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Conk Rot of Old-growth Douglas-fir in Western Oregon

By
John S. Boyce
J. W. Bruce Wagg

A joint research project of the
OREGON FOREST PRODUCTS LABORATORY
and the
Research Division
OREGON STATE FORESTRY DEPARTMENT

To conduct an investigation of this size and complexity, the combined efforts of a group of investigators are essential. The following men, who worked on the project for two or more field seasons, contributed so much in both ideas and technical direction that, if their other commitments had permitted, they would have shared in the authorship of this bulletin.

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The Oregon Forest Products Laboratory was established by legislative action in 1941 as a result of active interest of the lumber industry and forestry-minded citizens. It is associated with the State Board of Forestry and the School of Forestry at Oregon State College. The Dean of the School of Forestry is its Director.

An Advisory Committee composed of men from representative interests guides the research program that is directly pointed toward the fuller utilization of Oregon's forest resources. The following men constitute the present membership of the Advisory Committee:

Conk Rot of Old-Growth Douglas-fir in Western Oregon

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Acknowledgements

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Dennis Lavander, Research Division, Oregon State Forestry Department, worked on the field aspects of the project at various times and contributed materially to its progress by their interest and suggestions.

The initial planning, dissection studies and field sampling were done by W. A. Davies, J. B. Grantham and L. F. Roth of Oregon State College, and J. S. Boyce of Yale University and the Division of Forest Pathology, United States Department of Agriculture. Representatives of the Weyerhaeuser Timber Company, particularly C. D. Weyerhaeuser and Ted Gilbert, encouraged the initiation of the project and provided valuable assistance, especially during the planning stage. J. R. Dilworth collected the soil samples according to the advice of Robert Tarrant. The soil samples were analyzed by the Department of Soils, Oregon State College. J. W. Bruce Wagg, Research Division, Oregon State Forestry Department, Salem, computed the data and wrote the progress reports, the first report in collaboration with P. B. Proctor. Acknowledgment is made to G. H. Barnes of Oregon State College for his assistance in the statistical analysis of some of the data. Appreciation is also expressed to the many other individuals who have aided in the work.

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In 1945, the volume of Douglas-fir, *Pseudotsuga taxifolia* (Poir.) Britt., was estimated at 430 billion board feet or more than one half of all the saw timber in the United States (5)*. In western Oregon alone, there were 143 billion board feet of old-growth timber, 49 billion board feet of big young-growth 20 to 40 inches in diameter, and 12 billion board feet of small young-growth 16 to 20 inches in diameter (10, p. 9). This volume would have been much larger but for losses from decay, largely conk rot caused by *Fomes pini* (Thore) Lloyd. Defective old-growth will be a substantial part of the cut in Oregon for another 25 years or longer; in addition, some of the big young-growth may become highly defective before it is harvested. Losses from decay in old-growth vary by stands, ranging from less than 5 per cent to more than 60 per cent of the gross volume in board feet. The higher volumes of decay are reported from the drainages of the Umpqua and Rogue Rivers east of the Coast Range Mountains. In addition, Douglas-fir in the Coast Range, from the mouth of the Coquille River south into the Siskiyou Mountains, is heavily decayed.

Although decay in Douglas-fir has been studied previously (2, 3), the greatly increased value of Douglas-fir stumpage creates a need for more information either to confirm, modify, or extend previous findings. Consequently, this investigation has been aimed at discovering (1) the behavior of decay caused by *Fomes pini* in the individual tree, in order to improve cruising and utilization, and (2) the relation of such decay to stands, in order to improve management practices.

Decay caused by *Fomes pini* has long been referred to as conk rot, because this fungus is unique in producing numerous conks, or fruiting bodies, which follow closely the progress of the rot in living trees.

CONK ROT IN INDIVIDUAL TREES

It was considered of primary importance to obtain a thorough knowledge of conk rot in individual trees as basic information for the entire investigation.

* Numbers in parentheses refer to Literature Cited, page 91.

Experimental procedure

Fourteen sample plots, ranging from one-quarter to one-half acre in area and containing 292 Douglas-fir trees, were examined. These are termed dissection plots because all the Douglas-fir trees on each were felled and bucked for exact measurement. These plots were not representative of the average stands occurring in a locality but were selected to represent the most defective stands available, thus providing a large number of decayed trees for study. Nine plots were in the Cascade Mountains and five in the Coast Range. The location and a brief description of each plot is given in Appendix A.

Inasmuch as the physiography of western Oregon is extremely varied in climate and resultant flora, the region is divided into five geographical areas following the method of Peck (14, pages 10-30) with one modification. The northern Coast Mountain area is separated from the southern Coast Mountain and Siskiyou area by the Coquille River according to Peck. In the present study the two areas have been separated by the Siuslaw River to permit the inclusion of the Fairview and Wilson Creek plots in the southern Coast Mountain and Siskiyou area. This shift was desirable because the timber on these plots was similar to that found south of the Coquille River. The Cascade Mountain area is bounded on the south by the Umpqua-Rogue Headwater area. No plots were located in the Willamette Valley area, which includes the fringe of timber about the valley.

While the trees were standing, a general description was made for each plot including elevations, aspect, slope, major ground-cover species, and site and soil characteristics. For the Douglas-firs only, diameter at breast height (D.B.H.) and total height were measured. The gross volume, Scribner log rule, was estimated by 32-foot logs to a top limit of 40 per cent of the D.B.H.* The logs were graded according to accepted commercial standards.† The number, orientation, and height of indicators of decay, particularly of sporophores, swollen knots, and punk knots indicating decay by *Fomes pini*, were recorded and the volume of decay estimated. Tree characteristics such as form, crown, bark, limbs and various defects were noted. Species other than Douglas-fir were recorded by D.B.H. only.

The Douglas-firs were then felled and bucked. Logs were dissected as necessary to obtain more detailed information on the extent

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*Girard, J. W. and Bruce, Donald. *Tables for Estimating Board Foot Volume of Trees in 32-foot Logs.* 40 pp. Portland, Oregon: Mason, Bruce & Girard. Undated. According to the authors (p. 5), "These tables are based on a top diameter of 60 per cent of the top diameter of the first 32-foot log, except in cases of small trees which go to a minimum top of 8 inches. 60 per cent of the top diameter of the first 32-foot log corresponds very closely to a little over 40 per cent of D.B.H." These tables were converted to Scribner rule by adding a zero to each figure.

† *Log Scaling and Grading Rules.* 31 pp. Portland, Oregon: Columbia River Log Scaling and Grading Bureau, 710 U. S. National Bank Building. May 1, 1949.

of decay. For each tree, the lengths of all logs, breaks, tops and decayed sections were measured. Longitudinal and cross sectional diagrams of the various decay areas in the trees were drawn. All indicators of decay, particularly that caused by *Fomes pini*, were carefully located; the extent of both incipient and advanced decay above and below the nearest indicator was determined.

Based on log lengths as bucked, the gross volume in board feet, Scribner rule, was scaled for each Douglas-fir to 40 per cent of the D.B.H., to the nearest 12-foot log in the top. Unless stated otherwise, these board foot volumes are used in all tables. Deductions for conk rot caused by *Fomes pini* were scaled in board feet according to the procedure outlined by Neff (Appendix B) and according to standard rules for the measurement of decay caused by other fungi. No deduction was made for the incipient stage of decay caused by *Fomes pini*, commonly termed firm heart stain. Board foot volume is used throughout, because it simplifies computations, is sufficiently accurate for the purpose, and is more practical. Even cubic foot volumes may be approximations when the irregular distribution of decay in most logs is considered.

Tree age was determined by counting growth rings on the stump and adding five years to adjust the age to ground level. As an indicator of vigor, the radial increment was measured to the nearest 0.01 inch on the stump by ten-year intervals from the cambium to the pith.

General data for the plots is given in Table 1.

Losses caused by different fungi

Several fungi are responsible for decay or rot in Douglas-fir. A previous investigation showed that 80.8 per cent of the total board foot volume of decay found in Douglas-fir on plots in western Oregon and Washington was red ring rot or conk rot caused by *Fomes pini* (3, page 31). Nearly all the remainder was divided among red-brown butt rot, caused by *Polyporus schweinitzii;* brown trunk rot, caused by *Fomes laricis;* and yellow-brown top rot, caused by *Fomes roseus*—all three being brown cubical rots. These figures are essentially confirmed by the present investigation, as shown in Table 2, except that unknown brown rots are of more significance. Furthermore, the average loss for all the plots from decay caused by *Fomes pini* was slightly higher, amounting to 82.7 per cent of the total volume of decay.

The importance of *Fomes pini* as a cause of decay in Douglas-fir of western Oregon is shown by the fact that in all but three plots it was responsible for more than 80 per cent of the total decay volume, while in four plots it caused 90 per cent or more of the loss. In every

Table 1. DISSECTION PLOT DATA (Douglas-fir only).

Plot	Area	Number of trees (basis)	Tree ages			Average D.B.H.	Average height total	Average merchantable height*	Site class	Plot location
			Minimum	Maximum	Average					
	Acres		*Years*	*Years*	*Years*	*Inches*	*Feet*	*Feet*		
Cascade Mountain area										
1	0.50	17	210	455	286	34.6	163	112	III	Willamette N. F.
2	0.25	12	288	397	332	37.9	173	124	III	Buck Creek
3	0.30	35	96	178	152	25.9	157	109	III	Willow Creek
4	0.50	15	325	468	426	54.3	189	151	III	Molalla
5	0.50	19	332	415	387	47.4	213	158	II	Quartzville Creek
6	0.50	17	298	329	313	46.8	238	163	I	Calapooya
Umpqua-Rogue Headwaters area										
10	0.33	21	204	306	290	43.7	202	139	II	Wolf Creek
11	0.50	20	322	354	341	37.8	198	146	III	Nigger Creek
Southern Coast Mountain and Siskiyou area										
9	0.33	21	105	179	169	40.9	199	137	II	Fairview
7	0.50	28	238	309	284	38.2	196	131	III	Bone Mountain
8	0.50	29	180	287	239	39.7	209	140	II	Bone Mountain
12	0.50	16	315	395	364	61.8	233	161	II	Wilson Creek
Northern Coast Mountain area										
13	0.50	11	367	382	374	65.5	248	175	I	Valsetz
14	0.50	29	353	391	372	53.4	237	169	I	Valsetz

* Merchantable height taken to a top diameter equal to 40 per cent of the diameter at breast height.

Table 2. Decay Losses on the Dissection Plots (Douglas-fir only).

Plot number	*Fomes pini*		*Fomes roseus*[1]	*Fomes laricis*[1]	*Polyporus schweinitzii*[1]	*Poria weirii*[1]	*Poria* spp.[1]	Unknown brown rots[1]	Total[1]
	Of all decay	Of gross volume[1]							
1	2	3	4	5	6	7	8	9	10
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Cascade Mountain area									
1	81.5	42.8	....	....	0.1	....	....	9.6	52.5
2	86.4	69.2	....	6.6	0.6	2.9	0.8	....	80.1
3	99.2	25.5	....	....	0.2	....	....	....	25.7
4	94.7	53.5	Trace[2]	....	0.9	....	....	2.1	56.5
5	90.0	29.6	1.3	1.7	0.3	....	....	....	32.9
6	84.9	57.4	....	....	0.2	....	....	5.3	67.7
Umpqua-Rogue Headwaters area									
10	88.6	39.0	0.6	3.0	....	....	....	1.4	44.0
11	88.4	49.6	....	1.4	0.2	....	....	4.9	56.1
Southern Coast Mountain and Siskiyou area									
9	91.5	37.8	0.7	....	....	....	2.8	....	41.3
7	85.7	37.2	....	....	....	....	2.0	4.2	43.4
8	82.6	38.1	....	7.5	0.5	....	....	....	46.1
12	78.7	47.3	....	6.1	2.5	....	....	4.2	60.1
Northern Coast Mountain area									
13	66.8	20.7	0.1	7.8	1.8	....	....	0.6	31.0
14	39.2	11.1	....	8.3	7.2	....	...	1.7	28.3

[1] Expressed as a percentage of the gross board foot volume based on commercial deductions.
[2] Trace means that percentage of loss was less than 0.05.

plot, it accounted for more loss of otherwise sound wood than any other fungus. Furthermore, *Fomes pini* can attack Douglas-fir early in life. It has been found decaying a tree only 27 years old (3, page 33). On Willow Creek plot 3 and Fairview plot 9, where the Douglas-fir averaged 152 and 169 years respectively, more than 90 per cent of the decay was caused by *Fomes pini*. The dead trees on Fairview plot 9 also showed evidence of decay by *Fomes pini*. Since this fungus rarely if ever infects dead trees, the decay undoubtedly was present while the trees were alive. Although *Poria weirii*, the cause of a root and butt rot that results in death of infected trees, also can appear early in the life of stands, it was not a factor on these plots.

Most of the other decay-causing fungi appear later in the life of a stand. As a stand approaches stagnation and then declines, brown cubical rots, particularly brown trunk rot caused by the quinine fungus, *Fomes laricis*, become increasingly important. *Fomes laricis* attacks not only sound trees but those already infected with *Fomes pini*. In the latter instance, brown trunk rot is able to overrun conk rot. In Valsetz plots 13 and 14, where the Douglas-fir averaged 374 and 372 years, respectively, *Fomes laricis* accounted for a loss of 7.8 and 8.3 per cent, respectively, of the gross board foot volume, whereas *Fomes pini* was responsible for less volume loss on these two plots than on any of the others. Windfalls within the area, however, showed considerable evidence of decay by *Fomes pini*. Table 3 illustrates an aging stand in which *Fomes laricis* is supplanting *Fomes pini* as the principal cause of decay. *Fomes laricis* commonly follows the major attack of *Fomes pini*, and is the most important fungus in the final break up of old-growth Douglas-fir stands.

Polyporus schweinitzii, depending on wounds for entrance, may appear at any time during stand development. Its incidence is proportional to the amount of basal wounding. It occurred in greatest

Table 3. DECAY LOSSES ON ONE ACRE OF DOUGLAS-FIR NEAR SUTHERLIN, OREGON* (based on cubic foot volume between stump height and an 8-inch top).

Condition of trees	Percentage of gross cubic foot volume lost due to:						Gross volume
	Fomes pini	*Fomes roseus*	*Fomes laricis*	*Polyporus schweinitzii*	Other brown rots	Sap rot	
1	2	3	4	5	6	7	8
							Cubic feet
Living	4.2	1.1	7.7	0.9	1.0	....	26,599
Dead	32.7	0.6	2.6	0.4	7.0	8.7	3,033

* Data courtesy of Weyerhaeuser Timber Company, Tacoma, Washington, from SW/SE, S. 30, T. 23S., R. 2W.; age 297 years; site III.

abundance on Wilson Creek plot 12 where the trees had been injured by a ground fire and on Valsetz plot 14 where nearly all the trees showed signs of basal wounding.

Reduction of losses by planned bucking

Bucking that considers the external indicators of decay can effect considerable savings in logging and milling costs, particularly on operations unable to use material that is culled because of conk rot. The actual bucking in the woods of tree 14, age 284 years, on Bone Mountain plot 7 is compared with the theoretical bucking of the same tree in Figure 1. The theoretical bucking is based on the extent of conk rot in relation to sporophores, as obtained from Figure 5. Since no allowance for hidden defect is necessary after felling, the extent of decay in relation to indicators should be read from the lower solid line in Figure 5. The distances above the highest and below the lowest sporophore have been modified to produce logs of commercial length. Both the extent of decay in the trees and the commercially desirable log lengths should be considered in bucking practice.

Figure 1 reveals that both methods of bucking produced almost the same net scale. In the actual bucking, 1,090 board feet gross were logged to get 545 board feet net; in the theoretical bucking only 660 board feet gross would be logged to get 540 board feet net.

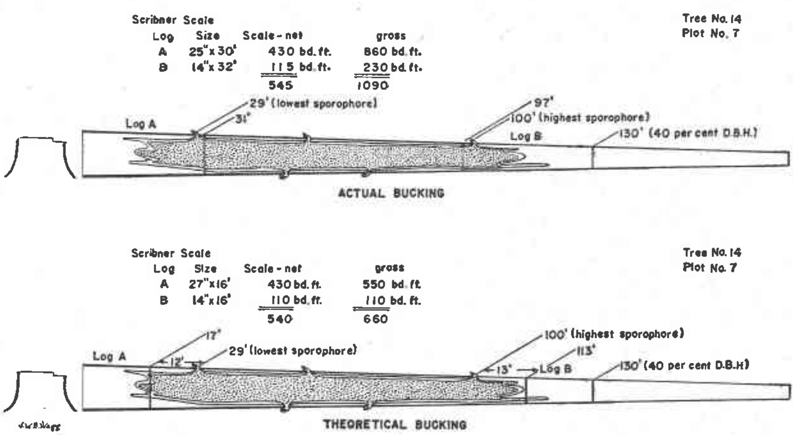


Figure 1. Actual and theoretical bucking of tree No. 14 on Bone Mountain plot 7. Actual bucking followed normal woods practice for this logging operation: theoretical bucking took into account the extent (above and below extreme sporophores) of conk rot prevalent on the plot, as well as standard log lengths.

In commercial scaling practice, if the volume of decay in a log is two thirds or more of the gross board foot volume, the log is a cull, i. e., 100 per cent of the volume is lost. In such cases the loss charged to decay is higher than that which actually occurs. A more accurate measure of decay loss is obtained when the volume of decay is scaled to the nearest 10 per cent. For example, by this method a log which is two-thirds decayed is considered to have 70 per cent of the gross volume lost, and not 100 per cent. The trees on eight of the plots were scaled by both methods and the resulting deductions for decay compared in Table 4.

Table 4. COMPARISON OF DEDUCTIONS FOR DECAY BY TWO SCALING METHODS (Commercial practice vs. scaling to the nearest 10 per cent in individual logs).

Plot number	Deductions for decay*		Difference
	Commercial	Nearest 10 per cent	
	Per cent	*Per cent*	*Per cent*
Umpqua-Rogue Headwaters area			
10	44.0	37.8	6.2
11	56.1	46.8	9.3
Southern Coast Mountain and Siskiyou area			
9	41.3	31.0	10.3
7	43.4	34.6	8.8
8	46.1	42.1	4.0
12	60.1	45.8	14.3
Northern Coast Mountain area			
13	31.0	23.7	7.3
14	28.3	23.3	5.0

* Expressed as percentage of the gross board foot volume.

As shown by the table, commercial scaling practice deducts from 4 to 14 per cent more than is deducted by scaling decay to the nearest 10 per cent of the log volume. The difference between deductions by the two methods will depend upon the amount of decay in a plot and the distribution of decay in individual trees.

Comparison of cruise and scale

Since logging and milling operations are based largely on an estimate or "cruise" of standing timber, it is important that the cruise closely approximate the actual volume. As a basis for comparison, the board foot volume for each of the 14 plots was determined by cruising and by subsequently scaling the felled trees. The cruise was more exact than usual since D.B.H. was taken with a diameter tape and height measured with an Abney level instead of by ocular estimate. The comparative volume data are given in Table

5. Decay volume includes only conk rot caused by *Fomes pini*; minor causes of loss, such as lesser decays, crook, pitch rings, shake, wounds, breakage and others, are not included.

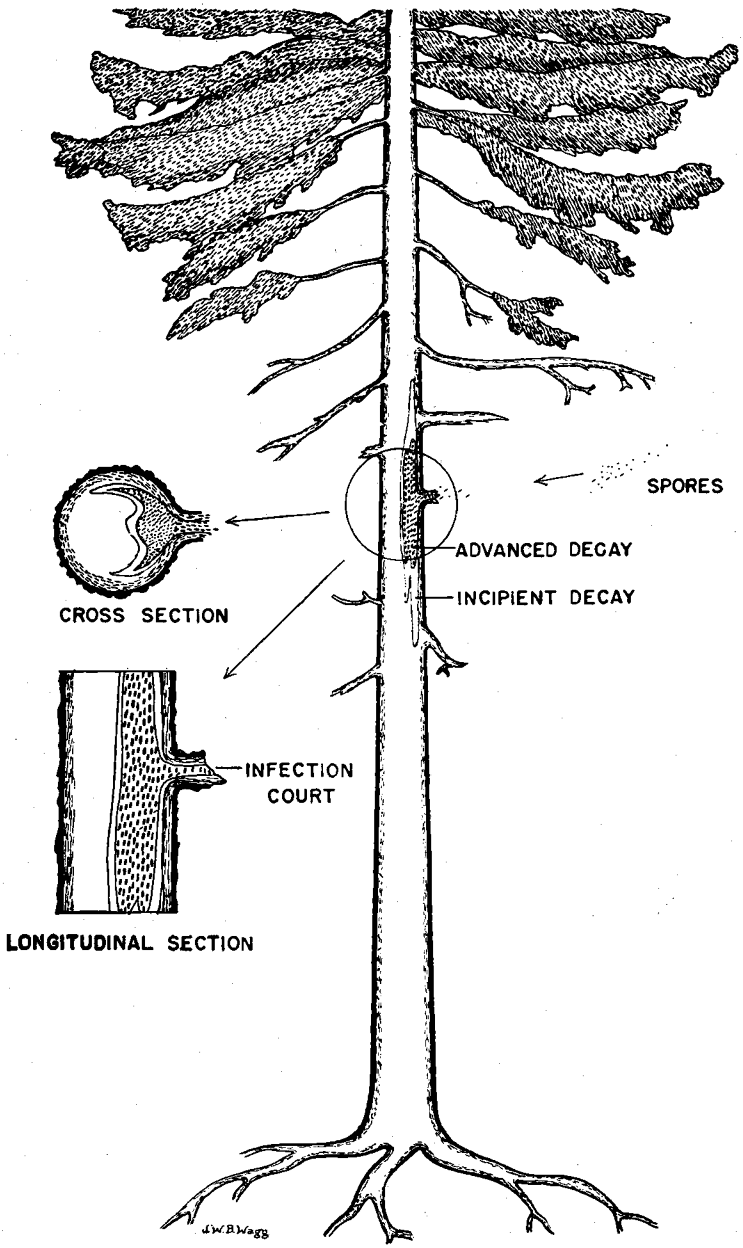
Table 5. GROSS VOLUMES AND DECAY VOLUMES AS CRUISED AND AS SCALED
(Decay volume deductions are for conk rot only)

Plot number	Estimate by 32-foot logs to nearest ½ log		Scale, as bucked to 40 per cent of D.B.H. to nearest 12-foot log in top		Scale, 32-foot log basis: To 40 per cent of D.B.H. to nearest 12-foot log in top	Scale, 32-foot log basis: To 8-inch top*
	Gross volume	Decay volume	Gross volume	Decay volume	Gross volume	Gross volume
	Board-feet	*Board-feet*	*Board-feet*	*Board-feet*	*Board-feet*	*Board-feet*
Cascade Mountain area						
1	68,320	15,664	76,444	32,744	79,224	79,964
2	114,360	67,956	127,580	88,300	116,240	118,680
3	145,300	44,147	135,933	34,999	133,767	135,333
4	208,960	106,434	213,240	114,040	217,140	221,260
5	200,220	63,994	184,940	54,788	197,380	201,960
6	180,760	109,956	178,414	102,494	179,260	188,400
Umpqua-Rogue Headwaters area						
10	257,460	92,820	249,990	97,620	....	....
11	122,380	38,000	118,660	58,840	....	....
Southern Coast Mountain and Siskiyou area						
9	243,900	125,505	232,350	87,825	....	....
7	176,260	62,828	167,500	62,260	....	....
8	191,200	75,620	186,180	70,870	....	....
12	314,620	134,380	297,960	140,880	....	....
Northern Coast Mountain area						
13	262,560	91,800	249,100	51,680	....	....
14	266,040	38,920	252,180	28,000	....	....

* Those interested in a further comparison of the gross volumes obtained by scaling to an 8-inch top rather than to 40 per cent of D.B.H. are referred to Appendix C.

The estimate made of the decay volume before felling was based on a rule suggested years ago (3, page 26). When there are several sporophores or swollen knots along a trunk, decay caused by *Fomes pini*, including incipient decay, will extend 20 feet above the highest and below the lowest sporophore and approximately 9.5 feet above the highest and below the lowest swollen knot. For a single sporophore or swollen knot or one compact group, however, eight feet of the trunk should be deducted in each direction.

Figure 2 represents a tree in the early stage of infection by *Fomes pini*. Because no visible external signs of decay are present, no allowance can be made for decay. It is rare, however, for a tree



Drawing by J. W. Bruce Wagg

Figure 2. Tree in early stage of infection by *Fomes pini*.

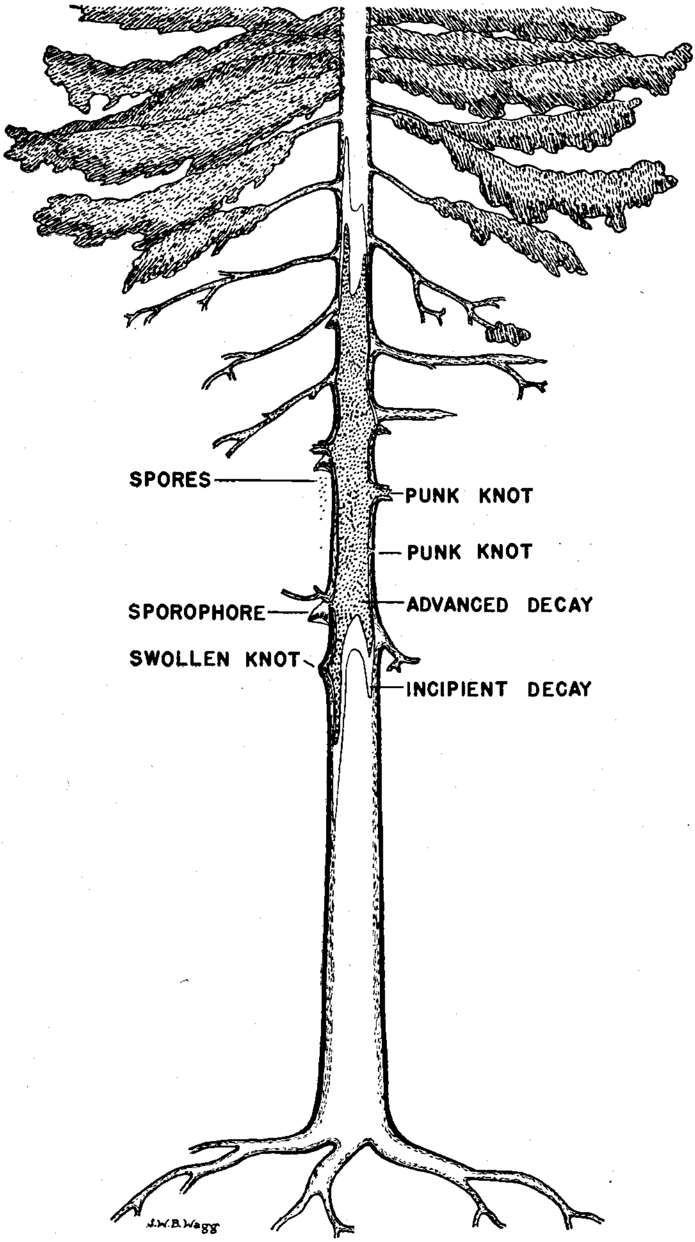
to have a significant amount of conk rot without external indicators. Figure 3 shows a tree in the late stage of infection with a sporophore and a swollen knot, making a deduction possible.

