

THE EFFECT OF THINNING AND PRESCRIBED FIRE ON FUEL LOADING IN THE CENTRAL HARDWOOD REGION OF MISSOURI

Jeremy J. Kolaks, Bruce E. Cutter, Edward F. Loewenstein, Keith W. Grabner,
George W. Hartman, and John M. Kabrick[†]

ABSTRACT.—We collected fuel loading data in the Southeast Missouri Ozarks to determine if aspect (north and east facing slopes (protected), south and west facing slopes (exposed), and no slope (ridge)) has an effect on fuel loading in stands that received either thinning, prescribed fire, both prescribed fire and thinning, or no management (control). Aspect affected fuel loading in several categories for pre-treatment, post-thinning, and post burn-thinning treatments. The general pattern was a progression from exposed slopes, < ridges, < protected slopes. Thinning increased total fuel loading about 300 percent with 100 and 1000-hr solid fuels replacing litter as the heaviest component of the total. The prescribed burn did not significantly consume 100 and 1000-hour fuels. Burning alone and burning in stands that had recently been thinned resulted in a 50 and 25 percent reduction in total fuel loading, respectively. In both treatments a majority of consumption occurred in fuels < 3 inches with litter being nearly 100 percent consumed on all aspects in both burn treatments. Horizontal continuity was disrupted in both cases making reburn very unlikely. However, a fire could carry though the stands soon after the first leaf fall.

Very little information is available on fuel loading, let alone the effects of harvesting or fire on fuel loading, in the Central Hardwood Region of the United States. A recent literature search for such information yielded very few references that addressed the subject. Most studies were completed before the development of modern fuel sampling techniques and timelag classes (Brown 1974). Paulsell (1957), Scowcroft (1965), Crosby and Loomis (1974), and Loomis (1975) all evaluated fuel loading in the Missouri Ozarks before the development of modern techniques. Crosby and Loomis (1967) and Loomis and Crosby (1968, 1970) evaluated the effect of thinning on fuel loading and the contribution of hardwood fuels after aerial herbicide application in pine stands located in southeast Missouri, also before the development of modern techniques.

Anderson (1982) developed fuel loading models using modern techniques which are used by the fire behavior prediction model BEHAVE. These models including general fuel loading values for oak-hickory (*Quercus-Carya*) leaf litter and hardwood slash in the eastern United States. Ottmar and Vihnanek (1999) developed a stereo photo series for quantifying natural fuels in mixed oak types located in the central states. However, reported fuel loadings are only representative of the area that falls within the view of the camera and no stereo photos were developed for the portion of the Central Hardwood Region that extends west of the Mississippi River.

It is known that fuel loading and vegetative structure have been altered from pre-settlement conditions and that they are still changing. Most accounts of the Missouri Ozarks prior to settlement describe open woodlands with little to no underbrush (Ladd 1991, Nigh 1992). This open forest structure was the result of an anthropogenic fire regime, dominated by light surface fires, maintained by Native Americans. The mean fire-free interval (MFI) during the Native American depopulated (1580-1700) and repopulated (1701-1820) periods were 17.7 and 12.4 years, respectively (Guyette and Cutter 1997, Guyette and Dey 1997).

[†]Graduate Research Assistant (JJK), Forestry Department, 203 ABNR, University Of Missouri – Columbia, Columbia, MO 65211; Professor of Forestry (BEC), Forestry Department, University Of Missouri – Columbia, 203B ABNR, Columbia, MO 65211; Assistant Professor of Silviculture (EFL), School of Forestry and Wildlife Sciences, 108 M White Smith Hall, Auburn University, Auburn, AL 36849; Ecologist (KWG), USGS Northern Prairie Wildlife Research Center, 262 McReynolds Hall, Columbia, MO 65211; Fire Ecologist (GWH), Resource Science Division, Missouri Department of Conservation, 1110 S. College, Columbia, MO 65201; and Research Forester (JMK), USDA Forest Service, North Central Research Station, 202 Natural Resources Building, Columbia, MO 65211. BEC is corresponding author: to contact, call (573) 882-2744 or e-mail at CutterB@Missouri.edu

Beginning in the early to mid 1800's, settlement began to have a substantial effect on the forest structure, fire regime, and fuel loading of the Missouri Ozarks. The MFI decreased to 3.7 years during the period of Euro-American settlement (1821-1940) (Guyette and Cutter 1997). A majority of the Ozarks was completely cutover in late 1800's and early 1900's to feed America's westward progression, and was conducted with little regard for regeneration (Cunningham and Hauser 1992, Nigh 1992, Guyette and Dey 1997, Guyette et al. 1999). Frequent fires and accumulations of slash, which resulted in intense fires, killed pine regeneration already in place and stimulated oak sprouting. This altered disturbance regime undoubtedly had an effect on pine regeneration and recruitment (Cunningham and Hauser 1992, Guyette and Dey 1997).

