Season of Burn Influences Fire Behavior and Fuel Consumption in Restored Shortleaf Pine–Grassland Communities

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Abstract

Pine forests of southeastern United States have been burned primarily in the dormant season to accomplish silvicultural objectives, but with increased emphasis on ecosystem restoration fires are now prescribed in other seasons. We observed fire behavior during both growing season and dormant season prescribed fires in shortleaf pine (*Pinus echinata*) stands managed as pine–grassland communities for the endangered Red-cockaded Woodpecker (*Picoides borealis*). Fuel beds for dormant season fires were characterized by lower amounts of live fuels, higher amounts of 1-hr time lag fuel and a greater total fuel load than growing season fires. Fuel consumption and percent of the total fuels consumed was greater in dormant season fires than in growing season fires. Fireline intensity, heat per unit area, reaction intensity, and rate of spread were greater in dormant season fires than in growing season fires. Lower fire intensity in growing season fires was possibly a function of lower amounts of 1-hr time lag fuels, higher amounts of live herbaceous fuels, and possibly a less porous fuel bed. Additionally, growing season fires had lower heat per unit area and reaction intensity and slower rates of spread. The Keetch-Byram drought index (KBDI) did not provide a good index for potential fire behavior on our drought-prone sandy loam soils. KBDI during growing season fires averaged over four times greater than during dormant season fires, but fire intensity was greater in dormant season fires. Low KBDI values may be misleading and give a false sense of security for dormant season fire prescriptions on sandy loam soils because the duff layer may dry more quickly as a result of inherent low water holding capacity. High KBDI values may result in prescribed burns being canceled because of conditions that are erroneously perceived to be outside the prescription window. We caution against over-reliance on KBDI as a determining factor for conducting prescribed burns on areas with sandy or sandy loam soils.

Key words: **Arkansas, fire management, Keetch-Byram drought index (KBDI), Ouachita National Forest, prescribed fire, Red-cockaded Woodpecker, restoration, shortleaf pine.**

Introduction

Prescribed burning of southeastern United States pine forests to accomplish silvicultural objectives has been confined largely to the dormant season until recently. Winter burns timed 1 to 3 days after a cold front has passed that delivered 1.3 to 2.5 cm of rain are preferred in dormant season fire prescriptions (Wade & Lunsford 1989). Burning conditions are predictable after passage of cold fronts because of the cold air mass that follows these fronts (Robbins & Myers 1992). Burning under the weather conditions after cold fronts also meets most silviculture objectives and minimizes direct effects on many wildlife species (Robbins & Myers 1992). However, some authorities suggest that dormant season fires do not mimic natural ecosystem processes and may not maintain habitats of many endemic species over the long term (Boerner et al. 1988; Robbins & Myers 1992).

The historic fire regime in the interior highlands of Arkansas and Oklahoma was apparently some combination of late growing season fires and dormant season fires (Foti & Glenn 1991; Masters et al. 1995). Lightning

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fires occurred with a bimodal distribution with peaks in the late spring (March–April) and in summer (July–August), whereas aboriginal fires occurred during all seasons with most in late summer and fall (Pyne 1984; Foti & Glenn 1991; Masters et al. 1995). Restoring and maintaining plant communities that resemble pre-settlement conditions will require pre-settlement fire regimes (Robbins & Myers 1992; Glitzenstein et al. 1995; Masters et al. 1996; Sparks et al. 1998, 1999).

Growing season fires in the southeastern pine forests of the United States are generally considered to be more effective at hardwood kill than dormant season fires and as a tool for restoring pine–grassland communities (Robbins & Myers 1992; Waldrop et al. 1992). Because research and experience with prescribed fire during the growing season is limited, particularly in interior highland regions of the southeastern United States, differences in fire behavior and prescription considerations between growing season and dormant season prescribed fires remain unclear.

