Title: Integrating fuel and forest management: Developing prescriptions for the central hardwoods region – Final Report

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Executive Summary

Federal, state, and non-governmental organizations in Missouri are using prescribed fire as a tool to restore Missouri Ozark forests to historic conditions. The principle objectives of prescribed fire management in the Ozarks are vegetation based: such as exotic species management/control, enhancement of native species, or reduction of shrubby vegetation. Prescribed fire in Missouri has not emphasized reducing fuel loads or altering fuel structure. Fuel beds are changing across the Ozarks primarily due to fire suppression and the accumulation of slash from timber harvests. Fuel reduction treatments can benefit the Ozarks by modifying stand structure to meet the objectives of forest management and changing fuel loads. We proposed to evaluate the effects of prescribed fire, with and without partial overstory removal, on fuel reduction and fire behavior in the Missouri Ozarks, on oak-hickory forests that have not experienced prescribed fire or wildfire for over 30 years.

The results of the work completed on this fuel treatment demonstration area show that aspect had a significant effect on vegetation patterns and prescribed fire flame lengths and influenced fuel loading and prescribed fire rate of spread, though differences were not statistically significant. The influence of aspect on vegetation, fuels, and fire behavior was anticipated and incorporated into the design of this project. Fuel reduction treatments also had an effect on ground flora richness. Ground flora responded to thin and prescribed fire and prescribed fire only treatments resulting in an increase in species richness. The thinning only treatment increased species richness but not to the same extent as fire. It appears that aspect and fuel reduction treatments interact. With the ability to continue monitoring these fuel reduction demonstration sites we will hopefully begin to understand how this interaction affects vegetation patterns in the short and long term.

The results of fuel reduction treatments show that thinning and prescribed fire have an effect on vegetation and fuels. The effects of the fuel reduction treatments on vegetation may be expressed over a long period of time. To account for the temporal affects of thinning and prescribed fire all data collection points were permanently marked, thus enabling future resampling to track the trajectory of the changes to both vegetation and fuels. The changes that we have seen on these demonstration sites represent only the initial changes and we expect the fuel and vegetation layers to be very dynamic over time. This final report is a summary of the work completed on this fuel reduction demonstration site. Additional information on this study has been presented through 7 proceedings publications, 3 gray literature publications, 6 presentations, 7 posters, 2 master's theses, and 6 site visits/training sessions that have occurred because of this fuel demonstration site.

Introduction

Oak dominated forests, woodlands, and savannas of eastern North America have evolved under the influence of fire for thousands of years. In the Ozarks of southern Missouri, in recent time (50-100 years), fire exclusion has changed fuel loading and vegetative structure. Currently fire is being used to modify existing vegetation. Monitoring programs have focused on species composition with fire behavior and fuels data being qualitative at best.

Many federal, state, and non-governmental organizations are using prescribed fire as a tool to restore Missouri Ozark forests to historic conditions. The principle objectives of prescribed fire management in the Ozarks are vegetation management, exotic species management/control, and enhancement of native species with little emphasis being given to fuel loadings or reducing fuel loads. Fuel loads are increasing across the Ozarks primarily due to fire suppression and the accumulation of slash from timber harvests. Fuel reduction treatments can benefit the Ozarks by modifying stand structure to meet the objectives of forest management and reducing fuel loads, thus reducing the chance or intensity of wildfires. We proposed to evaluate the effects of overstory thinning and prescribed fire on vegetation an d fuel reduction in the Missouri Ozarks, on oak-hickory forests that have not experienced prescribed fire or wildfire for over 30 years.

