fungi and insects, the chief agents of decay.

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APPENDIX

Data used in construction of the curves in figures 9 to 19, inclusive, are presented in tables 8 to 10, inclusive. It was impossible to show the numerous points and their significance for these curves on the figures. In the determination of the significance of an individual point not only the number of areas, trees, or logs, whichever the case involved, had to be considered, but also other characteristics of the basis. In figures 9 to 12, inclusive, it was important to consider the average sapwood thickness and the average size and age of the trees on each area. Data for these figures are presented in table 8. In figures 13 to 15, inclusive, it was necessary to consider the extreme environmental factors in some of the areas when determining the significance of the points. Data for these figures are presented in table 9. To determine the significance of the points in the construction of the curves in figures 16 to 19, inclusive, it was necessary to evaluate them not only on the basis of areas and logs but also on the relative original volume of the logs. For example, log 5 in a tall, Coast-type tree would be much larger than log 5 in a short, Cascade-type tree. Data used in the construction of these curves are presented in table 10.

TABLE 8.—*Average depth of general deterioration, average penetration of insect galleries beyond general deterioration, average sapwood thickness, and percentage of volume deteriorated in trees of each growth type in each area studied*

Type of growth and age of burn (years)	Average depth of general deterioration	Average penetration of insect galleries beyond general deterioration	Average sapwood thickness	Volume deteriorated	
				Cubic feet	Board feet
	Inches	*Inches*	*Inches*	*Percent*	*Percent*
Young growth:					
1	1.4	-	1.4	25.8	28.0
1	.5	-	1.1	7.2	6.5
2	1.5	-	1.3	24.7	27.3
2	1.6	-	1.6	36.5	49.0
3	1.6	0	1.0	10.6	22.0
3	3.1	-	2.3	50.7	68.6
4	4.8	-	1.5	89.9	100.0
4	2.3	-	1.3	52.4	65.6
5	4.6	-	2.0	76.1	100.0
5	2.8	-	1.4	52.4	74.4
8	5.1	0.7	1.5	52.7	72.8
9	5.8	.7	1.5	78.7	81.5
Intermediate growth:					
1	.5	-	1.8	3.4	6.2
1	1.0	-	1.4	11.8	14.6
1	.4	-	1.5	4.8	5.1
2	2.1	0	2.1	21.5	23.7
2	.8	[1].3	1.6	9.7	12.6
2	0	[1].5	1.6	0	0
2	.5	[1].5	1.7	6.5	7.7
3	1.5	0	1.5	23.2	26.5
3	2.0	0	2.6	27.8	34.0
3	.9	-	1.3	9.8	12.8
4	1.7	.2	1.5	18.9	21.3
4	1.4	-	1.4	21.2	23.0
5	2.0	.3	1.6	26.3	29.9
5	1.3	0	1.3	13.2	15.4
6	1.9	1.1	1.6	24.0	26.4

[1] In sapwood this penetration is caused by ambrosia beetles and is usually accompanied by blue staining around galleries.

TABLE 8.—*Average depth of general deterioration, etc.*—Continued

Type of growth and age of burn (years)	Average depth of general deterioration	Average penetration of insect galleries beyond general deterioration	Average sapwood thickness	Volume deteriorated	
				Cubic feet	Board feet
	Inches	*Inches*	*Inches*	*Percent*	*Percent*
Intermediate growth—Cont.					
6	1.6	.1	1.3	17.0	19.5
7	2.7	----	1.7	31.9	36.5
8	2.3	.7	1.1	30.4	52.5
9	3.3	1.9	1.0	40.2	44.0
10	4.0	.3	1.5	34.0	42.5
12	3.5	1.2	1.6	36.9	30.3
16	3.4	1.5	1.1	36.4	41.0
Old growth:					
1	0	[1].5	1.6	0	0
1	.4	----	1.3	3.1	2.4
2	.4	[1].9	1.9	2.9	3.3
2	0	[1].8	1.6	0	0
3	1.2	----	1.7	10.5	13.0
3	1.4	0	1.4	17.4	19.4
4	2.0	----	2.0	21.6	23.4
4	1.0	0	1.0	14.5	14.7
5	2.2	0	2.0	22.4	24.0
5	2.7	----	1.7	32.1	37.2
6	2.1	----	1.4	19.5	22.1
7	2.5	----	1.4	22.3	25.0
8	3.1	1.7	1.6	28.9	31.2
9	2.4	1.4	1.6	28.0	32.0
10	5.0	.3	1.7	42.0	48.4
10	4.9	1.6	1.7	25.9	28.9
11	2.9	1.7	1.7	23.0	26.2
11	3.1	2.5	1.2	24.4	28.8
12	5.1	.5	1.9	40.9	45.2
13	2.6	----	1.7	20.8	21.1
14	2.5	----	1.5	18.7	19.8
15	4.6	2.5	1.5	22.0	35.7
16	5.6	2.6	1.7	43.5	49.3
22	14.3	.8	1.8	61.5	68.7
32	([2])	.1	([3])	98.7	100.0
38	12.7	3.2	1.8	68.4	72.5
43	([2])	0	([3])	95.6	100.0
48	12.3	----	2.0	61.6	75.3
62	([2])	1.3	([3])	74.1	75.6

