ground was found to be about 10 percent greater than in those on the trees. It will be noted that the mortality of the hickory twig girdler is extremely high, being from 40 to 56 percent in the egg stage. Of the hatched larvae 62 to 75 percent die before reaching the pupal stage. Total mortality is very high since less than 20 percent reach maturity on the trees and less than 10 percent reach maturity on the ground. The cause of the heavy egg and larval mortality has not been determined. Parasites undoubtedly take a much heavier toll than the 5 percent observed, and it is believed that desiccation of the eggs may be the most important single mortality factor.

The following parasites have been reared locally from *Oncideres* larvae:

Horismenus new species[3] and *Eurytoma magdalidis* Ashm.[3]; two apparently undescribed species of *Heterospilus*[4], *Iphiaulax* sp.[4] and probably *Iphiaulax agrili* (Ashm)[4] (males only). The only reared predator was *Cymatodera undulata* Say.[5]

A few parasites were observed feeding on Agrilus larvae but none of these have been reared successfully. Brooks (*loc. cit.*) lists the following hymenopterous parasites from this borer: *Labena apicolis* Cress., *Monogonogaster agrili* (Ashm) and *Zatropus* sp. near *nigroaeneus* (Ashm.).

The associated insect species reared from twigs infested by the hickory twig girdler and the spiral borer are as follows: *Chramesus hicoriae* Lec.,[6] *Stephanoderes quercus* Hopk.,[6] *Stephanoderes dissimilis* (Zimm.),[6] *Stephanoderes* near *tridentatus*,[6] *Thysanoes fimbricornis* Lec.,[6] *Xylobiops basillare* (Say), and *Obrium maculatum* Oliv. These insects are of secondary importance, their presence in no way influencing the damage caused by the girdlers.

No satisfactory method of control has been developed for these insects under forest conditions. Where shade trees and pecan orchards are being damaged, collecting and destroying the infested twigs has been suggested. Stomach poisons can be used against the hickory spiral borer during early summer. It is believed that the removal of old hickory trees from the vicinity of reproduction would effectively protect young trees from serious damage by these insects.

[3]Determined by Dr. A. B. Gahan, Bureau of Entomology and Plant Quarantine.
[4]Determined by Mr. C. F. W. Muesebeck, Bureau of Entomology and Plant Quarantine.
[5]Determined by Dr. E. A. Chapin, Bureau of Entomology and Plant Quarantine.

[6]Identified by Dr. M. W. Blackman, Bureau of Entomology and Plant Quarantine.

Differences in Fire Danger with Altitude, Aspect, and Time of Day

G. L. Hayes
Northern Rocky Mountain Forest and Range Experiment Station

The measurement of fire danger has progressed remarkably since the early days of measuring humidity alone, or humidity and wind, or humidity, wind, and rain at a few valley bottom stations scattered widely apart over a forest of a million acres or more. Measuring the moisture content of the fuels directly is now known to be more accurate than measuring humidity and rain and then estimating the fuel moisture and inflammability. Other factors, such as the shade of timber canopies of different densities, north—versus south—facing slopes, valley bottom versus ridge top or mountain top exposure, the greenness of vegetation, etc., are also now being recognized as significant. Obviously, all *significant* factors deserve careful consideration if danger ratings of any kind are to be used most effectively by field men. The hope or dream of one single, simple factor to be measured only once or twice each day at one station as a criterion of fire danger over a large area has now been completely abondoned in most forest regions. Forest fire danger is "not that simple." Furthermore, the protection of our forest resources from fire is now recognized to be of great enough importance to warrant much more than one measurement per day at one or two stations per million acres to determine what measures must be applied to safeguard them from destruction.

