RESEARCH NOTES
SOUTHEASTERN FOREST EXPERIMENT STATION
Asheville, North Carolina

Number 114 January 1958

SOME BASIC THERMAL PROCESSES CONTROLLING THE EFFECTS OF FIRE ON LIVING VEGETATION

Both prescribed fire and wildfire produce their effects on living vegetation by means of certain basic thermal processes. Knowledge of these processes can be used to obtain better results with prescribed fire and to anticipate some of the effects of wildfire.

One of the primary factors controlling the effects of fire is the lethal temperature. As a first approximation it is convenient to think of the lethal temperature as a single quantity, say 140° F., which represents the borderline between killing and non-killing temperatures.

The quantity of heat required to raise the temperature of living vegetation up to the lethal temperature is directly proportional to the difference between this temperature and the initial vegetation temperature. For example, twice as much heat will be required to raise the temperature of pine needles or buds up to a temperature of 140° F. on a cool day when the initial vegetation temperature is 50° F. as on a hot day when this initial temperature is 95. Hence fires of equal intensity are more damaging on hot days than on cool days. Stated in another way, living vegetation can tolerate a more intense fire on a cool day than on a hot day. These relationships can be worked out mathematically and in some instances plotted as simple curves. In figure 1, for instance, height of scorch for constant low-intensity fires with flames 12 to 18 inches long is shown as a function of initial vegetation temperature. The main curve A is based on a lethal temperature of 140° F. Curve B is based on a lethal temperature of 135°. The plotted points represent observed height of scorch for experimental fires. A significant feature of the curves in figure 1 is the rapid increase in height of scorch line when the initial vegetation temperature is 95° F. or more. For shaded locations, the initial vegetation temperature is approximately equal to the air temperature but is somewhat greater in sunny exposures.

Initial vegetation temperature also affects temperature differentials between various susceptible parts of a tree subjected to fire. Suppose that on a cold day when the temperature is 40° F. a fire heats the needles of a pine to 220°. The crown would thus be completely scorched or browned. However, the buds with their higher heat capacity might be heated to only 100° or 105° F. and would remain undamaged. On a hot day when the initial vegetation temperature is 95, the needles of a similar tree could be heated to the same temperature of 220 by a somewhat lower intensity fire. In this case the buds might reach a temperature of 145° F. because of their high initial temperature. Hence, two different fires, one of which was relatively cool on a hot day and the other relatively hot on a cool day, may result in equal amounts of crown scorch. But the former may do considerably more damage to the trees than the latter because it should produce greater injury to the heavier parts of the tree such as the buds and cambium tissue. Thus, crown scorch is not always a reliable indication of total damage.

It has long been observed that summer fires do considerably more damage than winter fires. This has on occasion been explained by assuming that summer fires are more intense than winter fires or that trees are more susceptible during the growing season than during the dormant winter season. Some seasonal effects are undoubtedly present, as are indicated by the effectiveness of repeated summer fires in reducing the vigor of hardwood sprouting, which is discussed by Chaiken,[1] but the more direct and immediate effects can be mostly accounted for in terms of the basic thermal mechanisms.

Although approximate computations are simplified by assuming a constant lethal temperature of 140° F., the lethal temperature actually depends on duration of temperature. The time-temperature relation is shown by the curve in figure 2, plotted from the measurements of Nelson.[2] His data were obtained by the water bath method on pine needles of four different species (pitch, longleaf, slash, and loblolly). Because there was not much difference between species, the curve in figure 2 represents the average for the four different pines.

A value of 140° F. is probably about right for headfires. However, the time-temperature curve based on Nelson's data indicates that a temperature of 132° to 135° F. would be more realistic for the slower spreading backfires because of the longer exposure time. A somewhat lower value for the lethal temper-

1/ Chaiken, L. E. Annual summer fires kill hardwood root stocks. Southeast. Forest Expt. Sta. Research Note 19. 1952.

2/ Nelson, Ralph M. Observations on heat tolerance of southern pines. Southeast. Forest Expt. Sta. Paper 14. 1952.

ature, such as 135° F., has little effect on the height of scorch when the initial vegetation temperature is low, and has considerably more effect when the initial temperatures are high. This can be seen readily by comparing curve A (based on 140° F.) and curve B (based on 135° F.) in figure 1.

In a zone near the ground, fires spreading with the wind (headfires) are not necessarily hotter than fires spreading against the wind (backing fires). Figure 3 shows the temperature rise measured above headfires and backing fires in a predominantly grass fuel mixed with some pine needles. Measurements were made by thermometers with their bulbs insulated to reduce their sensitivity and to give about the same temperature response as fully developed longleaf buds. Headfires appear to be somewhat cooler than backing fires in a zone about 10 inches deep next to the ground. However, the depth of this zone, as well as the difference between the two types of fires, should in general depend on arrangement and quantity of fuel and the wind speed.

