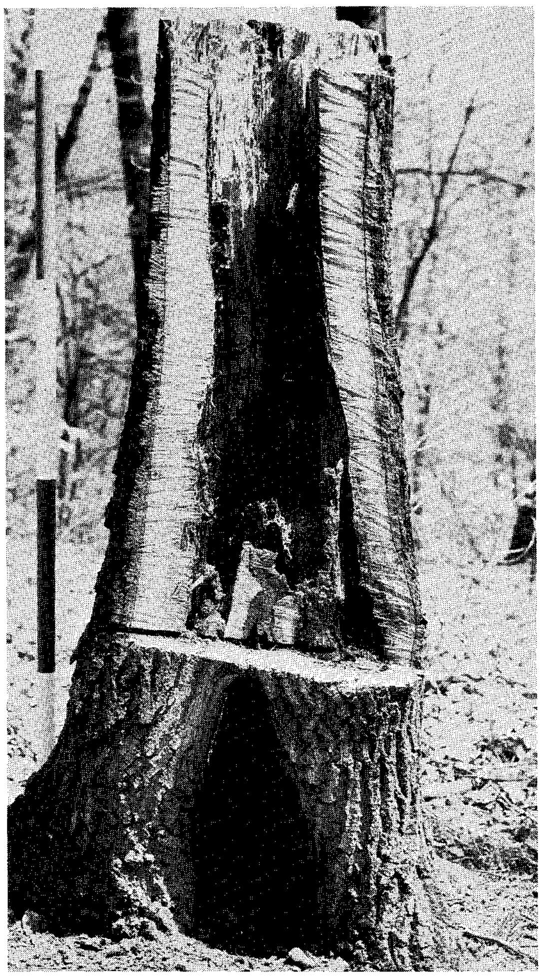
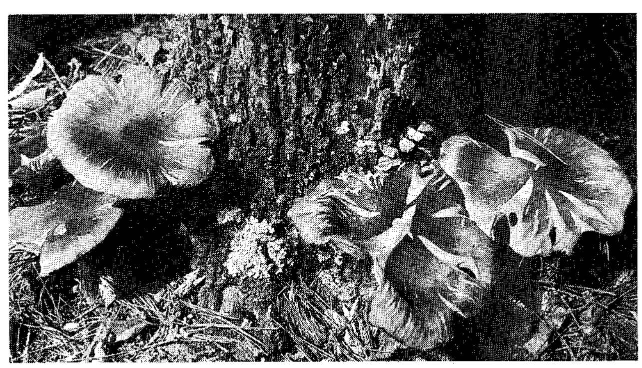
by Frederick H. Berry
and John A. Beaton

DECAY IN OAK
in the Central Hardwood Region





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OAK-HICKORY is the predominant forest type in the central hardwood region of Ohio, Indiana, Illinois, and Missouri. This type occupies almost 19 million acres, or about 65 percent of the commercial forest area in these states (fig. 1). These oak-hickory forests are of great economic importance. About 23 billion board feet of sawlog-size oak and 7 billion cubic feet of oak growing stock are found here. And over 500 million board feet of oak sawtimber are harvested annually *(2, 3, 5, 9)*.

Besides giving employment to thousands of workers in the woods and wood-related industries, these forests are heavily utilized by persons from metropolitan areas seeking recreation and relaxation.

Because oak is the leading timber species in the central hardwood region, it is necessary to manage these stands to provide the best possible utilization of this valuable hardwood resource. One of the most critical problems is loss from heartwood decay. More information is needed about this kind of loss.

We undertook a study of the four principal oak species in this region—black oak *(Quercus velutina* Lam.), scarlet oak *(Q. coccinea* Muenchh.), chestnut oak (*Q. prinus* L.), and white oak *(Q. alba* L.)—to determine the quantity of decay, the fungi associated with

Figure 1.—An even-aged upland oak stand in southern Missouri.

decay, and the relation of decay to external indicators, tree age, and diameter. Our aim was to provide forest managers with information to help them keep decay losses in these forests to a minimum.

