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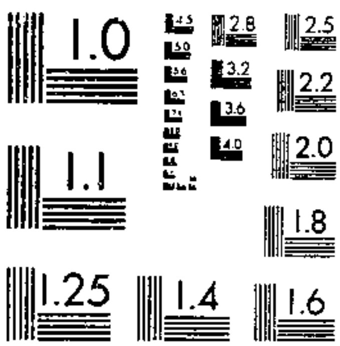

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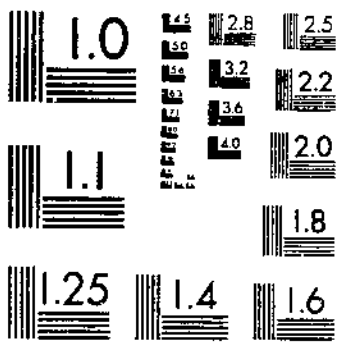

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BUTT ROT IN UNBURNED SPROUT OAK STANDS[1]

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CONTENTS

INTRODUCTION

The second-growth oak forests of the eastern and central United States are largely of sprout origin, and the proportion of sprout trees is generally increasing. Forest products worth many millions of dollars are produced annually from these stands. Under proper management and adequate fire protection these sprout-oak forests (pl. 1, *A*) will

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[2] The authors shared equally in the work. They wish to express their thanks to George H. Hepting, Carl Hartley, and L. W. R. Jackson, of the Division of Forest Pathology, and to R. M. Lindgren, formerly of the same Division, under whose direction different parts of this study were conducted, for their interest, guidance, and cooperation; to Ross W. Davidson, Bowen Crandall, Dorothy Blaisdell, and W. A. Campbell, of the same Division, for culturing and identifying the fungi; to L. O. Overholts, Pennsylvania State College, for his aid in identifying fungi; to Franklin G. Liming, formerly of the Division of Forest Pathology, for the help of his preliminary work; to W. A. Campbell, T. J. Grant, formerly of the Division of Forest Pathology, and Sidney Judkins, Civilian Conservation Corps enrollee, for their aid in taking field data. Without the cooperation of four national forests, especially the George Washington, and the State forestry departments of Pennsylvania, Connecticut, New Jersey, and Maryland, the breadth of the study would have been greatly reduced. Labor and tools from the Civilian Conservation Corps were used in most of the dissection work.

become a more important source of forest products than at present. They are usually well-stocked, make very good early growth, and are particularly suited for the production of cross ties, posts, mine props, and other products that do not require a long rotation.

It has been estimated (*32*) [3] that sprout growth makes up 75 to 90 percent of the second-growth oak forests in general, and that stands following charcoal cuttings and forest fires consist of 90 to 100 percent sprouts. This is in marked contrast with the virgin oak stands, which are considered to be largely of seedling origin. Sprout growth has both desirable and undesirable features. Abundant regeneration and rapid early growth, which are characteristic of sprout stands during early age, give a distinct advantage in short rotations, but frequent occurrence of butt rot often makes sprouts less desirable than seedlings on long rotations used for the production of high-quality lumber.

Unfortunately, all too often the loss from butt rot is unpredictable in the growing stand and its extent is learned only at the time of cutting. The economic importance of the problem has long been recognized but has received little technical attention. Wounds caused by fires in hardwoods have been studied as avenues of entrance for heartwood-destroying fungi (*17*, *18*), but the infection of sprouts from the stump from which they originate or from dead or cut companion sprouts has not been carefully investigated.

Graves and Fisher (*14*) in 1903 stated that second-growth hardwood forests in New York are composed principally of sprouts, which are inferior to seedling trees and are usually short-lived, because the old stumps from which they have sprung decay and finally infect them. They found that the decay is often so rapid in old sprout stands that the amount of wood added each year by growth is more than offset by the decay. For example, in a sprout forest in southern New York, the average yield per acre in cubic feet was less in 60-year-old stands than in those 50 years old, because of butt rot.

Leffelman and Hawley (*21*) state that sprouts form an independent root system and that the old roots that are not incorporated in the new root system "decay quickly and carry decay back into the heart of the new tree."

The chief objection to sprouts, according to Westveld (*31*), is their susceptibility to butt rot, as the parent stump offers an excellent opportunity for the entrance of wood-destroying fungi. He found that 32 percent of a group of sprouts cut on one of the college wood lots at East Lansing, Mich., were decayed at the base and that only 5 percent of the seedlings cut were decayed.

Vogenberger [4] expresses the opinion that wood-destroying fungi attack the parent stump and later extend into the heartwood of the sprout, where a large percentage of the butt log of the sprout is affected by heart rot.

In 1934 Davidson (*7*) reported that Nelson and Hedgcock found, upon examining a third-generation coppice growth at Mont Alto, Pa., in 1928, a number of trees with decay, 16 of which yielded cultures of *Stereum gausapatum* Fr. They thought that the parent stump or a dead companion sprout was the source of infection.

[3] Italic numbers in parentheses refer to Literature Cited, p. 41.

[4] VOGENBERGER, RALPH A. SPROUTING CAPACITY AND SPROUT DEVELOPMENT IN CERTAIN HARDWOOD SPECIES OF CENTRAL PENNSYLVANIA. Unpublished thesis for degree of master of science in forestry, Pennsylvania State College.

The present study was undertaken to determine what factors other than fire wounds are of importance in affecting the incidence of decay in sprout oak stands. Its primary purposes were to obtain information on (1) the manner in which butt-rotting fungi gained entrance into sprouts free of fire damage, (2) the decay hazard from cut or dead companion sprouts, (3) the percentage of trees infected, and the extent of decay in typical unscarred sprout stands, (4) the factors contributing to high or low decay incidence, (5) the relative susceptibility of the more important oak species to butt-rotting fungi, and (6) practices that would reduce decay losses in sprout stands.

The field work was begun in the fall of 1933 and continued until the fall of 1936. During that period memoranda were released on the progress of the work, with preliminary conclusions and recommendations for stand improvement.

ORIGIN AND DEVELOPMENT OF SPROUT STANDS

Sprouts generally originate in the region of the root collar in most hardwoods. Eventually some of these sprouts grow to mature trees. Sprouting usually takes place within the year following cutting, sometimes immediately after cutting, as in late spring and early summer, or it may be delayed as long as 8 months when trees are cut during the dormant season. Shortly after cutting, wood-destroying fungi attack the stump and gradually cause its decay.

The progress and period of fungal activity in a stump depend upon several conditions. A small, low, smoothly cut stump with one or more vigorously growing sprouts is soon grown over and the fungus dies out. On the other hand, large stumps will continue to decay for many years, and it takes several years after the stump is decayed for the new sprout growth to close over the old stump cavity. After a stump bearing a sprout has disappeared as a result of decay and has become covered with new wood, the sprout may easily be mistaken for a seedling. This obliterating of the parent stump by decay and subsequent sprout overgrowth makes it difficult to distinguish between seedlings and sprouts from small stumps after the trees reach a diameter at breast height of 5 to 6 inches.

GROWTH FORMS

Unfortunately, there has been some inconsistency in terms used to describe and distinguish between sprouts arising from different-sized stumps and successive generations of sprouts. In some cases an arbitrary parent-stump size has been used to separate them into two groups, seedling sprouts and sprouts. Leffelman and Hawley (*21*) have classed as seedling sprouts those that grow from stumps 2 inches or less in diameter at the ground line and utilize the old root system in its entirety, and as sprouts those that originate from a stump larger than 2 inches at the ground line and form an independent root system occasionally incorporating a part of the old root system but never all.

Because of the complexity of sprout development, any comprehensive classification should take into account the size of parent stump and number of subsequent sprout generations. In the present study, all trees arising from stumps, regardless of size of parent stump, are classed as sprouts; however, the term seedling sprout is sometimes used when speaking of sprouts from stumps 2 inches or smaller in diameter.

THE BUD TYPES FROM WHICH OAK SPROUTS ARISE

Oak sprouts arise from inconspicuous latent or dormant buds at or near the root collar and sometimes from the side of the stump, rather than from adventitious buds (pl. 2, *A* and *B*). These latent buds are formed originally as normal axillary or accessory buds that have continued to live by annually increasing in length, leaving what is known as a bud trace. These buds, which are formed as branch buds, are directly connected to the primary wood in seedling trees. Often this connection or bud trace (pl. 2, *B*) is destroyed by decay, in the case of stump sprouts. Latent buds, in their normal development, grow much as they would if they were producing branches, except much more slowly. Branching occurs frequently, often resulting in a cluster of buds around the root collar.

A distinguishing feature observed in many latent buds is the presence of a hard conical woody spur (pl. 2, *A*) that extends outward into and often nearly through the bark, the bud being attached to the apical end. The origin of very young sprouts from latent buds may be detected by the presence of old bud scales at the base of the young sprout, while old bud scales would be absent from the base of sprouts from adventitious buds. Latent buds were found to occur frequently on the bole of oak trees from which grow epicormic branches. Often following a heavy thinning these epicormic branches become numerous and the trees have been described as "feathering out."

ROOT DEVELOPMENT

In the development of sprouts from a stump, the old root system may or may not be entirely taken over by the new growth. The extent to which the old root system is utilized by the new growth is dependent on the size of the old stump and root system and the rapidity with which the new top develops to a size sufficient to meet the demands of the old root system. Vigorous sprouts from small stumps and consequently small root systems will utilize all or nearly all of the old roots, while at the other extreme, weak sprouts from large old stumps will utilize only a small part of the old root system. In this natural adjustment between the old root system and the new sprout growth, that part of the old root system in excess of the ability of the new sprout growth to support will gradually decay and disappear.

On the relation of sprouts to the root system, Schwarz (*29*) has reported that the old root system may not only be utilized by the new sprout growth but that new roots may be added to supply the needs of new top growth and to replace some of the old roots that decay and disappear. He also points out that there is a stronger tendency in some species to develop independent root systems than in others, and as this increases the resulting sprout growth approaches seedling growth in quality and value. This observation is not in agreement with that of Leffelman and Hawley (*21*), who point out that sprouts growing from stumps 2 inches and larger at ground level usually form an independent root system and are frequently subject to decay entering from rotting roots of the old root system.

A, Typical sprout oak stand of the Allegheny and Appalachian regions. B, Healthy 8-year-old black oak sprouts [illegible]. One or more of these sprouts will probably survive and make up part of the final stand.


A
B
W.D.

[illegible]

In the present study no evidence was found that would indicate that oak sprouts develop an independent root system regardless of the size of the parent stump. Several root systems were partly dug out, and in no instance were there any indications that an independent root system had developed.

AGE, SIZE, AND VIGOR OF PARENT STUMP IN RELATION TO SPROUTING

The sprouting capacity of stumps has been found by various investigators (*5, 10, 13, 32*) to be related to age, size, vigor, and species of parent stumps. Their evidence shows that sprouting capacity decreases as age and size of stump increase, but varies with different species. Oak stumps larger than 24 inches in diameter or older than 100 years are considered unlikely to sprout, although there are records of red oak stumps over 200 years old sprouting (*20*). Of the oaks studied by the writers, the decline in sprouting capacity occurred earliest in white oak and latest in red oak. To secure the best growth in coppice stands it has been the practice to select only small low-cut stumps 6 inches or under in diameter for reproduction purposes. It has been pointed out (*1, 20, 30*) that sprouting capacity when measured in number of sprouts per stump is not as important as the number of stumps sprouting, since seldom does more than one sprout from a stump survive. Thus the stocking of the mature second-growth stand is much more dependent on the number of stumps sprouting than on the original number of sprouts.

Supplementary data gathered from a series of experimental plots established on the George Washington National Forest show that the sprouting capacity of oak decreased with age and size of stump. The loss of sprouting capacity due to age and size was more noticeable in some species than in others. White oak was found to lose its sprouting capacity when younger and smaller than any of the other oaks. Good sprouting of white oak occurred until it was about 60 years old and 8 to 10 inches in diameter. After an age of 100 years and 12 to 14 inches in diameter, few if any white oak stumps produced sprouts. The other oak species sprouted to a somewhat older age and larger size. Approximately 25 percent of the scarlet oak stumps 200 years old and 24 inches in diameter produced sprouts.

Of 1,304 stumps of 5 oak species from 8 to 30 inches in diameter cut during the period 1931–36 on selective logging operations, only 48 percent produced sprouts. Most of these sprouts appeared healthy (pl. 1, *B*), and one or more sprouts per stump will probably survive and make part of the stand. In another series of plots where 681 stumps were cut during 1935–36, ranging in age from 35 to 65 years and from 4 to 12 inches in diameter, over 87 percent produced sprouts. No relation appeared to exist between vigor of the tree at the time it was cut and subsequent sprouting. There was a decided tendency for the older and larger stumps to sprout mostly at or below ground level, while the sprouts on small young stumps were not so limited. This agrees with Foster and Ashe (*8*), who found that stumps of young trees and seedlings of chestnut oak sprout from either the root collar or the stem, while sprouting of older stumps is practically limited to the root collar.

Graves (*13*), Frothingham (*10, 11*), and Buttrick (*5*) reported that a more vigorous crop of sprouts was produced when the trees were cut during the period of vegetative rest. Zon (*32*) states that extensive measurements on stumps cut at different seasons of the year invariably show poorer results from cuttings in summer than in winter, and that trees cut in summer failed in many cases to produce sprouts. In the 1,985 stumps mentioned above, a greater percentage of the large stumps sprouted when cut in the dormant season or in the early spring, while very little if any seasonal difference was found in the small stumps from young trees.

For the 1,304 stumps observed in the selectively cut areas, those stumps with a thin or dense canopy over them sprouted better than those in the open. In the case of the 681 smaller stumps, shade or partial shade did not appear to be a factor in sprout initiation.

COMPARATIVE DEVELOPMENT OF SEEDLINGS AND SPROUTS

The comparative value of seedling or seedling-sprout growth and sprout reproduction has been studied by several workers. Mattoon (*25*) found that chestnut sprouts from stumps of seedling trees made 25 percent greater height growth during the first 3 years than sprouts from coppice stumps of good average quality. Foster and Ashe (*8*) concluded that the diameter for cutting chestnut oak sprouts should not exceed 14 inches, breast high, since beyond that limit the rate of growth of sprouts is slow and the sprouting capacity of the stock begins to decrease. Spaeth (*30*) and Leffelman and Hawley (*21*) substantially agree that sprouts make their most rapid growth in youth and that the growth rate falls off slowly but steadily throughout the life of the tree; also that seedlings grow slowly during the early years, attain a very rapid growth rate during the period from 15 to 60 years of age, and decline slowly in growth rate from 60 to 90 years of age. Seedlings are considered the most desirable elements in a stand. Leffelman and Hawley state that seedlings, although characterized by slow growth during the early stages of development, finally catch up with the more rapid sprout and seedling-sprout growth and ultimately become dominant and codominant trees.

In the plots included in the present study there were 47 seedlings and 478 seedling sprouts in the 3,293 trees dissected, or slightly less than 16 percent of the total stand. More than 61 percent of the seedlings and seedling sprouts were included in the intermediate-suppressed group, as determined by growth rate and crown class. These results indicate that seedlings and sprouts from very small stumps constitute only a small part of even-aged sprout oak stands and that their chances of becoming dominant and codominant trees are fewer than has been supposed (*21*). However, it must be remembered that the present study dealt exclusively with young oak growth 15 to 90 years old. In the stands studied, located in widely separated areas, it is apparent that an abundance of vigorous sprout growth in a stand together with its more rapid early growth is not favorable to good seedling or seedling-sprout development. In most coppice stands a dense canopy is formed during the first few years, thus greatly retarding or eliminating the slower-growing forms, particularly seedlings. This condition is most commonly found where relatively young stands, either seedling or sprout, have been clear-cut for charcoal or cordwood. In older stands, where the larger stumps do not sprout, seedlings and seedling sprouts have a better chance to compete with the sprouts.

Kuenzel[5] in working with chestnut oak, concluded that clear-cutting of oak reproduction encourages rapid growth both of seedlings and of sprouts, but that the fast growth of the latter may threaten the ultimate development of the seedlings.

