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Predicting Changes in Chaparral Flammability

Richard C. Rothermel and Charles W. Philpot

ABSTRACT—A dynamic fuel model for the chaparral brush fields of southern California shows that (a) the fire threat for the first few years after a fire primarily is related to forbs and grasses; and (b) after 10 to 20 years, the brush fields will sustain very fast-spreading, high-intensity fires, depending upon the ratio of the live-to-dead fuel. The mathematical models described permit systematic analysis of the consequences of fuel treatment and fire control and projection of these consequences for the future.

So many fuel parameters are changed by aging or site manipulations that mathematical modeling is the only feasible method of assessing the large number of interactions that influence fire behavior. Predictions from the models allow planners to weigh long-term consequences of fire-control alternatives against short-term effects.

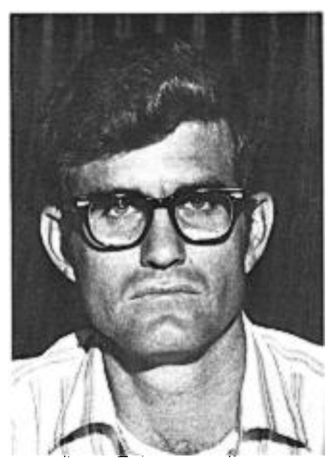
As an example, we used available growth and mortality data for chamise (*Adenostoma fasciculatum*) and mixed chaparral to analyze fuel changes due to age and time of year. We sought input parameters for Rothermel's fire spread model (*8*) that computes the rate of spread and intensity of a wildfire with a steady-state wind in a continuous stratum of fuel growing contiguous to the ground.

Although brush fires have a relatively continuous fuel bed, some discontinuities and variations prevent a sustained steady rate of fire spread. Nevertheless, predictions are very revealing about the expected fire behavior when key fuel or weather parameters are changed. While emphasizing vegetation changes caused by age or time of year, we recognize that better predictions of the true characteristics of plants on specific sites must also be based on site variables such as soil, elevation, aspect, and precipitation.

The Chaparral Fire Problem

In southern California, the flammability of chaparral, coupled with the Santa Ana wind condition, rugged topography, and intrusion of homes onto brush-covered slopes, poses a grave and challenging wildland fire threat. Chamise—a fire climax and major species in chaparral brush fields—occurs in nearly pure stands on many sites (*1*). This species substantiates the Mutch hypothesis on fire-dependent plant communities (*5*) in that it has many inherent characteristics that make it highly flammable.

Chamise sprouts from a root crown just beneath the soil surface after the stems and foliage are removed or



THE AUTHORS—Richard C. Rothermel is research physical scientist and Charles W. Philpot is research forester, USDA Forest Serv., Intermountain Forest and Range Exp. Sta. They are stationed in Missoula, Montana, at the Northern Forest Fire Laboratory.

LOADING OVER TIME

Chamise Stands

$$w_n = 0.0459A/(1.4459 + 0.0315A)$$

Mixed Stands

$$w_n = 0.0459A/(0.4849 + 0.0170A)$$

FRACTION DEAD

Average Mortality

$$F_d = 0.0694 \exp(0.0402\ A)$$

Severe Mortality

$$F_d = 0.1094 \exp(0.0385\ A)$$

FRACTION TOTAL BY SIZE CLASS

Dead Fuel

$$F_{d,0-\frac{1}{4}} = 0.347\ F_d$$
$$F_{d,\frac{1}{4}-\frac{1}{2}} = 0.364\ F_d$$
$$F_{d,\frac{1}{2}-1} = 0.207\ F_d$$
$$F_{d,1-3} = 0.085\ F_d$$

Living Fuel

$$F_{\ell,leaves} = 0.1957 - 0.305\ F_d$$
$$F_{\ell,0-\frac{1}{4}} = 0.2416 - 0.256\ F_d$$
$$F_{\ell,\frac{1}{4}-\frac{1}{2}} = 0.1918 - 0.256\ F_d$$
$$F_{\ell,\frac{1}{2}-1} = 0.2648 - 0.050\ F_d$$
$$F_{\ell,1-3} = 0.1036 - 0.114\ F_d$$

SEASONAL CHANGES LIVING FUEL

Moisture Content

$$M_{\ell,leaves} = 1/(0.726 + 0.00877\ D)$$
$$M_{\ell,stems} = 1/(1.454 + 0.0065\ D)$$

Heat Content

$$H_{\ell,leaves\ \&\ \frac{1}{4}} = 9613 - 1.00\ D + 0.1369\ D^2 - 0.000365\ D^3$$
$$H_{\ell,\frac{1}{2}-3} = 9509 - 10.74\ D + 0.1359\ D^2 - 0.000405\ D^3$$

DEFINITION OF SYMBOLS

w_n = net loading (lb/ft^2)
A = age of stand in years
F_d = dead fraction of net load
F_ℓ = living fraction of net load
D = number of days since May 1
M = moisture content, fraction dry weight
H_ℓ = heat content, BTU/lb.