Melton (1989) applied a heuristically based approach to fire management in which he associated the Keetch-Byram drought index (KBDI; Keetch & Byram 1968) to fire activity and fuel consumption. The KBDI was developed as a drought index for use in fire control and has been widely adopted in the southeastern United States as an indicator of potential fire behavior in pine forests. However, its application in the southeast for growing season fires and dormant season fires is largely untested even though it is widely used as a criterion for determining the appropriateness of conditions for conducting prescribed burns. Hence, dependence on KBDI when applying prescribed fires in ecosystem restoration poses a high level of uncertainty with regard to expected fire behavior.

We tested the hypothesis that as KBDI increases, fuel consumption, percent of total fuel consumed, and fireline intensity would increase in a linear fashion. Our primary objective was therefore to compare fuel consumption and behavior of fires in the growing season and dormant season in stands of shortleaf pine (*Pinus echinata*) managed as a pine–grassland community for the endangered Red-cockaded Woodpecker (*Picoides borealis*). We also sought to evaluate the KBDI as an indicator of potential fire behavior and therefore as a determining parameter for conducting prescribed fires.

Methods

Study Area

Our study sites were located in Scott County of west-central Arkansas on the Poteau Ranger District of the Ouachita National Forest (34°49′N, 94°8′W). The Ouachita National Forest lies within the 2,280,000-ha Ouachita Mixed Forest Meadow Province and comprises 648,000 ha throughout the Ouachita Mountains in Arkansas and Oklahoma (Neal & Montague 1991; Bailey 1995). The Ouachita Mountains are east-west trending, strongly dissected, and range in elevation from 150 to 790 m (Fenneman 1938). The thin and drought-prone soils of the Ouachita Mountains developed from sandstone and shale. A subhumid to humid climate prevails with hot summers and mild winters.

Our study focused on stands under active restoration for the endangered Red-cockaded Woodpecker within the recently expanded 60,000-ha Pine-bluestem Ecosystem Renewal Area (Wilson et al. 1995; Masters et al. 1996). Restoration practices included thinning midstory and codominant pine and hardwood trees followed by dormant season prescribed burning on a 3-year return interval. We randomly chose 12 stands that had been under this restoration regime from 1 to 5 years (Table 1).

Shortleaf pine was the dominant overstory tree species in all stands. Codominant and intermediate overstory species included post oak (*Quercus stellata*), blackjack oak (*Q. marilandica*), white oak (*Q. alba*), northern red oak (*Q. rubra*), black oak (*Q. velutina*), black hickory (*Carya texana*), and mockernut hickory (*C. tomentosa*). Tree height ranged from 15 to 23 m with a mean height of 18.3 m (SD = 3.1). Canopy cover ranged from 68 to 93% with a mean canopy cover of 84.1% (SD = 7.5). Hardwood sprouts and shrubs ($\leq$3 m) dominated the understory. The dominant understory woody species and vines included poison ivy (*Toxicodendron radicans*), low-bush huckleberry (*Vaccinium pallidum*), post oak, mockernut hickory, blackberry (*Rubus* spp.), Virginia creeper (*Parthenocissus quinquefolia*), New Jersey tea (*Ceanothus americanus*), muscadine (*Vitis rotundifolia*), white oak, and shortleaf pine (Sparks et al. 1998, 1999).

Most plants contributing to surface fuels in these forests are dormant from the first killing freeze in autumn until several weeks after the final killing freeze in spring. Average frost-free period in nearby Fort Smith is 231 days and occurs from about 23 March to 9 November (Ruffner & Bair 1981). For convenience and to correspond with convention, we describe the traditional burning season as the dormant season, which follows the first killing freeze of the autumn and continues for several weeks into the frost-free period. The growing season occurs during the frost-free period of the year in which perennial herbaceous plants that compose most of the surface fuels have live tissue above ground.

Treatments

We applied four treatments randomly, with two treatments consisting of growing season fires and two treatments of dormant season fires:

(1) Growing season burn (G30; $n = 4$): 30 months (three growing seasons) after previous dormant season burn;
(2) Dormant season burn (D36; $n = 4$): 36 months (three growing seasons) after previous dormant season burn;
(3) Growing season burn (G43; $n = 2$): 43 months (four growing seasons) after previous dormant season burn;
(4) Dormant season burn (D48; $n = 2$): 48 months (4 growing seasons) after previous dormant season burn.

