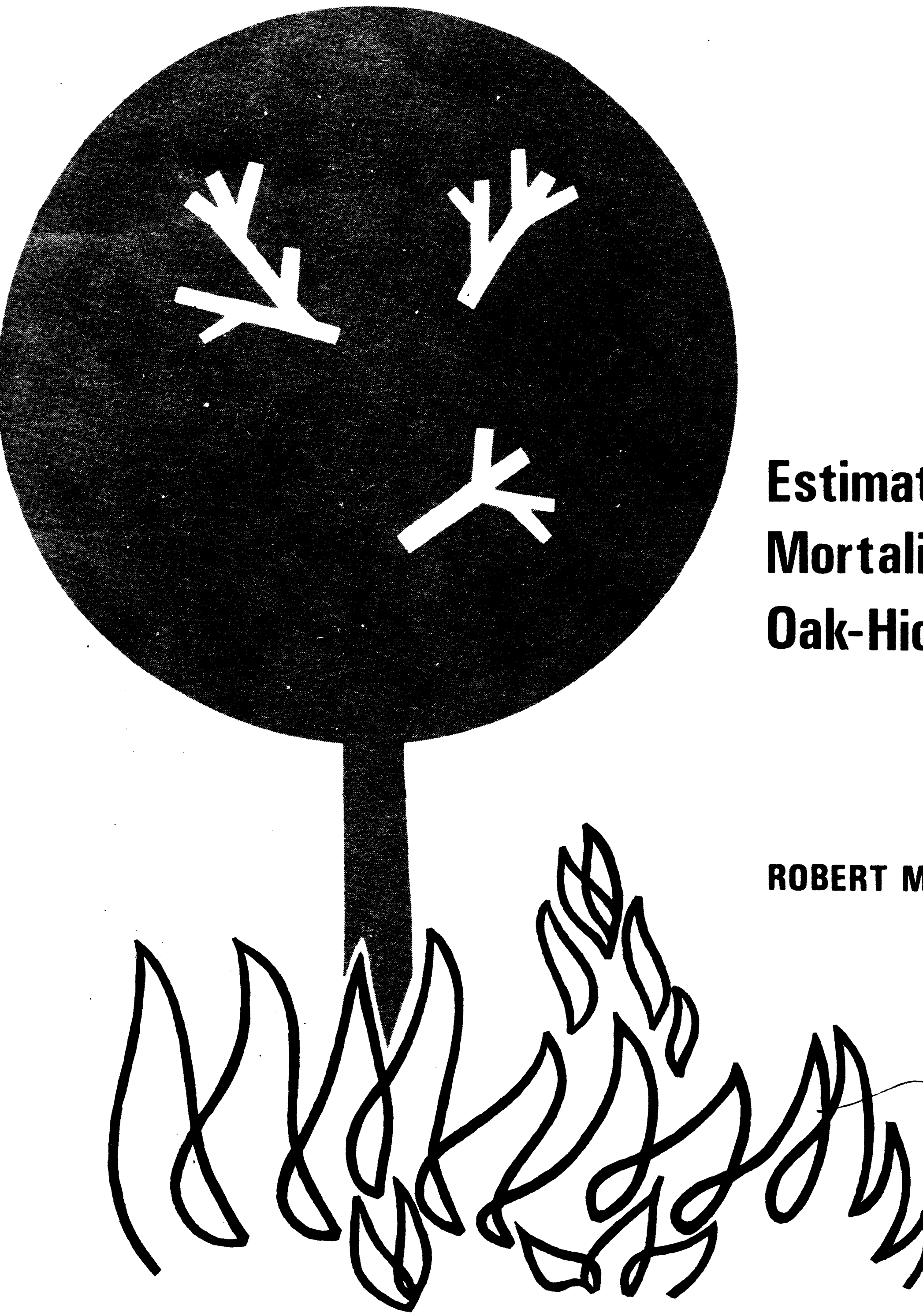
USDA FOREST SERVICE
RESEARCH PAPER NC-94
1973



Estimating Fire-Caused Mortality and Injury in Oak-Hickory Forests

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THIS PAPER IS AN EXPERIMENT IN COMMUNICATION.