Figure 1. Basic functions for dynamic fuel model.

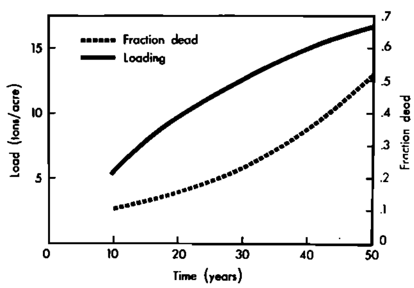


Figure 2. Fuel loading and fraction dead versus age for pure stands of chamise.

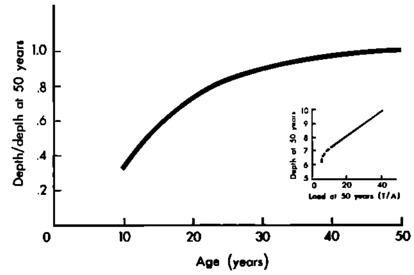


Figure 3. Two curves that can be used to predict plant height with age.

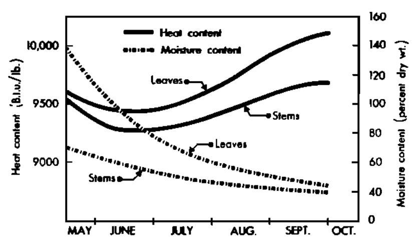


Figure 4. Changes in heat content and moisture content of living chamise, May through October.

are killed by fire. Some new chamise plants result from germination of heat-treated seed. Heat also creates soil conditions (*4*) that lead to germination of several annuals. These grasses and forbs occupy the site for about 5 to 7 years, until suppressed by chemicals produced by chamise. During this time, fast-moving, lower-intensity fires can occur in the grasses and forbs. About 10 years after the fire, the stand is nearly pure chamise again. As it matures, some stems die but remain upright within the plant. This dead material responds to changes in moisture dictated by daily fluctuations in humidity, temperature, and precipitation.

Dynamic Fuel Model

Dynamic fuel modeling is a new concept in forest fire research that accommodates the changing character of fuel over time. Chamise is well suited for such modeling because time zero can be fixed at the date of the last burn. Thus, time-dependent equations for above surface plant growth can be referenced to that date. Then too, chamise is multistemmed from the ground; consequently, it has a fairly uniform vertical distribution of size classes compared to other species. The chaparral brush fields of southern California, of which chamise is a major component, exist in large expanses of relatively continuous fuel that is contiguous to the ground. This satisfies assumptions made for Rothermel's fire spread model for which the fuel model generates input values.

Our dynamic fuel model (*Figure 1*) was developed from available data on fuel loading, fraction dead, and depth for chamise and mixed chaparral. But information on particle characterization, such as surface-area-to-volume ratio, particle density, and heat content, was not available for mixed chaparral. Therefore, these values were assumed to be the same as for chamise.

The basic fuel parameter considered was loading by living and dead size class. In so doing, we developed the chamise function for total fuel loading over time (*6*), as shown in Figures 1 and 2. The dynamic fuel model also contains a hypothetical loading that might be representative of mixed stands of chaparral vegetation (*Figure 1*) which would be heavier than the loading for stands in which chamise is dominant. The total fuel load was used as a base for computing the fraction of the fuel that was dead (lower curve, *Figure 2*). The functional relationship for the *average* "fraction-dead" condition (*Figure 1*) was derived from data collected from a limited sample of partially dead plants (*3*) plus the average value per acre for completely dead plants (*1*). The hypothetical function for *severe mortality* probably represents unique conditions following long dry periods or disease epidemics.

The functions for distribution of dead material by size classes were derived from data on individual shrubs (*3*). Past experience has indicated that the proportion of dead material in the smaller size-class samples increases as the fraction of the dead material in the whole plant increases. However, our analysis of the available data did not produce a significant nonlinear function. During age 10 to 19 years, the 1- to 3-inch size class of chamise is assumed to be nonexistent; the fuel loading—live and dead—was therefore uniformly prorated to the smaller size classes.

Another input required for the fire spread model is fuel depth. This is influenced by many site factors, including age of stand. To simplify the model, however, we assumed that the depth of the stand at age 50 years is related to the fuel load at 50 years. The curve developed for this function (inset, *Figure 3*), when coupled with the typical growth curve (*Figure 3*), can be used to obtain fuel depth values required for the fire spread model.

