Behave: Evaluated for Prescribed Fire Planning in Mountainous Oak: Shortleaf Pine Habitats

Ronald E. Masters; David M. Engle

Wildlife Society Bulletin, Vol. 22, No. 2. (Summer, 1994), pp. 184-191.

Stable URL:
http://links.jstor.org/sici?sici=0091-7648%28199422%2922%3A2%3C184%3ABEFPFP%3E2.0.CO%3B2-B

Wildlife Society Bulletin is currently published by Alliance Communications Group.

Your use of the JSTOR archive indicates your acceptance of JSTOR's Terms and Conditions of Use, available at http://www.jstor.org/about/terms.html. JSTOR's Terms and Conditions of Use provides, in part, that unless you have obtained prior permission, you may not download an entire issue of a journal or multiple copies of articles, and you may use content in the JSTOR archive only for your personal, non-commercial use.

Please contact the publisher regarding any further use of this work. Publisher contact information may be obtained at http://www.jstor.org/journals/acg.html.

Each copy of any part of a JSTOR transmission must contain the same copyright notice that appears on the screen or printed page of such transmission.

The JSTOR Archive is a trusted digital repository providing for long-term preservation and access to leading academic journals and scholarly literature from around the world. The Archive is supported by libraries, scholarly societies, publishers, and foundations. It is an initiative of JSTOR, a not-for-profit organization with a mission to help the scholarly community take advantage of advances in technology. For more information regarding JSTOR, please contact support@jstor.org.

http://www.jstor.org
Thu Jul 12 11:08:56 2007

Wildl. Soc. Bull. 22:184–191, 1994

BEHAVE—EVALUATED FOR PRESCRIBED FIRE PLANNING IN MOUNTAINOUS OAK–SHORTLEAF PINE HABITATS

RONALD E. MASTERS,[1] ***Oklahoma Department of Wildlife Conservation, 1801 North Lincoln Boulevard, Oklahoma City, OK 73105, and Department of Zoology, Oklahoma State University, Stillwater, OK 74078***

DAVID M. ENGLE, ***Oklahoma Agricultural Experiment Station, Oklahoma State University, Stillwater, OK 74078***

Key words: fire behavior, fireline intensity, fire models, forest management, habitat manipulation, Oklahoma, Ouachita Mountains, rate of spread

Land managers who use prescribed burning struggle with the tradeoff between liability risks from fire escapes and the benefits of fire for manipulating wildlife habitat. Computer models that predict burn outcomes under varying fuel and weather conditions can be used to reduce the risk of fire escape (Raybould and Roberts 1983, Andrews and Bradshaw 1990). BEHAVE is a wildland fire behavior and fuel modeling system developed by the U.S. Department of Agriculture Forest Service (Burgan and Rothermel 1984, Andrews 1986, Andrews and Chase 1989). Managers can select from 1 of 13 standard fuel models or customize a site-specific model. After the manager specifies environmental conditions, the program estimates attributes of fire behavior.

Fireline intensity, the rate of heat or energy released per unit time per unit length of fire front (Byram 1959:79), is of particular interest because it directly affects the above-ground portions of woody plants (Van Wagner 1973, Rothermel and Deeming 1980, Alexander 1982, Wright and Bailey 1982:416). For example, fireline intensity affects survival of small diameter shrubs and trees (Wade and Johansen 1986) and may also affect forage quality for wildlife (Dewitt and Derby 1955). Flame length, which is related to fireline intensity, is generally an accurate predictor of scorch height on conifers and may be used to predict mortality of trees (Van Wagner 1973). Fireline intensity and flame length are also used to interpret the difficulty of control and the potential for fire escape (Roussopoulos and Johnson 1975). Because BEHAVE estimates important fire behavior variables and removes some of the uncertainty involved in prescribed burning, it can be a valuable tool for habitat managers.

