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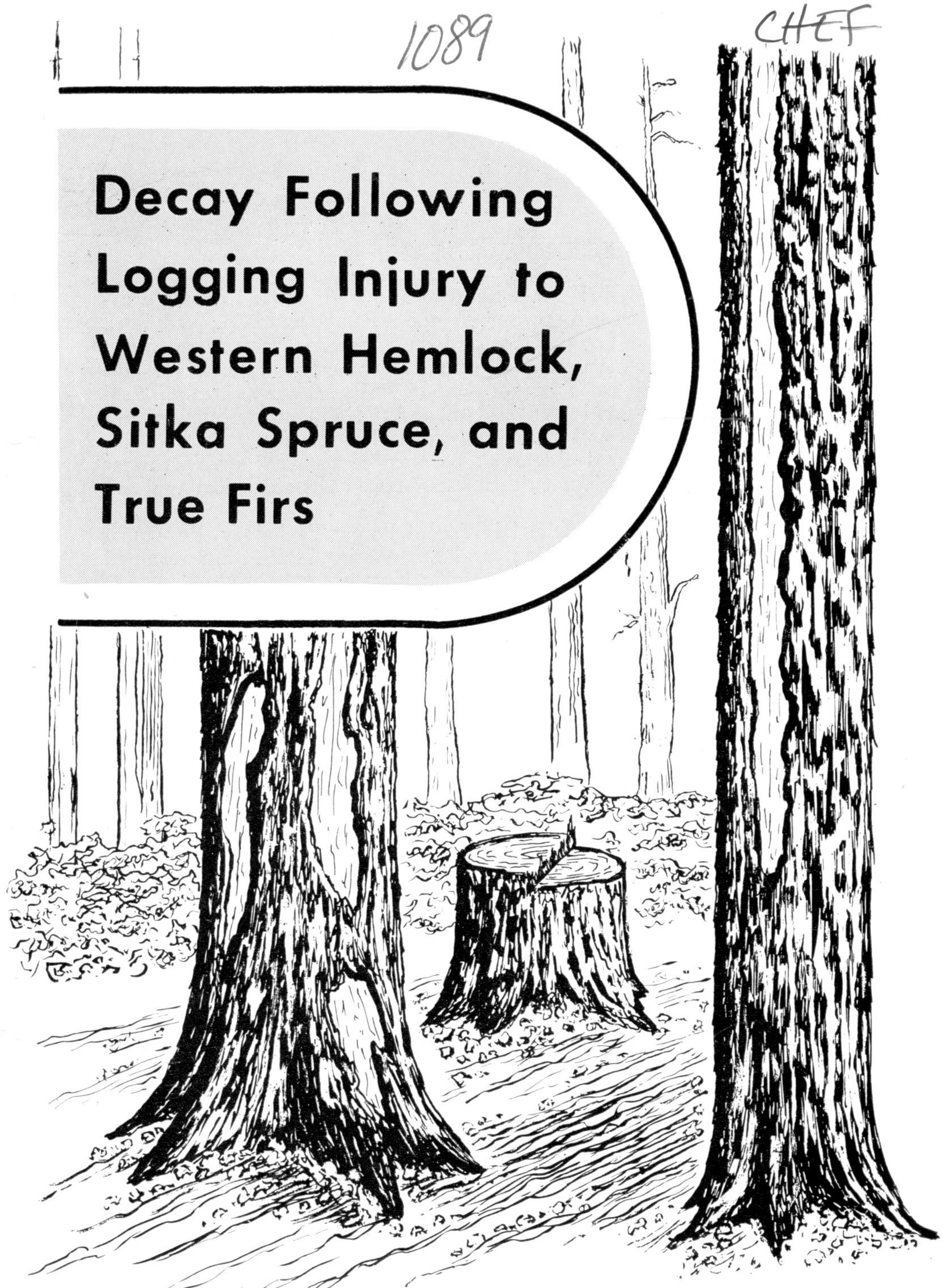
# Decay Following Logging Injury to Western Hemlock, Sitka Spruce, and True Firs



Technical Bulletin No. 1148 1956

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

## ACKNOWLEDGMENT

ACKNOWLEDGMENT for assistance and permission to sample injured trees is due the following: Northern Pacific Land Co., West Fork Logging Co., Peterman Logging Co., and the Weyerhaeuser Timber Co. in Washington; the Crown Zellerbach Corp., C. D. Johnson Lumber Corp., and Reed Estates in Oregon. Trees on the Mt. Baker, Olympic, and Gifford Pinchot National Forests in Washington and the Willamette, Siuslaw, and Siskiyou National Forests in Oregon were used in the study also.

Floyd A. Johnson and Edgel C. Skinner of the Pacific Northwest Forest and Range Experiment Station assisted in the statistical analyses of the data.

This study was begun by the Division of Forest Pathology, Bureau of Plant Industry, Soils, and Agricultural Engineering in 1941 and resumed as a cooperative project with the Pacific Northwest Forest and Range Experiment Station in 1943. Ross W. Davidson identified most of the fungi isolated, and J. L. Bedwell, T. W. Childs, and Arthur S. Rhoads, all of the Division of Forest Pathology, assisted in parts of the study. This division is now the Division of Forest Disease Research in the Forest Service.

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Washington, D. C.

Issued July 1956

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 15 cents

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# Decay Following Logging Injury to Western Hemlock, Sitka Spruce, and True Firs[1]

By Ernest Wright, *pathologist*, and Leo A. Isaac, *forester, Pacific Northwest Forest and Range Experiment Station, Forest Service*

## INTRODUCTION

Wounds on trees are well-known entry ports for wood-decay fungi. Little has been known, however, about the frequency and amount of decay associated with logging injury on western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), and the true firs, grand fir (*Abies grandis* (Dougl.) Lindl.) and Pacific silver fir (*A. amabilis* (Dougl.) Forbes). Because these species are thin barked, they are frequently injured and are highly susceptible to decay.

Hemlock, spruce, and true firs make up 31 percent of the timber volume in western Oregon and Washington. This represents a volume in standing timber of 168 billion board-feet Scribner scale, according to the latest U. S. Forest Service figures. Occasionally they are found as even-aged pure stands. More frequently they occur in mixture with Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) as uneven-aged understory trees. They are being harvested at an ever-increasing rate, often by partial cutting.[2] Partial cutting was formerly recommended for old-growth Douglas-fir and was widely used in overmature stands, but now is on the decline in old growth. Thinning and stand improvement, however, are rapidly increasing in young growth and mature timber.

All types of partial cutting result in some injury to the trees of the residual stand. The injury includes mechanical wounding of the tree trunks, broken tops, and sunscald of the exposed trunks. Windfall is often accelerated. To plan cuttings and modify logging practices, foresters and timber operators need to know the probability of occurrence and the rate of penetration of decay following logging injury. This bulletin reports the results of a study that provides such information. It is not a study of total decay volume in any one stand but does show how volume losses following logging injury may be determined. The results apply directly to western hemlock, Sitka spruce, and true firs in western Oregon and Washington, but they should be useful in estimating decay following logging in stands of these species in other localities.

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[1] Submitted for publication January 1956.

[2] Partial cutting as used here means any form of partial removal, either as single trees or small groups of trees, in stands of the Douglas-fir region.

In 1942 Englerth (*5*)[3] reported the occurrence of rot in virgin stands of western hemlock in western Oregon and Washington. He found that scars made by falling trees were important infection ports for wood-decay fungi. Of a total of 304 scars, 52.9 percent contained rot. Of 36 trees with broken tops, 44.4 percent were decayed. Many fungi were recorded as entering through the scars. The most common were *Fomes annosus* (Fries) Cooke, *F. pini* (Fries) Karst, and *F. pinicola* (Fries) Cooke.

Two years later Englerth and Isaac (*6*) reported the occurrence of decay entering logging injuries in a mixed stand of western hemlock, Douglas-fir, and western white pine (*Pinus monticola* Dougl.) on the Wind River Experimental Forest in south-central Washington. This area had been partially cut 12 years previously and more than half of the remaining trees had been damaged. A total of 46 trunk scars, 10 broken tops, and 5 sunscald injuries were recorded on 26 western hemlock trees felled for examination. All but 4 of the trunk scars and 1 sunscald lesion showed decay. *Fomes annosus* was the most frequent cause of the decays encountered.

A preliminary report on the present study (*19*), in 1947, gave additional data on decay following logging injury. *Fomes annosus* was found to be the principal wood-rotting fungus entering logging scars on western hemlock. Growth since partial cutting was frequently offset by decay. *F. pinicola* was the chief cause of rot in scarred Sitka spruce.

In 1949, Buckland, Foster, and Nordin (*4*) reported that, in the Franklin River area of Vancouver Island, 15 fungi caused decay of western hemlock and 11 of true fir. In 59 percent of the infections studied, the decay fungi entered through wounds. No consistent difference was found in decay volume between fast- and slow-growing trees. True fir, up to 350 years of age, appeared to be more decay resistant than western hemlock.

Foster and Foster (*8*) in 1951 reported that more fungus infections entered through logging scars than any other avenue of entrance; however, root infections were more important because of higher rate of decay and mortality.

## METHODS OF STUDY

Thirteen study areas were selected in western Washington and Oregon (fig. 1). Six areas were chosen in the coastal zone where comparatively mild and uniform climatic conditions prevailed. The remaining seven were farther inland on the east slope of the Coast Range and the west slope of the Cascade Range and were subject to greater temperature and moisture variation. Two of these areas, on the east slope of the Coast Range, can be regarded as intermediate in climatic features. The areas studied ranged in elevation from 100 to 2,300 feet (table 1).

In each study area, the trees with logging injuries were dissected and the extent of decay was traced. A total of 488 scarred trees were felled and dissected. These had 1,218 logging scars, 90 broken tops, and 37 sunscald lesions, the last being mainly on western hemlock. Samples were taken, cultures were made to identify the decays, and the data were compiled.

[3] Italic numbers in parentheses refer to Literature Cited, page 33.

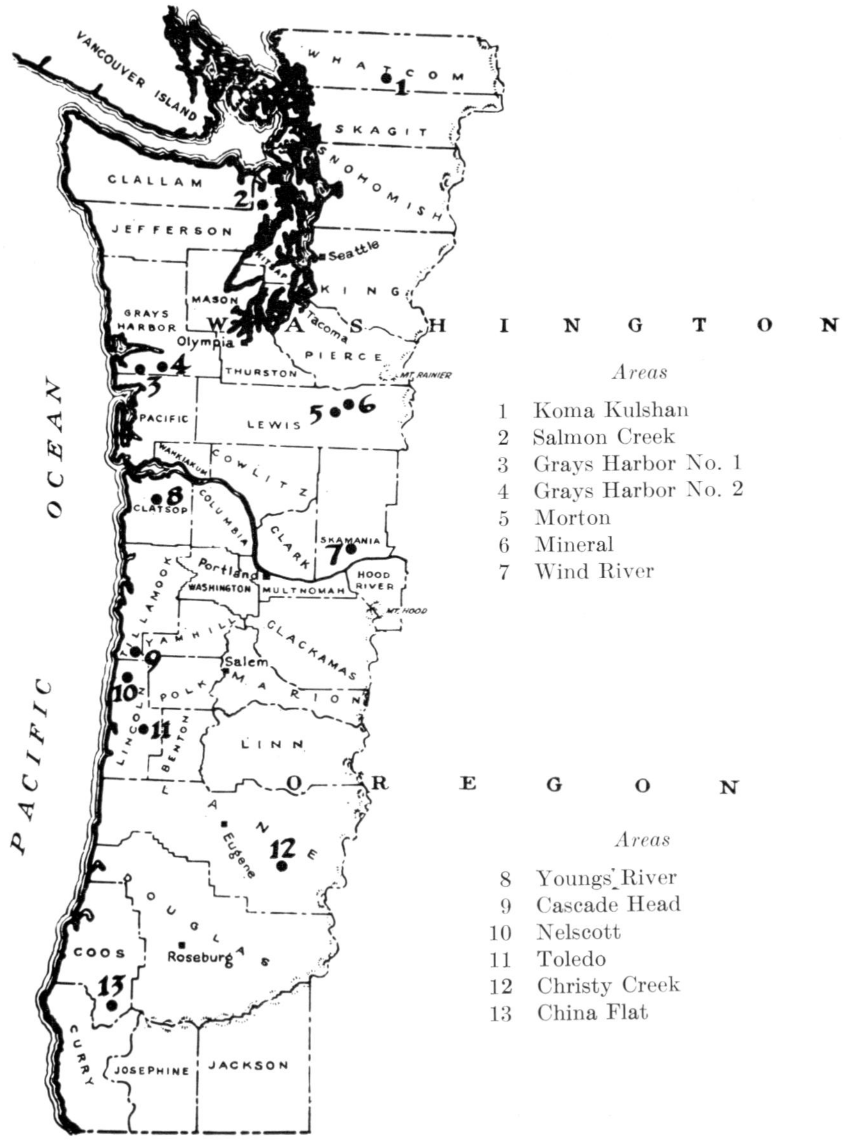


FIGURE 1.—Decay study areas in western Washington and Oregon.