The composition of present day Ozark forests is much different from that of pre-settlement composition. The second-growth forests are more dense and contain less pine than historic stands with hardwoods completely replacing pine in many places (Cunningham and Hauser 1992, Nigh 1992, Guyette and Dey 1997, Nigh et al. 2000). A 66-percent reduction in relative abundance of pine from historic levels (circa 1900) has been noted in some areas along with a reduction in range from an estimated 6.6 million acres to only about 400,000 acres of pine and oak pine forest in 1976 (Cunningham and Hauser 1992, Guyette and Dey 1997). Fire suppression began in the 1930's increasing the calculated fire rotation length during the period 1970-1989 to about 326 years statewide (Westin 1992). In an adjacent area, the Arkansas Ozarks, the MFI was greater than 80 years for the period 1921-2000 (Guyette and Spetich 2003). There is evidence that fire exclusion, changing stand structures, and timber harvest have increased fuel loadings (Guyette 1999). Suppression created favorable conditions for the development of dense oak forest and allowed fuel loading to increase, unchecked by periodic fire and controlled only by decomposition.

Today federal and state agencies, as well as private organizations and individuals, are using thinning, harvesting, prescribed fire, or combinations of these treatments as management tools. In 2002 the Missouri Department of Conservation alone mechanically treated almost 5,000 acres with about 2,800 of those acres receiving pre-commercial thinning and intermediate, unevenage, and shelterwood harvest (Anonymous 2002). Also in 2002, the same agencies and organizations applied prescribed fire to more than 60,000 acres throughout Missouri. However, the effects of management activities on fuels are poorly understood. There is a need to better understand these effects since these treatments are often used for restoration of habitat and biodiversity.

We collected fuel loading data in southeast Missouri as part of a cooperative study funded by the Joint Fire Science Program. The purpose this study is to determine existing fuel loads and whether aspect (exposed, ridge, and protected) has an effect on fuel loading in stands that received thinning, prescribed fire, both thinning and prescribed fire, or no management (control). This study is the most ambitious of its kind in this area to date.

Study Area

The study area is located in the southeastern Missouri Ozarks near Ellington, MO on land managed by the Missouri Department of Conservation (Figure 1). In an effort to minimize variation caused by potential vegetative differences, study sites were all installed within the Black River Oak/Pine Woodland/Forest Hills Landtype Association utilizing the Missouri Ecological Classification System, which utilizes the US Forest Service National Hierarchy of Ecological Units for landscape classification (Meinert et al. 1997, Nigh and Shroeder 2002).

This LTA is characterized by strongly rolling to hilly lands with steep slopes with flat land found only in creek and river bottoms. Historically oak and oak-pine woodlands and forest comprised the area. These forest types still dominate, however, woodlands are second growth and have grown more closed due to fire suppression (Nigh and Shroeder 2002). The Black River Hills LTA is in the center of one of the largest blocks of forest in the Midwest which also supports a substantial timber industry (Nigh et al. 2000).

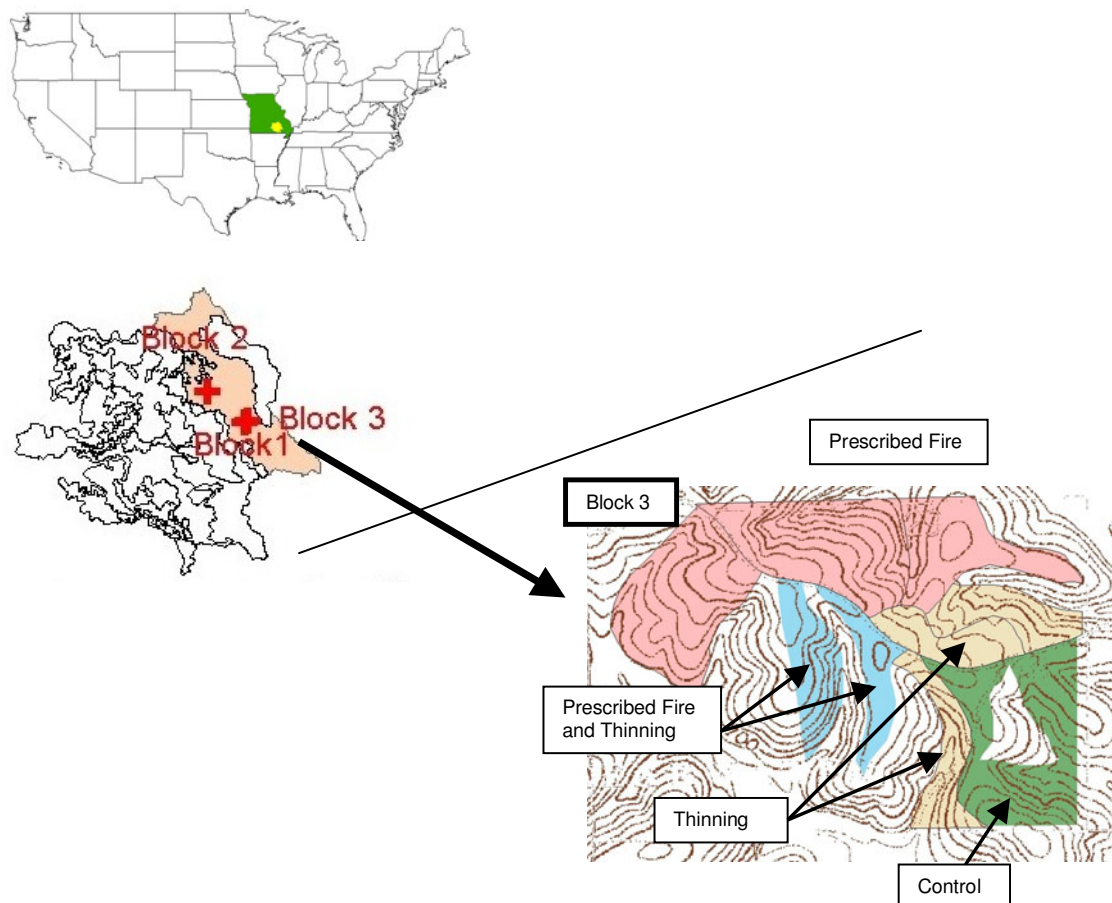


Figure 1.—Location of study sites within the United States and arrangements of treatments (block 3 used as an example).