METHODS

We located sample plots in areas that were representative of oak-hickory forests in the central hardwood region. We selected 113 sample areas in well-stocked, undisturbed (except for fire), even-aged stands 20 to 110 years old. About 75 percent of the areas were on National Forests (Wayne National Forest in Ohio; Hoosier National Forest in Indiana; Shawnee National Forest in Illinois; and Clark and Mark Twain National Forests in Missouri). The remainder were on private land and state forests. Field work, begun in 1962, was completed in 1968.

Sample areas consisted of concentric circular plots 1/20-, 1/10-, and 1/5-acre in size. All living trees 3.6 inches d.b.h. (diameter breast height) and larger were cut on the 1/20-acre plots; trees 5.6 inches d.b.h. and larger were cut on the 1/10-acre plots; and trees 11.6 inches d.b.h. and larger were cut on the 1/5-acre plots. Data collected from trees on the 1/20- and 1/10-acre plots were weighted so that all computations were based on 1/5 acre.

Trees meeting plot specifications were tallied; and d.b.h., age, crown class, and tree condition were recorded. Dead trees were ignored. The tallied trees were then cut at an average stump height of 1 foot. The main stem and merchantable branches were marked into 4-foot lengths up to a 4-inch top diameter (inside bark). Total height was recorded. The kind, extent, and location of all surface indicators of defects were recorded. Each tree was then cut into 4-foot bolts, which were examined for decay. Indicators of defects previously noted were examined; and if decay was associated with them, this was recorded. Where decay was encountered, the bolts were dissected to determine its extent.

The diameter inside bark at 16-foot intervals from stump height to a 4-inch-or-larger merchantable top was recorded. Top and bottom diameters and length of merchantable limbs were recorded. The maximum diameter of decay columns was located, diagrammed, and recorded. Lengths of decay columns were measured in both directions from the maximum diameter and recorded to the nearest 0.5 foot.

From the graphic tree-measurement sheets, we computed volumes in cubic feet, by Smalian's formula ($V = \frac{(B + b)}{2} L$ where B is equal to the basal area in square feet of the large end of the log; b is equal to the basal area of the small end of the log; and L is equal to the length of the log in feet). Gross tree volume was computed at 16-foot intervals from a 1-foot stump to a 4-inch-or-larger merchantable top diameter. No reduction in gross volume was made for trim or breakage. If decay was present, its volume was also computed in cubic feet and subtracted from the gross volume to determine the net tree volume.

Cultures were prepared from decay samples soon after collection to determine the fungi associated with decay. Sample blocks of decayed wood were split to expose a fresh face of infected wood. At least 6 cores of infected wood approximately 4 mm in diameter were removed with a sterilized increment hammer from each block and placed in test tubes containing 2.5-percent Fleischmann's diamalt with 2-percent agar. When the decay fungus was not isolated on the first attempt, re-isolations were attempted.

THE DECAY FUNGI

Occurrence of Fungi Causing Decay

Heart-rot fungi can usually be identified from the sporophores or fruiting bodies that develop on the infected trees. However, most of the fungi associated with decay in oaks rarely produce sporophores on living trees *(1)*, and it is seldom possible to determine the causal fungus from the type of decay alone. Therefore, to identify the fungi isolated from decay columns, it was necessary to compare pure cultures of these unidentified isolates with isolates from sporophores maintained in the reference collection of cultures at the Center for Forest Mycology Research at Madison, Wisconsin.

Twenty-nine species of fungi associated with decay of oak in the central hardwood region were isolated and identified (table 1). Their relative frequency was calculated by expressing the number of isolates of each fungus as a percentage of the total number of isolates. Most frequently isolated fungi were *Poria andersonii* (Ell. & Ev.) Neuman, *Stereum frustulatum* (Pers. ex Fr.) Fckl., *S. gausapatum* (Fr.) Fr., *Polyporus compactus* Overh., Unknown "H", *Irpex mollis* Berk. & Curt., *Hericium* spp., *Polyporus sulphureus* Bull. ex Fr., and *Poria oleracea* Davidson & Lombard. These nine species accounted for over 80 percent of the 715 infections identified. They were generally well distributed among the four species of oaks in the study.