Realizing that the needs and interests of our two major "clients" — the scientist and the practitioner — are different, we have been concerned whether our publications have been in a form and style equally useful to both. So we have decided to try a new format for some of our Research Papers, one that might serve this dual purpose better.

The Paper is divided into two separate parts: Application and Documentation. The Application section is specifically intended for the man on the ground or in the mill who has a particular job to do or problem to solve. This section describes briefly the situation and the problem, and then goes immediately to the solution, emphasizing the how-to-do-it aspect. It is a complete story in itself; the busy manager need read no further.

The Documentation section describes the details of the research process. It is for the reader interested in laboratory and field procedures, tabulations, statistical analysis, and philosophical discussion. This section, too, is self-contained.

Our purpose is to separate the practical aspects of our research results from the strictly academic ones yet still make both available to all readers. If the practitioner wants to find out how we arrived at our recommendations, the details are in the Documentation section for him to examine. If the scientist has a practical bent, he can turn to the Application section and see the results in action.

It is for you to decide whether we have created a well-matched team or a two-headed monster. ***We would like to have your opinion.***

ESTIMATING FIRE-CAUSED MORTALITY AND INJURY IN OAK-HICKORY FORESTS

Robert M. Loomis

APPLICATION

The effects of fire on trees in the central and eastern hardwood forests are variable. Some trees are unaffected, some are injured but survive, some are killed immediately, and others die a year or more later. The most accurate damage appraisal can be made after one or two growing seasons have passed. By this time most delayed mortality has occurred and wounding is evident. But appraisals are often needed immediately after a fire for estimating damages, for planning and scheduling timber salvage or rehabilitation operations, for statistical reporting, and for possible legal action (fig. 1).

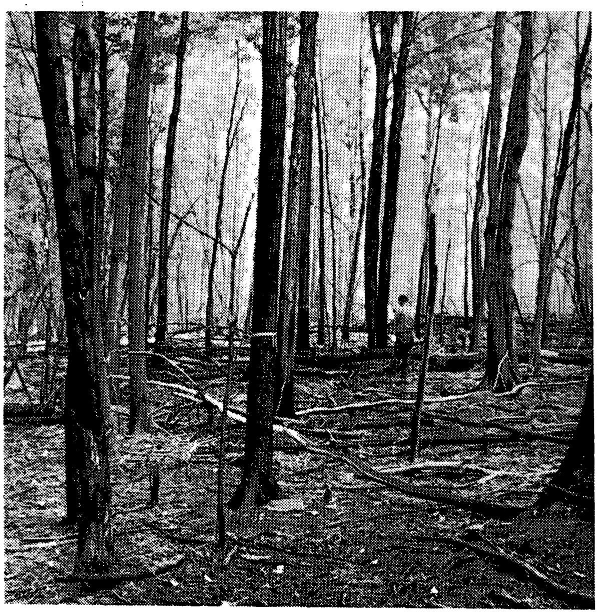

Figure 1.--*Appraisals are often needed immediately following fire.*

A method is presented here, applicable to the oak-hickory forest, for immediately predicting tree mortality and estimating basal wound size for surviving trees. This method can be used at any time of year; it requires only observations or measurements of (1) tree species, (2) tree d.b.h., (3) height of bark blackening,[1] and (4) width of bark blackening at 1 foot above ground (stump height). It is best applied to trees from 1 to 16 inches d.b.h. However, with caution it can be used for larger trees.

Mortality equations (table 1) were derived for black oak, white oak, post oak, and scarlet oak. The black oak formulas are also applicable to hickory and northern red oak. The mortality curves define the division between mortality and survival (figs. 2 and 3).

Equations for estimating wound dimensions on black and white oak are shown in table 2. The black oak equations may also be used for scarlet oak, northern red oak, hickory, and ash, and the white oak equations may also be used for post oak and chestnut oak.

The mortality graphs may be used to predict whether a tree will live or die. If survival is expected, then wound size equations may be used to estimate wound dimensions.