To make the volumes for cruise and scale in Table 5 more readily comparable, they are given on a percentage basis in Table 6. In all but five of the plots, the difference between the cruised and scaled deductions is less than 5 per cent. Since plots 1 and 2 were cruised when the crew lacked experience these estimates were less exact than those for the next four plots. Nigger Creek plot 11, on which decay volume was underestimated by 18.6 per cent, represented a stand in which the trees first infected by conk rot did not die but continued to grow. As the trees aged, the lower conks died and either dropped off the trunk or, if small, remained attached, well hidden in deep fissures of the bark. At times the small conks were completely covered with moss. Consequently, only the conks high up on the trunk, where the fungus was still active, could be seen consistently. Decay, however, extended well into the butt log or even into the stump, far lower than would be expected from the location of the observed conks. Fairview plot 9, on which decay volume was

Table 6. COMPARATIVE DEDUCTIONS FOR CONK ROT AS CRUISED AND AS SCALED

Plot	Average age	Deductions for conk rot*		Difference (cruise less scale)	Conk rot, as a percentage of total scaled volume of decay
		Cruise	Scale		
1	2	3	4	5	6
	Years	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Cascade Mountain area					
1	286	22.9	42.8	—19.9	81.5
2	332	59.4	69.2	— 9.8	86.4
3	152	30.4	25.6	+ 4.8	99.2
4	426	50.9	53.5	— 2.6	94.7
5	387	32.0	29.6	+ 2.4	90.0
6	313	60.8	57.4	+ 3.4	84.9
Umpqua-Rogue Headwaters area					
10	290	36.0	39.0	— 3.0	88.6
11	341	31.0	49.6	—18.6	88.4
Southern Coast Mountain and Siskiyou area					
9	169	51.5	37.8	+13.7	91.5
7	284	35.6	37.2	— 1.6	85.7
8	239	39.5	38.1	+ 1.4	82.6
12	364	42.7	47.3	— 4.6	78.7
Northern Coast Mountain area					
13	374	35.0	20.7	+14.3	66.8
14	372	14.6	11.1	+ 3.5	39.2

* Expressed as a percentage of the gross scaled board-foot volume.



Drawing by J. W. Bruce Wagg

Figure 3. Tree in late stage of infection by *Fomes pini*.

overestimated by 13.7 per cent, was a younger stand, and the relation of indicators to the extent of decay in young trees had not yet been determined. The decay volume on Valsetz plot 13 was overestimated by 14.3 per cent because in one tree the advanced conk rot was limited to a narrow area on one side of the trunk although there was a long extension of incipient decay. Of the other eight Douglas-firs on this plot, two contained an unusual amount of incipient decay in relation to the extent of advanced conk rot.

The results in Table 6 are based on only a few plots, which in certain instances were selected because they were considered difficult to cruise. Over larger areas, or with an increased number of plots representing a stand, estimates would be more exact.

The decay column

Columns of conk rot do not end in short or long cones as do columns of decay caused by many other fungi. Because of the frequent ringlike character of conk rot (as can be seen in Figure 7), conk rot columns usually end in streaks or spires with large areas of sound wood between. Furthermore, since the length of a decay column may vary considerably in different sections of the heartwood, it is difficult to determine its exact length and its correct volume.

In this investigation, incipient decay, known as firm heart stain, is not included in estimating the extent of the decay column or in calculating the decay volume.

Incipient decay does not reduce the net volume of a log but its extent may reduce the log grade. With the value of wood constantly increasing, there is a tendency to utilize all material with incipient decay; some operators even market material with advanced conk rot when conditions permit. Incipient decay extends radially only 2 or 3 inches beyond advanced conk rot, but longitudinally it extends much farther. Although the longitudinal extension of incipient decay was previously found to average 3.5 feet (2, page 16), the distance in certain individual trees was as much as 30 feet.

It has been shown that the average length of the decay column and the average height of the base of the decay column are greater in older stands.* The greater length of the decay column can be explained by the progressive growth of the decay; the greater distance between the ground and the base of the decay column is explained by the fact that later infections occur higher in the trees where branch stubs for entrance are still available. Natural pruning

* Childs, T. W. Unpublished research notes. Division of Forest Pathology, Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Department of Agriculture, Portland, Oregon. 1948.

Table 7. AVERAGE HEIGHTS OF THE BASE AND THE TOP OF THE ADVANCED DECAY COLUMN AND THE AVERAGE MERCHANTABLE LENGTH ABOVE THE DECAY COLUMN IN RELATION TO AVERAGE TREE AGE

Plots	Trees (basis)	Average age of plots	Average height of the base of the decay column above the ground	Average height of the top of the decay column above the ground	Average merchantable height above the decay column (as a percentage of total merchantable height)[1]
1	2	3	4	5	6
	Number	*Years*	*Feet*	*Feet*	*Per cent*
Cascade Mountain area					
3[2]	14	152	0.9	57	51
1	7	286	25.4	101	23
6	9	313	15.5	155	9
2	9	332	10.9	102	23
5	7	387	26.6	122	24
4	10	426	23.3	124	19
Umpqua-Rogue Headwaters area					
10	13	290	12.4	86	49
11	11	341	25.4	139	9
Southern Coast Mountain and Siskiyou area					
9[2]	16	169	6.9	75	50
8	14	239	18.2	100	36
7	13	284	9.7	103	29
12	12	364	1.3	99	36
Northern Coast Mountain area					
14	4	372	41.2	131	27
13	5	374	38.5	104	39

[1] Merchantable height established at a top diameter of 40 per cent of the D.B.H. to the nearest 12-foot log in the top.
[2] Plots 3 and 9 are of age classes more comparable to young-growth stands.

of dead branches and healing over of the stubs has been completed on the lower trunks of older trees.

The average height of the top of the advanced decay column on each plot is shown in column 5 of Table 7. Although irregular, these figures show an increase in the height of the top of the decay column in older stands. For stands less than 200 years old, the average height is 66 feet, for stands between 200 and 300 years old it is 98 feet, and for those older than 300 years it is 122 feet. The average length of merchantable bole above the decay column, expressed as a percentage of total merchantable height, is less in older stands. For the two stands less than 200 years old the percentage is 50, for the four stands 200 to 300 years old it is 34, and for the eight over 300 years it is 23.

Observations on conk rot in stands of all ages throughout the Douglas-fir region of western Oregon and Washington lead to the conclusion that sporophores occur lower on the trunk in younger stands. This indicates the possibility that the base of the rot column is higher in older stands. The possibility is substantiated by the data in column 4 of Table 7, particularly when the somewhat irregular values for the plots are grouped into broad age-classes and averaged. When this is done, the average height of the rot-column base is 3.9 feet for those stands less than 200 years old, 16.4 feet for those stands from 200 to 300 years in age, and 22.8 feet for those over 300 years. The fact that the base of the advanced-decay column is higher in older trees may be explained on the grounds that new infections of conk rot occur higher in older trees, and that part, possibly most, of the trees first infected die before the stand reaches maturity. The fact that trees first infected do die before stand maturity is proven by the presence in many stands of dead trees with conk rot, as occurred on Fairview plot 9. *Fomes pini* does not infect dead trees. Of course, the greater height in older stands of the decay-column base would be more pronounced if all of the earlier-infected trees died before stand maturity, but varying numbers do remain in a stand to an advanced age.

The greater height in older stands of both the base and the top of the decay column is revealed by Table 8, in which the trees on all plots are grouped by 40-year age-classes.

Table 8. AVERAGE HEIGHTS OF THE BASE AND THE TOP OF THE ADVANCED-DECAY COLUMN BY AGE CLASSES.

Age class	Average height of decay column above ground level			
	Trees (basis)	Base	Trees (basis)	Top
Years	*Number*	*Feet*	*Number*	*Feet*
121-160	10	2.5	9	46
161-200	20	5.0	18	79
201-240	10	14.7	10	80
241-280	15	17.7	15	104
281-320	26	12.5	25	111
321-360	30	16.6	29	132
361-400	25	21.7	25	116
401-440	9	30.1	9	119
441-480	4	10.6	3	131

Estimating the extent of conk rot

It is possible to estimate the extent of conk rot with reasonable accuracy because the development of sporophores of this fungus follows quite closely the progress of decay in the heartwood of

Douglas-fir, more so than do the sporophores of other wood-rotting fungi. The sporophores produced by *Fomes pini* may be large and conspicuous (Figure 4) or small and difficult to see. In fact, field glasses are necessary for accurate detection. Even so, it is sometimes difficult to distinguish sporophores and to differentiate between sporophores and burls.

Fresh, actively growing sporophores have a grayish-brown to rich-brown undersurface with velvety, golden-brown margins. The upper surface of all sporophores is dark grayish- or brownish-black, rough and furrowed. Their substance is brown in color, and corky or punky. They are connected directly through a decayed knot with the decayed heartwood (Figure 8).

Sporophores apparently die or become inactive when the portion of the decay column with which they are connected is so completely decomposed that little or no food material is left for the fungus. The larger, dead sporophores usually drop from the trunk. The smaller ones, from one half to two inches in width, however, are likely to adhere indefinitely. They are often inconspicuous because they are partly concealed in the bark crevices and may be moss covered. Indeed, they commonly resemble a fragment of moss-covered bark.

After a sporophore becomes inactive it may remain attached to the bark but lose its connection with the decayed knot from which it had grown through the formation of a layer of sound wood between sporophore and decayed heartwood. To such sporophores the name bark conk has been applied. Some observers consider that such conks do not indicate rot in the heartwood, but conks that are no longer directly connected with the decay column are as indicative of rot as those that are connected. The most striking example of this was in the third log of a tree on Fairview plot 9, where a large sporophore was separated from the decay column in the heartwood by eight inches of sound wood. The term "blind" conk is sometimes used to describe this condition but is more commonly applied to overgrown swollen knots as discussed later.

An accurate estimation of the extent of advanced decay above and below the indicators is important in cruising, bucking, and scaling. Advanced decay includes white pocket or white speck and the honeycomb stages of conk rot but not the incipient stage, known as firm heart stain. Table 9 shows the average extent of advanced conk rot above the highest and below the lowest sporophore of a series.

In all areas investigated, the extent of decay beyond the nearest sporophore of a series was greater in older stands, except in the

Photograph by J. W. Bruce Wagg

Figure 4. Sporophores of *Fomes pini* on Douglas-fir.

Table 9. AVERAGE EXTENT OF ADVANCED CONK ROT ABOVE THE HIGHEST AND BELOW THE LOWEST INDICATOR OF A SERIES

Plot	Average age of trees on plot	Average extent of decay beyond sporophores				Average extent of decay beyond swollen knots			
		Trees (basis)	Above highest sporophore	Below lowest sporophore	Combined	Trees (basis)	Above highest swollen knot	Below lowest swollen knot	Combined
1	2	3	4	5	6	7	8	9	10
	Years	*Number*	*Feet*	*Feet*	*Feet*	*Number*	*Feet*	*Feet*	*Feet*
Cascade Mountain area									
6	313	11	15.9	23.8	39.7	5	5.0	10.0	15.0
5	387	8	21.5	15.2	36.7	3	15.3	8.0	23.3
4	426	10	29.4	33.3	52.7	4	16.2	17.7	33.8
Umpqua-Rogue Headwaters area									
10	290	13	19.1	12.3	31.4	10	8.5	7.2	15.7
11	341	11	20.5	29.8	50.3	11	16.4	20.0	36.4
Southern Coast Mountain and Siskiyou area									
9	169	16	7.9	7.5	15.4	6	3.6	3.4	7.0
8	239	12	13.3	12.4	25.7	8	6.6	5.1	11.7
7	284	13	13.1	14.5	27.6	6	7.9	17.3	25.2
12	364	12	27.4	24.0	51.4	5	8.6	13.2	21.8
Northern Coast Mountain area									
14	372	4	22.9	13.4	36.3	2	10.2	0.0	10.2
13	374	5	19.5	11.8	31.3	3	17.0	10.0	27.0

northern Coast Mountain area where there were insufficient data to establish a trend.

In order to bring out more clearly the relationship of the extent of decay to stand age, the data in column 6 of Table 9 are plotted in Figure 5. The combined extent of advanced decay above and below the sporophore series increases about 15 feet every 100 years, between the ages of 150 and 450 years. The extent of decay beyond a sporophore series amounted to 11 feet at the age of 150 years. A previous investigation, based on stands with an average age of 238 years, found that the average extent of decay above the highest sporophore was 20.1 feet and below the lowest was 13.9 feet, a total of 34 feet (2, page 14). Since incipient decay, that had been found to extend an average of 3.5 feet beyond advanced decay, was included in this figure, a closer comparison would result from reducing the distance of 34 feet to 27 feet. Figure 5 reveals that the extent of decay beyond a sporophore series, as determined in the present study, was slightly over 24 feet at the age of 238 years.

In cruising, the actual extent of decay as estimated from the solid line in Figure 5 (based on observed sporophores) should be increased to allow for hidden conk rot, otherwise the volume of conk rot in a stand would be constantly underestimated. The broken line in Figure 5 makes an allowance for unobserved conk rot based on the findings of this and a previous study.

An allowance for unobserved rot is necessary, because all conks may fall from an older tree leaving the trunk without indicators. Some sporophores are too small to be visible from a distance and are overlooked. If some of the sporophores drop off, those that remain may not indicate correctly the linear extent of decay in the tree. Consequently, although in a previous investigation (2, page 16) the combined extent of conk rot beyond sporophores was found to be 34 feet (27 feet of advanced plus 7 feet of incipient decay), this was more or less arbitrarily increased to 40 feet (20 feet above and 20 feet below) to allow for hidden conk rot. Actually the allowance for hidden decay amounted to 13 feet, because the combined figure of 40 feet included the 7 feet of incipient decay that would result in degrade but not in cull.

The allowance for hidden decay is difficult to determine because of insufficient data, but more than a mere guess can be made on the basis of both old and new data. In the present investigation, the estimate or cruise was close to the scaled volume for Bone Mountain plots 7 and 8, and for Wolf Creek plot 10. In these three plots conk rot was underestimated by 1.6 per cent, overestimated by 1.4 per cent and underestimated by 3.0 per cent respectively. The stand ages for

Table 10. AVERAGE HEIGHT OF THE LOWEST AND HIGHEST SPOROPHORES OF A SERIES ON THE TRUNK OF DOUGLAS-FIR BY 20-YEAR AGE-CLASSES, ALL SITES COMBINED.

Age class	Height of conks above ground		Trees (basis)
	Lowest	Highest	
Years	*Feet*	*Feet*	*Number*
170	11.0	35.9	158
190	11.1	43.7	115
210	13.4	52.4	66
230	20.1	49.8	115
250	22.4	63.4	79
270	21.6	62.0	100
290	20.8	56.2	78
310	24.2	66.4	72
330	21.9	63.9	68
350	18.5	69.9	43
370	34.6	85.8	33
390	38.3	89.3	15
410	36.3	83.0	15
430	25.6	81.4	25
450	56.6	126.0	5

these plots were 284, 239, and 290 years, comparable to the 238-year average age of the trees in the early investigation. The combined extent of decay beyond the lowest and highest sporophore was 27.6, 25.7, and 31.4 feet, respectively. The average age for the three plots was 271 years and the average combined extent of conk rot was 28.2 feet. When an allowance of 40 feet for the combined extent of decay was used in cruising the three plots, the estimated board foot volume of decay was very close to the actual decay volume. Therefore, 11.8 feet, or for practical purposes a 40 per cent linear increase, was allowed for the hidden defect. The broken line in Figure 5 provides for this correction factor. Consequently, in cruising, the combined extent of decay (that is the decay beyond the highest and lowest sporophore) should be read from this broken line and not from the lower, solid line where no allowance is made for hidden decay.

The portions of the two lines in Figure 5 beyond 380 years are of uncertain value, because the regular development of conk rot, in relation to the stand, is upset by stand stagnation followed by decadence, which neither occurs at the same age nor has the same manifestations in all stands. Badly infected trees may drop out of a stand, leaving the residual stand with a lesser volume of conk rot. Trees on the better sites may deteriorate at an earlier age and be replaced by understory species, whereas trees on the poorer sites may stagnate for a long time, allowing no openings for other species to enter. If the two lines were extended to younger age-classes the portions below 140 years would necessarily change into curves that would not reach the no-decay line until the age of approximately 25

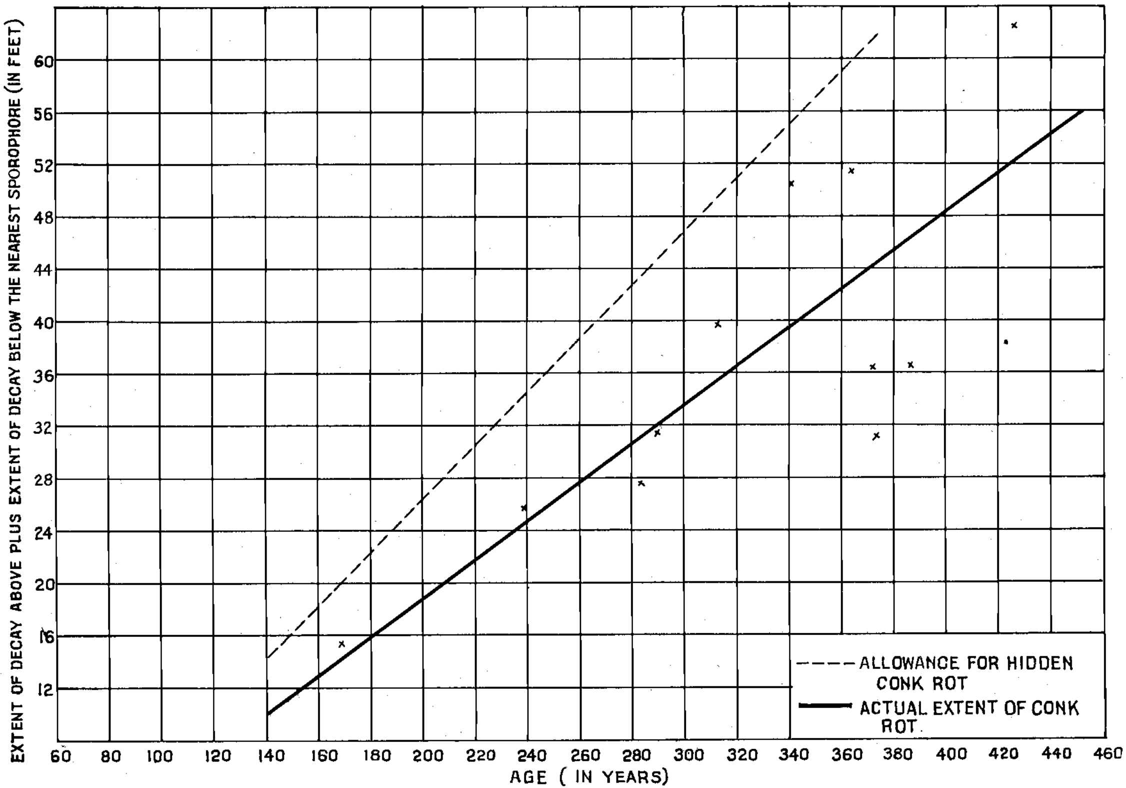


Figure 5. Combined extent of decay above the highest and below the lowest conk of a series in relation to stand age.

years, about the earliest age at which a rare tree with some decay and small conks has been found.

For a single sporophore, or for several in a close group, a deduction is made of 8 feet above and 8 feet below; that is, the equivalent of one 16-foot log. This, however, is based on insufficient data and applies principally to the younger age-classes considered in this investigation, since single sporophores occur infrequently in older timber.

Small and inconspicuous sporophores on old-growth trees are usually indicative of less decay than those of average size and larger. When small sporophores occur on the butt of the tree, one half of the 32-foot butt log should be culled for conk rot. They cannot be identified with certainty higher on the bole, so the deduction remains the same as for other sporophores either singly or in a series.

Experienced cruisers have felt that in older stands it was necessary to look higher for conks. This idea has had no previous substantiation, and the 14 dissection plots did not afford sufficient data to prove the theory. In later work, however, where large numbers of plots were cruised in standing timber, corroborative evidence was obtained. Table 10 shows that the average height of the lowest and highest sporophores in a series is greater in older stands. The 987 trees on which the table is based were from sites I to IV. The relationship is shown more clearly in Figure 6.

Swollen knots (Figures 3 and 7) also are indicators of conk rot but they are less prevalent than sporophores. Actually, a swollen knot is often the initial stage of a sporophore. When such a knot is dissected, the same punky, brown, conk-forming substance that composes a sporophore is found growing out through the knot, even though the sporophore may never fully develop. Less often, a swollen knot develops after a sporophore has dropped off. The swelling results from a tree's attempt to form living wood over a knot where a sporophore is being formed or has formed. The result is in marked contrast to the healing-over of a normal sound knot. Occasionally, as in the case of sporophores, a swollen knot is separated from the decay in the heartwood by a layer of sound wood. The term "blind conk" also has been applied to this condition, but "blind swollen knot" would be more appropriate. Punk knots contain the same brown, punky substance that is found in swollen knots, but are not associated with any swelling. Punk knots are practically impossible to detect on standing trees, unless they occur close to the ground. Their detection, however, is helpful in scaling.

The average extent of decay in relation to swollen knots is shown in Table 9. Averages of these figures show that the extension

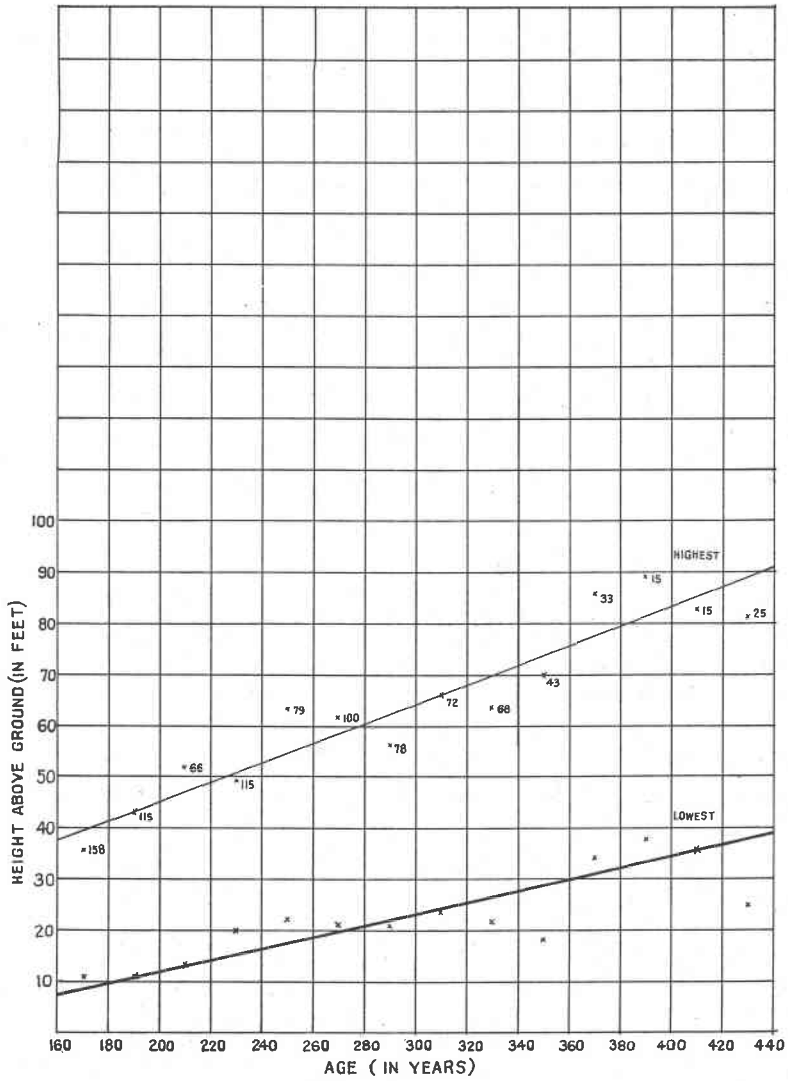
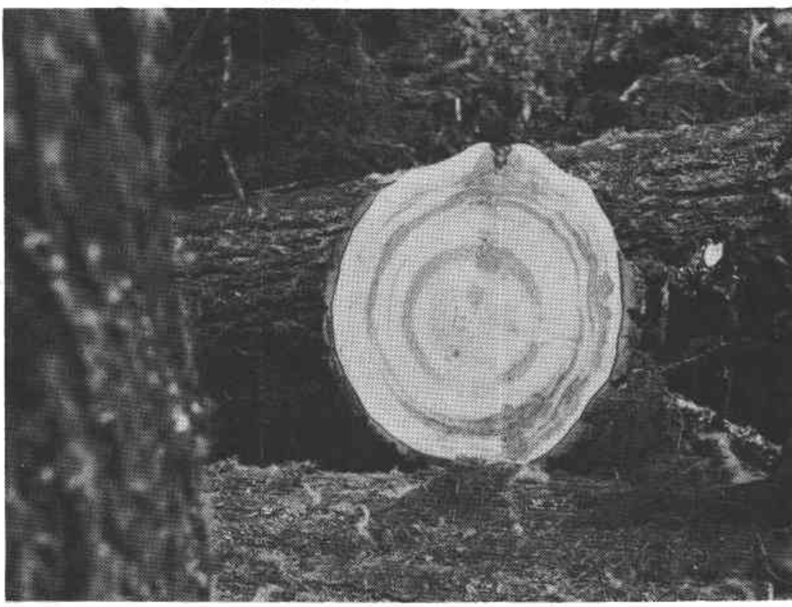


Figure 6. Average height of the lowest and highest sporophore of a series on the trunk of Douglas-fir.

of conk rot above the highest and below the lowest swollen knot in a series is about one half the extension beyond similarly located sporophores. The extension is greater in older stands as is true in the case of sporophores. If the extent of decay shown for sporophores in Figure 5 is halved, it can be applied to swollen knots. Thus, a series of swollen knots on a tree in a 220-year-old stand should require an allowance, including a provision for hidden decay, of 15 feet beyond the limits of the swollen-knot series. This is one half the combined extent of decay beyond the limits of a series of sporophores, as shown by the broken line in Figure 5. On the other hand a single swollen knot indicates a linear extent of conk rot of 4 feet in each direction, or a total of 8 feet.