Objectives

The purpose of this fuel treatment demonstration was to evaluate the effectiveness of prescribed fire, overstory thinning, and the interaction of these two treatments as fuel reduction tools in oak-hickory forests that have not been subject to fire within the last 30 years. We evaluated treatment effects on fuel structure and loading, fire behavior, and vegetation response. This study addressed the following five objectives:

1. Determine changes in fuel loading, by fuel size class and fuel type, in thinned and unthinned oak hickory stands following prescribed fire
2. Analyze the effects of fuel reduction treatments on ground flora, understory, and overstory vegetation
3. Evaluate differences in prescribed fire behavior (rate of spread, flame length, and fire line intensity) between treatments
4. Compare cost effectiveness and efficacy of three fuel reduction treatments
5. Develop the three study sites into demonstration areas where the effects of fuel treatments can be explained/interpreted

Methods

Study Area

The study area is located in southeastern Missouri, on lands managed by the Missouri Department of Conservation, near the town of Ellington. Study sites were installed within the Black River Oak-Pine Woodland/Forest Hills Landtype Association (Figure 1.). We did this to minimize variation caused by potential vegetative difference among landtype associations (Meinert et al. 1997, Nigh et al. 2000). Landtype associations are landscape scale ecological units, 10-100s of square miles in size that are similar with respect to local landforms, relief, geologic parent material, soils, and vegetation patterns which make them appropriate for planning and assessment (Nigh and Schroeder 2002). The Black River Oak-Pine Woodland/Forest Hills Landtype Association lies within the Black River basin and is characterized by a hilly topography with steep slopes. Soils are mainly cherty, low-base soils associated with the Roubidoux and Gasconade geologic

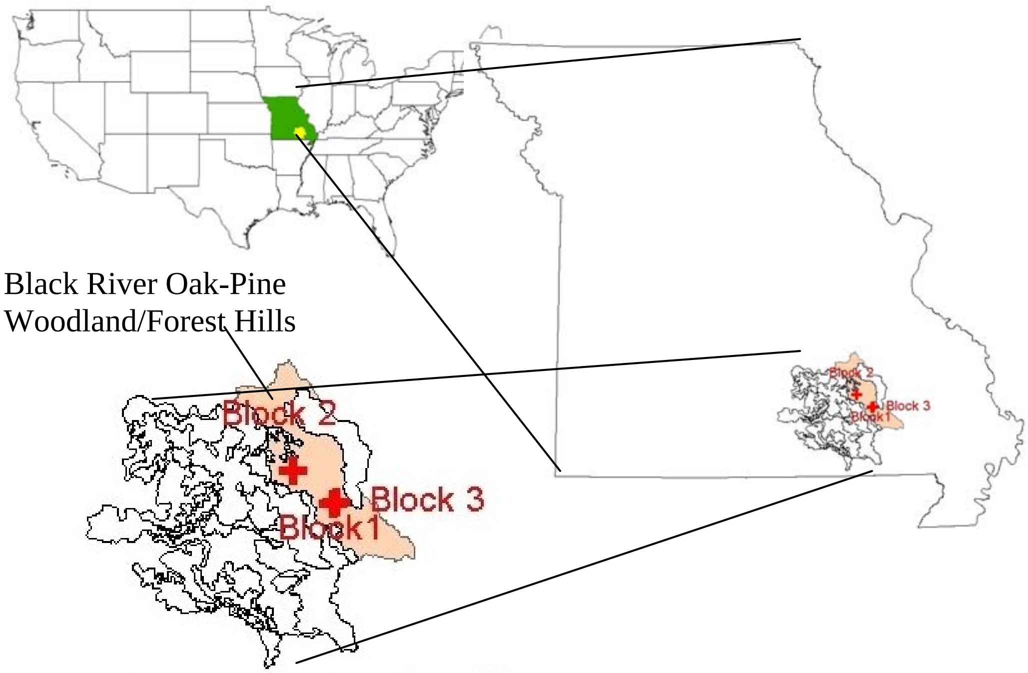

Figure 1. Locations (cross symbols) of fuel reduction demonstration areas. Note block 1 and 3 are located close together and the cross symbols nearly overlap in this figure.

formations (Nigh and Schroeder 2002). Two of the three study sites were located on Clearwater Conservation Area and the other was located on Logan Creek Conservation Area.