Methods

Site Selection

Stands selected for the study had no management or documented fire for 30 years. All stands were fully stocked and composed primarily of oak-hickory and oak-pine forest types. The study was replicated across three complete blocks of 12 stands (3 aspect classes X 4 treatments) with each stand being an aspect/treatment unit. Aspect classes included exposed backslopes (135-315 degrees), ridge, and protected backslopes (315-135 degrees) (Nigh et al. 2000).

Treatments

Treatments were randomly assigned and included thinning, prescribed burning, both thinning and prescribed burning, and no treatment (control). Commercial thinning of the overstory occurred during the summer and early fall 2002. Thinning was accomplished using a mark-leave method. Preference was given to individuals having fire tolerance, good form, and canopy dominance. Leave trees were marked and a logger was allowed to harvest the remaining trees. Any remaining unmarked trees were slashed after the harvest was complete. Stocking was reduced to 60-percent. This stocking level is commonly used in intermediate cuttings, shelterwood systems, and savanna/woodland restoration (Johnson et al. 2002). Prescribed burns were completed in spring 2003 utilizing the ring fire method under a prescription commonly used in the region (Table 1).

Data Collection

Data were collected at 15 points within each stand prior to and after treatments were applied. These points were along a main transect placed at a random azimuth in each stand. The fifteen points were installed at

Table 1.—Weather parameter and fuel moisture prescription used for prescribed burning and observed values.

Attribute	Prescription	Observed Average	Observed Range
Temp (°F)	45-65	64	45-74
Mid Flame Wind (mph)	0-7	2.5	0-7.5
Rel. Humidity (%)	25-45	22.4	9-46
Fuel Moisture:			
1-hr.	5-10	5.4	5-6
10-hr.	8-15	9.8	8-12
100-hr.	12-18	13.7	13-18
1000-hr.	> 20	17.6	17-20

randomly-chosen 20-meter intervals along the main transect. Pre-thinning data, including controls, were collected winter/spring 2002. Post-thinning and pre-burn data collection occurred during winter/spring 2003. Post-burn and 2nd year control data collection was completed after the burns in spring 2003.

Fuels were inventoried from each of the 15 sampling points using a modified transect intercept method. Woody fuels were separated into four size classes: 0.0 to 0.25 in (1-hour), 0.25 to 1.0 inch (10-hour), 1.0 to 3.0 inch (100-hour), and greater than 3 in (1000-hour). 1000-hour fuels were further separated into rotten and solid categories. From each sample point, 1 and 10-hour fuels were inventoried along a 6 foot segment, 100-hour fuels along a 12 foot segment, and 1000-hour fuels along the entire 50 ft length of the transect. Fuel height, litter and duff depths were measured using a yard stick at 5 foot intervals along the fuel transect starting 1 foot from the origin (Brown 1974, Brown et al. 1982, Grabner 1996, Anonymous 2001). Litter and herbaceous samples were collected from a 2.0 ft² clip-plot located at the end of each fuel transect. Samples were then dried to a constant weight at 140° F (60° C) and reported on a dry-weight basis (Grabner 1996).

Data Analysis

For analysis, fuel data were organized into the following categories: litter, 1-hour, 10-hour, 100-hour, all fuel < ¼ inches (litter and 1-hour fuel), all fuel < 3 inches (litter and all woody fuel up to and including 100-hour), 1000-hour solid, 1000-hour rotten, total fuel load, fuel height, litter depth, and duff depth. Reliable fuel loading constants, specific gravities and squared average-quadratic-mean diameters, could not be found for species in the Central Hardwood Region. To compute fuel loadings in the 1, 10, and 100-hour time lag classes, we used fuel loading constants for northern red oak (*Quercus rubra* L.) taken from the National Park Service's Fire Management Handbook Software (USDI National Park Service). For 1000-hour rotten fuels, the average specific gravity for northern red oak decay classes 1-3 (Adams and Owens 2001) was used. We used these constants because the specific gravity of northern red oak is similar to black oak (*Q. velutina* Lam.), the most abundant species in our study area. Specific gravities for 1000-hour solid fuels were taken from the Wood Handbook (Forest Products Laboratory 1999).

Analysis of variance was used to determine if differences in fuel loading were related to treatment and aspect. Data were analyzed using the MIXED procedure in SAS. This procedure was used because it allows covariates to vary within a subject (Wolfinger and Chang 1995). A p-value of 0.05 or less was considered significant.