Seasonal changes in fuels also must be taken into account. The inputs that we assumed to be seasonally

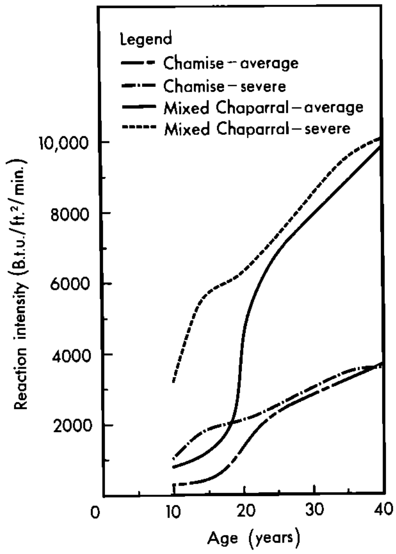


Figure 5. Predicted fire intensity by age of chamise and mixed chaparral with average and severe mortality.

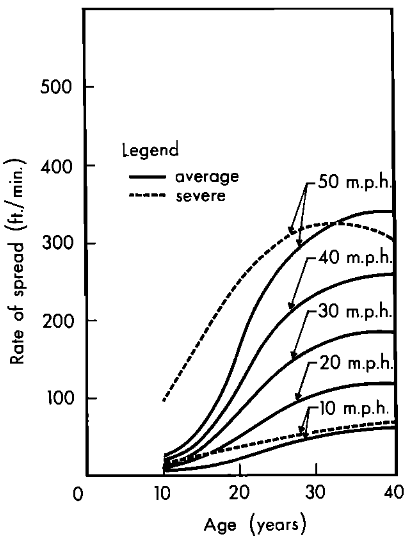


Figure 6. Predicted rate of fire spread for chamise, by age and level of mortality.

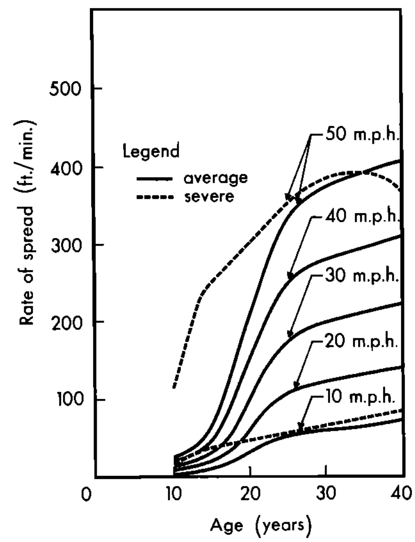


Figure 7. Predicted rate of fire spread for mixed chaparral, by age and level of mortality.

dependent are the heat content (7) and moisture content of the living vegetation (9), in Figure 4. Similar curves for dead vegetation were not developed because they are highly dependent upon day-to-day atmospheric variations. Instead, we assumed fuel moisture content (three percent) that would be typical of fuel conditions in early September in southern California.

Application of Spread Model

We recognized that over any projected period a whole range of fire behavior, highly dependent upon changing environmental influences, could be expected. Because we were interested in the effects of fuel changes rather than weather variations, we assumed a Santa Ana weather condition for early September. The moisture content of dead fine fuel would then be about three percent and variations in wind velocity would range from 10 to 50 mph (2). The slope was set at 50 percent. Moisture of extinction[1] of dead fuel was set at 20 percent. All other inputs are constants shown in Table 1.

The highest fire intensity predicted is for mixed chaparral with the severe-mortality condition (*Figure 5*). Intensity for this condition climbs steeply from vegetation age of 10 to 15 years, whereas the average-mortality condition does not show a steep rise until vegetation is 18 to 20 years old. The delay is caused by insufficient dead material to carry the fire, which is necessary to desiccate the green fuel and involve it in the combustion reaction. The chamise fuel shows a less severe increase in fire intensity with time. However, the curves do have the same characteristic shape.

Table 1. Physical and chemical constants for chamise by size class.

Size classes	Mean surface area-to-volume ratio	Silica-free mineral content	Particle density
	Ft^{-1}	*Fraction dry wt*	*Lb/ft*^{3}
Leaves	2,200	0.035	32
< ¼ inch	640	.015	46
¼–½ inch	127	.015	46
½–1 inch	61	.015	46
1–3 inches	27	.015	46

Predicted rates of fire spread for the average-mortality condition show a striking change near 15 years for both chamise and mixed chaparral (*Figures 6 and 7*). The severe-mortality condition shows a sharply rising rate of spread beginning as early as 10 years and leveling off between 30 and 35 years. The rise in spread rate between 15 and 20 years for average-dead coincides with the rise in intensity, which was attributed to the buildup of dead material. The leveling out of spread rate after 30 years in the severe-dead condition was attributed to the diminishing amount of fine material.