The mathematical fire spread model in BEHAVE is intended primarily to describe the flame front of a headfire carried by fine fuels (Rothermel 1983). Because 2 or more firing techniques (i.e., headfiring, backfiring, and flankfiring) are commonly used together in southern forests (Wade and Lunsford 1989), we compared field measurements of fire behavior with BEHAVE predictions. Our objective was to evaluate BEHAVE's predictions of the behavior of backfires, flankfires, and headfires. Specifically, we sought to determine if BEHAVE predictions of fire behavior differed from observed fire behavior in mountainous terrain in the southeastern United States where post-harvest vegetation management produced different fuel beds.

STUDY AREA AND METHODS

Study sites were located on the Pushmataha Wildlife Management Area (PWMA), approximately 6 km southeast of Clayton, Oklahoma in Pushmataha County. The climate is semi-humid to humid with hot summers and mild winters. The PWMA lies in the steep

---

[1] Present address: Department of Forestry, Oklahoma State University, Stillwater, OK 74078.

and rugged Kiamichi Mountains along the western edge of the Ouachita Highland Province. The study area is approximately 335 m in elevation on thin, rocky, drought-prone Carnasaw–Pirum–Clebit soils developed from cherty shales and resistant sandstones. The slope of the study area was 5–15% with a southeastern aspect (Masters 1991*a*:72).

The PWMA overstory plant community was dominated by post oak (*Quercus stellata*), shortleaf pine (*Pinus echinata*), and less commonly, blackjack oak (*Q. marilandica*) and mockernut hickory (*Carya tomentosa*). Dominant woody understory species and vines included farkleberry (*Vaccinium arboreum*), common poison-ivy (*Toxicodendron radicans*), Virginia creeper (*Parthenocissus quinquefolia*), greenbriars (*Smilax* spp.), and muscadine grape (*Vitis rotundifolia*). Predominant herbaceous plants were little bluestem (*Andropogon scoparius*), big bluestem (*A. gerardi*), panicums (*Panicum* spp.), and sedges (*Carex* spp., *Scleria* spp., *Rhynchospora* sp.) (Masters 1991*b*).

The PWMA was managed for game wildlife species including white-tailed deer (*Odocoileus virginianus*), elk (*Cervus elaphus*), and eastern wild turkey (*Meleagris gallopavo silvestris*). Timber management and prescribed fire were the primary means of habitat manipulation. Some harvested settings were maintained in early stages of secondary succession with prescribed fire on a 2–5 year burn cycle. Others were allowed to regenerate naturally under the influence of periodic prescribed fire.

Application of Treatments

This was a completely random experimental design with 2 replications of 3 treatments. Before test burns, pine timber was removed by commercial harvest during the summer of 1984 on 6 randomly chosen 1.2- to 1.6-ha experimental units (i.e., replicates). Pines were felled and delimbed with chainsaws; tree length logs were mechanically skidded to a loading area off each unit. Hardwoods >5 cm diameter breast height (DBH) were selectively thinned by single stem injection using the herbicide 2,4-D [(2,4-dichlorophenoxy)-acetic acid] to an approximate 9 m^2/ha basal area on 4 randomly selected experimental units in summer 1984. Hardwoods were not thinned on 2 experimental units. All experimental units were prescribed burned using strip-head fires (Wade and Lunsford 1989) in winter 1985 for initial slash removal. Observed fire behavior on burns conducted in 1988 were compared with model predictions. Each cultural treatment was replicated twice. Treatments codes and descriptions were as follows:

1. HT1—harvest pine timber (H), selectively thin hardwoods (T), and winter prescribed burn annually (1985–1988).
2. HT3—harvest pine timber, selectively thin hardwoods, and winter prescribed burn triennially (1985 and 1988).
3. HNT1—harvest pine timber, no thinning of hardwoods, and winter prescribed burn annually (1985–1988).

Before the 1988 test burns, these treatments resulted in an understory vegetation in all experimental units dominated by big bluestem, little bluestem, and to a lesser extent, yellow indiangrass (*Sorghastrum nutans*) and switchgrass panicum (*P. virgatum*). Midstory and overstory hardwoods <15 cm DBH were top-killed by previous fires and exhibited little re-sprouting on annually burned units. The remaining overstory was dominated by post oak with some blackjack oak and mockernut hickory.