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[1]*Bark blackening (scorch) includes all degrees of discoloration from a bark surface only slightly browned or blackened or where scattered discontinuous pitting has occurred, to a bark surface that has been reduced in thickness or consumed.*

Table 1.--*Equations for estimating mortality probability of eastern oak-hickory forest species by season of fire*

Species	Season	Number of trees	Mortality probability (M%) Equation[1]	R^2	Standard error
Black oak[2]	Dormant[3]	424	M% = 87.7 + 13.6 Sh - 121.3 Log d.b.h.	0.72	15.9
	Growing[4]	317	M% = 93.6 + 20.4 Sh - 125.2 Log d.b.h.	.77	17.6
White oak	Dormant	331	M% = 84.8 + 9.2 Sh - 121.3 Log d.b.h.		
	Growing	333	M% = 90.6 + 13.7 Sh - 125.1 Log d.b.h.	.71	19.7
Post oak	Dormant	89	M% = 51.4 + 8.7 Sh - 92.6 Log d.b.h.		
	Growing	69	M% = 54.9 + 13.1 Sh - 95.5 Log d.b.h.	.49	27.8
Scarlet oak	Dormant	156	M% = 108.4 + 14.0 Sh - 127.1 Log d.b.h.		
	Growing	109	M% = 115.7 + 20.9 Sh - 131.1 Log d.b.h.	.66	19.7

[1]D.b.h. = diameter breast height in 0.1 inch; Sh = height of bole blackening in 0.1 foot. When d.b.h. ≥ 11.0 inches, use 11.0 inches in equation.
[2]Also applicable for northern red oak and hickory.
[3]Dormant season--after leaves turn color in fall until they begin emerging in spring.
[4]Growing season--from time leaves begin emerging in spring until they turn color in fall.

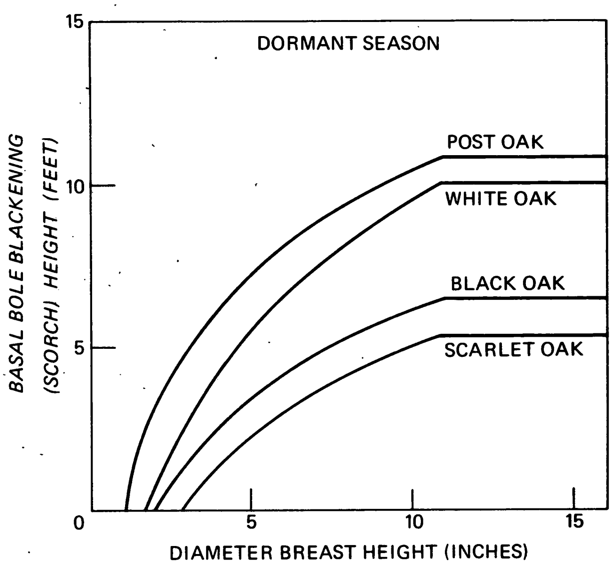

Figure 2.--*Fifty percent mortality probability for upland oaks after dormant-season fire. Probability greater than 50 percent above (mortality) and less than 50 percent below (survival) curve.*

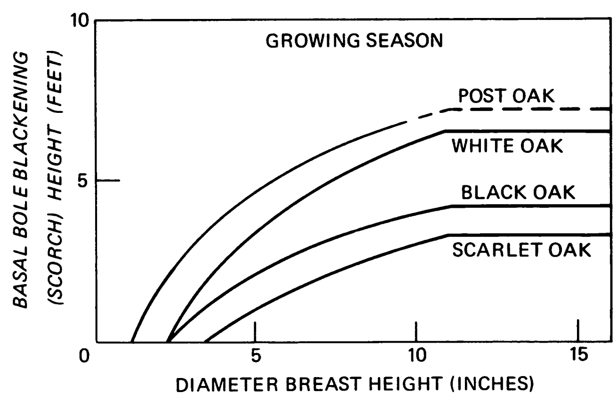

Figure 3.--*Fifty percent mortality probability for upland oaks after growing-season fire. Probability greater than 50 percent above (mortality) and less than 50 percent below (survival) curve.*

For example, assume a tree from a dormant-season fire is a black oak 9 inches d.b.h. with a basal scorch height of 5 feet and a scorch width at 1 foot of 1.3 feet. Select the mortality curve for dormant-season and black oak (fig. 2). Locate 5 feet (scorch height) along the left axis and 9 inches (d.b.h.) along the base. The point of intersection of these values is beneath the black oak curve, thus predicting tree survival.