Although data on punk knots are meager, such knots should be considered to indicate the same extent of decay as do swollen knots.

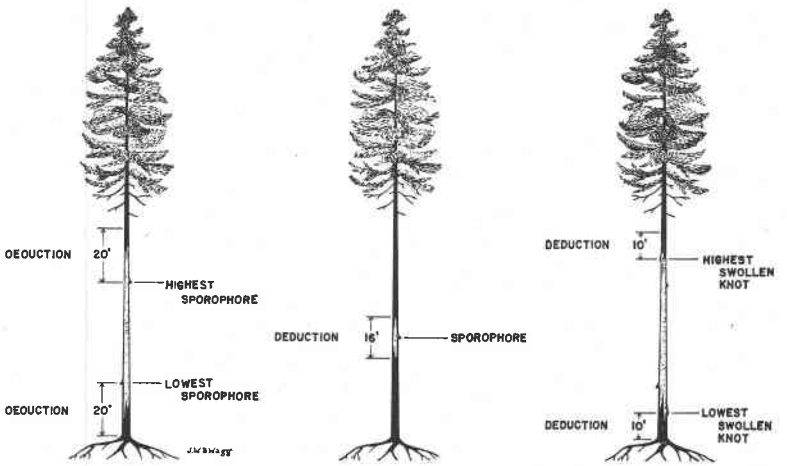
It must be emphasized that these rules for estimating conk rot in timber stands are accurate only by chance when applied to individual trees; their accuracy increases with an increase in the number of trees sampled.



Photograph by Lewis F. Roth

Figure 7. End of a log containing conk rot or red ring rot caused by the ring-scale fungus, *Fomes pini*. The ring-like character of the decay is shown. At the top of the section is a swollen knot.

The method of deducting for conk rot in standing Douglas-fir timber 260 years old is shown diagrammatically in Figure 8. Deductions will vary with the age of the stand.



Drawing by J. W. Bruce Wagg

Figure 8. Diagrammatic presentation of the method of deducting for conk rot caused by *Fomes pini* in standing Douglas-fir timber 260 years old.

If only the approximate stand-age is known, a deduction of 12 feet above the highest and 12 feet below the lowest sporophore in a series could be used for stands 100 to 200 years old, 19 feet in each direction for stands 200 to 300 years old, 26 feet in each direction for stands 300 to 400 years old, and 34 feet in each direction for stands over 400 years old. For swollen knots and punk knots, these deductions should be halved. Where it is possible to examine carefully a large number of trees infected with conk rot, deductions can be adjusted to fit local conditions.

Conk rot and tree growth

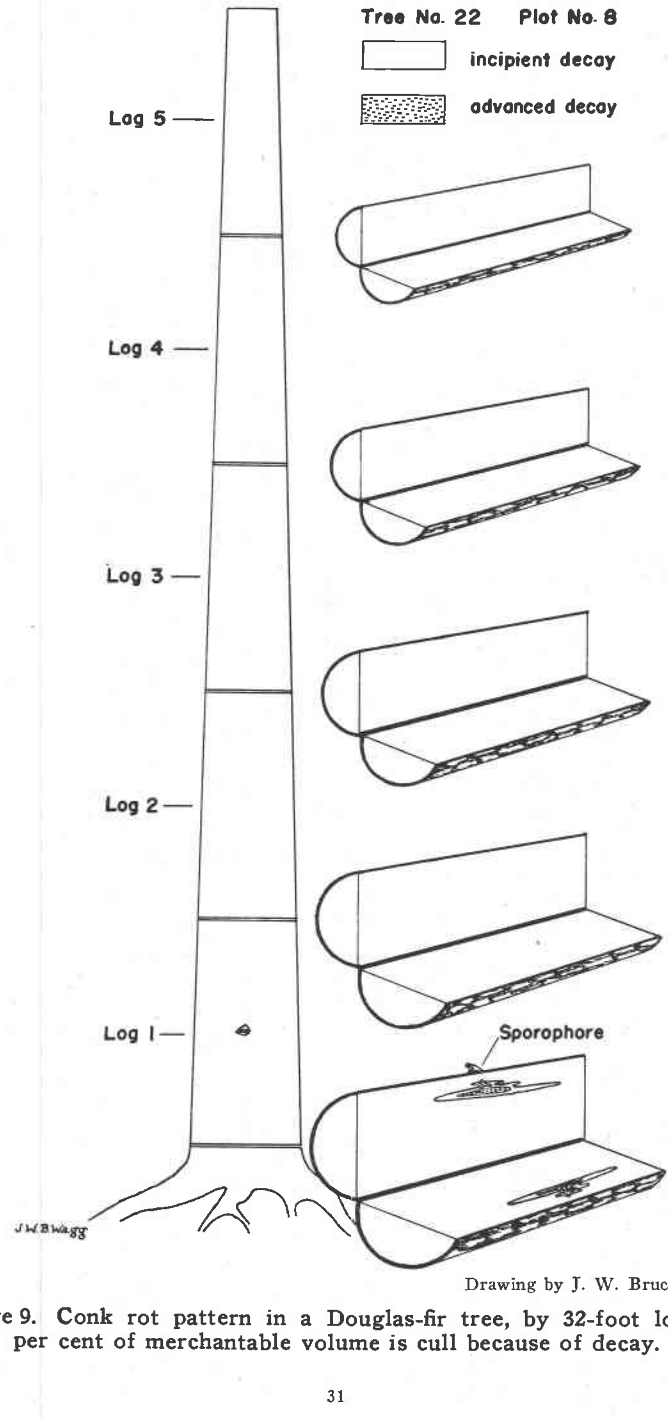
The present vigor of a tree can be determined by its height and diameter in relation to age, or, better, by recent height and diameter growth. Although its condition at any particular time in the past is not so readily determined, a study of a tree's growth rings makes it possible to trace its development back to the sapling stage. Then, by grouping the histories of individual trees on an area, it is feasible to reconstruct, in part, the history of that stand. To determine a relationship between tree vigor and conk rot, the rate of annual radial growth measured along an average radius of the stump was recorded. Trees with butt rot, among which red-brown rot caused by *Polyporus schweinitzii* was most prevalent, were not included in the radial growth measurements because butt rot in many instances is associated with abnormal growth of the trunk manifested as butt swell.

The trees on each plot were divided into the following classes: (a) sound trees without conk rot, (b) trees with 1 to 50 per cent of the gross board-foot volume lost by conk rot, and (c) trees with 51 to 100 per cent of the gross volume lost. Typical examples of decayed trees in the last two classes are shown in Figures 9 and 10.

The last 20 years of radial growth at stump height is shown in Table 11 both for sound trees and for those infected with conk rot. The blanks in the table indicate that no trees in that category were found on the plot. The radial growth of trees with 1 to 50 per cent of the gross volume decayed usually was greater than that of trees 51 to 100 per cent decayed. The growth of sound dominant and codominant trees was either faster or slower than that of the 1- to 50-per cent-decayed class, but in all plots except one, it was faster than that of the 51- to 100-per cent-decayed class. The few intermediate and suppressed trees were the slowest growing of all. This indicates that *Fomes pini* is more likely to infect the faster growing, and hence the larger, trees, but after decay becomes extensive in the heartwood, the growth of the trees slows down.

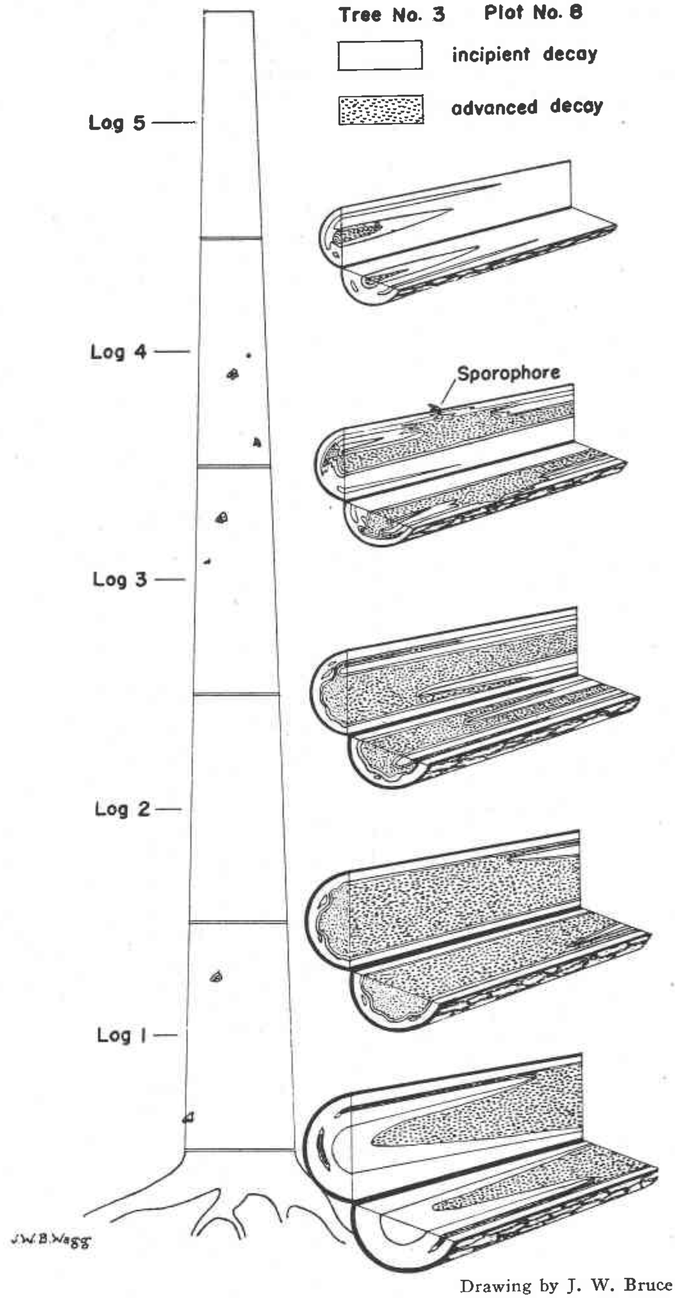
An examination of the ends of logs from trees infected with conk rot, particularly in the younger age-classes, frequently shows that the fungus attacks the living sapwood after it has caused considerable decay in the dead heartwood. It narrows the sapwood more or less uniformly around the stem or kills it in triangular shaped areas, the tip of the triangle extending to, or almost to, the cambium. *Fomes pini*, then, can be pathogenic to Douglas-fir, either causing the death of trees directly, or, which is more probable, weakening them so that they succumb to competition. Consequently, when a stand is beginning to open up, either through natural thinning in early life or through subsequent decadence, trees 1 to 50 per cent decayed will respond to release from competition by making fairly rapid growth. Those 51 to 100 per cent decayed will either grow slowly or decline, the beneficial effect of release being offset by the debilitating effect of the fungus. In time, trees in the 1- to 50-per cent-decayed class will change to the 51- to 100-per cent-decayed class, and growth will decline.

Substantiation of the fact that *Fomes pini* is more likely to infect the faster-growing, more vigorous trees is afforded by data



Drawing by J. W. Bruce Wagg

Figure 9. Conk rot pattern in a Douglas-fir tree, by 32-foot logs; 3 per cent of merchantable volume is cull because of decay.



Drawing by J. W. Bruce Wagg

Figure 10. Conk rot decay pattern in a Douglas-fir tree, by 32-foot logs; 96 per cent of merchantable volume is cull because of decay.

Table 11. AVERAGE RADIAL GROWTH AT STUMP HEIGHT DURING THE LAST 20 YEARS OF TREES WITH CONK ROT AND TREES WITHOUT CONK ROT.

Plot	Trees with conk rot		Sound trees	
	1 to 50 per cent decayed	51 to 100 per cent decayed	Dominant and codominant	Intermediate and suppressed
1	2	3	4	5
	Inches	*Inches*	*Inches*	*Inches*
Cascade Mountain area				
1	0.51	0.22	0.94	......
2	......	0.43	0.83	......
3	0.65	0.28	0.38	......
4	0.54	0.37	0.45	......
5	0.53	0.34	0.36	......
6	0.57	0.21	0.36	......
Umpqua-Rogue Headwaters area				
10	0.49	0.51	0.29	0.14
11	......	0.47	0.59	0.12
Southern Coast Mountain and Siskiyou area				
9	1.09	0.50	0.94	......
7	0.66	0.63	0.91	0.28
8	1.13	0.42	0.78	0.21
12	0.55	0.57	0.80	......
Northern Coast Mountain area				
13	0.87	0.48	0.74	......
14	0.35	0.33	0.55	......

from the large number of cruise plots in standing timber that were included in this study. The criterion used for determining growth and vigor was relative crown-density, since trees with the densest crowns are the most rapidly growing. Crown densities were classified as heavy, medium or light, the medium-density class being the average crown-density of the trees on a plot. Table 12, based on the 198 quarter-acre plots in the Willow Creek drainage, shows that 13.1 per cent of the trees with crowns of heavy density were infected with conk rot, but only 6.3 per cent of the trees with crowns of light density were infected.

Table 12. CROWN DENSITY AND INCIDENCE OF CONK ROT ON WILLOW CREEK CRUISE PLOTS (Douglas-fir trees 12 inches D.B.H. and larger).

Crown density	Number of trees (basis)	Trees with conk rot	
		Number	*Per cent*
Heavy	312	41	13.1
Medium	1,047	86	8.2
Light	381	24	6.3
TOTAL	1,740	151	8.7

Table 13. Average Radial Growth at Stump Height of Trees with Conk Rot and Trees without Conk Rot on Fairview Plot 9.

Age	Trees with conk rot		Sound trees dominant and codominant
	1 to 50 per cent decayed*	51 to 100 per cent decayed*	
Years	*Inches*	*Inches*	*Inches*
0-10	1.87	1.50	2.50
11-20	2.89	2.57	3.47
21-30	3.05	2.92	3.01
31-40	2.15	2.48	2.32
41-50	1.79	1.80	1.31
51-60	1.32	1.44	1.11
61-70	1.15	0.83	1.07
71-80	0.96	0.80	0.88
81-90	0.86	0.63	0.76
91-100	0.70	0.62	0.65
101-110	0.77	0.50	0.69
111-120	0.54	0.49	0.40
121-130	0.65	0.39	0.57
131-140	0.70	0.40	0.60
141-150	0.64	0.32	0.52
151-160	0.65	0.26	0.49
161-170	0.53	0.25	0.41
171-180	0.57	0.25	0.52

* Volume of decay expressed as a percentage of the gross volume in board feet to a top diameter equal to 40 per cent of the D.B.H. to the nearest 12-foot log.

Table 14. Average Radial Growth at Stump Height of Trees with Conk Rot and Trees without Conk Rot on Bone Mountain Plot 8.

Age	Trees with conk rot		Sound trees	
	1 to 50 per cent decayed*	51 to 100 per cent decayed*	Dominant and codominant	Intermediate and suppressed
Years	*Inches*	*Inches*	*Inches*	*Inches*
0-10	......	1.50	......	......
11-20	......	2.10	......	......
21-30	......	1.77	......	......
31-40	......	2.66	......	......
41-50	......	2.18	......	......
51-60	1.54	2.38	1.46	1.53
61-70	2.00	2.66	2.00	1.49
71-80	1.78	1.97	1.80	1.56
81-90	1.12	1.26	1.32	1.54
91-100	0.90	1.52	1.29	1.17
101-110	0.80	1.27	1.28	1.08
111-120	0.77	1.10	1.00	0.86
121-130	0.74	0.97	0.87	0.71
131-140	0.72	0.89	0.87	0.62
141-150	0.70	0.79	0.82	0.56
151-160	0.63	0.61	0.65	0.50
161-170	0.60	0.62	0.61	0.38
171-180	0.87	0.70	0.78	0.36
181-190	0.81	0.59	0.72	0.34
191-200	0.83	0.43	0.74	0.31
201-210	0.83	0.47	0.81	0.31
211-220	0.74	0.41	0.65	0.27
221-230	0.72	0.37	0.56	0.25
231-240	0.78	0.32	0.47	0.27
241-250	0.87	0.39	0.48	0.21
251-260	0.69	0.31	0.40	0.21
261-270	0.70	0.23	0.39	0.18
271-280	0.54	0.20	0.35	0.13
281-290	0.60	0.22	0.42	0.09

* Volume of decay expressed as a percentage of the gross volume in board feet to a top diameter equal to 40 per cent of D.B.H. to the nearest 12-foot log.

Table 15. AVERAGE RADIAL GROWTH AT STUMP HEIGHT OF TREES WITH CONK ROT AND TREES WITHOUT CONK ROT ON WILSON CREEK PLOT 12.

Age	Trees with conk rot: 1 to 50 per cent decayed*	Trees with conk rot: 51 to 100 per cent decayed*	Sound trees, dominant and codominant
Years	*Inches*	*Inches*	*Inches*
0-10	2.66	2.73	......
11-20	3.15	3.58	......
21-30	3.47	2.91	......
31-40	2.98	2.45	2.00
41-50	2.91	1.80	2.51
51-60	2.68	2.95	2.93
61-70	2.09	2.34	2.28
71-80	1.70	1.54	2.19
81-90	1.38	1.52	1.67
91-100	0.97	1.54	1.31
101-110	0.82	0.92	1.25
111-120	0.71	0.76	0.93
121-130	0.69	0.74	0.76
131-140	0.56	0.63	0.60
141-150	0.49	0.62	0.76
151-160	0.63	0.68	0.62
161-170	0.54	0.61	0.62
171-180	0.47	0.53	0.58
181-190	0.21	0.35	0.34
191-200	0.30	0.37	0.44
201-210	0.33	0.43	0.47
211-220	0.32	0.42	0.50
221-230	0.37	0.45	0.70
231-240	0.31	0.43	0.55
241-250	0.30	0.41	0.54
251-260	0.30	0.44	0.54
261-270	0.29	0.43	0.58
271-280	0.33	0.44	0.52
281-290	0.34	0.39	0.43
291-300	0.28	0.32	0.42
301-310	0.29	0.33	0.50
311-320	0.28	0.38	0.40
321-330	0.31	0.36	0.44
331-340	0.25	0.34	0.41
341-350	0.30	0.37	0.38
351-360	0.32	0.31	0.33
361-370	0.29	0.29	0.32
371-380	0.28	0.29	0.40
381-390	0.27	0.28	0.40
391-400	......	......	......

* Volume of decay expressed as a percentage of the gross volume in board feet to a top diameter equal to 40 per cent of the D.B.H. to the nearest 12-foot log.

When the trees on the dissection plots are considered as a group, some idea of the development of stands can be deduced. Tables 13, 14 and 15 give the average radial growth (at stump height) by ten-year intervals for infected and sound trees on three site II plots. From these tabulated data, the growth histories of the stands on the three plots were traced in Figures 11, 12 and 13. The growth of the trees on other plots was similar. In the following discussion, the first 30 years in the life of a stand are disregarded, because of the continual and rapid readjustments of the saplings to competition during that time.

The dissection-plot data provide evidence that the faster-growing trees in a stand are more subject to infection by *Fomes pini*. For example, based on the condition of the trees at the time of cutting the following data are shown:

- Figure 11 shows that on plot 9 both classes of infected trees were faster growing between about 45 and 65 years of age than were those trees that remained sound.
- Figure 12 shows that on plot 8 the trees that were 51 to 100 per cent decayed were faster growing up to about 85 years of age than were either sound trees or those that were 1 to 50 per cent decayed.
- Figure 13 shows that up to 70 years of age the trees on plot 12 that were 51 to 100 per cent decayed were growing at approximately the same rate as the sound trees, and faster than the trees that were 1 to 50 per cent decayed. The faster growth-rate of these more susceptible trees may or may not be the result of earlier establishment in the stand.

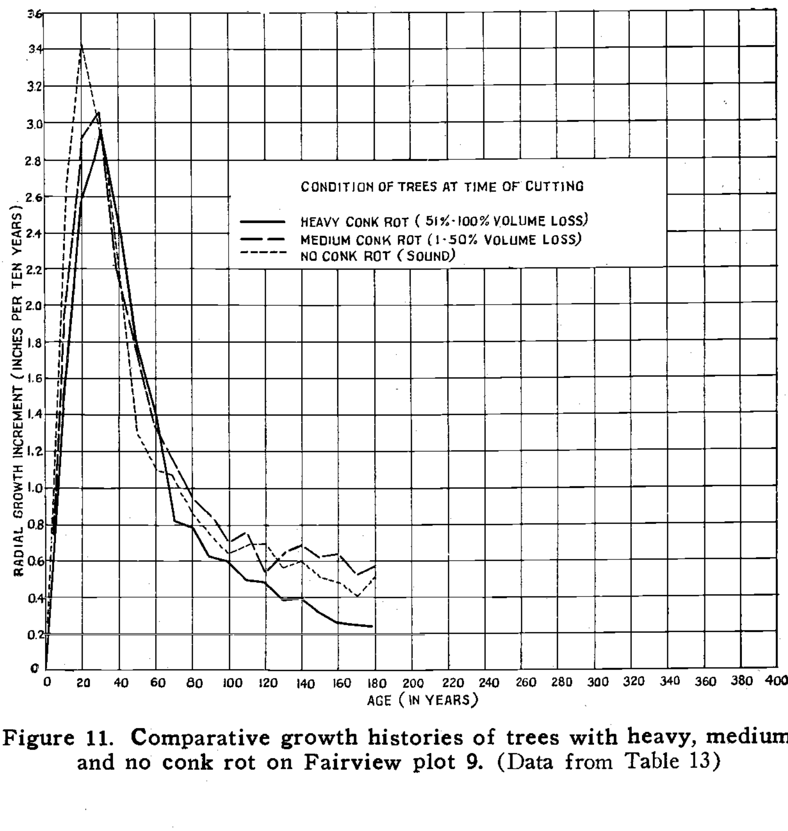


Figure 11. Comparative growth histories of trees with heavy, medium, and no conk rot on Fairview plot 9. (Data from Table 13)

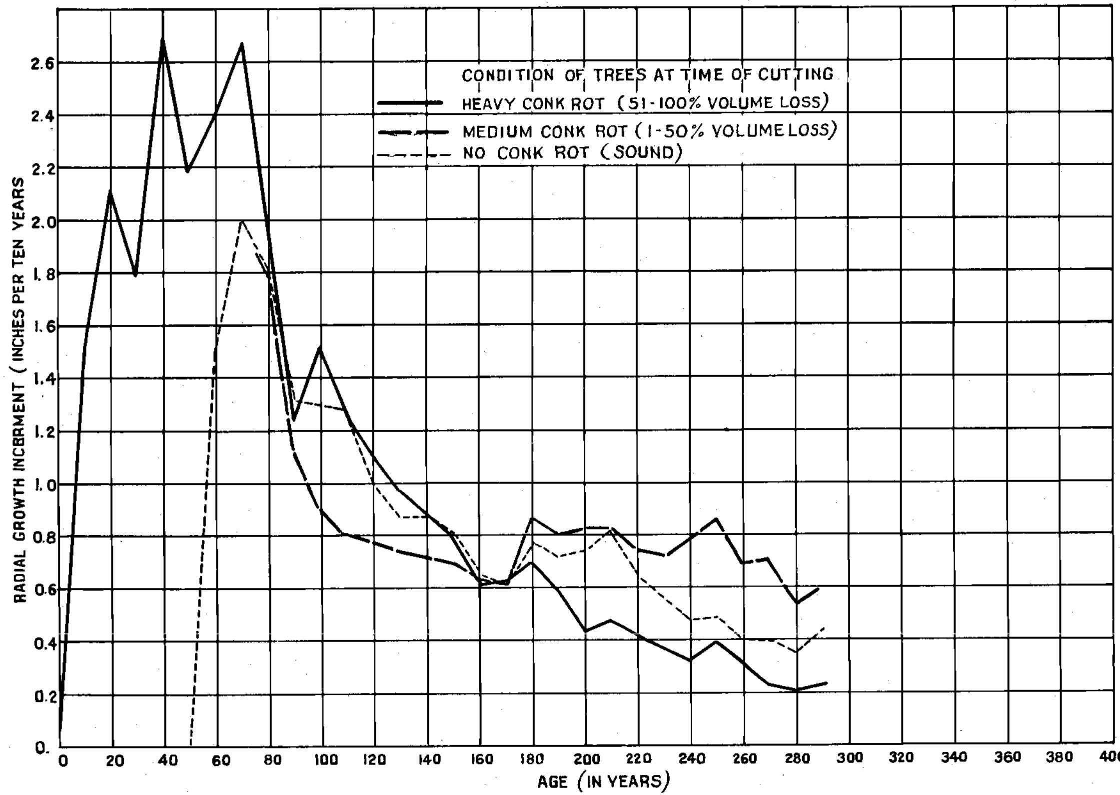


Figure 12. Comparative growth histories of trees with heavy, medium, and no conk rot on Bone Mountain plot 8. (Data from Table 14)

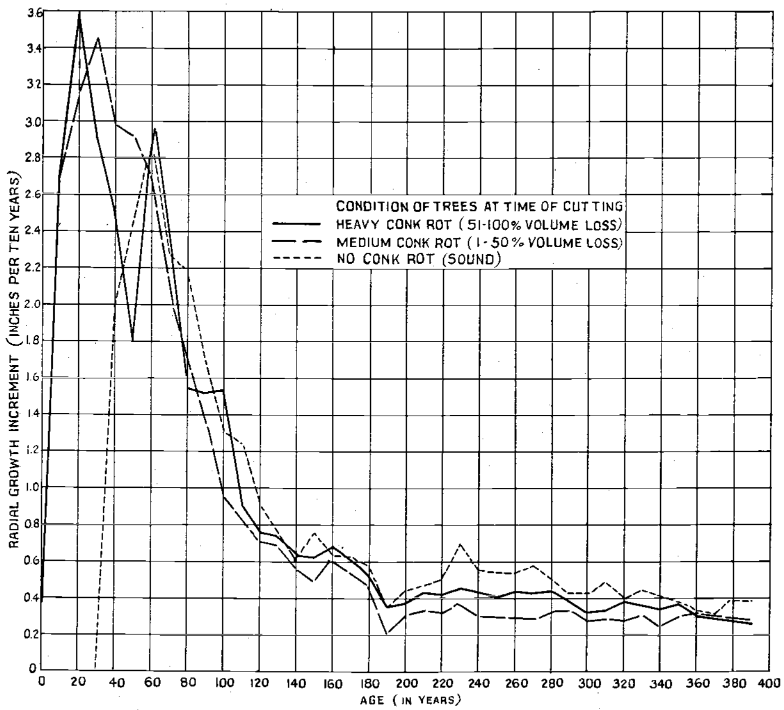


Figure 13. Comparative growth histories of trees with heavy, medium, and no conk rot on Wilson Creek plot 12. (Data from Table 15)

Infection by *Fomes pini* in relation to stand development appears to be cyclical; the periods of low infection correspond to periods of stand development during which the number of trees per acre is reduced through competition. Figure 11 shows that all of the tree groups on plot 9 maintained a somewhat similar growth-rate up to 45 years of age, but this was followed by a relative decrease in the growth-rate of those trees that remained sound. By the time the stand had attained an age of about 70 years, however, there was a change in the relative growth-rates of the tree groups. It appears probable that this change was caused by *Fomes pini* since the trees that showed the greatest decline in growth-rate were those most heavily decayed at the time the stand was cut. There were several dead snags heavily decayed by *Fomes pini* on this plot when the stand was cut at 180 years of age. It appeared probable that the other heavily decayed trees in the stand would have died within the next 20 to 30 years, thus ending what might be termed a cycle of conk rot infection.