Canopy cover was measured in September 1987 using a gridded sighting tube at 90 locations/experimental unit for input into BEHAVE. In each experimental unit, 10 permanent points were established at 19.8-m intervals on 2 randomly located transects perpendicular to the contour. Overstory canopy cover was determined using a 5-point grid in a sighting tube with vertical and horizontal levels at plot center and cardinal points at 2 m and 4 m from each permanent plot location (Mueller-Dombois and Ellenberg 1974:89). Mean canopy cover in 1987 for HT1, HT3, and HNT1 treatments was 5% (SE = 4), 11% (SE = 7), and 24% (SE = 7), respectively (Masters et al. 1993).

Fuel and Weather Measurements

Fuels were sampled <1 hour before burning in 6–9, 0.5- × 0.5-m randomly located quadrats/plot. We separated fuels into 1-hour (dead, fine fuels, less than 0.6 cm-diameter), green herbaceous, and 10-hour (woody, 0.6–2.5 cm-diameter) components. Standing 1-hour fuels and green herbaceous fuels were clipped to <2.5 cm high and used to approximate the amount of fuel left unburned. One-hour fuels were comprised of cured tall grasses and oak leaves. Green herbaceous fuels were comprised of winter rosettes of panic grasses and forbs. Ten-hour woody fuels included small twigs, bark, and woody fragments from residual logging slash. Larger fuels were either consumed in previous fires or charcoaled to the extent that they would not burn. Fuels were weighed immediately after collection, dried at 72 C to a constant weight, and reweighed to calculate percent moisture on a dry-weight basis.

Weather was measured with a belt weather kit. Relative humidity, temperature, cloud cover, and wind speed were recorded the day before burning as required in the SITE module of the FIRE1 program in BEHAVE to predict moisture content of fine dead fuels (1-hour fuel; Andrews 1986). Weather observations were also recorded immediately before, during, and immediately after burning each experimental unit.

Fire Behavior

Controlled burns were started at 0900 and were completed by 1630 on 1 March 1988. An approaching front arrived late in the afternoon and the last 2 experimental units were burned under a sporadic light misting rain. Backfires were ignited and fire behavior parameters were sampled after the fire burned 15 m. The same procedure was followed sequentially for flankfires and headfires on each replicate. Flankfires were sampled at least 50 m from backfires to reduce the effects of backfires on flankfire behavior. Headfires were set at least 100 m from backfires. Rate of spread (ROS) on each unit was measured by timing 1–5 five-meter runs for backfires, 1–3 five-meter runs for flankfires, and 1–3 ten-meter runs of headfires, for a total of 40 fire behavior samples. Flame length was estimated as described by Rothermel and Deeming (1980) using height reference markers located on 2–5 snags located within each fire type in experimental units. After burning a unit, residual fine fuel and woody fuel were collected using five 0.5- × 0.5-m quadrats placed at random in each backfire, flankfire, and headfire area within an experimental unit.

Fireline intensity was calculated by Byram's (1959: 79) formula ($I_B = hwr$), where I_B is frontal fire intensity (kW/m), h is net heat of combustion (kJ/kg) obtained by adjusting fuel high heat of combustion for percent moisture and heat of vaporization, w is fuel consumed calculated as pre-burn fuel minus post-burn residual fuel (kg/m^2), and r is rate of spread (m/sec). High heat of combustion of fuel samples was determined with a bomb calorimeter. Although Byram's (1959) fireline intensity was developed for forward spreading fires, we used it for flankfires and backfires for comparative purposes because BEHAVE generates outputs for each.