In studying the yield of second-growth stands in the southern Appalachians, Frothingham (*12*) says: "Where they have escaped fire damage such stands equal or excel in yields of lumber and other forest products the mature and overmature timber of the virgin forest." Occasionally second-growth mixed oak forests composed of sprouts 50 to 70 years of age yield lumber and ties of good quality with little loss from decay, on the George Washington National Forest in Virginia. For the production of certain types of forest products where small size and rapid growth are needed, sprouts may be more desirable than seedlings. The relative value of seedling and sprout stands must largely be determined by their use and length of rotation.

DISTRIBUTION AND DESCRIPTION OF WORKING AREAS

Study plots one-fifth or one-fourth acre in size and rectangular in outline were selected as representative samples of unburned oak growth in the several areas studied. The approximate locations of the

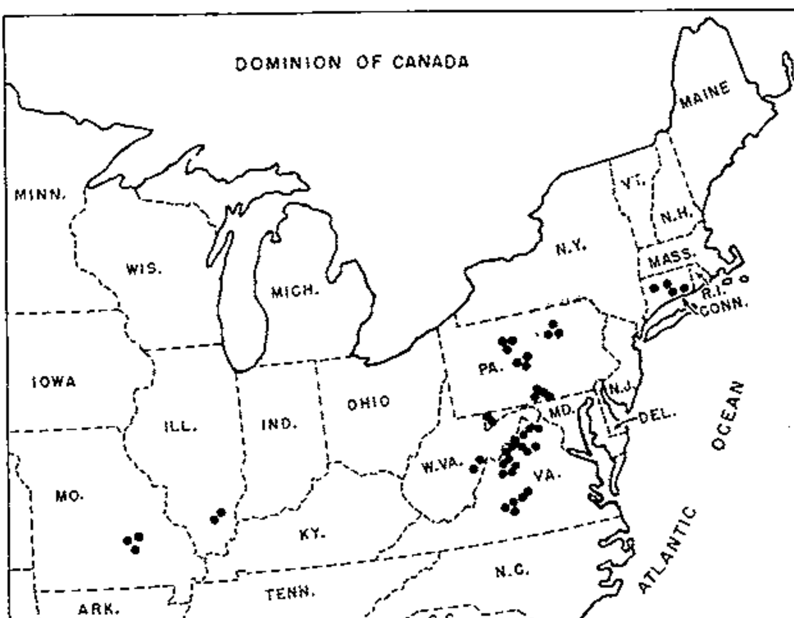


FIGURE 1.—Location of plots studied.

plots are shown in figure 1. The plots selected for study were free from visible fire wounds. Since little effort was made to select plots containing any certain oak species, it is believed that the percentage of a species cut in any given area is some indication of the abundance of that species in that particular area and site quality. The following

[5] KUENZEL, JOHN G. THE INFLUENCE OF CUTTING ON THE SURVIVAL AND EARLY GROWTH OF CHESTNUT OAK SEEDLINGS. U. S. Forest Expt. Sta., Cent. States Sta. Note 23, 3 pp. 1935. [Mimeographed.]

oak species were encountered and are listed according to their respective abundance: White (*Quercus alba* L.), scarlet (*Q. coccinea* Muench.), chestnut (*Q. montana* Willd.), black (*Q. velutina* Lam.), red (*Q. borealis* var. *maxima* (March.) Ashe), post (*Q. stellata* Wang.), and blackjack (*Q. marilandica* Muench.).

Most of the plots on which trees were dissected were located in medium to good sites, a majority being in the medium sites. The plots were clear-cut of all oak trees 2 inches or over in diameter at breast height. The trees were for the most part between 25 and 55 years old (fig. 2) in even-aged stands that had developed after charcoal or mine-prop cuttings or fires. Some of the areas had been clear-cut several times previous to dissection, and many of them had burned after cutting and before the establishment of the present stand.

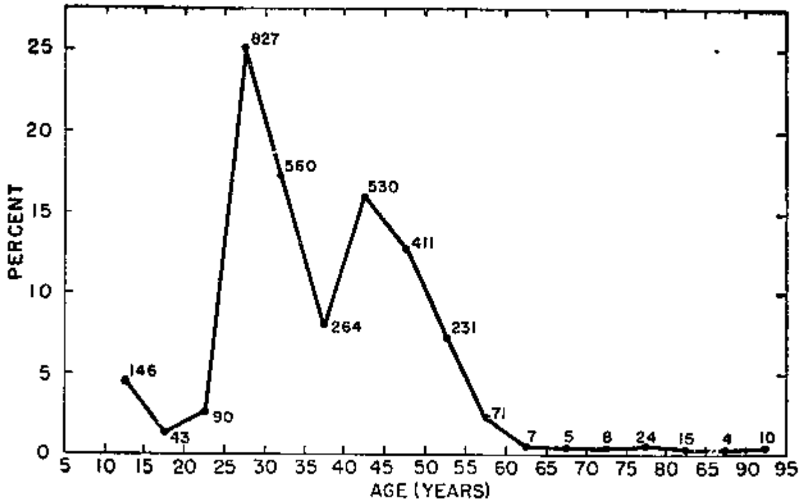


FIGURE 2.—Distribution of oak sprouts by age classes. The numbers beside the points indicate the number of trees studied.

FIELD AND LABORATORY METHODS

General notes on location, ground cover, forest types, site quality, associated species, stocking, and certain other information were taken for each individual plot.

In the dissection of a tree a definite procedure was followed. Cross-section cuts and measurements were made on all trees at stump and breast height, 12 and 54 inches, respectively. The average and current growth rates were measured at breast height. The current growth rate was based on the radial growth the tree had made during the last five growing seasons. The height of sprout origin was determined by splitting the sprout stump and following the primary wood or pith down to the parent stump Measurements and conditions of the parent stumps were obtained by partly or completely cutting off the sprout stump at ground level. In sprouts affected with decay the source of infection was traced and the upper limit of decay found by sawing and splitting sections of the trunk. Height of decay was measured to the highest point of evident incipient decay. Decay was measured as linear extent rather than volume, since most of the trees cut were below merchantable size for sawlogs. All measurements were taken in inches except tree height, which was taken in feet.

Specimens were taken from all sprouts for culturing. These specimens were about 3 inches long, 2 inches wide, and 1 inch thick. They were taken from final or intermediate decay, from the highest point of visible decay, and at 1-foot intervals for 3 feet above visible decay in all trees affected with butt rot. In some cases where the trees were badly decayed, specimens were taken as high as 5 or 6 feet above visible decay. In sound sprouts one specimen was taken immediately above the point of sprout origin. In all cases specimens were taken from the parent stumps and from stubs or dead companion sprouts if suitable material was available. At the end of each day's dissection the specimens were wrapped separately in newspaper and mailed in cloth bags to the laboratory in Washington for culturing.

COMPARISON OF AREAS WITH REGARD TO DECAY INCIDENCE

The basic data for the individual plots and species are shown in table 1. The plots are arranged according to the percentage of trees decayed.

TABLE 1.—*Basic data by species for areas studied*

Species and locality	Plot No.	Trees	Average age	Average diameter, breast high	Trees of sprout origin	Average height of sprout origin above ground level	Parent stump			Type of reproduction; after cutting (C), fire (F), or doubtful (?)[2]	Trees decayed	Decayed trees	
							Average diameter at ground level	Average observed height	Trees with open stump wounds[1]			Decayed from parent stump[3]	Average height of decay
White oak:		*No.*	*Yr.*	*In.*	*Pct.*	*In.*	*In.*	*In.*	*Pct.*		*Pct.*	*Pct.*	*In.*
Logan, Pa.	1	24	44	4.4	100	2	6	4	54	C	62	100	31
Hicks, Ill.	2	10	83	8.1	100	0	4	1	0	?	50	40	16
Logan, Pa.	2	45	44	4.8	100	2	6	4	24	C	49	100	44
Do	3	15	48	6.4	100	5	8	8	27	C	40	100	62
Natural Bridge, Va.	13	39	52	6.0	97	3	8	5	28	C	39	67	28
Shenandoah, Va.	4	60	30	4.1	100	3	5	7	59	C	38	100	38
Buena Vista, Va.	15	35	27	4.5	100	6	13	15	63	C	31	91	32
Deerfield, Va.	10	54	44	5.3	100	0	4	1	7	?	26	36	30
Frost, W. Va.	1	50	45	5.2	94	0	5	3	10	?	26	46	32
Buena Vista, Va.	16	13	66	6.9	77	1	9	2	0	C	23	100	128
Michaux, Pa.	1	35	28	4.3	100	3	11	5	48	?	23	100	37
Dix, Pa.	3	78	20	4.5	96	2	8	6	38	?	22	76	19
Buena Vista, Va.	17	29	57	6.3	65	1	6	4	0	C	21	83	23
Mont Alto, Pa.	2	19	50	5.3	100	4	18	8	37	C	21	100	69
Peoples, Conn.	1	34	40	3.5	100	1	3	2	15	?	17	100	20
Dix, Pa.	1	90	19	3.8	100	0	12	13	79	C	17	93	11
Strasburg, Va.	1	24	33	5.0	100	0	3	2	12	F	17	100	30
Mohawk, Conn.	1	26	40	3.9	100	2	10	3	27	F	15	100	61
Dix, Pa.	2	21	42	7.7	90	1	6	3	5	?	14	100	15
Pachaug, Conn.	1	43	42	4.4	100	1	5	3	19	?	14	100	42
Trainer School, W. Va.	2	99	32	4.0	100	1	8	5	36	F	13	85	22
Edinburg, Va.	1	60	30	4.5	100	1	4	1	22	F	10	57	26
Meshomasic, Conn.	1	11	40	4.7	100	2	10	4	36	C	9	100	12
Edinburg, Va.	2	13	32	4.1	100	0	4	3	23	F	8	100	82
Deerfield, Va.	12	81	32	3.6	96	0	3	0	6	F	7	17	------
Shenandoah, Va.	6	45	20	3.8	100	0	9	3	62	F	4	100	37
Swallow Falls, Md.	1	121	27	3.1	100	1	5	0	1	F	2	33	7
Deerfield, Va.	9	17	43	3.9	100	0	7	1	18	?	0	------	------
Suits, Ill.	1	12	36	5.0	100	0	3	1	0	F	0	------	------

[1] Opening at base of sprout caused by failure of sprout to grow completely over the parent stump.
[2] Reproduction following clear-cutting (C) or resulting from a severe burn (F). Uneven-aged stands often contained both types of reproduction. These were listed with the stands of doubtful origin (?).
[3] Heart-rotting fungi entered sprout from parent stump.

TABLE 1.—*Basic data by species for areas studied*—Continued

Species and locality	Plot No.	Trees	Average age	Average diameter, breast high	Trees of sprout origin	Average height of sprout origin above ground level	Parent stump: Average diameter at ground level	Parent stump: Average observed height	Parent stump: Trees with open stump wounds	Type of reproduction: after cutting (C), fire (F), or doubtful (?)	Trees decayed	Decayed trees: Decayed from parent stump	Decayed trees: Average height of decay
		No.	*Yr.*	*In.*	*Pct.*	*In.*	*In.*	*In.*	*Pct.*		*Pct.*	*Pct.*	*In.*
White oak—Continued.													
Bald Eagle, Pa	1	32	33	3.7	100	------	9	------	31	F	0	------	------
Deerfield, Va	11	13	32	4.2	100	1	2	0	0	F	0	------	------
Bald Eagle, Pa	2	25	36	4.0	100	------	9	------	28	F	0	------	------
Do	3	37	20	3.0	100	------	9	------	27	F	0	------	------
Bunker, Mo	6	40	50	7.2	100	0	5	0	0	F	0	------	------
Other areas (8) [4]	----	42	44	5.3	100	1	6	2	14	------	21	78	44
Chestnut oak:													
Strasburg, Va	2	30	20	4.2	100	1	8	4	69	?	22	100	16
Mont Alto, Pa	1	45	51	5.6	100	1	6	3	20	C	18	100	56
Shenandoah, Va	6	52	55	7.7	100	0	4	3	4	C	15	100	44
Logan, Pa	3	64	48	6.0	100	2	7	4	26	C	9	100	44
Michaux, Pa	1	75	28	3.9	97	1	8	3	47	?	9	100	41
Mont Alto, Pa	2	61	50	5.2	100	2	8	5	21	C	8	100	25
Shenandoah, Va	7	14	47	5.7	100	0	10	1	28	C	7	100	24
Buena Vista, Va	15	20	28	4.0	100	1	14	8	80	C	5	100	59
Strasburg, Va	3	50	45	4.9	100	−1	4	1	16	F	4	100	10
Do	1	19	32	4.3	100	0	6	4	37	F	0	------	------
Deerfield, Va	8	20	31	4.0	100	−1	14	8	60	F	6	------	------
Bald Eagle, Pa	1	95	34	3.5	100	------	7	------	57	F	0	------	------
Do	2	16	33	3.5	100	------	10	------	75	F	0	------	------
Do	3	67	21	3.1	100	------	8	------	37	F	0	------	------
Other areas (12) [4]	----	51	38	5.5	98	1	7	3	31	------	14	71	11
Scarlet oak:													
Natural Bridge, Va	14	14	74	10.7	93	1	8	2	7	C	66	100	81
Mont Alto, Pa	1	24	51	7.4	100	1	9	3	50	C	66	87	55
Logan, Pa	2	23	43	8.2	100	1	11	3	39	C	65	80	33
Natural Bridge, Va	13	10	48	8.1	100	2	10	5	70	C	60	100	50
Deerfield, Va	10	12	44	7.0	100	0	6	1	8	?	50	50	28
Meshomasic, Conn	1	45	40	6.1	100	1	12	2	47	C	49	100	19
Mont Alto, Pa	2	19	51	9.8	100	1	10	4	63	C	47	89	62
Do	3	12	43	9.1	100	1	10	2	17	C	41	100	78
Logan, Pa	1	28	47	8.9	100	0	10	2	30	C	39	82	31
Shenandoah, Va	7	14	47	5.7	100	0	9	1	78	C	35	100	74
Strasburg, Va	3	14	47	5.2	100	0	5	1	14	F	35	100	45
Deerfield, Va	9	54	35	4.9	100	0	11	1	74	?	31	100	28
Buena Vista, Va	16	24	47	6.6	83	0	11	4	62	C	29	100	43
Deerfield, Va	12	23	29	4.4	91	−1	5	0	13	F	26	17	18
Pachaug, Conn	1	32	44	6.2	100	0	6	2	16	?	25	100	56
Deerfield, Va	8	40	32	4.7	100	−1	6	0	15	F	20	88	4
Edinburg, Va	2	21	32	4.9	100	1	4	1	43	F	19	100	49
Shenandoah, Va	6	101	29	4.4	100	0	11	3	73	F	16	100	45
Suits, Ill	1	36	37	5.8	100	0	4	1	5	F	16	97	18
Bald Eagle, Pa	1	21	39	7.2	100	------	8	------	38	F	14	67	41
Edinburg, Va	1	11	30	4.9	100	−1	4	0	27	F	9	0	3
Mohawk, Conn	1	77	41	5.3	100	1	9	2	52	F	7	100	34
Swallow Falls, Md	1	34	26	4.4	100	−1	8	0	0	F	5	100	8
Deerfield, Va	11	38	34	5.8	100	−1	4	0	0	F	2	100	18
Bald Eagle, Pa	2	14	30	5.0	100	------	11	------	57	F	0	------	------
Do	3	13	20	3.8	100	------	7	------	40	F	0	------	------
Other areas (10) [4]	----	41	37	5.7	100	0	8	3	44	------	39	81	37
Black oak:													
Mont Alto, Pa	3	19	43	7.0	100	1	11	2	31	C	73	100	46
Shenandoah, Va	7	21	47	6.1	100	0	8	2	43	C	62	100	79
Do	4	74	30	6.2	100	3	9	8	89	C	58	100	52
Natural Bridge, Va	14	11	76	10.5	90	1	8	4	27	C	54	83	43
Buena Vista, Va	17	23	46	6.8	87	1	8	5	22	C	48	91	52
Deerfield, Va	12	11	33	4.1	100	0	4	0	18	F	45	40	32
Strasburg, Va	3	17	48	5.5	100	−1	6	0	20	F	41	100	8
Natural Bridge, Va	13	33	53	8.0	91	4	11	6	33	C	33	100	68
Edinburg, Va	2	19	34	5.6	100	−1	5	3	47	F	26	60	51
Shenandoah, Va	6	13	30	3.6	100	0	3	1	23	F	23	100	41
Peoples, Conn	1	15	45	7.7	100	0	6	2	0	?	20	100	5
Edinburg, Va	1	16	31	5.4	100	0	4	1	31	F	18	100	34
Strasburg, Va	1	17	34	6.6	100	1	7	6	29	F	17	100	28
Michaux, Pa	1	17	28	4.2	100	1	5	2	12	?	17	100	50
Deerfield, Va	11	30	33	5.5	97	1	4	0	0	F	0	------	------
Other areas (17) [4]	----	58	41	6.2	98	1	6	2	26	------	31	78	48

[4] Number in parentheses refers to number of areas included. Each area represents less than 10 trees.