TABLE 1.—*Description of study areas*

COASTAL AREAS

| Area | Location | Scar age [1] | Plot elevation | Topography | Soil type | Site [2] | Original stand composition |
|---|---|---|---|---|---|---|---|
| | | *Years* | *Feet* | | | | |
| Grays Harbor No. 1 | West of U. S. 101, 9 miles north of Raymond, Wash. | 11 | 500 | Gentle slope | Sandy loam; clay subsoil | II | Scattered old-growth Douglas-fir and spruce. |
| Grays Harbor No. 2 | 5 miles east of Arctic, Wash. | 32 | 1,500 | Rolling | Sandy loam | II | Scattered old-growth Douglas-fir with spruce and hemlock understory. |
| Youngs River Nos. 1 and 2. | 10 miles southeast of Astoria, Oreg. | 9–11 | 600–1,200 | Flat to steep slope | Deep loam; clay subsoil | I, II | Scattered old-growth Douglas-fir and spruce with spruce and hemlock understory. |
| Cascade Head | 3 miles north of Otis, Oreg. | 12 | 1,000 | Rough | Sandy loam | ---- | Typical 100-year-old spruce-hemlock. |
| Nelscott No. 1 | 1½ miles north of Nelscott, Oreg. | 14–16 | 100 | Gentle rolling | Ancient dune, sandy loam; hardpan subsoil. | III | Typical spruce-hemlock old growth. |
| Nelscott No. 2 | Adjacent to the east side of Nelscott No. 1. | 5–7 | 100 | Gentle rolling | Ancient dune, sandy loam; hardpan subsoil. | III | Young stand of spruce and hemlock. |
| Toledo Nos. 1 and 2 | Siletz River drainage, 8 miles northwest of Toledo, Oreg. | 15–25 | 1,000 | Rough | Deep sandy loam; heavy duff. | II | Transition between Douglas-fir and hemlock-spruce. |

INTERIOR (INTERMEDIATE) AREAS

| Area | Location | Scar age [1] | Plot elevation | Topography | Soil type | Site [2] | Original stand composition |
|---|---|---|---|---|---|---|---|
| Salmon Creek | 15 miles northwest of Quilcene, Wash. | 10 | 1,500 | Gentle slope | Sandy loam; deep duff | II | Douglas-fir and western redcedar overstory; hemlock, true firs, and western redcedar understory. |
| China Flat | 10 miles south of Powers, Oreg. | 10–11 | 1,500 | Moderate slope | Sandy loam | II | Port-Orford-cedar and Douglas-fir mixed with hemlock and true firs. |

INTERIOR (CASCADE SLOPE) AREAS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Koma Kulshan | 12 miles north of Concrete, Wash. | 7 | 1,800 | On bench | Sandy loam | III | Old-growth Douglas-fir with hemlock and true firs understory. |
| Morton Nos. 1 and 2 | Divide between Morton and Riffe, Wash. | 10–11 | 1,300–1,800 | Moderate slope | Sandy loam; clay subsoil. | III | Old-growth Douglas-fir with hemlock understory. |
| Mineral | 15 miles southeast of Mineral, Wash. | 12 | 2,300 | Gentle slope | Sandy loam | III | Old-growth Douglas-fir with high percent true firs and hemlock. |
| Wind River | 10 miles northeast of Carson, Wash. | 3–5 | 1,800 | Moderate slope | Shallow sandy loam | III | Defective Douglas-fir overstory; hemlock and true firs understory. |
| Christy Creek | 25 miles northeast of Westfir, Oreg. | 6 | 2,000 | On bench | Sandy loam; mixture of broken rock. | IV | Defective Douglas-fir overstory; hemlock and true firs understory. |

[1] Age of scars includes the year of majority of logging injuries.
[2] Site classification based on U. S. Dept. Agr. Tech. Bul. 201 (*13*).

The types of injuries studied were as follows: (1) Scars resulting from injuries caused by falling trees, logs being skidded, tractors, cables, or other mechanical equipment, and the blazes and ax chops incidental to logging; (2) broken tops, caused by either logging or wind; and (3) sunscald on the exposed boles of trees.

Falling-tree scars ranged from occasional scattered wounds (fig. 2, *A* and *B*) to long continuous trunk scars, which sometimes extended for many feet (fig. 3, *A* and *B*). Falling-tree scars were most prevalent on the lower half of the bole and frequently extended to the ground. Scratches from stubs of broken limbs of falling trees made short, narrow scars. Short wounds resulted from raked-off branches.

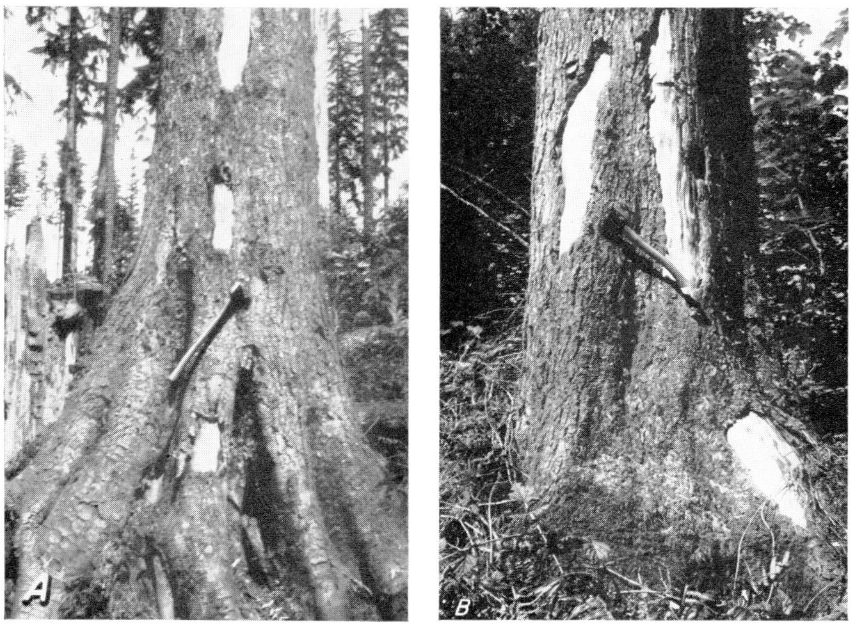


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FIGURE 2.—Falling trees caused these logging scars on western hemlock. *A*, Tree 92 years old, 24.3 inches d. b. h.; scars 8 years old. *Fomes annosus* was isolated from this tree. *B*, Tree 185 years old, 31.1 inches d. b. h.; scar 11 years old. *Polyporus abietinus* was found fruiting at the base of this tree, but only superficial decay had developed.

Scars made during log skidding were confined to the butt of the tree and to surface roots. In such injuries chunks of bark and sapwood usually were torn from the tree base (fig. 4, *A*). Mechanical wounds made by crawler tractors were generally deeper and more damaging than other types of ground-level injuries. Frequently the tractor splintered and tore away surface roots.

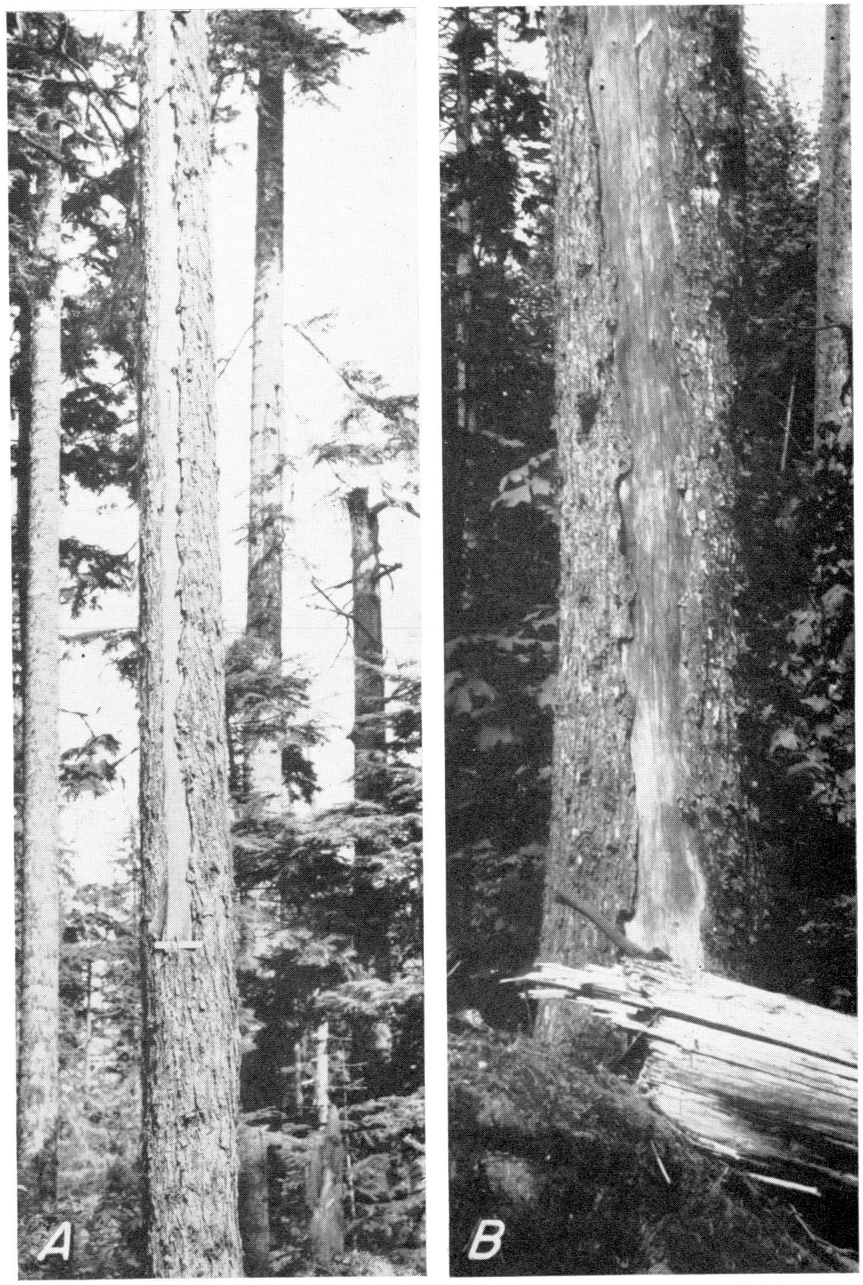


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FIGURE 3.—Extensive falling-tree scars on western hemlock. *A*, Tree 12.5 inches d. b. h.; scar extending from 7.2 to 21.5 feet was 10 years old. *Polyporus abietinus* was isolated from this scar. *B*, Tree 26.5 inches d. b. h.; scar extending from 4.4 to 15.4 feet was 8 years old. *Stereum sanguinolentum* and *Fomes annosus* were isolated from this scar.

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FIGURE 4.—*A*, Falling-tree injury enlarged by skidding. *B*, Seven-year-old logging scar on western hemlock, 20.5 d. b. h. Tree base and roots were torn by crawler tractor.

## Collection of Field Data

All diameter, height, increment, and scar measurements were taken with instruments. Trees were cut at convenient stump heights. Since most of the trees felled were not utilized, they were bucked or chopped as required, to trace and measure the extent of decay. Where decay was apparent on the stump cut, its extent downward below the cut was determined by chopping. Butt rots and heart rots not connected with logging injury were disregarded.

Since falling-tree scars appear alike, whether they are due to logging or to windfall, no attempt was made to distinguish between them. However, it was known that only a few scars were caused by windfall on the areas studied. No scars had resulted from fire on the trees studied.

