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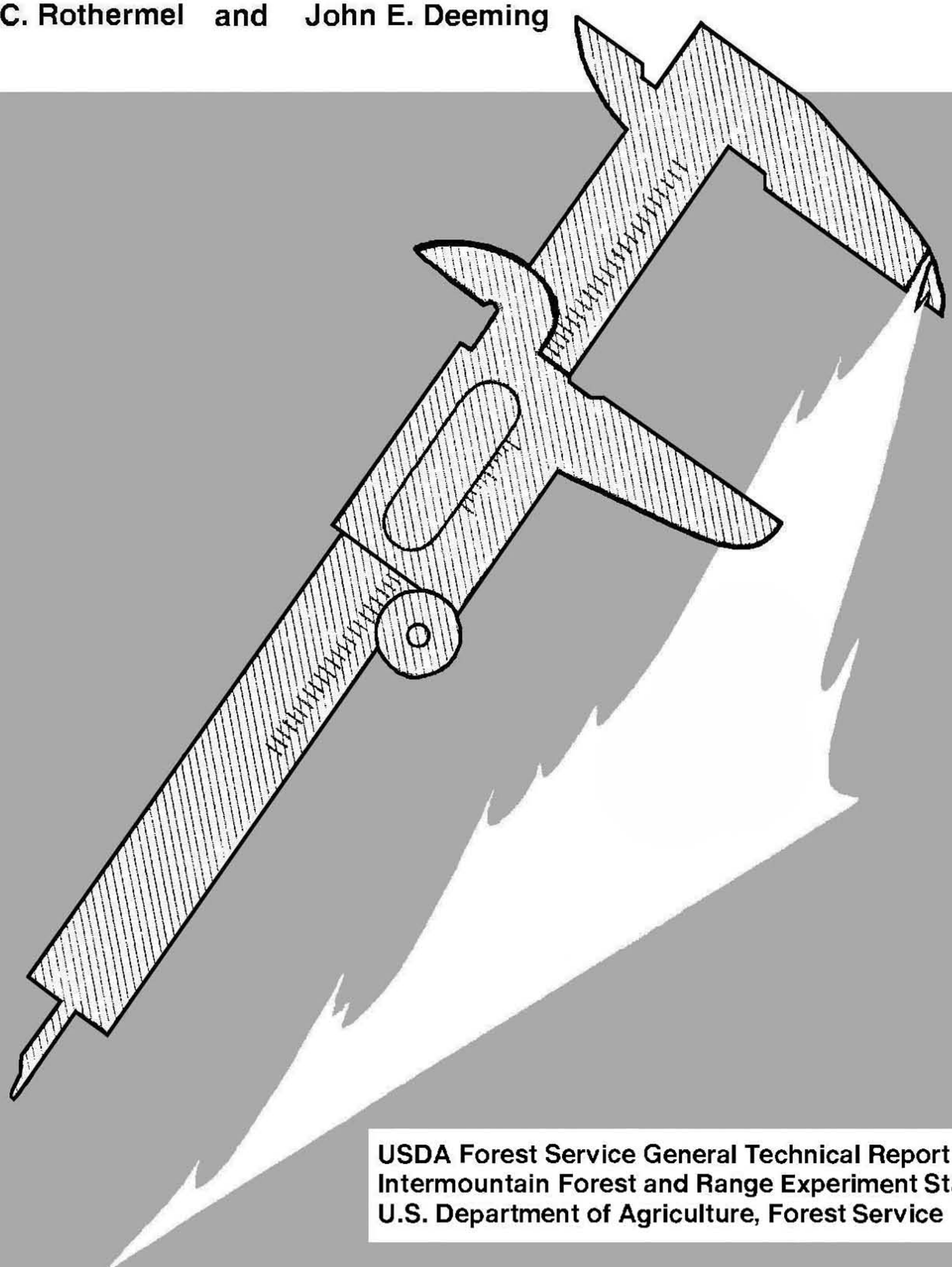

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THE AUTHORS

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JOHN E. DEEMING received his bachelor's degree in forestry from Utah State University in 1959. He has done graduate work in meteorology and biometeorology at the University of California at Los Angeles, the University of Hawaii, and Colorado State University. He served in the U.S. Air Force from 1960 to 1966 as a weather officer. In 1966 he joined the research staff at the Southern Forest Fire Laboratory, Macon, Ga., to work on fire control methods. In 1970 Deeming transferred to the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo., where he worked on the development of the 1972 National Fire Danger Rating System. From 1975 to 1978, he was leader of the National Fire Danger Rating System research work unit at the Northern Forest Fire Laboratory, Missoula, Mont. He is currently the regional meteorologist with Region 6 of the Forest Service in Portland, Oreg.