The growth history of the stand on plot 8 (Figure 12) indicates a later cycle of conk rot infection. The trees that were 51 to 100 per cent decayed and those that were sound at the time of cutting were growing faster between 100 and 160 years of age than were those 1 to 50 per cent decayed at the time of cutting. During this 100- to 160-year age period, new infections probably were occurring in the faster-growing trees. Meanwhile the badly decayed trees of a first cycle (Figure 11) remained in the stand until about 155 to 170 years of age, as indicated by a period of low and uniform growth of all the trees. These then dropped out in increasing numbers. Between 170 and 180 years of age, the constitution of the stand changed in such a manner that there was an increase in the growth-rate of all trees except the intermediate and suppressed individuals, which were beyond recovery and continued their steady decline. In order to simplify Figure 12, the intermediate and suppressed trees are not plotted but their behavior is illustrated by Table 14. The change in the stand at 180 years of age probably resulted from the death of both some badly decayed trees and some suppressed trees. After the age of 180 years the trees that were 51 to 100 per cent decayed grew much more slowly than either the sound trees or those that were 1 to 50 per cent decayed. At 220 years the sound trees were growing more slowly than those that were 1 to 50 per cent decayed. At 240 years, there was a temporary increase in growth-rate, probably due to the death of some trees. By 280 years the trees from 51 to 100 per cent decayed were growing slowly and probably the majority of them were dying, thus ending the second cycle at around 300 years. Meanwhile, new infections probably were occurring in the faster-growing trees.

Figure 13 illustrates imperfectly the third and fourth cycles. These are largely speculative, because so many trees had died in this old stand before it was cut. The stand approached stagnation at about 300 years of age, by which time some badly infected trees and even a few sound trees had died, allowing some residual trees to make a short spurt of increased growth. At about 300 years, the second cycle had definitely terminated, but meanwhile at between 200 and 280 years faster-growing trees were infected, thus beginning the third cycle. The third cycle was completed at around 400 years, while the fourth cycle had begun somewhat prior to that age. The initiation of the fourth cycle of infection had little relation to the rate of growth of the trees. By that time, the stand had become so open that the trees were not competing vigorously for space.

One other consideration must be added—few trees were able to withstand the effects of *Fomes pini* infection well enough to remain in the stand from one cycle to another.

The following theoretical relationship between Douglas-fir stand-development and *Fomes pini* infection is based largely on the histories of the stands shown in Figures 11, 12, and 13 and discussed in the foregoing paragraphs. Figure 14 graphically presents this theoretical relationship.

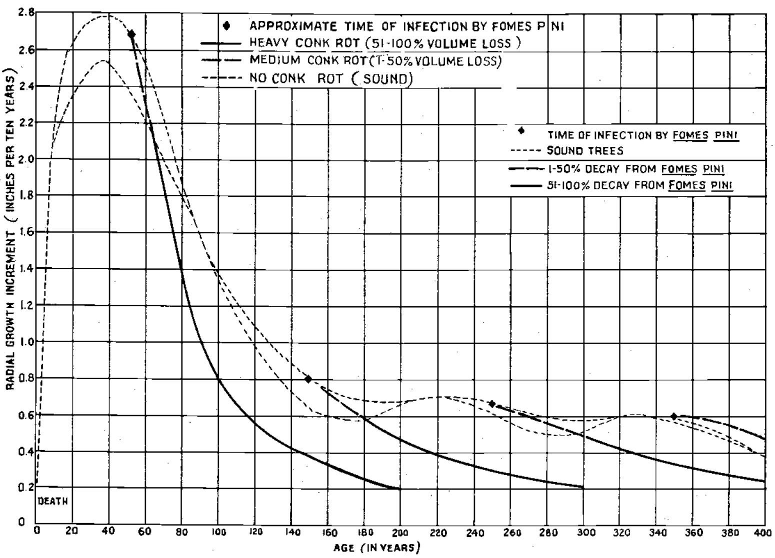


Figure 14. Theoretical cycles of infection of Douglas-fir by *Fomes pini*.

After a stand of Douglas-fir has passed the sapling stage, the trees can be differentiated into various classes based on the relative rates of annual radial growth. The faster-growing trees are more subject to infection by *Fomes pini*, which probably occurs first when the stand is around 50 years of age. Although the fungus has only limited ability to attack sapwood, the attack is severe enough to reduce physiological activity in some trees, which begin to grow at a slower rate than some uninfected trees. Figure 14 is drawn to show that while these initially infected trees are 1 to 50 per cent decayed their growth-rate is greater than that of many sound trees. After a period of years the infected trees become more than 50 per cent decayed. At this time their growth-rate falls below that of most sound trees.

Infected trees continue in the stand for another 150 to 170 years, then die at an age of about 200 years due to the weakening action of the fungus and natural competition with the other trees. The first cycle thus is completed. Observations not yet substantiated by sufficient data indicate that another cycle may end at around 100 years and that there may possibly be one at an even earlier age.

At about 150 years of age, the faster-growing sound trees become infected. Some 40 years later, when this group of infected trees is more than 50 per cent decayed, their rate of growth declines below that of most sound trees. They remain in the stand until about 300 years of age when they succumb to competition, thus completing the second cycle. Meanwhile, when the initially infected trees die out of the stand at about 200 years, the growth-rate of many sound trees increases; and, at about 250 years, the faster-growing sound trees are infected. These trees continue to grow until their death at about 400 or more years. This terminates the third cycle of infection. In the interim, the fourth cycle probably begins at around 350 years. By this time there is little or no competition between trees; the stand is stagnant; and the infection is not related to the growth-rate of the trees. This is the twilight of growth and the starting point of true stand-decadence.

CONK ROT IN STANDS

The information obtained from the 14 dissection-plots made it apparent that a large number of plots in stands of various ages and conditions would be needed to determine the factors affecting the development of conk rot in Douglas-fir. It also was apparent that time and cost precluded the examination of a sufficient number of plots, if felling and dissection were required. Consequently, it was decided to obtain information on the required number of plots by estimating decay in standing timber. The basis for this decision was the conviction that the opportunity of covering a large number of plots would compensate for the inevitable inaccuracies of estimating individual trees.

Experimental procedure

Each temporary plot, termed a cruise plot, was circular with a radius of 58.9 feet, this being equivalent to one-quarter acre. The legal description, aspect, and slope were recorded. The average age was determined from Douglas-fir stumps in the immediately adjacent logged area. The heights of 3 to 5 dominant and codominant trees were measured with an Abney level to determine site class. Notes were made on fire or any other obvious disturbance, on major ground-cover species and on soil characteristics such as moisture, drainage, litter and texture.

For the individual trees on a plot, the data included crown-class and density, diameter at breast height, total number of recoverable 32-foot logs and the grade of each, radial growth at breast height (by 20-year intervals for the past 100 years, based on increment borings from two sound trees and two trees infected with *Fomes pini*), the location by cardinal directions and height of all observed indicators of *Fomes pini* such as sporophores, swollen knots, and punk knots, and deductions for decay caused by *Fomes pini* or other fungi. Deductions for decay caused by *Fomes pini* followed the procedure outlined in the preceding section entitled "Estimating the Extent of Conk Rot."

Series of plots purposely were placed around cut-over areas, about two chains inside the border of the standing timber, in order that the average age of the stand could be determined from stumps in the adjacent area. This distance was flexible, depending on whether or not the stand had been disrupted by a slash fire, by pole cutting, or by some other abnormal occurrence. The distance between plots was five chains, except that where unnatural openings occurred the five-chain interval was increased or decreased in order to obtain a plot with not less than the arbitrarily set, minimum requirement of five trees.

The collection of data for this phase of the study was largely concentrated in an area on the Middle Fork of the Willamette River south of Oakridge, Oregon, in that part of the Willamette National Forest where Pope and Talbot, Inc., was logging at the time. This area has an unusually good representation of all age-classes. The elevation ranges from about 1,500 to nearly 4,500 feet. The average annual rainfall is about 40 inches around Oakridge and increases with elevation to nearly 60 inches. At the time of the study, the area was being logged in staggered settings. About 80 acres of timber were removed in each setting, and all trees 12 inches D.B.H. and larger were cut regardless of condition. The settings were so spaced that about two thirds of the forest was left untouched. The remainder will be cut later in two operations, each operation removing the timber from about one third of the original area. In all, 291 plots were examined on the Middle Fork, of which 198 plots on Willow Creek formed a homogeneous group. Only these latter plots have been used in the analysis of factors that might conceivably be influenced by a too wide geographical distribution of plots.

Additional plots were examined on an operation of the Weyerhaeuser Timber Company along the South Fork of the Molalla River.

Others were examined on an operation of the Long-Bell Lumber Company, both on company lands and on O. and C. lands* located along the headwaters of the Siuslaw River and on O. and C. lands in the vicinity of Mary's Peak within the Siuslaw National Forest.

In all, 459 plots were examined. Their distribution by 20-year age-classes and by site classes is given in Table 16.

Table 16. DISTRIBUTION OF PLOTS BY AGE AND SITE CLASSES.

Age	Number of plots in site class					Total
	V	IV	III	II	I	
Years						
50	....	....	....	3	1	4
70	....	5	7	8	2	22
90	....	3	7	15	4	29
110	....	1	1	5	....	7
130	....	1	2	2	....	5
150	....	1	6	9	2	18
170	....	9	20	26	2	57
190	....	11	16	11	1	39
210	1	4	8	6	5	24
230	....	11	23	12	3	49
250	1	5	9	15	2	32
270	....	8	23	6	....	37
290	....	7	18	7	2	34
310	....	5	10	9	1	25
330	....	....	5	9	1	15
350	....	....	8	5	....	13
370	....	1	6	5	2	14
390	....	2	5	3	....	10
410	....	1	4	3	....	8
430	....	3	7	2	1	13
450	....	....	2	2	....	4
TOTAL	2	78	187	163	29	459

The trees on each plot were divided into two groups, one group composed only of Douglas-fir and the other of associated species. The latter comprised western red cedar (*Thuja plicata* D. Don.), western hemlock (*Tsuga heterophylla* Rafn.) Sarg., grand fir (*Abies grandis* Lind.), sugar pine (*Pinus lambertiana* Dougl.), western white pine (*P. monticola* Dougl.), ponderosa pine (*P. ponderosa* Dougl.), and incense cedar (*Libocedrus decurrens* Torr.). These were found in various combinations depending on the locality. The plots, however, were mostly in stands classed as pure Douglas-fir. The gross volume, expressed as board feet of Douglas-fir for each plot, was determined from volume tables (Girard and Bruce) based on the Scribner Decimal C log rule which was converted to Scribner scale. The decay volume, which included only the board-foot volume loss caused by *Fomes pini* in Douglas-fir, was calculated for each plot. Both the gross volume and decay volume then were converted to a volume-per-acre basis.

* Revested Oregon and California railroad grant lands.

To determine by statistical methods the factors that are related to conk rot, it was necessary to establish a simple, accurate, and workable basis for correlation. The ratio between the number of infected Douglas-fir trees and the total number of Douglas-fir trees on a plot was used as the basis for analysis. The trees on a plot can be counted readily and those with evidence of conk rot are detected easily. In contrast, if volume is used, it is necessary not only to determine the number of infected trees, but also to estimate the amount of decay in each tree. The possibility of error is increased by the estimate both of gross volume and decay volume.

The chi square test (15) was used to determine the significance of an individual factor on infection by *Fomes pini*. The data in all tables that include total number of trees, number of trees infected, and percentage of trees infected have been tested by this method. The data were insufficient for determining the interaction of the different factors on conk rot by means of multiple correlation analysis. Even if the data had been sufficient, it is questionable whether the results obtained by this method of analysis would be of more than academic interest.

Growth, yield, and conk rot

Existing yield-tables for Douglas-fir are based on fully stocked stands (11). Actually, stands are normally understocked, fully stocked stands being decidedly in the minority according to Meyer (12). Although Meyer's conclusion was based on young-growth, it seems logical that the same situation is true for old-growth. Since existing yield tables cover only the first 160 years of growth, definite information on the behavior of old-growth was lacking before this current investigation was undertaken. The yield data that appear in subsequent tables and figures are based on plots located at fixed intervals along compass lines that followed the boundaries of cut-over areas, not on plots selected because they were fully stocked. Presumably, the majority of the stands represented by the plots were understocked, but it is impossible to state the degree of understocking because no yield study based on fully stocked stands has been made in old-growth Douglas-fir. Table 17 cites the number of trees per acre for Douglas-fir and for the associated species by 20-year age-classes; Figure 15 presents the data graphically for sites II and III.

The data show that in old-growth stands the number of Douglas-fir trees per acre decreases with increasing stand age and also decreases on better sites. The same trend occurs in young growth. Pure stands of Douglas-fir are characteristic of young growth, but Figure 15 shows the increase in the number of the associated species at the

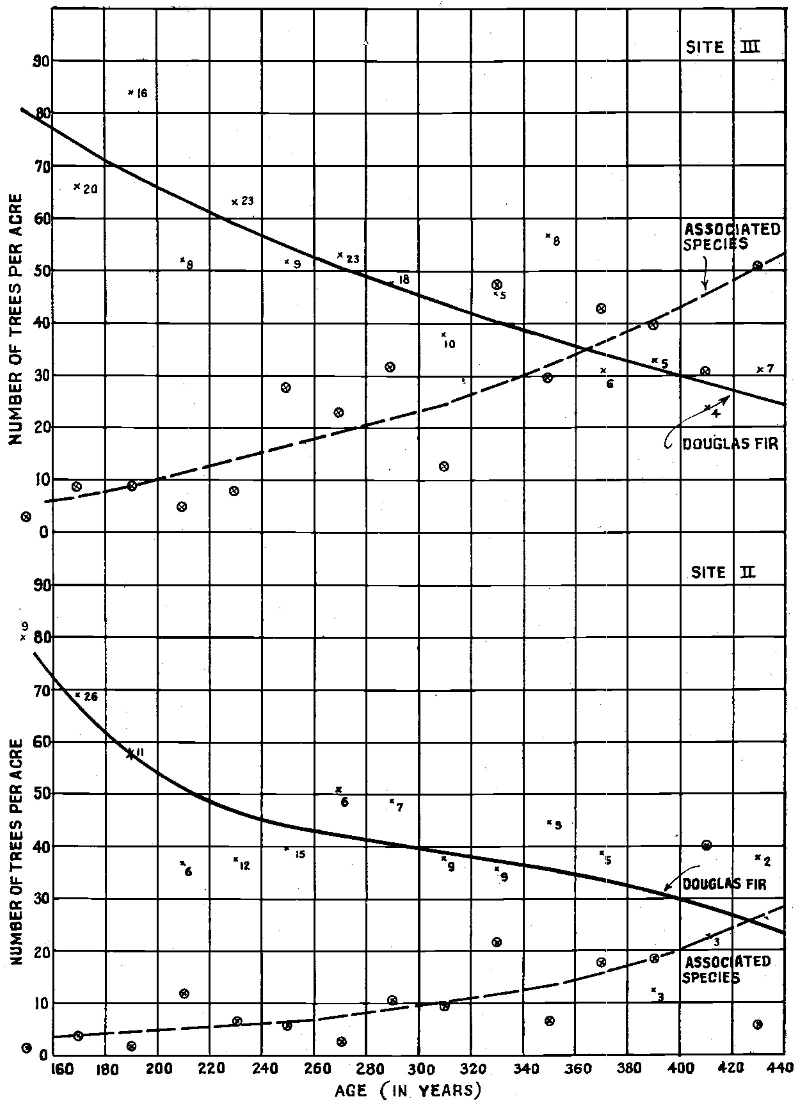


Figure 15. Relationship of age to number of trees, 12 inches D.B.H. and greater, per acre on sites II and III.

Table 17. STAND COMPOSITION BY SITES AND AGE CLASSES (Number of trees 12 inches D.B.H. and larger per acre).

Age	Site IV		Site III		Site II	
	Douglas-fir	Other species	Douglas-fir	Other species	Douglas-fir	Other species
Years						
170	71	10	66	9	69	4
190	87	21	84	9	58	2
210	57	12	52	5	37	12
230	73	19	63	8	38	7
250	62	26	52	28	40	6
270	59	35	53	23	51	3
290	50	44	48	32	49	11
310	55	20	38	13	38	10
330	....	....	46	47	36	22
350	....	....	57	30	45	7
370	32	56	31	43	39	18
390	46	52	33	40	13	19
410	16	28	24	31	23	40
430	29	48	31	51	38	6
450	....	....	24	40	26	18

expense of Douglas-fir in old-growth stands until, at about 365 years on site III and at about 425 years on site II, other species equal Douglas-fir in number and from then on surpass it. Old-growth stands should be cut before this age is reached. Other species increase in old-growth stands because Douglas-fir cannot compete with the more shade-enduring species. When trees die, there are few young Douglas-firs in the understory to replace them; the vacant places are taken by western hemlock, western red cedar, grand fir and several others.

The timber crop of an area is the result of a combination of many natural factors that induce or otherwise influence timber growth. Not all of these factors are favorable, but nevertheless they have an integral part in stand development. Fungi that destroy the heartwood of living trees occur naturally in all forests, reducing yield to a greater or lesser degree. It will never be possible, even under intensive management, to rid forests completely of such fungi. Nor would such be desirable, because some of the fungi that decay heartwood of living trees also perform the useful function of decomposing larger slash. Enough should be known about their relationship to the stand that the large losses now caused by certain of them can be reduced to a tolerable amount in managed forests of the future.

Investigations of decay in Douglas-fir and in other species have shown invariably that the amount of decay increases with stand age (4, page 362). Furthermore, the increase in decay was more or less regular in successive age-classes. Whether the increase is slow or rapid depends on species and stand age. This seemed to be true when conk rot in Douglas-fir was previously investigated although the volume of data available was meager (3, page 36). The volume of data gathered during the present investigation is far greater than has been available previously on decay in any species. Indications that conk rot was cyclical were revealed by analyzing the dissection studies (Figures 11, 12, 13); proof of this relationship was provided by measuring a large number of plots of different stand-ages.

Table 18 brings out the relationship between age, site, and the percentage of Douglas-firs infected with conk rot. The curves in Figures 16 and 17 were drawn from these data. There is no curve, however, for site IV because of insufficient data.

Figure 16 clearly shows the cyclical behavior of conk rot. Chi square tests applied to the data indicate that the high points at 200 and 320 years of age are significantly different from the low points at 120, 250 and 350 years. There is also some evidence of a high point at approximately 90 years, but the difference between this point and the low point at 120 years is not significant. Beyond 360 years the trend is not clear. On this site, it probably would continue to rise to a new high and then drop steadily as the stand breaks up with Douglas-fir being replaced by other species. It also is apparent that with increasing stand age the number of trees with both low and high percentages of decay increases, causing a general upward trend in the proportion of infected trees. This trend would probably continue until the final decline of Douglas-fir in the stand.

Although cyclical development of a fungus which decays the heartwood of living trees heretofore has neither been demonstrated nor suspected, there is nothing extraordinary about such a development since it commonly occurs among other groups of fungi. Usually, cyclic behavior is controlled by weather conditions and the cycles develop during a single season or during the course of a few years. With conk rot, the cycles require a number of years for completion. The factors controlling cycles of conk rot are not obvious, because nothing is known about the conditions governing inoculation and subsequent growth of *Fomes pini* in the heartwood of Douglas-fir except that entrance is effected through dead branches.

The same cyclical trend occurs on site II, as can be seen in Figure 17. The cycles of infection, however, occur earlier on site II than on site III. For example, on site II a high point is reached at 170 years of age when conk rot occurs in 22 per cent of the Douglas-firs, but the corresponding high on site III is not attained until 195 years when 23 per cent of the trees are infected. Similarly, the high point on site II which occurs at 270 years, when 38 per cent of the Douglas-firs are infected, corresponds to the high on site III of

Table 18. Total Number of Douglas-fir Trees and the Number Infected with Conk Rot on 428 One-quarter-acre Plots by Stand Age and Site Classes (trees 12 inches D.B.H. and larger).

Age	Site IV			Site III			Site II		
	Total	Decayed trees		Total	Decayed trees		Total	Decayed trees	
1	2	3	4	5	6	7	8	9	10
Years			*Per cent*			*Per cent*			*Per cent*
50	......	......	......	......	......	......	60	0	0.0
70	114	8	7.0	115	6	5.2	138	0	0.0
90	52	1	1.9	162	12	7.4	270	8	3.0
110	21	0	0.0	31	0	0.0	80	3	3.8
130	22	2	9.1	60	2	3.3	32	4	12.5
150	23	0	0.0	100	23	23.0	181	35	18.8
170	159	23	14.5	331	62	18.7	412	91	22.1
190	214	25	11.7	325	67	20.6	158	19	12.0
210	57	10	17.5	103	25	24.3	55	15	27.3
230	181	23	12.7	330	42	12.7	106	34	32.1
250	56	5	8.9	109	9	8.3	150	54	36.0
270	117	10	8.6	306	51	16.7	77	35	45.4
290	92	15	16.3	214	38	17.8	86	22	25.6
310	62	8	12.9	94	33	35.1	85	35	41.2
330	......	......	......	62	24	38.7	80	43	53.8
350	......	......	......	109	20	18.3	56	28	50.0
370	8	0	0.0	46	10	21.7	49	17	34.6
390	23	5	21.7	41	10	24.4	10	2	20.0
410	4	2	50.0	24	10	41.7	17	3	17.6
430	22	5	22.7	55	8	14.5	19	11	57.9
450	......	......	......	12	2	16.7	13	4	30.8
All ages	1,227	142	11.6	2,629	454	17.3	2,134	463	21.7

Table 19. Gross Volume and Conk-rot Volume per Acre by Stand Age and Site Classes (in board feet, Scribner scale, for Douglas-fir trees 12 inches D.B.H. and larger).