TABLE 1.—*Basic data by species for areas studied*—Continued

Species and locality	Plot No.	Trees	Average age	Average diameter, breast high	Trees of sprout origin	Average height of sprout origin above ground level	Parent stump: Average diameter at ground level	Parent stump: Average observed height	Parent stump: Trees with open stump wounds	Type of reproduction after cutting (C), fire (F), or doubtful (?)	Trees decayed	Decayed trees: Decayed from parent stump	Decayed trees: Average height of decay
		No.	*Yr.*	*In.*	*Pct.*	*In.*	*In.*	*In.*	*Pct.*		*Pct.*	*Pct.*	*In.*
Red oak:													
Logan, Pa.	3	10	48	7.9	100	2	10	5	30	C	50	80	61
Dix, Pa.	3	44	25	5.2	100	5	13	9	68	?	32	93	25
Buena Vista, Va.	15	37	27	4.0	100	2	8	5	81	C	27	100	19
Strasburg, Va.	2	33	31	4.5	100	1	4	4	51	?	27	78	30
Do.	1	27	33	5.4	100	0	5	2	41	F	22	100	37
Dix, Pa.	2	15	43	5.7	100	1	10	2	53	?	20	66	48
Do.	1	52	15	3.4	100	0	18	14	92	C	17	80	11
Swallow Falls, Md.	2	28	42	5.4	96	0	5	0	0	F	3	100	6
Other areas (17) [4]	..	75	42	6.5	100	1	10	3	32	-----	16	100	25
Other species:													
Bunker, Mo.	1, 6	25	50	6.8	92	0	3	0	8	F	0	-----	-----
All species:													
Hicks, Ill.[5]	2	14	84	8.3	100	0	4	0	0	?	64	33	55
Natural Bridge, Va.	14	37	74	9.5	92	1	8	3	10	C	62	91	62
Logan, Pa.	2	73	45	6.0	100	1	7	3	31	C	55	92	40
Do.	1	63	46	7.1	100	2	9	3	49	C	48	93	31
Shenandoah, Va.	4	155	30	4.7	100	3	7	8	76	C	47	100	47
Mont Alto, Pa.	3	47	43	7.1	100	1	8	2	21	C	47	100	50
Meshomasic, Conn.	1	58	40	6.0	100	1	12	2	45	C	40	100	19
Natural Bridge, Va.	13	92	52	7.1	95	3	10	6	35	C	39	84	46
Shenandoah, Va.	7	49	47	5.9	100	0	9	2	49	C	39	100	75
Mont Alto, Pa.	1	69	51	6.2	100	1	7	3	30	C	35	92	56
Buena Vista, Va.	17	54	52	6.5	76	1	7	4	11	C	33	89	42
Deerfield, Va.[5]	10	76	44	5.7	100	0	5	1	9	?	33	44	28
Frost, W. Va.[5]	1	62	45	5.4	95	0	5	3	11	?	27	53	27
Buena Vista, Va.	16	41	52	6.6	80	1	10	3	29	C	27	100	74
Dix, Pa.	3	122	28	4.8	98	3	10	7	49	?	26	84	22
Buena Vista, Va.	15	98	27	4.2	100	3	11	9	74	C	26	96	26
Strasburg, Va.	2	69	30	4.4	100	0	6	4	61	?	25	88	20
Deerfield, Va.	9	82	37	4.7	100	0	10	10	66	?	24	100	26
Dix, Pa.	2	44	43	6.9	95	1	8	3	32	?	20	78	24
Logan, Pa.	3	97	48	6.2	100	2	7	4	30	C	20	95	55
Mont Alto, Pa.	2	107	51	5.6	100	2	10	5	34	C	19	95	51
Peoples, Conn.	1	60	42	5.4	100	1	5	2	10	?	18	100	14
Pachaug, Conn.	1	82	43	5.4	100	1	6	2	16	?	17	100	50
Strasburg, Va.	3	82	46	5.0	100	−1	5	4	18	F	17	100	32
Dix, Pa.	1	143	17	3.6	100	0	14	14	83	C	17	92	11
Strasburg, Va.	1	88	32	6.3	100	0	5	3	29	F	16	100	35
Edinburg, Va.	2	64	32	4.9	100	−1	4	2	37	F	16	80	64
Deerfield, Va.[5]	12	115	32	3.8	98	0	4	0	9	F	15	23	19
Shenandoah, Va.	5	61	56	8.5	100	0	5	3	10	C	15	100	40
Michaux, Pa.	1	131	28	4.1	98	2	9	4	41	?	14	100	39
Deerfield, Va.	8	84	32	4.7	100	1	8	2	24	F	14	92	8
Shenandoah, Va.	6	163	29	4.7	100	0	10	3	66	F	13	100	44
Bunker, Mo.	2	15	24	5.2	100	0	5	1	0	F	13	0	22
Trainer School, W. Va.	2	101	32	4.0	100	−1	7	5	36	F	13	85	22
Edinburg, Va.	1	97	30	4.7	100	−1	4	1	24	F	11	64	26
Sults, Ill.	1	53	37	5.7	100	0	3	1	4	F	11	67	19
Mohawk, Conn.	1	103	41	5.0	100	0	10	2	46	F	10	100	45
Swallow Falls, Md.	2	39	43	5.7	97	0	5	0	0	F	5	50	30
Do.	1	155	27	3.4	100	−1	6	1	1	F	3	60	7
Bald Eagle, Pa.	1	152	34	4.0	100	-----	6	-----	48	F	2	67	41
Deerfield, Va.	11	82	33	5.4	99	−1	3	0	0	F	1	100	18
Bald Eagle, Pa.	2	62	35	4.1	100	-----	10	-----	43	F	0	-----	-----
Do.	3	120	20	3.1	100	-----	8	-----	34	F	0	-----	-----
Bunker, Mo.	6	66	50	7.1	97	0	4	0	3	F	0	-----	-----
Do.	1	10	41	7.3	100	0	3	1	0	F	0	-----	-----

[5] Some decay, mostly inactive, was due to old grown-over fire wounds.

It will be noted that those plots having a high percentage of decay have certain characteristics in common. Those plots in which there was a high percentage of decay incidence, with the exception of questionable cases, originated from cuttings in which no fires had occurred after the cuttings and previous to the establishment of the stand (table 1, reproduction following cutting, indicated by C). On the other hand, plots in which there was a low percentage of decay cases had been burned either shortly before the cutting or after the cutting but previous to the establishment of the stand (table 1, reproduction following fire, indicated by F). Evidences of fires in the stands were charred stumps and healed fire wounds in some of the older trees. The year at which the burning took place was determined by the ages of the fire wounds. That a high percentage of decay is correlated with previous history of the stand rather than locality is further emphasized by comparing Shenandoah plot 4 with Shenandoah plot 6. These plots are composed of similar species, and, all other conditions being equal, plot 6 might be expected to have had a greater percentage of decay than plot 4, since it contained a greater percentage of the more susceptible species. Yet plot 4 had a much higher percentage of trees decayed than plot 6. The fire in plot 6 before the establishment of the stand may have been largely responsible for the difference in decay incidence.

It will be noted in table 1 that some of the plots, located in widely separated areas (fig. 1), especially those on the Bald Eagle State Forest in Pennsylvania, on the Clark National Forest in Missouri, and on the Swallow Falls State Forest in Maryland, contain a low number of decay cases; likewise, some of the plots from other sections of Pennsylvania and Virginia. High decay incidence was found in widely separated plots, there being no particular locality to which this condition was peculiar. This fact suggests that factors other than regional differences are responsible for high decay incidence in sprout oak stands.

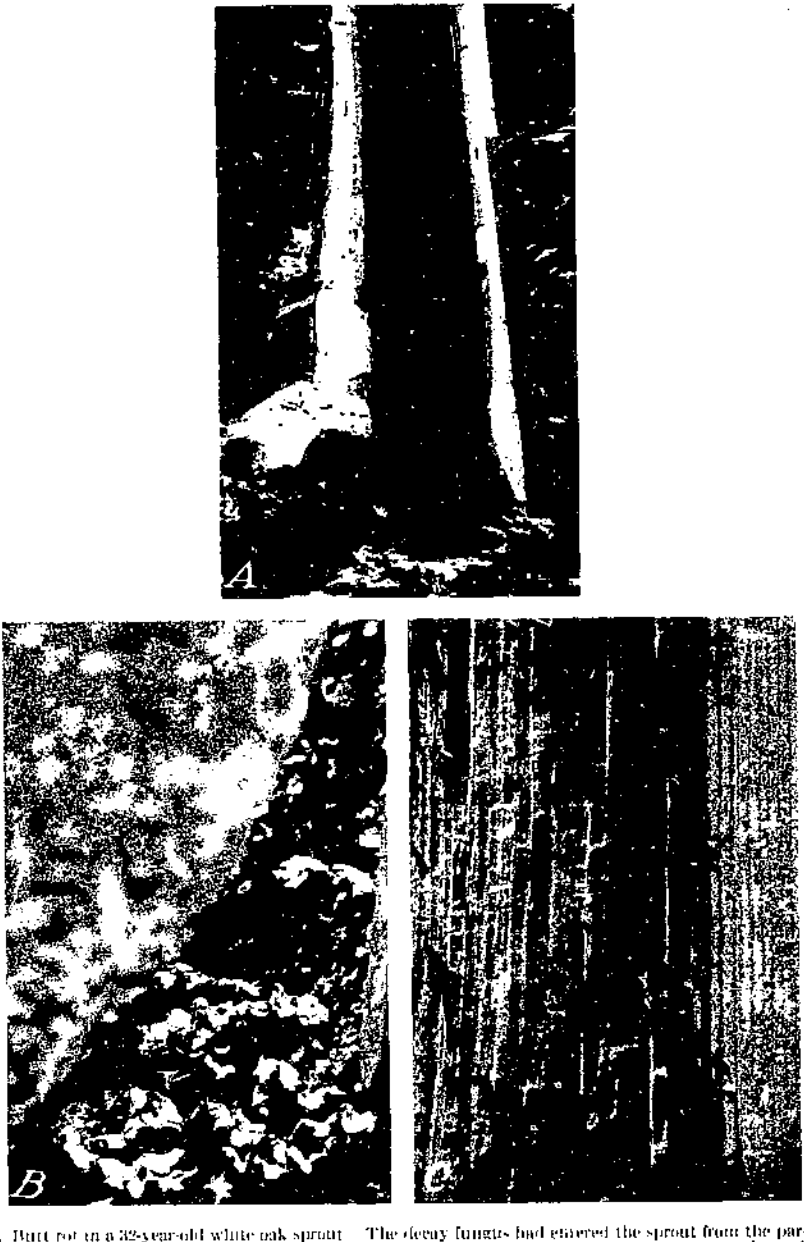
AVENUES OF ENTRANCE OF DECAY FUNGI

The parent stump was found to be the principal avenue through which heartwood-destroying fungi entered sprout oaks in stands free of visible basal wounds (pl. 3, *A*). Table 2 shows that in 86 percent of the sprouts affected with butt rot the fungus entered the sprout from the parent stump. Entrance of wood-destroying fungi through cut or dead companion sprouts occurred in 3 percent of the cases. This low percentage may be accounted for by the comparatively young stands examined and the small number of plots in thinned stands. Where thinning had been done, a sufficiently long period had not elapsed for infection and subsequent decay to have progressed far. As the age of a stand increases, infections from dead sprouts and through wounds made in thinning or cutting operations will increase.

TABLE 2.—*Avenues of entrance of butt-rotting fungi* [1]

Species of tree	Decayed trees	Percentage with avenues of entrance indicated		
		Parent stump	Stub [2]	Others [3]
	Number	*Percent*	*Percent*	*Percent*
White oak	307	82	4	14
Scarlet oak	293	84	3	13
Black oak	210	90	1	9
Chestnut oak	77	95	1	4
Red oak	69	91	3	6
All species	956	86	3	11

[1] Includes preliminary as well as later data.
[2] Both cut and dead companion sprouts are included under stubs.
[3] Included in this group are fire wounds, mechanical wounds, and questionable points of entrance.



A, Butt rot in a 32-year-old white oak sprout. The decay fungus had entered the sprout from the parent stump. Note narrow margin of sound heartwood. *B*, Sporophores of *Stereum gausapatum* at base of an old black oak stump. *C*, Intermediate or typical *S. gausapatum* decay in white oak.


A
B
C
D
E
F

In nearly 6 percent of the sprouts with butt rot the source of infection was undetermined. Those cases in which the fungus might have entered from two or more sources were listed as undetermined. In most of these cases the fungus had entered either from the old stump or from a stub. Trees with butt cavities and badly decayed companion sprouts were common in this group.

Though an effort was made to obtain stands free of visible fire injury, old fire wounds served as a point of entry for decay fungi in somewhat less than 5 percent of the decayed sprouts. However, in most cases infection resulting from fire wounds had died out before dissection. The fire-wounding had occurred, generally, when the trees were young and before heartwood had formed. The killed sapwood decayed quickly and the fungi became inactive and finally died out as the wounded parts were covered by callus growth. At the time such trees were cut no wounds were visible.

No definite evidence was found of roots serving as an avenue of entrance for the fungi. The downward progress of decay from the cut surface of the old stump usually ended in the root crown. Heartwood was seldom observed to extend downward or out into the larger roots more than a foot or two at the most. The lack of heartwood in the roots prevented their invasion by heartwood-rotting fungi from the old stump, and as long as the roots were kept alive by the sprouts, invasion of the parent stump and sprout by fungi working up from the roots was prevented.

It is evident that the parent stump is a more important avenue of entrance for butt-rotting fungi than it has been considered in the past. Even if it were possible to eliminate forest fires, the parent stump would continue to be a serious decay hazard unless its potentialities were minimized by silvicultural efforts. With this possibility in mind, an effort was made to determine the more important factors concerned with the entrance of butt-rotting fungi from the parent stump.

FACTORS AFFECTING INCIDENCE OF DECAY IN SPROUT OAK STANDS

Some of the factors correlated with incidence of decay in sprout oak stands are shown in table 3. It is often difficult to separate the effect of one factor from that of another because of their interrelationship. For example, within certain limits the effect of height of sprout origin is influenced by stump diameter and height of stump. Likewise, the percentage of visible stump wounds occurring in a sprout stand is influenced by the diameter and height of the parent stumps and the age of the sprouts. The presence or absence of heartwood at the point of sprout origin, in either the parent stump or the sprout, may be dependent upon a number of factors, such as age, vigor, and species. The complexity of the interrelationships led the authors to consider only the gross relationships of the different factors to decay incidence, in most cases. Multiple regression analysis was used, however, to determine the net effects of some of the variables in white and black oak in Virginia and West Virginia. In table 3, factors affecting decay incidence may be evaluated by their weighted averages.