IN the northern Rocky Mountain region where 70 to 85 percent of the fires are caused by lightning, fire prevention work cannot be relied upon to greatly reduce the number of fires nor the cost of their control. The solution here undoubtedly lies in maintaining an adequate force of properly trained and equipped men that can be assigned to fire control duties quickly, whenever and wherever needed. By adapting the size of that fire control force to the degree of current danger, the force can be expanded to meet increasing danger, but costs can be held down whenever and wherever danger does not warrant a large force.

One feature of this highly desirable refinement in fire control which has never before been investigated systematically is the effect of the topographic elements, altitude and aspect, upon the distribution of fire danger. When the mountain tops and slopes are still under snow and only the valley bottoms are dry enough to burn, then the fire control force needed and the cost of that force can and obviously should be held to a minimum. As the season develops and first the south slopes, next the mountain tops, and then the north slopes become burnable, the full "regular" force will be warranted, but still not the "peak load" or 100 percent organization. In this region it is only in July and August, and for a few days in September, that moderate to bad fire danger becomes universal on all aspects and at all altitudes so that it can then peak quickly, with exceptionally bad weather, thereby justifying the full peak load force and highest cost. Altitude and aspect obviously are two essential elements of fire danger distribution which must be carefully considered if adequate fire control is to be obtained at minimum cost.

There is, moreover, a further need for detailed and more accurate knowledge of variations in fire danger according to altitude, aspect, and even time of day. The ranger or fire dispatcher who must decide how many men to send to each new fire appreciates the need for this knowledge better than anyone else. He knows, from long experience, that on the clear and dry day which is typical of July and August in the northern Rocky Mountain region, a new fire "part way up the ridge" will not behave the same as a similar fire in the same fuel type in the valley bottom. Some keenly observant rangers and dispatchers long ago noticed that this difference in behavior was least during midday and most during the night. But they have not known why, nor how much, nor how far up the ridge this difference occurs or does not occur. The average fire dispatcher has sent too many men and spent too much money on many a fire that was only smoldering when the men arrived. He has occasionally erred the other way by sending too few men, thereby losing big acreage. In both cases the errors were often made because he misjudged, or had no knowledge of, the effect of altitude, aspect, or time of day. More widespread and more accurate knowledge of the effect of these basic factors has obviously been needed to help reduce both costs and damages.

In recognition of that need, research was started in 1934 at the Priest River Experimental Forest in northern Idaho to obtain measurements —not merely observations—concerning these basic differences in burning conditions. On the east side of the 7-mile wide Priest River Valley, which runs from Canada 60 miles due south to enter the Pend Oreille River, measuring stations were located along a ridge that rises from the valley bottom at 2,300 feet elevation, due east to a mountain top at 5,500 feet. Pairs of measuring stations were installed, one of each pair on the north and one on the south side of this ridge at elevations of 2,700, 3,800, and 5,500 feet. The two stations of each pair were in no case more than 200 yards apart. Their differences were in aspect only.

In the valley bottom at 2,300 feet elevation, the "clear-cut" and "half-cut" stations, reported upon by Jemison, [1, 2] were utilized to complete the altitudinal range and to relate this new study to earlier research which had shown differences in fire danger caused by differences in timber canopy density. All eight stations were then similarly equipped with recording instruments to give 24-hour-per-day records of air temperature, relative humidity, wind movement, and the moisture content of duff and litter on the ground and half-inch diameter sticks 10 inches above the ground. With the exception of the "half-cut" or "half-shaded" station, all the fuel moisture measurements were made in full exposure to the sun. Temperature and relative humidity were recorded in ventilated instrument shelters 4½ feet above the ground. Precipitation was measured both at the standard height above ground and by specially modified "sloped orifice" gages sunk into the ground, with the orifice cut parallel to the ground surface and sloping with it. Fibrous mats around these gages prevented rain from splashing into them. The maximum temperature of the surface layer of duff was also measured but not recorded automatically. The accuracy of all instruments at all eight stations was checked twice weekly.

Data for four consecutive summers, 1935-1938, have been summarized in detail in U. S. Dept.