Both intensity and rate of spread generally increase during the fire season in chamise of average-mortality condition (*Figure 8*). These increases reflect the seasonal changes, especially in moisture content of living fuel. All of these seasonal predictions are based on a dead fuel moisture content of three percent and a windspeed of 30 mph. However, it is noteworthy that a

[1]Moisture of extinction is the fuel moisture content above which significant fire spread is not expected.

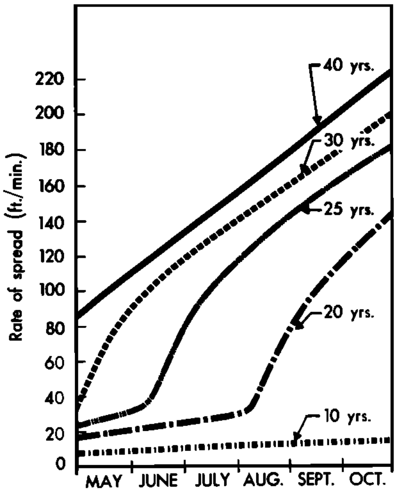


Figure 8. Seasonal change in rate of fire spread, predicted for chamise of average-dead condition, 3 percent dead-fuel moisture, and 30 mph wind.

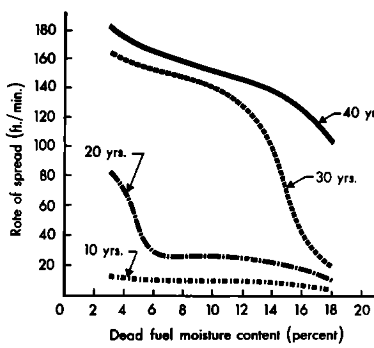


Figure 9. Rate of fire spread in chamise of average-dead condition, by moisture content of dead fuel.

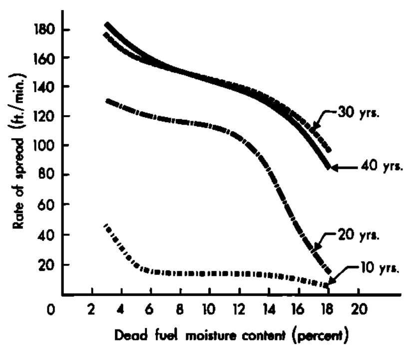


Figure 10. Rate of fire spread in chamise of severe-dead condition, by moisture content of dead fuel.

significant increase in fire severity occurs during the season. Fires in older fuels, with higher amounts of dead material, will be more difficult to control if periods of drought occur early in the season.

To show the effect of moisture content of dead fuel, rate-of-spread curves were computed for chamise on September 1, and with an assumed windspeed of 30 mph. For the average-mortality condition (*Figure 9*), a modest rate of spread is predicted beyond 6 percent moisture content for any fuel younger than 20 years. For the severe-mortality condition (*Figure 10*), a fast rate of spread is predicted up to 12 to 14 percent moisture content for 20-year-old fuel. As in previous curves, the older fuels are predicted to support a much faster rate of fire spread.

Conclusions

As expected, our results show that both rate of spread and intensity of fire increase with age of chaparral fuels. These increases are not constant. They change, depending upon fuel conditions. Abrupt changes in fire behavior, depending upon the condition of the fuels, are predicted during the fire season. The effect of changes in dead fuel moisture content—an indication of environmental changes—is also shown.

Our analysis confirms that southern California brush fields are relatively nonflammable in early years after a fire, except that in the first 10 years annuals can produce low-intensity, fast-spreading fires. Fires burning under high-wind conditions in brush fields beyond 20 years of age produce fire intensities and spread rates that often make them uncontrollable. The model also confirms that autumn fires may be expected to be more severe than spring fires even under the same weather conditions, and it quantifies the expected differences.

Since there is a fuel age beyond which fires often become uncontrollable, our conclusions indicate that fire management concepts must be designed to cope with dynamic situations that vary with age of vegetation and season. The outputs from this model indicate that age-class mosaics could be effective as a land management tool by developing broad areas on which young brush is interspersed with areas of older brush. To maintain a balance, a fuel rotation cycle would have to be established. Research still is needed to develop methods for fuel management in chaparral. Studies must include ecological characteristics, fire behavior, and fire-control techniques. More definitive modeling is needed to relate expected fire behavior to specific sites. We hope that the model described in this paper can be used as a guide in such extended research.

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