Fungi associated with decay in the heartwood normally do not attack the sapwood. The decay is compartmentalized in tissues present at the time of wounding *(8)*. Thus, trees may grow to maturity and outwardly

Table 1.—*Occurrence of fungi causing decay in living oaks in the central hardwood region, by tree species and type of rot*

Fungus species	Identified infections					
	Scarlet oak	Black oak	White oak	Chestnut oak	Total	Frequency of infection
	No.	*No.*	*No.*	*No.*	*No.*	*Percent*
			WHITE ROT			
Poria andersonii (Ell. & Ev.) Neuman	12	56	36	13	117	16.36
Stereum frustulatum (Pers. ex Fr.) Fckl.	54	32	7	6	99	13.85
Stereum gausapatum (Fr.) Fr.	28	28	10	6	72	10.07
Polyporus compactus Overh.	15	37	5	5	62	8.67
Unknown "H"[1]	37	2	8	2	49	6.85
Irpex mollis Berk. & Curt.	2	26	13	7	48	6.71
Hericium spp.	4	14	24	3	45	6.29
Polyporus obtusus Berk.	2	3	8	2	15	2.10
Armillaria mellea (Fr.) Quél.	2	3	4	3	12	1.68
Merulius tremellosus Schrad. ex Fr.	2	3	2	3	10	1.40
Hymenochaete rubiginosa Dicks. ex Lév.	8	1	—	—	9	1.26
Polyporus dryophilus Berk.	4	—	2	3	9	1.26
Polyporus versicolor L. ex Fr.	3	3	2	—	8	1.12
Stereum complicatum (Fr.) Fr.	—	3	2	1	6	.84
Polyporus frondosus Dicks. ex Fr.	3	—	2	—	5	.70
Polyporus adustus Willd. ex Fr.	—	2	—	2	4	.56
Poria mutans Pk.	3	—	—	—	3	.42
Pleurotus ostreatus (Jacq. ex Fr.) Kumm.	2	—	—	—	2	.28
Stereum subpileatum Berk. & Curt.	1	1	—	—	2	.28
Rigidoporus vitreus (Pers. ex Fr.) Dounk.	—	—	—	2	2	.28
Corticium galactinum (Fr.) Burt	—	1	—	—	1	.14
Polyporus fissilis Berk. & Curt.	—	—	1	—	1	.14
Steccherinum setulosum (Berk. & Curt.) Miller	—	1	—	—	1	.14
Total	182	216	126	58	582	81.40
			BROWN ROT			
Polyporus sulphureus Bull. ex Fr.	41	12	3	1	57	7.97
Poria oleracea Davidson & Lombard	35	5	—	—	40	5.59
Poria cocos (Schw.) Wolf	4	5	1	6	16	2.24
Polyporus spraguei Berk. & Curt.	13	3	—	—	16	2.24
Poria nigra (Berk.) Cke.	1	2	—	—	3	.42
Fistulina hepatica (Huds.) Fr.	1	—	—	—	1	.14
Total	95	27	4	7	133	18.60
All species	277	243	130	65	715	100.00

[1]Misidentified as *Corticium lividum* Pers. ex Fr. in U. S. Dep. Agr. Tech. Bull. 785, FUNGI CAUSING DECAY OF LIVING OAKS IN THE EASTERN UNITED STATES AND THEIR CULTURAL IDENTIFICATION, by Ross W. Davidson, W. A. Campbell and Dorothy B. Vaughn. 1942.

appear healthy and vigorous. *Irpex mollis*, however, differs from most other wood-rotting fungi, because it also attacks living sapwood and the cambium, causing cankers to form on the trunk.

Wood-decay fungi are divided into two types—the white rots and brown rots. As implied by their names, the two types can be distinguished by the color of the decayed wood. The brown rots are not so numerous in oaks as the white rots. Over 80 percent of the total number of infections were due to white-rot fungi, and seven of the nine most commonly isolated fungi were members of this group (table 1).

