The Bee Fire: A Case Study Validation of BEHAVE in Chaparral Fuels

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Abstract

The Bee Fire burned 9,620 acres of grass and chaparral in the San Bernardino National Forest in southern California from June 29 to July 2, 1996. Rate of spread data were determined from successive fire perimeters and compared with rate of spread predicted by the Rothermel rate of spread model using fuel model 4 (heavy brush) and a custom fuel model for chamise chaparral. A linear relationship between observed and predicted rate of spread was found (R^2 = 0.60). The two fuel models performed similarly with only a difference in scale. Observed spread rates were approximately 80 percent of the spread rates predicted with fuel model 4 and 380 percent of the spread rates predicted with the custom model. The regression models did not fit 4 of the 28 observations, but no apparent cause for the lack of fit was found.

Introduction

Fire is a common occurrence in the Mediterranean climate of California. In any given year, thousands of acres of chaparral and other shrub types are burned by wildfires. Much effort has focused on attempting to describe the manner in which fire spreads through the chaparral fuels; however, some fire managers believe that existing fire spread models do not work well in chaparral and that additional work should be conducted to develop a fire spread model for chaparral that can be used to assist in tactical decisions associated with suppression and prescribed burning as well as in strategic decisions such as fire budget planning. Other fire managers have adapted existing models or created other decision tools to aid in these decisions (Raybould and Roberts 1983).

To our knowledge, existing fire spread models have not been systematically validated for the chaparral fuel types or for other shrubby fuel types in the western United States. Limited validation of the Rothermel model has occurred (Albini and Anderson 1981, Stevenson et al. 1974). We are currently conducting a validation study of fire spread models in chaparral and other shrub type fuels by using information from chaparral wildfires that have occurred in California. The purpose of the study is to identify the set of conditions where current operational models perform well and to identify the set of conditions where improvements need to be made.

This paper describes results of a comparison of fire spread rates predicted by the Rothermel fire spread model (Albini 1976, Rothermel 1972) with fire spread rates derived from a fire perimeter growth map.

Methods

The Bee Fire was accidentally ignited at 1647 hours, June 29, 1996 on a southern aspect in a chaparral fuel type dominated by chamise (*Adenostoma fasciculatum* H&A) at an elevation of 2,200 ft (677 m) on the San Jacinto Ranger District of the San Bernardino National Forest in southern California. This fire can best be described as a "heat wave" fire as opposed to a Santa Ana fire. Local suppression forces initially battled the fire; by the morning of July 1, a Type I Incident Command Team assumed control of the fire due to its complex nature and the multiple resources that were at risk. A Fire Behavior team consisting of a Fire Behavior Analyst, two Fire Behavior Analyst trainees, and two Field Observers was assigned to support the Incident Command Team. During the next week, the Fire Behavior team reconstructed fire perimeter growth from June 29 to July 1 through interviews and documented fire perimeter growth from July 1 to July 2, 1996 at which point the fire was declared contained at 9620 acres (3848 ha). The team worked with a Geographic Information System Specialist and a Meteorologist to digitize the fire perimeter maps, gather and modify weather data from the Keenwild Remote Automated Weather Station (RAWS), and generate fuel, slope, and aspect maps for use with FARSITE™.

The fire perimeter map produced by the Fire Behavior team (fig. 1) consisted of 28 polygons representing the perimeter location at different times. For each polygon, an "effective"

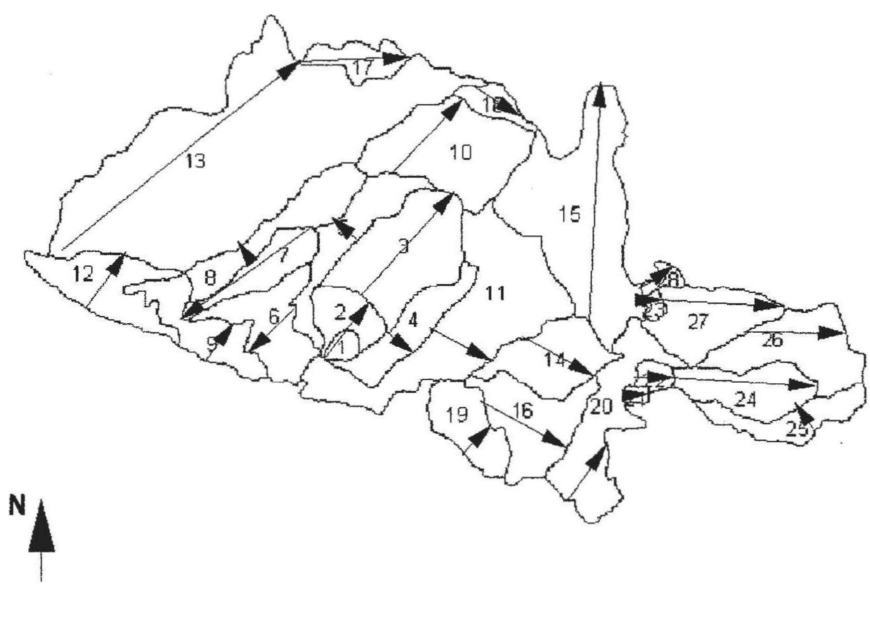

Figure 1. *Fire perimeter map for the Bee Fire, San Bernardino National Forest, California, which occurred June 30 to July 3, 1996 and burned 9620 acres of chaparral vegetation. Each numbered polygon indicates a separate spread episode.*