Results and Discussion

Pretreatment Fuel Loading

With exception to 1000-hour solid fuels, pretreatment fuel loading by timelag categories did not significantly vary between aspects (Kolaks et al. 2003). On average there was a progression of increasing total fuel load from exposed, to ridge, and finally to protected slopes. Differences worth noting (nearing

Table 2.—Pretreatment fuel loading and vertical structure.

	Fuel loading (tons/acre)							Vertical structure (in)		
	Litter	1-hour	10-hour	100-hour	1000-hour		Total	Fuel Height	Litter Depth	Duff Depth
E	3.0	0.5	0.3	1.0	0.80a	1.4	6.8	2.5	2.3	0.6
R	3.2	0.4	0.4	1.0	0.9a	1.8	7.9	3.0	2.7	0.7
P	2.9	0.4	0.3	1.6	2.1b	1.2	8.6	3.0	2.7	0.7

Aspects: E = exposed, R = ridge, P = protected

Different letters within columns indicate significant ($p < 0.05$) difference.

Table 3.—Fuel loading differences in tons/acre as result of commercial thinning.

	Fuel loading (tons/acre)							Vertical structure (in)				
	Litter	1-hour	10-hour	100-hour	1000-hour		Total	Fuel Height	Litter Depth	Duff Depth		
E	-0.7	0.4a	0.4	1.4a	-0.37*	1.4a*	13.1	1.5*	14.6	9.1a	-0.9	-0.20*
R	-0.2*	0.7	0.8	3.8b	0.42*	4.5b	13.3	1.2*	18.3	9.8	-1.1	0.1*
P	-0.7	0.7b	0.7	3.3b	-0.02*	4.5b	13.3	1.6*	19.6	12.8b	-1.0	-0.3*

Aspects: E = exposed, R = ridge, P = protected

Different letters within columns indicate significant ($p < 0.05$) difference.

*Differences not significant ($p < 0.05$).

significance $p = 0.10-0.05$) occurred between exposed slopes and ridges in 10-hour fuels, exposed and protected slopes in total fuel loading, between exposed and protected slopes as well as exposed slopes and ridges in fuel height, and exposed and protected slopes in litter depth (Table 2) (Kolaks et al. 2003).

Thinning

Changes Caused by Thinning. Commercial thinning reduced litter weight, all fuel $< \frac{1}{4}$ in, litter depth, and duff depth (Table 3). All other categories showed an increase with 1000-hour solid fuels contributing the most followed by 100-hour fuels. However, the change in all fuel $< \frac{1}{4}$ in, 1000-hour rotten, and duff depth on any aspect, as well as litter weight on ridges was not significantly different from pretreatment levels.

Increases were significantly higher on ridges and protected slopes than on exposed slopes in the 100-hour and all fuel < 3 in categories. Fuel height increases were also significantly higher on protected slopes as opposed to exposed slopes. Though not significant, the difference between exposed slopes and ridges in 1-hour fuels, exposed slopes and ridges in 10-hour fuels, and ridges and protected slopes in 100-hour fuels are worth noting (approaching significance ($p = 0.10-0.05$)).

Reduction in litter weight, litter depth, and duff depth is most likely the result of the mechanical harvesting operation (rubber-tire skidder) that moved litter and duff laterally across the landscape. Many areas were completely devoid of litter and duff due to skid trails and landings. In addition, a more open overstory allows greater wind velocities at ground level that could remove or concentrate loose leaf-litter making it less likely to be sampled. Though not significant, the increase in duff depth on ridges could be attributed to uphill skidding during harvesting operations that deposited organic material from the surrounding exposed and protected slopes.

Post-Thinning Fuel Loading. There was an increase, albeit non-significant, in total fuel load from exposed slopes, $<$ ridge, $<$ protected slopes (Table 3). The end result of thinning was an increase in total fuel loading of about 300% (Table 4). 1000-hour solid fuel replaced litter as the heaviest component of total fuel loading. 10-hour fuel loading was significantly higher on ridges than on exposed slopes. Both ridges

Table 4.—Post-thin fuel loading and vertical structure.

	Litter	Fuel Loading (tons/acre)			1000-hour		Total	Vertical Structure (in)		
		1-hour ¹	10-hour ¹	100-hour	Solid	Rotten		Fuel Height	Litter Depth	Duff Depth
E	2.6	0.9	0.8a	2.4a	14.3	2.7	22.5	12.4	1.8	0.6
R	2.6	1.1	1.2b	4.7b	14.6	2.2	25.7	13.2	1.9	1.1
P	2.7	1.2	1.1	4.5b	17.3	2.3	28.4	16.3	1.9	0.7

Aspects: E = exposed, R = ridge, P = protected

¹Different letters within a column indicate significant (p<0.05) difference.

and protected slopes showed significantly higher fuel loading than exposed slopes in 100-hour and all fuel < 3 inches categories. Fuel height was also significantly higher on protected slopes as opposed to exposed. Nearing significance (p=0.10-0.05) was the differences in exposed and protected slopes for both 1 and 10-hour fuels. Differences among aspect trends were similar to those found in pre-treatment fuel loading; progression from exposed, < ridge, < protected.