[2] Deteriorated to center in all trees. [3] Sapwood sloughed.

TABLE 9.—*Average percentage of volume lost through general deterioration in the various d. b. h. classes within each growth-type on burns of different ages*

Type of growth and d. b. h. class (inches)	Age of burn	Basis of trees	Cubic-foot volume		Board-foot volume	
			Total	Cull	Total	Cull
Young growth:	*Years*	*Number*	*Cubic feet*	*Percent*	*Board feet*	*Percent*
11-20	3	4	380	65.3	1,630	100.0
	4	11	649	71.3	2,520	80.6
	5	2	77	76.6	220	100.0
	9	2	108	100.0	390	100.0
21-30	1	6	1,355	15.4	7,110	17.6
	2	8	1,243	28.1	5,930	33.9
	3	7	1,526	37.5	8,100	44.7
	4	6	991	52.4	4,880	65.4
	5	6	656	62.4	2,820	83.7
	8	5	886	46.7	4,700	64.5
	9	7	901	80.8	4,240	84.2
31-40	1	4	1,847	22.0	10,760	22.9
	2	4	1,688	26.3	9,850	29.5
	3	4	2,209	25.2	14,040	28.4
	5	3	505	60.4	2,130	82.6
	8	3	910	43.4	4,780	76.2
	9	1	195	56.9	980	62.2
41-50	2	1	806	24.6	5,010	25.6
	3	4	3,417	18.2	22,340	20.1
	8	2	948	67.2	5,510	77.0
51-60	3	1	1,307	19.2	8,870	23.0

TABLE 9.—*Average percentage of volume lost through general deterioration in the various d. b. h. classes, etc.*—Continued