rate of spread was estimated by drawing a vector from one perimeter to the next successive perimeter, determining the elapsed time between these perimeters, and calculating the rate of spread by using $R_e = L/T$, where R_e is "effective" rate of spread, L is the distance between successive perimeters, and T is the elapsed time between successive perimeters (Fujioka 1985). Real-time rate of spread measurements are more detailed than rates of spread derived from fire perimeters reconstructed after the fact. However, for the purposes of this paper, the level of detail is sufficient. Fire behavior prediction input variables were estimated along each of the vectors assuming uniform conditions and established techniques used by fire behavior analysts. The DIRECT module of BEHAVE (Andrews 1986) was used to calculate the "predicted" rate of spread for each set of input variables for the Fire Behavior Prediction System fuel model 4 (FBPS4) and for a custom fuel model CHAMISE2 (Weise 1997). If one of the input variables changed along the vector within the polygon (such as a change in slope or fuel type), an additional "predicted" rate of spread was derived. Thus, more than one predicted rate of spread may exist for a polygon. In the case of multiple predicted spread rates, the harmonic mean, H, (eq. 1) spread rate was calculated (Fujioka 1985) where a_i is a weighting coefficient and R_i is the predicted rate of spread for a uniform set of conditions. For this analysis, $a_i = l_i / L$, where l_i is the distance the fire spread at rate R_i.

$$H = \frac{1}{\sum_{i=1}^{n} a_i / R_i} \qquad (1)$$

We estimated coefficients for a regression model of the form $OROS = a + bH$ where H and $OROS$ are predicted and observed spread rates, respectively. Coefficients were estimated separately for the FBPS4 and CHAMISE2 fuel models. In addition to providing a measure of the relationship between predicted (by BEHAVE) and observed spread rates, this regression model may also provide a mechanism to correct BEHAVE predictions. Analysis of residuals was performed to identify any systematic error in prediction that can be attributed to BEHAVE input variables.

Results and Discussion

Rate of spread was predicted using environmental and fuel input values (Table 1). Relative humidity ranged from afternoon lows of 18 percent to highs of 38 percent in the early morning (0200 hours). Similarly, temperatures ranged from night time lows of 60 °F to low 90's in the afternoon. Live fuel moistures were somewhat lower than normal for this time of the year for chamise and an average value of 60 percent for live woody moisture was used for FBPS4. CHAMISE2 has two live fuel components. We assumed live fuel moistures for foliage and fine branchwood were 80 percent and 60 percent, respectively. Dell and Philpot (1965) found that only chamise foliage moisture content varied appreciably annually and that fine branch moisture content ranged from 40 to 60 percent throughout the year.

Table 1. *Input variables used to predict rate of spread with the DIRECT module of BEHAVE on the Bee Fire, San Bernardino National Forest, San Bernardino, California.*