Fire behavior was modeled using the SITE module of the FIRE1 program in BEHAVE (Andrews 1986, For. Resour. System Inst., Florence, Ala., unpubl. computer prog.). The fuels in the study were similar to those in tallgrass prairie or ungrazed 1- to 4-year-old clearcuts in southeastern Oklahoma (see Masters 1991*b*, Masters et al. 1993). Large woody materials did not burn and were not considered fuel. Thus, we used standard fuel model 3 for tall grasses which is described by Rothermel (1983) as the appropriate fuel model when the primary carrier of the fire is grass and the grass fuel can be described as coarse structured, above knee level, and difficult to walk through. The SITE module estimated fine dead fuel moisture from weather and solar heating information such as canopy cover, cloud cover, and aspect (Andrews 1986). Model input values for each type of fire were mean fuel, canopy cover, and weather conditions recorded for each experimental unit. Fireline intensity was predicted using BEHAVE for each experimental unit and fire type.

Statistical Analysis

Treatment differences in fuel and weather conditions were analyzed with a protected *F*-test such that in the presence of significant differences, means were separated with the least significant difference (LSD; Steel and Torrie 1980:176). Because of the small number of replications we used descriptive statistics and the difference between observed and predicted fire behavior parameters to make an initial assessment of model performance.

RESULTS AND DISCUSSION

The fuel bed of HT1 was discontinuous, with 22% of the ground cover either rock or bare ground. Fuel beds of HT3 and HNT1 were more continuous, with 13% and 6% rock or bare ground, respectively. The 3 fuel beds differed in the weight of fine, woody, and green fuels (Table 1). The 1-hour fuel moisture predicted from BEHAVE from weather data the day before burning, 12.4% (SE = 0.9), was not different from field measurements of 1-hour fuel moisture measured the day of burning, 13.7% (SE = 0.8), averaged over treatment and fire type.

BEHAVE predicted substantially higher fireline intensity of backfires than observed fireline intensity on all units (Table 2). Relative error was higher for backfire fireline intensity than either flankfire or headfire fireline intensity. Flankfire fireline intensity predictions were consistently higher than observed but the mean difference was lower for flankfires than backfires. Although the mean difference between predicted and observed headfire fireline intensity was low, the standard error of the mean difference was much higher than backfire or flankfire fireline intensity. However, relative error was lowest for headfires (Table 2). The large variation in differences between observed and predicted fireline intensity was a result of the inherent variation of the advancing fire front, which varies with fuel continuity, fuel moisture, and wind speed (Brown and Davis 1973, Trollope 1984).

BEHAVE predicted flame lengths within 50% of observed flame lengths for most backfires, flankfires, and headfires (Table 2). Predictions of ROS for most backfires were within 10% of observed ROS. Flankfire predictions of ROS had a relative error of 0–52% compared to observed ROS (Table 2). However, BE-

HAVE under-predicted the ROS of headfires by a considerable margin. Observed ROS of headfires was 2.3 times greater than BEHAVE predictions.

Headfire ROS may have been greater than predicted because the headfire may have been influenced by backing and flanking fires within a unit. On each experimental unit fires were set in sequential order of backfire, flankfire, and headfire. Given the burning sequence, the low fireline intensity, and the spatial separation of samples, backfires and flankfires were unaffected by each other. After headfires were ignited but before behavior of headfires was measured, a ring fire developed that contained an unburned central area of 0.8–1.2 ha. Convection in ring fires can effectively increase windspeed within the actively burning area (Wade and Lunsford 1989). Thus, ROS in headfires may have been influenced by convective winds not gauged in our pre-burn weather measurements. Adjustments to BEHAVE for this influence may be needed in similar small-scale ring fires in this region, but further study is needed on headfire predictions that are free from such confounding influences.

The SITE module of the FIRE1 program in BEHAVE is based on Rothermel's (1972) model and Albini's (1976) additions. It was developed for predicting large wildland fires in relatively homogeneous, porous fuels. The model is heavily weighted to relate to fine fuel characteristics and is intended to describe headfires (Rothermel 1983). The model can produce erroneous output in discontinuous and heterogeneous fuels (Sneeuwjagt and Frandsen 1977, Brown 1982). For example, although ROS was accurately predicted in sagebrush types, predictions of flame length and intensity were erroneous (Brown 1982). Sneeuwjagt and Frandsen (1977) found Rothermel's model to be useful in predicting grassland fire behavior but expressed reservations about the inaccuracies of flame length and combustion zone depth.