[1]Jemison, G. M. The significance of the effect of stand density upon the weather beneath the canopy. Jour. Forestry 32:446-451. 1934.

[2]Jemison, G. M. Influence of weather factors on moisture content of light fuels in forests of the northern Rocky Mountains. Jour. Agric. Research 51:885-905. 1935.

Agric. Circular 591, *Influence of Altitude and Aspect on Daily Variations in Factors of Forest-Fire Danger*.[3] The principles and major differences found by this study on this particular ridge have since been tested by similar measurements made at three other locations in the northern Rocky Mountain region: (1) in the Salmon River Canyon at elevations from 1,850 feet up to 7,700 feet; (2) on Desert Mountain near Glacier National Park from 3,250 feet up to 6,400 feet; and (3) on the precipitous side of Rock Creek Canyon, northeast of Yellowstone National Park, where the elevation changes from 7,450 feet in the "bottom" to 10,500 feet on top of the plateau within a horizontal distance of only 2 miles.

By tests at these three spots the principles found on the ridge on the Priest River Experimental Forest were subjected to trial throughout the altitudinal extremes of the entire northern Rocky Mountain region. The Priest River Valley is broad with relatively gentle slopes rising to only moderate heights on either side; the Desert Mountain test area is typical of the large basins so often found at the confluence of two or more large rivers in a mountainous country; the Salmon River flows through a narrow, mile-deep canyon in a rugged, mountainous plateau of moderate height; and Rock Creek Canyon is a precipitous, glaciated gash in the high and wind-swept Beartooth Plateau.

These tests showed that, with slight modifications for different types of topography, the Priest River principles are applicable throughout the northern Rocky Mountain region. Hence, by use of charts showing the degree or class of danger on north and on south aspects at all ordinary altitudes and for each hour of the day and night, it is now possible to interpret measurements made at an individual station into data more dependably applicable to a larger part of the adjacent topography.

Figure 1 shows these conditions, in Part A for south and Part B for north slopes, on the median or most common type of day in August. This type of day is fair, with the air temperature at 80° to 95° F., humidity in the twenties, and with a "light to gentle" or 3- to 12-mile southwesterly wind. Such days comprise 60 to 80 percent of our July-August weather. The "contour" lines on these charts show the altitude and time of day of occurrence of certain classes of "fire behavior" as rated by model 5 of the Northern Rocky Mountain fire danger meter. This "fire behavior" scale, explained on slide B of the meter, rates behavior lowest, class 1.0, in early season when vegetation is green and a fire retardent, *if* the dead fuels are also wet, the humidity not below 15 percent, and the wind not more than 3 m.p.h. It rates fire behavior highest, class 7.0, only between July 11 and September 10, when vegetation is normally curing to cured, *if* the dead fuels are extremely dry—with moisture contents under 5 percent, *if* the atmospheric humidity is less than 15 percent, and *if* the afternoon wind reaches velocities of 25 m.p.h. or more. On this scale, classes 4.0 to 5.0 are the normal or most usual afternoon behavior ratings in our region during July and August.

The distribution of "fire behavior," shown by Figure 1, reveals the answers to many previously unanswered questions. How much, for example, does fire behavior change from night to day? On the valley bottom, as shown by the intersection of the fire behavior "contour" lines with the base line of Figure 1-A, the rating rises from a minimum of about class 2.5 at the end of the night period to a maximum of more than 4.5 in the middle of the day period, an increase of two full classes. Farther up the ridge, in the thermal belt and high zones, the fire behavior "contours" for the south slopes show an increase of only about one and one-half classes, from about 3.5 to 5.0 in the middle of the thermal belt, and from about 3.25 to 4.75 in the upper part of the high zone. The greater night-to-day change on the valley bottom is caused by the occurrence there of much lower danger at night than in and above the thermal belt. For north slopes, Part B of Figure 1 shows the night-to-day change to be slightly less than on south slopes, but here also the change is greater in the low zone than in the thermal belt or high zone. Hence, it is obvious that the night-to-day change is greatest on the valley bottom and least in the thermal belt and high zone.