Fuel descriptions for any of the 13 standard fuel models did not accurately describe our post-thinning fuel loadings (Anderson 1982) (Table 5). Post-thinning fuel load for all fuel < 1/4 in are most closely approximated by fuel model 9, hardwood leaf litter; 10, timber; and 12, medium logging slash. For all fuel < 3 in, fuel model 11, light logging slash, most closely describes ridges and protected slopes while fuel model 6, dormant brush and hardwood logging slash, best describes exposed slopes. Since significant difference exist between aspects in all fuel < 3 in, a different fuel model may need to be utilized on exposed slopes than on ridges and protected slopes. Also, since no single fuel model best describes overall post-thinning fuel loading, the selection of a fuel model based on fire behavior may be warranted (Ryan 1981, Anderson 1982).

Prescribed Burning

Consumption. For the most part, all burns were conducted within prescription. Average relative humidity (RH) was below prescription, however, ignition operations were completed before the RH dropped below the lower threshold (Table 1). Weather and 10-hour fuel moisture were taken by an on-site automated weather station. One, 100, and 1000-hour fuel moistures were taken from 2 automated weather stations that experienced similar weather patterns located in relatively close proximity (9 and 15 miles).

Average flame length was greater in the burn-thin treatment, 23 in, than in the burn only treatment, 18 in. However, the difference between treatments was not significant except when accumulations of slash were encountered. Flame length off of slash accumulations ranged from 5 to 50 ft with 14 ft being most common. Average flame lengths varied from 21 to 27 in on protected and exposed slopes, respectively, and 13 in on ridges. Observed rates-of-spread were higher on the slopes than on ridges.

Prescribed burning reduced fuel loading and vertical structure in all categories in both thinned and unthinned treatments (Table 6 and 7). Fuel consumption decreased as timelag size class increased (Table 6 and 7). Consumption did not significantly vary among aspects for either treatment. However, the data

Table 5.—Comparison of fuel loading in commercially thinned stands and loadings assumed by BEHAVE.

	Fuel loading (tons/acre)	
	< 1/4 in (1-hr)	< 3.0 in (100-hr)
Anderson (1982)		
Fuel Model 6	1.5	6.0
Fuel Model 9	2.9	3.5
Fuel Model 10	3.0	12.0
Fuel Model 11	1.5	11.5
Fuel Model 12	4.0	34.6
This Study		
Exposed	3.5	6.74a
Ridge	3.4	9.51b
Protected	3.9	9.43b

Different letters within a column indicate significant (p<0.05) difference.

Table 6.—Consumption of fuel for the burn-only treatment by aspect and fuel loading category.

Aspect ¹	Litter	Fuel Loading (tons/acre)					1000-hour		Vertical Structure (in)			
		1-hour	10-hour	100-hour*	< 1/4 in	< 3 in	Solid*	Rotten*	Total	Fuel Height	Litter Depth	Duff Depth
E	-2.9	-0.3	-0.2	-0.3	-3.2	-3.7	-0.1	-0.5	-3.9	-2.4	-2.1	-0.3
Percent	99	60	45	35	93	78	30	60	67	91	98	45
R	-3.0	-0.2*	-0.1	-0.1	-3.2	-3.6	-0.1	-0.2	-3.5	-2.8	-1.9	-0.3*
Percent	97	48	19	16	92	79	12	9	49	91	97	35
P	-2.5	-0.3	-0.1	-0.3	-2.8	-3.0	-0.1	-1.1	-3.5	-2.5	-2.0	-0.2*
Percent	96	27	16	19	89	62	37	41	47	90	96	27

¹Aspects: E=exposed, R=ridge, P=protected

*Consumption not significant (p<0.05) for individual value or entire category.

Table 7.—Consumption of fuel by aspect for the burn-thin treatment by fuel loading category and percent.

Aspect ¹	Litter	Fuel Loading (tons/ acre)					1000-hour		Vertical Structure (in)			
		1-hour	10-hour	100-hour	< 1/4 in	< 3 in	Solid	Rotten*	Total	Fuel Height	Litter Depth	Duff Depth
E	-2.8	-0.5	-0.4*	-1.1*	-3.3	-4.6	-1.7	-1.0	-6.0	-7.0	-1.9	-0.30*
Percent	100	56	53	5	89	66	12	51	28	50	98	38
R	-2.7	-0.9	-1.0	-1.6	-3.6	-6.1	-0.7*	-0.05	-7.20	-6.4	-2.0	-1.0
Percent	97	75	66	30	91	57	5	3	27	41	93	68
P	-3.0	-1.0	-0.6*	-1.1*	-3.9	-5.6	-1.3*	-1.0	-6.6	-8.0	-2.1	-0.40*
Percent	100	73	57	26	91	58	7	39	24	43	99	45

¹Aspects: E=exposed, R=ridge, P=protected

*Consumption not significant (p<0.05) for individual value or entire category.

suggest that a greater proportion of consumption occurred on exposed slopes in 1, 10, and 100-hour timelag classes than on ridges and protected slopes.

In all cases nearly 100 percent of litter was consumed. Litter was responsible for the consumption of about 90 percent of all fuel < 1/4 in and about 75 percent of all fuel < 3 in for un-thinned sites as well as 75 and 50 percent, respectively, for thinned sites. Scowcroft (1965) found somewhat similar results reporting that 90 to 85 and 80 to 70 percent of leaf litter was consumed on unthinned annually burned and periodically burned (every five years) sites, respectively.