TABLE 3.—*Factors related to decay incidence in different oaks*

Species and condition of tree	Trees	Trees infected	Parent stump: Average diameter at ground level	Parent stump: Observed height	Average height of sprout origin above ground level	Trees with open stump wounds	Heartwood in sprout at point of origin
	Number	*Percent*	*Inches*	*Inches*	*Inches*	*Percent*	*Percent*
Black oak:							
Sound	235		5.5	2.3	0.4	21	96
Decayed	148	39	9.4	5.7	2.2	64	100
Scarlet oak:							
Sound	531		7.6	1.3	.3	36	98
Decayed	209	28	10.7	3.1	.8	53	100
Red oak:							
Sound	239		9.5	5.6	1.1	60	86
Decayed	69	22	11.1	7.4	2.3	72	100
White oak:							
Sound	1,045		6.4	3.3	.5	22	81
Decayed	243	19	8.3	6.8	2.3	51	99
Chestnut oak:							
Sound	451		7.1	3.5	.6	31	88
Decayed	53	11	8.3	4.5	1.5	47	100
Other oaks:							
Sound	23		2.6	.8	−.2	0	100
Decayed	0						
Total of all species:							
Sound	2,524		7.0	3.0	.5	29	88
Decayed	722	22	9.4	5.4	1.8	56	100

SIZE OF PARENT STUMP AND CONDITION AT POINT OF SPROUT ORIGIN

Sprouts arising from stumps of large diameter, such as shown in plate 4, *A* and *B*, were more subject to butt rot than those arising from smaller stumps. Table 4 shows an increase in the percentage of butt-rotted trees with an increase in stump diameter, both within a species and for all oak species. For 3,246 sprouts from 42 widely separated plots it was found that the larger the stumps, at least up to a certain size, the greater the percentage of decay cases present. The low origin of sprouts from stumps of large diameter tended to offset the influence of stump diameter. Table 3 shows that for all species the average diameter of the parent stumps was 2.4 inches greater for the trees with butt rot than for the sound trees. The greatest difference in diameters between sound and decayed trees was found in the black oaks while the least difference was found in chestnut oaks, 4 inches and 1 inch, respectively. Within each species the average diameter of parent stumps of sprouts with butt rot exceeded that of sound sprouts.

TABLE 4.—*Relation of diameter of parent stump to decay incidence in different oaks*

Species	Trees from parent stumps of indicated diameter at ground level: 1 to 2 inches: Trees	1 to 2 inches: Trees infected	3 to 4 inches: Trees	3 to 4 inches: Trees infected	5 to 6 inches: Trees	5 to 6 inches: Trees infected	7 to 8 inches: Trees	7 to 8 inches: Trees infected	Over 8 inches: Trees	Over 8 inches: Trees infected
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Black oak	58	3	86	22	56	30	54	40	129	62
Scarlet oak	78	4	136	20	120	23	104	38	302	37
White oak	213	4	320	17	254	10	181	23	320	20
Red oak	28	7	44	16	45	16	50	28	141	28
Chestnut oak	86	4	113	12	102	9	54	15	149	13
Other oaks	15	0	4	0	2	0	2	0		
All species	478	4	703	17	579	10	445	20	1,041	33

In general, sprouts from high stumps as shown in plate 4, *B*, were more subject to butt rot than those from low stumps (pl. 4, *C*). The observed heights of the parent stumps of butt-rotted trees were 2.4 inches greater than those of sound trees. In stands over 25 years old and in areas that had been burned before the establishment of the present stands, the observed heights of the parent stumps, in a great many cases, were less than the original stump heights (pl. 4, *D*, *E*, and *F*). The number of parent stumps or remains of parent stumps visible in older stands depended to some extent on the history of the stand, diameter and height of the original stump, height of sprout origin, and vigor of the sprout. As observed for stump diameters, there was in every species an appreciable difference between the heights of parent stumps of decayed trees and those of sound trees. Since stump-height measurements are correlated with origin heights, this relationship to decay may be largely due to origin height.

Plate 2, *B*, shows active decay progressing in a large parent stump. It will take longer for high large stumps to decay than it will for low small ones; consequently, the decay in the larger stumps will remain active longer and present a hazard to the sprouts over a greater number of years than in the case of small stumps. This may in part account for the greater percentage of decay cases in sprouts originating from high, large stumps.

The condition of the parent stump at the point of sprout origin was important, in that 73 percent of the stumps of uninfected trees and only 5 percent of the stumps of decayed trees were sound at this point. Plate 5, *A*, shows a sprout not decayed, although decay was present in the old stump, but not at the point of origin. In a small number of sprouts dissected, decay fungi had entered the sprouts from fire wounds, stubs, and other sources, which account for the 5 percent of decayed sprouts with parent stumps sound at the point of origin. The 27 percent of the sound trees with stumps decayed at the point of sprout origin consisted of sprouts that at the time of dissection did not have a heartwood connection with the parent stump or in which the decay in the parent stump had become inactive before a heartwood union had formed (pl. 5, *B*).

HEIGHT OF SPROUT ORIGIN

The height at which sprouts originate on the parent stump was found to be an important factor in the presence or absence of decay in a sprout stand (pl. 6, *A* and *B*). High and low sprout origins on a parent stump are illustrated in plate 6, *C* and *D*. Table 5 shows that the percentage of decay cases increases with the height of sprout origin up to 4 inches, after which increase was questionable. Some species show a greater increase in the percentage of decay cases with a corresponding increase in height of sprout origin than do others (table 5). There was in every species a higher origin for trees with butt rot than for sound trees. As shown in table 3, some species tend to originate sprouts higher on the parent stumps than do others. Variations among plots depended somewhat on the previous history of the stand and the species involved.

TABLE 5.—*Relation of height of sprout origin to decay incidence in different oaks*

Species	Trees from sprouts originating as indicated in relation to ground level (inches above ground)							
	Below ground		0 inch		1 inch		2 inches	
	Trees	Trees infected	Trees	Trees infected	Trees	Trees infected	Trees	Trees infected
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Scarlet oak	223	13	303	27	117	38	43	53
Black oak	104	17	114	33	54	41	36	61
Red oak	63	16	134	22	36	17	22	27
White oak	368	5	475	16	166	28	79	30
Chestnut oak	128	6	133	9	106	11	55	16
Other oaks	8	0	9	0	2	0	3	0
All species	894	9	1,168	20	481	27	238	35

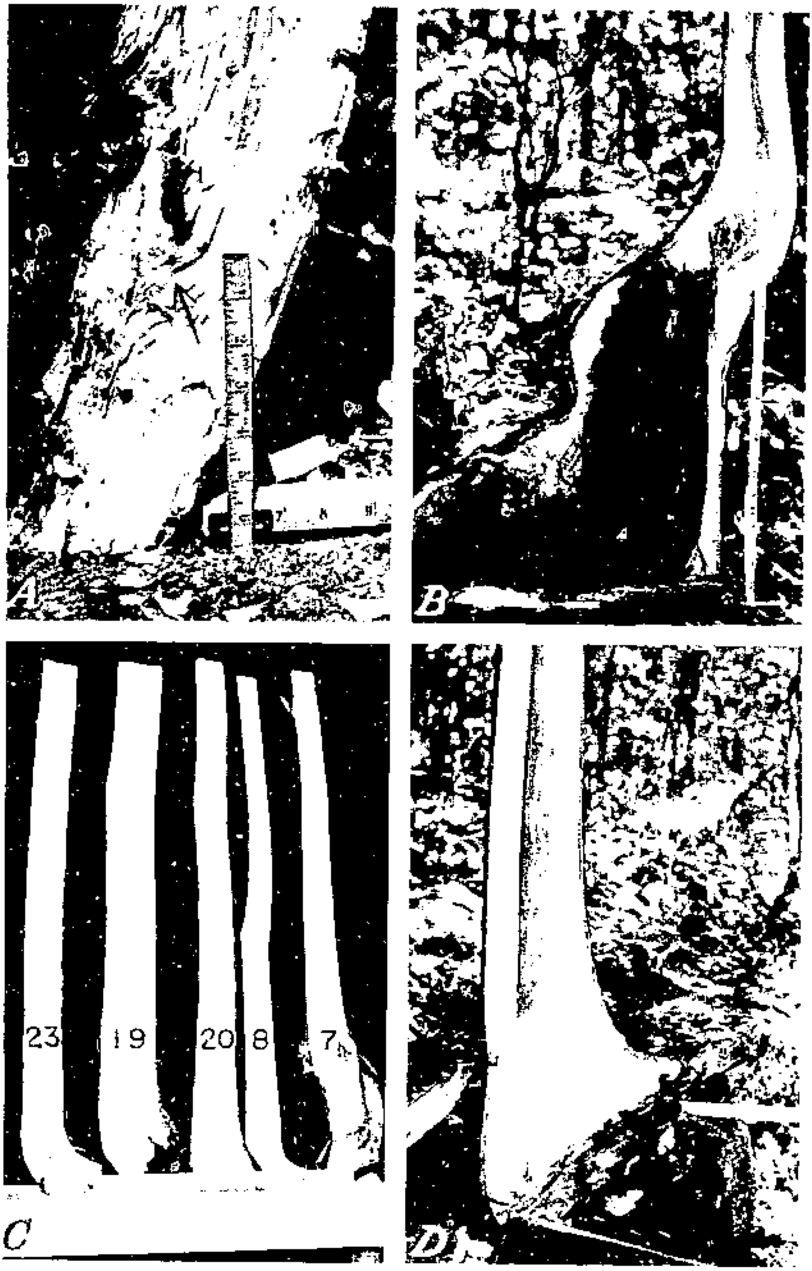
Species	Trees from sprouts originating as indicated in relation to ground level (inches above ground)							
	3 inches		4 inches		5 to 7 inches		8 to 22 inches	
	Trees	Trees infected	Trees	Trees infected	Trees	Trees infected	Trees	Trees infected
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Scarlet oak	30	47	13	77	9	78	2	0
Black oak	17	76	11	54	24	67	23	57
Red oak	13	23	11	27	13	54	16	31
White oak	51	30	38	45	63	37	48	33
Chestnut oak	29	10	22	18	22	14	9	22
Other oaks	1	0						
All species	141	38	95	42	131	43	98	37

WOUNDS IN SPROUTS CAUSED BY PARENT STUMPS

Most young sprouts are readily recognized as such by the presence of parent stumps or stump wounds at their bases. In this study the sprout was classed as having an open stump wound unless it had completely overgrown the remains of the old stump and presented an unbroken bark surface (pl. 7). Several types of open wounds were recognized, depending on size and position of the opening in relation to the parent stump.

Open base wounds were those extending to the ground line (pl. 7, *E* and *F*); loose wounds were those where the sprout had partly grown around the stump but which still had parts of the stump protruding from the opening (pl. 7, *C*); tight wounds were those where the sprout had grown around a portion of the old stump and at the time of dissection tightly held it (pl. 7, *D*). The last two types of open wounds were found more often in sprout groups.

In cases where the sprout had grown over the parent stump but still left evidences of being a sprout, by a swollen base or twin trees, the wounds were classified as closed (pl. 7, *B*). Where the sprouts had grown over the stumps and were not readily recognized as being of sprout origin until dissected, they were classified as having no wounds (pl. 7, *A*). It can be readily seen that the larger the parent stumps and the higher the point of origin of the sprout, the more likely are stump wounds to occur in a stand. Table 6 shows that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E
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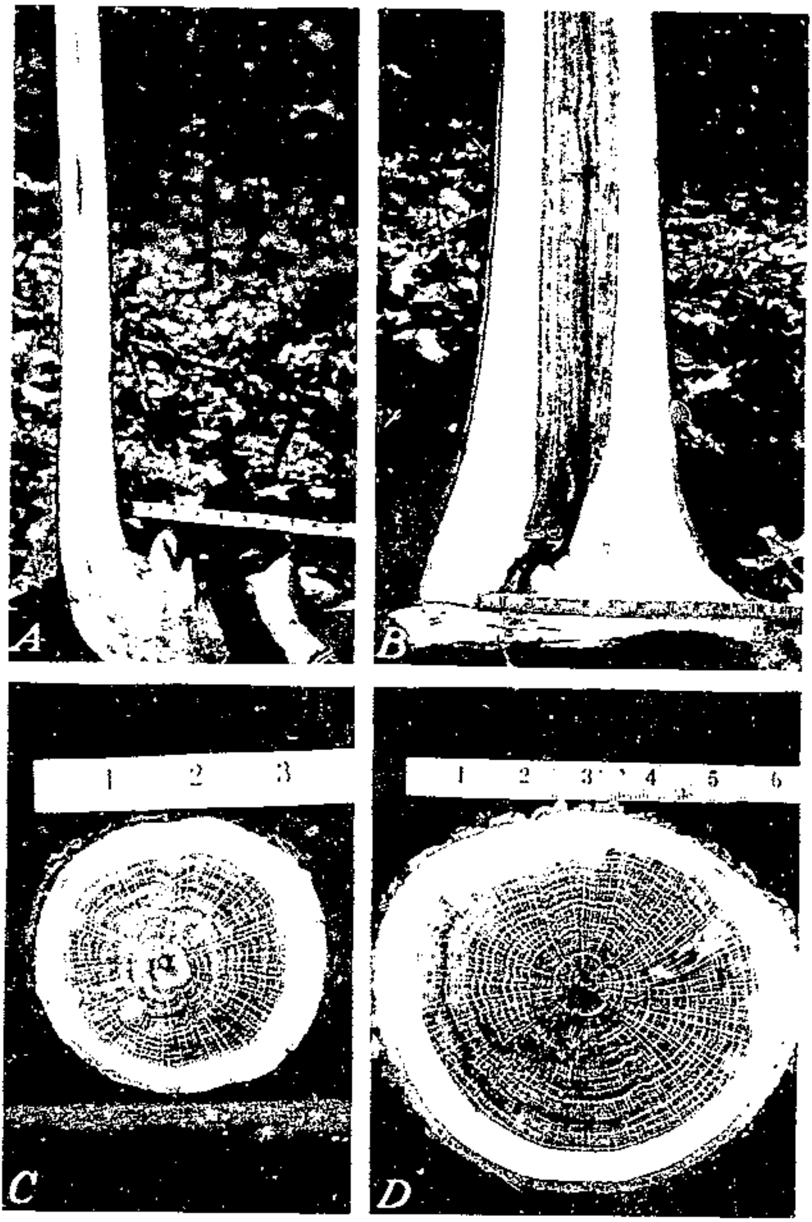
A
B
C
1 2 3
D
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[illegible]

more of the sprouts having open wounds were decayed than those with closed or with no wounds.

TABLE 6.—*Relation of types of stump wounds to decay incidence in different oaks*

Species	Trees with stump wounds of types indicated					
	No wounds		Closed wounds		Open wounds	
	Trees	Trees infected	Trees	Trees infected	Trees	Trees infected
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Black oak	148	20	89	27	146	65
Scarlet oak	266	18	170	29	304	36
White oak	531	11	400	16	357	34
Red oak	79	11	59	17	170	29
Chestnut oak	163	9	177	7	164	15
Other oaks	18	0	3	0	2	0
All species	1,205	13	898	18	1,143	35

By referring to table 3 it is evident that in every species the trees with butt rot had a greater percentage of open wounds than the sound trees, though the species having the most open wounds were not always the ones with the most infected trees. In the majority of cases the parent stump does not cause a definite decay hazard after it has been healed over by the sprout unless active decay is present in the stump at the time of healing over. This is not true of sprouts with open wounds, since these openings remain as possible entrance points for decay-producing fungi until they are closed. Infections through stump wounds but from sources other than the old stump decay are apparently not common in stands up to 50 years old, but it is believed that this factor will cause an increase in infection as the stands become older. Although the presence or absence of stump wounds is closely related to stump size and height of sprout origin, they are considered as contributing to the ultimate amount of decay in a stand.

TIME AND EXTENT OF HEARTWOOD FORMATION

Heartwood usually appears in an oak sprout at an age of from about 8 to 15 years, depending somewhat on the size, species, and rate of growth. The position of first formation and development of heartwood in oak sprouts is shown in plate 5, *C* and *D*. Heartwood first appears [5] at a point in the stem from 1 to 3 feet above the point of sprout origin and usually extends upward in the stem to a point where the stem is from 12 to 15 years old and 1.5 to 2 inches in diameter. The upper heartwood is not necessarily a continuous cylinder, as small isolated patches of heartwood may be found at the bases of branches or adjacent to knots. Heartwood formation does not as a rule follow any particular ring, either in the same cross section or at different heights in the tree.

Some of the factors that influence the formation of heartwood in a sprout are age, growth rate or vigor, and distance from active cam-

[5] These observations on first appearance and development of heartwood in sprout oaks agree substantially with those contained in an office report to the Division of Forest Pathology by F. G. Liming on preliminary sprout dissection done in Virginia.

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bium. Distance from the cambium appears to be more important than age in the initiation of heartwood and prolonging the life of the parenchymatous wood. In suppressed sprouts, particularly white oak and chestnut oak, the innermost ring of sapwood was found to be several years older than the innermost sapwood ring in fast-growing trees. The difference in the number of sapwood rings between dominant and suppressed sprouts was surprisingly greater than the difference in width.

