BASAL FIRE WOUNDS ON SOME SOUTHERN APPALACHIAN HARDWOODS[1]

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Data from 317 oaks and yellow poplars wounded by a spring fire in Virginia were analyzed by means of multiple linear correlation. A method was obtained whereby the size of wound can be predicted provided the areas of discolored bark and diameters of injured trees are known. The method of prediction so far is safely applicable only to groups of trees similar to those studied. Of the species examined, yellow poplar was most resistant to basal damage, scarlet oak was the most susceptible, and black, white and chestnut oak were intermediate.

BASAL wounding is only one of the several forms of fire damage to standing timber, but its effects upon the growth and value of the timber are serious and widespread. These wounds interfere with the conduction of food and water in damaged trees and are avenues of entrance for destructive heart-rotting fungi. It is estimated that 90 per cent of the butt rots in hardwoods in the eastern part of the United States enter through fire wounds.[4] The evident importance of basal wounding in the hardwood forests of the Southern Appalachians suggested a special study, the results of which are here summarized. The study is a part of a more comprehensive project now being conducted by the Appalachian Forest Experiment Station to investigate all forms of fire damage to hardwood forests and devise methods for appraising such damage.

The purposes of the study of basal wounding were to determine the correlation between areas of exterior bark discoloration and areas of interior wound as indicated by dead phloem and cambium tissues; to devise methods for estimating sizes of wounds without removing bark; and to compare the reaction of several important hardwood species in the formation of basal wounds by fire.

AREAS AND SPECIES STUDIED

Field data were collected on freshly burned areas in the McFalls Creek watershed, Botetourt County, Virginia, in the Natural Bridge National Forest. These areas are moderately rough with slopes as steep as 70 per cent and with elevations ranging from 1400 to 2000 feet. The forested slopes bore thrifty stands of a variety of desirable species. A number of forest types were found, the gradual transition from cove hardwoods[5] to shortleaf pine-oak or scarlet oak-black oak being characteristic of the lower and middle slopes, with a preponderance of chestnut oak on the upper slopes and ridges. Site qualities ranged from II to IV,[6] being largely dependent on topography.

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[4]Hedgcock, G. G. Fire-scar Damage in Woodlands Heavy. U. S. Dept. Agr. Yearbook 1926: 363-364. 1927.

[5]This association now differentiated into Types 50 to 57 in "Cover Types of the Eastern United States," Jour. Forestry 30:451-498, 1932. Type 55, Yellow poplar-white oak-red oak, most nearly approaches the study conditions.

[6]Frothingham, E. H. Timber Growing and Logging Practice in the Southern Appalachian Region. U. S. Dept. Agr. Tech. Bul. 250, 36 p., illus. 1931.

On April 10 to 12, 1930, a very severe fire swept over the entire watershed of McFalls Creek under conditions of high inflammability. At this time buds had burst, and the small unfolding leaves, "about the size of squirrel ears," were highly susceptible to the intense heat generated by the fire. The fire burned briskly on the lower slopes and increased in intensity to such a degree, as it burned uphill, that the stands on the upper half of many of the ridges were completely killed.

Yellow poplar (*Liriodendron tulipifera* L.), white oak (*Quercus alba* L.), black oak (*Quercus velutina* Lam.), chestnut oak (*Quercus montana* Willd.), and scarlet oak (*Quercus coccinea* Muench.)[7] were selected for study because of their importance throughout the Southern Appalachians. Yellow poplar is probably the most important of the hardwood species of the coves and the oaks are of greatest economic and silvicultural significance on the slopes.

Field Measurements

Trees which had been killed outright by fire, those with severe crown injury or extremely buttressed roots, or those which showed signs of previous injury as indicated by old scars or abnormalities, were excluded from the study. Because of the exclusions and the effort that was made to obtain a fairly even representation of the different diameter classes, the distribution of the data by species and diameters does not represent the actual distribution of these on the areas studied. Occasionally trees were found which obviously had been subjected to exceptionally high temperatures, either because of an unusual accumulation of fuel provided by the branches or boles of fallen trees near the base, or from adjacent snags. Such exceptional trees were also excluded.