The significant effect of altitude alone on fire behavior conditions at any particular hour of the day is evident in Figure 1. At 6 a. m., the end of the night period and the time of least danger, Part A shows that in going from the valley bottom up a south slope the danger increases rapidly at first, reaches a maximum in the thermal belt and then decreases slightly as follows: 2,300 feet—class 2.4, 2,500—2.7, 3,000—3.3, 3,500—

[3]Obtainable from the Superintendent of Documents, Gov. Ptg. Office, Washington, D. C., at 10 cents per copy.

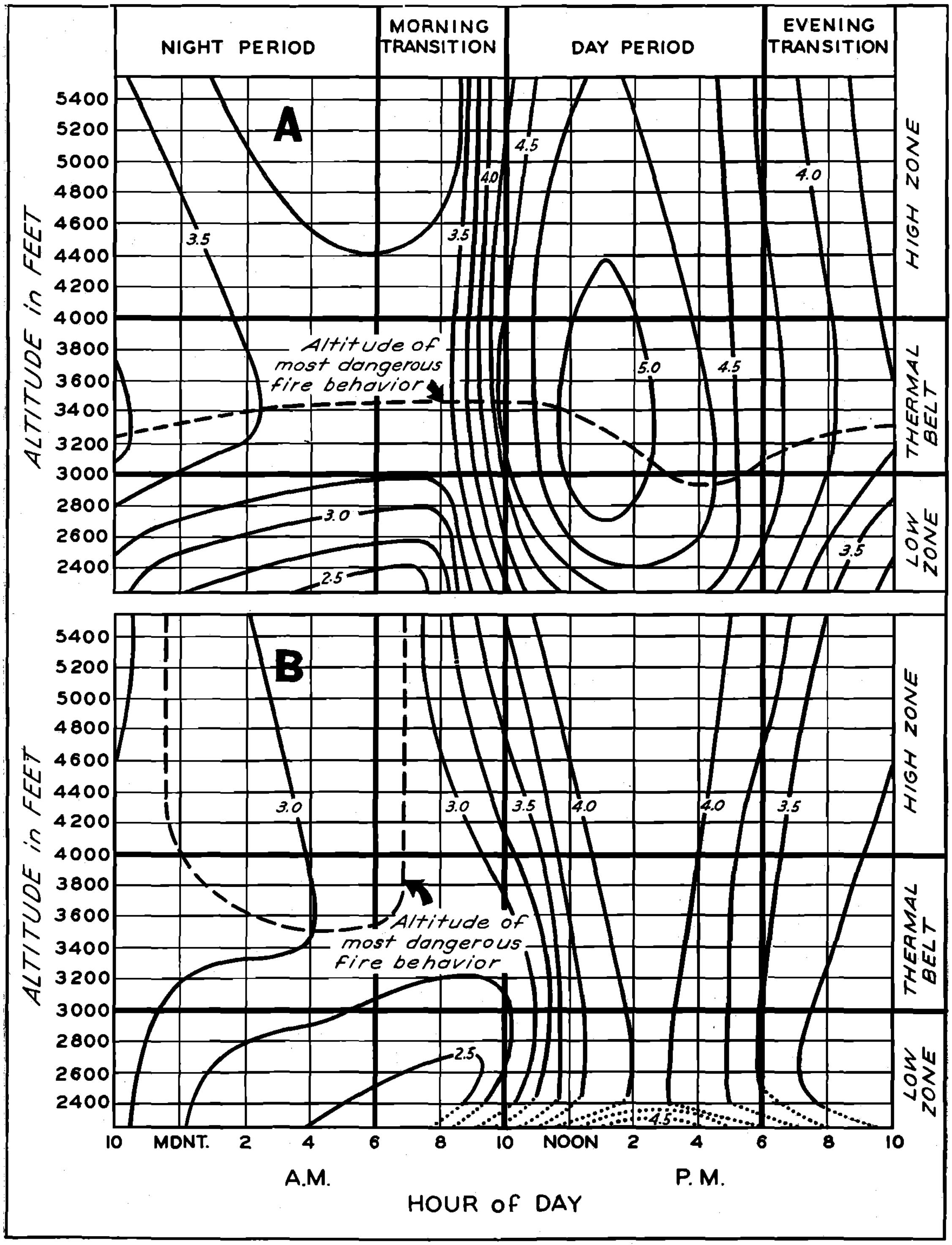

Fig. 1.—Forest-fire behavior ratings shown for different altitudes (vertical scale), different hours of the day and night (horizontal scale), and on south (Part A) and north (Part B) slopes for the median day of August 1935-38 on the Priest River Experimental Forest. The isograms, or "contour" lines, are lines of equal fire behavior.

3.4, 4,000—3.3, 4,500—3.2, 5,000—3.2, 5,500—3.1. At 2 p. m., approximately the peak of the day period, altitudinal differences on south slopes, although less pronounced than at 6 a. m., are still decidedly significant. The rating at that hour of 5.0 in the thermal belt exceeds the valley bottom rating by one-half class and the mountain top rating by one-quarter class. On north slopes, as shown by Part B, the ratings differ less between altitudes than on south slopes at any hour of the day. In going from the low zone to the thermal belt and high zone, the behavior ratings increase only half a class at 6 a. m. and not even one-quarter of a class at midafternoon, the most critical part of the day.

From the facts presented above it is apparent that the greatest advantage can be taken of the altitudinal distribution of fire behavior conditions at night when the differences between altitudes are greatest. At 6 a. m., for example, a fire that would only smolder on the valley bottom may burn briskly in similar fuels within the thermal belt where the behavior rating is nearly a full class greater on south, and a half a class greater on north, slopes. Clearly these altitudinal differences can be profitably considered in determining tactics on a going fire.