DatePolygon	Time	Elapsed Elevation (hr)	Slope (ft)	Temp. (pct)	RH (°F)	1 (%)	10	Fuel Moistures(pct)[1] 100	Live	Actual	Wind Direction Relative[2] (°)	Speed (°)	Wind Direction (mph)	Spread
6/29/96	1	0.2	2200	28	84	19	3	4	5	60	293	243	5	Max
	2*	0.8	2600	30	84	19	3	4	5	60	293	243	5	Max
	3	0.3	3000	34	75	24	3	4	5	60	345	282	4	Max
	3	0.3	3200	34	75	24	3	4	5	60	345	34	4	Max
	3	0.1	3400	53	75	24	3	4	5	60	345	302	4	Max
	4	4.5	2800	48	61	28	5	5	6	60	99	55	0	94
6/30/96	5	7.5	2800	17	60	28	7	6	6	60	83	155	2	Max
	6	0.5	2200	23	60	38	7	6	6	60	83	220	2	Max
	7*	0.5	2400	34	60	28	7	6	6	60	83	144	2	Max
	8	0.8	2200	26	70	34	7	6	6	60	100	280	0	320
	9	1.0	2000	33	70	34	7	6	6	60	100	241	0	360
	10	0.3	4000	42	93	14	3	4	5	60	302	352	8	Max
	11	4.4	3000	54	93	14	3	4	5	60	302	280	0	98
	12	0.3	2000	15	90	16	3	4	5	60	257	220	4	Max
	12	0.3	2000	34	90	16	3	4	5	60	257	220	4	Max
	13	0.7	2000	14	93	14	3	4	5	60	303	316	7	Max.
	13	0.1	2200	17	93	14	3	4	5	60	303	250	7	Max.
	13	0.2	2400	30	93	14	3	4	5	60	303	250	7	Max.
	14	3.0	3000	76	93	14	3	4	5	60	303	270	7	90
	14	2.5	3400	50	93	14	3	4	5	60	303	270	7	90
	15	0.8	3800	33	85	17	5	5	6	60	293	255	7	328
	15	0.7	4600	33	85	17	5	5	6	60	293	287	7	Max.
	16	0.3	2400	13	85	17	5	5	6	60	293	170	7	Max.
	16	0.1	2400	25	85	17	5	5	6	60	293	240	7	Max.
	17	0.5	3000	40	85	17	5	5	6	60	293	205	7	Max.
	18*	1.1	4600	25	85	17	5	5	6	60	293	172	7	Max.
7/1/96	19	0.5	2400	33	74	27	7	6	6	60	70	25	2	Max.
	20	0.8	3200	40	74	27	7	6	6	60	70	5	2	Max
	21	0.1	3600	33	97	15	3	4	5	60	264	175	8	Max.
	22*	0.1	3800	33	97	14	3	4	5	60	289	210	7	Max.
	23	0.1	3600	50	97	14	3	4	5	60	289	200	7	Max.
	24	0.5	4600	17	97	14	3	4	5	60	289	289	7	Max.
	25	0.1	4800	14	92	15	3	4	5	60	305	247	6	Max.
	26	0.6	4800	33	92	15	3	4	5	60	305	233	6	Max.
	27	0.3	4400	29	92	15	3	4	5	60	305	215	6	Max.
	27	0.2	4800	20	92	15	3	4	5	60	305	215	6	Max.
7/2/96	28	0.3	3800	50	96	23	7	6	6	60	198	300	3	Max.

[1] The fuel moistures are for 1-hour, 10-hour, and 100-hour timelag dead fuels and live woody fuels.

[2] Wind direction relative to uphill direction; 0° indicates upslope wind, 180° indicates downslope wind.

* denotes polygon for which observed rate of spread was classified as an outlier.

Observed spread rates ranged from 3 to 265 chains/hr (1 to 89 meter/min) (table 2). Reported average forward spread rate (for 6 hours or longer time intervals) in chaparral for large historical fires was 10 ch/hr and 95 percentile rate was 40 ch/hr (Chandler and others 1963). Predicted forward spread rates ranged from 9 to 274 chains/hr for FBPS4 and from 2 to 57 chains/hr for CHAMISE2. A linear relationship between predicted and observed spread rates was noted for both fuel models (fig. 2). Plots of predicted spread rates for FBPS4 and CHAMISE2 versus observed spread rates were very similar--the primary difference between the fuel models was the range of predicted spread.

Table 2. *Observed and predicted rates of spread for 28 spread events in chaparral on the Bee Fire, June 30 to July 3, 1996 on the San Bernardino National Forest, San Bernardino, California.*

PolygonObserved		Predicted[1]				
			FBPS4		CHAMISE2	
	(ch/hr)	(m/min)	(ch/hr)	(m/min)	(ch/hr)	(m/min)
1	152	51	120	40	26	9
2*	28	10	120	40	26	9
3	138	46	110	37	24	8
4	5	2	9	3	2	0.7
5	3	1	28	9	4	1.3
6	106	36	27	9	4	1.3
7*	189	64	22	7	3	1
8	17	6	24	8	2	0.7
9	32	11	16	5	3	1
10	259	87	274	92	57	19
11	11	4	10	3	2	0.7
12	73	24	84	28	18	6
13	208	70	199	67	42	14
14	10	3	7	2	2	0.7
15	110	37	88	29	18	6
16	166	56	175	59	35	12
17	163	55	154	52	31	10
18*	29	10	168	56	33	11
19	57	19	49	16	7	2.3
20	57	19	58	19	8	2.6
21	189	64	219	73	46	15
22*	265	89	182	61	39	13
23	170	57	155	52	33	11
24	201	67	201	67	43	14
25	189	64	160	54	34	11
26	126	42	150	50	32	11
27	167	56	152	51	33	11
28	101	34	82	28	11	4

[1] Rate of spread predicted using DIRECT module of BEHAVE program. FBPS4 is fuel model 4 (heavy brush) for the Fire Behavior Prediction System (formerly NFFL fuel model 4) and CHAMISE2 is a custom fuel model developed specifically for chamise fuels (*Adenostoma fasciculatum*).
* denotes polygon for which observed rate of spread was classified as an outlier.