The near 100 percent consumption of leaf litter along with the remaining percentages of fine fuel (all fuel < 3 in) eliminated surface fuel continuity, and a major influence on fire behavior (Davis 1959, Brown and Davis 1973, Anderson and Brown 1987) making the potential for immediate reburn virtually nonexistent. However, reburn can occur shortly after the first leaf-fall. Scowcroft (1965) reported that in the three years following a burn, 4 tons/acre of litter accumulated. He also reported an increased percentage of woody fuel on burned sites that fell from trees killed by the fire. With 50 percent of equilibrium litter accumulation being regained in 2.5 years, and 75 percent in five years after a fire (Guyette 1999), surface fuels and horizontal continuity return very quickly.

One hundred, 1000-hour solid, 1000-hour rotten, and duff depth consumption resulting from the burn was not significant for both treatments on most aspects (Tables 5 and 6). Burn-only treatment data suggest that a greater percentage of 1000-hour fuels were consumed on slopes of either aspect than on ridges. Higher intensity fires on the slopes likely caused this while fire behavior on the ridges was mostly only wind driven. However, this effect was not observed in the burn-thin treatment.

Table 8.—Post burn fuel loading by aspect for burn-only and burn-thin treatments.

										Vertical Structure (in)		
¹Aspect	Litter	Fuel Loading (tons/acre)					1000-hour			Fuel	Litter	Duff
		1-hour	10-hour	100-hour < 1/4 in	< 3 in	Solid	Rotten	Total	Height	Depth	Depth	
<u>Burn-only</u>												
E	0.03	0.2	0.2	0.6	.2	1.0	0.2	0.3	1.9	0.2	0.05a	0.4
R	0.08	0.2	0.2	0.5	.3	1.0	0.8	1.5	3.7	0.3	0.06	0.5
P	0.10	0.8	0.3	1.3	.4	1.9	0.1	1.6	4.0	0.3	0.08	0.6
<u>Burn-thin</u>												
E	0.01	0.4	0.4	1.5a	.4	2.3a	12.2	1.0	15.6	7.1a	0.04a	0.5
R	0.08	0.3	0.5	3.8b	.4	4.6b	13.3	1.7	19.5	9.4	0.14b	0.5
P	0.00	0.4	0.5	3.2b	.4	4.0b	15.6	1.6	21.3	10.8b	0.03a	0.5

¹Aspects: E = exposed, R = ridge, P = protected

Different letters within a column indicate significant (p<0.05) difference

*Differences between treatments not significant (p<0.05) for category

The lack of consumption indicates that under weather conditions conducive to prescribed burning larger woody debris and duff will not be substantially reduced. However, wildfire during high-risk conditions such as high temperatures, low relative humidity (< 20 percent), and low 1000-hr fuel moistures (< 15 percent) could yield different results. Our prescribed burn consumption results are contrasted by memorable fire seasons in Missouri, 1980 (Westin 1992) and 1999-2000, when 1000-hour fuels were readily consumed. This consumption was mostly likely the result of high wildfire risk conditions brought on by prolonged drought. Prescribed burning under these conditions could compromise objectives and holding efforts.

If prescribed fire is used as a site preparation tool for shortleaf pine regeneration several applications may be needed for sites that have not been previously burned. Burning only reduced the duff layer an average of 46 percent (Table 6 and 7). A layer of duff about ½ in thick (Table 8) remained after the burn on all aspects and in both treatments. This could possibly inhibit the establishment of pine seedlings from natural regeneration or direct seeding (Burns and Honkala 1990).

Overall burning reduced total fuel loading by about 50 percent on burn-only stands and 25 percent on burn-thin stands (Table 6 and 7). Seventy percent of all fuel < 3 in was consumed in burn-only stands and 60 percent in burn-thin stands compared to 50 percent consumption of fuel < 3.15 in reported by Clinton et al. (1998) in mixed white pine-hardwood stands of the southern Appalachians. In general, consumption in all categories except litter was less than what occurs in timbered stands of the western US (Kauffman and Martin 1989).

The Effect of Aspect on Post-Burn Fuel Loading

Burn Only. There were no post-burn significant differences between aspects in all categories of the burn-only treatment (Table 8).

Burn-Thin. Several categories, including 100-hour, all fuel < 3 in, fuel height, and litter depth exhibited post-burn differences between aspects in the burn-thin treatment (Table 8). Since 100-hour fuels are a component of all fuels < 3 in, it was not surprising that both categories were greater on protected slopes and ridges than on exposed slopes (Table 8). These differences are almost identical to those observed after thinning (Table 3). However, burning also produced a near significant (p=0.10-0.05) difference in total fuel loading, not observed pre-burn.

Fuel height was greater on protected slopes compared to exposed slopes. Although not indicated in post-thinning data, litter depth on ridges was greater than both protected and exposed slopes after the burn (Table 8). This greater depth was most likely the result of greater fragmentation of horizontal

continuity observed on ridges from increased mechanical harvesting traffic. Small islands of unburned fuel were common in high traffic areas and could have affected litter depth compared to areas where consumption and surface fuel continuity were more uniform.