Another of the major features of the topographic distribution of fire behavior which is clearly brought out by Figure 1 is the measurement of the well-known difference between north and south slopes. It is evident at a glance that in the thermal belt at midday, for example, the south slope rates about 5.0, which is a full class greater than the 4.0 rating on north slopes. Although these differences *between north and south slopes* are large and highly important during the day, especially at low elevations, they are relatively minor at night. During the day period at low elevations a fire on south slopes can be expected to spread much more rapidly than one in similar fuels on north slopes, but at high elevations the difference in rate of spread should not be so great. Although it is probably true that a body of fuel on a south slope is always more dangerous than a similar body of fuel on the north slope, rates of spread will differ less between the two slopes at high elevations than at low. The south slope fuels are, moreover, drier, hence susceptible to ignition by a carelessly dropped match or cigarette, for a longer period of each day. But, again, the high north slopes are susceptible to ignition from small firebrands for a longer period than low north slopes. During the night, north and south slopes rate more nearly the same so rates of spread should differ but little.

Since the meteorological reasons for these decidedly significant differences are explained in detail in Circular 591 (previously cited) they will not be repeated here. It should be pointed out, however, that the reduced fire danger and fire behavior in the valley bottom is due to the settling there of the heavy cold night air. But this layer of cold, damp air is *not* very deep. Consequently, rangers and fire dispatchers should not assume that because it is damp and relatively safe down at their headquarters it is also cold and damp and equally safe all the way up the ridge. Lacking danger measurements at all altitudes, and on north and south slopes at all hours of the day, to show the exact conditions at every spot where a fire might occur, the ranger or fire dispatcher still does not need to act on the basis of guesses only. He can make allowances according to the general principles shown by Figure 1, and he can even modify or change the quantity of his allowance according to other data that are to follow.