Results of the regression analyses further supported the similarity in performance of the two fuel models. Both regression equations accounted for 60 percent of the variation in OROS. Neither intercept (a) estimate was significantly different from 0 at the $\alpha = 0.05$ level. Both slope (b) estimates were significantly different from 0 at $\alpha = 0.05$ (eq. 2, 3). The same 4 observations (polygons 2, 7, 18, and 22) had influential residuals (defined here as studentized residual > 1.5 where studentized residual is the residual divided by its standard error) for both regression equations. Wind direction for all four observations was generally downslope (144° to 243°

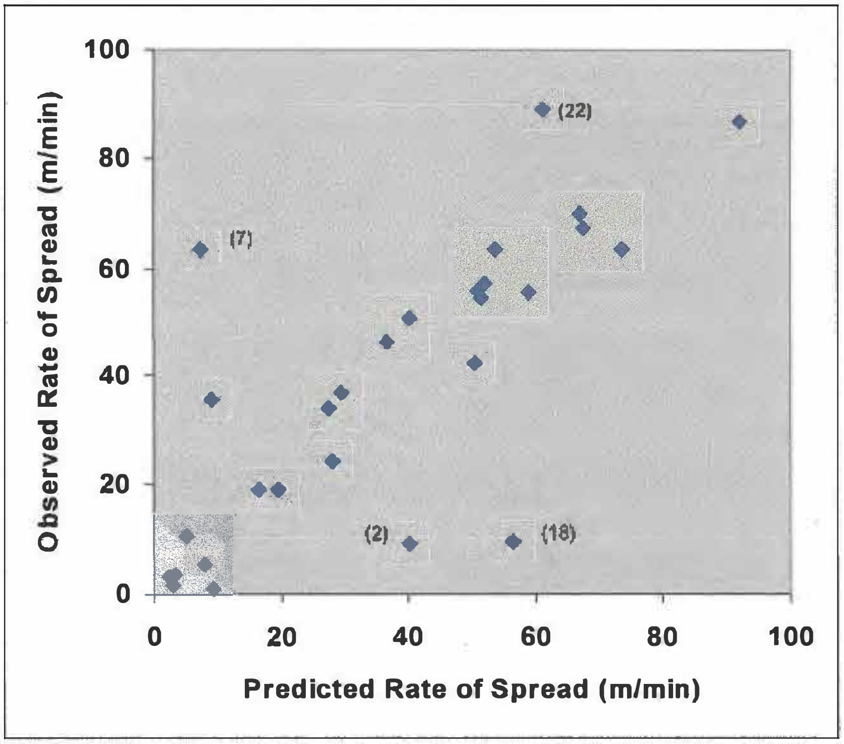

Figure 2. *Observed and predicted fire spread rates in chaparral fuels from the Bee Fire, June 29-July 3, 1996. Spread rates predicted using the BEHAVE implementation of the Rothermel rate of spread model and FBPS fuel model 4 (heavy brush). A plot of predicted spread rates using a custom fuel model for chamise was similar to this figure except the range in predicted rate of spread was 0 to 19 m/min.*

where 0° or 360° indicates wind blowing directly upslope). Wind direction was generally downslope for several other observations also. Plots of residuals against all possible independent variables did not reveal any discernable trends in the residuals. As a result, no additional attempts to improve the regression models were made.

$$OROS = 31.5 + 3.79(CHAMISE2) \quad (2)$$

$$OROS = 25.4 + 0.82(FBPS4) \quad (3)$$

From this analysis, there is some evidence of correlation between predicted and observed rate of spread in chaparral fuels. For the Bee Fire, observed spread rates were about 80 percent of those predicted using FBPS fuel model 4 and about 380 precent of those predicted using the custom fuel model CHAMISE2. As mentioned previously, the only difference between rate of spread predictions for the two fuel models appears to be a matter of scale, even though the fuel model parameters were quite different. Perhaps the manner in which the individual components of the fuel models are averaged greatly reduced the perceived differences between the two fuel models. Limitations in the formulation of the Rothermel model as applied to live fuels have been identified (Albini and Anderson 1981, Cohen et al. 1995, Martin and Sapsis 1987, Weise and Biging 1997). Further analysis is needed to understand fuel model performance.

With the exception of the four "outliers", the Rothermel model predictions correlated well with observed spread rates for the Bee Fire. Under similar fuel and weather conditions, it may be possible to use either of the equations to correct BEHAVE outputs to predict spread rates in chamise chaparral. Additional validation work with other spread data is necessary to identify the conditions under which the Rothermel model works best in chaparral fuels.

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