Difficulty of control and potential for severe

Table 1. Fuel and weather conditions before burning on harvested oak-pine sites in the Ouachita Mountains of southeastern Oklahoma, 1 March 1988.

	Treatment[a],[b]								
	HT1 (n = 2)			HT3 (n = 2)			HNT1 (n = 2)		
Fuel and weather conditions	$\bar{x}$	SE	Range	$\bar{x}$	SE	Range	$\bar{x}$	SE	Range
Heat of combustion (kJ/kg)	17,441	152	15,770–18,802	17,049	717	8,543–22,487	17,307	859	16,448–18,166
Fuel load (kg/ha)									
Fine fuels	1,150b	25	240–2,240	1,497a	77	480–3,480	855c	47	0–1,600
Woody fuels[c]	1,579ab	221	0–9,880	1,297b	23	0–4,200	2,102a	50	0–9,560
Green fuels	80ab	14	0–720	36b	19	0–240	102a	4	0–360
1 hr fuel moisture (%)	15	2	0–26	12	2	3–26	15	2	9–29
Weighted fuel moisture (%)	17	3	3–33	20	4	10–36	19	1	9–44
Air temperature (C)	14	0	13–15	14	1	12–15	14	1	13–15
Wind speed (km/h)	5b	0	1–16	6a	0	1–13	6a	0	3–10
Relative humidity (%)	56a	0	56–57	39b	0	32–43	55a	2	52–57

[a] Row means followed by the same letter were not different ($P > 0.05$). Ranges given are for subsample within replicates.

[b] HT1 = harvest pine timber, thin hardwoods, winter burn annually; HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle; HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually.

[c] Woody fuels were primarily 3.5 year old residual logging slash comprised of bark, small twigs, and limbs <2.5 cm diameter.

Table 2. Observed versus BEHAVE-predicted fireline intensity, flame length, and rate of spread on harvested and burned oak-pine sites in the Ouachita Mountains of southeastern Oklahoma, 1 March 1988.

			Fireline intensity (kW/m)			
Fire type/ treatment[a]	Unit	n[b]	Observed $\bar{x}$	Predicted $\bar{x}$	Difference	Relative error (%)
Backfire						
HT1	20	3	34	182	148	435
HT1	21	5	49	183	134	273
HT3	6	2	57	103	46	81
HT3	9	3	33	107	74	224
HNT1	19	3	133	182	49	271
HNT1	22	1	46	182	136	296
Mean (SE)			59 (15)	157 (16)	98 (19)	
Flankfire						
HT1	20	2	113	199	86	76
HT1	21	1	115	200	85	74
HT3	6	3	107	107	0	0
HT3	9	2	104	115	11	11
HNT1	19	1	140	199	59	42
HNT1	22	1	70	199	129	184
Mean (SE)			108 (9)	170 (19)	62 (20)	
Headfire						
HT1	20	2	1,173	810	−363	31
HT1	21	2	632	815	183	29
HT3	6	3	561	758	197	35
HT3	9	2	696	693	−3	<1
HNT1	19	3	1,186	810	−376	31
HNT1	22	1	429	780	351	82
Mean (SE)			779 (132)	777 (20)	−1.8 (125.0)	

[a] HT1 = harvest pine timber, thin hardwoods, winter burn annually; HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle; HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually.

[b] Number of samples/unit.

fire behavior can be interpreted from fireline intensity and flame length of headfires (Roussopoulos and Johnson 1975, Rothermel 1983). These interpretations are valuable to prescribed fire practitioners because of the ever present potential for fire escape and the resulting need for suppression. Headfires with fireline intensity <345 kW/m (flame length <1.2 m) can generally be attacked at the head or flanks by persons using handtools. Headfires with fireline intensity >345 kW/m (flame length >1.2 m) and <1,730 kW/m (flame length <2.5 m) are too intense for direct attack on the head by persons using handtools although equipment including plows, dozers, pumpers, and retardant aircraft can be effective. On our fires, fireline intensity and flame length of headfires fell within the range in which handtools would be ineffective (Table 3), indicating firebreaks and backfires set from fire breaks should be of sufficient width to ensure a breakout or spotfire does not occur (assuming fuels outside the firebreak are similar to those inside). If sufficient firebreaks or backfire cannot be provided, the prescribed burner should have sufficient equipment present to suppress escaped fires. BEHAVE predictions, although sometimes lower than our observations of fireline intensity, fell within the same interpretation range (Table 3). The relative error of fireline intensity predictions was lowest for headfires, which are generally more critical in terms of fire suppression and safety.