Dominant sprouts were found to have more heartwood in cross section, both in rings and in percentage of basal area, than suppressed sprouts (pl. 8, *C* and *D*). Fifty each of dominant and suppressed sprouts were selected at random from the two age classes studied (table 7). It will be noted that in the older age class the percentage of basal area of the heartwood in the suppressed group more nearly approaches that of the dominant group than in the younger age class. In both instances the number of rings of sapwood are less in the dominant group. This condition was found to be true for all species studied.

TABLE 7.—*Comparison of heartwood at breast height in cross section of dominant and suppressed sprouts by species in 2 age classes*

Age, crown class, and species	Trees	Basal area of heartwood	Rings of heartwood	Rings of sapwood	Width of sapwood	Average current radial growth rate
	Number	*Percent*	*Number*	*Number*	*Inches*	*Inch*
20–30 years old, dominant:						
Red oak	10	69	21	5	0.8	0.059
Scarlet oak	10	68	21	6	.8	.063
Black oak	10	58	20	8	1.1	.066
Chestnut oak	10	51	18	8	1.2	.074
White oak	10	50	17	7	1.0	.073
All species	50	60	19	7	1.0	.067
20–30 years old, suppressed:						
Red oak	10	69	18	7	.5	.030
Scarlet oak	10	66	17	9	.6	.028
Black oak	10	52	16	11	.8	.023
Chestnut oak	10	45	14	13	.9	.023
White oak	10	43	14	12	.8	.024
All species	50	55	16	10	.7	.026
40–50 years old, dominant:						
Red oak	10	83	42	7	.6	.054
Scarlet oak	10	82	39	6	.8	.057
Black oak	10	73	34	9	1.0	.049
Chestnut oak	10	68	36	11	1.1	.050
White oak	10	68	34	10	1.2	.054
All species	50	75	37	9	1.0	.053
40–50 years old, suppressed:						
Scarlet oak	10	81	34	10	.5	.022
Red oak	10	79	36	10	.5	.023
Black oak	10	79	32	11	.7	.024
Chestnut oak	10	68	32	15	.8	.016
White oak	10	67	23	20	.8	.015
All species	50	73	32	13	.7	.020

From the point of initiation the heartwood extends down the stem until there is a heartwood connection with the parent stump. This heartwood connection usually takes place, depending on the height of sprout origin and vigor of the sprout, when the sprout is 12 to 18 years old (pl. 5, *C* and *D*). Individual cases were observed where a heartwood union had not taken place in suppressed sprouts 35 years old. Of 3,246 sprouts dissected, with an average age of 38 years, over 9 percent did not have a heartwood union at the point of sprout origin. Most of these cases were in age classes younger than 25 years and were for the most part confined to slow-growing sprouts of low origin.

The time at which a heartwood union forms between the parent stump and the sprout affects decay transmission in that no infections were observed to have taken place through live sapwood. If active decay is present in the parent stump at the time such a union is formed, the possibility of decay transmission is high.

Sprouts of the white oak group as a rule were found to form a heartwood union with the parent stump later than sprouts of the black oak group. Of the sprouts dissected having only a sapwood union with the parent stump, more than 80 percent were in the white oak group. This in part accounts for the fact that in all cases the species in the black oak group contained a higher percentage of decay cases than did the species in the white oak group. This condition existed in plots wherever the two groups were growing together.

Young, rapidly growing trees are likely to become infected earlier than slow-growing sprouts, because a heartwood union between stump and sprout forms earlier in the more vigorous trees. In sprout stands originating from small, low stumps the decay might become inactive before a heartwood union is formed, especially in suppressed trees, while it might still be active when a union was formed in dominant trees. Plate 8, *A* and *B*, shows a suppressed sprout without and a dominant sprout with heartwood at the point of origin.

The importance of the time of formation of a heartwood union as a factor in decay incidence cannot be disregarded. In small, low parent stumps decay may run its course and become inactive before a heartwood union is formed. In such a case, provided the sprout encloses the stump, there is no further danger of infection from this point. On the other hand, large parent stumps require longer to decay. In these cases the possibilities of infection from the parent stumps are greater, since the heartwood in the sprout has had sufficient time to unite with the parent stump before the decay becomes inactive. The possibility of decay becoming inactive in a parent stump before a heartwood union is formed depends upon a number of factors, the most important of which are stump size, height of sprout origin, vigor of sprout, and fungus attacking the stump.

PRESENCE OF COMPANION SPROUTS

The presence of companion sprouts in a sprout stand increases the decay hazard. In many thinning operations, mine-prop, post, or fuel-wood cuttings, one or more stems of a sprout group are often removed and others are eliminated from the stand by competition. In either case a wound is created through which decay fungi may enter. Although the decay incidence caused by cut stubs or dead companion sprouts found during this study was small, a definite hazard does exist from this source. More than 11 percent of the 3,246 sprouts dissected had stubs over 2 inches in diameter so connected as to be potential entrance points for wood-destroying fungi. Less than 3 percent of all the decay encountered entered the sprouts from cut stubs or dead companion sprouts, but decay fungi were isolated from stubs in more than 30 percent of the cases. It is evident that even though the percentage of decay cases attributed to stubs in the sprouts dissected was small, the chances of its increasing from this source were great. Aside from the trees already having had stubs or dead companion sprouts present, 29 percent of all the sprouts dissected were found in sprout groups (table 8).

TABLE 8.—*Comparison of decay incidence in single-stemmed sprouts with that in multiple-stemmed sprout groups*

Species	Trees	Trees in sprout groups	Parent stump diameter		Trees with butt decay	
			Single-stemmed sprouts	Trees in sprout groups	Single-stemmed sprouts	Trees in sprout groups
	Number	*Percent*	*Inches*	*Inches*	*Percent*	*Percent*
Black oak	383	20	6	11	34	56
Scarlet oak	740	29	6	13	28	20
Red oak	308	54	6	13	24	21
White oak	1,288	28	5	11	18	21
Chestnut oak	504	30	5	13	11	10
Other oaks	23	17	3	2	0	0
All species	3,246	29	6	12	21.5	23.9

The possibility of the number of stubs increasing as a stand grows older is evident, and hence the number of infections from the cut stubs or dead companion sprouts will increase. For the stubs encountered, the average length of time that they had been cut or dead was 7 years. It is not known what the hazard from these stubs would have been in 5 or 10 more years, but it is certain that it would have been greater. Plate 9, *A* and *B*, illustrates the rapid healing of stubs 2 inches or less in diameter. In most cases they do not form a definite decay hazard. The larger a wound left by cutting a sprout from a group, the greater will be the chance of the stub's becoming infected before it is healed over (pl. 9, *C*). The type of cut is also an important factor in rate of healing, as shown in plate 9, *C*, *D*, and *E*. Dead standing companion sprouts in the trees dissected were not as a rule a common source of infection. Only one or two cases were observed in which decay coming through a dead standing companion sprout had entered the remaining sprout, while several cases were observed in which the dead sprout had fallen over and created a hazard very similar to a cut surface. As is the case with cut stubs, this mode of entrance will probably increase as the sprouts grow older and the dead sprouts decay and fall over.

The occurrence of twin stems in a stand implies a connection between the twins. Hepting (*16*) describes three types of twins commonly found. In the high-union type the stems are fused for a distance of a foot or more above ground level; in the low-union type the stems are fused close to the ground; while in the separated type the stems are separated at least to ground level. There are many variations of the three types of crotches described, the most common of which are the V- and the U-type crotches, as shown in plate 10, *A* and *C*. The difference between these two types is generally associated with the angle at which the sprouts arise from the stump and the distance between the points of origin of the sprouts.


A
B
C
D

In the V-type crotch the sprouts have generally originated close together on the parent stump, while in the U-type crotch they are generally farther apart. The crotch type and height are very important factors to consider when dealing with cut stubs or dead companion sprouts.

In twin sprouts, especially where there is a high crotch, as shown in plate 10, *A* and *B*, there is a union of the heartwood of the twins about 2 inches below the saddle formed by them. When one of the twins dies or is cut, decay fungi gain entrance through the cut surface of the dead sprout and follows the heartwood connection into the remaining stem. This mode of entrance has been observed in the case of all types of high crotches and in the case of low V-type crotches.

If the crotch is of the low U-type or of the separated type the chances of infection are not so great, since there is usually a wide saddle of sapwood between the stub and the remaining sprout, and hence no direct heartwood connection through which decay fungi can enter (pl. 10, *D*). In general, the length of time required for infections to progress from cut stubs to sprouts will depend on the directness of the heartwood connection between the cut surface and the remaining sprout.

CORRELATION ANALYSIS ON RELATION OF TREE AGE, HEIGHT OF SPROUT ORIGIN, AND PARENT STUMP DIAMETER TO DECAY INCIDENCE[4]

Tables or diagrams showing the gross relationship of one variable (for example, height of sprout origin) to another (for example, percentage of trees with butt rot) are useful, but their usefulness is often limited to preliminary analyses. To plot one variable over another, disregarding variation in other possibly important variables, may give an approximation of the net relationship between the two, but may also either fail to do so altogether or indicate trends counter to the net relationship. A case might be assumed in which decay incidence increases slightly with height of origin but decreases considerably with increase in diameter of parent stump. If height of origin were positively correlated with stump diameter, and incidence of decay plotted over height of origin, disregarding stump diameter, a negative correlation would probably be obtained, when actually the net correlation is positive.

It seemed highly desirable in the present instance to determine the net regressions of decay incidence on sprout age, height of sprout origin, and diameter of parent stump, expressing incidence as percentage of trees with basal decay having its origin in the parent stump. This analysis was made for white oak and black oak, representing respectively species with low and high average decay incidence. In order to minimize the place effect, if any, only trees from one reasonably compact geographical unit, embracing the George Washington and the southeastern part of the Monongahela National Forests in western Virginia and eastern West Virginia, were used.

The method of successive approximations described by Bruce and Reineke (*4*) was used to determine the regressions. Only a brief account of the procedure followed is given here. For each species a

[4] Correlations worked out by George H. Hepting, of the Division of Forest Pathology.

linear regression equation was calculated, and alinement charts were prepared. The following are the equations:

For white oak, $Y=-0.00089+0.00131X_1+0.03414X_2+0.01395X_3$.
For black oak, $Y=0.06997+0.00098X_1+0.02409X_2+0.03141X_3$.
When Y=percentage of trees with basal decay,
X_1=age of sprout,
X_2=height above ground of sprout origin,
X_3=diameter of parent stump.

The residuals were then plotted around the straight lines. In the cases of Y on X_2 and Y on X_3 there were definite indications of curvilinearity. The following is a summary of the steps taken, for each species separately, to obtain the curves shown in figures 3 and 4.

The observed values of Y were plotted over the estimated (from the equation) and a curve fitted. The Y axis of the alinement chart was then regraduated to correct for the failure of the points on the "observed" over "estimated" graph to define a straight line of 45°, with origin at zero. Having regraduated the Y axis, new estimates of Y for the different values of X_1, X_2, and X_3 were obtained. These may be called the second estimates.

New residuals were then computed and plotted around the new regression lines. Curves were fitted to these residuals and the X_1, X_2, and X_3 axes of the chart were altered to conform to the new curves. New estimates of Y for the different values of X_1, X_2, and X_3 were then read from the chart. These may be called the third estimates. The observed values of Y were then plotted over the third estimates and a new curve fitted. The Y axis was then regraduated to correct again for the failure of the points to fall along a 45° straight line with zero origin. The alternate steps of regraduating the dependent variable axis and the independent variable axes were continued until the estimated values of Y defined a satisfactory balanced curve through the residuals for each independent variable and until the observed values of Y, when plotted over the estimated, defined the proper 45° line.

Figures 3, *A*, and 4, *A*, indicate some increase in percentage of trees with basal decay with increase in tree age over the age range studied. The considerable deviation of residuals from the regression lines and the slight slope of the lines indicate that these lines might not be significantly different from horizontal. However, if the relationships indicated by these figures are true, the risk of infection from the parent stump exists for a great many years. This is apparently true for those sprouts from large stumps in which an open stump wound continues to exist. The method of analysis so far as possible frees these regressions of percentage of infection on tree age from the effects of varying heights of sprout origin and stump diameters, through holding these variables constant at their mean values.

Figures 3, *B*, and 4, *B*, show a decided relation between height of sprout origin and decay incidence. Sprouts arising below ground appear to have the least likelihood of decay. From 1 inch below ground to about 3 inches above ground the likelihood of decay increases rapidly. A maximum decay incidence appears to be reached when the sprouts arise from 5 to 8 inches above ground. There is an indication in both figures that the likelihood of decay may decrease again when the sprouts arise as high as 1 foot above ground, and a similar indication is found in table 5, in which all trees of all species are

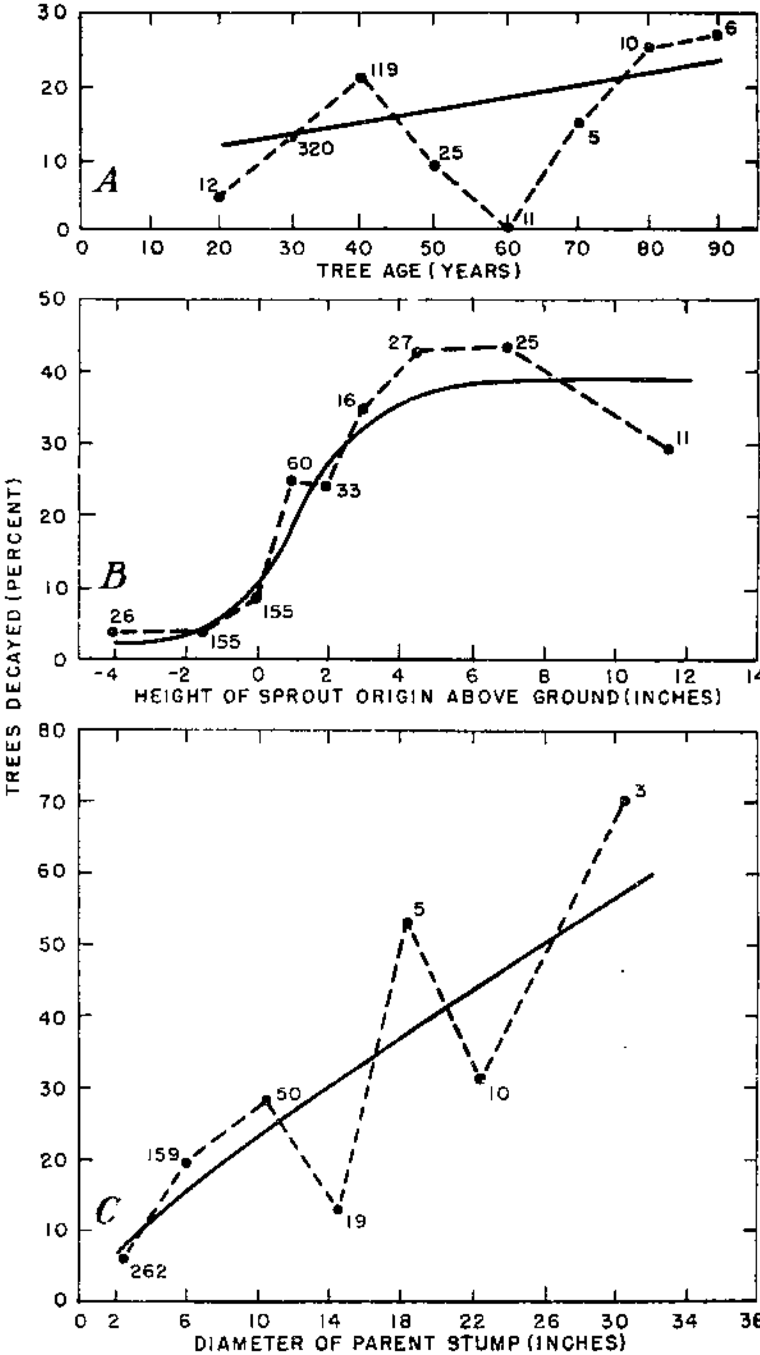

FIGURE 3.—Regression lines showing net effects of three factors (*A*, tree age; *B*, height of sprout origin above ground; *C*, diameter of parent stump), each independent of the other, on incidence of decay for white oak in Virginia and West Virginia. The numbers beside the points indicate the number of trees upon which each point is based.