In this study, field data collected and recorded for analysis were as follows:

(1) Stand history, stand description, and date of logging on the respective areas.

(2) Scar data including age, position, and exposure on the bole; length, width, and height above the ground; whether open or healed; and whether sound or decayed.

(3) Identity of rot where the decay was sufficiently advanced to be characteristic or was accompanied by fruiting bodies. Radial penetration, width, and vertical extent were recorded and notes made as to whether or not the rot from one scar merged with that from another. Blocks for cultures and specimens were taken from rot associated with logging scars or similar injuries.
(4) Volume measurements included diameter at breast height, bark thickness, height of stump, log diameters at intervals of 40 feet or less to an 8-inch merchantable top, length of tip, and diameter of tops broken by logging.
(5) Tree age was determined from annual ring counts of all stumps, except where advanced basal rot made such counts impossible. Allowances were made for growth to stump height.
(6) Pertinent data on tree vigor and general condition were also recorded.

## Compilation and Analysis of Data

Data for each area were recorded on master sheets. Tree volume in cubic feet was obtained from plotted data by planimeter or from volume curves. Decay volumes were computed in a similar manner. For permanent record, diagrams of the occurrence of decay in sample trees, showing position and extent of rot, were made in the field (fig. 5).

## Determination of Scar Age

The age of the scars studied was recorded because this information is related to depth of penetration and volume of decay. Age was determined for 1,218 scars (table 2). Several of the areas had more than one well-defined period of partial cutting.

TABLE 2.—*Number of scars studied, by age of scar and tree species* [1]

[488 trees]

| Scar age (years) | Western hemlock | Sitka spruce | True firs | Total |
|---|---|---|---|---|
| 2–5 | 155 | 12 | 10 | 177 |
| 6–10 | 387 | 26 | 40 | 453 |
| 11–15 | 283 | 79 | 10 | 372 |
| 16–20 | 44 | 0 | 0 | 44 |
| 21–25 | 24 | 1 | 0 | 25 |
| 26–30 | 36 | 1 | 0 | 37 |
| 31–35 | 46 | 4 | 0 | 50 |
| 36–40 | 5 | 1 | 0 | 6 |
| 41–45 | 5 | 0 | 0 | 5 |
| 46–50 | 10 | 0 | 0 | 10 |
| 51–75 | 20 | 0 | 1 | 21 |
| 76–100 | 13 | 1 | 1 | 15 |
| 101–126 | 2 | 1 | 0 | 3 |
| Total | 1, 030 | 126 | 62 | 1, 218 |

[1] Hemlock occurred on all 13 areas studied, spruce on 7 coastal areas, and true firs as single scattered trees on inland sites.

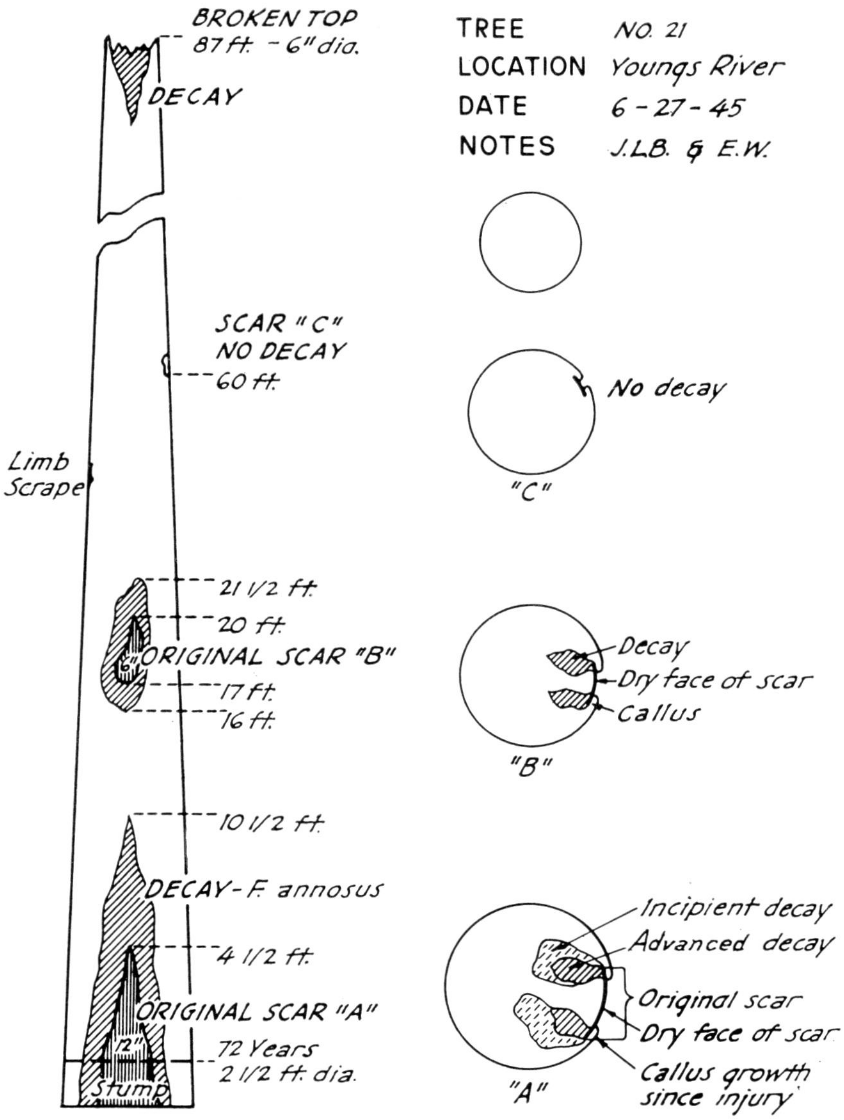


FIGURE 5.—Sample of field drawing of the occurrence of rot associated with logging scars.

## Identification of Decay

Decays associated with logging scars were determined from the fungi isolated in culture when possible. If repeated attempts at isolation failed and fruiting bodies were not present, determination of decay was based on the character of the rot. Sometimes the occurrence of sporophores and advanced decay were used to identify the rot. Such instances were in the minority. A number of sap rots, particularly those associated with sunscald, could be identified from the sporophores fruiting on or near the lesions. Identified rots are not grouped by genera but are listed according to frequency of occurrence in the coastal areas. Except for *Fomes annosus* the same frequency of occurrence does not prevail on the interior areas (table 3).

TABLE 3.—*Fungi isolated from decayed wood of individual logging scars, broken tops, and sunscald on western hemlock, Sitka spruce, and true firs*

WESTERN HEMLOCK

| Fungi | Scars with decay in coastal areas | | Scars with decay in inland areas | |
|---|---|---|---|---|
| | *Number* | *Percent* | *Number* | *Percent* |
| *Fomes annosus* (Fries) Cooke | 76 | 63. 3 | 120 | 39. 9 |
| *F. pinicola* (Fries) Cooke | 8 | 6. 7 | 11 | 3. 6 |
| *Stereum sanguinolentum* Fries | 8 | 6. 7 | 32 | 10. 6 |
| *Armillaria mellea* (Fries) Quél | 8 | 6. 7 | 0 | 0 |
| *Polyporus versicolor* Fries | 5 | 4. 1 | 9 | 3. 0 |
| *Ganoderma oregonense* Murr | 3 | 2. 5 | 0 | 0 |
| *Fomes applanatus* (Wallr.) Gill | 3 | 2. 5 | 0 | 0 |
| *Polyporus abietinus* Fries | 2 | 1. 7 | 12 | 4. 0 |
| *Poria weirii* Murr | 2 | 1. 7 | 2 | . 7 |
| *Fomes robustus* Karst | 1 | . 8 | 1 | . 3 |
| *Lentinus lepideus* Fries | 1 | . 8 | 0 | 0 |
| *Poria subacida* (Peck) Sacc | 1 | . 8 | 2 | . 7 |
| *Poria* spp | 0 | 0 | 11 | 3. 6 |
| *P. carbonica* Overh.[1] | 0 | 0 | 11 | 3. 6 |
| *P. cocos* Wolf.[2] | 0 | 0 | 2 | . 7 |
| *P. albipellucida* Baxter | 0 | 0 | 1 | . 3 |
| *Stereum* spp.[3] | 0 | 0 | 46 | 15. 3 |
| *Coniophora cerebella* Pers | 0 | 0 | 1 | . 3 |
| *Trechispora raduloides* (Karst.) Rogers | 0 | 0 | 1 | . 3 |
| Unidentified [4] | 2 | 1. 7 | 39 | 13. 1 |
| Total | 120 | 100. 0 | 301 | 100. 0 |

SITKA SPRUCE

| Fungi | Number | Percent | Number | Percent |
|---|---|---|---|---|
| *Fomes pinicola* | 18 | 34. 0 | | |
| *Lentinus kauffmanii* Smith | 6 | 11. 3 | | |
| *Stereum* spp | 4 | 7. 5 | | |
| *S. sanguinolentum* | 4 | 7. 5 | | |
| *Fomes pini* (Fries) Karst | 3 | 5. 7 | | |
| *Polyporus guttulatus* Peck | 1 | 1. 9 | | |
| *Poria monticola* Murr | 1 | 1. 9 | | |
| *Coniophora cerebella* | 1 | 1. 9 | | |
| *Fomes annosus* | 1 | 1. 9 | | |
| *Hydnum* sp | 1 | 1. 9 | | |
| Unidentified [4] | 13 | 24. 5 | | |
| Total | 53 | 100. 0 | | |

See footnotes at end of table.

TABLE 3.—*Fungi isolated from decayed wood of individual logging scars, broken tops, and sunscald on western hemlock, Sitka spruce, and true firs*—Continued

TRUE FIRS (grand fir and Pacific silver fir)

| Fungi | Scars with decay in coastal areas | | Scars with decay in inland areas | |
|---|---|---|---|---|
| | *Number* | *Percent* | *Number* | *Percent* |
| *Fomes annosus* | | | 15 | 32. 0 |
| *Stereum* spp. | | | 6 | 12. 8 |
| *Polyporus abietinus* | | | 4 | 8. 5 |
| *Poria* spp. | | | 3 | 6. 4 |
| *Fomes pinicola* | | | 1 | 2. 1 |
| *Trechispora* sp. | | | 1 | 2. 1 |
| *Odontia* sp. | | | 1 | 2. 1 |
| Unidentified [4] | | | 16 | 34. 0 |
| Total | | | 47 | 100. 0 |

[1] All isolated from scarred trees on Hollis Creek area (Area 7, fig. 1).
[2] The first collection from the Pacific Northwest.
[3] Atypical for *Stereum sanguinolentum;* therefore classified as *Stereum* spp.
[4] Includes contaminated cultures where identity of the fungus causing the wood decay was obscured and cases where isolation attempts were unsuccessful.

Some study areas were revisited several months after the felling to recheck the extent of decay, note the occurrence of new sporophores, and collect additional rot samples for culturing. Wood-rotting fungi were thus finally isolated from a number of scars from which fungi had not previously been cultured. In all, more than 1,500 cultures of wood-rotting fungi were made. Sometimes several isolations from one scar were necessary to determine extent of spread and penetration of the decay. Fungi were listed as unidentified if determination was not possible from cultures, fruiting bodies, or typical decay.

## MOST IMPORTANT DECAYS

### Fomes Root and Butt Rot

Fomes root and butt rot, caused by *Fomes annosus*,[4] affects many species of conifers and especially pines (*3, 10, 18*). It is a common rot in dead and down trees in the coastal areas of the Pacific Northwest (*3*). Englerth (*5*) found that *F. annosus* is the most important heart rot fungus of western hemlock in western Washington and Oregon. This rot usually is confined to the butt log but sometimes extends upward 40 feet or more. Rhoads and Wright (*15*) found that infection commonly enters hemlock through wounds and not necessarily through the roots.

In western hemlock and true firs, *Fomes annosus* in the incipient stage is usually reddish brown in color and is quite easily recognized (fig. 6, *A*). In the later or advanced stage, the rot forms small white pockets, which finally change into a spongy white mass of cellulose containing black flecks (fig. 6, *B*). Sporophores are perennial, occurring infrequently on standing trees but occasionally appearing in

[4] Fungi identified in this study are listed in table 3.