CONCLUSIONS

This initial evidence suggests that BEHAVE has the potential to provide useful predictions

Table 2. Extended.

Flame length (m)				Rate of spread (m/min)			
Observed $\bar{x}$	Predicted $\bar{x}$	Difference	Relative error (%)	Observed $\bar{x}$	Predicted $\bar{x}$	Difference	Relative error (%)
0.4	0.8	0.4	100	1.1	1.0	−0.1	9
0.4	0.9	0.5	125	0.9	1.0	0.1	11
0.5	0.7	0.2	40	1.1	1.0	−0.1	9
0.5	0.7	0.2	40	1.1	1.0	−0.1	9
0.6	0.8	0.2	33	1.7	1.0	−0.7	41
0.2	0.8	0.6	300	0.7	1.0	0.3	42
0.4 (0.06)	0.8 (0.03)	0.35 (0.07)		1.1 (0.14)	1.0 (0.0)	−0.1 (0.14)	
0.6	0.9	0.3	50	2.0	2.0	0.0	0
1.1	0.9	−0.2	18	1.6	2.0	0.4	25
0.8	0.7	−0.1	12	2.0	1.0	−1.0	50
0.8	0.7	−0.1	12	2.1	1.0	−1.1	52
1.4	0.9	−0.5	36	3.2	2.0	−1.2	38
0.6	0.9	0.3	50	1.5	2.0	0.5	33
0.9 (0.13)	0.8 (0.04)	−0.05 (0.13)		2.1 (0.25)	1.7 (0.21)	−0.4 (0.32)	
2.7	1.7	−1.0	37	20.0	6.0	−14.0	70
2.6	1.7	−0.9	35	15.2	6.0	−9.2	60
2.1	1.6	−0.5	24	12.6	7.0	−5.6	94
1.9	1.6	−0.3	16	10.3	6.0	−4.3	42
2.0	1.7	−0.3	15	17.8	6.0	−11.8	66
1.1	1.7	0.6	54	8.3	6.0	−2.3	28
2.1 (0.23)	1.7 (0.02)	−0.4 (0.23)		14.0 (1.82)	6.2 (0.17)	−7.9 (1.86)	

of fire behavior for prescribed burning in fuels similar to tallgrass prairie or ungrazed 1- to 4-year-old clearcuts in southeastern Oklahoma (See Masters 1991*b*, Masters et al. 1993). However, because of wide variation, BEHAVE predictions of headfire fireline intensity should be interpreted with caution, especially on small prescribed burns. On most units, BEHAVE predicted flame lengths and ROS of backfires and flankfires within 50% of observed values. The model over-predicted backfire fireline intensity and under-predicted headfire ROS. Because of the consistency of the deviations of these 2 parameters, calibration of the model may be realistic. Considering the variability of terrain, weather conditions, and fuels and the interacting influence of fire types, the model produced useful outputs but only within a small portion of the potential range of fireline intensities. These data reflect initial estimates and suggest that further study on larger scale fires should be conducted to determine if BEHAVE predictions fall within the observed fire suppression class for a broader range of fireline intensities and flame lengths.

This study demonstrated the need for managers to be aware of limitations in BEHAVE. As a hypothesis for further testing, we suggest that the most important limitation affecting the model's utility in prescribed burning in these southern forests is the assumption that a given fire is free of influences from drafts of other fires (Rothermel 1983). According to this assumption, fire behavior is not influenced by the method or pattern of ignition (Andrews and Bradshaw 1987). This feature is related to the fact that BEHAVE is intended for use with large-scale wildland fires in which the headfire is relatively free from the influence of other fires (Andrews and Bradshaw 1990).