Age	Site IV			Site III			Site II		
	Gross Volume	Conk rot		Gross Volume	Conk rot		Gross Volume	Conk rot	
		Volume	Percentage of gross volume		Volume	Percentage of gross volume		Volume	Percentage of gross volume
1	2	3	4	5	6	7	8	9	10
Years	*Board feet*	*Board feet*	*Per cent*	*Board feet*	*Board feet*	*Per cent*	*Board feet*	*Board feet*	*Per cent*
170	49,931	5,057	10.1	79,949	9,336	11.7	117,013	18,826	16.1
190	55,406	7,191	13.0	90,700	13,529	14.9	110,436	13,760	12.5
210	55,420	8,255	14.9	63,330	16,648	26.3	122,646	25,818	21.0
230	69,838	8,222	11.8	105,061	12,071	11.5	130,893	27,739	21.2
250	86,707	4,822	5.6	86,886	5,540	6.4	138,953	39,533	28.5
270	75,020	6,507	8.7	94,518	17,671	18.7	154,140	37,964	24.6
290	68,874	5,984	8.7	105,173	15,458	14.7	130,971	27,074	20.7
310	69,640	6,945	10.0	99,180	27,022	27.2	142,910	40,275	28.2
330	......	......	......	125,784	43.767	34.8	159,546	55,015	34.5
350	......	......	......	115,225	17,700	15.4	193,288	73,729	38.1
370	88,720	0	0	84,047	18,022	21.4	179,720	48,206	26.8
390	93,840	17,186	18.3	98,788	17,338	17.6	76,560	16,959	22.2
410	46,560	17,108	36.7	106,152	40,706	38.4	114,627	9,361	8.1
430	74,360	18,847	25.3	93,050	15,525	16.7	150,960	81,116	53.7
450	......	......	......	73,768	14,388	19.5	154,794	16,814	10.9

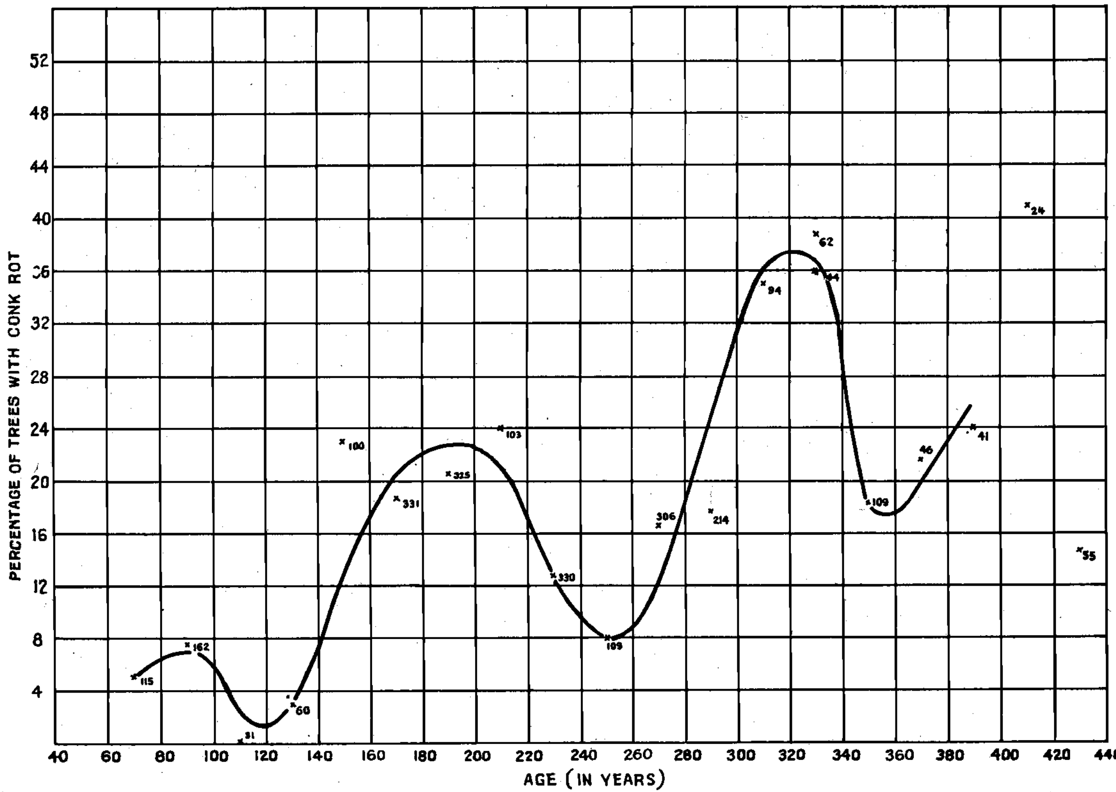


Figure 16. Percentage of Douglas-fir trees with conk rot in relation to stand age on site III, trees 12 inches D.B.H. and larger. (Data from Table 18)

about 37 per cent at 325 years. Finally, the high point on site II of about 54 per cent at 335 years probably would correspond to a high on site III at nearly 450 years if sufficient data had been obtained to complete this portion of the curve.

Although the percentage of trees infected with *Fomes pini* may serve to indicate the general condition of the stand, it also is important to know the actual volume lost because of conk rot. Presumably, but not necessarily, the volume lost through conk rot should follow the same pattern as the number of decayed trees. Table 19 shows the relationship between the percentage of gross volume decayed by *Fomes pini* and the stand age for sites II, III, and IV. These percentages were plotted against stand age for sites II and III and smooth curves drawn (Figures 18 and 19). The data for site IV were insufficient for a satisfactory curve.

The curves show a cyclical change in the percentage of the gross volume infected with conk rot in relation to stand age, paralleling the cycles shown by the percentage of infected trees in Figures 16 and 17. For site III, the proportion of conk rot based on volume is low at 250 and 360 years of stand age and high at 210 and 325 years (Figure 18). Probably there would be a low at about 120 years and a high at about 450 years. The volume of conk rot is approximately 6 per cent at 250 years and increases to slightly over 30 per cent at 325 years. This amounts to an increase of slightly over 24 per cent in 75 years or 0.32 per cent yearly, which is the greatest and most rapid increase of a cycle on site III. On site II the lows are at 190, 290, and 390 years and the highs at 250 and 345 years. The volume of rot increases from 12 per cent at 190 years to 28 per cent at 250 years, and from 20 per cent at 285 years to 36 per cent at 345 years, amounting to 16 per cent in each cycle or 0.27 per cent yearly. In a previous investigation, it was shown that on site II with an average volume of rot, the most rapid increase in decay amounted annually to 0.29 per cent of the gross volume during the period between 400 and 450 years (3, page 39). This figure included all decay, not just conk rot.

The change in the percentage of decay is cyclical because the weakening action of *Fomes pini* and the competitive action of associated trees cause the death of many infected trees, thus affording release to the remainder. This has a twofold influence on the volume of decayed wood in the stand. The decay volume is reduced by death of the infected trees, and at the same time, the rate of growth of sound trees increases. For example, in stands on site III such a development occurs between 210 and 250 years, and again between 325 and 360 years.

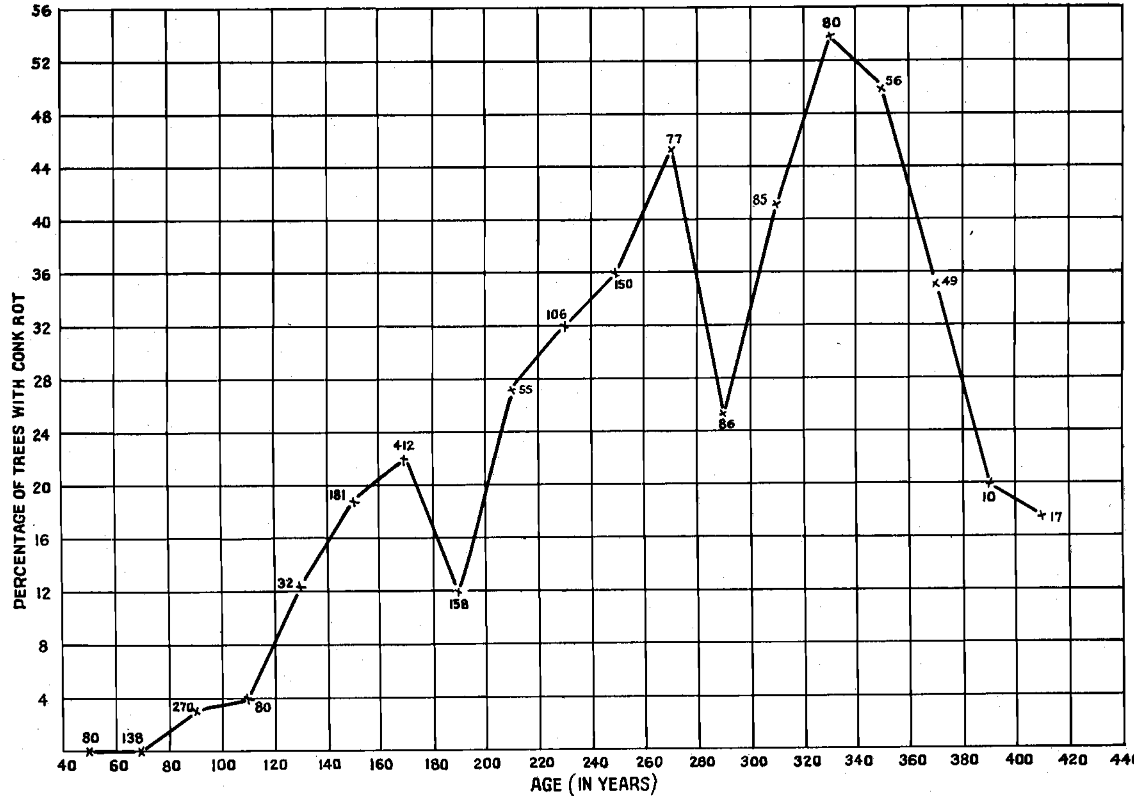


Figure 17. Percentage of Douglas-fir trees with conk rot in relation to stand age on site II, trees 12 inches D.B.H. and larger. (Data from Table 18)

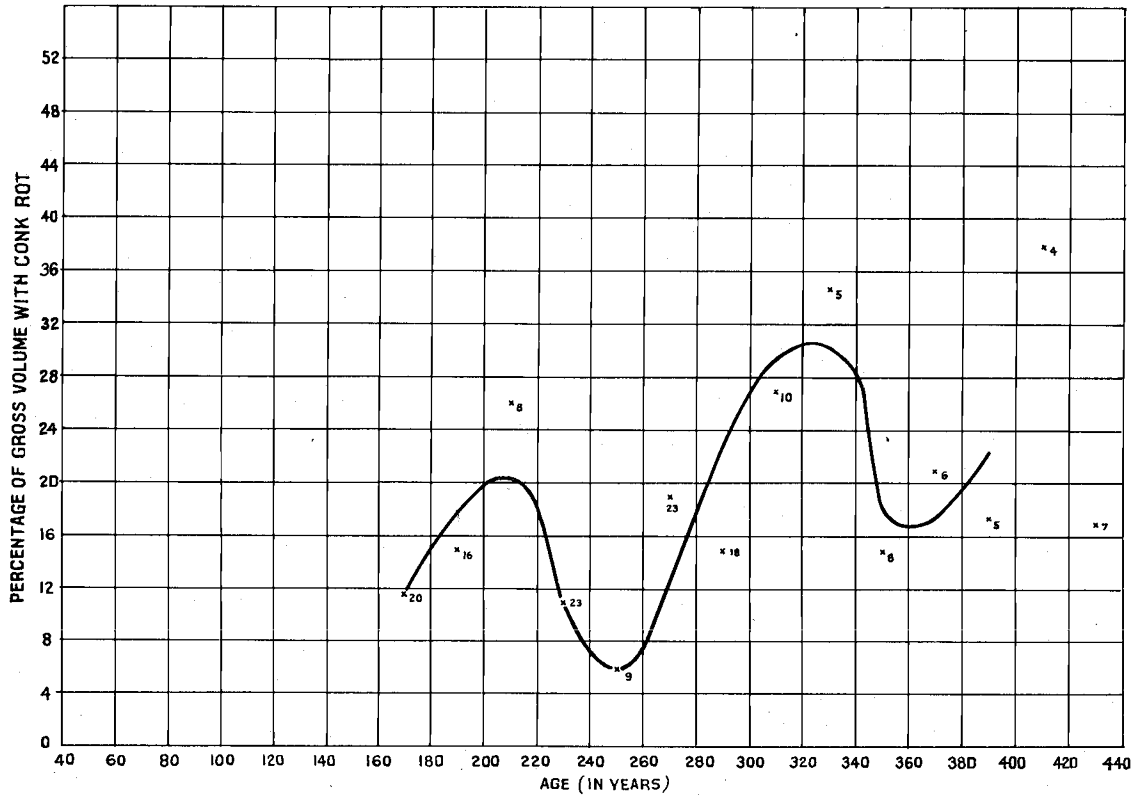


Figure 18. Conk-rot volume as a percentage of gross volume per acre in relation to stand age on site III, volume of Douglas-fir trees 12 inches D.B.H. and larger. (Data from Table 19)

The gross volumes per acre in relation to stand age as compiled in Table 19 are plotted in Figures 20 and 21. In young growth, because of the rapid growth-increment, the cyclical development of conk rot probably would not be reflected in gross volume, since the lost volume of infected trees would be more than offset by the increased growth-rate of the remaining stand. In old growth, on the other hand, the gross volume of the stand might be expected to follow a cyclical pattern, increasing relatively rapidly while the decay volume is decreasing but increasing slowly or even decreasing when the decay volume is increasing. Although the plotted points in Figures 20 and 21 give an indication of such cycles, the data are inadequate to demonstrate cycles. It has been necessary, therefore, to draw the usual orthodox smooth curves for gross volume in relation to age. These curves show that the gross volume rises steadily with age, but at a decreasing rate until a maximum is attained, and then falls off. The decline reflects the breaking-up of the stand when Douglas-fir is being replaced by other species.

From these curves were read the gross volumes in columns 3 and 7 of Table 20. The percentages of conk rot shown in columns 2 and 6 were read from Figures 18 and 19. The volumes of conk rot in columns 4 and 8 were calculated by multiplying the gross volumes in columns 3 and 7 by the percentages of conk rot in columns 2 and 6. The sound volumes then were obtained by subtraction. The

Table 20. GROSS VOLUME, CONK-ROT VOLUME AND SOUND VOLUME PER ACRE IN RELATION TO STAND AGE ON SITES II AND III (Volumes of Douglas-fir 12 inches D.B.H. and larger).

Age	Site III				Site II			
	Conk rot percentage of gross volume[1]	Volume			Conk rot percentage of gross volume[3]	Volume		
		Gross[2]	Conk rot	Sound		Gross[4]	Conk rot	Sound
1	2	3	4	5	6	7	8	9
Years	*Per cent*	*M board feet*	*M board feet*	*M board feet*	*Per cent*	*M board feet*	*M board feet*	*M board feet*
170	12	75	9	66	16	113	18	95
190	18	83	15	68	12	119	14	105
210	20	88	18	70	16	126	20	106
230	11	93	10	83	24	132	32	100
250	6	97	6	91	28	136	38	98
270	13	100	13	87	24	142	34	108
290	23	102	23	79	21	146	31	115
310	29	103	30	73	28	149	42	107
330	30	104	31	73	34	153	52	101
350	18	105	19	86	35	154	54	100
370	18	104	19	85	28	156	44	112
390	22	103	23	80	22	155	34	121
410	....	102	....	....	25	154	39	115
430	....	....	....	....	30	153	46	107

[1] From Figure 18. [2] From Figure 20. [3] From Figure 19. [4] From Figure 21.

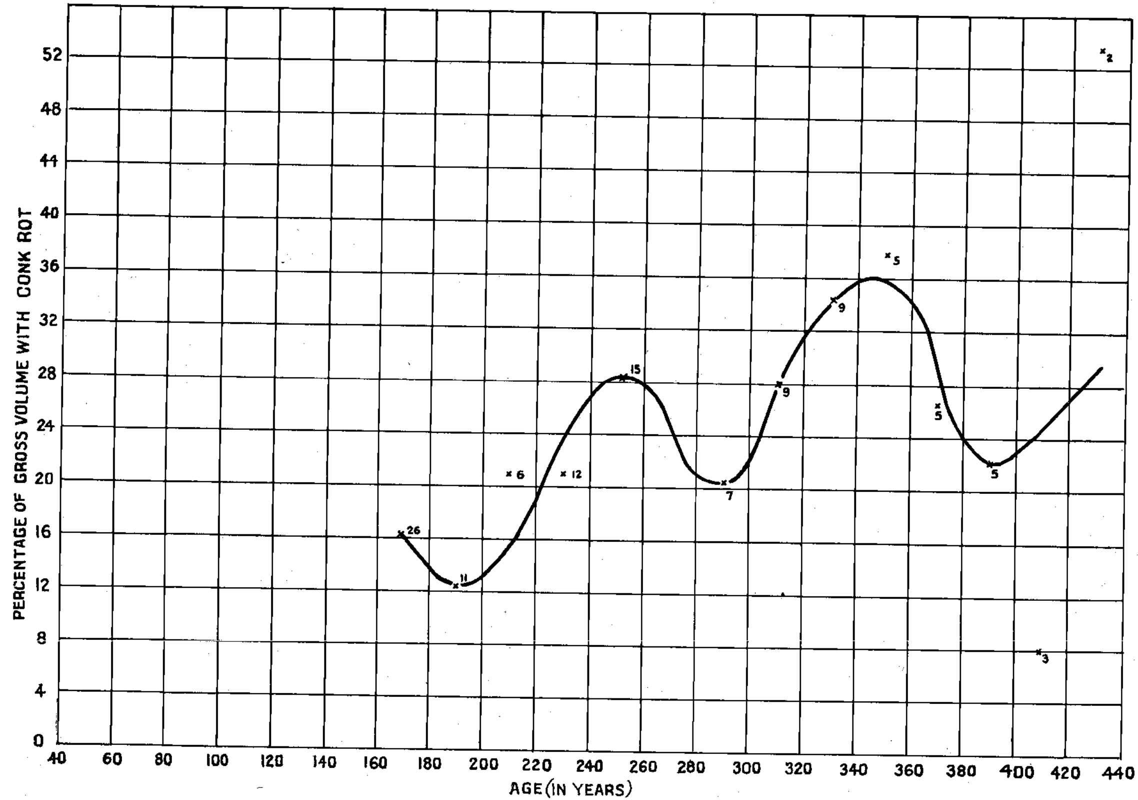


Figure 19. Conk-rot volume as a percentage of gross volume per acre in relation to stand age on site II, volume of Douglas-fir trees 12 inches D.B.H. and larger. (Data from Table 19)

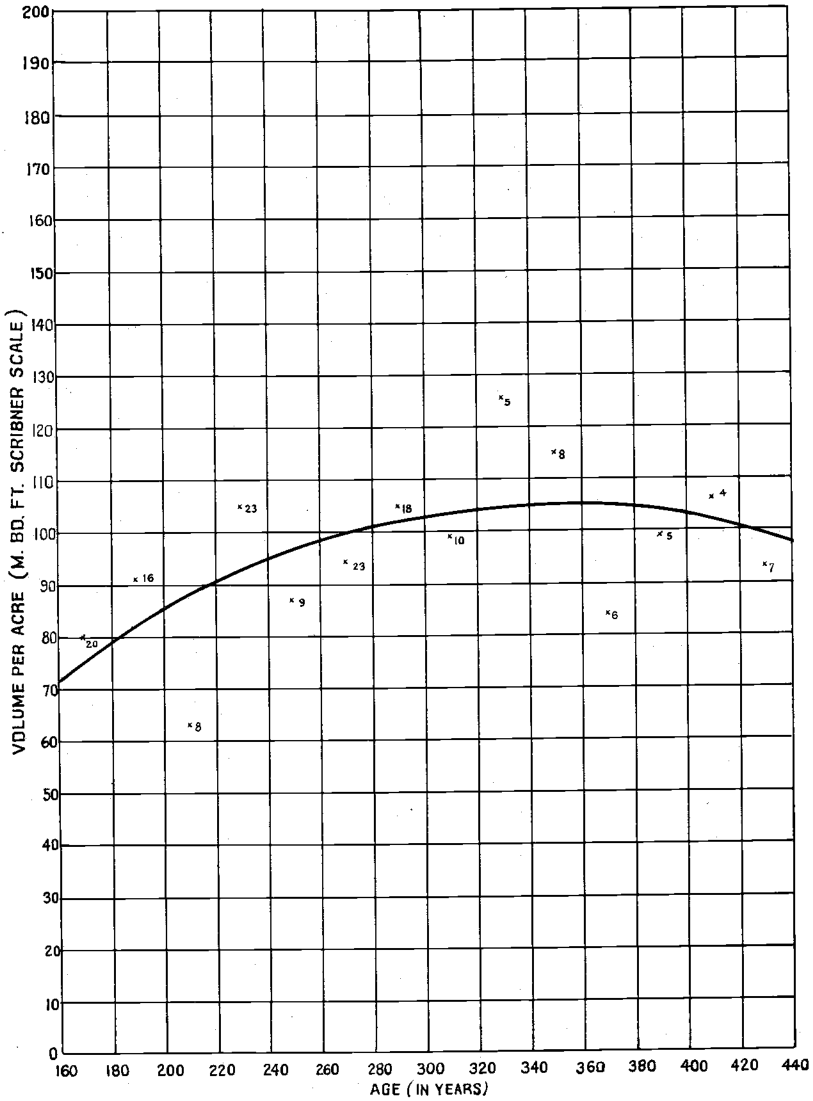


Figure 20. Gross volume of Douglas-fir per acre in relation to stand age on site III, trees 12 inches D.B.H. and larger. (Data from Table 19)

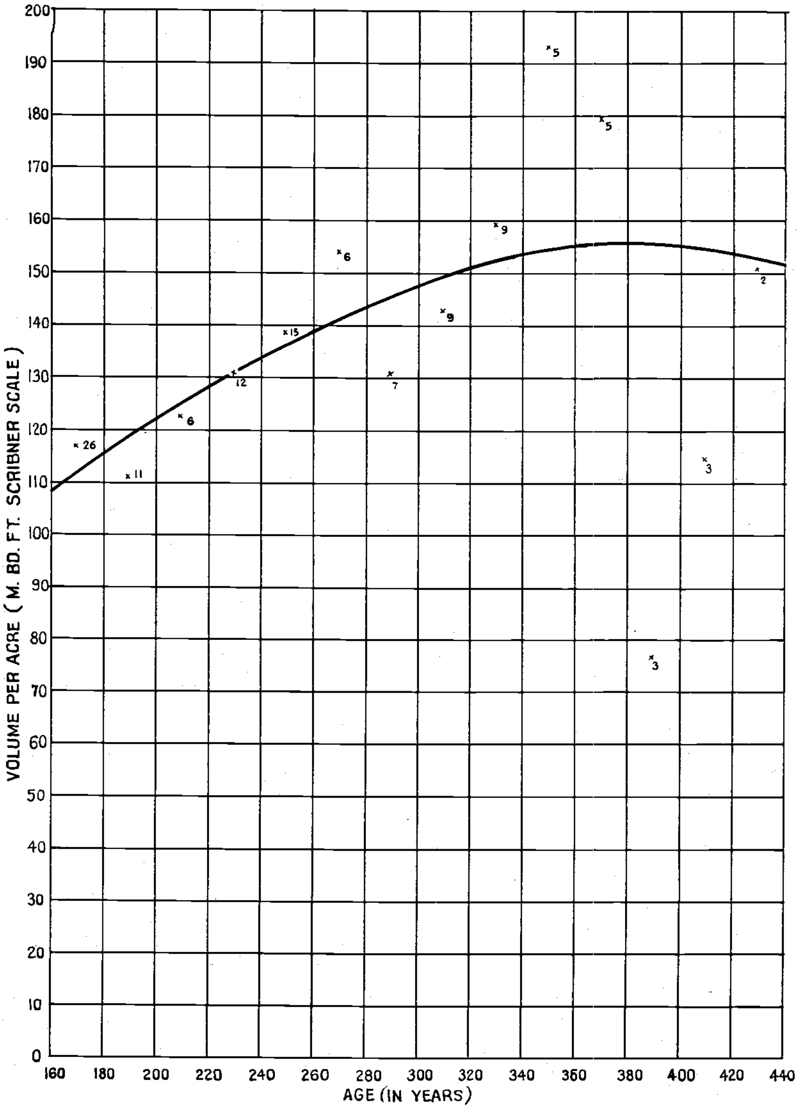


Figure 21. Gross volume of Douglas-fir per acre in relation to stand age on site II, trees 12 inches D.B.H. and larger. (Data from Table 19)

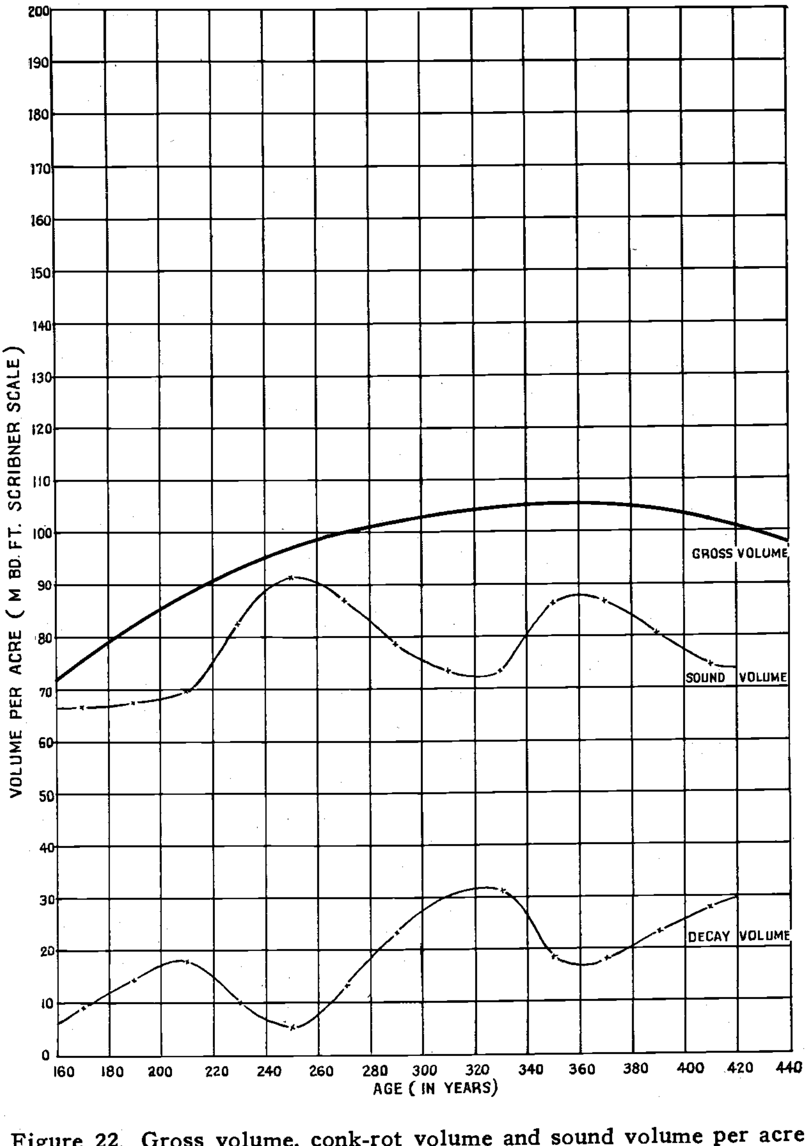


Figure 22. Gross volume, conk-rot volume and sound volume per acre in relation to stand age on site III, volumes of Douglas-fir only, 12 inches D.B.H. and larger. (Data from Table 20)

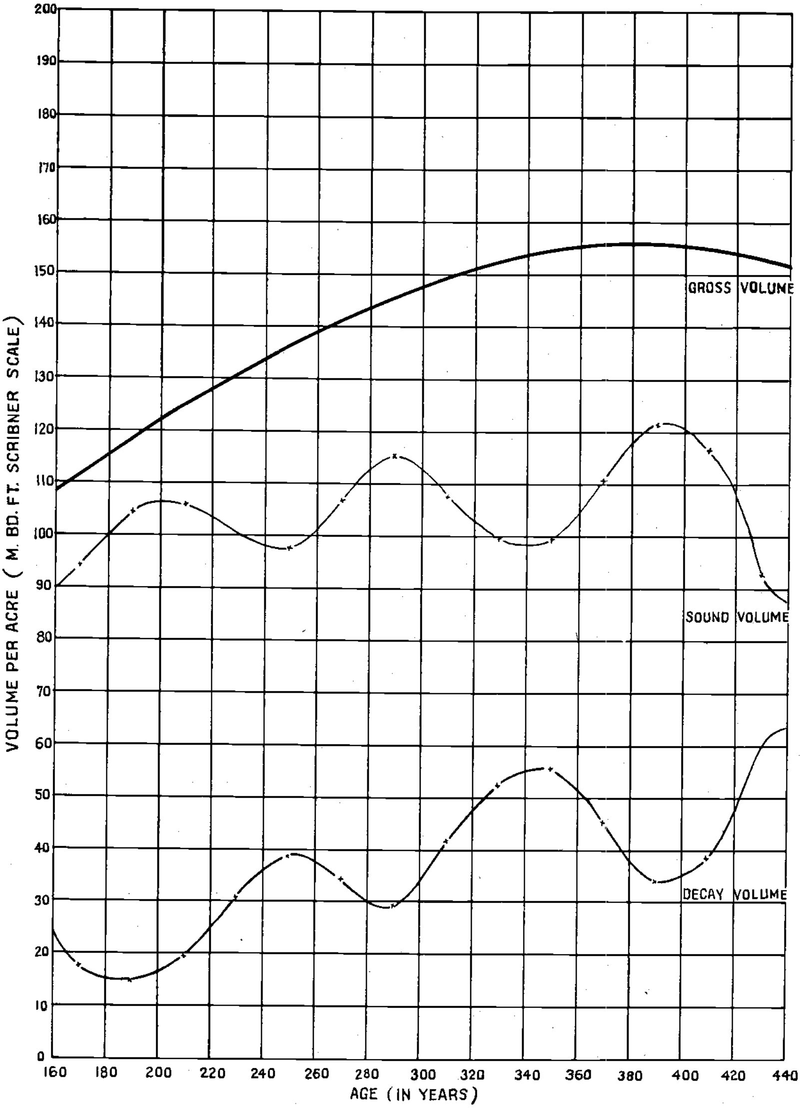


Figure 23. Gross volume, conk-rot volume, and sound volume per acre in relation to stand age on site II, volumes of Douglas-fir only, 12 inches D.B.H. and larger. (Data from Table 20)

curves in Figures 22 and 23, based on data read directly from Table 20, demonstrate the relationship between gross volume, sound volume, and conk-rot volume.