Type of growth and d. b. h. class (inches)	Age of burn	Basis of trees	Cubic-foot volume		Board-foot volume	
			Total	Cull	Total	Cull
	Years	*Number*	*Cubic feet*	*Percent*	*Board feet*	*Percent*
Intermediate growth:						
21-30	4	5	1,481	21.9	8,140	25.4
	8	9	1,914	38.5	10,000	50.3
31-40	2	1	708	10.0	4,730	13.5
	3	8	3,834	29.1	23,650	36.2
	4	6	3,073	21.1	19,170	22.0
	5	5	2,284	19.5	13,870	22.6
	6	2	922	22.1	5,270	25.8
	8	1	294	44.9	1,630	65.6
	12	1	491	38.7	3,050	43.6
	16	2	685	30.7	3,700	37.6
41-50	1	8	5,657	6.6	35,370	8.9
	2	11	9,439	8.2	61,410	9.0
	3	14	10,837	19.1	69,290	23.1
	4	11	9,327	19.6	59,380	21.2
	5	9	6,186	23.2	39,380	26.1
	6	10	7,956	21.4	49,490	24.1
	7	5	3,017	34.5	18,100	40.7
	9	5	3,670	43.6	24,190	47.5
	10	2	1,358	36.7	8,200	40.5
	12	5	4,023	38.2	25,260	43.9
	16	3	1,854	29.9	10,960	35.3
51-60	1	1	1,124	5.1	7,230	12.2
	2	20	24,654	11.2	163,290	13.2
	3	16	18,958	12.2	124,200	15.2
	4	6	6,562	21.2	42,540	23.9
	5	5	5,158	17.1	33,029	19.9
	6	8	9,756	20.2	63,850	22.5
	7	4	4,797	30.8	30,950	34.1
	9	4	4,712	36.9	31,390	42.0
	10	7	6,684	34.6	42,000	41.9
	12	3	3,279	37.9	20,990	35.3
	16	3	2,865	30.8	17,580	34.4
61-70	2	2	4,213	11.3	28,790	13.0
	3	2	3,421	9.3	22,700	12.6
	4	1	1,422	17.4	9,430	20.9
	5	1	1,128	19.7	7,570	24.4
	7	1	973	29.3	5,960	36.1
	9	1	1,466	42.1	10,070	47.6
	10	1	1,113	34.6	6,950	41.2
	12	1	1,355	20.8	8,460	59.5
	16	1	1,699	82.8	11,140	88.2
71-80	1	1	2,278	7.9	15,410	9.1
	3	2	3,948	9.9	26,850	12.4
	16	1	2,217	15.5	15,340	19.0
Old growth:						
21-30	11	2	331	69.2	1,570	100.0
31-40	1	1	409	0	2,550	0
	4	1	560	31.1	3,410	38.7
	22	2	792	95.2	4,880	100.0
	32	3	1,472	92.3	9,760	100.0
41-50	2	2	2,076	0	13,800	0
	3	4	2,435	21.0	14,050	23.1
	4	5	4,003	16.3	24,620	18.0
	5	3	1,935	31.0	12,070	37.5
	7	1	654	33.5	4,130	40.2
	8	5	4,522	38.0	29,340	41.5
	9	2	1,805	30.5	11,900	30.9
	10	2	1,664	47.2	10,160	53.3
	11	1	1,002	23.5	6,650	25.7
	12	2	1,814	38.7	11,860	41.9
	16	3	2,847	53.1	19,150	57.7
	22	4	3,725	64.3	25,500	69.1
	32	4	3,577	100.0	23,440	100.0
	38	3	3,122	64.4	21,330	66.0
	43	1	778	96.3	5,220	100.0
51-60	1	4	5,658	2.4	37,540	2.1
	2	1	1,205	0	7,610	0
	3	5	5,262	15.6	32,520	18.0
	4	11	12,915	17.0	82,700	19.8
	5	10	11,583	28.1	74,960	31.2
	6	6	8,174	21.6	53,930	24.5

Table 9.—*Average percentage of volume lost through general deterioration in the various d. b. h. classes, etc.*—Continued

Type of growth and d. b. h. class (inches)	Age of burn	Basis of trees	Cubic-foot volume		Board-foot volume	
			Total	Cull	Total	Cull
	Years	*Number*	*Cubic feet*	*Percent*	*Board feet*	*Percent*
Old growth—Cont.						
	7	5	5,954	22.2	38,580	24.6
51-60	8	2	2,920	28.6	20,940	32.0
	9	6	5,851	25.8	37,050	29.3
	10	4	5,137	37.7	32,950	45.3
	11	8	10,004	19.0	64,300	29.7
	12	2	3,067	37.9	20,890	42.9
	14	1	1,066	24.6	6,790	25.8
	15	1	1,409	34.1	9,810	35.6
	16	9	12,298	41.4	84,330	47.9
	22	4	5,358	63.4	35,740	66.3
	32	3	3,856	100.0	25,680	100.0
	38	7	10,321	48.0	72,610	53.1
	43	2	2,182	98.3	14,280	100.0
	62	3	3,382	72.8	21,540	77.3
61-70	1	1	2,370	0	16,730	0
	2	6	11,233	1.1	75,600	1.1
	3	4	5,767	13.4	37,530	15.1
	4	5	7,526	15.6	48,000	16.4
	5	2	3,161	21.1	20,570	22.9
	6	1	1,741	18.4	11,740	21.3
	7	3	5,303	21.2	35,020	26.1
	8	3	6,220	22.4	43,370	23.9
	9	2	3,031	30.7	20,600	34.2
	10	4	7,668	31.2	53,640	34.3
	11	5	9,844	23.6	67,080	28.8
	12	2	3,855	46.1	26,220	50.2
	14	4	7,191	19.2	48,500	21.1
	15	4	6,977	32.0	46,720	30.8
	16	1	2,641	42.8	19,310	47.0
	22	4	8,897	63.7	63,340	67.9
	38	5	7,105	84.2	47,200	87.7
	43	4	8,573	97.4	60,270	100.0
	62	4	6,450	96.6	41,140	100.0
71-80	1	2	4,051	2.9	26,940	1.7
	2		11,137	1.1	78,040	1.0
	3	2	3,599	10.3	22,650	12.6
	4	9	18,764	15.9	122,350	15.7
	5	2	3,994	22.8	25,510	24.4
	6	2	4,512	18.8	30,710	21.2
	7	1	2,301	22.0	15,420	23.4
	10	9	24,986	27.7	174,440	31.1
	11	4	8,544	27.2	58,160	31.0
	12	3	7,630	40.6	52,620	45.5
	13	4	9,154	21.5	60,820	21.3
	14	1	2,611	26.0	17,570	25.8
	15	3	7,264	29.9	50,560	35.3
	22	3	11,082	65.6	81,350	78.4
	38	1	4,018	96.1	30,140	100.0
	43	1	2,098	85.5	13,960	100.0
	62	1	2,740	22.8	19,240	21.7
81-90	1	1	2,942	0	20,720	0
	2	1	2,503	7.7	15,010	9.1
	3	4	9,541	10.1	62,780	11.2
	4	5	13,600	14.9	80,930	14.6
	5	1	2,442	18.9	16,180	20.5
	6	1	3,110	15.6	20,970	17.4
	10	1	3,066	48.3	21,140	53.2
	11	1	3,548	23.9	24,510	28.1
	12	1	3,188	39.2	22,130	42.3
	13	2	5,411	20.4	36,230	21.4
	14	2	5,914	20.4	39,020	22.4
	22	2	7,828	59.0	57,540	66.3
	48	2	5,795	63.0	39,590	73.3
91-100	2	3	9,803	3.5	61,890	4.2
	13	1	4,192	19.6	29,150	20.5
	14	1	4,403	11.7	30,180	14.4
	15	2	10,495	33.2	74,900	36.2
	22	1	5,702	48.1	42,500	52.6
	48	1	3,808	59.7	26,250	78.5
101-110	2	1	3,625	0	23,560	0
	14	1	4,330	13.9	29,870	15.0