Based on their position in the tree, decays are also divided into two categories, trunk rot and butt rot. Most of the fungi isolated from oak can cause both types of rot (table 2). However, there are some species (*Armillaria mellea* [Fr.] Quél., *Polyporus frondosus* Dicks. ex Fr., *P. spraguei* Berk. & Curt., and *Poria cocos* [Schw.] Wolf) that cause root and butt rots that rarely extend more than a few feet up the bole (fig. 2). Infected stumps serving as a food base may be important infection sources of root- and butt-rot fungi. Although the number of root and butt infections was less than half the number of trunk infections, the former accounted for a greater

Table 2.—*Fungi causing decay in oak in the central hardwood region and their relation to the portion of the tree bole affected*

Fungus species	Identified infections			Decay volume		
	In butt[1]	In trunk	Total	In butt[1]	In trunk	Total
	No.	*No.*	*No.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
			WHITE ROT			
Poria andersonii	13	104	117	22.19	69.93	92.12
Stereum frustulatum	22	77	99	13.41	47.70	61.11
Stereum gausapatum	19	53	72	25.78	39.49	65.27
Polyporus compactus	10	52	62	18.73	22.90	41.63
Unknown "H"	19	30	49	16.84	7.48	24.32
Irpex mollis	1	47	48	11.78	28.28	40.06
Hericium spp.	27	18	45	40.24	4.47	44.71
Polyporus obtusus	6	9	15	.77	5.42	6.19
Armillaria mellea	12	—	12	12.89	—	12.89
Merulius tremellosus	9	1	10	18.80	.07	18.87
Hymenochaete rubiginosa	—	9	9	—	2.11	2.11
Polyporus dryophilus	1	8	9	6.38	13.49	19.87
Polyporus versicolor	2	6	8	8.45	.61	9.06
Stereum complicatum	—	6	6	—	.36	.36
Polyporus frondosus	5	—	5	3.58	—	3.58
Polyporus adustus	3	1	4	4.04	.05	4.09
Poria mutans	—	3	3	—	1.50	1.50
Pleurotus ostreatus	—	2	2	—	.04	.04
Stereum subpileatum	1	1	2	2.18	1.02	3.20
Rigidoporus vitreus	—	2	2	—	.14	.14
Corticium galactinum	—	1	1	—	.51	.51
Polyporus fissilis	1	—	1	1.77	—	1.77
Steccherinum setulosum	1	—	1	—	10.48	10.48
Total	152	430	582	207.83	256.05	463.88
			BROWN ROT			
Polyporus sulphureus	32	25	57	101.36	58.98	160.34
Poria oleracea	7	33	40	20.29	12.19	32.48
Poria cocos	16	—	16	47.32	—	47.32
Polyporus spraguei	16	—	16	16.41	—	16.41
Poria nigra	—	3	3	—	5.81	5.81
Fistulina hepatica	1	—	1	2.67	—	2.67
Total	72	61	133	188.05	76.98	265.03
All species	224	491	715	395.88	333.03	[2]728.91

[1]Decay originating at stump height or below was considered as butt decay.
[2]Decay volume associated with identified infections; in addition there were 446.57 cubic feet of decay volume in which the causal fungi were unknown.