From the foregoing data on the number of trees with conk rot and the volume lost through this infection, it is apparent that, in order to reduce losses in the future, stands must be cut before they reach the age at which decay becomes consequential. It is evident also that, for old-growth stands in which decay is already serious because of the cyclical development of conk rot, the age at which a stand is cut will have a profound effect on the sound volume recovered. In order to obtain greater sound volume, it may be necessary to postpone cutting an old-growth stand for some years. On site III, as can be seen from column 5 of Table 20, the best ages at which to cut old-growth Douglas-fir stands such as represented in this investigation are about 250 and 350 years. Since the volume of conk rot per acre follows so closely the number of infected trees, the age of 120 years is also a favorable time for cutting such a stand, as shown by Figure 16. Again, Table 20, column 9, shows that on site II the most advantageous ages at which to cut such old-growth stands for maximum sound-volume production are about 210, 290, and 390 years.

Diameter and conk rot

Diameter at breast height is a function of age, although in uneven-aged stands (particularly if mixed) the relationship may be obscure. In even-aged stands comprising a single species such as Douglas-fir the relationship is close. As stands increase in age, the trees increase in diameter. Even so, diameter is must less desirable than age as a basis for formulating cutting plans in old-growth.

Table 21 gives both the total number of trees and the number with conk rot, arranged by two-inch diameter-classes, for sites II, III and IV. The percentage of decayed trees is highest on site II and lowest on site IV. On all sites, the percentage of infected trees increases as the diameter increases. This is shown also by Figure 24, where the combined data for the three sites are graphed.

Figures 25 and 26, which are plotted from data in Table 21, show the inverse relationship between the number of trees per acre and the average diameter of the trees in a stand. For some purposes it may be desirable to know the approximate number of sound and of decayed trees in each two-inch diameter-class for various periods in the life of a stand. Consequently, this information is given in Tables 22 and 23 for sites II and III covering the ages of 161 to 460 years.

Table 21. Total Number of Douglas-fir Trees per Acre and Number with Conk Rot by Diameter and Site Classes (trees 12 inches D.B.H. and larger).

D.B.H. class	Site IV				Site III				Site II			
	Number of plots (basis)	Trees per acre	Trees with conk rot		Number of plots (basis)	Trees per acre	Trees with conk rot		Number of plots (basis)	Trees per acre	Trees with conk rot	
1	2	3	4	5	6	7	8	9	10	11	12	13
Inches				*Per cent*				*Per cent*				*Per cent*
14	4	99	2	2.0	2	108	8	7.4	1	190	0	0.0
16	4	125	9	7.2	5	120	2	1.7	4	182	0	0.0
18	2	86	0	0.0	6	121	10	8.3	2	108	0	0.0
20	1	105	10	9.5	4	121	6	5.0	7	93	1	1.1
22	11	95	11	11.6	6	97	11	11.3	5	81	5	6.2
24	12	67	5	7.5	11	78	9	11.5	8	93	6	6.4
26	12	70	10	14.3	13	72	9	12.5	17	79	8	10.1
28	8	54	11	20.4	23	68	11	16.2	11	61	10	16.4
30	7	56	7	12.5	16	59	10	17.0	6	62	18	29.0
32	5	60	8	13.3	23	49	10	20.4	11	60	15	25.0
34	4	45	6	13.3	23	55	13	23.6	10	59	19	32.2
36	4	42	12	28.6	16	41	10	24.4	15	44	12	27.3
38	2	44	12	27.3	9	40	13	32.5	13	42	14	33.3
40	....	....	....	....	5	34	6	17.6	10	40	17	42.5
42	1	32	0	0.0	8	33	11	33.3	9	36	12	33.3
44	2	14	4	28.6	6	29	5	17.2	8	34	13	38.2
46	....	....	....	....	4	29	9	31.0	5	32	16	50.0
48	....	....	....	....	3	23	11	47.8	6	32	13	40.6
50	....	....	....	....	....	....	....	....	8	29	15	51.7

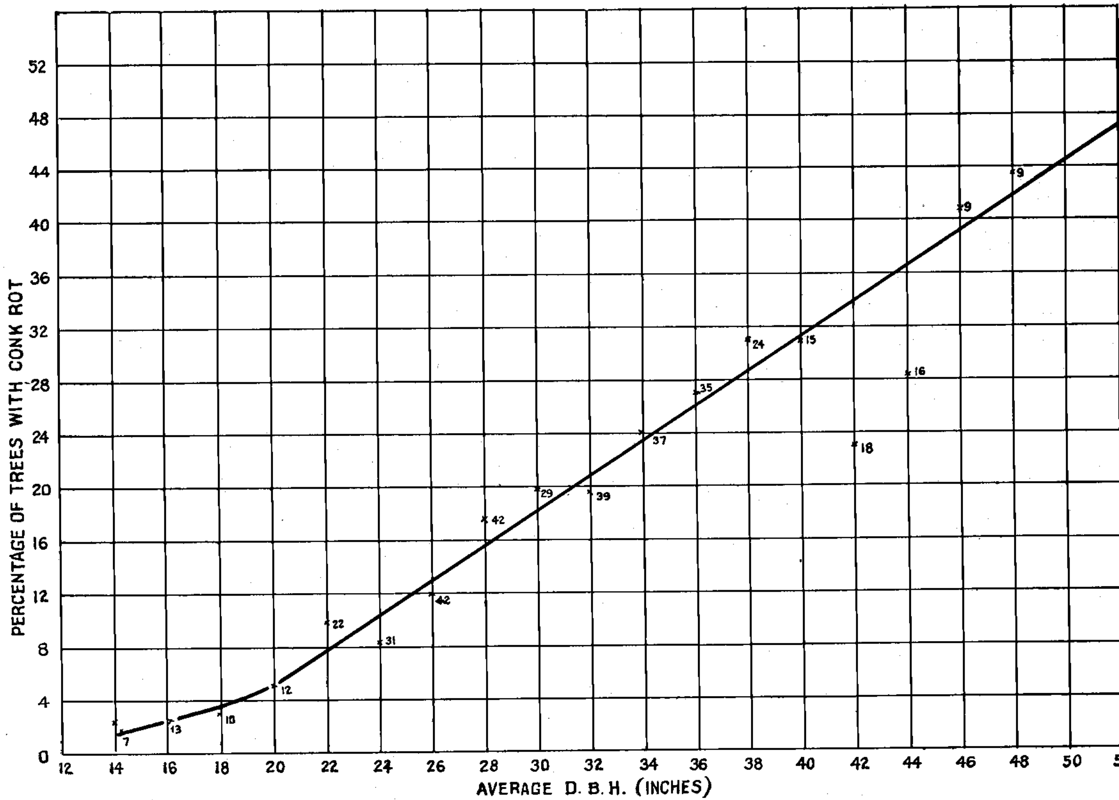


Figure 24. Incidence of conk rot in relation to average stand-diameter on sites II, III and IV combined, Douglas-fir trees 12 inches D.B.H. and larger. (Data derived from Table 21)

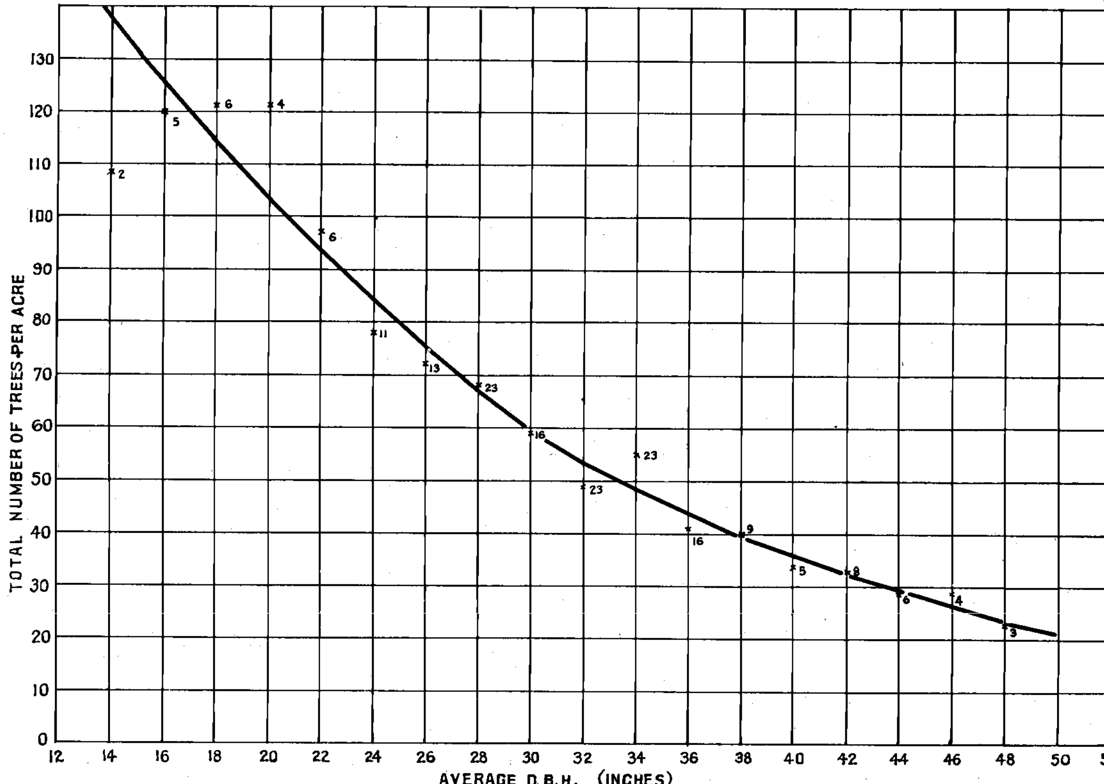


Figure 25. Stand density in relation to average stand-diameter on site III, Douglas-fir trees only, 12 inches D.B.H. and larger. (Data from Table 21)

Table 22. Stand Table for Douglas-fir Showing Number of Trees per Acre and Number Infected with Conk Rot on Site III* (trees 12 inches D.B.H. and larger).

D.B.H. class	161-180		181-200		201-220		221-240		241-260		261-280		281-300	
	Total	Infected	Total	Infected	Total	Infected	Total	Infected	Total	Infected	Total	Infected	Total	Infected
Inches														
12	1	----	2	1	1	----	----	----	----	----	----	----	----	----
14	2	----	2	----	2	----	1	----	1	----	----	----	1	----
16	5	1	3	----	5	----	1	----	1	----	2	----	1	----
18	6	----	5	----	5	----	2	----	2	----	1	----	1	----
20	4	1	6	1	4	1	3	----	4	----	1	----	1	1
22	2	----	6	1	2	----	2	----	2	----	3	----	2	----
24	6	1	5	1	4	----	4	----	3	----	4	1	2	----
26	7	2	6	1	6	----	5	----	2	----	4	----	3	----
28	8	1	7	2	4	1	4	1	4	1	4	----	4	----
30	7	2	5	1	4	1	6	1	8	----	4	----	5	1
32	4	1	8	2	5	2	7	1	5	----	3	1	4	1
34	5	1	4	1	3	1	5	1	4	1	4	1	4	1
36	4	1	4	1	2	----	5	1	4	----	4	1	4	1
38	3	1	3	1	3	1	4	1	4	----	3	1	4	2
40	2	1	----	----	5	3	3	1	3	1	3	1	4	1
42	1	----	1	1	2	1	1	----	3	1	8	----	3	1
44	3	1	1	1	2	1	2	----	1	----	1	----	2	1
46	1	1	----	1	1	----	2	1	2	----	1	----	1	1
48	1	----	----	----	1	----	1	----	1	----	1	----	1	----
50	1	----	----	----	1	1	----	----	----	----	----	----	----	1
52	1	----	----	----	1	----	1	----	----	----	----	----	----	----
54	----	----	----	----	----	----	----	----	----	----	----	----	----	----
56	----	----	----	----	----	----	----	----	1	----	----	----	----	----
58	----	----	----	----	----	----	----	----	----	----	----	----	----	----
60	----	----	----	----	----	----	----	----	----	----	----	----	----	----
62	----	----	----	----	----	----	----	----	----	----	----	----	----	----
64	----	----	----	----	----	----	----	----	----	----	----	----	----	----
66	----	----	----	----	----	----	----	----	----	----	----	----	----	----
68	----	----	----	----	----	----	----	----	----	----	----	----	----	----
70	----	----	----	----	----	----	----	----	----	----	----	----	----	----
TOTAL	74	15	68	16	63	13	59	8	55	4	51	6	47	12

*Curved values read from Figure 15.

Table 22. Stand Table for Douglas-fir Showing Number of Trees per Acre and Number Infected with Conk Rot on Site III* (trees 12 inches D.B.H. and larger).—Continued

D.B.H. class	301-320		321-340		341-360		361-380		381-400		401-420		421-440		441-460	
	Total	Infected	Total	Infected	Total	Infected	Total	Infected	Total	Infected	Total	Infected	Total	Infected	Total	Infected
Inches																
12	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....
14	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....
16	....	....	1	....	1	....	....	....	1	....	....	....	....	....	....	....
18	1	1	2	....	1	....	1	....	....	....	....	....	....	....	....	....
20	1	....	1	1	1	....	3	....	....	....	....	....	1	....	....	....
22	2	....	....	....	1	....	1	....	....	....	....	....	1	....	2	....
24	2	1	3	1	2	....	1	....	....	....	....	....	....	....	....	....
26	3	....	2	1	2	1	1	....	1	....	1	....	1	....	....	....
28	2	....	1	....	3	1	2	....	1	....	1	....	1	....	....	....
30	3	2	1	....	3	....	2	....	1	....	1	....	1	....	....	....
32	1	....	3	1	3	1	3	....	1	....	....	....	2	....	4	....
34	3	1	2	1	3	1	2	....	1	1	1	....	3	1	2	2
36	4	1	3	2	3	1	4	1	2	....	....	....	4	....	....	....
38	3	1	3	....	2	....	1	....	2	....	1	....	4	....	2	....
40	4	2	1	1	2	....	3	1	3	1	1	....	3	1	....	....
42	2	1	5	1	3	1	1	1	2	1	2	....	1	1	4	....
44	3	1	2	1	1	....	1	....	2	1	2	....	1	....	2	....
46	2	1	3	1	2	....	2	1	1	....	2	1	1	....	4	....
48	1	1	3	1	1	....	1	....	1	1	3	1	1	....	4	2
50	3	1	....	....	2	1	1	1	3	....	6	2	....	1	....	....
52	1	....	....	....	....	....	....	....	1	....	3	2	1	....	....	....
54	1	1	1	1	....	....	1	....	1	....	2	1	....	1	....	....
56	1	....	....	....	....	....	1	....	1	....	1	....	....	....	....	....
58	....	....	1	1	....	....	1	1	3	1	1	....	....	....	....	....
60	1	....	....	....	1	1	....	....	1	....	....	....	....	....	....	....
62	....	....	....	....	....	....	1	....	1	....	1	1	....	....	....	....
64	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
66	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
68	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	....
70	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
TOTAL	44	15	40	14	37	8	34	6	31	6	29	8	26	5	24	4

*Curved values read from Figure 15.

Table 23. STAND TABLE FOR DOUGLAS-FIR SHOWING NUMBER OF TREES PER ACRE AND NUMBER INFECTED WITH CONK ROT ON SITE II* (trees 12 inches D.B.H. and larger).

D.B.H. class	161-180		181-200		201-220		221-240		241-260		261-280		281-300	
	Total	Infected	Total	Infected	Total	Infected	Total	Infected	Total	Infected	Total	Infected	Total	Infected
Inches														
12	....	....	....	....	....	....	....	....	....	....	....	....	....	....
14	2	....	2	....	....	....	1	....	1	....	....	....	1	....
16	3	....	....	....	....	....	....	....	1	....	1	....	1	....
18	3	....	4	....	....	....	1	....	1	....	2	....	1	....
20	5	....	4	....	....	....	1	....	1	....	1	....	1	....
22	5	1	6	....	1	....	1	....	1	....	....	....	2	....
24	6	1	3	....	2	....	1	....	2	....	3	1	1	1
26	5	1	5	....	1	....	2	....	1	....	3	2	2	1
28	4	1	5	....	1	....	1	....	2	1	3	1	1	....
30	5	1	3	....	2	....	2	....	2	....	2	2	2	1
32	5	1	4	....	7	....	3	1	3	....	2	1	5	1
34	5	1	4	1	1	....	4	1	3	....	3	1	2	1
36	4	1	2	....	6	1	3	1	2	1	2	2	6	1
38	3	1	4	1	6	2	3	1	4	2	3	1	2	1
40	3	1	2	1	2	....	4	2	3	1	4	1	2	1
42	3	1	2	1	4	1	2	....	2	1	1	1	2	....
44	1	1	1	1	5	2	3	1	3	1	1	....	2	....
46	1	1	4	1	1	1	5	2	3	2	2	1	2	1
48	1	....	1	1	2	2	3	1	2	1	2	1	2	1
50	1	1	2	....	3	1	1	1	2	1	1	....	2	1
52	1	....	....	....	3	2	1	1	2	2	1	....	....	....
54	....	....	....	....	1	1	1	1	....	1	....	....	1	1
56	....	....	....	....	2	....	1	1	1	1	1	....	....	....
58	....	....	....	....	....	....	....	....	2	1	1	....	4	....
60	....	....	....	....	....	....	....	....	....	....	1	....	....	....
62	....	....	....	....	....	....	1	1	....	....	1	1	....	....
64	....	....	....	....	....	....	1	....	....	....	....	....	....	....
66	....	....	....	....	....	....	....	....	....	....	1	....	....	1
68	....	....	....	....	....	....	....	....	....	....	....	....	....	....
70	....	....	....	....	1	....	1	....	....	....	....	....	....	....
TOTAL	66	14	58	7	51	13	47	15	44	16	42	16	41	13

*Curved values read from Figure 15.

Table 23. Stand Table for Douglas-fir Showing Number of Trees per Acre and Number Infected with Conk Rot on Site II* (trees 12 inches D.B.H. and larger).—Continued

D.B.H. class	301-320		321-340		341-360		361-380		381-400		401-420		421-440		441-460	
	Total	Infected	Total	Infected	Total	Infected	Total	Infected	Total	Infected	Total	Infected	Total	Infected	Total	Infected
Inches																
12	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
14	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
16	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
18	....	....	1	....	2	....	....	....	....	....	....	....	....	....	....	....
20	1	....	1	....	1	....	....	....	....	....	....	....	....	....	....	....
22	....	....	....	....	....	....	1	....	....	....	....	....	....	....	....	....
24	2	1	1	....	1	....	1	....	....	....	....	....	....	....	....	....
26	1	....	1	....	....	....	1	....	....	....	....	....	....	....	....	....
28	1	....	1	....	1	....	....	....	....	....	....	....	....	....	....	....
30	1	....	1	....	2	1	1	1	....	....	....	....	....	....	....	....
32	2	1	1	1	2	1	1	....	....	....	....	....	....	....	....	....
34	2	1	1	1	1	....	2	....	....	....	1	....	....	....	....	....
36	2	1	2	1	....	....	1	....	1	....	1	....	1	....	....	....
38	3	2	....	....	2	....	1	1	2	....	....	....	1	1	....	....
40	1	....	2	1	2	2	1	1	2	....	2	....	2	....	2	....
42	2	....	2	1	1	....	2	1	2	1	3	1	2	....	2	....
44	4	2	3	1	3	2	2	1	1	....	....	....	2	1	....	....
46	3	2	3	2	2	1	2	....	2	1	4	1	3	1	....	1
48	2	....	1	....	2	1	2	2	1	1	2	....	5	2	2	....
50	4	2	2	1	6	4	2	2	2	....	5	1	3	2	4	1
52	2	2	5	4	1	....	4	2	2	1	3	....	....	....	2	....
54	2	1	2	1	2	2	4	1	3	....	2	1	2	1	2	1
56	1	1	2	2	1	1	2	....	3	1	2	....	....	....	....	....
58	2	....	1	1	1	1	....	....	3	....	2	....	2	1	4	....
60	1	....	1	1	....	....	1	....	3	1	1	....	....	....	2	1
62	....	....	1	1	1	1	1	....	2	....	1	1	1	1	....	....
64	....	....	1	1	....	....	1	....	1	....	....	....	....	....	2	1
66	....	....	1	....	1	....	1	....	2	1	....	....	....	....	....	....
68	....	....	....	....	1	1	....	....	....	....	....	....	....	....	....	....
70	....	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....
TOTAL	39	16	37	20	36	18	34	12	32	7	29	5	25	10	22	5

*Curved values read from Figure 15.

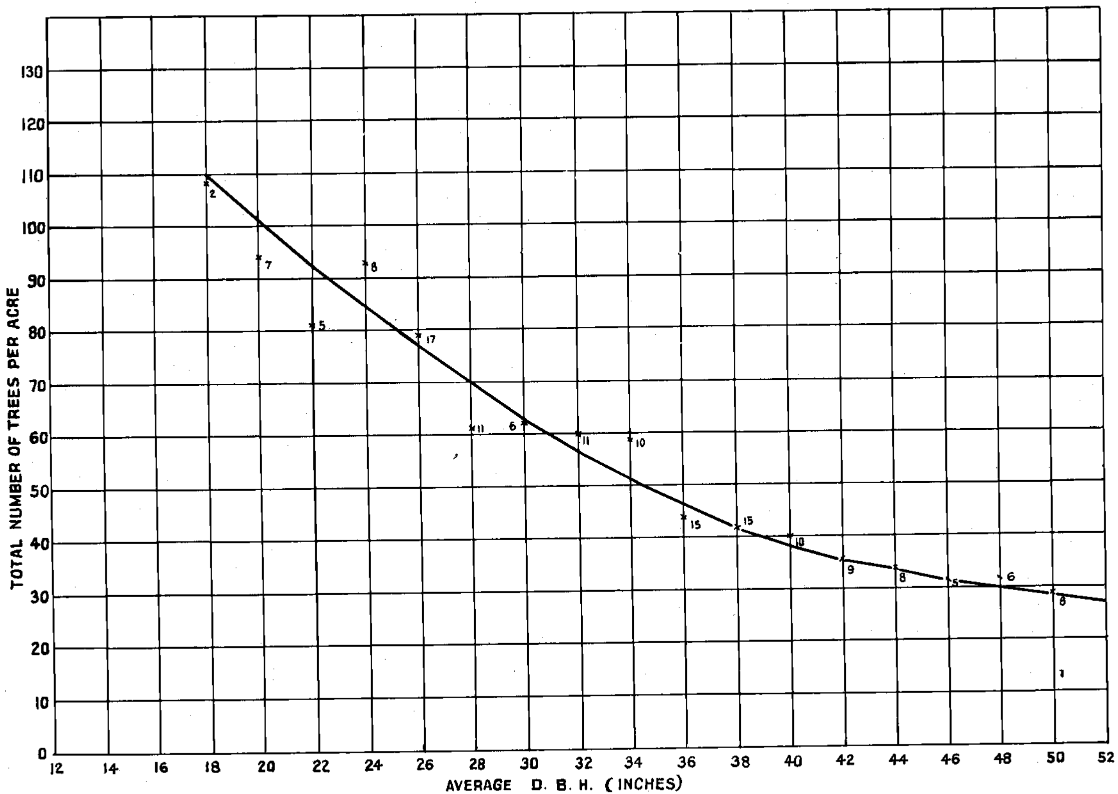


Figure 26. Stand density in relation to average stand-diameter on site II, Douglas-fir trees only, 12 inches D.B.H. and larger. (Data from Table 21)

Site and conk rot

It is apparent from Figures 16 and 17 that, subsequent to the stand age of 110 years, not only are the trees infected earlier on site II than on site III but that a greater percentage of the trees develop conk rot. This is further shown at the foot of Table 18 in which the proportion of infected trees is shown by site and age classes. Conk-rot infected trees comprise 11.6 per cent of the Douglas-fir trees on site IV, 17.3 per cent on site III, and 21.7 per cent on site II. It was suggested by Boyce (3, page 37), from scanty data, that in the younger age-groups decay was more severe on the poorer sites. This is corroborated in Figures 16 and 17 by the portions of the two curves below 110 years. These show a higher percentage of trees with conk rot on site III than on site II. More data on the younger age-classes is necessary, however, to definitely determine this relationship.