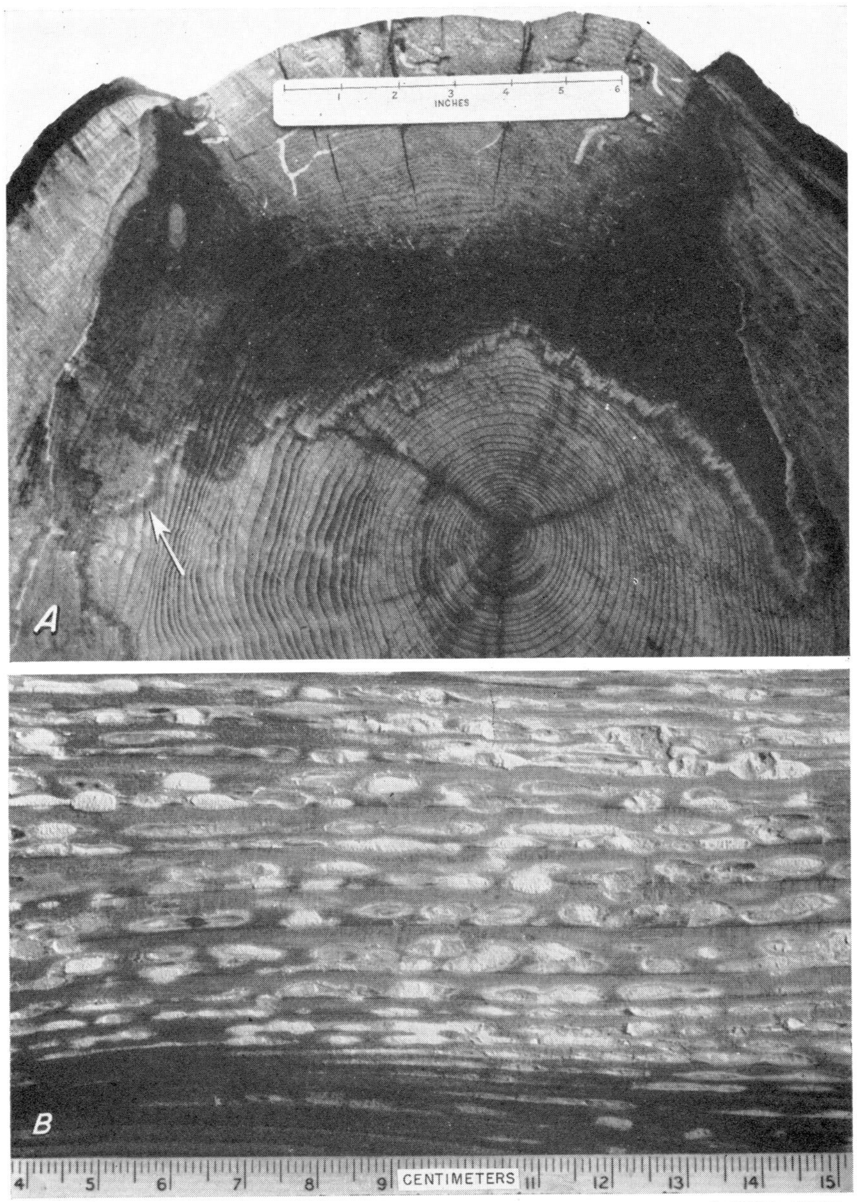


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FIGURE 6.—*A*, Incipient stage of rot caused by *Fomes annosus*. The fungus entered this western hemlock through the 8-year-old logging scar, which extended from 4 to 29 feet above ground. The face of the scar is dried out (casehardened). In 8 years rot had penetrated more than half way to the center of this 124-year-old western hemlock (26 inches d. b. h.). The arrow points to the white aerial mycelium, which defines the extent of decay. The mycelium developed after dissection. *B*, Advanced stage of rot caused by *Fomes annosus*. Pockets are filled with white mycelium and occasional black flecks. In this stage of the rot the wood is reduced to cellulose.

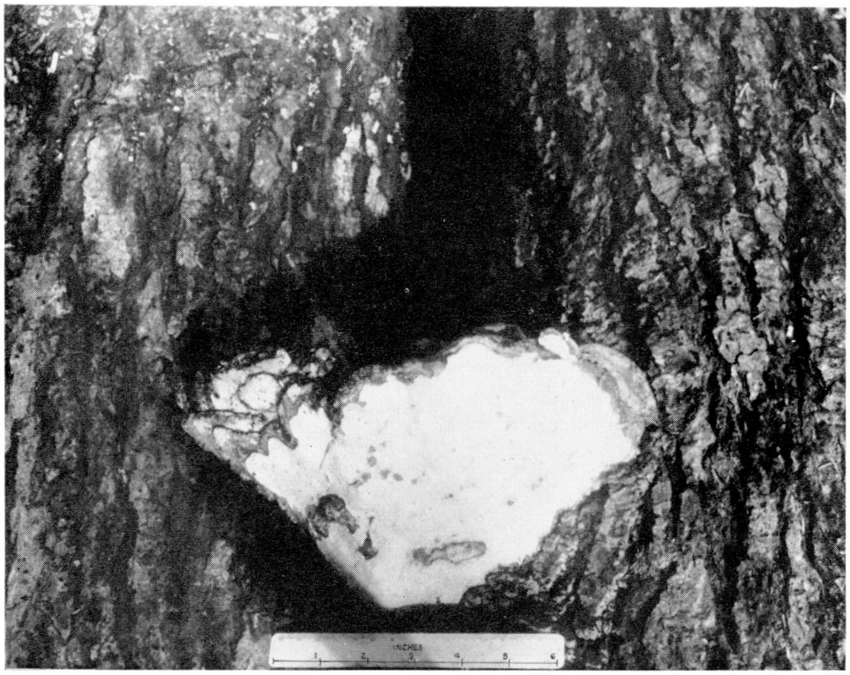


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FIGURE 7.—*Fomes annosus* sporophore, showing hymenium or pore undersurface. This sporophore was found fruiting just below an old cavity, 20 feet above the ground, in a living western hemlock. The fungus entered a falling-tree scar about 1864.

root crotches or in hollow butts. The sporophores are shelflike or flat, are brown on the upper surface, and have a white- to cream-colored pore undersurface (fig. 7).

Although *Fomes annosus* generally is classed as a root rot fungus, in this study it was isolated from several places other than root scars—from basal scars, from scars high on the bole, from sunscald lesions, and even from broken tops. The extent of the decay varied with the age of the scar through which infection took place. Decay develops rapidly in its early stages and more slowly in its advanced stage. Since *F. annosus* destroys primarily the lignin, the decayed wood, except in the most advanced stage of decay, is still valuable for paper pulp (*2*).

## Stereum Rots

Rots caused by *Stereum sanguinolentum* and other species of *Stereum* were encountered so frequently in association with logging scars of western hemlock that they ranked second numerically to rot caused by *Fomes annosus*. These rots were particularly prevalent on inland sites. They have been recognized as widespread in North America in coniferous slash and especially as a heart rot of balsam fir (*1, 7, 14, 17*). Species of *Stereum* also have been associated with dying of young Douglas-fir, true firs, and pines (*12*). Frequently stereum rots occur in dead sapwood; there the infection takes place through wounds on living trees. It has been reported that stereum rot, like rot caused by *Fomes annosus*, does not make the wood useless for pulp (*16*).

Stereum rot in western hemlock and the true firs is a brown friable decay. It penetrates the scar through exposed sapwood and spreads into the heartwood in irregular form (fig. 8). Later it may be obscured by other, faster growing rots. Frequently small, thin, annual conks, partly flat and partly bracketlike, are present (fig. 9). These facilitate

F-478342

FIGURE 8.—Rot caused by *Stereum sanguinolentum*. Cross section cut from falling-tree scar on a western hemlock. Scar extended from 7 to 21 feet above the ground and was 10 years old when photographed. The rot is outlined on the cross sections at 8 feet (left) and 20.5 feet (right), near the bottom and top of the scar. It has extended well into the heartwood. The irregular discoloration at the bottom of the left section is pathological (false) heartwood and not decay.

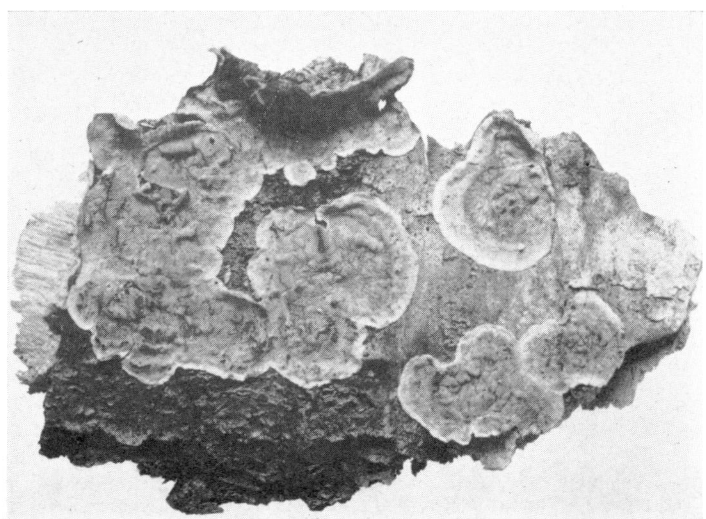

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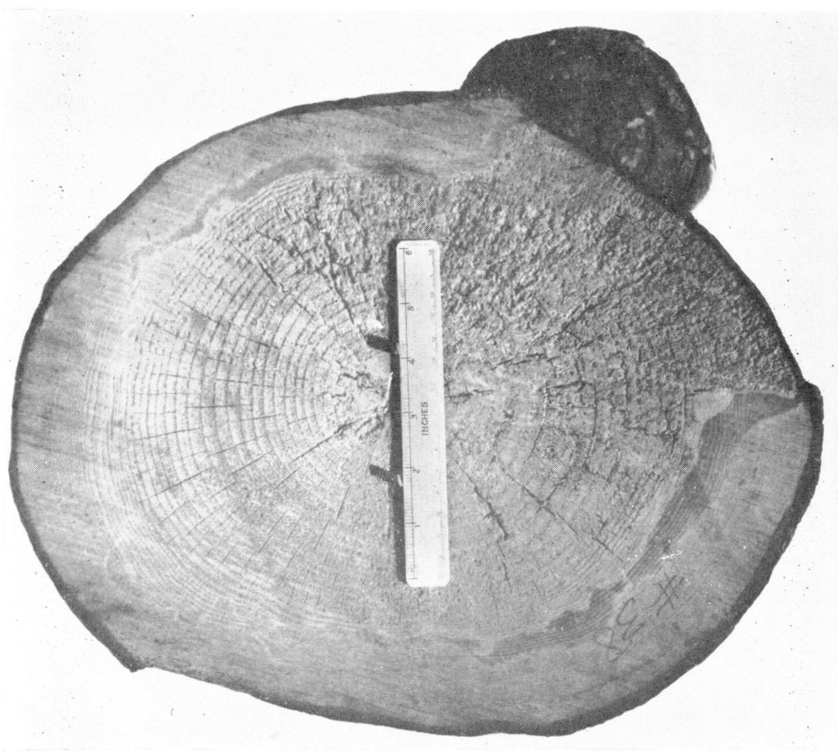
FIGURE 9.—Typical dried-out sporophores of a species of *Stereum*. This is the stage most frequently encountered. Natural size.

identification of the rot. They seldom exceed 2 inches in width. The upper surface of the conk is silky and pale olive gray to buff in color and dries to a grayish-brown color. The undersurface is smooth and bleeds readily when fresh. This rot did not cause as great a volume of decay as most of the other rots encountered. Furthermore, most of the scars infected by species of *Stereum* were relatively young, commonly 5 to 7 years of age.

## Brown Crumbly Rot

Brown crumbly rot, caused by *Fomes pinicola*, was the most common rot found in Sitka spruce. It also caused appreciable volume loss in western hemlock and true firs.

The incipient stage of the decay is indicated by a faint yellowish or brownish discoloration. Wood in the advanced stage of decay becomes a light reddish-brown crumbly mass that eventually breaks into cubes. Prominent white mycelial felts may develop in the shrinkage cracks (fig. 10). Sporophores are very common and appear as hard, woody, perennial shelf- to hoof-shaped conks of fairly large



F-478333

FIGURE 10.—Typical brown crumbly rot, which entered western hemlock through an 11-year-old scar. The scar extended from 6 to 13 feet aboveground and varied from 6 to 8.4 inches in width. The white mycelial felts, typical of this decay, are just beginning to show near the center of the tree, to the left of the ruler. This decay resulted in long-butting and cutting a short log.

size (figs. 11 and 12). The upper surface of the conk is generally smooth, zoned, gray to black in color and sometimes has a wide red margin. The undersurface is white to yellowish in color when fresh but becomes cream to brownish upon drying. The interior of the conk is moderately firm, with a characteristically light yellow color. Brown crumbly rot rapidly renders the wood useless for pulp, lumber, or even fuel. Both dead sapwood and heartwood are attacked.