Since the degree of injury was obviously influenced by the intensity of the heat of the fire, it was at first considered necessary to establish criteria by which these intensities could be determined Three types of discoloration were arbitrarily chosen: burn, char, and scorch, in descending order of intensity. Burn was considered to be that condition in which the bark had been entirely blackened even to the bottom of the fissures, and in which the tops and edges of the ridges had at least been partially consumed. Areas of bark in which the ridges were blackened but not reduced, with their sharp edges intact, and with the bottoms of the fissures blackened or browned were designated as charred. Areas with ridges browned or incompletely blackened, and with the bottoms of the fissures lightly browned or not discolored, were regarded as scorched. In this paper the subsequent use of the terms scorch, char, burn, discoloration, and wound will refer to their respective areas; the word discoloration will be used to refer to all visible indication of burning included in the terms scorch, char, and burn.

It is evident that the character of the bark introduced a possible source of error; but even though similar intensities of fire possibly produced different types of discoloration on the barks of different species, it is believed that within the same species, the error was small. Repeated consultation fixed these different types of discoloration so sharply in mind that frequent checks on measured trees by different members of the crew rarely disclosed a difference of opinion.

The intensities of bark discoloration were first carefully determined and outlined in chalk on the bark of the tree (Fig. 1) and a centerline drawn vertically through the highest point of discoloration to the ground. The intersec-

[7]Nomenclature according to Sudworth, G. B. Check List of the Forest Trees of the United States, Their Names and Ranges. U. S. Dept. Agr. Misc. Circ. 92, 295 p. 1927.

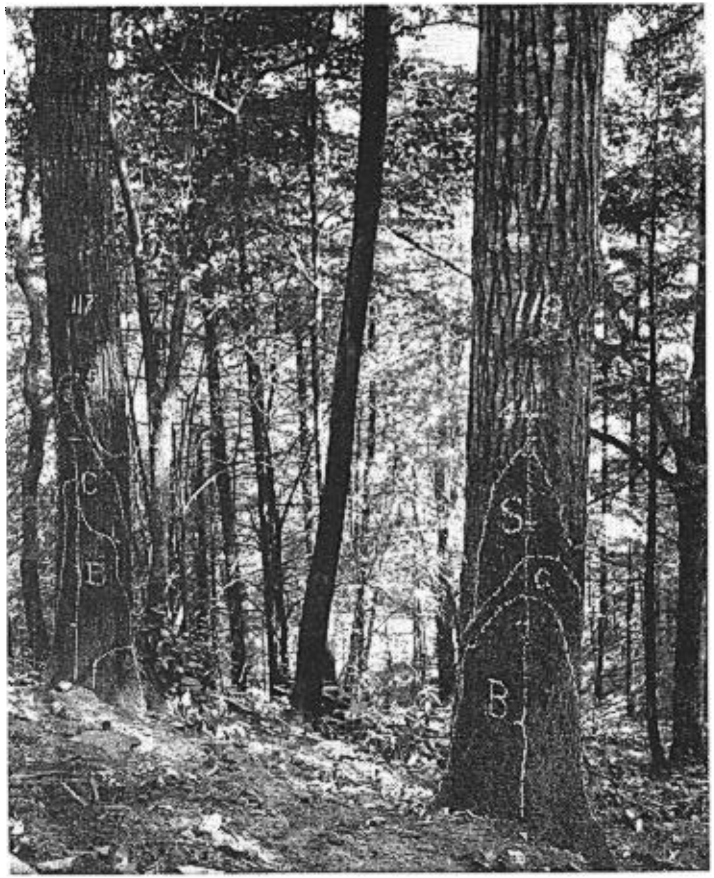

Fig. 1.—A 12.8-inch black oak (No. 117) and a 12.8-inch scarlet oak (No. 118) with areas of burn (B) char (C), and scorch (S) outlined preliminary to diagramming on special coordinate paper.