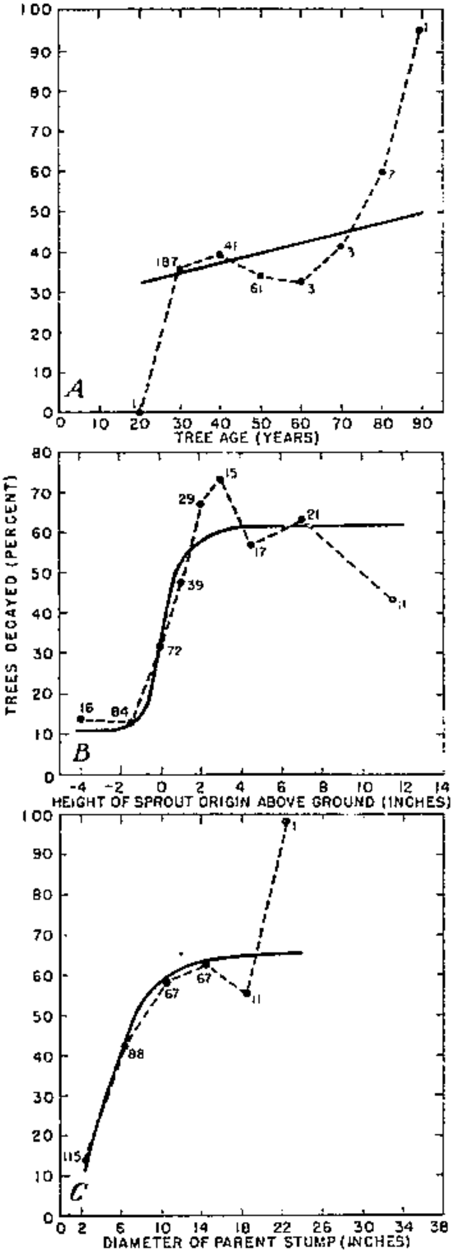

FIGURE 4.—Regression lines showing net effects of three factors (*A*, tree age; *B*, height of sprout origin above ground; *C*, diameter of parent stump), each independent of the other, on incidence of decay for black oak in Virginia and West Virginia. The numbers beside the points indicate the number of trees studied.

included. Figures 3, *B*, and 4, *B*, were developed holding tree age and stump diameter constant at their means, while table 5 shows gross relations only. In both these figures and in table 5 the number of trees serving as a basis in high origin classes is too small to justify any final conclusion; it is suggested, however, that the lower percentage of decay-affected trees in the very high origin classes may be due in part to some of these having broken over and dropped out of the stand because of earlier infection and badly weakened bases.

A decided increase in percentage of trees decayed, with increase in parent stump diameter, is shown in figures 3, *C*, and 4, *C*. Since measurements of parent stump diameter are subject to great errors because of destruction of much of the stumps by decay, the absolute diameter values mean little. The difference in shape of the curves for the two species may represent true differences but may also be due to chance variation.

While the relation of proportion of trees decayed to the three variables included in the analysis is in general similar, black oak stands out as definitely more subject to decay than white oak, since the levels of the black oak curves are much higher. Although the means of the independent variables in the case of black oak are somewhat higher than the means for white oak, the differences are not great enough to account for the much higher levels of the black oak curves.

The correlation index for the white oak was 0.613 and for the black oak, 0.737. Squaring these coefficients, it is found that 38 percent of the variance in percentage of trees decayed in white oak and 54 percent in black oak has been accounted for by the three independent variables studied.

The results of the net regression analysis supports the gross relationships of the variables used, as brought out earlier in the text and in tables 4 and 5. The refinement in analysis has been particularly successful in bringing out the critical range in height of sprout origin.

FACTORS NOT RELATED TO SPROUT GROWTH

In addition to killing trees, fire causes basal wounds through which heart-rotting fungi enter. Any mechanical wounding of sprouts that serves to expose the heartwood offers avenues of entrance for decay-producing fungi. The most common of this type of wound is caused by logging practices, particularly felling and swamping. In sprout stands in which many trees are already infected from the parent stump, fires will greatly increase the percentage of trees with butt rot and may make the difference between a profitable short-rotation crop and a nonprofitable one.

RELATION OF TREE SPECIES TO BASAL DECAY

Difference of tree species in relation to decay is dependent upon the susceptibility to infection and resistance to fungal penetration after infection takes place. The lowest percentage of butt-rotted sprouts was found in chestnut oak, followed in order by white oak, red oak, scarlet oak, and black oak. The percentage of black oaks with butt rot was nearly four times that for chestnut oak and twice that for white oak (table 9). This apparent difference in susceptibility to infection between the white oak and black oak groups is probably due in part to later heartwood union between sprout and stump in the white oaks and to the generally smaller size of the stump from which the sprouts came; tyloses, durability of heartwood in the root collar, and nature of sprout development may also have been factors in these differences. For example, there was a decided tendency for chestnut oak sprouts to come off lower and at a less acute angle from the parent stump than for the other oak species. Smaller stumps and later union of sprout and stump heartwood often permit sufficient time to elapse for butt-rotting fungi to die out in the parent stump before infection can take place in the white oaks.

The average decay height in butt-rotted sprouts was lower in chestnut and white oaks than in scarlet and black oaks (table 9). The low height of decay in red oak may be accounted for by the small number of sprouts in the older age classes. It is believed that the earlier age of infection may be chiefly responsible for the greater height of decay in black and scarlet oaks.

TABLE 9. *Comparison of decay incidence in different oak species*

Species	Trees	Average age	Trees decayed	Average height of visible decay
	Number	*Years*	*Percent*	*Inches*
Black oak	383	39	30	50
Scarlet oak	740	39	28	40
Red oak	308	32	22	27
White oak	1,288	36	19	32
Chestnut oak	504	42	11	34

RELATION OF CROWN CLASS AND DIAMETER GROWTH RATE TO DECAY

The relation of crown class and growth rate to decay has been studied by a number of workers. Some have studied decay in suppressed and dominant trees on the basis of percentage of volume of each decayed; others have expressed differences in linear extent of decay in the two groups, while still others have expressed differences between the two groups based on age of infection.

Kaufert (*19*) found practically no difference in percentage of volume decayed between fast- and slow-growing balsam fir, but in each age class the absolute volume of decay in the fast-growing trees was from 2.5 to 3 times that in the slow-growing trees. McCallum (*22*), working with balsam fir, reported more decay in fast-growing than in slow-growing trees. Meinecke (*26, 27*) states that decay begins at an earlier age in white fir affected with *Echinodontium tinctorium* Ell and Ev. and in aspen affected principally with *Fomes igniarius* (L.) Gill. if the trees are suppressed. Schmitz and Jackson (*28*) report no relation between crown class and volume percentage of rot in aspen, but the actual decay volume in the fast-growing trees was greater than in the slow-growing ones. Boyce (*3*) reports for Douglas fir a somewhat higher decay volume percentage in the faster grown trees for sites II and III, and practically no relation between vigor and decay for site I. In working with incense cedar he reports (*2*) that in the younger age classes, 40 to 240 years, slow-growing trees were more subject to rot than fast-growing ones. Between 160 and 240 years of age his data show a larger volume percentage of decay in the suppressed trees, while above this age the relation is reversed.

The relation of crown class and growth rate to decay for the last 5 years is given in table 10. There is little indication that trees in the dominant-codominant group are more subject to butt rot than those in the intermediate-suppressed group. The apparent difference, though small, between the groups is probably due to the fact that the more susceptible species are heavily represented in the dominant-codominant group and the less susceptible species in the intermediate-suppressed group. The difference between the two groups is reduced to 1.9 percent when calculated by the harmonic means of the individual species. At lea t in the present instance the difference between the two crown classes is not large enough to be of practical importance.

TABLE 10. *Relation of crown class and radial growth rate at breast height to decay incidence*

Species	Dominant-codominant group				Intermediate-suppressed group			
	Trees	Trees infected	Average current growth rate of sound trees	Average current growth rate of infected trees	Trees	Trees infected	Average current growth rate of sound trees	Average current growth rate of infected trees
	Number	*Percent*	*Inch*	*Inch*	*Number*	*Percent*	*Inch*	*Inch*
Black oak	231	30	0.053	0.051	152	30	0.032	0.030
Scarlet oak	450	31	.062	.055	290	24	.031	.027
Red oak	220	23	.072	.063	79	20	.032	.026
White oak	547	19	.057	.050	741	19	.030	.023
Chestnut oak	209	12	.051	.053	304	10	.023	.021
Other oaks					23	0	.032	
All species	1,657	24.5	.058	.053	1,580	19.8	.029	.025

There are several factors that may influence decay susceptibility of dominant and suppressed sprouts, such as (1) earlier heartwood formation in dominant or rapidly growing sprouts; (2) dominant sprouts may originate higher on the parent stump than suppressed sprouts because of apical dominance; (3) a larger proportion of the susceptible and faster-growing species are in the dominant group, as shown by tables 10 and 11; (4) dominant sprouts are mostly from medium-sized stumps; (5) the fast growth of the dominant sprouts enables them to close the stump wounds earlier; and (6) some of the suppressed trees drop out of the stand earlier. Although these factors would be expected to result in more decay in the fast-growing trees, the actual findings suggest that some compensating factors tend to hinder infection of the faster-growing trees in such a way as to make unimportant the net effect of either growth rate or crown class on decay incidence.

TABLE 11.—*Height of visible incipient decay in dominant and suppressed crown classes*

Species	Average age	Trees with butt rot: Dominant-codominant	Trees with butt rot: Intermediate-suppressed	Average height of incipient decay: Dominant-codominant	Average height of incipient decay: Intermediate-suppressed	Average height of incipient decay: All trees
	Years	*Number*	*Number*	*Inches*	*Inches*	*Inches*
Black oak	41	89	59	48	52	50
Scarlet oak	43	138	71	37	45	40
Chestnut oak	44	23	30	26	40	34
White oak	40	104	139	32	32	32
Red oak	32	53	16	27	27	27
All species	41	407	315	36	39	38

Decay was found to extend upward in the dominant-codominant sprouts and in the intermediate-suppressed sprouts at about the same rate after infection. Taking into consideration the later development of heartwood in the intermediate-suppressed trees, there is an indication that decay fungi penetrate suppressed trees slightly faster than dominant ones, although this difference is not great enough to be considered important.

Site as a factor influencing butt rot was not studied; however, it is unlikely that the influence of site quality, as determined by growth rate, on decay incidence is very important. The earlier heartwood formation in sprouts on the better sites makes them subject to butt rot at an earlier age, but it is doubtful if this earlier formation of heartwood will ultimately result in more decay on the better sites.

RELATION OF TYPE OF SPROUT GROUP TO DECAY

A typical second-growth sprout stand consists of a variety of growth forms, including seedlings, single seedling sprouts, multiple seedling sprouts, and sprouts. They are defined by Leffelman and Hawley (*21*) and McIntyre (*23*). Some of these growth forms are shown in plate 11. The growth forms with which this study is concerned are sprouts that consist of single-stemmed trees (pl. 11, *A*), twin-stemmed trees (pl. 11, *B* and *C*), and multiple-sprout groups (pl. 11, *D*). It has been generally observed (*20, 21, 23, 29*) that stumps in sprouting produce a number of stems; this number gradually decreases as the stand grows older, and there are few stumps with two or more stems after 30 years of age.

Multiple seedling sprouts, as has been reported (*21*), were found to be practically nonexistent in the sprout-oak stands dissected. After a sprout reaches an age of from 15 to 20 years, depending somewhat upon the growth rate and the height of sprout origin, it is difficult to determine the size of the parent stump without first dissecting the stem. As the sprouts dissected ranged in age from 15 to 90 years, it is recognized that many of the seedling sprouts that were single-stemmed at the time of dissection may have been the surviving member of a multiple seedling-sprout group. Of the 957 trees found in sprout groups in widely separated areas, only 18, or 1.9 percent, were from stumps 2 inches or less in diameter. Of these 18 trees, 89 percent were in the intermediate-suppressed group. Multiple seedling sprouts may occur frequently in very young stands but disappear as the stand grows older. Most of the twin stems from stumps 2 inches or less in diameter were found to be making slow growth. This was also found to be true of single-stemmed seedling sprouts, of which over 64 percent were in the intermediate-suppressed group.

Twenty-nine percent of the sprouts dissected were found in sprout groups (table 8). This agrees closely with an observation by McIntyre (*23*) in which he found that over 25 percent of the total number of stems and the basal areas of young second-growth oak forests were in sprout groups. Of the stems found in sprout groups during the present study, 79 percent had two sprouts per clump, 16 percent had three, 4 percent had four, while only 1 percent had more than four sprouts per group. Of the single-stemmed trees dissected, 21.5 percent were found to contain decay. The percentage of decayed trees for those located in sprout groups was 23.9.

More than 61 percent of the sprouts in sprout groups had open stump wounds. The average diameters of the parent stumps for single-stemmed sprouts dissected was 6 inches, as compared with more than 12 inches for those sprouts found in sprout groups. The difference in parent stump diameters, together with the larger percentage of open wounds, probably accounts for the larger percentage of decay cases in this group.

From the results obtained during this study it is believed that multiple seedling sprouts are relatively unimportant in most even-aged sprout oak stands. The great majority of the twin stems over 15 years old are from parent stumps considerably over 2 inches in diameter. Sprout groups from stumps of diameters larger than 2 inches are more likely to persist than groups from smaller stumps; they are likely to have a larger percentage of open stump wounds and also to contain a greater percentage of decay cases in the final stand than single-stemmed trees.

DECAY IN SPROUT STANDS THAT ARISE AFTER FIRE

After a severe burn, trees and stumps are capable of producing sprouts, provided some of the latent buds at or below ground line escape injury. Greeley and Ashe (*15*) found that white oak sprouted readily from the stumps of seedlings and saplings that had been killed


A
B
C
D

by fire. Zon (*32*) points out that oak stumps may continue to sprout during 30 or 40 years of periodic fires, but that they finally lose their sprouting capacity.

Nearly one-half of the plots cut were located in stands that arose after fire (table 1). These fires had occurred either after the cuttings, or in some cases the cuttings were made immediately after a fire. The percentage of decay cases in the burned plots were much lower than in the unburned plots (table 1).

Hot fires and repeated burnings more often than not kill the cambium down to ground level, thereby destroying all latent buds above that point. This being the case, only those buds that occur at or below ground level can produce sprouts. As previously pointed out, the percentage of decay cases in a stand increases with increase in height of sprout origin. The sprouts in severely burned areas, by arising low on the parent stumps (pl. 2, *C* and *D*), do not keep any of the stump alive above ground level; consequently the stump decays more quickly than if sprouts originated from the sides of it. If no other factors were involved, the sprouts from stumps in burned-over areas should have a lower percentage of decay cases than those in unburned areas, because of lower sprout origin.

Actual consumption of part of the stumps by fire may take place where there are repeated burns or very hot fires. In such cases, when a stump is infected, the fungus will be able to decay the unburned part of the stump and become inactive in less time than it otherwise would had the stump not been partly burned. For example, a 6-inch stump in a fire-free stand might ordinarily infect a sprout, whereas if it were partly consumed by fire the decay might easily run its course and become inactive before a heartwood union was formed with the parent stump. Partial consumption of the stump by fire will also enable the sprout to enclose the stump in a shorter period of time and there will be a smaller percentage of stump wounds.

The consumption by fire of debris on which decay fungi fruit, before the establishment of the stand, no doubt has some effect on reducing the number of sporophores found in an area and may in this way influence to some degree the amount of decay in a stand

It was found that stands in areas that had been burned preceding regeneration had fewer high-crotch twin sprouts than stands in unburned areas. This was a result of a reduction in the number of buds that could develop, with consequent greater average distance between sprout origins on the same stump.

The effects of fire on type of sprout reproduction are especially interesting in that they suggest cultural practices that may be employed to keep decay losses at a minimum without the undesirable results that follow burning. By destroying sprouts that originate above ground level, and by cutting the stumps low, it may be possible to bring about the same results attained by fire. Practices encouraging low sprout origin together with low-cut stumps are now being studied on the George Washington National Forest in Virginia.

