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OBSERVATIONS ON HEAT TOLERANCE of Southern Pine Needles

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When forest fires burn through southern pine stands, effects on tree crowns range from no observable injury to complete browning and even total consumption of all needles. Mortality and loss of growth that may follow are largely determined by the extent of damage to the foliage, particularly to the buds and twigs. Height of scorch line, as marked by yellowing or browning needles, is a rough measure of damage.

Four major interacting elements determine whether pine needles are damaged by fire. These are fire intensity, initial vegetation temperature, length of exposure to heat, and lethal temperature of needles. Fire intensity varies according to fuel, weather, and rate of spread. Initial vegetation temperature is highly significant because a tree crown on a cold day at a temperature of 40° F. requires about two-and-one-half times as much heat to reach a lethal temperature as does a crown on a hot sunny day at 100° F. Duration of heat is also a significant variable because the longer needles are exposed to heat the more likely they are to be killed. For example, it can be assumed that a fast-burning headfire which may subject foliage to heat for only a fraction of a minute will cause less damage than a slow-burning backfire of equal intensity which may take several minutes to pass a given point. Finally, the degree of ability of cells within pine needles to tolerate heat has a direct bearing on the extent of foliar injury.

The purpose of the study reported here was to determine some of the time-temperature relations as they affect the death of pine needles. The study is one phase of a project designed to provide information on fire behavior, intensity, and effects which will be helpful in prescribed burning and damage appraisal.

RESULTS OF OTHER WORKERS

Although considerable investigation has been made of the heat tolerance of northern and western conifer seedlings, little information was found that would give more than a general clue to the lethal temperature for pine needles. Bates and Roeser (2) report that seedlings of the western conifers tested suffered critical injury when exposed to a temperature of 141° F. (about 60° C.) for one minute. Baker (1) found that 1- to 3-month seedlings of representative conifers of western America were quickly killed when subjected to a temperature of 54° C. but could withstand a temperature only a few degrees lower for some time. Shirley (4) states that the maximum temperature which needles of some northern conifer seedlings could withstand was 49° C. for a two-hour period. In moist air they could tolerate 50° C. and in dry air 54° C. for a five-hour period. According to Lorenz (3) cortical parenchyma cells of catalpa, American elm, red pine, northern white pine, and white spruce seedlings, were killed in 30 minutes when exposed to temperatures between 57° and 59° C. One minute was required to kill the cells at 65° to 69° C. From a review of the publications cited, as well as others, it is clear that different methods and durations of exposure to heat, interpretation of heat injury, and kind and age of material tested can greatly modify results. The commonly accepted statement that plant protoplasm is killed at 60° C. has little meaning unless properly qualified.

EQUIPMENT

Equipment used for testing the heat tolerance of southern pine needles consisted of a vacuum-jacketed calorimeter and a perforated cover (fig. 1). The cover was made of 5 layers of aluminum foil separated by layers of desk-pad blotter stock all fastened together with ordinary desk staples. A tightly fitting rim of heavy cardboard served to hold the top in place. Holes approximately 1/8 inch in diameter were spaced in a circle at intervals of about 7/8 inches. A central hole was made to hold the thermometer which was kept at the desired depth of immersion by tightly wound circles of a rubber band about it. All perforations were coated with clear waterproof cement.

Figure 1.--Calorimeter used to determine lethal temperatures for southern pine needles.

It was possible to control the temperature of water in the calorimeter far more closely than was expected. In pre-tests, by directing the beams of several 100-watt infra-red lamps at the lower one-third of the calorimeter, the temperature could be maintained at a constant level or even increased if desired. For example, in one test with three lamps at about 6 inches from the calorimeter, the temperature increase was 1.3° C. in one hour. In another test by changing the number of lamps and their distance from the calorimeter, temperature during a 2-hour period was raised from 59.5° to 60.9° and reduced to 59.6° C. by the end of the test. In actual use, the beginning and end temperatures rarely varied as much as 0.2° C. and in most tests temperature variations were not detectable by a thermometer read to 0.1° C. This simple method of temperature control obviated the need for more elaborate equipment such as stirrers and thermoregulators.

MATERIALS

One-year-old needles of pitch, slash, loblolly, and longleaf pine were used in determining killing temperatures. Pitch pine fascicles were collected in Asheville, N. C., and those of other species in the vicinity of Charleston, S.C., and Brunswick, Ga., in March and April of 1951. They were tested within several days after collection. No particular effort was made to be selective in collecting the needles. For the most part they were taken from the ends of branches within easy reach on trees ranging in height from 6 to 35 feet.