Detailed and localized application of the major differences shown by Figure 1 requires careful consideration and in some cases more information than is yet readily available. If a fire should start at 3,800 feet elevation on a north slope at 6 p. m. on a typical August day, for example, Figure 1 shows that the burning conditions at the fire should rate about 0.9 class less than those measured on the valley bottom at 4:30 p. m., the "standard" hour for measurement. Statistical tests have shown that Figure 1 can be used in this manner with a high degree of reliability in determining the fire behavior rating at any time of day or night and at any elevation on north or south slopes on the Priest River Experimental Forest. All days are not "typical," however, and the settling of cold, wet "night air" in valley bottoms, known to meteorologists as "temperature inversion," is not equally active in all kinds of weather. During stormy, rainy weather, these altitudinal and aspect differences are greatly diminished and may even disappear during and following a rain. A strong wind may and usually does reduce altitudinal differences, but it may increase the difference between the windward and leeward aspect. Allowance must be made for such weather. During the common "fair weather" of the northern Rockies, however, inversions were found on 96 percent of the nights in July and 99 percent of the nights in August.

Type of topography is another and very important factor that affects the occurrence and intensity of inversions even in fair weather, and the 1940 tests emphasized that Figure 1 is not equally applicable in all kinds of topography. Valleys, in the ordinary sense of the term, are most subject to great differences in fire behavior with altitude such as those shown by Figure 1. Deep and precipitous canyons generally do not have such marked altitudinal differences because the well known "down-canyon" winds at night prevent the accumulation of cold air. If such winds do not occur, however, then marked inversions can be expected even in canyons. North and south slope ratings differ from each other the most in steep, and the least in gentle sloping, topography. Day to night differences are greatest in low-lying areas where pronounced inversions occur at night, and least in or above a thermal belt. Even the type of vegetation has been found to affect inversion intensity. Greater inversions, hence less dangerous burning conditions, occur in green-timbered than in cut-over or burned-over valleys.

In any detailed and highly localized application of this information, such as the dispatching of men to a particular fire, it is highly essential that the dispatcher consider the *kind* of *fuel* as well as the *fuel type* in which the fire is burning. In all dispatching in the northern Rocky Mountain region, the fuel type, as classified and described by Hornby,[4] is taken into consideration. In so doing, the dispatcher makes allowance for the inescapable fact that the more fuel available to a fire, other things being equal, the hotter and faster it will burn. Hence, fires starting on a green-timbered area where there is little but duff to burn, even though it is on a south slope in the thermal belt, will not burn as hot or fast as a heavily fueled old slashing that is fully exposed to the sun and wind. Further refinements in the dispatcher's estimate of "how the fire will behave" may be made, however, by considering the *kind* of fuel in relation to Figure 1, which is based in part upon duff (litter) moisture and half-inch-diameter-wood moisture. Finely divided fuels, such as duff and dry grass, which become extremely dry and inflammable when exposed to the midday sun and low humidities, absorb moisture and quickly lose their high inflammability when exposed to cool, moist night air after sundown. Larger and coarser fuels lose moisture more slowly during the day, but also gain it more slowly at night. Consequently, old slashings containing large branchwood, snags, and windfalls may burn furiously at night, even on a valley bottom, at a time when a cheat grass area that would have burned even more rapidly and furiously at midday, will not even carry fire. Fine fuels, therefore, may be expected to burn faster during the day and slower at night, and coarse fuels more slowly during the day and faster at night than the ratings in Figure 1 indicate.

Fire danger rating, in any of its forms, of ignition alone, of rate of spread, or of size of organization needed, is clearly an intricate procedure. There are, however, a few basic features of such ratings and their uses, which have been identified and are being measured with increasing accuracy and thoroughness. Mere recognition of each of these basic features is certain to contribute to more nearly adequate fire control and to aid in reducing fire costs.

[4]Hornby, L. G. Fuel type mapping in region one. Jour. Forestry 33:67-72. 1935.