TABLE 10.—*Average percentage of cull in each log of the modal d. b. h. classes in different-aged burns of each growth type*

Type of growth and log No.	Age of burn	Basis		Cubic-foot volume		Board-foot volume	
		Areas	Logs	Total	Cull	Total	Cull
Young growth: [1]	*Years*	*Number*	*Number*	*Cubic feet*	*Percent*	*Board feet*	*Percent*
1	1	2	6	496	9.7	3,130	12.1
	2	2	8	527	26.9	3,070	34.2
	3	2	7	622	28.5	4,060	37.4
	4	2	6	404	47.3	2,380	57.1
	5	2	6	333	57.1	1,810	74.0
	8	1	5	391	34.3	2,480	53.2
	9	1	7	445	75.3	2,480	77.8
2	1	2	6	341	11.1	2,000	13.0
	2	2	8	329	30.1	1,650	37.0
	3	2	7	417	37.7	2,400	47.9
	4	1	5	253	49.4	1,450	66.2
	5	2	4	163	62.0	750	100.0
	8	1	5	260	48.2	1,750	72.0
	9	1	6	261	85.4	1,440	91.7
3	1	2	6	234	17.1	1,270	25.2
	2	1	3	124	20.2	680	23.5
	3	2	4	192	40.1	1,040	46.2
	4	1	5	156	55.1	710	74.7
	5	1	2	53	75.5	190	100.0
	8	1	3	93	90.3	350	100.0
	9	1	2	46	100.0	140	100.0
Intermediate growth: [2]							
1	1	3	8	1,751	2.3	11,660	4.9
	2	4	11	2,893	7.3	20,050	7.2
	3	3	14	3,320	12.0	22,760	14.2
	4	2	11	2,929	16.6	19,890	17.8
	5	2	9	1,967	17.7	13,670	16.5
	6	2	10	2,588	17.2	16,870	16.4
	7	1	5	1,005	28.0	6,570	31.1
	9	1	5	1,039	36.7	7,810	38.9
	10	1	2	490	26.3	3,400	32.9
	12	1	5	1,298	26.5	8,460	30.9
	16	1	3	686	11.7	4,200	11.2
2	1	3	8	1,274	5.5	9,410	6.3
	2	4	11	2,104	7.7	15,440	8.0
	3	3	14	2,479	16.3	18,030	20.1
	4	2	11	2,078	18.7	14,960	18.2
	5	2	9	1,500	20.1	11,110	22.4
	6	2	10	1,786	19.3	12,750	19.9
	7	1	5	690	33.3	4,730	36.4
	9	1	5	862	40.1	6,650	38.4
	10	1	2	333	34.8	2,160	38.9
	12	1	5	933	33.9	6,980	35.5
	16	1	3	445	21.1	3,240	32.7
3	1	3	8	1,019	5.7	7,360	6.1
	2	4	11	1,660	8.1	12,220	9.6
	3	3	14	1,897	22.4	13,570	25.4
	4	2	11	1,598	20.0	11,520	21.5
	5	2	9	1,119	23.8	7,600	28.3
	6	2	10	1,320	21.4	9,590	26.3
	7	1	5	505	35.8	3,480	45.7
	9	1	5	679	42.3	4,830	45.3
	10	1	2	225	44.0	1,480	62.2
	12	1	5	743	39.0	5,440	51.3
	16	1	3	329	46.8	2,220	46.9
4	1	3	8	783	8.8	4,790	17.3
	2	4	11	1,196	9.9	7,840	11.7
	3	3	14	1,368	25.4	9,010	32.4
	4	2	11	1,159	21.5	7,820	26.9
	5	2	9	739	29.5	4,330	37.9
	6	2	10	957	25.1	6,000	31.5
	7	1	5	365	40.8	2,130	55.4
	9	1	5	473	44.6	3,040	56.9
	10	1	2	140	49.3	790	70.9
	12	1	5	516	48.1	3,060	60.5
	16	1	3	200	67.5	1,060	100.0