RESEARCH SUMMARY

Attempts to correlate fire behavior to fire effects have been handicapped by the lack of clearly identifiable parameters for quantifying fire behavior.

The authors identify two key parameters of fire behavior—heat per unit area and fireline intensity—and offer methods for quantifying them from simple field observations of flame height and rate of spread.

Adoption of these practices will improve experimental procedures, facilitate communication among fire behavior specialists, and provide for more precise correlation of fire behavior and fire effects.

The methods outlined are effective in fine porous fuels distributed uniformly over the burn area. Experimenters must devise means for coping with variations in experimental conditions.

INTRODUCTION

Fire is a natural and frequent disturbance on forests and rangelands. As such, its ecological role and impact on wildland resources are popular subjects for research. Research publications on fire effects and discussions among investigators reveal a serious problem: seldom is a subject fire described in quantitative terms. Often, the fire is not described at all—only its occurrence is documented. Observers may describe a fire as cool or hot, or in terms such as smoldering, running, crowning, or spotting.

As a consequence of using nonstandard qualitative descriptors, our knowledge of fire behavior and fire's effects is of limited value because it is impossible, or at best very difficult, to correlate and communicate results of different studies. Of course, fire behavior is not the only consideration necessary for explaining fire effects. The physiological state and age of vegetation, as well as the moisture of the duff and soil can be very important. It is also important to know whether the fire is being driven by the wind, or backing into it. The design of a particular study must consider all of the influencing variables.

In this paper we are proposing some standardized methods for describing fire behavior. Fire characteristics that are intuitively related to certain fire effects have been selected, and the means for deriving those characteristics from simple field observations are shown. The descriptions have been written for scientists not usually involved in fire studies, who will be designing and conducting experiments, and for fire researchers who need a system for predicting fire effects. For the near future, these relatively unsophisticated techniques are suggested because direct physical links to fire effects require knowledge of variables that are not only difficult to measure, but even more difficult to predict, such as the form and amount of heat flux, the time-temperature relationships, and so on. Until such detailed models can be assembled, general correlations must suffice.

PROPOSED METHODS

The method proposed for describing fire is based on our work in fire behavior prediction; it uses descriptors of fire intensity that should be useful as correlation parameters. The descriptors can be measured during an experimental burn and are predictable with a fair degree of accuracy. Thus fire effects that can be related to the descriptors will become predictable to the extent that the other physiological factors can also be accounted for. The method proposed is not universally applicable because of wide variations in fuels and fire behavior. The method will work best in surface fuels that are relatively uniform and porous such as grass, shrubs, long-needle pine litter, or loosely packed leaves and thinning slash. Bunched or clumped fuel will cause variations in fire behavior that will be difficult to quantify. Severe fire behavior associated with crowning, spotting, and fire whirls and concentrations of large fuels cannot be described with these simple correlations.

The field observations and analysis presented will provide assessments of two different forms of intensity: (1) fireline intensity, and (2) heat per unit area. Fireline intensity, which relates well to flame length, should be used to predict the effect of fire on items in the flame and in the hot convective gases above the flame. The heat per unit area should be used to measure heat directed to the surface and to relate fire effects in the duff and soil. Other indicators that may be helpful are given in the analysis section. A sample correlation is shown in figure 1, wherein Van Wagner (1972) related scorch height to fireline intensity.

FIELD OBSERVATIONS

Fireline intensity can be determined from observations of flame length. Heat per unit area requires measurements of both flame length and rate of spead.

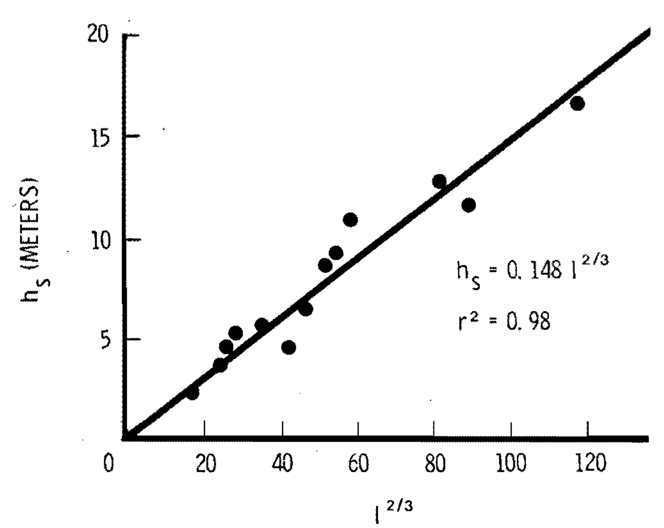

Figure 1.— Correlation between scorch height and fireline intensity.