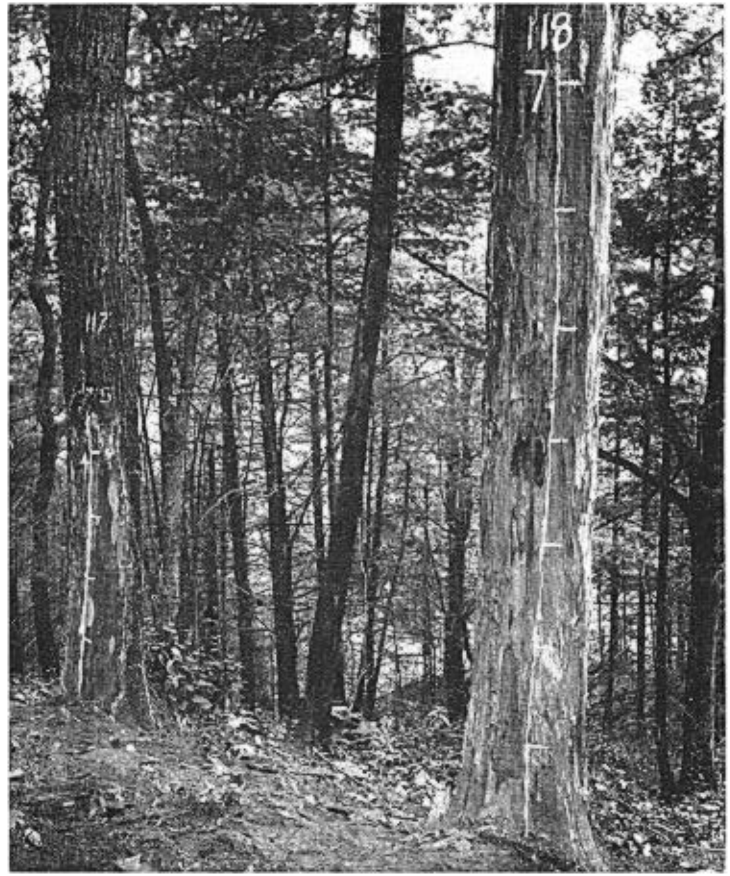

Fig. 2.—Trees shown in Figure 1, after removal of bark to expose the wounds. The light margin and patches on Tree No. 117 are the edges of living cambium. The wound on No. 118 extended more than half way around the tree and to a height of approximately 20 feet

tion of the centerline and groundline was taken as the origin from which coordinates of points on the boundaries of the discolorations were measured to the nearest inch. These points were plotted on special coordinate forms and connected, and an accurate diagram of discoloration thus obtained. The scale commonly used was 1″=16″.

The extent of wounds was determined by removing the dead bark. Since the examinations were made during the first growing season after the fire, callus growth, or, where this was lacking, living phloem and cambium marked the limits of the wounds. (Fig. 2.) Diagrams of wounds were obtained by the method described above, and superimposed on diagrams of the discolorations. The diagrams were later planimetered and the actual surface areas of discoloration and wound determined in square feet to two decimal places.

Diameter measurements were taken at breast height—4.5 feet above ground—outside the bark to the nearest tenth inch with a steel tape.

Analyses of Field Data

With areas of scorch, char, and burn, and diameter as independent variables, and area of wound as the dependent variable, linear correlations[8] were computed for the five species. (Table 1.)

A consideration of the coefficients of multiple correlation and their standard errors for different species in Table 1 indictated that the combined effect of independent variables was definitely associated with area of wound.[9] It also appeared from regression coefficients and their standard errors that the correlation between some of these independent variables with size of wound, holding the other independent variables constant at their means, was small or doubtful. As would be expected, the regression coefficients for the different types of discoloration were in most cases positive, indicating that the size of the wound increased with an increase in area of discoloration. The areas of scorch were less well correlated with wound than were areas of char or burn, and in most cases char less than burn. The coefficients for diameter were negative due, at least in part, to the greater insulating value of the thicker bark of larger trees.