BEHAVE is increasingly being used to plan prescribed fires (Andrews and Bradshaw 1987).

Table 3. Interpretations of headfire behavior for fire suppression (from Rothermel 1983).

Flame length (m)	Fireline intensity (kW/m)	Interpretations
<1.2	<345	Fires can generally be attacked at the head or flanks by persons using handtools. Hand line should hold the fire.
1.2–2.4	345–1,730	Fires are too intense for direct attack on the head by persons using handtools. Hand line cannot be relied on to hold fire. Equipment such as dozers, pumpers, and retardant aircraft can be effective.
2.5–3.4	1,730–3,450	Fires may present serious control problems such as crowning and spotting. Control efforts at the fire head will probably be ineffective.
>3.4	>3,450	Crowning, spotting, and major fire runs are probable. Control efforts at the head of fire are ineffective.

Despite the limitations, experienced managers can learn to calibrate BEHAVE outputs to more closely match observed fire behavior (Rothermel 1983).

SUMMARY

We compared actual fire behavior with predictions generated from BEHAVE on harvested oak-pine sites in the Ouachita Mountains of eastern Oklahoma. Three treatments were replicated twice in a completely random design on 6 (1.2–1.6 ha) units. The treatments were: harvest pine, selectively thin hardwoods, and annual burn; harvest pine only and annual burn; and harvest pine, selectively thin hardwoods, and burn every 3 years. Headfire fireline intensity and headfire ROS predictions were considerably different than observed measures of these parameters. Because BEHAVE predictions of headfire fireline intensity fell within the same interpretation range of observed fireline intensity, BEHAVE provided useful predictions of fire behavior in fuels similar to tallgrass prairie or ungrazed 1- to 4-year-old clearcuts in southeastern Oklahoma, but only within a small portion of the potential range of fireline intensities.

The most important limitation affecting the model's utility in prescribed burning in these southern forests may be that the model assumes the fire is free of influences from drafts of other fires; therefore, fire behavior is not influenced by the method or pattern of ignition. Experienced managers can overcome this limitation by calibrating BEHAVE outputs to more closely match observed fire behavior.

Acknowledgments.—This project was conducted on a research area developed with funds provided by Oklahoma Federal Aid to Wildlife Restoration Project W-80-R, Study 4, Job 2. We extend our appreciation to R. Robinson for assistance in establishing and conducting this study, J. Kulbeth for bomb calorimetry of fuel samples, and M. Payton for assistance with statistical analysis. This is Journal Article J5901 of the Oklahoma Agricultural Experiment Station.

LITERATURE CITED

ALBINI, F. A. 1976. Estimating wildfire behavior and effects. U.S. For. Serv. Gen. Tech. Rep. INT-30. 92pp.

ALEXANDER, M. E. 1982. Calculating and interpreting forest fire intensities. Can. J. Bot. 60:349–357.

ANDREWS, P. L. 1986. BEHAVE: fire behavior prediction and fuel modeling system—BURN subsystem, Part 1. U.S. For. Serv. Gen. Tech. Rep. INT-194. 130pp.

———, AND L. S. BRADSHAW. 1987. A system for defining windows of acceptable burning conditions for prescribed fire based on desired fire behavior. Pages 49–56 *in* Proc. Ninth Conf. on Fire and For. Meteorol. Am. Meteorol. Soc., Boston, Mass.

———, AND ———. 1990. RXWINDOW: defining windows of acceptable burning conditions based on desired fire behavior. U.S. For. Serv. Gen. Tech. Rep. INT-273. 54pp.

———, AND C. H. CHASE. 1989. BEHAVE: fire behavior prediction and fuel modeling system—BURN subsystem, Part 2. U.S. For. Serv. Gen. Tech. Rep. INT-260. 93pp.

BROWN, A. A., AND K. P. DAVIS. 1973. Forest fire: control and use. McGraw Hill Book Co., New York, N.Y. 548pp.