F-478344

FIGURE 11.—Felled western hemlock, showing the decay caused by *Fomes pinicola*, mostly in the incipient stage, at the margins of the scar. In the living tree the scar extended from the ground up to 6 feet and was 1 foot wide. The decay extended to 10 feet. In addition to *F. pinicola*, *F. annosus* was isolated from this scar.

F-478334

FIGURE 12.—Typical shelflike sporophores of *Fomes pinicola*, growing on the base of a western hemlock snag near Grays Harbor, Wash. This is the typical red belt form of the sporophore.

## DECAY BY AREAS AND TREE SPECIES

### Coastal and Inland Forests

*Fomes annosus* caused 63 percent of the infections in western hemlock in coastal plots but only 40 percent of the infections inland (table 3). Rots caused by *Armillaria mellea*, *Fomes applanatus*, and *Ganoderma oregonense* were found only on trees along the coast. The rot caused by *Stereum sanguinolentum* was somewhat more abundant in scarred western hemlock in inland stands than in coastal stands, and the rots caused by most of the *Poria* species also were more abundant inland. Rot caused by *Fomes pinicola* was most abundant in coastal spruce but occurred in all stands.

Of 883 classified scars on hemlock, 561, or 63.5 percent, had decay. Along the coast 51 percent were infected, and east of the Coast Range 78 percent were infected.

Scars of Sitka spruce, sampled only along the coast, showed 58 percent infection. Scars of grand fir and Pacific silver fir, sampled only on inland areas, showed 90 percent infection.

### Hemlock, Spruce, and True Firs

The 521 logging injuries from which wood-decay fungi were isolated (table 3) are somewhat less than half of the injuries examined. Actually, an overall average of 65 percent of the scars were infected, but frequently several scars occurring close to each other were all infected with the same rot fungus and were listed as one infection. Not uncommonly, a single scar had more than one infection and could not be credited to any specific one. For these reasons, the listing of infections by host species will not check with the total number of injuries with infections.

*Western hemlock.*—*Fomes annosus* was the rot fungus most frequently associated with logging injuries in western hemlock. *Stereum* species were second numerically and often were confined to the sapwood. *Fomes pinicola* was third in number. *Poria weirii*, the destructive root rot fungus common in Douglas-fir young growth, was responsible for the rot in 4 scars on hemlock, all aboveground. Of all the rot fungi listed for hemlock, all but *Poria cocos* had been reported previously in this region.

*Sitka spruce.*—*Fomes pinicola* was the most destructive and most frequently encountered rot fungus in Sitka spruce. *Lentinus kauffmanii* and *Polyporus guttulatus* were found only on Sitka spruce, and *Fomes annosus* was rarely found on this species. Of the total of 126 scars studied in Sitka spruce on the coast areas, 73, or 58 percent, were infected with at least 1 of the 11 or more rot fungi found on this species.

*True firs.*—In grand fir and Pacific silver fir, as in hemlock, *Fomes annosus* was the most common cause of rot. *Stereum* species, other than *sanguinolentum*, were second in occurrence. But *S. sanguinolentum*, common in both hemlock and spruce, was not recorded in the true firs. Of the total of 62 scars found on true firs east of the Coast Range, 56, or 90 percent, were infected with at least 1 of the 8 or more rot fungi found in these species.

## FACTORS AFFECTING DECAY IN LOGGING SCARS

Some of the factors that have a bearing on the incidence of decay when associated with logging scars have been evaluated. Records are presented here for western hemlock only, but results were similar for the other species studied. The stands studied were normally stocked. To determine the effects of percent of cut on the distribution of scars on the trees, the frequency of decay, and the amount of sunscald and windfall loss, the areas studied were roughly grouped as light, medium, or heavy cuttings. Removal of more than 45 percent of the board-foot volume was classed as a heavy cut, 30 to 45 percent was classed as a medium cut, and less than 30 percent was classed as light.

*Relation of scar height to percent of cut.*—Light cutting produced a higher percentage of scars near the base of the trees than above breast height, as indicated in the following tabulation of 1,030 scars on western hemlock:

| Intensity of cut: | Scars below 4.5 feet (number) | Scars below 4.5 feet (percent) | Scars above 4.5 feet (number) | Scars above 4.5 feet (percent) |
|---|---|---|---|---|
| Heavy | 124 | 33 | 252 | 67 |
| Medium | 166 | 54 | 144 | 46 |
| Light | 229 | 67 | 115 | 33 |

The results, while statistically significant, are not thoroughly understood. Possibly there is a higher percentage of basal scars after a light cut because more trees are left in the stand to be injured by skidding, whereas a heavy cut leaves fewer trees to be injured. Also, in heavy cutting, a skid trail is often reused so that only a few new scars are made after the first skidding. Heavier cuts caused significantly more scars at points higher than 4.5 feet.

*Relation of scar height to occurrence of decay.*—Frequency of infection decreased significantly from the ground up, as shown by the following tabulation of 1,030 logging scars with and without decay:

| Scar location: | *Total scars (number)* | *Scars with decay (number)* | *Scars with decay (percent)* |
|---|---|---|---|
| In roots | 33 | 27 | 82 |
| 0–2 feet above ground | 303 | 251 | 83 |
| 2.1–4.5 feet | 183 | 123 | 67 |
| Lower trunk (4.5 feet to base of crown) | 399 | 215 | 54 |
| Upper trunk (base of crown to 8-inch top diameter) | 81 | 38 | 47 |
| Top (above 8-inch diameter but not including broken tops) | 31 | 15 | 48 |

The probable reason for this decrease is that moisture conditions close to the ground are more favorable for the start of decay than are the drier conditions higher on the trunk.

*Relation of the percent of cut to occurrence of decay.*—If light cutting results in a higher percentage of scars near the base of the tree and if decay is more frequent in the lower scars, the highest incidence of decay per scar should occur in the areas cut most lightly. This relationship proved true in this study, as shown by the following data on logging scars with decay:

| Intensity of cut: | *Total logging scars (number)* | *Scars with decay (number)* | *Scars with decay (percent)* |
|---|---|---|---|
| Heavy | 376 | 185 | 49 |
| Medium | 310 | 192 | 62 |
| Light | 344 | 292 | 85 |

The trend proved statistically significant.

*Relation of scar exposure to occurrence of decay.*—The direction that 321 logging scars faced was recorded to determine if exposure influenced the occurrence of decay. Scar exposure was listed according to points of the compass, and decay occurred in 287 of them as follows:

| Exposure: | *Total logging scars (number)* | *Scars with decay (number)* | *Scars with decay (percent)* |
|---|---|---|---|
| North | 41 | 34 | 83 |
| Northeast | 30 | 28 | 93 |
| Northwest | 46 | 38 | 83 |
| South | 24 | 21 | 87 |
| Southeast | 41 | 37 | 90 |
| Southwest | 46 | 45 | 98 |
| East | 45 | 41 | 91 |
| West | 48 | 43 | 90 |

Differences between exposures were not statistically significant. Normally a shaded, moist exposure is more favorable for decay than a sunny, dry one. But most scars studied were fairly well shaded because the scarred trees were in stands only partially cut.

*Relation of scar size to occurrence of decay.*—Small scars were more numerous than large ones and were less frequently decayed, as indicated in the following tabulation of 968 logging scars in western hemlock where the limits of decay could be definitely established:

| Scar area (square feet): | *Total logging scars (number)* | *Scars with decay (number)* | *Scars with decay (percent)* |
|---|---|---|---|
| 0.1–0.5 | 358 | 143 | 40 |
| 0.5–1.0 | 163 | 108 | 66 |
| 1.1–2.0 | 156 | 119 | 76 |
| 2.1–7.0 | 210 | 176 | 84 |
| 7.1–17.0 | 81 | 81 | 100 |

Of the 521 scars 1 square foot or less in area, only 48 percent were decayed. For scars larger than 1 square foot in area the percentage of decay increased rapidly. It reached 100 percent for scars larger than 7 square feet in area. This information is important to the forester since it has a direct bearing on management practices. Trees with wounds larger than 1 square foot should be salvaged at once and not left until the next cutting cycle. Conversely, trees with scars smaller than 1 square foot in area can be more safely left for a future harvest.

## DECAY ASSOCIATED WITH OTHER INJURIES

### Sunscald

Sunscald lesions were reported by Huberman (*11*) in 1943 to have damaged eastern white pine in New England. There sunscald was found regularly on the southwest face of tree trunks and occurred when cambial temperatures reached 43° C. (110° F.) or higher.

In Pacific Coast forests, sunscald had been largely unreported before the present study. In this study, however, the frequent recording of sunscald in partially cut stands of western hemlock showed it to be of major importance in this species. Sunscald damage occurred mostly on the southwest face of the trunk. It occurred most frequently in stands with broken tops.

Sunscald of western hemlock commonly results when the thin-barked trunk is suddenly exposed to full sunlight. Recent sunscald lesions are not always noticeable, but after a few months sunken areas of bark, where the cambium has been killed, are apparent (fig. 13). Exploratory chopping shows the extent to which the cambium has been killed. Well-developed sunscald lesions show pronounced cracking and loosening of the bark, and frequently sporophores of *Polyporus abietinus* are present (fig. 14). Only one spruce tree showed sunscald damage, and this was of limited extent.

Decay was almost always associated with sunscald of western hemlock. Only one lesion without decay was found in this study. Trees that had sunscald injury for several years were a total commercial loss. The wood-rotting fungi associated with sunscald were *Polyporus abietinus*, *Stereum* species, *Lentinus lepideus*, *Fomes annosus*, and *F. pinicola*.

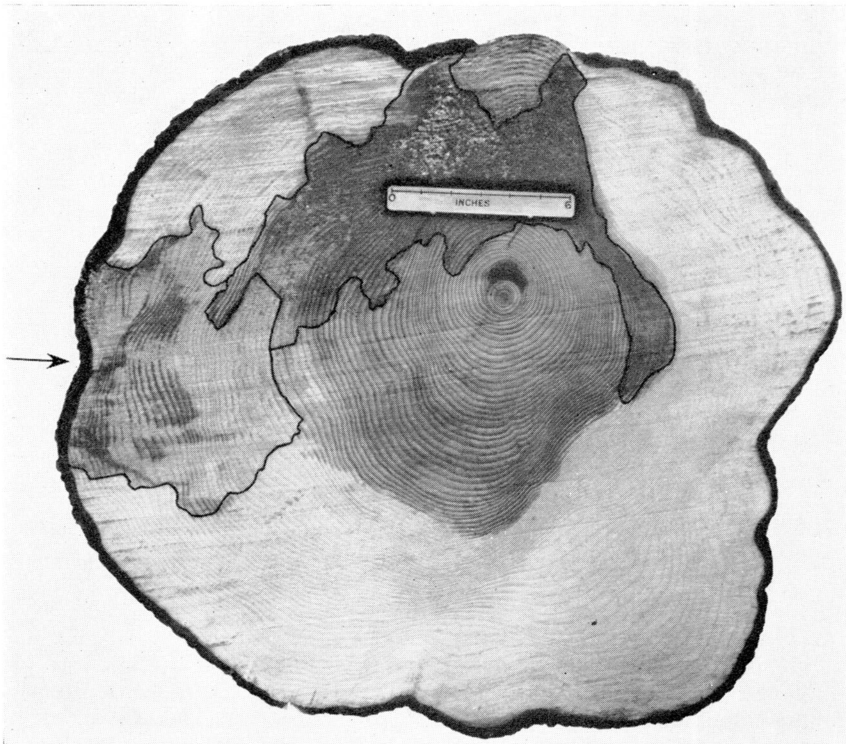



FIGURE 13.—Sunscald damage in cross section from butt of 92-year-old western hemlock, 24 inches d. b. h. At left (arrow), the cambium was killed by sunscald and the trunk was invaded by an unidentified rot fungus. Logging scar, above ruler, was invaded by *Fomes annosus*.