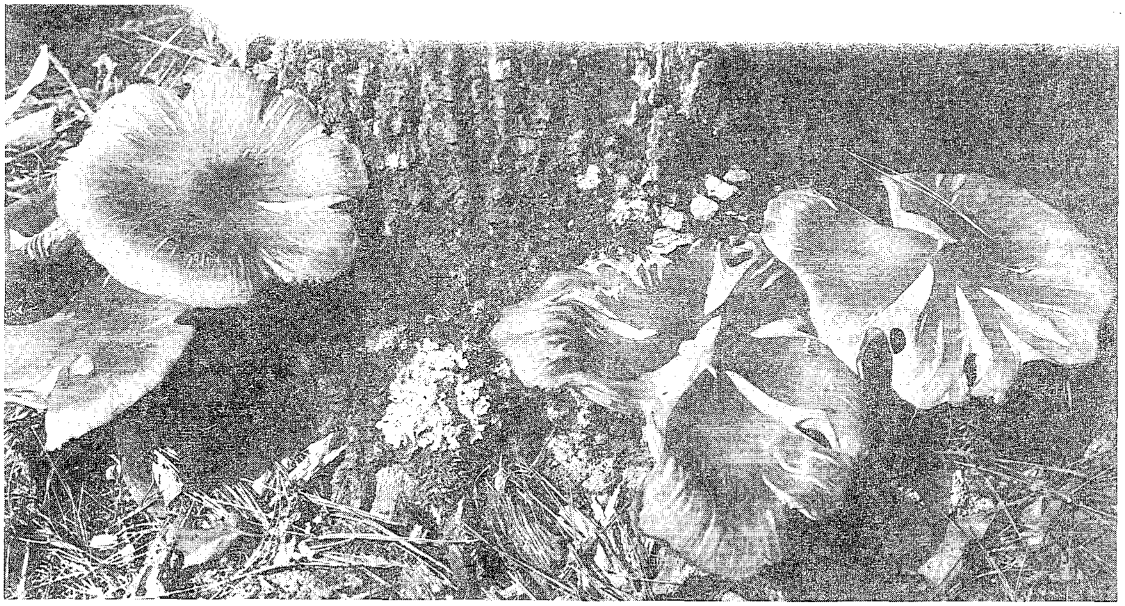

Figure 2.—Fruiting bodies of the honey mushroom, *Armillaria mellea* (Fr.) Quél., at the base of an oak tree infected with butt rot.

Table 3.—*Relative importance of fungi causing decay in living oaks in the central hardwood region, by tree species and type of rot*

Fungus species	Decay volume				Total identified decay volume	
	Scarlet oak	Black oak	White oak	Chestnut oak		
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Percent*
			WHITE ROT			
Poria andersonii	3.27	44.21	31.34	13.30	92.12	12.64
Stereum gausapatum	28.05	18.38	9.55	9.29	65.27	8.95
Stereum frustulatum	29.36	24.18	4.01	3.56	61.11	8.38
Polyporus compactus	12.03	19.71	3.77	6.12	41.63	5.71
Hericium spp.	.46	26.96	16.79	.50	44.71	6.13
Irpex mollis	.48	15.20	10.08	14.30	40.06	5.49
Unknown "H"	16.72	4.58	1.68	1.34	24.32	3.34
Polyporus dryophilus	11.19	—	.80	7.88	19.87	2.73
Merulius tremellosus	6.03	6.75	5.04	1.05	18.87	2.59
Armillaria mellea	1.18	.68	5.88	5.15	12.89	1.77
Steccherinum setulosum	—	10.48	—	—	10.48	1.44
Polyporus versicolor	8.48	.26	.32	—	9.06	1.24
Polyporus obtusus	.10	.86	3.77	1.46	6.19	.85
Polyporus adustus	—	3.83	—	.26	4.09	.56
Polyporus frondosus	3.52	—	.06	—	3.58	.49
Stereum subpileatum	1.02	2.18	—	—	3.20	.44
Hymenochaete rubiginosa	2.00	.11	—	—	2.11	.29
Polyporus fissilis	—	—	—	1.77	1.77	.24
Poria mutans	1.50	—	—	—	1.50	.21
Corticium galactinum	—	.51	—	—	.51	.07
Stereum complicatum	—	.32	.04	—	.36	.05
Rigidoporus vitreus	—	—	—	.14	.14	.02
Pleurotus ostreatus	.04	—	—	—	.04	.01
Total	125.43	179.20	93.13	66.12	463.88	63.64
			BROWN ROT			
Polyporus sulphureus	94.72	59.16	4.52	1.94	160.34	22.00
Poria cocos	2.41	26.09	3.00	15.82	47.32	6.49
Poria oleracea	31.07	1.41	—	—	32.48	4.45
Polyporus spraguei	15.22	1.19	—	—	16.41	2.25
Poria nigra	4.36	1.45	—	—	5.81	.80
Fistulina hepatica	2.67	—	—	—	2.67	.37
Total	150.45	89.30	7.52	17.76	265.03	36.36
All species	275.88	268.50	100.65	83.88	[1]728.91	100.00

[1]Decay volume associated with identified infections; in addition, there were 446.57 cubic feet of decay volume in which the causal fungi were unknown.

amount of cull—395.88 cubic feet compared to 333.03 cubic feet in the trunk.

Relative Importance of Fungi Causing Decay

Over one-fifth (22 percent) of the total decay volume for which fungi were identified was caused by *Polyporus sulphureus*, the sulfur fungus (table 3). This fungus species, widespread in the United States on both hardwoods and conifers, was isolated from all four oak species.

Other fungi associated with appreciable decay losses were *Poria andersonii, Stereum gausapatum, S. frustulatum, Hericium* spp., *Polyporus compactus, Poria cocos,* and *Irpex mollis*. These seven species, together with *Polyporus sulphureus*, accounted for 552.56 cubic feet, or about 75 percent, of the total identified decay volume.