Since some of the individual regression coefficients were small, an attempt was made to determine whether any of the independent variables could be eliminated or combined without materially decreas-

Table 1

STATISTICAL MEASURES[1] FROM A CORRELATION BETWEEN THE INDICATED INDEPENDENT VARIABLES AND WOUND AS THE DEPENDENT VARIABLE

Species	No. of trees		Independent variables: Scorch	Char	Burn	Diam.	R
Yellow poplar	57	b	.349	.351	.449	—.446	.540 ± .094
		δ	.216	.159	.216	.110	
Chestnut oak	51	b	—.140	.881	1.142	—.343	.819 ± .046
		δ	.234	.205	.192	.109	
Scarlet oak	77	b	.778	—.369	1.211	.005	.328 ± .099
		δ	.724	.515	.631	.248	
Black oak	67	b	.318	.494	1.059	—.571	.726 ± .058
		δ	.208	.150	.172	.110	
White oak	65	b	.306	.414	.770	—.146	.548 ± .087
		δ	.247	.201	.235	.086	

[8]Computed by methods presented in: Ezekiel, M. Methods of Correlation Analysis. 427 p., illus. New York, 1930.

[9]Association may be considered as not significantly different from zero unless the coefficient is at least twice its standard error, in which case odds are 24 to 1 that the association is not due to chance. Pearson, K. Tables for Statisticians and Biometricians. Ed. 3, pt. 1. London, 1930.

ing the measure of correlation and accordingly not increasing the standard errors of estimate. A preliminary set of regression equations was computed for the combined data from white oak, chestnut oak, and black oak, in which certain types of discoloration were eliminated or combined with others. Each succeeding equation (Table 2) represents a progressive simplification in procedure. Equation 5 represents a great advance over equation 1 since total area of discoloration, without regard to intensity as indicated by the scorch, char, and burn, is correlated with wound. The standard error of estimate[10] of equation 5 (2.812) was considered to be not significantly larger than that of equation 1 (2.687).

A series of regression equations, in which total discoloration and diameter were correlated with size of wound, was computed for each of the 5 species. The standard error of estimate for each is given in line 2, Table 3.

The simplification already effected suggested the possibility that the use of less exact measurements of discoloration would not materially reduce the correlation. Accordingly, products obtained by multiplying the greatest width of discoloration, measured along the groundline, by the greatest height, each to the nearest foot, were then correlated with wound. The standard errors of the regression equations for each species are given in line 3, Table 3.

A comparison of the standard errors of estimate (lines 1 to 3, Table 3) obtained when different independent variables were used, show relatively small differences. In general, however, combination of independent variables was accompanied by an increase in the standard errors. The greatest increase (0.397) was found in chestnut oak, between lines 1 and 3.

Throughout the analysis of the data, it was recognized that bark thickness must be a very important factor in affecting the size of wound. However, the thickness of bark was believed to be closely correlated with diameter, and its influence

TABLE 2

STATISTICAL MEASURES FROM CORRELATIONS BETWEEN DIFFERENT COMBINATIONS OF ORIGINALLY CONSIDERED INDEPENDENT VARIABLES AND WOUND, FOR THE COMBINED SPECIES WHITE OAK, BLACK OAK, AND CHESTNUT OAK

Independent variables	Statistical measures			
	b	δ	R	S[1]
(1) Scorch	.138	.133		
Char	.558	.109		
Burn	.943	.114		
Diameter	—.284	.055		
			.675 ± .040	2.687
(2) Char	.533	.106		
Burn	.962	.112		
Diameter	—.271	.053		
			.675 ± .040	2.688
(3) Burn	1.166	.122		
Diameter	—.158	.052		
			.618 ± .058	2.864
(4) Char + Burn	.738	.062		
Diameter	—.283	.054		
			.664 ± .041	2.723
(5) Scorch + Char + Burn	.652	.057		
Diameter	—.279	.057		
			.636 ± .044	2.812

[1]Standard error of estimate (square feet).

[10]Standard error of estimate measures the range above and below the regression line within which lie two-thirds of the actual values.

largely accounted for by the use of tree diameter as an independent variable.