We conducted growing season burns between 1200 and 1800 hr on 10 to 13 September 1994 and 14 and 15 October 1995. We conducted dormant season burns between 1000 and 1800 hr on 31 March to 2 April 1995 and 2 to 4 March 1996. We ignited backfires and allowed them to burn more than 50 m into the stand before igniting strip headfires and sampling fire behavior parameters of the strip headfires. Strip headfires are commonly used in southeastern U.S. forests to reduce fire intensity (Wade & Lunsford 1989).

Meteorological Data

We recorded weather observations immediately before igniting each fire, as we observed fire behavior parameters, and immediately upon completion of the fire. We measured wind at 2 m within each stand using a totalizing anemometer (Taylor Instrument Consumer Products Division, Arden, NC, U.S.A.) and wet- and dry-bulb temperature with a sling psychrometer (Princo Instruments, Inc., Southampton, PA, U.S.A.). Computed KBDI data from 1985 to 1996 for the Oden Ranger District, Arkansas were obtained from the U.S. Forest Service, Ouachita National Forest.

Fuel Sampling

We sampled fuels less than 1 hr before burning at three random locations within each stand ($n = 36$). At each location we harvested all fuels no more than 1.5 m tall in 4 to 10, 0.5 × 0.5–m quadrats at 5-m intervals and parallel to the firefront. We hand separated fuels into live (grasses, forbs, and hardwood leaves and stems less than 0.6 cm diameter) and dead (1-hr time lag [<0.6 cm diameter] and 10-hr time lag [0.6–2.5 cm diameter]) categories. Dead fuel time lag categories correspond with the amount of time required for equilibration of moisture in the fuel with ambient relative humidity. Most dead fuel in the 100-hr time lag class was consumed in previous burns so we did not sample this category. We weighed fuels immediately after harvest. After burning we collected fuel residue at locations paired with pre-fire fuel samples by sampling residual dead and live vegetation. All fuel samples were dried at 70°C to a constant weight. Fuel moisture was calculated on a dry weight basis.

To determine fuel heat of combustion we selected three random samples of dried fuels from each stand burned during the dormant season of 1995 and growing season of 1994 ($n = 24$). We combined live and 1- and 10-hr dead fuel components for each pre-burn observation, ground samples to a fine powder, and compressed them into 1-g pellets. We then combusted these pellets in a bomb calorimeter (Parr Instruments, Moline, IL, U.S.A.) to determine high heat of combustion. We ad-

Table 1. Stand characteristics at time of growing season and dormant season fires, Ouachita National Forest, Arkansas, U.S.A. in 1994, 1995, and 1996.

Stand, Treatment	*Fire Date*	*Month Since Last Fire*	*Stand Size (ha)*	*Slope (%)*	*Mean Basal Area (m^2/ha)*	*Mean Height (m)*	*Mean DBH (cm)*	*Mean Crown Length (m)*	*Mean Crown Diameter (m)*	*Mean Canopy Cover (%)*
Dormant season										
1313, D36	3/31/95	36	13.8	7	24	15.0	27.9	6.5	5.4	90
1274, D36	4/1/95	36	16.2	7	25	16.5	28.2	7.0	5.3	94
1289, D36	4/1/95	36	16.2	7	17	15.0	29.1	6.0	5.4	82
1257, D36	4/2/95	36	16.2	7	20	15.5	31.5	7.0	6.3	88
1257, D48	3/2/96	48	18.2	9	14	17.0	32.6	9.0	7.1	68
1313, D48	3/3/96	48	26.7	8	23	15.0	26.9	7.0	4.9	84
Growing season										
1274, G30	9/10/94	30	24.3	3	23	22.0	30.7	10.0	6.1	87
1289, G30	9/11/94	30	13.8	8	17	21.0	32.8	9.0	5.9	81
1257, G30	9/12/94	30	16.2	13	18	20.5	32.3	9.5	6.1	81
1259, G30	9/13/94	30	16.2	9	17	21.5	33.4	10.0	6.5	72
1265, G43	10/14/95	43	16.2	4	23	21.5	29.7	9.0	5.7	93
1274, G43	10/15/95	43	17.8	15	26	23.0	27.6	10.0	5.2	92

DBH, diameter at breast height.

justed high heat of combustion for fuel moisture and heat of vaporization (Alexander 1982).