The fact that in older stands the higher percentage of trees with conk rot occurs on the better sites is unexpected. It has been generally accepted that native parasites attack forest trees less effectively on better sites. Of course, because *Fomes pini* develops largely in dead heartwood, it is not primarily a pathogen, although it does attack the living sapwood of Douglas-fir to a limited extent. There is no obvious explanation for the greater incidence of conk rot on the better sites. An inspection of Figure 15 will reveal that stands on site II contained a higher proportion of Douglas-fir trees than did stands on site III, and it is in the purer stands that the higher percentages of Douglas-fir trees are infected (see Table 31). On the other hand, it may be that because stands on good sites have fewer trees per acre, the branches attain a larger size and form more heartwood before they die and offer larger infection courts for the fungus. Although the greatest volume of wood is produced on the best sites, it is well known that in Germany the best sites do not produce the best quality Scotch pine (*Pinus sylvestris* L.). Both the greater diameter growth and presumably the presence of larger and more persistent branches on the trees are associated with a greater incidence of conk rot in Douglas-fir. Again, it may be that the broad-ringed, less-dense wood of the more rapidly growing Douglas-fir on the better sites is decayed more quickly by *Fomes pini*, or possibly the lower resin content in the faster-growing wood* enables the fungus to work more rapidly.

Topography and conk rot

The topography of an area influences the broader climatic conditions of that area as well as the local climate of units within the

* Wagg, J. W. B. *The formation of resin canals in the wood of Douglas-fir as influenced by environment.* Thesis, Oregon State College, Corvallis, Oregon. 1948.

larger area. Elevation, in its extremes, will influence temperature and precipitation over larger areas whereas topographic position, aspect, and slope influence the local climate of widely separated as well as contiguous units. Elevation and curvature of slope were found to have no relation to the incidence of conk rot, but aspect, position of slope, and degree of slope did have an influence.

Elevation. Although it is the considered opinion of some experienced observers that conk rot is more severe at certain elevations, an analysis of the plots on Willow Creek showed no significant differences between stands at elevations between 1,500 and 4,500 feet. Since temperature and precipitation, particularly the former, are so closely controlled by elevation, it might be expected that stands at lower elevations would have the highest percentage of conk rot because, as will be seen from later data, *Fomes pini* causes more decay on warmer sites. It is possible that, within a narrow geographic area such as the Willow Creek drainage, elevation does not modify temperature sufficiently to influence the percentage of conk rot in the stand. Further consideration of the relation of conk rot to elevation must await the sampling of more stands over a wider geographical area and at lower elevations.

Curvature of Slope. There was no relationship between the curvature of slope, i.e., convex or concave, and the percentage of trees with conk rot, even though convex curvature is more common for the upper slopes and concave for the lower.

Percentage of Slope. That the steepness of slope definitely influenced the incidence of conk rot is brought out in Table 24. On slopes of more than 40 per cent, 24.3 per cent of the trees were infected, whereas on slopes of less than 20 per cent, only 15.9 per cent of them were infected. Since data for Table 24 were predominately from plots having southerly or westerly exposures, as is revealed in Table 25, this relationship between slope and the incidence of conk rot may be more typical for southern aspects than for northern aspects.

Table 24. PERCENTAGE OF SLOPE AND PROPORTION OF DOUGLAS-FIR TREES WITH CONK ROT ON WILLOW CREEK (trees 12 inches D.B.H. and larger).

Slope	Trees (basis)	Trees with conk rot	
Per cent			*Per cent*
0-20	967	154	15.9
21-40	908	165	18.2
41+	900	219	24.3
TOTAL	2,775	538	19.4

Aspect. The percentage of Douglas-fir trees with conk rot is influenced by aspect as is demonstrated by Table 25. On south slopes, 21.5 per cent of the trees had conk rot whereas on north slopes 12 per cent were infected. On the three combined southerly aspects 22.6 per cent of the trees had conk rot, but on the three northerly aspects only 11.8 per cent were infected. On the east slopes, 9.8 per cent of the trees were infected and on the west slopes 20.0 per cent. This is strong evidence that decay caused by *Fomes pini* is more severe on warmer aspects.

Table 25. ASPECT AND PROPORTION OF DOUGLAS-FIR TREES WITH CONK ROT ON WILLOW CREEK (trees 12 inches D.B.H. and larger).

Aspect	Trees (basis)	Trees with conk rot	
			Per cent
NW	260	28	10.8
N	308	37	12.0
NE	18	4	22.2
E	51	5	9.8
SE	101	20	19.8
S	882	190	21.5
SW	549	136	24.8
W	475	95	20.0
TOTAL	2,644	515	19.5

Topographic Position. Conk rot is influenced by the position of the stand on the slope, as is shown in Table 26. On upper slopes, 23.3 per cent of the Douglas-fir trees were infected, whereas on bottom lands 16.4 per cent were infected. These figures represent respectively a 3.8 per cent increase and a 3.1 per cent decrease in the percentage of infected trees over the average of 19.5 per cent for all the trees on the Willow Creek plots.

The term "ridge top" needs explanation, since both broad and narrow types are grouped together. "Bottom lands" refer to the narrow creek bottoms at higher elevations as well as to the broad

Table 26. TOPOGRAPHIC POSITION AND PROPORTION OF DOUGLAS-FIR TREES WITH CONK ROT ON WILLOW CREEK (trees 12 inches D.B.H. and larger).

Topographic position	Trees (basis)	Trees with conk rot	
			Per cent
Ridge tops	429	62	14.5
Upper slopes	801	187	23.3
Middle slopes	753	153	20.3
Lower slopes	324	64	19.8
Benches	231	38	13.9
Bottom lands	180	25	16.4
TOTAL	2,718	529	19.5

flats bordering on the large rivers. Infection on benches, bottom lands, or ridge tops is less pronounced than on lower, middle, or upper slopes. Temperature again seems to be an influencing factor, since benches, bottom lands, and broad ridges are less exposed to the sun.

The infection of timber on the narrow type of ridge or hog-back measuring two or three chains in width resembles that on upper slopes. This type of ridge commonly has extremely defective open stands, nearly all the trees having conk rot. The proportion of infected trees on hog-backs exceeds the proportion of infected trees on upper slopes. On the slopes, a somewhat greater volume of conk rot was found in trees on the upper slopes than on middle or lower slopes.

The combined effect of aspect and position is brought out by Figure 27. The proportion of infected trees on a lower slope with a northwest aspect is about 11 per cent; with a northeast aspect, about 15 per cent; with a southeast aspect, about 19 per cent; and with a southwest aspect, about 25 per cent.

From the data on topography, it is evident that all factors found to influence conk rot—percentage of slope, aspect, and topographic position—are basically related to temperature. Stands in the warmer locations have the greater percentage of infected trees. This agrees with earlier observations that Douglas-fir in the southern portion of the Cascade Mountains (where summer temperatures are generally higher and humidities are probably lower) is in general more decayed than that in the northern portion, which begins approximately with the Cowlitz River watershed in Washington and extends north (3, page 46).

Soil and conk rot

Although there is evidence of a relationship between soil characteristics and the development of certain fungi which cause root rot in trees, information on the possible influence of soil on fungi that decay the heartwood of living trees is meager and contradictory and is based on uncontrolled observations rather than on exact measurements. For example, *Fomes pini* on Norway spruce (*Picea abies*) in western Europe was found by one investigator to be most severe on trees growing on poor soils or on very rich soils, because low-quality wood which decayed easily was developed in rich soils (7, page 354). Another investigator, however, decided that there was no relation between quality of wood and decay of Scotch pine (*Pinus sylvestris*) caused by *Fomes pini* (13, page 201).

Drainage. Soil drainage is the movement of water in the soil as influenced by topography, position of the ground-water table, and

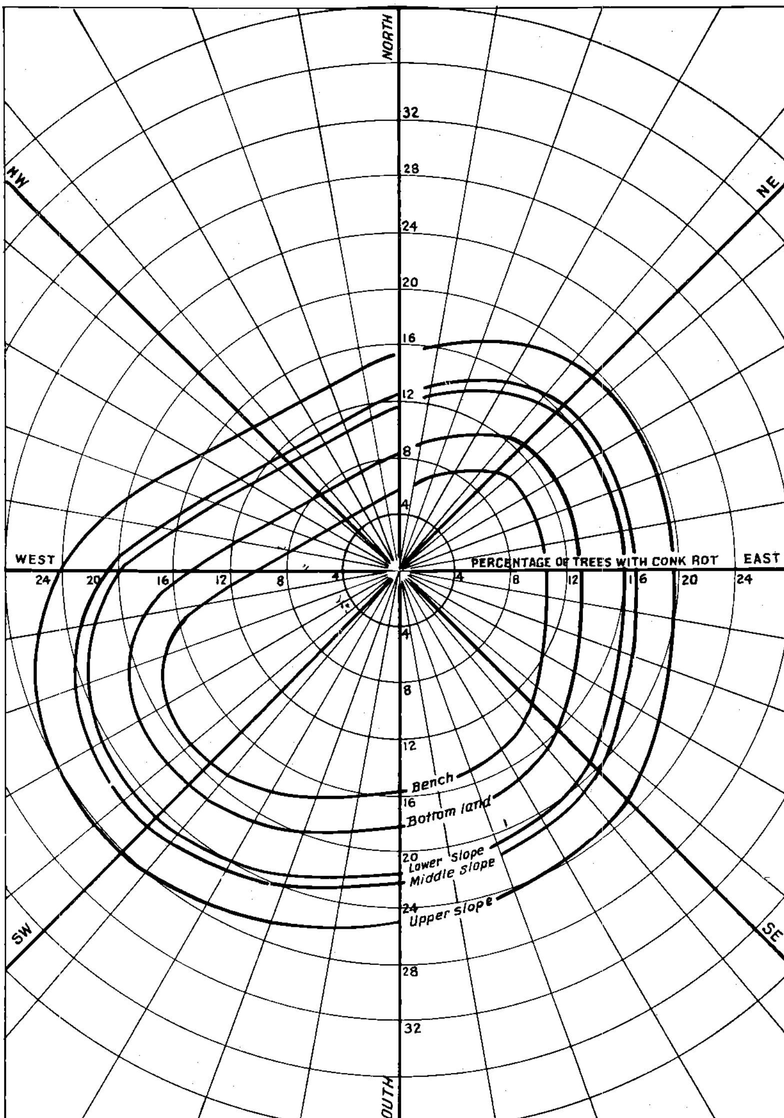


Figure 27. Proportion of Douglas-fir trees with conk rot in relation to aspect and topographic position on Willow Creek, trees 12 inches D.B.H. and larger.

permeability of the soil. Of the Douglas-fir trees growing on soils with excessive drainage, 28.3 per cent had conk rot. Whereas, only 14.3 per cent of trees in soils with restricted drainage were infected (Table 27). Excessive drainage is attributed to greater runoff, increased porosity of the soil, and a low water-table—all of which are usually associated with upper and steep slopes.

Table 27. SOIL DRAINAGE AND PROPORTION OF DOUGLAS-FIR TREES WITH CONK ROT ON WILLOW CREEK (trees 12 inches D.B.H. and larger).

Drainage	Trees (basis)	Trees with conk rot	
			Per cent
Restricted	420	60	14.3
Good	879	187	21.3
Excessive	184	52	28.3
TOTAL	1,483	299	20.2

Depth. The soil profile is considered to comprise three horizons: A, the horizon of leaching; B, the horizon of accumulation; and C, the horizon of parent material. In the podsol soils of the Douglas-fir region, the three horizons are not well defined.

Horizon A terminates at the depth of most of the herbaceous roots. It is generally darker in color and more porous than the underlying horizon B. No relationship was found between the depth of horizon A and the percentage of Douglas-fir trees with conk rot.

Shallow soils, which are less than 12 inches in depth through horizons A and B to the parent material, tend to support more heavily decayed timber than deeper soils (as can be seen from Table 28). In soils 12 inches or shallower to horizon C, 28.4 per cent of the Douglas-firs had conk rot, whereas in soils deeper than 19 inches, approximately 19 per cent of the trees were infected. Beneath most of the shallow soils, the C horizon is bed rock. Since these shallow soils occur mostly on hogbacks and steep upper slopes, on southern aspects in this area, it is questionable whether the controlling factor is shallowness of the soil, or temperature.

Table 28. DEPTH OF SOIL TO PARENT MATERIAL AND PROPORTION OF DOUGLAS-FIR TREES WITH CONK ROT ON WILLOW CREEK (trees 12 inches D.B.H. and larger).

Depth of soil	Trees (basis)	Trees with conk rot	
Inches			*Per cent*
0-12	102	29	28.4
13-18	155	36	23.2
19-24	358	69	19.3
25-30	868	165	19.0
TOTAL	1,483	299	20.2

Texture. Soil texture is determined by the proportions of sand, clay, and silt present (18, page 43). The soils of the Willow Creek plots were mostly sand-silt complexes. The Bouyoucos hydrometer method (1) was used to analyze mechanically the percentage of sand, clay, silt, and total colloids in the soil. No relationship was found between the texture of the soil and the percentage of trees with conk rot on Willow Creek, nor was the percentage of total colloids, which varied from 17 to 49 per cent, of any significance.

Acidity. Soil acidity as measured by the hydrogen ion concentration (pH) had no effect on the incidence of conk rot on the Willow Creek plots. The pH values, which were between 4.9 and 6.4, were determined by the quinhydrone electrode method.

Nitrogen. The Kjeldahl method was used to determine the percentage of total nitrogen in the soil; it varied from 0.082 to 0.342 per cent in the Willow Creek plots. That the proportion of Douglas-firs with conk rot was related to total nitrogen content is shown by Table 29. When the percentage of total nitrogen was 0.120 or below, the percentage of trees with conk rot was 15.9, but when the soil contained over 0.170 per cent total nitrogen, the proportion of infected trees increased to 24.4 per cent.

Table 29. PERCENTAGE OF TOTAL NITROGEN IN THE SOIL AND PROPORTION OF DOUGLAS-FIR TREES WITH CONK ROT ON WILLOW CREEK (trees 12 inches D.B.H. and larger).

Total nitrogen	Trees (basis)	Trees with conk rot	
Per cent			*Per cent*
0.082-0.120	471	75	15.9
0.121-0.170	513	102	19.9
0.171-0.342	499	122	24.4
TOTAL	1,483	299	20.2

How the total nitrogen in the soil can influence a wood-destroying fungus, such as *Fomes pini,* that develops principally in the dead heartwood of living trees, is obscure. *Fomes annosus,* that causes a root and butt rot in conifers, attacks Norway spruce most severely in rich soils high in nitrogenous material, because such soils favor the development of the fungus (8). However, the relationship between soil, *F. annosus,* roots, and butt is much more direct than between soil, *Fomes pini,* and the heartwood of Douglas-fir. The percentage of total nitrogen apparently is not controlled by temperature, because the increased temperature that appears to favor conk rot has caused a decrease in soil nitrogen elsewhere (9, page 147), although no tests have yet been made on soils in the Douglas-fir region. Nor is site in any way responsible, because the percentage of total nitrogen is not correlated with site quality in the Douglas-fir region (17).

Plant indicators and conk rot

The development of the lesser vegetation depends upon the prior history of the stand as well as upon climatic conditions. Plant indicators may be an index to conditions that are either favorable or unfavorable to the development of conk rot in a stand, since it has been established that there is a relationship between the lesser vegetation and the height of the dominant stand of Douglas-fir in British Columbia (16, page 38).

The study of plant indicators was not detailed. Only the predominating species on each plot were listed, and no arithmetical rating of abundance or vigor was made. Table 30 shows the correlation between the frequency of occurrence of certain plant indicators on a plot and the percentage of Douglas-firs with conk rot on the same

Table 30. PER CENT OCCURRENCE OF PLANT INDICATORS AS RELATED TO THE INCIDENCE OF CONK ROT ON THE WILLOW CREEK PLOTS (Douglas-fir trees 12 inches D.B.H. and larger).

Plant indicator	Infection class*			
	0-10 per cent 62 plots	11-20 per cent 54 plots	21-40 per cent 64 plots	Over 41 per cent 17 plots
	Per cent	*Per cent*	*Per cent*	*Per cent*
Acer c. Vine maple	19.4	21.8	39.1	47.1
Achlys t. Vanilla-leaf	11.3	14.5	34.4	29.4
Chimaphila m. Prince's pine	11.3	9.1	15.6	5.9
Corylus c. Beaked hazelnut	6.4	3.6	9.4	23.5
Gaultheria s. Salal	19.4	16.4	17.2	11.8
Holodiscus d. Ocean spray	12.9	14.8	23.4	18.8
Linnaea a. Twinflower	16.1	9.3	3.1	6.3
Mahonia spp. Oregon grape	77.4	78.2	92.2	64.7
Oxalis spp. Oxalis	12.9	13.0	9.4	37.5
Polystichum m. Sword fern	17.7	16.7	21.9	25.0
Rhododendron c. Rhododendron	45.2	22.2	4.7	6.3
Rhus d. Poison oak	4.8	11.1	18.8	12.5
Rosa spp. Rose	21.0	31.5	40.6	43.8
Rubus v. Western dewberry	6.5	9.3	10.9	12.5
Vicia spp. Vetch	4.8	3.7	12.5	18.8

* Infection class: Percentage of Douglas-fir trees with conk rot in relation to total number of Douglas-fir trees.

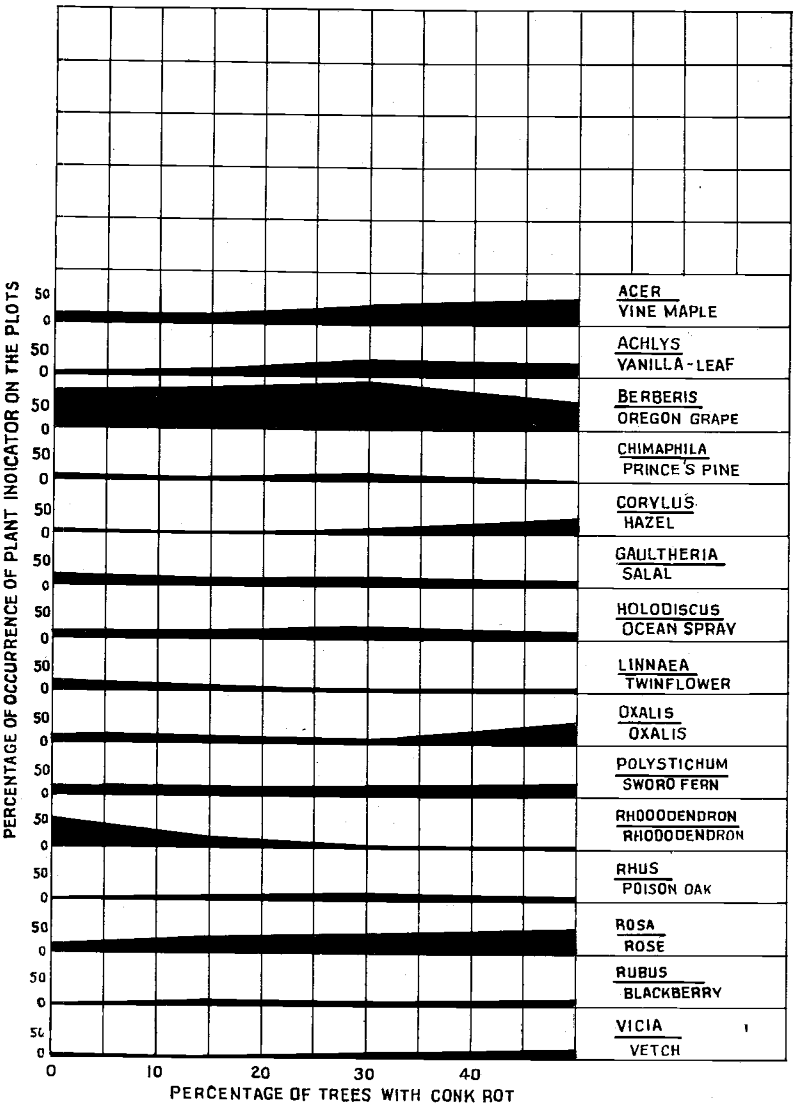


Figure 28. Occurrence of plant indicators as related to the incidence of conk rot on the Willow Creek plots, Douglas-fir trees 12 inches D.B.H. and larger.

Table 31. PERCENTAGE OF DOUGLAS-FIR IN THE STAND AND THE INCIDENCE OF CONK ROT ON THE WILLOW CREEK PLOTS (trees 12 inches D.B.H. and larger).

D.B.H. class of Douglas-fir	Douglas-fir, percentage of all trees 12 inches D.B.H. and larger											
	Less than 55 per cent			56-70 per cent			71-95 per cent			96-100 per cent		
	Total trees	Trees with conk rot		Total trees	Trees with conk rot		Total trees	Trees with conk rot		Total trees	Trees with conk rot	
1	2	3	4	5	6	7	8	9	10	11	12	13
Inches			*Per cent*			*Per cent*			*Per cent*			*Per cent*
22	23	1	4.3	......	......	......	111	27	24.3	152	25	16.4
24	23	2	8.7	48	4	8.3	176	23	13.1	93	18	19.4
26	11	1	9.1	69	5	7.2	166	30	18.1	102	24	23.5
28	28	0	0.0	63	5	7.9	139	32	23.4	201	45	22.4
30	59	6	10.2	41	5	12.2	57	10	17.5	88	25	28.4
32	81	5	6.2	30	6	20.0	77	13	16.9	88	28	31.8
34	53	7	13.2	42	9	21.4	110	29	26.4	58	24	41.4
36	57	6	10.5	35	3	8.6	80	19	23.8	16	8	50.0
38	13	3	23.1	......	......	......	40	13	32.5	7	4	57.1
40	......	......	......	......	......	......	......	......	......	......	......	......
42	52	9	17.3	19	6	31.6	14	3	21.4	......	......	......
44	26	3	11.5	19	9	47.4	......	......	......	......	......	......
46	22	5	22.7	......	......	......	......	......	......	......	......	......
48	......	......	......	10	4	40.0	......	......	......	......	......	......
50	......	......	......	......	......	......	......	......	......	......	......	......
AVERAGE			10.7			14.9			20.8			25.0

plot. Plants which indicated a high percentage of Douglas-firs with conk rot in the stands were vine maple, vanilla-leaf, oxalis, and rose; whereas those which indicated a lower incidence of infection were salal, twinflower, and rhododendron (as shown in Table 30 and Figure 28). Vine maple and oxalis in particular indicate a high incidence of conk rot, and rhododendron is an almost specific indicator of low incidence.

Stand composition and conk rot

The percentage of conk rot in Douglas-fir varies with the degree of purity of the stand as can be seen in Table 31. When Douglas-fir trees comprised less than 55 per cent of the total number of trees in a stand, only 10.7 per cent of the Douglas-firs had conk rot. When this species comprised 96 to 100 per cent of the stand, 25 per cent had conk rot. That pure stands are subject to a higher degree of infection by fungi than are mixed stands is axiomatic in forest pathology. Presumably, the screening effect of other species in a mixed stand reduces the chances for infection by the wind-borne spores. There is another consideration. It has been shown previously that conk rot in old-growth Douglas-fir is more severe on better sites and that stands on better sites contain a greater proportion of Douglas-fir. Consequently, it is impossible to determine from the data at hand whether stand purity or site quality is basically responsible for increasing the incidence of conk rot.

The tree species associated with Douglas-fir indicate trends in the percentage of Douglas-fir trees with conk rot (Table 32). Western red cedar and western hemlock usually are present in plots where

Table 32. OCCURRENCE OF TREE INDICATORS AS RELATED TO THE INCIDENCE OF CONK ROT ON THE WILLOW CREEK PLOTS (trees 12 inches D.B.H. and larger).

Tree indicator	Infection class*			
	0-10 per cent (62 plots)	11-20 per cent (55 plots)	21-40 per cent (64 plots)	Over 41 per cent (17 plots)
	Per cent	*Per cent*	*Per cent*	*Per cent*
Abies grandis Grand fir	32.2	23.6	31.2	17.6
Libocedrus decurrens Incense cedar	33.9	36.4	39.1	47.1
Thuja plicata Western red cedar	64.5	50.9	21.9	11.8
Tsuga heterophylla Western hemlock	64.5	45.4	23.4	23.5
Pinus lambertiana Sugar pine	6.4	9.1	4.7	5.9
Pinus monticola Western white pine	12.9	3.6	4.7	5.9

* Infection class: Percentage of trees with conk rot in relation to the total number of Douglas-fir trees.

the incidence of conk rot is low. Incense cedar indicates a high degree of infection. While western red cedar and western hemlock prefer the flatter areas on benches, lower slopes, and bottom lands, incense cedar is found on the drier, warmer, upper slopes and hogbacks. Furthermore, incense cedar occurs only in the southern part of the Douglas-fir region. On better sites, the tolerant associated species are restricted to the understory. On poorer sites, they not only form the understory but also compete for a dominant position in the stand. In dense stands, incense cedar is usually a dominant tree, but in open stands it behaves like an understory species. Western white pine and sugar pine are dominant when present. The former occurs in stands with a low degree of infection with conk rot. Grand fir is present regardless of the degree of infection.

Stand quality and conk rot

Stand quality is dependent on stand development. Stands of poor quality, therefore, could be the result of (a) poor stocking in the pole stage; (b) uneven age-development (the older trees being larger and having larger and more persistent branches than the younger); and (c) shallow, rocky soils in which root competition limits the proximity of the stems. The grades of the first two logs of all trees with average D.B.H., or larger, were used to determine the differences in stand quality. Trees below the average D.B.H. often have low-grade logs only because of the size requirements for high-grade logs and not because of the "roughness," i.e., knottiness, of the logs themselves. Furthermore, only the first two logs were used for the comparison between plots on which the trees might average 3 to 5 logs each, because basal logs reveal conditions during the earlier development of the stand, whereas upper logs indicate later conditions.