Flame Length

Flame length can be estimated at the fire and from photos if an object of known length provides scale. Steel posts with 1-foot sections alternately painted red and white or metal flags attached every 3 feet (the choice depends on the expected scale of the flames) set in the burn area work very well.

The real difficulty is identifying the dimension that represents flame length. Flame length (fig. 2) is the distance between the tip of the flame and the ground (or surface of the remaining fuel) midway in the zone of active flaming. Because the flame tip is a very unsteady reference, your eye must estimate average length over a reasonable time period. Flame length can be estimated from photos of narrow fuel beds, but photographs of large burns with great masses of flame are of little use.

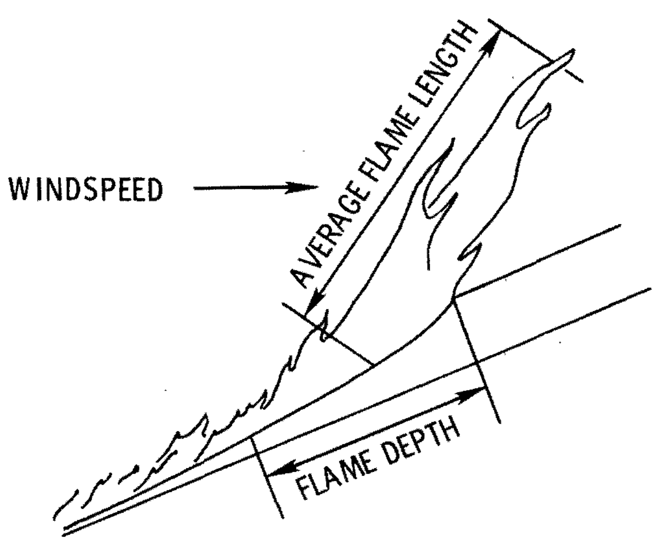

Figure 2.—Flame dimensions shown for a wind-driven fire on a slope.

Rate of Spread

Measuring rate of spread requires only a stopwatch and known distance of fire advance. Premeasured markers can be placed or metal tags can be dropped or thrown at the leading edge of the fire and the distances measured after the fire. A range finder can be very useful during the burn. The fire must be allowed to reach a steady state before data is taken. This is usually a very short time in the fine fuels suggested. The flame length and rate of spread measurements should be made simultaneously for the same run of the fire. The methods suggested in this paper do not apply to fires in piled fuel or fires ignited around a perimeter and burning toward a center. A line fire is necessary; however, it may be backing into the wind, which should be noted.

Residence Time

Fire studies often require measurement of residence time—the length of time for the fire front to pass a point. This measurement can be difficult because of the indefinite trailing edge of the fire. If there are accumulations of large fuels, say 1 inch in diameter and bigger, as well as fine fuels, two waves of heat can pass over the area. Brown (1972) measured consumption of fuel by size classes in thinning slash that illustrates the gradation of consumption. The burnout of the larger fuels may be more important than the passage of the fire front in the fine fuels. The methods for determining fire intensity suggested here are not applicable to the burnout of the larger fuels. The burnout time of the large fuels can be useful by itself, but should not be considered a residence time for the fire front.

Residence time can be measured or inferred from a calculation. By monitoring fuelbed temperature with thermocouples wired to a strip chart recorder, the time from initial temperature rise to time of definite drop can be used to indicate residence time. Residence time can also be taken with a stopwatch, observing the time for the fire front to pass a definite point. Take care to distinguish between the fire front and burning of larger pieces of fuel.

Residence time can be calculated from the rate of spread and flame depth[1] (fig. 2). Measuring flame depth from photographs is possible but must be done carefully because of the indefinite trailing edge and the problems of scaling without good references. If flame depth can be obtained, then

$$t_r = \frac{D}{R} \text{ min.}$$

where:
D is flame depth, ft (m)
R is rate of spread, ft/min (m/min).

An approximation of residence time can be made from the fuel particle size. Anderson (1969) found that a good approximation of the flaming time of fuel particles burning in a uniform fuel array was that the residence time in minutes was 8 times the fuel particle size measured in inches, or 3.15 times the particle size in centimeters. For example, a ¼-inch stick would have a residence time of 2 minutes.

[1]Flame depth is the distance at the base of the flame from the leading edge to the rear.