To help define the conditions favoring sunscald in the mild coastal climate, cambial temperatures in several recently exposed western hemlock boles were recorded in one locality.[5]

The temperatures necessary to cause sunscald of western hemlock have not yet been fully determined, but preliminary records indicate that sunscald starts at the relatively low cambial temperature of 92° F. Temperatures as high as 106° were recorded over a 2-year period.

Sunscald was significantly greater in stands heavily cut than in those lightly cut, as shown by the following figures on damage to 381 western hemlock trees:

| Intensity of cut: | *Trees examined (number)* | *Trees with sunscald lesions (number)* | *(percent)* |
|---|---|---|---|
| Heavy | 123 | 20 | 16 |
| Medium | 105 | 14 | 13 |
| Light | 153 | 8 | 5 |

[5] Cambial temperature readings were taken, with specially designed thermometers, under the direction of R. H. Ruth, Forester, Cascade Head Experimental Forest, near Otis, Oreg.

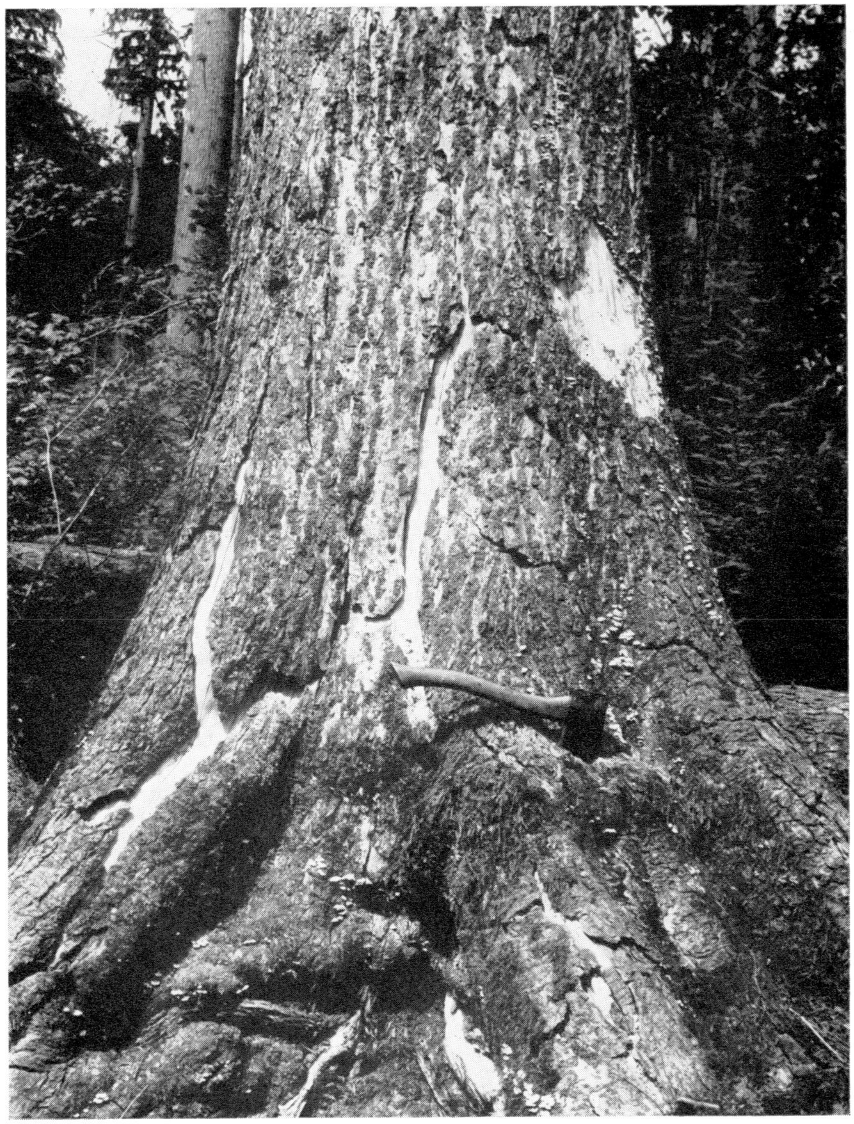


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FIGURE 14.—Severe sunscald extending from ground to 15 feet on living western hemlock tree, 240 years old and 35 inches d. b. h. *Polyporus abietinus* is fruiting on dead bark.

The one sunscald lesion without decay was in a lightly cut stand. Also, sunscald lesions were larger in the heavily cut areas, and the loss from decay was higher.

## Broken Tops

All broken-top trees resulting from partial cutting were recorded. The number of broken tops varied with the percent of cut. In comparable stands, heavy partial cutting resulted in more broken tops than did light cutting.

Of 79 broken-top trees, 36 were 8 inches or larger in diameter at the break and 43 were less than 8 inches in diameter. Of the 8-inch or larger group, 60 percent had decay at the point of break; only 44 percent of those under 8 inches were infected. This difference is probably directly related to time since the break, size of the target presented to spores of fungi, and the amount of moisture collected and retained by the broken tops. The fungi most frequently causing decay in broken tops were *Fomes pinicola* and *F. annosus*.

## Windfall

Windfall, or the probability of windfall, is important in any study of partial cutting and of decay entrance through wounds in trees. Falling trees strike and injure those that remain standing and open the stand to further windfall and sunscald injury. Windfall loss is extremely variable, but, in a partially cut stand of Douglas-fir with a mixture of hemlock and other species, loss increases roughly with the percent of cut. Any cut heavier than 20 to 25 percent of the board-foot volume may result in prohibitive loss.

Records were available for the original cut and subsequent windfall losses on three of the areas included in this decay study. One area, near Morton, Wash., was typical of many overmature old-growth stands in the middle elevations of the northern Cascade Range. This stand consisted of about 12 large old-growth Douglas-firs per acre and many smaller hemlocks, cedars, and true firs. Although more than half of the board-foot volume was removed by cutting most of the large trees, a well-stocked forest of smaller trees remained. Ten percent of the uncut trees were destroyed in logging, and 30 percent of the remainder were injured. Ten years after logging, half of this reserve stand had windfallen, and more than half of the trees that remained standing were scarred and injured.

The second area, at Christy Creek, Oakridge, Oreg., was typical of the defective old-growth Douglas-fir stands of the southern Oregon Cascade Range. A third of the old stand was cut, 5 percent of the understory was killed, and 20 percent was injured by logging operation. In the next 10 years, 10 percent of the reserve stand had windfallen, and the percent of injured trees increased from 20 percent to 25 percent.

The third area, near Grays Harbor, Wash., was typical of coastal spruce-hemlock stands. This stand consisted of scattered old trees of Douglas-fir, Sitka spruce, and hemlock, and a 100-year-old understory of hemlock and spruce. More than half of the board-foot volume was removed by cutting the large old trees and a few of the 100-year-old trees. About 10 percent of the reserve stand was destroyed in logging, and 25 percent of the remaining trees were injured. Ten years after logging, 85 percent of the 100-year-old reserve stand had windfallen, and more than half of the trees that remained standing bore windfall injuries.

These three areas are fair samples of the results of medium or heavy partial cuts in the Douglas-fir region; a great deal of injury to the reserve stand is associated with partial cutting, and the injury is increased by subsequent windfall. Sunscald injury has not been included in the foregoing figures but can be expected to increase in proportion to the percent of partial cut and windfall. Since windfall injuries and sunscald are both points of entry for decay fungi, the significance of their occurrence with medium and heavy partial cuts is readily apparent.

## RELATION OF SCAR AGE TO ENTRANCE AND SPREAD OF DECAY

An overall average of 63.2 percent of 840 scars on 300 western hemlock trees were decayed. The percent of scars with decay are grouped by age of scars as follows:

| Scar age [1] (years): | *Trees (number)* | *Scars [2] (number)* | *Scars with decay (percent)* |
|---|---|---|---|
| 3–4 | 28 | 49 | 83 |
| 5–6 | 56 | 152 | 60 |
| 7–8 | 53 | 145 | 70 |
| 9–10 | 43 | 168 | 50 |
| 11–12 | 59 | 224 | 64 |
| 13–14 | 14 | 19 | 70 |
| 15–16 | 11 | 22 | 50 |
| 17–20 | 8 | 17 | 77 |
| 21–24 | 3 | 9 | 77 |
| 25–29 | 7 | 4 | 75 |
| 30–34 | 18 | 31 | 74 |

[1] Scars older than 34 years were omitted.
[2] If several scars occurred on a single rot column, they were not included in this tabulation.

Although the highest percentage of decay was in the youngest scars, there was no consistent relationship between scar age and presence of decay. Usually decay developed at the edge of the scar. Decay normally progressed from the callus edges into the trunk (fig. 6, *A*). The face of the scar often dried out, became casehardened, and remained sound.

### Radial Penetration

The yearly penetration of decay after logging injury directly affects the net merchantable volume of wood. The same rot penetration that would destroy a tree of small diameter would be relatively unimportant in a tree of large diameter. To determine the rate of radial penetration of rot, depth of decay was measured in even-aged scars on trees in several areas logged at different dates. Rate of decay varied between areas and between kinds of rots, so the relationship of age of scar to rate of penetration showed some irregularity. But the averages established a definite trend in rate of penetration for scars 3 to 15 years old (fig. 15). For the first 3 years the rate of penetration was rapid. After that, penetration was slower but continued, even in the oldest group of scars studied. Rot caused by *Fomes annosus* penetrated most rapidly of all and was about 1 inch deeper than the other rots under 11-year-old scars. In younger scars the difference was smaller.

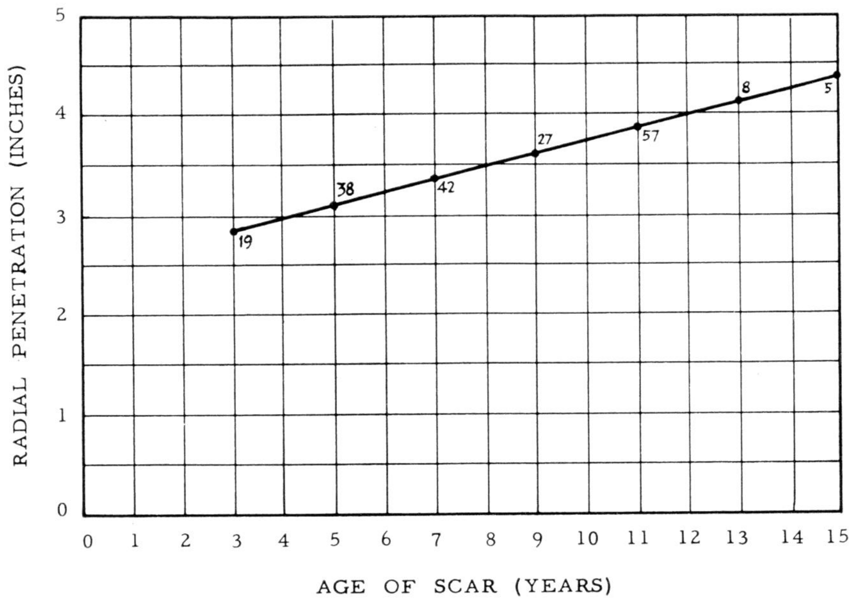


FIGURE 15.—Average rate of radial penetration of decay for western hemlock scars 3 to 15 years old. Scars younger than 3 years were excluded as relatively unimportant in this study.

## Vertical Spread

The vertical spread of decay in western hemlock was determined by measuring the rate in groups of even-aged scars. The vertical spread, like the radial, was rapid for the first 3 years, then less rapid but still advancing at the end of 15 years (fig. 16). Vertical spread

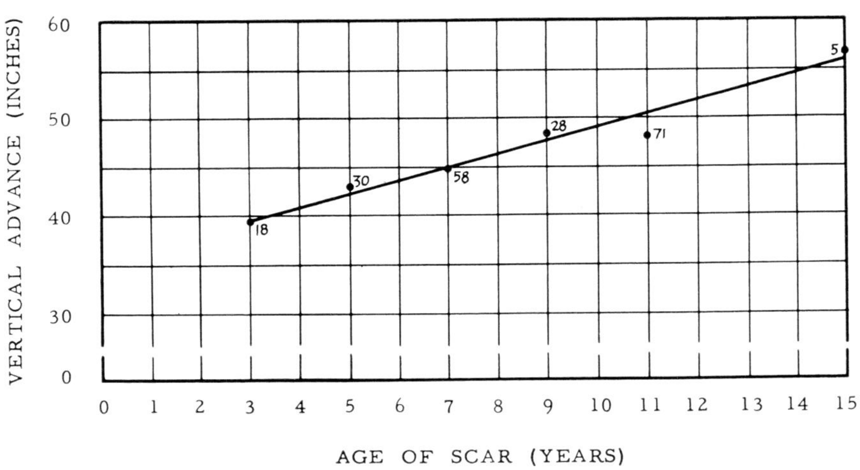


FIGURE 16.—Average vertical advance of decay for western hemlock scars 3 to 15 years old. Scars younger than 3 years were excluded as relatively unimportant in this study.

had not ceased at 34 years. Again decay caused by *Fomes annosus* showed the most rapid advance. In scars 11 years old, its vertical spread was about 30 inches greater than that of the other rots.