Fire Behavior Observations

We recorded rate of spread, flame length, flame depth, and residence time at all three fuel sampling locations within each stand ($n = 36$). Before igniting a headfire we placed three sets of 2-m freestanding stakes, with heights marked at 0.5-m intervals, at 5 m apart and perpendicular to the firefront. Three observers estimated fire behavior parameters by observing and timing the fire as the firefront passed each set of stakes, as described by Rothermel and Deeming (1980). We repeated this procedure at least two times at three locations within each stand ($n \geqslant 18$).

We calculated fireline intensity by Byram's (1959) formula ($I_B = hwr$), where I_B is frontal fire intensity (kW/m), h is net heat of combustion (kJ/kg), w is fuel consumed (kg/m^2) calculated as pre-burn fuel load minus post-burn residual fuel, and r is rate of spread (m/sec). We estimated the total energy released in the active flame front, or heat per unit area (kJ/m^2) (H_a), by dividing fireline intensity (kW/m) by rate of spread (m/min) (Rothermel & Deeming 1980). We determined reaction intensity (kW/m^2) (I_R), or the rate of energy release per unit area of flaming zone, by dividing fireline intensity (kW/m) by flame depth (m) (Albini 1976; Alexander 1982). We tested all variables for homogeneity of variance using Levene's test (Snedecor & Cochran 1980). None of these tests was significant, indicating homogeneous variances. We then used a 2 × 2 factorial analysis of variance to test for differences between years, burn season, and for an interaction between year and burn season. We separated means ($p \leqslant 0.05$) with the protected least-significant difference test (Steel & Torrie 1980). Finally, we used correlation and regression analysis to examine the relationship between fire behavior, fuels, and weather conditions (Steel & Torrie 1980).

Results and Discussion

KBDI and Weather

KBDI levels differed ($p = 0.040$) by season and averaged 80.5 for dormant season fires and 329.0 for growing season fires (Table 2). Growing season fires represented a broader range of KBDI than dormant season fires. All dormant season fires fell within the lowest KBDI category (0–150) described by Melton (1989) (Table 2). We had one set of growing season fires in the 0 to 150 category, three in the 150 to 300 category, and two in the 500 to 700 category.

On-site weather conditions were somewhat different between both seasons of prescribed burns. Temperatures averaged 8.8°C higher ($p = 0.004$), and relative humidity was an average of 10.5% higher but more variable in the growing season (Table 2). Wind speeds and cloud cover were somewhat variable by individual burns but not different between seasons (Table 2).

Fuel Conditions

Our fuel conditions differed significantly for the growing and dormant season fires (Table 3). One-hour time lag fuels were the greatest portion of the fuel beds in both seasons and differed significantly by season. One-hour time lag fuels composed 89.5% of the fuel bed for

Table 2. Mean weather conditions during growing season and dormant season prescribed fires in Ouachita National Forest, Arkansas, U.S.A. in 1994, 1995, and 1996.

Stand, Treatment	*Fire Date*	*Mean Temperature (℃)*	*Mean Relative Humidity (%)*	*Mean Wind Speed (km/hr)*	*Mean Cloud Cover (%)*	*Keetch-Byram Drought Index*
Dormant season						
1313, D36	3/31/95	14	43	5	17	79
1274, D36	4/1/95	20	26	2	55	85
1289, D36	4/1/95	19	34	11	17	85
1257, D36	4/2/95	24	25	5	5	95
1257, D48	3/2/96	14	29	4	3	68
1313, D48	3/3/96	15	38	5	0	71
Growing season						
1274, G30	9/10/94	27	53	3	19	137
1289, G30	9/11/94	28	53	4	25	155
1257, G30	9/12/94	30	50	7	22	172
1259, G30	9/13/94	30	49	7	20	189
1265, G43	10/14/95	19	30	2	0	659
1274, G43	10/15/95	25	23	3	0	662

Table 3. Fuel conditions during growing and dormant season fires in the Ouachita National Forest, Arkansas, U.S.A. in 1994, 1995, and 1996.