There was no significant difference between the burn-only and burn-thin treatments in litter, 1-hour, all fuel < ¼ in, 1000-hour rotten, litter depth, and duff depth categories following the burn (Table 8). This is not surprising considering that many of the same categories were not significantly different from pre to post-thinning conditions (Table 3).

Conclusion

The results from this study indicate that aspect affects some categories of fuel loading in both unburned and unthinned stands as well as thinned stands. Thinning significantly alters 1, 10, 100-hour, and 1000-hour solid fuel loading while not affecting the others. In both thinned and unthinned stands there is a progression in fuel loading from exposed slopes, < ridge, < protected slopes. Significant changes in fuel loading due to position in the landscape could be more prevalent at smaller scales of ecological classification. Further research is also needed in developing constants for calculating fuel loadings in the Central Hardwood Region.

Consumption during prescribed fires was not significantly affected by aspect. Post-burn aspect differences were almost identical to pre-burn differences found primarily in heavy fuels not significantly affected by burning. With litter making up 50 percent or greater of all fuel < 3 in, prescribed burning will only temporarily reduce the threat of fire in the Central Hardwood Region. Since fine fuels return fairly quickly surface fuel continuity will soon be restored. One and 10-hour fuels are likely to increase after the burn due to the contribution of branch wood from tree killed by the fire (Scowcroft 1965). This combined with the additional curing time had by 100 and 1000-hour fuels not consumed by the first fire, could result in high intensity fires in the near future.

Acknowledgments

Thanks to Mike Morris, Cliff Smith, Randy Jensen, David Whitener, Keith Crabtree, the Ellington Work Team, Ironton Work Team, Garwood Work Team, and other employees of the Missouri Department of Conservation who helped as well as Kenneth Davidson, Chris Hopfinger, Tim Parsons, Texas Nall, Ralph Yohai, Bill Dijak and Shawn Maijala of the USDA Forest Service North Central Research Station and the Mark Twain National Forest. Also thanks to Dr. Adnan Akyuz of the Missouri Climate Center for the use of a portable automated weather station and interpretation of weather data. Finally I would like to especially thank Sandra Clark, Nick Cahill, Michael Garcia, and Dr. Mark Ellerseick as well as my fellow students.

Literature Cited

- Anonymous. 2001. **Fire Monitoring Handbook**. US Department of Interior, National Park Service. 274 p.
- Anonymous. 2002. **2001-2002 Annual Report**. Missouri Department of Conservation. 94 p.
- Adams, M.B.; Owens, D.R. 2001. **Specific gravity of coarse woody debris for some central Appalachian hardwood forest species**. NE-RP-716. USDA Forest Service, Northeastern Research Station. 4 p.
- Anderson, H.E. 1982. **Aids to determining fuel models for estimating fire behavior**. GTR-INT-122. USDA Forest Service, Intermountain Forest and Range Experiment Station. 22 p.
- Anderson, H.E.; Brown, J.K. 1987. **Fuel characteristics and fire behavior considerations in the wildlands**. In: Symposium and Workshop on Protecting People and Homes from Wildfire in the Interior West. Missoula, MT. USDA Forest Service, Intermountain Research Station: 124-130.
- Brown, A.A.; Davis, K.P. 1973. **Forest Fire Control and Use. second edition**. New York: McGraw-Hill. 686 p.

- Brown, J.K. 1974. **Handbook for inventorying downed woody material**. INT-GTR-16. USDA Forest Service, Intermountain Forest and Range Experiment Station. 24 p.
- Brown, J.K.; Oberheu, R.D.; Johnston, C.M. 1982. **Handbook for inventorying surface fuels and biomass in the interior west**. INT-GTR-129. USDA Forest Service, Intermountain Forest and Range Experiment Station. 22 p.
- Burns, R.M.; Honkala, B.H. 1990. **Silvics of North America: 1. Conifers**. Agriculture Handbook 654. USDA Forest Service. 877 p.
- Clinton, B.D.; Vose, J.M.; Swank, W.T.; Berg, E.C.; Loftis, D.L. 1998. **Fuel consumption and fire characteristics during understory burning in a mixed white pine-hardwood stand in the southern Appalachians**. SRS-RP-12. USDA Forest Service, Southern Research Station. 11 p.
- Crosby, J.S.; Loomis, R.M. 1967. **How thinning effects fuel weights in shortleaf pine stands in southeast Missouri**. Journal of Forestry. 65(12): 901-902.
- Crosby, J.S.; Loomis, R.M. 1974. **Some forest floor fuelbed characteristics of black oak stands in southeast Missouri**. Research Note NC-162. USDA Forest Service, North Central Forest Experiment Station. 4 p.
- Cunningham, B.; Hauser, C. 1992. **The decline of the Missouri Ozark forest between 1800 and 1920**. In: Journet, A.R.P.; Spratt, H.G. eds. Towards a Vision for Missouri's Public Forests. Cape Girardeau, MO. Southeast Missouri State University: 14-19.
- Davis, K.P. 1959. **Forest Fire Control and Use**. New York: McGraw-Hill. 584 p.
- Forest Products Laboratory. 1999. **Wood handbook - wood as an engineering tool**. USDA Forest Service, Forest Products Laboratory. 463 p.
- Grabner, K.W. 1996. **Validation of BEHAVE fire behavior predictions in established oak savannas**. University of Missouri - Columbia. 150 p. Masters Thesis.
- Guyette, R.P. 1999. **Litter accumulation and fire intervals in the Ozark forest**. The School of Natural Resources, University of Missouri - Columbia. 9 p.
- Guyette, R.P.; Cutter, B.E. 1997. **Fire history, population, and calcium cycling in the Current River watershed**. In: Pallardy, S.G., Cecich, R.A., Garrett, H.G.; Johnson, P.S. eds. Proceedings of the Eleventh Central Hardwood Forest Conference. Columbia, MO. NE-GTR-188. USDA Forest Service, Northeastern Research Station: 354-372.
- Guyette, R.P.; Dey, D.C. 1997. **Historic shortleaf pine (*Pinus echinata* Mill.) abundance and fire frequency in a mixed oak - pine forest (MOFEP, Site 8)**. In: Brookshire, B.L.; Shifley, S.R. eds. Proceedings of the Missouri Ozark Forest Ecosystem Project Symposium. St. Louis, MO. NC-GTR-193. USDA Forest Service, North Central Research Station: 136-149.
- Guyette, R.P.; Dey, M.; Dey, D. 1999. **An Ozark fire history**. Missouri Conservationist. 60(3): 4-7.
- Guyette, R.P.; Spetich, M.A. 2003. **Fire history of oak-pine forests in the Lower Boston Mountains, Arkansas, USA**. Forest Ecology and Management. 180: 463-474.
- Johnson, P.S.; Shifley, S.R.; Rogers, R. 2002. **The Ecology and Silviculture of Oaks**. New York: CABI Publishing. 503 p.