Shortly after being plucked from the trees, needles were placed on end with the sheath down in glass jars containing an inch or two of water. In the laboratory they were similarly kept in water except for brief periods of examination. All had the same initial temperature before immersion. At no time was there any indication that storing needles in this manner had a harmful effect, because control needles continued to transpire and remained in their original green condition until discarded. Needles have been kept in this way for as long as 5 weeks without apparent loss of turgor or color.

Only sound, entire fascicles were used in the laboratory tests. Here again, no particular pains were taken to sort out material on the basis of length, plumpness, or other physical characteristics. Differences within a species, however, are not believed to have been great.

METHODS

After water in the calorimeter had been brought to the desired temperature, fascicles which had previously been inserted in holes in the perforated top were quickly plunged into the water bath. Fascicles were immersed for about half their length and were kept at the desired position by means of small numbered tabs made of ordinary drafting tape which encircled the fascicles. Time of immersion was measured with a stopwatch. Fascicles were removed in order from the water bath as each in turn reached the predetermined time of exposure. Thus, both time and temperature of immersion were easily and accurately controlled.

Prior to the main experiment, a series of pitch pine fascicles were immersed at 60° C. for periods ranging from 0.25 to 2.0 minutes, the intervals being 0.25 minutes. Corresponding tests were made at 58°, 56°, and 54° C. but at other time intervals. Approximate values having thus been determined, after some days of observation, a second experiment was made to bracket the lethal temperatures more closely by lessening the time intervals of immersion. Subsequent tests with the other species followed the same pattern but over a greater temperature range--from 64° to 52° C. at two-degree intervals.

In the reported investigation a pronounced yellowing of the needles was considered a sure sign of injury. The procedure followed was to place a series of fascicles that had been exposed to the same temperature, but for different lengths of time, on a black surface for color comparison. Ordinarily, affected needles could be rather easily distinguished. At times, however, it was difficult to determine the exact breaking-point; as for example whether at 60° C. the critical time should be noted as 0.75 or 1.0 minute. Occasionally there were aberrant fascicles. One immersed for a minute might appear less injured than one immersed for three-quarters of a minute. Here an element of judgment entered into a determination of the death point and for that reason no precise time-temperature figure is claimed for every point. In addition to comparing one fascicle with another in the same series, and with untreated controls, a check of waning natural color was made between the treated and untreated parts of a fascicle. This permitted a 3-way comparison of affected and unaffected needle tissue.

Injury to fascicles that had been subjected to lethal temperatures, within the range used here, was not immediately discernible. At the higher temperatures and longer exposures, symptoms sometimes appeared within a few hours. Conversely, a week or more might elapse before a sure determination could be made for the shorter times and lower temperatures.

RESULTS

Results of the experiment are graphed in figure 2. The most significant fact shown by the graph is that pine needles were killed almost instantaneously at 64°, whereas at 52° they withstood 9 to 11 minutes of heat. Except for slash pine, each point on the graph is an average of two independent tests. It will be seen that at the higher temperatures, death points for the several species were in very close agreement but at the lower temperatures there was considerable divergence. The solid line in the graph represents an arithmetic average of the death points of the several species as best they could be judged.

From the data it appears that pitch pine may be somewhat the most tolerant species to heat, and slash the most susceptible. Whether there are real differences between species cannot be determined from the information at hand. If slight differences do exist, these are probably too small to be of any practical significance.

There are undoubtedly a number of factors beside time and temperature which can influence results of tests such as were made by the writer. Variability in test material such as needle mass, position of fascicles in the tree crown, their relative exposure to the sun, their age and physiological activity, all conceivably can have an effect.

Pine needles can probably suffer varying degrees of injury from exposure to high temperatures. Whether a large or small number of cells must stop functioning permanently before death ensues is not known. As Lorenz (3) points out: "True indices of heat injury, which make it possible to determine accurately the extent to which life functions of plants have been impaired, are noticeably wanting." There was no evidence from the investigations reported here that fascicles can be partly killed and then recover. More refined techniques will have to be used before this point can be determined.

Pine fascicles subjected to the same high temperatures in a fire as in a water bath may not react in the same way. Shirley (4) states that for comparable material the killing temperature was higher in air than in water and higher in dry air than in moist air. He also found that seedling needles could tolerate several more degrees of heat when exposed in dry air than in moist air. The difference was attributed to the cooling effect of transpiration.

The writer has no evidence that a free-burning forest fire either increases or decreases the relative moistness of the air surrounding a tree crown. Forest fuels during combustion release quantities of water vapor but the amounts undoubtedly depend upon the type of fire, fuel, and stand. Perhaps in most fires the water vapor is quickly dissipated or otherwise has no moderating effect on lethal temperatures. Whatever these phenomena are, it may not be unreasonable to assume that thermal death points in a fire should not differ greatly from those in a water bath.