	*Treatment**	
Fuel Conditions	*Dormant Season* (n = 6)	*Growing Season* (n = 6)
Fuel load (kg/ha)		
Live fuels	240^{b} (30)	930^{a} (120)
1-hr time lag	$10{,}030^{a}$ (740)	$7{,}610^{b}$ (410)
10-hr time lag	930 (60)	1,020 (180)
Total fuel load	$11{,}210^{a}$ (700)	$9{,}600^{b}$ (540)
Post burn residual fuel (kg/ha)	5,710 (520)	5,670 (570)
Fuel consumption (kg/ha)	$5{,}480^{a}$ (320)	$3{,}910^{b}$ (180)
Fuel consumption (%)	49^{a} (6)	41^{b} (6)
Fuel moisture (%)		
Live	125 (10)	110 (3)
1 hr	20 (3)	14 (2)
10 hr	30 (5)	31 (3)

Values are means with SE in parentheses.
* Row means without letters were not different ($p > 0.05$).

dormant season fires and 79.3% of the fuel bed for growing season fires (Table 3). Ten-hour time lag fuels constituted less than 10% of the fuel bed for both seasons and were not different. We found live fuels were significantly different by season of burn and composed 2.1% and 9.7% of the fuel beds by weight of dormant season and growing season fuel beds, respectively (Table 3). Total fuel load was significantly higher and more variable (higher standard error) for the dormant season burns (range, 9,113–13,052 kg/ha) than for growing season burns (range, 8,196–11,801 kg/ha).

We attribute the increase in fuel load during the dormant season to hardwood leaf fall in late autumn and early winter (Engle & Stritzke 1995). Accumulated leaf litter persists throughout the winter because of slow rates of litter decomposition that accompany low air temperature and low humidity of the dormant season (Engle & Stritzke 1995). Most of the aerial portions of herbaceous plants are dormant in the dormant season, which also contributes to 1-hour time lag fuel loading, whereas most herbaceous plants are actively growing during the growing season in this region.

Fuel consumption and percent fuel consumption were significantly less in growing season fires than in dormant season fires (Table 3; Fig. 1, a & b) despite a four times greater average KBDI during the growing season and marginally lower 1-hr live and dead fuel moistures (Table 2). The greater the KBDI, the greater the surface fuel available for combustion (Melton 1989). Melton (1989) noted that when KBDI values are 300 to 500, fires consume most of the surface litter. However, off-setting the influence of drought in our growing season fires was high relative humidity, light and variable winds, lower fuel loads, possibly a more compact fuel bed, and possibly the presence of live vegetation, which combined to reduce fuel consumption (Tables 2 & 3).