The plots were divided into three classes, based on the percentage of Number 2 or better logs among the total number of logs used for comparison on each plot. The results of this classification are given in Table 33. As would be expected, on plots with less than

Table 33. STAND QUALITY AND PROPORTION OF DOUGLAS-FIR TREES WITH CONK ROT ON WILLOW CREEK PLOTS (trees 12 inches D.B.H. and larger).

No. 2 or better logs	Plots (basis)	Trees (basis)	Trees with conk rot	
Per cent				*Per cent*
Less than 70	60	922	204	22.1
71-90	59	870	171	19.6
91-100	79	983	163	16.6
TOTAL	198	2,775	538	19.4

70 per cent No. 2 or better logs, 22.1 per cent of the trees had conk rot, but on plots with 91 to 100 per cent No. 2 or better logs, 16.6 per cent were infected. The fewer knots in the higher-grade logs simply mean that branches are less persistent and drop off sooner after death. The knot then can be grown over, reducing the infection courts through which *Fomes pini* can enter.

Fire and conk rot

Since fire alters the normal development of a stand when it occurs in an established stand, it is reasonable to suppose that it might have an effect on the degree of infection by *Fomes pini*. In this investigation, stands exhibiting charred bark on living trees were considered as burned, those with charcoal on moss-covered stumps or on the ground as questionable, and those without either of these signs as unburned. Stands of questionable nature were not included in this analysis, since it was not possible to determine whether fire occurred previous to the time of regeneration or after the stand was established.

There were 4.2 per cent more trees with conk rot in the burned-over stands than in the unburned, according to Table 34.

Table 34. FIRE AND THE PROPORTION OF DOUGLAS-FIR TREES WITH CONK ROT ON WILLOW CREEK PLOTS (trees 12 inches D.B.H. and larger).

Condition of stand	Trees (basis)	Trees with conk rot	
			Per cent
Burned	1,327	293	22.1
Unburned	1,448	245	17.9
TOTAL	2,775	538	19.4

PRACTICAL SIGNIFICANCE OF RESULTS

Although it is evident that nothing can be done to change conditions in present old-growth stands, much can be done to mitigate the enormous losses by securing the maximum volume of sound wood from these stands.

In cruising

Both the constant and, of late years, the extremely rapid rise in stumpage values and the great increase in manufacturing costs emphasize the importance of more accurate timber inventories. Based on information now available, cruising of Douglas-fir can be reasonably exact, in fact more exact than for any other species with a high incidence of decay.

It has been found that nearly 83 per cent of the volume of all decay in Douglas-fir in western Oregon is conk rot caused by *Fomes pini*. Fortunately, there is rarely any consequential development of conk rot in a tree without the appearance of indicators on the trunk. Furthermore, these indicators have a fairly definite relation to the extent of the decay column in the heartwood. Let it be emphasized, however, that the extent of conk rot in relation to indicators is based on averages. Consequently, estimating conk rot in a single tree will be inexact, except by chance. Nevertheless, as the number of trees involved in an estimate increases, so does the accuracy of the estimate.

The most important, frequent, and readily visible indicators of conk rot are sporophores, or conks (Figure 4). These perennial fructifications issue from the decayed tree through knots. The extent of decay above the highest and below the lowest sporophore in a series varies with age, the distance increasing as the trees become older. As shown in Figure 5, the combined extent of conk rot beyond the sporophores is 22 feet at 180 years (11 feet above the highest sporophore and 11 feet below the lowest), while at 300 years the combined distance is 47 feet. The upper broken line in Figure 5 is used in cruising because it provides an allowance for hidden conk rot, i.e., decay volume not revealed by external indicators. For a single sporophore, or several in a close group, a deduction of 8 feet above and 8 feet below (the equivalent of one 16-foot log) should be made. Small and inconspicuous conks are usually indicative of less decay than larger ones. When they occur on the butt of the tree, one half of the 32-foot butt log should be culled. Since such sporophores cannot be identified with certainty when they occur higher on the bole, the deduction should be the same as for other sporophores that occur either in series or singly.

Swollen knots (Figures 3 and 7), which occur much less frequently than sporophores, are the next best indicators of conk rot. One half of the volume deduction for sporophores should be used for swollen knots. For example, the combined distance to allow for swollen knots in a 180-year-old tree would be 11 feet and for a 300-year-old tree would be 24 feet, that is, one half the distance shown in Figure 5 for sporophores. A single swollen knot would indicate a linear extent of conk rot 4 feet each way from the knot. Punk knots should be considered to indicate the same extent of decay as swollen knots.

For relatively exact cruising, it is necessary to know the approximate age of a stand. If the age is known only in a broad way, a deduction of 8 feet above the highest and 8 feet below the lowest sporophore in a series could be used for stands 100 to 200 years old, 19 feet in each direction for stands 200 to 300 years old, 29 feet in each direction for stands 300 to 400 years old, and 39 feet in each direction for stands over 400 years old. For swollen knots and punk knots, half these distances should be used.

Furthermore, when cruising, it should be remembered that for stands of the same age a greater amount of conk rot usually can be expected on better sites, in pure Douglas-fir stands, and in stands of poor quality (those with knotty trees), on southern aspects, on steep slopes, on upper slopes, and on hogbacks. The degree of infection will be less on poor sites, in mixed stands, in stands of high quality (those with trees relatively free from knots), and in stands on northern aspects, on moderate slopes, on flats, on lower slopes, and on benches. Where vine maple, vanilla-leaf, oxalis, or rose predominate in the lesser vegetation, the percentage of conk rot tends to be high; but where salal, twinflower, or rhododendron predominate, the percentage of conk rot is usually lower.

Although no exact data regarding other decays of Douglas-fir were obtained in this investigation, it seems advisable for the benefit of the cruiser to include that which has been learned previously (3). Most of the other decays are brown cubical rots in which the wood is reduced to a charcoal-like consistency, easily crumbled to a fine powder between the fingers. Brown trunk rot caused by the quinine fungus, *Fomes laricis*, is next in importance to conk rot. In the advanced stage this decay is characterized by conspicuous, leatherlike, white mycelial felts in the shrinkage cracks. The large, conspicuous, whitish perennial sporophores issue through knots or old wounds. A tree with a single sporophore should be considered completely unmerchantable. Unfortunately, the sporophores do not develop abundantly, and many trees with brown trunk rot have no external indicators. Sometimes the rot can be seen in a large broken-off branch; this also signifies an unmerchantable tree. Broken-topped trees are frequently infected.

Yellow-brown top rot caused by the rose-colored conk, *Fomes roseus,* is a yellowish-brown, crumbly rot with white mycelial felts which are less frequent and less conspicuous than those characterizing brown trunk rot. The perennial bracket-like sporophores (with a rough, zoned, black upper surface and a pale rose-colored under-surface) occur so high up on the trees in old-growth stands that they are usually overlooked. This is of little consequence since the rot occurs in the upper part of the trunk where the logs are of low quality or in the top beyond the merchantable limit. However, observations show that in young-growth this rot sometimes develops in the butt, with the infection entering through wounds. The relation of the sporophores to the extent of the rot column is unknown.

Red-brown butt rot is caused by the velvet top fungus, *Polyporus schweinitzii.* The decay is usually confined to the roots and butt, commonly not extending beyond the first 16-foot log. The brown, crumbly rot has thin, crustlike layers of mycelium in the shrinkage cracks. The annual sporophores are various shades of brown, depending on their stage of development. They issue from old wounds on the butts of infected trees or more often from the ground nearby, coming up from decayed roots. On the tree, the conk is a relatively thin bracket, whereas on the ground, when viewed from above, it is circular in shape, sunken in the center and tapers to a short thick stalk. When cruising old-growth, the first 8 feet of the butt log should be culled in any tree with a conk on the butt or on the ground nearby. Only a minority of infected trees have sporophores. Butt wounds, particularly fire scars, however, are indications of the presence of this decay if the fungus is known to occur in a locality. Each tree with a butt wound, whether open or healed over, should be considered infected. Swollen or churn butts usually indicate an old butt wound. Decay should be considered as extending about 2 feet higher than the scar, and the trunk should be culled from ground level to that height.

There are several other butt rots in old-growth Douglas-fir, all of them inconsequential, in the aggregate, as a cause of cull. The fungi responsible for some of these butt rots are not yet known. When fructifications are found on the butt of a tree which are different from any of those described, about all that can be said is that culling procedure should be the same as that used when sporophores of *Polyporus schweinitzii* are found.

In bucking and scaling

Bucking felled timber in accordance with the position of the indicators will result in a greater net-recovery from the gross volume handled, with a consequent reduction in costs. The extent of decay in relation to the indicators can be obtained from the lower, solid, line in Figure 5, since no allowance is necessary for hidden conk rot in felled trees.

Observations made during the course of this investigation show that more careful marking for bucking would increase recoverable volume. To be effective, however, the work must be done by a man who thoroughly understands decay in Douglas-fir.

In management

Forest management in the Douglas-fir region has been largely concerned with the growth and yield of young forests. Old-growth forests have received little attention other than exploitation motivated primarily by economics. Old-growth forests have been considered to be wasting space by producing little or no sound-volume, or to be subject to decay and insect infestations that were absent from young forests. Even though old-growth stands produce little volume, it is from them that high-quality logs come, particularly the so-called "peeler" logs which command such a high price. Since young stands do not provide this quality wood, old-growth should be managed to produce the maximum of sound material. Despite rapid cutting, old-growth will be a substantial part of the cut in western Oregon for another 25 years or more, and some owners have enough to last about 80 years at the present rate of cutting.

When it was generally accepted that decay in Douglas-fir, as in other species, increased more or less regularly with age from age-class to age-class, proper management consisted mainly of selecting the oldest and most defective old-growth stands and cutting them as soon as possible. However, now that it is known that the development of conk rot is cyclical, the age at which timber is cut is the most important factor affecting losses from conk rot. For example, a stand at 190 years may yield 68 M board feet of sound volume per acre; at 250 years 91 M board feet, an increase of 23 M board feet per acre; at 330 years 73 M board feet, a decrease of 18 M board feet; and at 370 years 85 M board feet, another increase of 12 M board feet (see Table 20, column 5). Obviously, 250 and 370 years are more advantageous ages at which to cut, from the standpoint of volume production, than are 190 and 330 years. The financial difference at present stumpage prices is consequential.

The first requisite for adequate management of an old-growth Douglas-fir forest is an inventory which (for various stands composing it) includes the average age, the number of trees per acre, the percentage of Douglas-fir trees with conk rot, and the site quality. The gross volume and the volume loss by conk rot are not essential, because the proportion of gross volume lost by conk rot may be estimated accurately when the proportion of trees with conk rot and stand age are known. Thus, a simple tree-count, which can be made more rapidly than a volume cruise, will suffice. A knowledge of the proportion of trees with conk rot in a stand is enough to establish the cyclical development of conk rot by plotting curves, such as are shown in Figures 16 and 17, provided that there is a sufficiently broad representation of age classes available. The low and high points of infection can be read from such curves, and the advantageous cutting-ages decided upon, modified of course by other factors that influence cutting, particularly the current trend of stumpage values. Cutting should be avoided when the volume of sound wood is increasing.

If the age classes represented are too few to permit the construction of curves for new areas, the percentage of trees with conk rot for the few ages available can be compared with the curves in Figures 16 and 17. Curves can be drawn in the same form but in which the highs and lows may deviate somewhat—in amount and in the time at which they occur. Although the majority of plots on which the determination of the cyclical development of conk rot is based were on the Middle Fork of the Willamette River, the volume of data from plots in other localities was such that the tables and curves bearing on cyclical development can be considered representative for most of western Oregon, except possibly for the immediate coastal areas.

A uniform age-class may cover an extensive area even up to thousands of acres, so that no opportunity is afforded to adjust cutting to the age classes with the greatest sound volume. Factors other than age then become paramount in determining the logging priority of stands. The greatest amount of conk rot usually can be expected on the best sites, in stands of high purity, in stands of poor quality (those with knotty trees), on southern aspects, on steep slopes, on upper slopes, and on hogbacks. Even for an extensive stand of a uniform age-class, a determination of the proportions of trees with conk rot in different parts of the stand will be necessary, because for all of these factors with which a high incidence of conk rot is associated, there are stands that prove to be exceptions. Although it is generally true, for example, that stands on southerly slopes have the highest incidence of conk rot, occasional stands may be found on northerly slopes with as great a proportion of infection. Likewise, stands on poor sites, mixed stands, high-quality stands, those on moderate slopes or flats, and those on lower slopes and benches, although usually characterized by a lower incidence of conk rot, may occasionally be highly defective. Soils with excessive drainage and shallow soils generally support defective stands. Such soils are usually characteristic of upper slopes and hogbacks. Where vine maple, vanilla-leaf, oxalis, or rose are abundant in the secondary vegetation, conk rot is usually severe. Salal, twinflower, and rhododendron indicate less conk rot.

In advance of the actual appearance of conk rot, it is not possible to predict definitely which stands, much less which individual trees, will be affected.

Stands of higher quality (those composed of trees with the fewest branch stubs or large knots) were found to have less conk rot than those of poor quality. A stand of good quality indicates that it was fully stocked at an early stage of its development, which favored early natural pruning. Hence, stands should be fully stocked at the sapling stage. The regeneration of Douglas-fir on clear-cut or burned-over areas is now largely left to nature with the result that the majority of young-growth stands are understocked. Under intensive management of young timber, it probably will not be economically feasible to wait for some stands to become fully stocked naturally or to accept understocking for others as a permanent condition. Full stocking, or at least a reasonable approximation of it, will be assured by interplanting. Thus, the amount of conk rot will be reduced in young-growth.

Mixed stands were found to be less defective than the nearly pure Douglas-fir stands. The presence of other species increases the stand density and promotes the natural pruning of Douglas-fir, particularly when the associated species function in part as an understory. The species composition of a stand can be changed by planting. However, it is not established whether the associated species have a beneficial influence that could not be obtained by growing Douglas-fir in dense stands.

In the Douglas-fir region of western Oregon, the state law requires that 5 per cent of the area on each quarter-section (160 acres) be left uncut, or that the equivalent of 2 seed trees of commercial species per acre be left. These reserved trees, except in rare instances, will not survive until the next cut, so it is advisable to leave trees with conk rot for this purpose. Since much of the reproduction may be established by seed from both sound and decayed trees in the surrounding stand, the use of defective seed trees can have, at worst, only a limited effect on the future stand. Trees can be examined for external evidences of decay, and the amount of conk rot estimated as in cruising. Trees with the least sound-volume can be selected for seed trees. Occasionally in very old stands, it is difficult to decide whether a tree is moderately or severely decayed, because so many of the conks have dropped off. However, rate of growth can be helpful. If an infected tree is growing more slowly than the adjacent sound trees, probably more than 51 per cent of the gross merchantable volume has been lost from decay, whereas if it is growing more rapidly than the sound trees, 50 per cent or less of the volume is likely to be lost. By comparing the rate of radial growth for the last 20 years, an infected tree can be rated as relatively fast or slow growing, and its probable decay status determined.

It will not be possible to completely eliminate conk rot caused by *Fomes pini* from the young stands of the future. Trees as young as 27 years have been found to be infected, and infection in 40- to 60-year-old trees is common. This is earlier than most Douglas-fir stands will be cut. Even now, however, the amount of conk rot in young stands is small, and under intensive management will be even less. Actually, using as a basis the behavior of pure coniferous stands of other species that have been under intensive management for a long time in western Europe it can be predicted that losses from *Fomes pini* will be secondary, and that damage by root- and butt-rot fungi, notably *Poria weirii*, will be more important and more difficult to control in the young Douglas-fir stands of the future.

SUMMARY

There is enough old-growth Douglas-fir remaining in western Oregon to assure its cutting for years to come. Losses from decay in these old stands, however, vary from 5 to 50 per cent of the gross board-foot volume. More than 80 per cent of the decay volume is conk rot caused by the fungus, *Fomes pini*. Consequently, this investigation has been aimed at (1) discovering the behavior of decay caused by *Fomes pini* in the individual tree in order to improve cruising and utilization, and (2) establishing the relationship of decay caused by *Fomes pini* to stand conditions in order to improve management practices.

The Douglas-fir trees on 14 plots, one quarter to one half acre in area, were felled, bucked, and scaled for gross volume and volume of conk rot in board feet. Before felling, an estimate was made of the gross volume and the decay volume based on the presence of indicators on the tree. The estimate was within 5 per cent of the actual scale in 10 of the plots, and within 14 to 20 per cent in the remaining 4. The height above ground of the base and the top of the column of conk rot progressively increased with increasing stand age. The principal indicators of conk rot used in this study were sporophores and swollen knots. The average extent of conk rot above the highest and below the lowest conk rot indicator in a series increased as the stands aged. An analysis of radial growth indicated that the development of conk rot in a stand is cyclical. *Fomes pini* is somewhat pathogenic, commonly encroaching on the sapwood, resulting either in the death of the tree directly or, as seems more likely, reducing its vigor so that it succumbs to competition. The most rapidly growing trees are infected first, their growth is reduced, and finally they drop out of the stand. Meanwhile, new infections are occurring in the remaining trees, and the process is repeated.

An estimate of gross volume and volume of conk rot was made for all the Douglas-fir trees, 12 inches D.B.H. and larger, on 459 quarter-acre plots in stands of various ages and on different sites. The number of trees with conk rot and the decay volume increased progressively with increasing stand age. However, the increase was not regular but cyclical; that is, an increase in decay followed by a decrease was repeated several times during the life of a stand. Decay incidence was greater in stands of greater diameter, as would be expected in even-aged stands where diameter is closely related to age. Significant volume-losses due to conk rot occurred earlier in stands on site II than in stands on site III. Furthermore, subsequent cycles of heavy conk rot infections followed this trend, oc-

curring earlier in stands on site II throughout the life of the stands. as can be seen in Table 20.

The data from a homogeneous group of plots in one drainage were used in the analysis of factors that might be influenced by a too-wide geographical distribution of sampling. No relationship was found between the number of trees with conk rot in a stand and such factors as elevations ranging from 1,500 to 4,500 feet, curvature of slope, texture of the soil, and acidity of the soil. A greater amount of conk rot occurred in trees on steep slopes, on southerly aspects, on upper slopes or hogbacks, on soil with excessive drainage, and on shallow soil. In nearly all instances higher temperature is associated with the foregoing factors, so possibly temperature is the controlling factor. The incidence of conk rot was lower in stands that were on moderate slopes, on northerly aspects, on lower slopes and benches, on soils with good to restricted drainage, and on deep soils. Soils with a high percentage of total nitrogen produced more decayed trees than those with a low percentage. Where vine maple, vanilla-leaf, oxalis, or rose predominated in the secondary vegetation, the incidence of conk rot was high, whereas salal, twinflower and rhododendron indicated a lower incidence of decay. Pure stands contained greater volumes of conk rot than did mixed stands; stands of poor quality were more defective than those of good quality; and stands that had been damaged by fire had more conk rot than those that had not been burned.

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APPENDIX A

DESCRIPTION OF PLOTS

Plot 1

Location: Middle Fork Willamette River, Oakridge
Legal description: NW/SE, S.2, T.22 S., R. 3 E.
Operation and ownership: Pope and Talbot, Inc., Willamette National Forest
Area: 0.5 acres
Composition of stand: Pure Douglas-fir with scattered western hemlock understory
Slope: Level
Aspect:
Topographic position: Broad valley
Elevation: 1,300 feet
Soil: Clay loam

Plot 2

Location: North side, Buck Creek Road, Oakridge
Legal description: NE/NE, S.9, T.23 S., R. 3 E.
Operation and ownership: Pope and Talbot, Inc.
Area: 0.25 acres
Composition of stand: Pure Douglas-fir
Slope: 20 per cent
Aspect: West
Topographic position: Lower sidehill
Elevation: 1,600 feet
Soil: Red clay

Plot 3

Location: Willow Creek, Oakridge
Legal description: NE/NW S.25, T.22 S., R.3 E.
Operation and ownership: Pope and Talbot, Inc.
Area: 0.3 acres
Composition of stand: Pure Douglas-fir
Slope: 43 per cent
Aspect: West
Topographic position: Upper sidehill
Elevation: 2,800 feet
Soil: Clay loam

Plot 4

Location: Molalla
Legal description: NE/NE, S.33, T.7 S., R.4 E.
Operation and ownership: Weyerhaeuser Timber Company
Area: 0.5 acres.
Composition of stand: Mixed Douglas-fir and western hemlock
Slope: Level
Aspect: West
Topographic position: Upper sidehill
Elevation: 3,100 feet
Soil: Loam

Plot 5

Location: Quartzville Creek
Legal description: NW/NE, S.22, T.12 S., R.2 E.
Operation and ownership: Lucky Four Logging Company, Weyerhaeuser Timber Company
Area: 0.5 acres
Composition of stand: Douglas-fir with western hemlock understory
Slope: Level
Aspect:
Topographic position: Bench
Elevation: 2,500 feet
Soil: Rocky

Plot 6

Location: Calapooya
Legal description: SW/NW, S.24, T.24 S., R.3 W.
Operation and ownership: Weyerhaeuser Timber Company
Area: 0.5 acres
Composition of stand: Douglas-fir mixed with western red cedar and western hemlock
Slope: Level
Aspect:
Topographic position: Bench
Elevation: 2,100 feet
Soil: Clay

Plot 7

Location: Bone Mountain, Coquille
Legal description: SW/NE, S.11, T.31 S., R.10 W.
Operation and ownership: Coos Bay Lumber Company
Area: 0.5 acres
Composition of stand: Pure Douglas-fir with scattered western hemlock understory
Slope: 20 per cent
Aspect: West
Topographic position: Medium sidehill
Elevation: 2,950 feet
Soil: Sandy loam with sandstone outcrops

Plot 8

Location: Bone Mountain, Coquille
Legal description: NW/NW, S.27, T.31 S., R.10 W.
Operation and ownership: Coos Bay Lumber Company
Area: 0.5 acres
Composition of stand: Pure Douglas-fir with western hemlock, western red cedar and Port Orford cedar understory
Slope: 10 per cent
Aspect: Southwest
Topographic position: Upper sidehill
Elevation: 2,500 feet
Soil: Clay loam

Plot 9

Location: Fairview
Legal description: SW/NW, S.24, T.26 S., R.11 W.
Operation and ownership: Coos Bay Lumber Company
Area: 0.33 acres
Composition of stand: Pure Douglas-fir
Slope: 70 per cent
Aspect: Northeast
Topographic position: Ridge top
Elevation: 1,640 feet
Soil: Loam

Plot 10

Location: Wolf Creek
Legal description: SW/SE, S.27, T.27 S., R.2 W.
Operation and ownership: Associated Plywood
Area: 0.33 acres
Composition of stand: Pure Douglas-fir with western hemlock understory
Slope: 20 per cent
Aspect: West
Topographic position: Upper sidehill
Elevation: 3,700 feet
Soil: Clay loam

Plot 11

Location: Nigger Creek
Legal description: NW/NE, S.26, T.27 S., R.2 W.
Operation and ownership: Associated Plywood
Area: 0.5 acres
Composition of stand: Mixed Douglas-fir and western hemlock
Slope: 10 per cent
Aspect: North
Topographic position: Cove
Elevation: 2,900 feet
Soil: Gravelly

Plot 12

Location: Wilson Creek
Legal description: NE/SE, S.31, T.27 S., R.8 W.
Operation and ownership: Weyerhaeuser Timber Company
Area: 0.5 acres
Composition of stand: Pure Douglas-fir
Slope: Level
Aspect:
Topographic position: Ridge top
Elevation: 2,600 feet
Soil: Loam

Plot 13

Location: Valsetz
Legal description: SE/SW, S.22, T.9 S., R.9 W.
Operation and ownership: Valsetz Lumber Company
Area: 0.5 acres
Composition of stand: Decadent Douglas-fir with understory of large western hemlock
Slope: Level
Aspect:
Topographic position: Ridge top
Elevation: 2,050 feet
Soil: Loam over clay

Plot 14

Same as plot 13.

APPENDIX B

SCALING RULES FOR CONK ROT IN DOUGLAS-FIR

(Neff, L. Digest of log grading rules. Unpublished manuscript. United States Forest Service. 1946).

Visual evidences of decay by *Fomes pini* that will cull a log:

1. A log showing advanced decay over one entire end and visible decay at the other end should be culled.

2. A log that has twisted grain and shows advanced decay covering one-half of the cross-section of the log at both ends, but the affected halves are on opposite sides of the log, should be culled. Obviously, the rot has followed the spiral grain so that a straight cut could not be made through the log without hitting rot.

3. Conk pockets and flaky heart covering both ends of the log will cull the log.

4. A log having a single conk 7 feet from the end of the log and that end entirely covered with decay should be given one third of the gross scale for net scale.

5. A log that shows decay in the upper half at both ends of the log and has a rotten knot 16 feet from one end will have a net volume of one third the gross volume.

6. A log that has the upper half of one end decayed, a rotten knot 8 feet from that end, and a small indicator of rot on the upper half at the other end should have a length deduction equal to one half the gross length.

7. A log that shows two-thirds decayed on one end but has no conks or indicators of rot at the other end should have its gross length reduced by one-third.

APPENDIX C

Data was requested on how much gross volume would be increased if old-growth Douglas-fir were scaled to an 8-inch top rather than to a top diameter equivalent to 40 per cent of D.B.H. To answer this request all Douglas-fir trees on Plots 1 through 6 were scaled to two top diameters and the comparative gross volumes shown in Table 5. The percentage increases in gross volume obtained by scaling to an 8-inch top are shown for each plot in Table 35.

The greatest volume difference was on the highest site quality, which is natural, since the tallest trees with the least taper are on site quality I. Economically, the volume gained by cutting to an 8-inch top is inconsequential in the big timber found on these plots, because the increase is confined to low-grade top logs. Furthermore, since top logs in big timber are so frequently broken in felling, the increase in net volume would be even less important.

Table 35. INCREASE IN GROSS VOLUME WHEN CUTTING TO AN 8-INCH TOP INSTEAD OF TO 40 PER CENT OF D.B.H.* (based on 32-foot logs).

Plot	Volume increase in cutting to an 8-inch top	Site quality
	Per cent	
1	0.9	III
2	2.1	III
3	1.3	III
4	1.9	III
5	2.3	II
6	4.9	I

* Scaled to the nearest 12-foot log in the top.