DECAY RELATIONS

Entry Courts and Infection

In oaks, the central core of heartwood is surrounded by living sapwood, which is protected by the bark. Since sapwood is ordinarily not attacked by heart-rot fungi, the sapwood and bark protect the heartwood from attack. Before most heart-rot fungi can successfully invade the heartwood, a wound that penetrates to the heartwood or dead tissue extending to the heartwood is required (fig. 3).

Tree wounds are caused in a number of ways. In the central hardwood region, we found that fire surpassed all other causes of wounds through which heart-rot fungi may enter. Almost 25 percent of all infections originated at fire scars, and over 40 percent of the total decay volume was associated with fire scars (table 4). Because of the large area of exposed wood and the long period of time required for the growth of protective callus, fire scars are particularly vulnerable to decay (fig. 4).

Dead branch stubs were second only to fire scars as entry points for heart-rot fungi (fig. 5). However, decay loss was only about one-third that of fire scars, since many of the infections from fungi entering through dead branch stubs frequently result in relatively minor amounts of decay. Scarlet oak, which tends to retain its branches longer than the other oak species, was particularly vulnerable to infection entry through branch stubs.

The comparative effectiveness of defect indicators visible on the tree bole as indicators of hidden decay is shown in table 5. Open fire scars were the only indicator with which hidden decay was consistently found. However, decay was associated in two out of three trees with either closed fire scars or dead or dam-

Figure 3.—Manner in which heart-rot fungi may enter a tree. From *Pathology of Trees and Shrubs,* by T. R. Peace, reproduced by special permission and courtesy of the Forestry Commission of Great Britain.

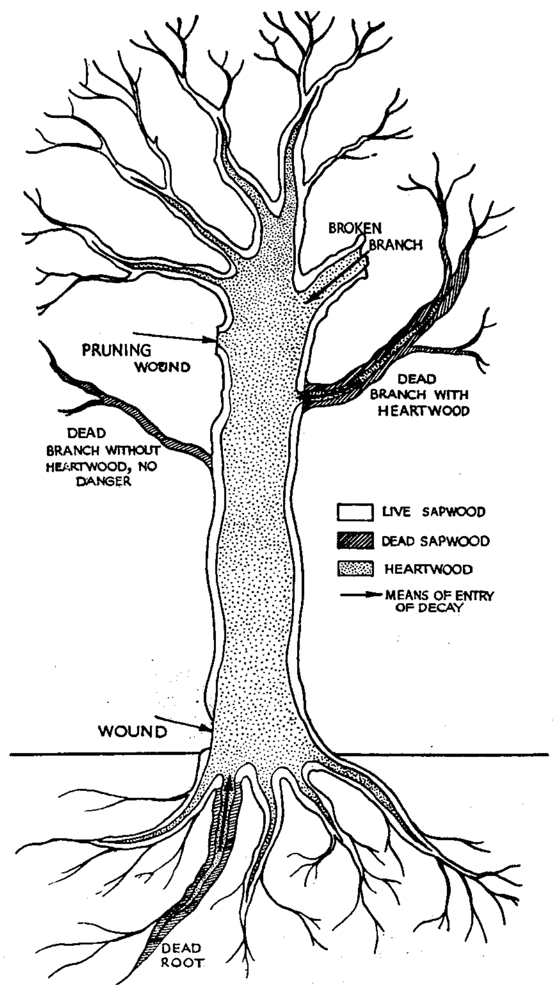

Table 4.—*Relationship of entry courts to incidence of infection and volume of decay*

Infection court	Infections		Volume of decay	
	No.	*Percent*	*Cu. ft.*	*Percent*
Fire scars	446	24.45	470.94	40.06
Dead branch stubs	402	22.04	158.07	13.45
Branch bumps	238	13.05	130.28	11.08
Insect wounds	181	9.92	52.96	4.51
Parent stumps	168	9.21	111.58	9.49
Mechanical injuries	101	5.54	48.89	4.16
Open branch stub scars	99	5.43	81.61	6.94
Damaged or dead tops	96	5.26	76.56	6.51
Roots	70	3.84	35.83	3.05
Woodpecker injuries	23	1.26	8.76	.75
Total	1,824	100.00	1,175.48	100.00

Figure 4.—A fire-scarred black oak cut lengthwise to show decay in trunk.