This belief was substantiated by evidence from another series of regression equations in which bark thickness in tenths of inches at approximately 6 inches above the ground, product of width by the length of discoloration, and diameter as independent variables, were correlated with wound for yellow poplar, chestnut oak, and scarlet oak. In these equations, the coefficient of multiple correlation for scarlet oak and yellow poplar was slightly increased and chestnut oak remained about the same. However, the addition of the variable, bark thickness, did not significantly reduce the standard errors below those obtained when bark thickness was not included. (Table 3, line 4.)

Graphical Presentation of Results

Regression equations obtained by correlating the product of the width and height of discoloration, and diameter, with wound, for the 5 species, are presented graphically in Figure 3.

The influence of diameter of tree on size of wound was significant only for yellow poplar, chestnut oak, and black oak. For scarlet oak and white oak, diameter had so slight an effect that all classes were grouped to make a single regression line.

Comparison of species and closeness with which the regression equations fit the data is shown graphically in Figures 4 and 5. In Figure 4, the slope of wound on diameter for a discoloration product of 30 is plotted, and in Figure 5 the slope of wound on discoloration is plotted for the mean diameter for the species. Deviations of actual from estimated wounds are plotted from these lines. The distance between the regrssion lines and the points shows, for the data at hand, the error in estimating wound from the product of width and height of discoloration, and diameter.

Discussion

Applicability of Results

The degree to which the regression lines in Figure 3 are applicable for other

Table 3

COMPARISON OF STANDARD ERRORS OF ESTIMATE IN SQUARE FEET OBTAINED BY CORRELATIVE DIFFERENT INDEPENDENT VARIABLES WITH WOUND

Independent variables	Yellow poplar	Chestnut oak	Species Scarlet oak	Black oak	White oak
(1) Scorch, Char, Burn, Diameter	2.193	2.179	7.735	2.678	2.647
(2) (Scorch + Char + Burn), Diameter	2.196	2.489	7.956	2.836	2.645
(3) Width × Height of discoloration, Diameter	2.174	2.576	7.974	3.000	2.808
(4) Width × Height of discoloration, Bark thickness, Diameter	2.046	2.550	7.656	-------	-------

Fig. 3.—The linear relation between area of wound and the discoloration product, by 4 inch diameter classes.

Fig. 4.—The effect of tree diameter on wound, for a discoloration product of 30. Deviations of actual from estimated wounds are plotted about the regression lines. The point below the abscissa of the graph for yellow poplar represents a tree with a discoloration product of 48 feet, an estimated wound of 3 feet, but with no actual wound.

Fig. 5.—The relation between the discoloration product and wound, for the mean diameter of each species. Deviations of actual from estimated wounds are plotted about the regression lines