Sampling

Consider fire the same as any other experimental variable. For instance, flame length and rate of spread are not constant; hence, some careful thought must be given to the statistics that have the most meaning in the experiment. The mean value of the intensity may serve to predict particulate emissions; but for plant mortality, perhaps the form of the characteristic's distribution and its variance are needed.

Predicting the effects of fire on plants can be compared to the problem of predicting the effectiveness of poison on ants or rats, or the effect of a herbicide on dandelions. Knowing the average concentration of the chemical is of little use. What is of use, however, is knowing the portion of the population subjected to critical or greater doses.

If one needs more than the mean values of the fire characteristics, several, or perhaps many, samples must be taken. Besides the variability of the cause, the scale of the effect being studied should also be taken into account. For instance, shrub and tree responses occur on a spatial scale on the order of a square foot; soil loss occurs on a scale of hundreds of acres.

ANALYSIS

Fireline Intensity

Byram (1959) related the length of flames at the fire front to fireline intensity. The process can be reversed, yielding a simple expression for fireline intensity:

$$I = 5.67\, F_L^{2.17}\ \text{Btu/ft/s} \qquad (1a)$$

where F_L = flame length, ft.

The metric version of the equation for fireline intensity is:

$$I = 258\, F_L^{2.17}\ \text{kW/m} \qquad (1b)$$

where F_L is given in meters.

Heat Per Unit Area

The heat released per unit area can be calculated from the fireline intensity determined above simply by dividing by the rate of spread:

$$H_A = \frac{60\, I}{R}\ \text{Btu/ft}^2 \qquad (2a)$$

where:
I = fireline intensity, Btu/ft/s
R = rate of spread, ft/min.

The 60 is required to correct units since I utilizes seconds and R utilizes minutes. The metric version of the equation is identical in form, but units of measure are as follows:

H_A is given in kJ/m^2
I is given in kW/m
R is given in m/min

Interpretation of the equation: for the same fireline intensity, the faster the rate of spread, the less heat will be directed to the site. Conversely, slow-moving fires with the same fireline intensity as fast-moving fires will concentrate considerable heat on the site. If this seems implausible, note that the condition of the example is for the same fireline intensity, not just a fast- and slow-moving fire.

The total energy or heat relased from an area can be estimated by multiplying the heat per unit area by the area of the fire which produced it. This calculation may be useful for particulate emission studies.

Once calculated, fire parameters can be treated like any other independent parameter in regression equations. Again, it is suggested that other variables of site conditions may have to be included to explain as much of the variance as possible.

SUMMARY

In addition to describing the biological and physical environment associated with a burn, fire behavior must be described in quantitative terms before fire effects can be explained. Two aspects of fire behavior can be related to fire effects: fireline intensity and heat per unit area. Fireline intensity can be determined from observations of flame length. Heat per unit area requires measurement of both flame length and rate of spread. The proposed method works in fine porous fuels that are distributed relatively uniformly over the burn area.

Studies that utilize these methods will offer the opportunity for inferring fire effects beyond the conditions of the original experiment, which was not possible heretofore.

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Identifies and describes methods for quantifying from field observations. two key parameters of wildfire behavior: fireline intensity and heat per unit area. Proposes standardization of terms and techniques as a means of improving experimental procedures and communication among fire behavior specialists, and as a means of correlating fire behavior and fire effects.

KEYWORDS: fire behavior. fire modeling, wildfire

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The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

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Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

Correlation increases with firing rate in the strong asynchronous regime. We next sought a possible relationship between pairwise correlationsâ€"quantified via the Pearsonâ€™s correlation coefficient for spike counts, â€"and single-cell firing rates.Â To investigate this we plotted pairwise correlations for each distinct excitatory pair Ïij, versus the geometric mean of the firing rates , in both regimes (asynchronous and strong asynchronous), for a range of time scales (blue stars in Fig 2). We focus here on excitatory-excitatory (E-E) pairs, because excitatory synaptic connections provide the predominant means of propagating cortical sensory information. Proposes standardization of terms and techniques as a means of improving experimental procedures and communication among fire behavior specialists, and as a means of correlating fire behavior and fire effects. Notes. No copyright page found. No table-of-contents pages found. Camera. Canon EOS 5D Mark II. Copyright_message. As noted previously, fire behavior modeling and retrospective approaches are appropriate for addressing different sets of questions about how bark beetle outbreaks may affect subsequent wildfire activity. Fire behavior models are particularly useful in revealing insights about how beetle-killed fuels might result in uncharacteristic fire behavior at a stand scale that is, in turn, of fundamental importance to firefighter safety. Taken as a whole and extrapolated to larger landscapes, however, modeling-based studies lead to the expectation that, in general, beetle-killed forests should exhibit