EXTENT OF DECAY

Other important considerations in a decay study dealing with butt rot are the fungi causing the decay, the rate of penetration in the heartwood by the fungus after initial infection, the height of visible decay, and the extent of mycelial penetration above incipient decay. Generally the entire cylinder of heartwood is rendered unfit for utilization to the upper limit of the final decay zone and often well into the zone of intermediate decay. It is possible that wood from the zone of incipient decay and the still higher zone of nonvisible infection may prove weak or the fungus may continue to work after sawing. An effort was made to ascertain the extent of penetration in different age classes and the maximum upward extent of decay. Unfortunately, some of the older age classes were not available because of the difficulty of locating stands free of fire injury.

HEIGHT OF DECAY

The linear extent of evident decay averaged slightly more than 3 feet above ground level in the 744 sprouts affected with butt rot. Cultures from the butt-rotted sprouts did not yield wood-destroying fungi in all cases. Evidently the decay fungi had died out in some cases, rendering the decay process inactive. The average height of active decay was 42 inches, as compared with an average height of 25 inches for those yielding no fungi in culture.

Considerable variation was found in the extent of incipient decay caused by different fungi (table 12). Incipient decay of *Stereum gausapatum* Fr. averaged 55 inches with a maximum height of 206 inches, while the next two most frequently isolated fungi, *Armillaria mellea* (Vahl) Quel. and *Fistulina hepatica* (Huds.) Fr., averaged 13 inches with a maximum height of 54 inches. For 10 fungi the maximum height of incipient decay was 4 feet or more above ground level, while 4 fungi were not found above 2 feet.

TABLE 12.—*Fungi and host trees*

Species of fungi	Cases in— White oak	Cases in— Chestnut oak	Cases in— Scarlet oak	Cases in— Black oak	Cases in— Red oak	Total cases	Infections from parent stump	Incipient decay: Average height	Incipient decay: Maximum height
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Inches*	*Inches*
Stereum gausapatum Fr.	109	19	69	86	32	315	302	55	206
Armillaria mellea (Vahl) Quel.	19	9	8	6	10	52	44	13	54
Fistulina hepatica (Huds.) Fr.	3	2	42	2	1	50	50	13	54
Poria cocos (Schw.) Wolf.	2	0	9	4	1	16	13	35	68
Polyporus sulphureus (Bull.) Fr.	0	1	10	1	0	12	9	13	37
Polyporus zonalis Berk.? [1]	3	0	4	3	1	11	11	11	24
Hydnum erinaceus Bull.	3	2	2	3	0	10	0	50	134
Stereum frustulosum (Pers.) Fr.	3	0	5	1	1	10	6	16	24
Polyporus spraguei Berk. and Curt.	0	0	7	0	0	7	7	33	54
Polyporus compactus Overh.	0	0	2	3	1	6	6	28	39
Corticum lividum Pers.	0	0	1	2	0	3	3	94	186
Polyporus frondosus (Dicks.) Fr.	1	2	0	0	0	3	2	23	36
Polyporus versicolor (L.) Fr.	1	0	1	1	0	3	0	16	18
Polyporus spp.	1	0	0	2	0	3	3	15	22
Polyporus croceus (Pers.) Fr.	0	0	2	0	0	2	2	66	66
Ustilina vulgaris Tul.	0	0	0	0	2	2	2	27	48
Polyporus berkeleyi Fr.	0	0	0	1	0	1	1	58	58
Daedalea quercina (L.) Fr.	0	0	1	0	0	1	1	5	5
Pholiota sp.	0	0	1	0	0	1	1	4	4
All species	145	35	164	115	40	508	472	42	--------
Cases that yielded no decay fungi	102	20	57	36	21	236	--------	25	222
Total, all decay cases [2]	247	55	221	151	70	744	--------	30.4	--------

[1] According to type of rot and cultural characteristics this fungus is closely related to *Polyporus zonalis*, but it consistently differs in several minor growth characters.

[2] Includes preliminary as well as later data.

The height of incipient decay in the suppressed trees was slightly higher than in the dominant trees (table 11 and fig. 5), despite the fact that they include a smaller proportion of the more susceptible species. This difference was most pronounced in chestnut oak sprouts, where decay averaged 14 inches higher in suppressed than in dominant sprouts. In white and red oaks the incipient-decay height was the same in the two crown classes. The importance of the difference

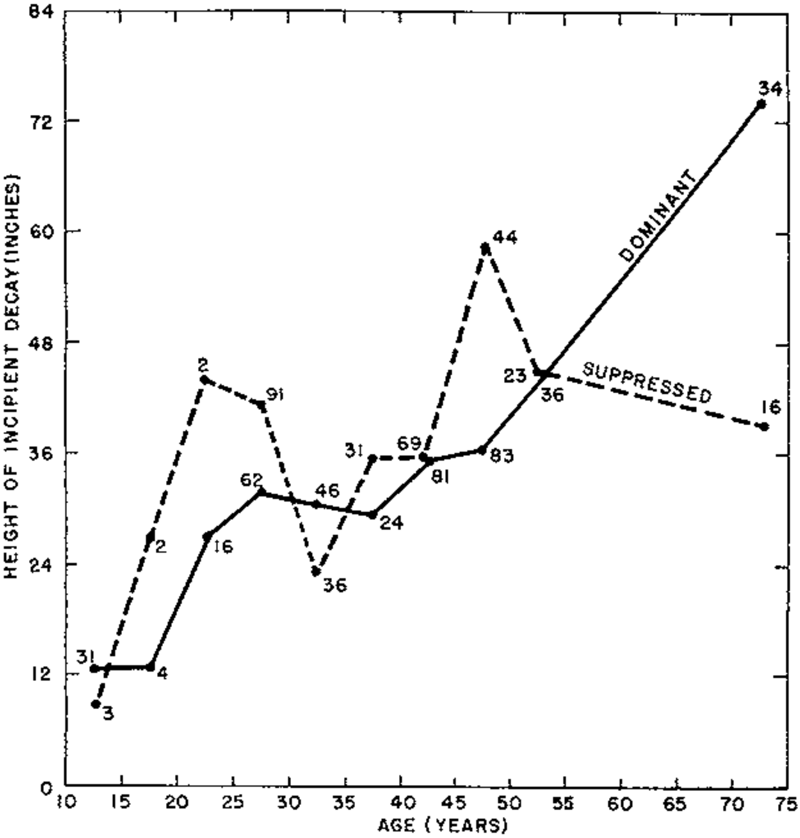

FIGURE 5.—Relation between heights of incipient decay and age in dominant and suppressed sprouts. The numbers beside the points indicate the number of trees studied.

between the two crown-class groups (table 11) cannot be evaluated without taking the age of the trees into consideration.

The height of decay was found to increase with the age of a stand. The height of decay increased from 18 inches in the 16- to 20-year-age class to 45 inches in the 46- to 50-year-age class (fig. 5), an increase of 27 inches in 30 years, or approximately an average annual increase of 1 inch. It should not be concluded from this that decay advances only 1 inch a year, because the infected trees in the older age classes include not only those trees in which decay was active at an early age but also those that become infected much later. New infections make height of decay divided by sprout age a poor expression of decay rate.

EXTENT OF INFECTION BEYOND VISIBLE DECAY

An effort was made to obtain information on the penetration of decay fungi beyond the zone of incipient decay, because of its possible practical importance to the wood-using industries. A large number of the specimens taken above incipient decay for culturing yielded the same wood-rotting fungus as specimens taken from the zones of incipient, intermediate, and final decay within the same tree. A considerable number of the blocks taken above incipient decay did not yield any fungi. The latter result was not wholly unexpected, since only one block was taken from a given cross section, and the position from which the specimen was chosen was often a matter of chance. Also, the uppermost specimens taken were no doubt in many cases well above any fungal penetration. Where the incipient decay ended in a small, thin streak, the advanced hyphae would likewise be confined to a small cross-section area at any given point beyond incipient decay. This condition often made it difficult to procure infected specimens from the zone of nonvisible infection.

Table 13 shows the average distances at which seven of the more common fungi had penetrated above incipient decay. The maximum distances above incipient decay at which decay fungi were isolated ranged from 12 inches for *Polyporus compactus* to 72 inches for *P. sulphureus*. *Stereum gausapatum* was isolated a number of times 4 feet and in one instance 5 feet above incipient decay. *Armillaria mellea*, the third most frequently isolated butt rotter, was isolated in only one instance above incipient decay.

TABLE 13.—*Cases in which decay fungi were isolated above visible incipient decay*

Species of fungi	Trees in which fungus was isolated above incipient decay		Average observed height of decay	Average height isolated above decay	Maximum distance isolated above decay
	Number	*Percent*	*Inches*	*Inches*	*Inches*
Stereum gausapatum Fr.	84	27	56	22	60
Fistulina hepatica (Huds.) Fr.	11	22	18	19	42
Hydnum erinaceus Bull.	5	50	55	25	45
Polyporus sulphureus (Bull.) Fr.	5	42	15	33	72
Stereum frustulosum (Pers.) Fr.	4	40	16	24	42
Polyporus compactus Overh.	3	50	31	12	12
Poria cocos (Schw.) Wolf	2	13	41	18	22

It is not known with any degree of certainty how serious a problem in wood utilization is created by the mycelial invasion of the heartwood above incipient decay. However, when heartwood is used for some purposes the nonvisible infection zone is of little or no consequence, while in others, where the period of use is a matter of years and the wood remains moist, this type of decay may be of considerable importance. The length of time fungi causing heart rot in living trees will continue to live in manufactured products is not known. If they die out when the product is thoroughly seasoned their presence will be of no importance. *Stereum gausapatum*, the most common fungus encountered, was isolated from cross ties cut from wood just above incipient decay after the ties had seasoned in the open for over 6 months.

THE FUNGI INVOLVED

Considerable progress has been made in recent years in the determination of decay fungi by laboratory culture technique. A number of wood-destroying fungi of conifers were studied in culture by Fritz (*9*), and a key was worked out for their identification on the basis of cultural characteristics. Hepting (*17*), in a study of decay in young hardwoods of the Mississippi Delta region, obtained satisfactory results in determining wood-destroying fungi on the basis of cultural characteristics.

Determination of the fungi by culture technique was used in the present study because other methods, such as association of sporophores with decay and identification of the causal fungus by comparison of so-called typical decay samples, were not satisfactory. For example, *Daedalea quercina* and other fungi were observed more or less frequently to be the only fungus fruiting on parent stumps, and *Stereum gausapatum* or some other fungus would be isolated from the decayed sprouts. As Davidson (*7*) has pointed out, it is very difficult to determine the causal organisms from decayed wood alone because of the similar appearance of many decays caused by different fungi. For example, in some of the earliest preliminary work on butt rot in sprout stands *Hydnum erinaceus* was thought to be the fungus causing most of the butt rot in a third-generation coppice stand. Later, by the use of culture technique, *S. gausapatum* was found to be the causal fungus. As the present study progressed, several fungi hitherto unreported as butt rotters have been so determined by cultural methods. One of the most important features of the culture method was that it made possible the identification of decay fungi in the incipient decay stages and the determination of the extent of mycelial progression beyond incipient decay. In those cases where only incipient decay was present, the determination of the fungus was possible only by making cultures.

SPECIES OF FUNGI ISOLATED

The fungi determined as causing butt rot, their chief avenues of entrance, and their host species are listed in table 12. Three fungus species were responsible for 82 percent of the butt rot cases for which decay fungi were determined. *Stereum gausapatum* was isolated in 62 percent and *Fistulina hepatica* and *Armillaria mellea* each in 10 percent of the decay cases determined. The remaining 18 percent consisted of 16 fungus species. Ten genera were represented by the 19 species isolated from the butt-rotted sprouts. The genus *Polyporus* included nine species, *Stereum* two species, and the remaining eight genera one species each. The genus *Fomes*, many species of which cause important trunk rots, was not included in the determinations. Of the more frequently isolated fungi none belonged to the genus *Polyporus*, while the three most frequent fungi belonged to different families. *S. gausapatum* belongs to the Thelophoraceae, *A. mellea* to the Agaricaceae, and *F. hepatica* to the Polyporaceae. Since *S. gausapatum* appears in so many trees and causes so much more decay per infected tree than the other fungi frequently encountered, its importance as a cause of sprout butt rot overshadows all the others combined.

Fistulina hepatica is of peculiar interest as a butt rotter. Davidson [8] considers it to be primarily a discoloring fungus. In the advanced stages of infection and disintegration the wood becomes dark brown and finally punky, but never soft and crumbly like most butt rots. In the incipient stages the heartwood has a mottled grayish brown appearance that gradually merges into a very light brown color near the upper limits of infection.

The results of the cultural determinations agree with Hepting's conclusion (*17*) that as a rule only one fungus was responsible for the major decay in any one tree. In only 5 out of 508 cases were 2 or more species of decay fungi isolated from the same sprout. In these sprouts no two fungi were found to have entered at the same point. The old stump served as one point of entrance and a dead sprout or branch stub the other. In one white oak sprout 95 years old, *Stereum frustulosum* was isolated at 102 inches, *Corticium lividum* at 200 inches, *Polyporus sulphureus* at 276 inches, and *S. gausapatum* at 320 inches. In a scarlet oak sprout 52 years old, *S. gausapatum* extended from ground level to 132 inches, *Hydnum erinaceus* was isolated at 168 inches, and *C. lividum* at 180 inches. In each of these cases the respective fungi were isolated free of any contaminants. These two trees are no doubt exceptional cases, but they indicate that as a tree increases in age the possibility of its being infected with more than one fungus increases because of an increase in the number of available entrance points.

MODE OF ENTRY OF IDENTIFIED FUNGI

For the 508 decay cases in which the causal fungus was identified, 93 percent of the fungi entered the sprout from the parent stump, 4 percent from a cut or dead companion sprout, and 3 percent through other avenues. To serve as an added check on the avenues of entrance, specimens of decay were taken from the parent stump and stub wherever possible in both decayed and sound sprouts. In 105 cases the decayed sprout and parent stump yielded the same fungus, and in 9 cases the sprout and stub yielded the same fungus. In 7 cases the parent stump yielded a different fungus from that found in the decayed sprout. In 121 cases where the sprout was sound, decay fungi were isolated 85 times from the parent stump and 36 times from a cut or dead companion sprout. The chances are good that within a few years some of these 121 sprouts would have been invaded by the fungi present in the parent stump or stub. This condition strongly indicates that the total number of decay-affected sprouts increases with the age of the stand. *Stereum gausapatum* and *Armillaria mellea* were the fungi most frequently isolated from the parent stumps and stubs where the sprouts were sound. In addition to the fungi listed in table 12, *Poria nigra* Berk. and *Hymenochaete rubignosa* Dick. ex Leveille were isolated from a stub and a parent stump respectively. These two fungi are considered as butt rot fungi. In one instance *P. nigra* was found fruiting in a large open butt cavity of a mature white oak.

[8] DAVIDSON, ROSS W. FOREST PATHOLOGY NOTES. U. S. Bur. Plant Indus. Plant Disease Rptr. 19: 94-97. 1935. [Mimeographed.]

HOST RELATIONSHIPS OF THE FUNGI

No definite relationship between hosts and the fungi causing butt rot was found. Table 12 shows that the different species of fungi were well distributed among the five species of oaks. In those instances where a fungus was isolated but a few times, 16 or less, 1 or more of the 5 oaks failed to yield the given fungus, and in about one-half of the cases fewer cultures were obtained than there were host species. *Fistulina hepatica* appeared to show a preference for scarlet oak, as it was isolated in 42 cases out of 50 from this host. This apparent preference may be due not to specialization but to local conditions such as soil, moisture, and temperature especially favorable to the propagation of this fungus; 15 of the 42 cases came from a single Connecticut plot. *Stereum gausapatum* attacked all oak species without apparent discrimination and produced decay in one oak host as readily as in another (table 14). In view of the foregoing, and also because of the similarity of the species of a tree genus and the more or less cosmopolitan habits of heartwood-rotting fungi, it is unlikely that there is a definite specialization of the fungi isolated to any particular oak species.