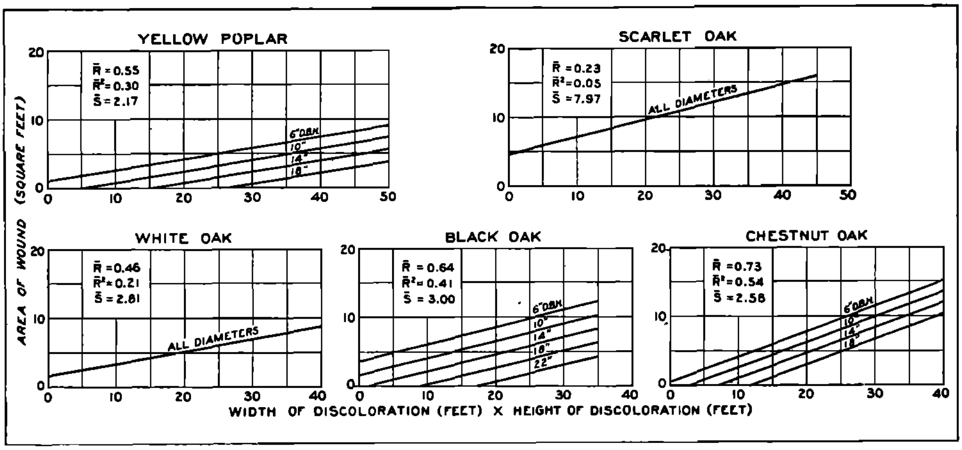

Figure 3

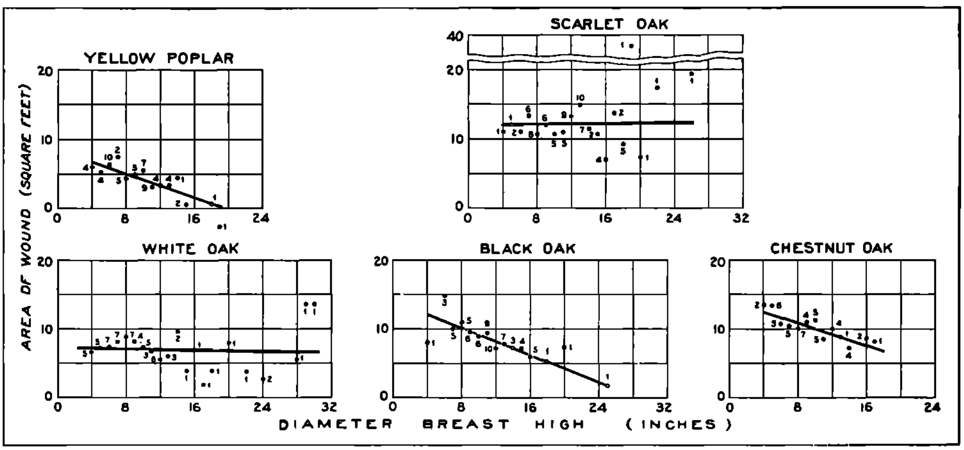

Figure 4

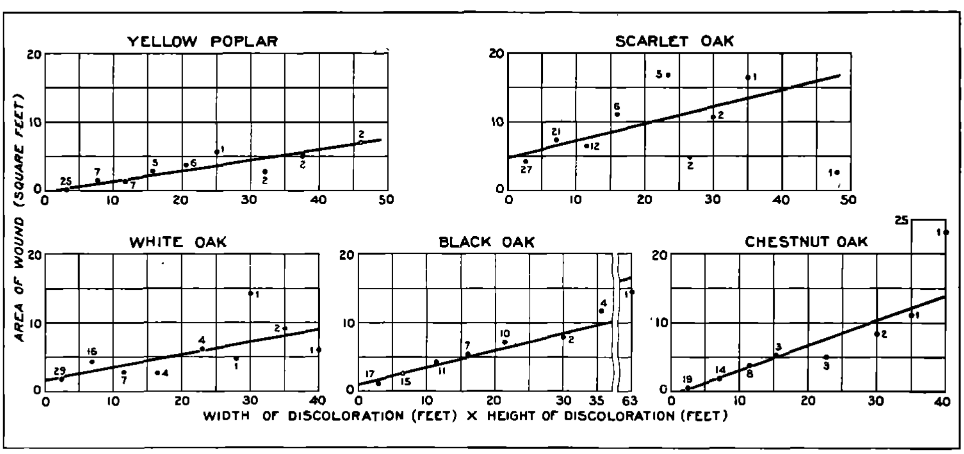

Figure 5

(Explanation of figures on page 834)

areas and regions is not known. Nor is it known whether these data from a spring fire can be used for predicting basal injury resulting from fires at other seasons of the year. Seasonal differences may possibly be expected to exert an influence on the relative charrability of bark, on the relative insulating properties of bark, and on the thermal death point of cambium.