Wound size can now be estimated by using formulas from table 2. By multiplying the observed scorch height of 5 feet by the factor 0.9, a wound height of 4.5 feet is obtained. By multiplying the observed scorch width of 1.3 feet by the factor 0.6, a wound width of 0.8 foot is obtained.

Mortality equations and graphs are not reliable for trees less than 3 inches d.b.h. The observer should depend more on his judgment, considering the general appearance of the fire area and indicated fire intensity.

Table 2.--*Equations to estimate wound dimensions for eastern oak-hickory forest species by season of fire*

Species	Season	Number of trees	Wound height (Wh)		Wound width (Ww)	
			Equation[1]	Standard error	Equation[1]	Standard error
Black oak[2]	Dormant[3]	170	Wh = 0.9 Sh	2.1	Ww = 0.6 Sw	0.5
	Growing[4]	104	Wh = 1.2 Sh	1.8	Ww = .7 Sw	.4
White oak[5]	Dormant	174	Wh = .7 Sh	1.5	Ww = .6 Sw	.4
	Growing	70	Wh = 1.0 Sh	.9	Ww = .7 Sw	.3

1/Sh = height of bole blackening in 0.1 foot; Sw = width of bole blackening in 0.1 foot at 1 foot above ground.

2/Also applicable for scarlet oak, northern red oak, hickory, and ash.

3/Dormant season--after leaves turn color in fall until they begin emerging in spring.

4/Growing season--from time leaves begin emerging in spring until they turn color in fall.

5/Also applicable for post oak and chestnut oak.

DOCUMENTATION

Methods

Observations and measurements were made on about 2,100 trees from 28 fires in Missouri, Pennsylvania, and West Virginia. Trees selected had good vigor before the fire and were free from prior basal injury. Some of the variables observed or measured were: bark blackening, tree species, d.b.h., and season of fire occurrence. We recognized the following degrees of bark blackening:[2]

1. *Burn.*--Continuous blackening of bark ridges; outstanding reduction in bark thickness. White ash on bark surface and black fissures (very recent fires).

2. *Char.*--Continuous charring and, in some instances, reduced thickness of ridges or bark scales. Little or no fissure discoloration. Also includes the areas classified as burn.

3. *Scorch.*--Slightly browned or blackened bark surface; scattered or discontinuous pitting of bark ridges; fissures usually unchanged in color. Also includes areas classified as char and burn.

Analysis showed the scorch degree to be best for prediction. However, awareness of the other degrees can be helpful in field appraisal.

Black oak and white oak had the best overall distribution of sample trees and variables (tables 3 and 4). Thus they were used in developing the equations for all species.

Mortality has immediate significance in damage appraisal, but wounding has delayed effects related to wound size. For example, fire scars are often the entry point for decay fungi (fig. 4). Berry (1969), in studying decay in the upland oak stands of Kentucky, found fire scars to be the most important means of entry for decay fungi. He also found that more than one-fourth of all infections came from fire scars, and almost one-third of the total decay volume was associated with fire scars in the 30- to 110-year-old even-aged oak or oak-hickory stands he observed.

The trees having a single dominant wound larger than 2 inches in length or width were used in developing the wound size estimating equations.

[2]*These three degrees of bark blackening are similar but not identical to those described by Nelson* et al. *1933.*

Discussion

The standard errors of estimate associated with the equations indicate the wide range of prediction response. The response is, of course, due to interaction of many variables, with a limited number of the more significant used for prediction. Thus, the estimated damage for individual trees or fires may vary greatly from the actual. Reliability increases with increase both in number of sample trees and number of fires.

Table 3.--*Summary of data used in developing the fire-caused mortality predictions*