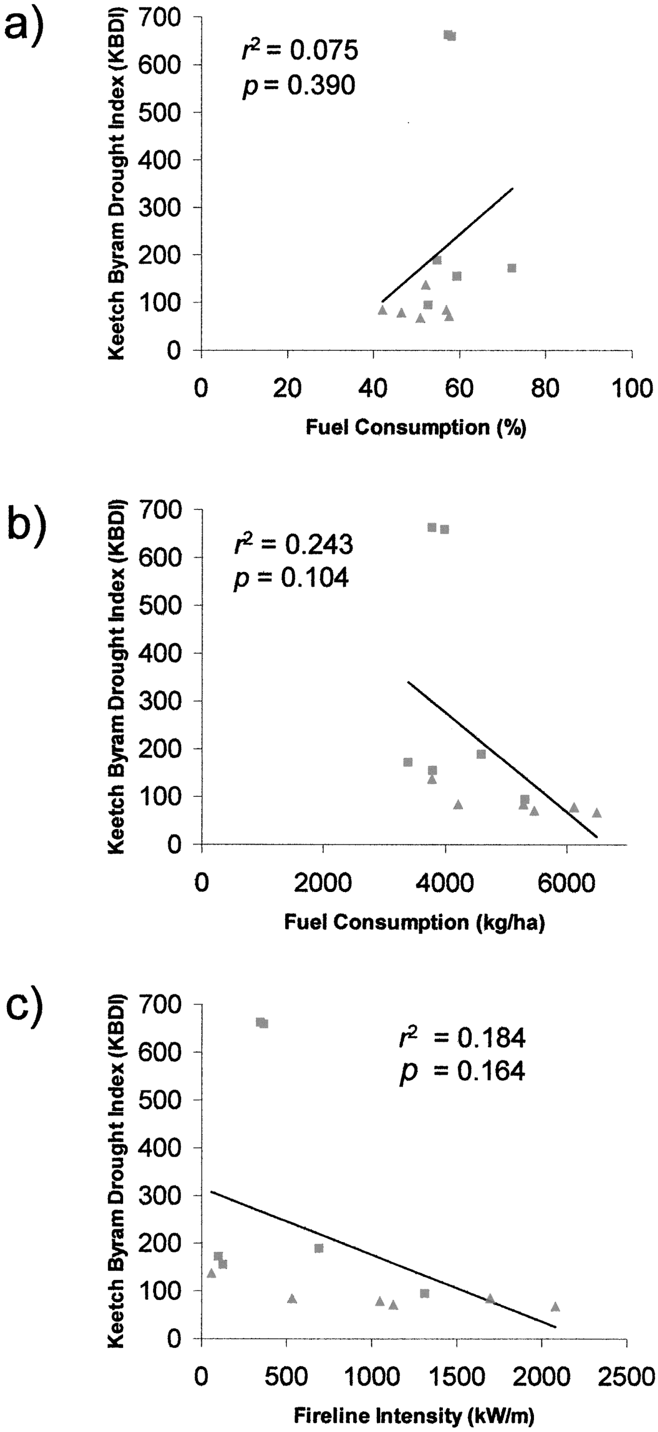

Figure 1. Mean Keetch-Byram drought index versus (a) percentage of fuel consumed, (b) total fuel consumption, and (c) observed Byram's fireline intensity on Ouachita National Forest, Arkansas, U.S.A. (1994, 1995, and 1996). Triangles indicate dormant season fires and squares indicate growing season fires.

Correlation analysis revealed that fuel consumption was related to date of the burn, temperature, rate of spread, percent moisture of 1-hr dead fuels, weight of 1-hr dead fuels, weight of 1-hr live fuels, and weight of total fuels (Table 4). Fuel moisture did not differ between seasons despite the difference in KBDI (Table 3). Although moisture of 1-hr time lag dead fuel is often a primary controlling factor of fire behavior along the fire front, moisture content of live fuels can influence ignition and fire spread patterns (Andrews 1986). Live vegetation may have been a factor limiting fire spread and fuel consumption in growing season fires, but because live vegetation was sparse in the dormant season, fuel consumption was greater in dormant season fires (Table 3).

Fire Behavior and Relating Fire Behavior to KBDI

Intensity, heat per unit area, reaction intensity, and rate of spread were greater in the dormant season fires than in the growing season fires (Table 5; Fig. 1c). We found no differences between years and no interaction between year and burn season. Fireline intensity was positively related ($p < 0.05$) to percent moisture in 1-hr live fuels ($r = 0.75$) and percent fuel consumed ($r = 0.63$) and negatively related to air temperature. We detected no differences in flame characteristics between fires in the two seasons (Table 5). Our estimates of flame length and flame depth possibly suffered from inaccuracy, which may be expected given a variable fire front (Rothermel & Deeming 1980). Flame length and fireline intensity are not always highly correlated nor does the relationship follow a standard mathematical function, so other fire behavior parameters are generally recommended over flame characteristics (Clark 1983; Nelson & Adkins 1986; Finney & Martin 1992).