With conditions similar to those under which the original data were taken, the regression lines in Figure 3 can be used for estimating basal wounds. It is apparent from the standard errors in Figure 3 that the prediction for a single individual may be valueless. For instance, if a single white oak with a discoloration product of 10 square feet is estimated to have a wound of 3.3 square feet, the chances are 2 out of 3 that the wound is 3 3$\pm$2.8, or between 0.5 and 6.1 square feet. Obviously, such a wide range makes the estimate for a single tree almost worthless. However, if 100 trees are measured, the chances are 2 out of 3 that if the average estimated wound is 3.3, the true average wound is 3.3$\pm$.28 or between 3.0 and 3.6 square feet. Similarly, if an average wound of 7.2 square feet is found for 100 scarlet oaks, the chances are 2 out of 3 that the true average is 7.2$\pm$.8.

Wound can be estimated almost as accurately by using the product of width and height of discoloration measured to the nearest foot, as by using precise measurements and divisions of discoloration. The simplified method will permit the examination of ten or more trees in the same length of time required for the examination of a single tree by the method first presented. Results from the greater number of trees will be more accurate than those from fewer trees measurd by the more involved method.

Statistical measures given in previous sections of the paper have demonstrated, for the data at hand, that wounds on individual trees cannot be satisfactorily predicted. However, the greatest need is not a measure of injury to individual trees but a broad method for appraising damage to burned stands on an acre basis. It is believed that if a simple method for predicting basal wounds, such as is given in Figure 3, is combined with a method of correlating wounds with tree growth and entrance and growth of wood-destroying fungi, a valuable tool for appraising fire damage will have been devised.

COMPARISON OF SPECIES

Correlation analyses substantiated the field observations that considerable differences existed in the relative resistance of different species to basal damage. Yellow poplars in the larger diameter classes appeared to have relatively small wounds, even when the areas of bark discoloration was large; whereas scarlet oaks were frequently found to be severely wounded even when areas of discoloration were comparatively small. In this latter species, wounds were often found to extend far above the region of bark discoloration.

In Figure 3 it may be seen that for a given area of discoloration yellow poplar always has the smallest wound, and scarlet oak the largest, the three remaining species being intermediate. The relative order of resistence in which black oak, chestnut oak, and white oak stand is dependent upon the size of discoloration and diameter of tree which is selected as a basis for comparison. For instance, in 18-inch trees having a product of width and length of 20 square feet of discoloration, the relative order in decreasing resistance is black oak, chestnut oak, white oak. For 6-inch trees with a product of 10 square feet the order is white oak, chestnut oak, black oak.

For the area and species studied, it can safely be said that yellow poplar was the species most resistant, and scarlet oak the least resistant to basal injury. The average wound on yellow poplar was 1.6 square feet while the average wound on scarlet oak was 7.2 square feet.

The coefficients of determination[11] (R^2, Fig. 3) ranged from 5 per cent in scarlet oak to 54 per cent in chestnut oak. If other factors, such as minimum bark thickness, values for insulating properties of bark based on its character and quality, and values for the relative ease of bark discoloration, could have been included among the independent variables, no doubt higher coefficients of determination for all species would have been obtained. Also excluded from the correlation were such nonmeasurable factors as the time-temperature relation, the possible flue action provided by trees of different diameter, the gusty movement of superheated volumes of air, and inherent biological variation in individual trees.

Summary

1. A technic was devised for accurately measuring and recording areas of discolored bark and killed cambium of burned trees.

2. Measurements from 317 trees comprising the species yellow poplar, black oak, white oak, scarlet oak, and chestnut oak were obtained from a spring burn in Virginia.

3. Various combinations of independent variables, areas of scorch, char, burn, diameter of tree at breast height, and product of width of discoloration by length, were found to be correlated with wound; the simplest combination being the product of width and height of discoloration, each measured to the nearest foot, and diameter of tree at breast height.

4. A method was evolved for each of the 5 species by which it is possible to predict, for groups from a similar set of trees, areas of basal wound on burned trees with a fair degree of accuracy.

5. Of the species studied, yellow poplar appears to be most resistant to basal injury from fire, and scarlet oak the least resistant. Black, white, and chestnut oak are intermediate, their relative order being dependent upon the diameter and size of discoloration which is selected as a basis for comparison.

[11]Coefficient of determination measures in per cent, the proportion of the variance in the dependent variable which is associated with the independent variables.