[1] Trees n the 21- to 30-inch d.b.h. class.
[2] Trees in the 41- to 50-inch d.b.h. class.

TABLE 10.—*Average percentage of cull in each log of the modal d. b. h. classes in different-aged burns of each growth type*—Continued

Type of growth and log No.	Age of burn	Basis		Cubic-foot volume		Board-foot volume	
		Areas	Logs	Total	Cull	Total	Cull
Intermediate growth—Continued	*Years*	*Number*	*Number*	*Cubic feet*	*Percent*	*Board feet*	*Percent*
	1	3	8	437	20.1	1,810	26.5
	2	4	9	670	5.5	3,060	12.4
	3	3	13	807	28.6	4,120	44.2
	4	2	10	698	24.0	3,730	30.0
	5	2	7	379	40.8	1,860	62.9
5	6	2	8	540	32.2	2,870	42.2
	7	1	4	198	47.0	880	60.2
	9	1	5	289	62.2	1,010	88.2
	10	1	2	71	63.4	300	100.0
	12	1	4	285	82.3	1,200	100.0
	16	1	2	70	95.7	210	100.0
Old growth:[3]							
	1	2	4	1,562	1.3	11,260	1.1
	2	1	1	436	0	3,170	0
	3	1	5	1,981	9.3	13,660	10.5
	4	2	11	3,667	14.0	24,500	17.4
	5	2	10	3,405	21.2	23,310	25.2
	6	1	6	2,236	16.4	16,130	17.8
	7	1	5	1,763	18.4	12,740	19.9
	8	1	2	700	20.3	5,580	21.5
	9	1	6	2,103	15.8	16,130	19.6
	10	1	4	1,719	27.5	12,130	34.3
1	11	2	8	3,192	12.0	21,810	13.5
	12	1	2	917	20.3	7,050	22.7
	14	1	1	310	23.9	2,060	23.8
	15	1	1	364	18.0	2,900	18.6
	16	1	9	3,572	28.2	27,100	30.0
	22	1	4	1,712	54.5	12,920	54.8
	32	1	3	1,256	100.0	9,380	100.0
	38	1	7	2,682	31.2	20,540	30.2
	43	1	2	746	98.9	5,480	100.0
	62	1	3	1,312	68.8	10,050	77.7
	1	2	4	1,203	1.6	9,000	1.3
	2	1	1	300	0	2,060	0
	3	1	5	1,320	16.5	9,190	18.1
	4	2	11	2,655	16.8	19,500	17.7
	5	2	10	2,475	20.2	17,830	26.9
	6	1	6	1,715	19.5	12,880	23.0
	7	1	5	1,353	19.7	9,860	18.9
	8	1	2	602	20.8	4,780	24.7
	9	1	6	1,606	20.7	11,420	23.7
2	10	1	4	1,218	33.9	8,910	35.2
	11	2	8	2,235	14.5	16,400	15.8
	12	1	2	730	30.8	5,650	39.7
	14	1	1	227	21.2	1,600	18.1
	15	1	1	315	18.1	2,540	18.0
	16	1	9	2,876	32.8	22,630	40.8
	22	1	4	1,322	58.6	9,840	63.3
	32	1	3	983	100.0	7,040	100.0
	38	1	7	2,153	36.6	16,550	40.1
	43	1	2	551	100.0	4,120	100.0
	62	1	3	929	73.6	6,070	69.5
	1	2	4	950	1.7	6,820	1.2
	2	1	1	190	0	1,220	0
	3	1	5	924	18.0	6,440	20.7
	4	2	11	2,166	18.6	15,280	17.3
	5	2	10	1,994	29.8	14,300	30.4
	6	1	6	1,402	21.5	9,810	22.0
	7	1	5	1,075	22.1	7,720	26.0
	8	1	2	504	22.2	3,810	24.4
	9	1	6	1,069	28.6	6,790	35.9
3	10	1	4	888	38.6	5,080	48.5
	11	2	8	1,704	16.1	12,560	17.8
	12	1	2	532	43.2	3,610	51.5
	14	1	1	189	23.8	1,420	22.5
	15	1	1	279	16.9	2,240	17.4
	16	1	9	2,261	39.7	16,200	46.3
	22	1	4	983	67.3	6,890	77.2
	32	1	3	770	100.0	5,490	100.0
	38	1	7	1,763	35.5	13,540	35.3
	43	1	2	404	100.0	2,780	100.0
	62	1	3	586	73.2	3,950	79.5