KBDI was not correlated with fire intensity in these fires (Fig. 1c) nor with any other variable that we measured. KBDI peaks in the late growing season in the Ouachita Mountains, so if KBDI is a reliable indicator of fire intensity, late growing season fires should have been more intense than dormant season fires. Indeed, the average KBDI during growing season fires was over four times greater (80.5 vs. 329.0) than during dormant season fires, yet fire intensity was greater in dormant season fires (Table 5; Fig. 1c). We recognize that only two of our growing season burns fell into the higher KBDI categories but point out that across the entire range of KBDI, associated variables were largely unresponsive (Fig. 1).

Our growing season fires were less intense than the KBDI would indicate because of the relatively large amount of live fuels that were present in the growing season. However, growing season fires conducted under extreme conditions (i.e., small amounts of live fuels) that accompany unusually dry summers or lengthy drought could possibly produce greater fireline intensity than we observed in our study, if 1-hr time lag fuels increased at the expense of live herbaceous fuels during the drought.

A more porous dead fuel bed or a reduction in canopy cover could also increase fire intensity. In a nearby area Masters and Engle (1994) observed more intense dormant season fire than we observed in our study. Their fires were conducted in open stands dominated by *Quercus* spp. (canopy cover, 5–24%) with surface fuels dominated by standing dormant grasses. Canopy cover in our stands was 84% and surface fuels were

Table 4. Relationship (correlation) between fuel consumption, percent fuel consumption, and fireline intensity with selected fire behavior, weather, date of burn, and fuel characteristics during growing and dormant season fires in the Ouachita National Forest, U.S.A. in 1994, 1995, and 1996.

	*Pearson Correlation Coefficients**		
Parameter	*Fuel Consumption*	*% Fuel Consumed*	*Fireline Intensity*
Date	−0.84	NS	NS
Temperature	−0.77	NS	−0.64
Live fuel weight	−0.68	NS	NS
1-hr time lag fuel weight	0.78	NS	NS
Total fuel load weight	0.65	NS	NS
Fuel consumption weight	—	—	NS
Fuel consumption (%)	—	—	0.63
Live fuel moisture	NS	NS	0.75
1-hr fuel moisture	0.60	0.64	NS
Rate of spread	0.84	NS	NS
Flame depth	NS	0.72	0.72
Fireline intensity	NS	0.63	—

* Significance level = $p < 0.05$; NS, nonsignificant.

dominated by pine needles and hardwood leaf litter with only scattered patches of grass. Pine needles contributed less to fire spread in our fires than did the grass fuels in the fires of Masters and Engle (1994), possibly because unweathered conifer needles often behave more like fuels with 10-hr or greater time lags (Anderson 1990; Hartford & Rothermel 1991). Although fuel bed porosity (i.e., packing ratio) was not measured in either study, we believe fuel bed porosity differed greatly between these two studies, with much greater packing of the fuel beds in our study. Where fire season is held constant, weather is the overriding influence on fire behavior (Bessie & Johnson 1995), but fuel condition is also an important variable in forests where fuel conditions vary widely (Schimmel & Granstrom 1997).

Our results contrast with those studies from the coastal plain pine–grassland forests of southeastern United States that found some growing season fires to be more intense than dormant season fires (Komarek 1965; Waldrop et al. 1992). However, inherent differences in fuel continuity and flammability may contribute to our observed differences in fire behavior from coastal plain studies, as well as regional climatic differences (Sparks et al. 1999). Additionally, burns may have been executed in a different fashion. Our fuel bed had a high proportion of surface rock and different species composition in the understory with possibly lower flammability during the growing season than coastal plain fuel beds. Yet we attempted to burn under hotter drier conditions (KBDI > 650) to create more extreme fire behavior in the growing season of the second year of this study, but these fires were also less intense than dormant season fires burned under cool fairly wet conditions (KBDI < 100) (Table 2). Our use of strip headfires contributed to lower fireline intensity in all stands. Fires utilizing other fire ignition techniques (e.g., ring fires) may have increased the intensity. However, the risk of overstory damage would increase if high-intensity fires were used during the growing season when temperatures are higher and particularly when light winds prevail (Robbins & Myers 1992).