## RELATION OF SCAR AGE AND AREA TO VOLUME OF DECAY

In southeastern United States, Hepting (9) found a relationship between width and age of scar and volume of decay on fire-scarred oaks. The present study showed a more complex relationship; a multiple regression including area and age of scar gave a significant average measure of volume of decay. For western hemlock, 596 scars, with and without decay, were included in the calculation (fig. 17 and table 4).[6] For scars 3 to 30 years of age and 1 to 10 square feet in area, decay ranged from 0.68 to 7.65 cubic feet.

Similar regressions were developed for Sitka spruce to show the relation between age, area of scar, and decay volume. For Sitka spruce, only 88 scars, with and without decay, were usable in the computations. Nevertheless, the data indicate progress of decay entering scars on Sitka spruce (fig. 18 and table 5).[7] Decay apparently starts more slowly in Sitka spruce than in western hemlock; after it is established, however, it progresses considerably faster. The resinous character of Sitka spruce probably helps to protect the species against early entry of wood-decay fungi.

Because of inadequate data, no attempt was made to calculate values for true firs.

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[6] Regression formula for western hemlock

$Y_c = 0.0944x_1 + 0.4910x_2 - 0.0929$

where $Y_c$ = estimated rot volume in cubic feet

$x_1$ = scar age in years

$x_2$ = scar area in square feet

Multiple correlation coefficient $(R) = 0.4717$

Standard error of estimate $(s) = \pm 5.86$

[7] Regression formula for Sitka spruce

$Y_c = 0.4296x_1 + 0.3393x_2 - 2.8914$

where $Y_c$ = estimated rot volume in cubic feet

$x_1$ = scar age in years

$x_2$ = scar area in square feet

Multiple correlation coefficient $(R) = 0.4024$

Standard error of estimate $(s) = \pm 12.51$

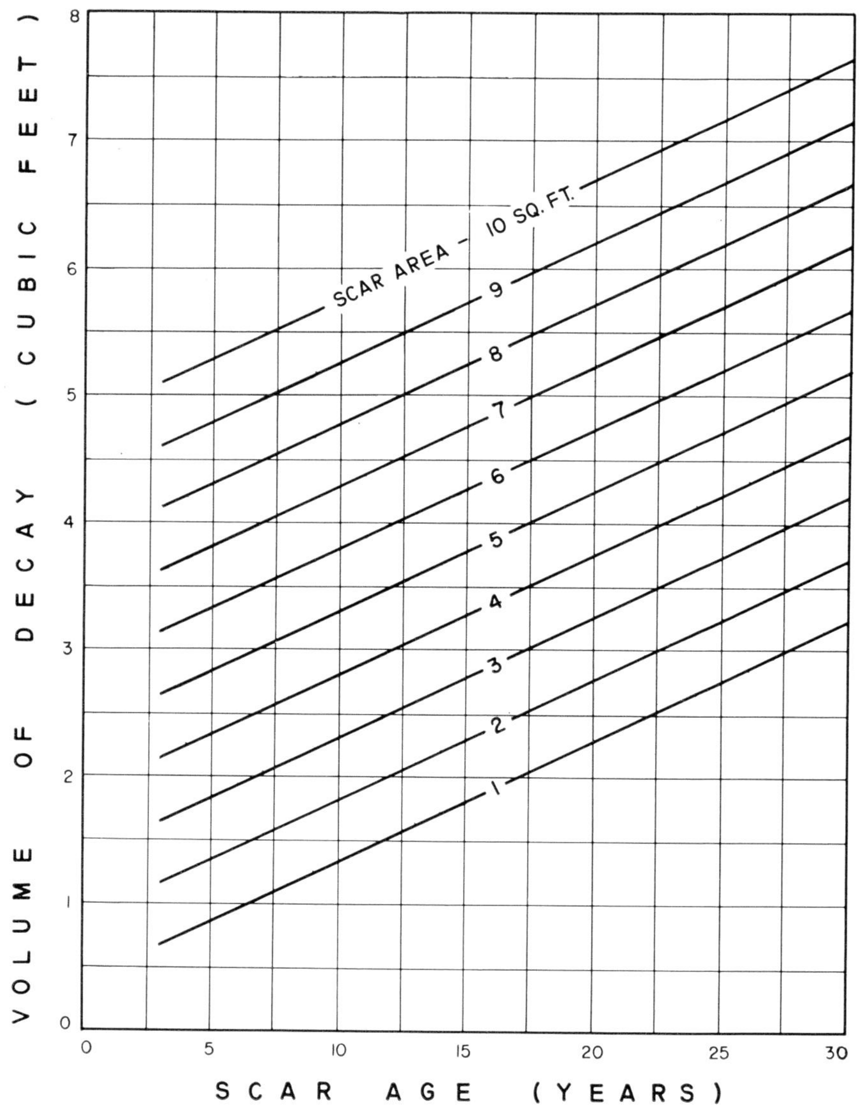


FIGURE 17.—Relation of age and area of scar to average cumulative volume of decay in cubic feet for western hemlock. Scars were 3 to 30 years old.

TABLE 4.—*Calculated volume of decay in western hemlock by age and area of logging scars*

[Basis: 596 scars with and without decay]

| Scar age (years) | Volume of decay when area of scar (square feet) is— | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | *Cu. ft.* | *Cu. ft.* | *Cu. ft.* | *Cu. ft.* | *Cu. ft.* | *Cu. ft.* | *Cu. ft* | *Cu. ft.* | *Cu. ft.* | *Cu. ft.* |
| 3 | 0. 68 | 1. 17 | 1. 66 | 2. 15 | 2. 65 | 3. 14 | 3. 63 | 4. 12 | 4. 61 | 5. 10 |
| 4 | . 78 | 1. 27 | 1. 76 | 2. 25 | 2. 74 | 3. 23 | 3. 72 | 4. 21 | 4. 70 | 5. 19 |
| 5 | . 87 | 1. 36 | 1. 85 | 2. 34 | 2. 83 | 3. 33 | 3. 82 | 4. 31 | 4. 80 | 5. 29 |
| 6 | . 96 | 1. 46 | 1. 95 | 2. 44 | 2. 93 | 3. 42 | 3. 91 | 4. 40 | 4. 89 | 5. 38 |
| 7 | 1. 06 | 1. 55 | 2. 04 | 2. 53 | 3. 02 | 3. 51 | 4. 00 | 4. 50 | 4. 99 | 5. 48 |
| 8 | 1. 15 | 1. 64 | 2. 14 | 2. 63 | 3. 12 | 3. 61 | 4. 10 | 4. 59 | 5. 08 | 5. 57 |
| 9 | 1. 25 | 1. 74 | 2. 23 | 2. 72 | 3. 21 | 3. 70 | 4. 19 | 4. 68 | 5. 18 | 5. 67 |
| 10 | 1. 34 | 1. 83 | 2. 32 | 2. 82 | 3. 31 | 3. 80 | 4. 29 | 4. 78 | 5. 27 | 5. 76 |
| 11 | 1. 44 | 1. 93 | 2. 42 | 2. 91 | 3. 40 | 3. 89 | 4. 38 | 4. 87 | 5. 36 | 5. 86 |
| 12 | 1. 53 | 2. 02 | 2. 51 | 3. 00 | 3. 49 | 3. 98 | 4. 48 | 4. 97 | 5. 46 | 5. 95 |
| 13 | 1. 63 | 2. 12 | 2. 61 | 3. 10 | 3. 59 | 4. 08 | 4. 57 | 5. 06 | 5. 55 | 6. 04 |
| 14 | 1. 72 | 2. 21 | 2. 70 | 3. 19 | 3. 68 | 4. 17 | 4. 67 | 5. 16 | 5. 65 | 6. 14 |
| 15 | 1. 81 | 2. 31 | 2. 80 | 3. 29 | 3. 78 | 4. 27 | 4. 76 | 5. 25 | 5. 74 | 6. 23 |
| 16 | 1. 91 | 2. 40 | 2. 89 | 3. 38 | 3. 87 | 4. 36 | 4. 85 | 5. 35 | 5. 84 | 6. 33 |
| 17 | 2. 00 | 2. 49 | 2. 98 | 3. 48 | 3. 97 | 4. 46 | 4. 95 | 5. 44 | 5. 93 | 6. 42 |
| 18 | 2. 10 | 2. 59 | 3. 08 | 3. 57 | 4. 06 | 4. 55 | 5. 04 | 5. 53 | 6. 03 | 6. 52 |
| 19 | 2. 19 | 2. 68 | 3. 17 | 3. 66 | 4. 16 | 4. 65 | 5. 14 | 5. 63 | 6. 12 | 6. 61 |
| 20 | 2. 29 | 2. 78 | 3. 27 | 3. 76 | 4. 25 | 4. 74 | 5. 23 | 5. 72 | 6. 21 | 6. 71 |
| 21 | 2. 38 | 2. 87 | 3. 36 | 3. 85 | 4. 34 | 4. 84 | 5. 33 | 5. 82 | 6. 31 | 6. 80 |
| 22 | 2. 47 | 2. 97 | 3. 46 | 3. 95 | 4. 44 | 4. 93 | 5. 42 | 5. 91 | 6. 40 | 6. 89 |
| 23 | 2. 57 | 3. 06 | 3. 55 | 4. 04 | 4. 53 | 5. 02 | 5. 52 | 6. 01 | 6. 50 | 6. 99 |
| 24 | 2. 66 | 3. 15 | 3. 65 | 4. 14 | 4. 63 | 5. 12 | 5. 61 | 6. 10 | 6. 59 | 7. 08 |
| 25 | 2. 76 | 3. 25 | 3. 74 | 4. 23 | 4. 72 | 5. 21 | 5. 70 | 6. 20 | 6. 69 | 7. 18 |
| 26 | 2. 85 | 3. 34 | 3. 83 | 4. 33 | 4. 82 | 5. 31 | 5. 80 | 6. 29 | 6. 78 | 7. 27 |
| 27 | 2. 94 | 3. 44 | 3. 93 | 4. 42 | 4. 91 | 5. 40 | 5. 89 | 6. 38 | 6. 87 | 7. 37 |
| 28 | 3. 04 | 3. 53 | 4. 02 | 4. 51 | 5. 01 | 5. 50 | 5. 99 | 6. 48 | 6. 97 | 7. 46 |
| 29 | 3. 14 | 3. 63 | 4. 12 | 4. 61 | 5. 10 | 5. 59 | 6. 08 | 6. 57 | 7. 06 | 7. 55 |
| 30 | 3. 23 | 3. 72 | 4. 21 | 4. 70 | 5. 19 | 5. 69 | 6. 18 | 6. 67 | 7. 16 | 7. 65 |