BROWN, J. K. 1982. Fuel and fire behavior prediction in big sagebrush. U.S. For. Serv. Res. Pap. INT-290. 10pp.

BURGAN, R. E., AND R. C. ROTHERMEL. 1984. BEHAVE: fire behavior prediction and fuel modeling system—FUEL subsystem. U.S. For. Serv. Gen. Tech. Rep. INT-167. 126pp.

BYRAM, G. M. 1959. Combustion of forest fuels. Pages 61–89 *in* K. P. Davis, ed. Forest fire: control and use. McGraw Hill Book Co., New York, N.Y.

DEWITT, J. B., AND J. V. DERBY, JR. 1955. Changes in nutritive value of browse plants following forest fires. J. Wildl. Manage. 19:65–70.

MASTERS, R. E. 1991*a*. Effects of timber harvest and prescribed fire on wildlife habitat and use in the Ouachita Mountains of eastern Oklahoma. Ph.D. Thesis, Oklahoma State Univ., Stillwater. 351pp.

———. 1991*b*. Effects of fire and timber harvest on vegetation and cervid use on oak-pine sites in Oklahoma Ouachita Mountains. Pages 168–176 *in* S. C. Nodvin and T. A. Waldrop, eds. Fire and the environment: ecological and cultural perspectives. Proc. of an international symp. U.S. For. Serv. Gen. Tech. Rep. SE-69.

———, R. L. LOCHMILLER, AND D. W. ENGLE. 1993. Effects of timber harvest and prescribed fire on white-tailed deer forage production. Wildl. Soc. Bull. 21:401-411.

MUELLER-DOMBOIS, D., AND H. ELLENBERG. 1974. Aims and methods of vegetation ecology. John Wiley and Sons, Inc., New York, N.Y. 547pp.

RAYBOULD, S., AND T. ROBERTS. 1983. A matrix approach to fire prescription writing. Fire Manage. Notes 44:7–10.

ROTHERMEL, R. C. 1972. A mathematical model for predicting fire spread in wildland fuels. U.S. For. Serv. Res. Pap. INT-115. 40pp.

———. 1983. How to predict the spread and intensity of forest and range fires. U.S. For. Serv. Res. Pap. INT-143. 161pp.

———, AND J. E. DEEMING. 1980. Measuring and interpreting fire behavior for correlation with fire effects. U.S. For. Serv. Gen. Tech. Rep. INT-93. 4pp.

ROUSSOPOULOS, P. J., AND V. J. JOHNSON. 1975. Help in making fuel management decisions. U.S. For. Serv. Res. Pap. NC-112. 16pp.

SNEEUWJAGT, R. J., AND W. H. FRANDSEN. 1977. Behavior of experimental grass fires vs. predictions based on Rothermel's fire model. Can. J. For. Res. 7:357-367.

STEEL, R. G. D., AND J. H. TORRIE 1980. Principles and procedures of statistics, a biometrical approach. Second ed. McGraw-Hill Book Co., New York, N.Y. 633pp.

TROLLOPE, W. S. W. 1984. Fire behavior. Pages 199–217 *in* P. de V. Booysen and N. M. Tainton, eds. Ecological effects of fire in South African ecosystems. Springer-Verlag, New York, N.Y.

VAN WAGNER, C. E. 1973. Height of crown scorch in forest fires. Can. J. For. Res. 3:373–378.

WADE, D. D., AND R. W. JOHANSEN. 1986. Effects of fire on southern pine: observations and recommendations. U.S. For. Serv. Gen. Tech. Rep. SE-41. 14pp.

———, AND J. D. LUNSFORD. 1989. A guide for prescribed fire in southern forests. U.S. For. Serv. Tech. Pub. R8-TP 11. 56pp.

WRIGHT, H. A., AND A. W. BAILEY. 1982. Fire ecology: United States and southern Canada. John Wiley and Sons, Inc., New York, N.Y. 501pp.

Received 10 August 1992.
Accepted 8 December 1993.
Associate Editor: Flather.