- Kauffman, B.J.; Martin, R.E. 1989. **Fire behavior, fuel consumption, and forest-floor changes following prescribed understory fire in Sierra Nevada mixed conifer forests.** Canadian Journal of Forest Research. 19: 455-462.
- Kolaks, J.; Cutter, B.E.; Loewenstein, E.F.; Grabner, K.W.; Hartman, G.; Kabrick, J.M. 2003. **Fuel loading in the central hardwoods.** Paper 1A-3. In: Proceedings of the 2nd International Wildland Fire Ecology and Fire Management Congress (CD-ROM). Coronado Springs Resort, Orlando, FL. American Meteorological Society: 6 p.
- Ladd, D. 1991. **Reexamination of the role of fire in Missouri oak woodlands.** In: Proceedings of The Oak Woods Management Workshop at Eastern Illinois University. Charleston, IL. The Morton Arboretum: 67-79.
- Loomis, R.M. 1975. **Annual changes in forest floor weights under a southeast Missouri oak stand.** NC-RN-184. USDA Forest Service, North Central Forest Experiment Station. 3 p.
- Loomis, R.M.; Crosby, J.S. 1968. **Fuel evaluation for a Missouri pine plantation released by aerial spraying.** Research Note-NC-64. USDA Forest Service, North Central Forest Experiment Station. 4 p.
- Loomis, R.M.; Crosby, J.S. 1970. **Fuel hazard from breakup of dead hardwoods in Missouri.** Journal of Forestry. 68(8): 490-493.
- Meinert, D.; Nigh, T.; Kabrick, J. 1997. **Landforms, geology, and soils of the MOFEP study area.** In: Brookshire, B.L.; Shifley, S.R. eds. Proceedings of the Missouri Forest Ecosystem Project Symposium: an experimental approach to landscape research. St. Louis, MO. NC-GTR-193. USDA Forest Service, North Central Research Station: 56-68.
- Nigh, T. 1992. **The forest prior to European settlement.** In: Journet, A.R.P.; Spratt, H.G. eds. Towards a Vision for Missouri's Public Forest. Cape Girardeau, MO. Southeast Missouri State University: 6-13.
- Nigh, T.; Buck, C.; Grabner, J.; Kabrick, J.; Meinert, D. 2000. **An ecological classification system for the Current River Hills Subsection, a working draft.** Missouri Ecological Classification System and MORAP. 44 p.
- Nigh, T.A.; Shroeder, W.A. 2002. **Atlas of Missouri Ecoregions.** Missouri Department of Conservation. 213 p.
- Ottmar, R.D.; Vihnanek, R.E. 1999. **Stereo photo series for quantifying natural fuels volume V: midwest red and white pine, northern tallgrass prairie, and mixed oak types in the central states and lake states.** PMS 834. National Wildfire Coordinating Group. 99 p.
- Paulsell, L.K. 1957. **Effects of burning on Ozark hardwood timberlands.** Research Bulletin 640. University of Missouri College of Agriculture, Agricultural Experiment Station. 24 p.
- Ryan, K.C. 1981. **Evaluation of a passive flame height sensor to estimate forest fire intensity.** Research Note PNW-390. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 13 p.
- Scowcroft, P.G. 1965. **The effects of fire on the hardwood forest of the Missouri Ozarks.** University of Missouri. 126 p. Masters Thesis.
- Westin, S. 1992. **Wildfire in Missouri.** Missouri Department of Conservation. 161 p.
- Wolfinger, R.; Chang, M. 1995. **Comparing the SAS GLM and MIXED procedures repeated measures.** In: SUGI Proceedings. SAS Institution, Inc.: 11 p.