TABLE 14.—*Height and rate of penetration of Stereum gausapatum*

Tree species	Trees infected	Average age	Height of decay: Average height	Height of decay: Maximum height of incipient decay	Height of decay: Maximum height at which fungus was isolated	Calculated[1] annual fungus penetration: Average rate	Calculated[1] annual fungus penetration: Maximum rate[2]
	Number	*Years*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Scarlet oak	69	44	72	206	216	2.5	7.5
Black oak	86	36	64	176	200	2.8	8.6
Chestnut oak	19	41	57	132	132	2.0	4.9
White oak	109	33	40	102	120	2.0	5.3
Red oak	32	29	38	96	150	3.0	15.0
All species	315	38	55	142	164	2.3	8.2

[1] The annual rate of penetration was calculated by dividing the average age less 10 years into the average height at which the fungus was isolated. Entrance of a heartwood-decaying fungus does not take place before heartwood has formed in the sprout. Such formation is unlikely to occur before the sprout is 10 years old.

[2] Based on individual trees.

INACTIVE DECAY

Nearly one-third of the sprouts that were affected with butt rot and so recorded in the field failed to yield cultures of decay fungi in the laboratory. Many of these were contaminated with molds and bacteria, some yielded only molds or bacteria, while others were sterile (table 12). Contaminants were not unexpected, since specimens of all sorts of decay, both active and inactive, were collected, and it is likely that in some cases molds and bacteria had supplanted wood-destroying fungi. In many cases, however, badly decayed trees yielded no organisms whatever. The negative results obtained in the latter cases can hardly be accounted for on the assumption that too few specimens for culturing were taken. It is scarcely possible that the fungi failed to survive the 2- or 3-day interval between the removal of the decay specimens from the tree and their arrival at the laboratory. The dying out of fungi in living trees probably occurs in a large number of cases. In some cases a small cavity in the base of a tree was the only evidence that a wood-destroying fungus had been active, while in others the decayed wood was dark, crumbly to powdery, with no zone of intermediate or active decay separating it from the sound wood. On the other hand, it is not improbable that imperfect culture technique may account for a small percentage of the negative isolation results, since some fungi are very sensitive to environmental conditions such as nutrition, moisture, and temperature. Unquestionably a higher percentage of successful cultures would have been desirable, but the 68 percent of successful attempts is considered very satisfactory under the circumstances and is believed to give a fairly accurate index of the fungi responsible for butt rot in sprout oak stands within the areas studied.

STEREUM GAUSAPATUM

Because of its particular importance, *Stereum gausapatum* will be discussed somewhat in detail. This fungus (pl. 3, *B*) was found to be by far the most common butt rotter in sprout oak stands. Of 508 cases in which butt-rotting fungi were isolated, 315, or 62 percent, yielded it. It is interesting to note that this fungus had not been reported in this country as a heartwood-rotting organism before 1934, 1 year after the present study started (*7*). *S. gausapatum* has been reported (*24*) as causing considerable damage to holm oak in Italy. In England and France, *S. spadiceum* Fr., which probably is synonymous with *S. gausapatum*, has been reported (*6*) as causing a rot in the heartwood of standing oaks.

In the early stages of decay *Stereum gausapatum* forms white lines through the sound wood, producing a mottled appearance when viewed longitudinally (pl. 3, *C*). These white lines or channels usually follow the springwood vertically, but they branch frequently and sometimes penetrate through the annual growth rings. Gradually the summerwood becomes decayed, and in the final stages all the wood becomes light colored and brittle. In the incipient and intermediate stages, decay caused by *S. gausapatum* is very similar to that produced by *Hydnum erinaceus*.

For the oak sprouts dissected in the present study, with an average age of 38 years, the height of visible decay for those trees yielding *Stereum gausapatum* was 55 inches. Owing to the scarcity of unscarred sprouts in the older age classes, little data were obtained on the height of decay caused by *S. gausapatum* in merchantable stands. However, an idea of the probable upward extent of decay in older trees is possible from figure 6. While the upper portion of the curve in this figure is poorly supported, there is a definite indication that the fungus will continue to spread upward in the heartwood.

The loss in sprout stands affected with butt rot would be lowest when utilized for short-rotation products. In the production of posts and mine props from sapling stands the expected loss from *Stereum gausapatum* decay would be in the neighborhood of 3 to 4 feet per infected tree. For fuel-wood purposes the loss would be negligible. Likewise, if there is a demand in the future for oak in pulp or chemical wood operations, the loss from this source will be small.

In stands requiring 50 years or more to produce the product desired, the loss may be expected to increase with the age of the stand. For cross-tie production, which requires trees somewhat larger than those used for mine props, commonly 60 to 80 years old, the trees will of necessity be older and, based on figure 6, would have from 8 to 9 feet of cull per infected tree. In sprout stands used for the production of high-quality saw timber the loss from butt rot caused by *Stereum gausapatum* would be still higher than for cross ties. If the end of the curve in figure 6 is extended, the probability is that in sprouts 100

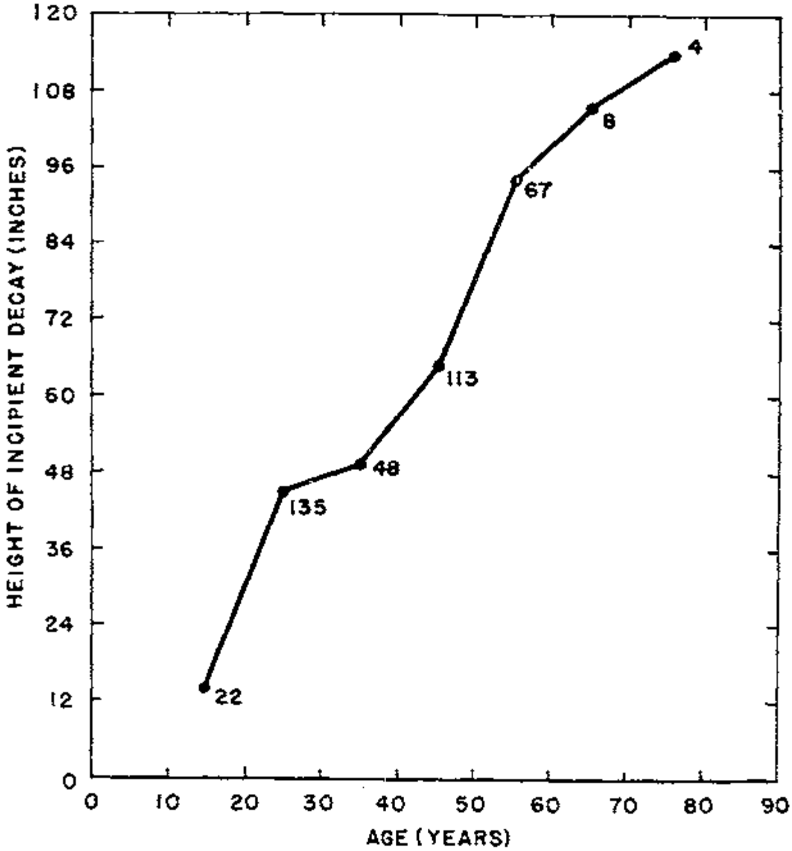

FIGURE 6.—Heights of incipient decay caused by *Stereum gausapatum* for all species studied, by 10-year age classes. The numbers beside the points indicate the number of trees studied.

to 150 years of age a considerable portion of the butt log will be decayed.

The average rate of decay progression caused by various fungi has been estimated (*2*, *17*) to range from 1 to 5 inches per year. The average rate for *Stereum gausapatum* in the different oak species ranged from 2 to 3 inches (table 14). In calculating the annual rate of penetration, decay height was divided by the age of the sprout less 10 years. It was assumed that no heartwood formation had taken place before the sprout was 10 years old. This was considered to be a conservative assumption for two reasons—(1) heartwood does not usually form in oak sprouts before 8 to 10 years—and (2) heartwood in the sprout does not usually connect with the old stump until sometime after it has made its appearance in the sprout. Thus in the sprouts selected as a basis to calculate rate of fungal penetration it was assumed that a 10-year-old sprout was the youngest in which infection was likely to occur. Much infection probably started later, and the actual rate was therefore somewhat more rapid than that calculated.

Table 14 shows the average and maximum calculated rate of penetration for *Stereum gausapatum*. The average annual rate of penetration was lowest in white oak and in chestnut oak, 2.0 inches, and highest in red oak, 3.0 inches. The maximum rate of spread was nearly twice as rapid in the members of the black oak group as in those of the white oak group. Tyloses may be responsible for this lower rate of penetration, as they occur abundantly in white and chestnut oaks and are almost always absent in scarlet, black, and red oaks.

SUGGESTED PRACTICES TO KEEP BUTT ROT IN SPROUT OAK STANDS AT A MINIMUM

There are two types of stands to be considered in any recommendations dealing with sprouts—(1) very young stands, in which decay can be kept to a minimum by correct treatments throughout the life of the stand; and (2) the older sprout stands, which are already established but in which the total decay can be somewhat reduced by proper cultural treatments. In either case the principal method of attack is to favor in cultural operations the sprouts least likely to be infected.

In working with very young stands (up to 3 inches at breast height and not over 20 years old) the factors affecting the incidence of decay are more readily recognized, and treatment should be undertaken wherever possible at this young stage. The following recommendations are offered for these stands:

(1) Seedlings or seedling sprouts should be favored as crop trees.

(2) Sprouts from small stumps (preferably less than 3 or 4 inches and not over 6 inches in diameter at ground level) should be favored over those from larger stumps. After a stand is more than 10 to 15 years old there is difficulty in determining the size of the stump from which the sprout originated without dissecting it.

(3) Wherever possible, sprouts originating low on the parent stumps (near ground level or below) should be favored over those of higher origin. The height of sprout origin cannot be determined for older stands without dissection. Sprouts from low-cut stumps should be favored over those from high-cut stumps.

(4) In the selection and thinning of fused sprouts, the procedure recommended is to cut flush at the crotch, or as nearly flush as can be done without injury to the favored sprout, so that rapid healing-over may take place. Care should be taken not to loosen the bark at cuts, or healing-over will be retarded. With sprouts less than 1 inch in diameter, flush cutting may be inadvisable because of increased cost.

Recommendations for stands already established (more than 3 inches at breast height and generally over 20 years old) are as follows:

(1) Single sprouts are preferable to fused sprouts, particularly if the latter require thinning. It was found during the present study that as a rule single-stemmed trees came from smaller stumps than twin trees.

(2) Sprouts with the stump wounds not yet grown over or with enlarged butts should be discriminated against. These sprouts are likely to be from larger stumps and to have higher origins than sprouts with closed or no stump wounds.

(3) Clumps of large sprouts that are fused for some distance above ground level, or that have low V-type crotches, should be either entirely cut or left entirely intact and should ordinarily be avoided as crop trees. Sometimes it may be advisable to leave such sprouts as trainers for crop trees.

Recommendations that apply to stands of any age are as follows:

(1) For some short-rotation crops, such as cordwood, losses due to decay will ordinarily be of minor importance and no special precautions are necessary. However, in areas used for mine-prop and post production, decay may be more important than is now realized. In general, the longer the expected rotation the more attention should be paid to keeping decay at a minimum.

(2) The trees on areas that have been repeatedly cut over are likely to be highly defective and should be avoided for the growing of long-rotation crops. Improvement operations in such stands may be difficult, and the chances of obtaining a sound stand are poorer than in stands that have been less frequently cut. When a young stand is already badly infected from the parent stump, a short-rotation crop is advisable, with later efforts directed at converting the stand to seedling, seedling sprout, or better sprout growth. Where infection is not common, emphasis should be on increased care in improvement work.

(3) When trees are badly wounded by fire, the butt rot hazard is already high. Precautions taken to reduce stump and stub decay transmission in such stands are less likely to reduce subsequent loss due to butt rot than had the trees been unscarred.

The effectiveness of any treatment will depend on sound judgment and careful work on the part of both supervisors and workers. The recommendations herein presented apply in a general way wherever stand-improvement work is being carried on in sprout oak stands and less directly to sprout growth of some other species. However, they do not necessarily cover all conditions encountered in the field.

SUMMARY

A study of butt rot in unburned sprout oak stands of the Allegheny, Appalachian, and Central States regions was conducted from 1933 to 1936. Two or more plots were clear-cut in each of the following States: Connecticut, Illinois, Maryland, Missouri, Pennsylvania, Virginia, and West Virginia. Over 3,200 trees of 7 oak species were dissected and analyzed.

Oak sprouts develop from latent buds at or near the root collar and sometimes higher on the stump. Latent buds give rise to epicormic branches, resulting in the condition known as "feathering out" that often occurs in heavily thinned stands.

All or a part of the root system of the parent stump is utilized by the new sprout growth in the case of the seven oak species studied. No evidence was found to indicate that the sprouts develop an independent root system.

Sprouting capacity of oak stumps decreases with an increase in size and age. White oak loses its ability to sprout at a somewhat earlier age and smaller size than the other oaks.

Sprout stands that had arisen following severe burns had a lower decay incidence than those resulting from cutting operations without fire. Fire preceding the establishment of a stand kills the cambium and latent buds above the ground line on the stumps, thereby forcing sprout regeneration from buds at or below ground level, creating a condition unfavorable for infection of sprouts from the parent stump.

For 45 clear-cut plots the average age per plot ranged from 17 to 84 years and the number of decay cases ranged from none to 64 percent, with an average height of decay in affected trees from 7 to 74 inches.

The parent stump is the common source of entrance for decay fungi in unburned sprout oak stands. Heart-rotting fungi entered from the parent stump in 86 percent of the cases.

Decay incidence is correlated with diameter of parent stump. Sprouts from large stumps are more subject to butt rot than sprouts from small stumps.

Sprouts arising below ground have the least likelihood of being affected with heart-rotting fungi from the parent stump. The chances of infection increase rapidly with the height at which the sprouts come off the old stump, between ground level and 4 inches above; for sprouts with origins more than 4 inches high the hazard is little if any greater than at 4 inches.

The presence of stump wounds is correlated with presence of butt rot in sprout oak stands.

The time of heartwood formation and subsequent connection with the parent stump determines the time that earliest infection from the parent stump can occur. Heartwood does not usually occur in oak sprouts younger than 8 to 10 years and seldom forms a stump connection until after 10 years.

The initiation and formation of heartwood are dependent on age, size, and distance from active cambium.

Young sprouts in the dominant crown class have more heartwood in cross section, both in rings and in percentage of basal area, than suppressed sprouts of the same age.

The net regressions of decay incidence on sprout age, height of sprout origin, and diameter of parent stump were worked out for white and black oak sprouts dissected in Virginia and West Virginia. These three independent variables accounted for 38 percent of the variance in percentage of trees decayed in white oak and 54 percent in black oak.

Chestnut oak had the lowest percentage of decayed sprouts, 11 percent, white oak 19 percent, red oak 22 percent, scarlet oak 28 percent, and black oak the highest, 39 percent. The tendency of white oak to sprout only from small stumps is a factor in its relatively low infection percentage.

No definite relationship was found between crown classes and percentage of trees infected. In trees once infected the upward extension of the decay was slightly more rapid in the suppressed class.

Twin and multiple-stem sprout groups came from larger stumps than single-stem sprouts. A higher percentage of twin and multiple-sprout stems were decayed than single-stem sprouts.

The linear extent of evident decay averaged slightly more than 3 feet above ground line in the 744 sprouts affected with butt rot.

Seven of the butt rot fungi found in evidently infected wood were also found in some of the trees in apparently sound wood farther up the tree. The average extension of the fungi beyond evident decay in these trees was about 2 feet.

Of 508 decayed sprouts from which butt-rotting fungi were isolated, 315, or 62 percent, yielded *Stereum gausapatum*. *Fistulina hepatica* and *Armillaria mellea* were the next two most frequently isolated fungi. In all, 19 species of wood-rotting fungi were isolated from the wood of living sprouts.

No relationship could be established between the various fungi and host trees, with the possible exception of *Fistulina hepatica* and scarlet oak.

In a number of trees decay appeared inactive. Cultures from decayed wood in such trees yielded no wood-rotting fungi, indicating that the causal fungus had died out.

The average annual rate of penetration of *Stereum gausapatum* ranged from 2 to 3 inches, with a maximum rate of 5 to 15 inches for different oak species. The average height of *S. gausapatum* decay was 55 inches, and in a few cases the fungus was isolated 200 inches high.

Practices are suggested for keeping decay losses at a minimum in sprout oak stands.

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