The higher temperatures measured near the ground for backing fires appear to be a result of most of the combustion taking place at the lower levels. This effect would probably be greatest in grass-type fuels in which a slow-spreading fire would burn the base of grass stems before burning their tops. Then the stems would tend to topple over and burn near the ground. In fast-spreading headfires, however, grass stems should burn in the reverse order, with much of the combustion occurring at higher levels.

The rate of spread of headfires, and hence their intensity several feet above the ground, is very sensitive to changes in wind speed. This is shown by the curve in figure 4, in which the rate of spread of both headfires and backing fires in feet per minute is plotted as a function of wind speed in miles per hour as measured about three feet above ground. The test fires were in rather light grass-pine needle fuels. Wind speeds are shown as negative for backing fires. Since measurement of rate of spread was not the main purpose of the test fires in the study on which these data were taken, there are only a few measurements for headfires. The position of the curve is, therefore, somewhat uncertain in the headfire region and is for this reason shown by a broken line. Owing to the increase in oxygen supply, backing fires spread faster into a strong wind than into a light wind, but their rate of spread is much less sensitive to changes in wind speed than is that of headfires. For most prescribed backing fires it would be difficult to get a rate of spread much in excess of three feet per minute--especially in denser stands where the wind speed is low.

Headfires should result in lower mortality in areas where most of the reproduction consists of longleaf in the grass stage. The same should also be true for young longleaf up to 5 or 6 feet tall, which is more likely to be killed by heat-girdling near the base of the main stem than by injury to the well-protected buds.

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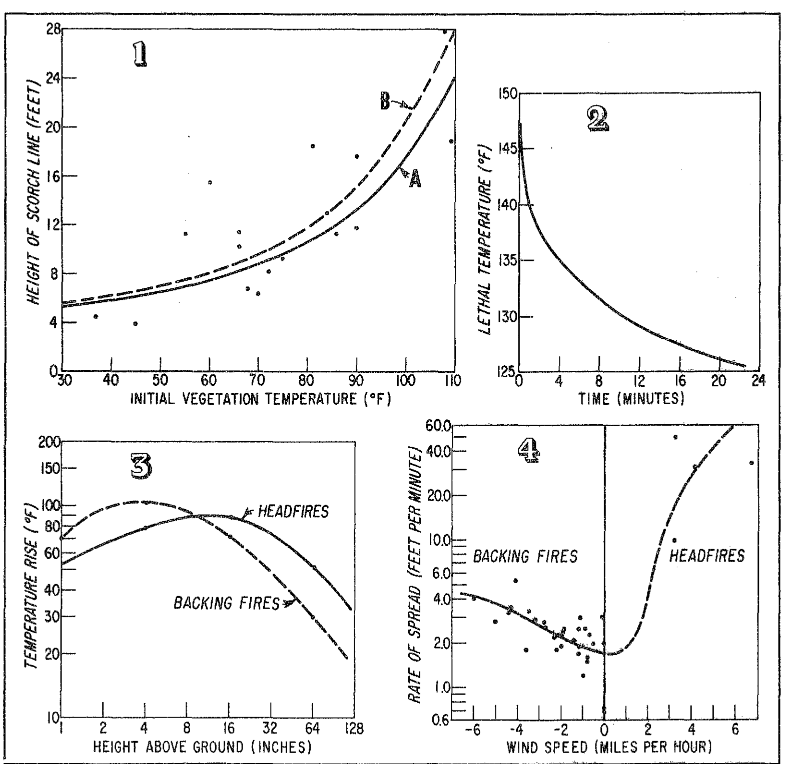

Figure 1.--Height of scorch line for low-intensity fires is shown as a function of the initial vegetation temperature. Curve A represents the theoretical or computed relationship between these two variables when the lethal temperature is taken to be 140° F., and curve B the relationship if the lethal temperature is taken to be 135° F.

Figure 2.--Lethal temperature is plotted as a function of time of exposure. This curve is the average for four different pine species (pitch, longleaf, slash, and loblolly) on which Nelson determined the time-lethal temperature relationship by the water bath method.

Figure 3.--The temperature rise at different heights over backing fires and headfires as measured by thermometers with insulated bulbs. Scales are logarithmic.

Figure 4.--Rate of spread for backing fires and headfires as a function of the wind speed measured about three feet above ground level. Rate of spread scale is logarithmic. Wind speeds for backing fires are shown as negative.