Figure 5.—A black oak with a dead branch stub about 12 feet up trunk.

Table 5.—*The comparative effectiveness of visible indicators of decay*

Indicator	Frequency of occurrence			Frequency of decay
	Decay present	Decay absent	Total	
	No.	*No.*	*No.*	*Percent*
Open fire scars	77	1	78	98.72
Closed fire scars	369	205	574	64.29
Dead or damaged tops	96	62	158	60.76
Unsound branch stubs[1]	60	135	195	30.77
Mechanical injuries	101	295	396	25.50
Branch bumps[1]	45	149	194	23.20
Open branch stub scars	99	707	806	12.28
Unsound branch stubs[2]	102	841	943	10.82
Stem bulges	55	459	514	10.70
Sound branch stubs[1]	24	221	245	9.80
Branch bumps[2]	111	1,484	1,595	6.96
Woodpecker injuries	23	866	889	2.59
Sound branch stubs[2]	50	2,231	2,281	2.19
Unsound branch stubs[3]	95	4,437	4,532	2.10
Branch bumps[3]	82	5,864	5,946	1.38
Sound branch stubs[3]	71	11,331	11,402	.62

[1]4 inches and more in diameter.
[2]2-4 inches in diameter.
[3]1-2 inches in diameter.

aged tops, and one out of three trees with unsound branch stubs 4 inches and more in diameter.

Decay in Relation to Age and Diameter

Gross and decay volumes of the four oak species were calculated and analyzed to determine the relationship between percent decay and tree age and diameter. Estimates of the percent of decay for trees of various ages and diameters are shown in tables 6 and 7. These estimates were obtained by fitting a weighted polynomial regression line to the actual data. The standard error of each estimate is also given in the tables.

The percentage of decay volume increased progressively with increasing age. As trees become older, the relative proportion of heartwood becomes greater, opportunities for infection multiply, and the rate of wound healing becomes slower. But important differences in decay occur between stands of the same age, depending on prevalence of wounds, time of wounding, seedling or sprout origin of the trees, and site *(6)*.

The percentage of decay volume also increased progressively with increasing diameter.

Estimated decay percentages for the various oak species differ considerably. Scarlet oak had the greatest amount of decay, followed by black oak, chestnut oak, and white oak, in that order (fig. 6).

Table 6.—Estimated decay in oak stands in the central hardwood region, by age and species

Age *(years)*	Scarlet oak		Black oak		Chestnut oak		White oak	
	Decay	Standard error of estimate	Decay	Standard error of estimate	Decay	Standard error of estimate	Decay	Standard error of estimate
	Percent		*Percent*		*Percent*		*Percent*	
20	0.80	1.13	0.00	.28	0.00	1.17	0.00	.15
30	1.69	.63	.39	.22	.00	.71	.13	.12
40	2.81	.39	1.23	.17	.03	.42	.61	.10
50	4.15	.42	2.07	.15	1.12	.34	1.10	.09
60	5.72	.52	2.92	.18	2.08	.37	1.58	.12
70	7.51	.62	3.76	.23	2.92	.39	2.06	.15
80	9.53	.79	4.69	.30	3.64	.38	2.54	.19
90	11.77	1.13	5.44	.38	4.23	.42	3.02	.23
100	14.24	1.66	6.29	.45	4.70	.63	3.50	.27
110	16.94	2.38	7.13	.53	5.04	1.02	3.98	.31

Table 7.—Estimated decay in oak stands in the central hardwood region, by diameter and species

Diameter *(inches)*	Scarlet oak		Black oak		Chestnut oak		White oak	
	Decay	Standard error of estimate	Decay	Standard error of estimate	Decay	Standard error of estimate	Decay	Standard error of estimate
	Percent		*Percent*		*Percent*		*Percent*	
4.5	3.73	1.09	1.59	0.32	0.69	0.63	1.07	0.18
6.5	4.25	.62	1.93	.24	1.52	.45	1.25	.14
8.5	4.73	.45	2.28	.19	2.35	.33	1.43	.14
10.5	5.19	.51	2.62	.18	3.18	.34	1.61	.20
12.5	5.62	.61	2.97	.22	4.02	.47	1.79	.27
14.5	6.01	.70	3.31	.29	4.85	.66	1.96	.34
16.5	6.38	.87	3.66	.37	5.68	.87	2.14	.43
18.5	6.71	1.23	4.00	.45	—	—	2.32	.51
20.5	7.01	1.80	4.35	.54	—	—	2.50	.60
22.5	7.29	2.58	4.69	.64	—	—	2.68	.68