Species	Season	Number of fires	Number of trees: D.b.h. (inches) 1.0-4.9	5.0-10.9	11.0-15.9	16.0+	Total	D.b.h. (inches) Mean	Range	Height of bark blackening (feet) Mean	Range	Mortality percent Mean	Std. dev.
Black oak	Dormant[1]	16	98	274	44	8	424	7.5	1.9-22.5	4.2	0.6-12.0	43	30
	Growing[2]	10	122	160	35	0	317	4.8	1.1-15.8	2.7	.2-13.0	52	37
White oak	Dormant	14	161	155	14	1	331	5.5	1.5-16.5	4.6	.4-18.0	23	27
	Growing	8	273	57	2	1	333	3.6	1.1-17.7	3.4	0-34.0	69	36
Post oak	Dormant	9	52	35	2	0	89	5.0	1.7-15.3	4.4	.6-14.0	38	40
	Growing	7	53	16	0	0	69	4.2	1.4- 9.9	3.1	.4-10.5	39	38
Scarlet oak	Dormant	8	9	123	24	0	156	8.3	3.1-15.9	2.9	.7- 9.1	25	33
	Growing	6	56	46	6	1	109	5.9	2.2-20.5	2.5	0-14.0	69	33
Northern red oak	Dormant	3	23	37	15	8	83	8.4	1.8-19.1	4.2	.7-12.0	36	37
Hickory	Dormant	9	50	16	3	0	69	4.4	1.4-14.5	2.3	.5- 9.0	26	24
	Growing	4	17	5	2	0	24	4.4	1.7-13.8	1.9	.5- 6.5	75	36

[1]Dormant season--after leaves turn color in fall until the new ones begin emerging in spring.
[2]Growing season--from time leaves begin emerging in spring until they turn color in fall.

Table 4.--*Summary of data used in developing the equations for estimating fire-caused basal wound dimension*

Species	Season	Number of fires	Number of trees	D.b.h. (inches) Mean	Std. dev.	Range	Height of bark blackening (feet) Mean	Std. dev.	Range	Width of bark blackening at 1 foot (feet) Mean	Std. dev.	Range	Wound height (feet) Mean	Std. dev.	Range	Wound width at 1 foot (feet) Mean	Std. dev.	Range
Black oak	Dormant1/	14	170	7.7	3.5	3.2-22.5	3.8	1.8	0.9-12.0	1.6	0.9	0.0-5.0	3.6	2.3	0.2-15.0	1.1	0.8	0.0-4.3
	Growing2/	9	104	7.2	3.1	2.2-15.6	2.4	1.3	.2- 6.0	1.2	.9	.0-3.8	3.0	2.1	.3-12.0	.9	.8	.0-3.3
White oak	Dormant	11	174	5.6	2.7	1.8-15.8	4.4	2.8	.8-14.0	1.0	.6	.0-3.7	3.4	2.4	.4-14.0	.6	.5	.0-3.3
	Growing	8	70	4.6	2.0	1.1-10.7	2.2	1.6	.4- 7.3	.7	.6	.0-2.8	2.4	1.6	.4- 7.3	.5	.4	.0-1.9
Post oak	Dormant	7	35	5.4	2.4	2.2-11.6	4.0	1.9	.7- 8.5	1.3	.6	.0-2.6	2.8	1.7	.3- 8.2	.8	.5	.0-1.8
	Growing	6	33	4.3	1.8	1.7- 9.5	2.7	1.9	.8-10.5	.8	.5	.0-2.4	2.3	1.8	.3-10.0	.5	.4	.0-2.2
Scarlet oak	Dormant	5	46	8.1	2.3	4.6-12.9	2.7	1.2	.9- 6.2	1.5	.7	.0-3.3	3.0	2.4	.4-10.0	.9	.6	.0-2.6
	Growing	5	30	6.5	3.6	2.5-20.5	1.9	.8	.9- 4.2	.8	.6	.0-2.1	4.9	2.7	.6- 9.0	.8	.4	.0-2.1
Northern red oak	Dormant	3	49	8.2	4.3	2.0-19.1	3.7	2.2	.7-11.0	1.7	1.4	.0-6.0	5.9	3.4	.3-13.0	.9	.7	.0-3.4
Chestnut oak	Dormant	2	47	7.8	2.8	2.5-14.0	4.6	2.5	1.2-11.0	1.4	.7	.3-3.2	2.5	1.8	.4-10.0	.5	.4	.0-1.6
Hickory	Dormant	7	36	4.3	2.5	1.9-14.5	2.3	1.6	.5- 9.0	.6	.4	.0-2.2	3.6	3.3	.4-11.0	.4	.3	.0-1.7
Ash	Dormant	1	6	4.0	1.0	2.6- 5.0	4.2	2.3	1.6- 7.5	.8	.4	.4-1.5	4.0	2.6	1.4- 7.3	.5	.2	.3- .9

1/Dormant season--after leaves turn color in fall until the new ones begin emerging in spring.
2/Growing season--from time leaves begin emerging in spring until they turn color in fall.