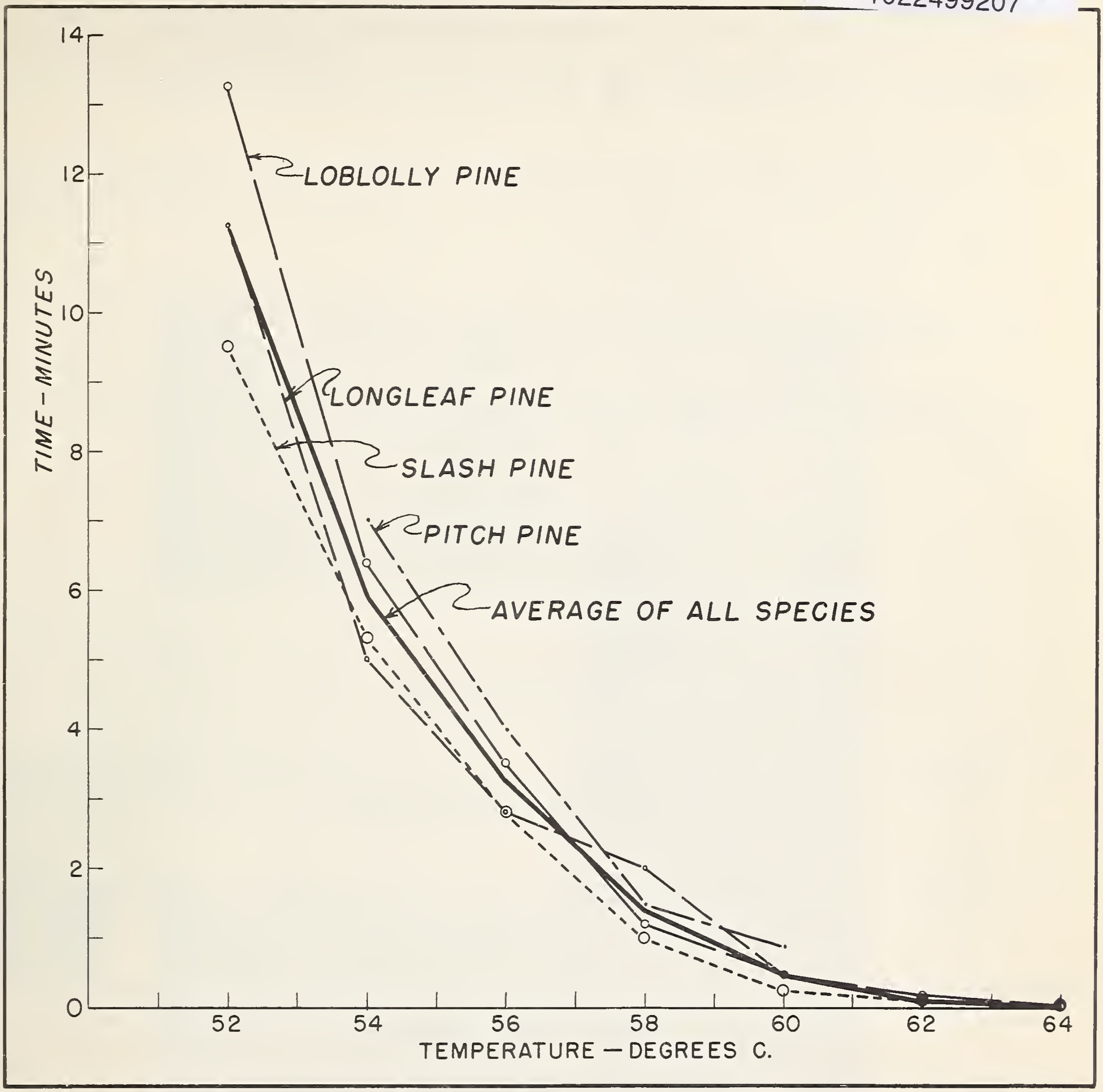

Figure 2.--Killing temperatures for southern pine needles when immersed in a water bath.

SUMMARY

(1) Fascicles of slash, loblolly, and longleaf pine were immersed in a water bath at temperatures ranging from 52° to 64° C. (respectively 125.6° and 147.2° F.), at two-degree intervals. Time of immersion ranged from 1-1/2 seconds to 14 or more minutes.

(2) Average lethal temperatures for the three species, supplemented by data from pitch pine, were as follows: at 64°, 3 seconds; at 62°, 5 seconds; at 60°, 31 seconds; at 58°, 1.4 minutes; at 56°, 3.25 minutes; at 54°, 5.9 minutes; and at 52° C., 11.3 minutes.

(3) Temperature of the water bath could be closely regulated by directing beams of infra-red lamps at the base of the calorimeter.

(4) Tests were not sufficiently replicated to determine whether species have significantly different thermal death points. If so, they are believed to be small.

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