Application

Prescriptions for dormant season burning commonly include mid-flame wind speed between 3 and 15 km/hr, relative humidity of 30 to 55%, and temperature below 16°C (Wade & Lunsford 1989). The acceptable ranges for these parameters will not occur during the growing season. Relative humidity during the growing season tends to be higher because of the influx of moisture from the Gulf of Mexico. Air temperature in the growing season is also considerably warmer than acceptable for dormant season fires (Table 3). Winds during the growing season are generally light and variable and can change suddenly and unexpectedly with afternoon convective storms (Robbins & Myers 1992).

Growing season fires were generally of low intensity with slow rates of spread. Growing season burns present problems: (1) periodic afternoon thunderstorms reduce the ability to anticipate a suitable burning day, hence reducing the ability for efficient preparation; (2) widely scattered rainfall cannot be predicted, so the site must be examined the day of the burn; and (3) the risk of crown damage to pines increases with high ambient air temperature and lack of steady winds to dissipate heat (Robbins & Myers 1992). This region is characterized by numerous successive days during the growing season with ambient air temperatures higher than 32°C (Chang et al. 1996).

If crown scorching and escape risk are major concerns for those inexperienced with growing season fires, we recommend performing several small-scale fires, allowing for additional experience and modification of prescriptions. To reduce crown scorching of pine trees, burning should be conducted with cooler ambient

Table 5. Fire behavior in growing season and dormant season fires in Ouachita National Forest, Arkansas, U.S.A. in 1994, 1995, and 1996.

	*Treatment**					
	Dormant Season (n = 6)			*Growing Season* (n = 6)		
Fire Behavior Parameter	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*
Flame length (m)	0.5	0.4	0.8	0.5	0.3	0.8
Flame depth (m)	0.8	0.5	1.4	0.4	0.2	0.7
Rate of spread (m/min)	8.5[a]	4.9	12.6	2.9[b]	0.6	6.2
Residence time (sec)	11	8	15	26	14	54
Fireline intensity (kW/m)	1,300[a]	534	2,082	281[b]	58	691
Heat per unit area (kJ/m^2)	8,827[a]	6,745	10,415	5,803[b]	5,150	6,668
Reaction intensity (kW/m^2)	1,955[a]	905	2,767	618[b]	394	961

* Row means without letters were not different ($p > 0.05$).

air temperatures and greater wind speeds (Wade & Lunsford 1989; Robbins & Myers 1992). Limiting the amount of crown scorch and damage to overstory pines is a major restoration consideration. For example, the Red-cockaded Woodpecker, a key indicator species of pine–grassland ecosystems, requires large cavity trees, which may be limited in some stands and can be further reduced with fires sufficiently intense to cause crown scorch.

Conclusions

We found no linear relationship nor positive association between KBDI and fireline intensity, fuel consumption, or percent fuel consumption. The two most extreme values of KBDI exhibited some of the lowest values for fuel consumption and fireline intensity. Therefore we conclude that KBDI is not a reliable indicator of potential fire behavior or fuel consumption under our conditions. Our results suggest that growing season fires, within similar fuel and weather parameters, will be of low intensity even when the KBDI is in excess of 600 because of a possible damping effect on fire intensity of live herbaceous plants, less porous fuel beds, and lower fuel loads. Our results support the observations by Burgan (1993) that KBDI was not reliable for sandy soil types in the southeast. Our soils were sandy loam and drought prone (i.e., low water-holding capacity). Further KBDI may not be a useful index in dormant season burns on our soil types because of limited water-holding capacity, in effect creating a false sense of security about burn conditions when site-specific information, such as fuel load, fuel moisture, and weather parameters, would be a better guide for determination of the appropriateness of burning conditions. We also suspect that KBDI may not be a reliable indicator on other soil types where the site has been subject to frequent fire over long periods of time with a subsequently reduced duff layer.

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