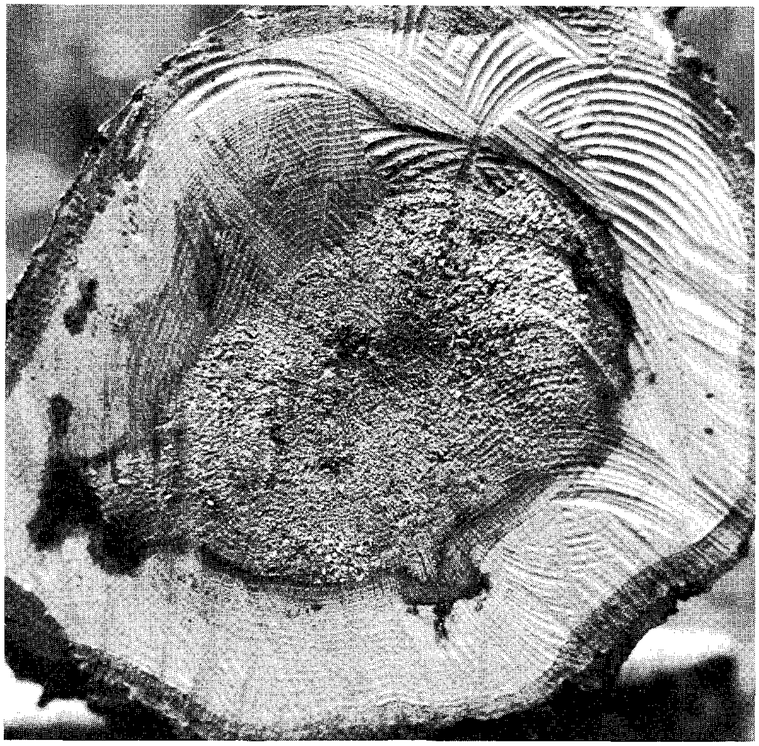

Figure 6.—Heart rot in a scarlet oak log.

CONTROL

Although heart rot causes considerable loss in oak stands in the central hardwood region, these losses can be reduced.

We found that many infections followed fire injury. Therefore, more adequate fire protection can greatly reduce the incidence of decay in these stands.

Improved management and silvicultural practices can further reduce losses. Many oak stands are of sprout origin. Butt rot can be reduced by thinning oak sprouts before heartwood forms at the base to act as a bridge for decay from the parent stump. Lower sprouts should be favored over the more decay-susceptible sprouts higher on the trunk *(7)*.

Control of stand density can also lessen decay hazard through regulation of branch size and reduction of wind and ice damage. Density in young stands should be high enough so that branches do not form heartwood before being shaded out *(4)*.

Rotations (number of years trees are grown until harvested) should be sufficiently short so that the trees are cut before decay becomes a problem.

And even-aged management, utilizing clearcutting to regenerate stands, will cause less felling and skidding injuries and subsequently less decay.

CONCLUSIONS

Although 29 species of fungi were found associated with decay in oak in the central hardwood region, 9 species accounted for over 80 percent of the identified infections. The most commonly isolated decay fungi were *Poria andersonii, Stereum frustulatum, S. gausapatum, Polyporus compactus*, Unknown "H", *Irpex mollis, Hericium* spp., *Polyporus sulphureus*, and *Poria oleracea. Polyporus sulphureus* caused more decay volume loss than any of the other species.

Fire scars were the most important entry courts for decay fungi. Almost 25 percent of all infections originated at fire scars and over 40 percent of the total decay volume was associated with fire scars.

Decay volume increased progressively with increasing age and diameter. Scarlet oak had the greatest amount of decay, followed by black oak, chestnut oak, and white oak.

The considerable losses caused by decay fungi in oak stands in the central hardwood region can be reduced by better fire control and improved management and silvicultural practices.

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