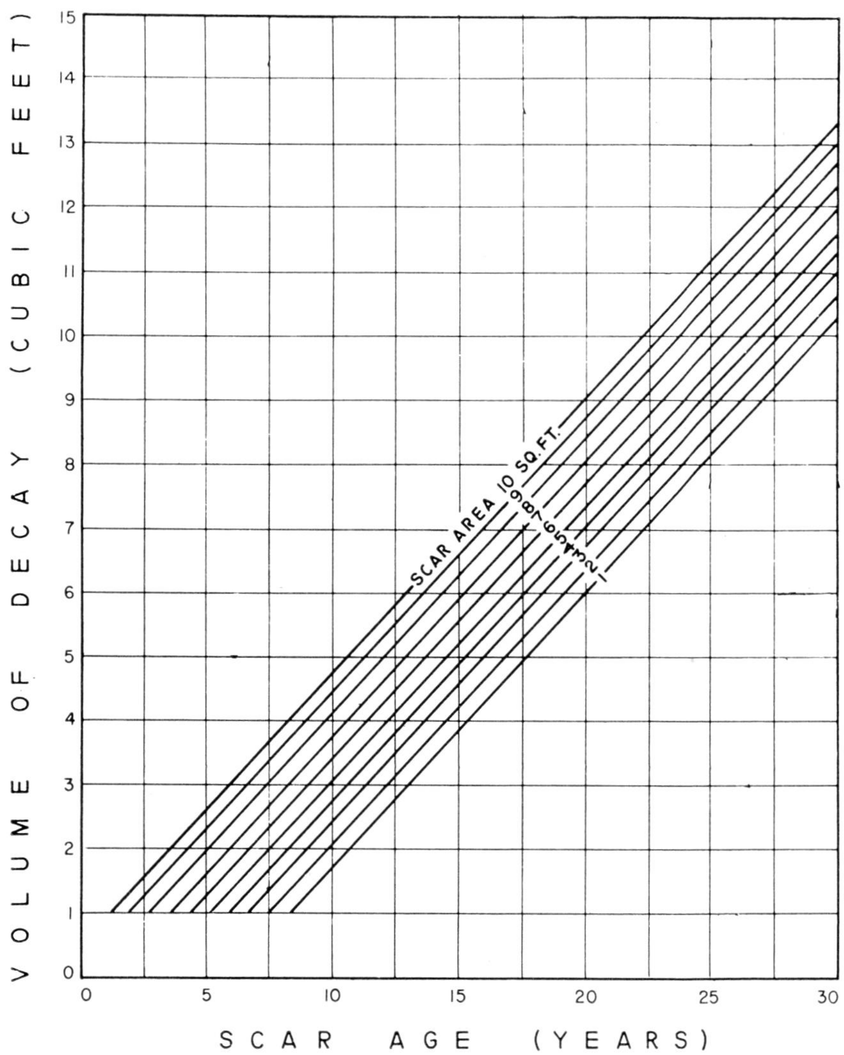


FIGURE 18.—Relation of age and area of scar to average cumulative volume of decay in cubic feet for Sitka spruce. Scars were 3 to 30 years old.

TABLE 5.—*Calculated volume of decay in Sitka spruce by age and area of logging scar*

[Basis: 88 scars with and without decay]

| Scar age (years) | Volume of decay when area of scar (square feet) is— | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | *Cu. ft.* | *Cu. ft.* | *Cu. ft.* | *Cu. ft.* | *Cu. ft.* | *Cu. ft.* | *Cu. ft.* | *Cu. ft.* | *Cu. ft.* | *Cu. ft.* |
| 3 | ------ | ------ | ------ | ------ | 0. 09 | 0. 43 | 0. 77 | 1. 11 | 1. 45 | 1. 79 |
| 4 | ------ | ------ | ------ | 0. 18 | . 52 | . 86 | 1. 20 | 1. 54 | 1. 88 | 2. 22 |
| 5 | ------ | ------ | 0. 27 | . 61 | . 96 | 1. 29 | 1. 63 | 1. 97 | 2. 31 | 2. 65 |
| 6 | 0. 03 | 0. 36 | . 70 | 1. 04 | 1. 38 | 1. 72 | 2. 06 | 2. 40 | 2. 74 | 3. 08 |
| 7 | . 46 | . 79 | 1. 13 | 1. 47 | 1. 81 | 2. 15 | 2. 49 | 2. 83 | 3. 17 | 3. 51 |
| 8 | . 88 | 1. 22 | 1. 56 | 1. 90 | 2. 24 | 2. 58 | 2. 92 | 3. 26 | 3. 60 | 3. 94 |
| 9 | 1. 31 | 1. 65 | 1. 99 | 2. 33 | 2. 67 | 3. 01 | 3. 35 | 3. 69 | 4. 03 | 4. 37 |
| 10 | 1. 74 | 2. 08 | 2. 42 | 2. 76 | 3. 10 | 3. 44 | 3. 78 | 4. 12 | 4. 46 | 4. 80 |
| 11 | 2. 17 | 2. 51 | 2. 85 | 3. 19 | 3. 53 | 3. 87 | 4. 21 | 4. 55 | 4. 89 | 5. 23 |
| 12 | 2. 60 | 2. 94 | 3. 28 | 3. 62 | 3. 96 | 4. 30 | 4. 64 | 4. 98 | 5. 32 | 5. 66 |
| 13 | 3. 03 | 3. 37 | 3. 71 | 4. 05 | 4. 39 | 4. 73 | 5. 07 | 5. 41 | 5. 75 | 6. 09 |
| 14 | 3. 46 | 3. 80 | 4. 14 | 4. 48 | 4. 82 | 5. 16 | 5. 50 | 5. 84 | 6. 18 | 6. 52 |
| 15 | 3. 89 | 4. 23 | 4. 57 | 4. 91 | 5. 25 | 5. 59 | 5. 93 | 6. 27 | 6. 61 | 6. 94 |
| 16 | 4. 32 | 4. 66 | 5. 00 | 5. 34 | 5. 68 | 6. 02 | 6. 36 | 6. 70 | 7. 04 | 7. 37 |
| 17 | 4. 75 | 5. 09 | 5. 43 | 5. 77 | 6. 11 | 6. 45 | 6. 79 | 7. 13 | 7. 46 | 7. 80 |
| 18 | 5. 18 | 5. 52 | 5. 86 | 6. 20 | 6. 54 | 6. 88 | 7. 22 | 7. 56 | 7. 89 | 8. 23 |
| 19 | 5. 61 | 5. 95 | 6. 29 | 6. 63 | 6. 97 | 7. 31 | 7. 65 | 7. 98 | 8. 32 | 8. 66 |
| 20 | 6. 04 | 6. 38 | 6. 72 | 7. 06 | 7. 40 | 7. 74 | 8. 08 | 8. 41 | 8. 75 | 9. 09 |
| 21 | 6. 47 | 6. 81 | 7. 15 | 7. 49 | 7. 83 | 8. 17 | 8. 50 | 8. 84 | 9. 18 | 9. 52 |
| 22 | 6. 90 | 7. 24 | 7. 58 | 7. 92 | 8. 26 | 8. 60 | 8. 93 | 9. 27 | 9. 62 | 9. 95 |
| 23 | 7. 33 | 7. 67 | 8. 01 | 8. 35 | 8. 69 | 9. 02 | 9. 36 | 9. 70 | 10. 04 | 10. 38 |
| 24 | 7. 76 | 8. 10 | 8. 44 | 8. 78 | 9. 12 | 9. 45 | 9. 79 | 10. 13 | 10. 47 | 10. 81 |
| 25 | 8. 19 | 8. 53 | 8. 87 | 9. 21 | 9. 54 | 9. 88 | 10. 22 | 10. 56 | 10. 90 | 11. 24 |
| 26 | 8. 62 | 8. 96 | 9. 30 | 9. 64 | 9. 97 | 10. 31 | 10. 65 | 10. 99 | 11. 33 | 11. 67 |
| 27 | 9. 05 | 9. 39 | 9. 73 | 10. 06 | 10. 40 | 10. 74 | 11. 08 | 11. 42 | 11. 76 | 12. 10 |
| 28 | 9. 48 | 9. 82 | 10. 16 | 10. 49 | 10. 83 | 11. 17 | 11. 51 | 11. 85 | 12. 19 | 12. 53 |
| 29 | 9. 91 | 10. 25 | 10. 58 | 10. 92 | 11. 26 | 11. 60 | 11. 94 | 12. 28 | 12. 62 | 12. 96 |
| 30 | 10. 34 | 10. 68 | 11. 01 | 11. 35 | 11. 69 | 12. 03 | 12. 37 | 12. 71 | 13. 05 | 13. 39 |

## SUMMARY

Thinning and stand improvement cuttings are certain to increase in the forests of the Douglas-fir region, and any form of partial cutting will cause some damage to the reserve stand. Therefore, the occurrence of decay after logging injury will be of increasing concern to practicing foresters in the region.

To study the entrance and spread of decay following logging injury to residual trees in partially cut stands, 13 areas, widely distributed in western Washington and Oregon, were sampled. Decays were studied in logging injuries of all descriptions and in sunscald lesions. The study was confined to the thin-barked species, western hemlock, Sitka spruce, and the true firs (grand fir and Pacific silver fir).

Twenty different fungi causing rot in western hemlock were identified, 11 in Sitka spruce, and 8 in the true firs. Some occurred in 2 species and some in all 4. A total of 27 different fungi were identified. Some rots were readily identified in the field, but samples were taken of all rots, and about 1,500 cultures were made in the laboratory, for identification of the causal organisms.

Fomes root and butt rot, caused by *Fomes annosus*, was the most common rot on scarred western hemlock. It amounted to 63 percent of the rots on that species along the coast, and 40 percent east of the Coast Range. Stereum rots were second; they made up 7 percent of the rot along the coast and 26 percent inland. Rots on the true firs followed the same pattern as on hemlock: Fomes root and butt rot was most common and made up 32 percent of the rots, and stereum rots were second with 13 percent. On Sitka spruce, brown crumbly rot, caused by *Fomes pinicola*, was identified in 34 percent of the scars, stereum rots in 15 percent, and brown pocket rot, caused by *Lentinus kauffmanii*, in 11 percent.

Decay occurred more frequently east of the Coast Range than along the coast. Western hemlock on the coast had rot in 51 percent of the scars; east of the Coast Range 78 percent of the scars were infected. The average for the region was 63 percent. Sitka spruce on the coast had 58 percent of the scars infected. The true firs that occur east of the Coast Range had rot in 90 percent of the scars.

From the incidence of decay in relation to the intensity of the partial cut and from the position and size of logging scars, the forester can estimate roughly the probability of decay in a stand under particular cutting practices. In this study, root injuries and scars close to the ground showed a greater incidence of decay than injuries occurring 4.5 feet or more aboveground. Less than half of the scars 1 square foot or smaller in area had decay in them, whereas all scars larger than 7 square feet in area were infected.

Decay per scar was greater after a light cut than after a heavy cut. Nevertheless, windfall records indicate that the light cut is safer. Anything more than a light partial cut (less than 30 percent of the board-foot volume) is likely to result in destruction of the stand, either from a sudden blowdown or from gradual windfall losses. Each falling tree lets in more sunlight to sunscald its thin-barked neighbors, and many of the falling trees wound other standing trees. Thus the

percent of cut and windfall may affect not only the spread of decay in the residual trees, but if too heavy, may endanger the entire stand.

Sunscald, previously almost unnoticed in this region, was prevalent on exposed hemlock trunks. Practically every sunscald injury contained decay. Sunscald was significantly greater in stands heavily cut than in those lightly cut, thereby emphasizing the need to avoid exposing residual hemlocks to full sunlight.

Scars on hemlock ranged in age from 2 to 126 years. Infection occurred mostly during the first few years after logging. Young scars were infected about as frequently as old ones, and percent of infections did not increase with scar age.

Radial and vertical penetration of decay was directly related to the age of scar. Penetration in both directions was rapid during the first few years, then declined gradually, but had not ceased entirely even in the oldest group of scars studied. By using the graphs, the forester, if he knows the age of a logging scar, can determine the radial and vertical extent of decay in an individual scar and make allowance in log bucking.

A multiple regression of area and age of scar, with and without decay, provides an estimate of average cubic-foot volume of decay for any size scar up to 10 square feet in area and at any age from 3 to 30 years. Older and larger scars were studied, but most scars fell within these limits. The records indicate that the spread of decay was most rapid for the first 3 years. As cubic volume of decay increased, the rate of spread decreased, so that in later years decay accumulated at about the same rate each year. Regressions were calculated for both western hemlock and Sitka spruce. The trends were similar, but the rate of spread for spruce was slower at the start; after decay was established, it was faster in Sitka spruce than in western hemlock.

This report provides information on probability of occurrence of decay and its rate of spread after logging injury to western hemlock, Sitka spruce, and the true firs. The forest manager or owner can use these data for estimating average volume of decay in injured trees when area and age of scar have been recorded. He can then determine how much damage can be tolerated in his timber stands and decide on cutting practices to keep injury within allowable limits.

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U. S. GOVERNMENT PRINTING OFFICE: 1956