Figure 4.--*Fire scars are often the entry point for decay fungi. In this tree heartrot followed wounding, and the wound face never closed.*

Independent Variables

Heat-killing temperature varies inversely with exposure time; the relation between time and temperature is exponential within the biokinetic (living temperature) zone according to Hare (1961). Hare also states: "...a fairly high temperature may cause no apparent injury during comparatively long exposures, whereas a few degrees higher will kill in a brief time." Bark blackening is a visible expression of time and temperature. Thus, blackening or its absence is a good indicator regardless of season.

Trees may be killed by heat either in the crown or on the lower bole. Obviously, the taller the tree, the less likely it is to be killed by heat in the crown. The lower bole also becomes less subject to fire injury with increase in tree size and age because the bark is thicker, offering more protection to the cambium. Thus, d.b.h. relates to heat injury both because of bark thickness and tree height.

D.b.h., although a significant variable for predicting mortality, was not found to contribute enough to estimating wound size when added to scorch dimension to warrant its use.

Some prediction variation is due to physiological and anatomical differences. Kayll (1968), working primarily with conifer seedlings, found dormant seedlings generally more heat tolerant than those physiologically active. He also found heat tolerance differences between species. Species may account for bark differences as well as heat tolerance differences. Season may also account for some differences in heat tolerance.

Radiant solar energy is another interacting variable. This heat energy is probably most effective in raising initial cambium temperature of the lower bole just before hardwood leaves emerge, when the angle of the sun is high, and the boles are not shaded by leaves. The data suggest that the highest mortality and greatest injury may occur when buds are breaking and small leaves are emerging. Radiant energy is partly accounted for by season. Air temperature at time of fire is only recognized to the extent that season is accepted as a variable.

Season is also a significant variable because within the eastern hardwood forest, convective heat dispersal from a fire is probably much less effective when hardwoods are in leaf than during the dormant season. This could mean longer exposure of the tree to high temperatures when trees are in leaf.

Air movement and heat dispersal are also affected by topography, slope, aspect, and wind speed and direction. Bark blackening is related to these as well as to other variables. The bark blackening pattern is usually found on the leeward or uphill side of trees.

Additional Observations

A helpful observation possible following growing-season fires is the height to which foliage, buds, and small branchwood cambium are killed. This can assist in mortality prediction. Although the amount of kill in the crown was not included as a predictor, because it is not evident at all times of the year, it should be observed and considered whenever possible.

Wounds are often evident if growth has occurred since the fire. Cracking of bark along wound margins or unevenness of the bole may show where new callus growth is forming. Cutting through the bark to the cambium layer can show whether the cambium area is white and living or discolored and dead. Discoloration may not be evident immediately after a fire.

The degrees of bark blackening are helpful in anticipating dead cambium. The more severe (from scorch to char to burn) the greater the probability of underlying dead cambium. Also, dead cambium is more likely to be present and to extend vertically on the tree bole more than horizontally. Bark blackening that indicates cambium kill for the full circumference of a tree (girdling) would indicate mortality.

Our data showed that, as a general rule, the width of "char" at 1 foot (stump height) defined the width of the wound for the species observed. Toole (1959) had similar results with southern bottomland oaks and hickory.

LITERATURE CITED

Berry, F. H. 1969. Decay in the upland oak stands of Kentucky. USDA For. Serv. Res. Pap. NE-126, 16 p., illus. Northeast. For. Exp. Stn., Upper Darby, Pa.

Hare, R. C. 1961. Heat effects on living plants. USDA For. Serv., South. For. Exp. Stn. Occas. Pap. 183, 32 p.

Kayll, A. J. 1968. Heat tolerance of tree seedlings. Annu. Tall Timbers Fire Ecol. Conf. Proc. 8: 89-105, illus.

Nelson, R. M., Ivan H. Sims, and Margaret S. Abell. 1933. Basal fire wounds on some southern appalachian hardwoods. J. For. 31: 829-837, illus.

Toole, E. R. 1959. Decay after fire injury to southern bottom-land hardwoods. USDA For. Serv. Tech. Bull. 1189, 25 p., illus.

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