[3] Trees in the 51- to 60-inch d. b. h. class.

TABLE 10.—*Average percentage of cull in each log of the modal d. b. h. classes in different-aged burns of each growth type*—Continued

Type of growth and log No.	Age of burn	Basis		Cubic-foot volume		Board-foot volume	
		Areas	Logs	Total	Cull	Total	Cull
Old growth—Cont.	*Years*	*Number*	*Number*	*Cubic feet*	*Percent*	*Board feet*	*Percent*
4	1	2	4	746	3.9	5,020	3.6
	2	1	1	127	0	810	0
	3	1	5	543	21.7	2,780	35.6
	4	2	11	1,694	18.9	11,840	21.7
	5	2	10	1,568	32.0	10,800	30.2
	6	1	6	1,066	23.6	7,210	27.2
	7	1	5	781	25.7	4,680	32.3
	8	1	3	404	25.7	2,290	28.4
	9	1	6	571	55.2	3,010	73.4
	10	1	4	590	51.5	3,810	70.3
	11	2	8	1,232	20.9	8,400	25.7
	12	1	2	353	47.6	2,270	42.3
	14	1	1	154	24.7	1,000	25.0
	15	1	1	220	68.2	1,470	100.0
	16	1	9	1,670	51.6	11,890	79.0
	22	1	4	670	76.7	4,300	76.7
	32	1	3	473	100.0	2,580	100.0
	38	1	7	1,443	53.4	10,860	60.8
	43	1	2	260	100.0	1,590	100.0
	62	1	3	305	93.8	1,360	100.0
5	1	2	4	537	4.8	3,500	3.0
	2	1	1	70	0	320	0
	3	1	3	116	45.7	310	100.0
	4	2	11	1,237	21.4	7,740	27.0
	5	2	10	1,100	38.0	6,220	45.5
	6	1	6	761	27.6	4,940	34.2
	7	1	4	442	31.9	2,400	37.5
	8	1	2	315	38.7	2,320	60.3
	9	1	2	129	81.4	460	100.0
	10	1	4	333	68.2	1,740	81.6
	11	2	8	740	44.7	4,070	56.5
	12	1	2	236	67.4	1,540	100.0
	14	1	1	99	26.3	500	42.0
	15	1	1	118	100.0	500	100.0
	16	1	9	1,013	79.7	5,310	93.0
	22	1	4	342	86.8	1,620	100.0
	32	1	3	176	100.0	550	100.0
	38	1	7	1,082	87.7	7,300	100.0
	43	1	2	105	100.0	300	100.0
6	1	2	4	329	4.0	1,460	7.5
	4	2	9	665	24.5	3,110	33.1
	5	2	10	591	45.2	2,150	65.0
	6	1	6	481	33.9	2,420	47.5
	7	1	2	199	30.7	900	39.4
	8	1	2	205	62.0	1,150	72.2
	10	1	2	79	84.8	260	100.0
	11	2	7	277	71.1	900	100.0
	12	1	1	113	100.0	670	100.0
	14	1	1	48	39.6	140	100.0
	16	1	5	251	94.4	940	100.0
	22	1	1	29	100.0	70	100.0
	38	1	6	555	99.8	2,750	100.0

END