Site Selection

Sites selected for fuel reduction treatments 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. This study was replicated across three complete blocks. Each block contained four treatments (control, prescribed fire only, thinning only, and thin and prescribed fire) across three aspect classes. The three aspect classes were: protected slopes (315^{o}-135^{o}), exposed slopes (135^{o}-315^{o}), and ridges (Nigh et al. 2000). Average block size was 136.33 acres (55.17 hectares); block 1 was 135 acres (54.6 hectares), block 2 was 142 acres (57.5 hectares), and block 3 was 132 acres (53.4 hectares) in size.

Fuel Reduction Treatments

Fuel reduction treatments included thinning, prescribed fire, thinning and prescribed fire, and controls. Fuel reduction treatments were completely replicated between blocks and were randomly assigned within each block.

Thinning: Thinning operations were conducted during the summer and early fall of 2002. Stocking of thinned stands was reduced to about 40 ft^2/acre (3.7 m^2/ha). Non-commercial trees were fallen by hand crews after the initial harvest. Fire tolerant species were the preferred leave-trees (i.e. uncut), and included White Oak (*Quercus alba*), Post

Oak (*Quercus stellata*), and Shortleaf Pine (*Pinus echinata*). Missouri Department of Conservation employees supervised the commercial thinning operations conducted on the study sites.

Prescribed Fire: Prescribed fire treatments were first conducted in the spring of 2003 before leaf out. The Missouri Department of Conservation conducted all prescribed fires on our study sites. Prescribed fires were conducted as ring head fires under the prescription outlined in Table 1 (Kolaks 2004).

Table 1. Prescribed fire burn prescription weather parameters (Kolaks 2004).

Attribute	Prescription
Temp (°F)	45-65 (7-18°C)
Mid Flame Wind (mph)	0-7 (0-11 km/h)
Rel. Humidity (%)	25-45
Fuel Moisture:	
1-hr.	5-10
10-hr.	8-15
100-hr.	12-18
1000-hr.	> 20

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Vegetation Data Collection

Permanent vegetation subplots were installed during the summer of 2001. A modified transect method was used for sampling three types of subplots: overstory, woody regeneration, and ground flora. Pre-treatment sample was conducted between May-August 2001 and post-treatment sampling was conducted May-July 2003. Vegetation data was not collected during 2002 because thinning operations were being conducted on the study sites.

Overstory Subplots: Three 0.1ha circular overstory plots were randomly located within each treatment/aspect class. All live trees (dbh>4cm) were identified to species and dbh was measured. In post-treatment samples tree health was monitored to identify effects from thinning or prescribed fire.

Woody Regeneration Subplots: Fifteen circular 0.001ha woody regeneration subplots were randomly located within each treatment/aspect class. Additionally, five regeneration subplots were located in each overstory subplot. A total of 30 regeneration subplots were sampled within each treatment/aspect class combination. Woody regeneration data included: species and height class, in 30 cm (1 ft) increments, for all stems with a dbh<4cm.

Ground Flora Subplots: One 1m^2 quadrat was associated with each woody regeneration subplot. Within each quadrat all live herbaceous plants were identified to species and cover was estimated to the nearest 1%. Physical site characteristics were described at each quadrat by measuring percent slope, aspect, crown cover (densitometer), and the percent cover of bare soil, leaf litter, exposed rock, and downed dead woody material was estimated to the nearest 1%.

Fuel Data Collection

Fuel data were collected at 15 randomly located points within each treatment/aspect class combination. Fuels were sampled using a modified transect intercept method. Woody fuels were sampled by fuel timelag class: 0.0-0.25in (0.0-0.61cm)(1-hour), 0.25-1.0in (0.61-2.54cm)(10-hour), 1.0-3.0in (2.54-7.62cm)(100-hour), and greater than 3inches (>7.62cm) (1000-hour). 1000-hour fuels were separated into solid and rotten categories for sampling. Fuels were sampled along a 50 ft. (15.24m). transect with 1- and 10-hour fuels being sampled along the first 6 ft (1.83m) of the transect, 100-hour fuels were sampled along the first 12 ft (3.66m)of the transect, and 1000-hour were sampled along the entire 50 ft (15.24m) transect (Brown et al. 1982, Grabner 1996). Litter and herbaceous fuels were collected from a 2.0ft^2 (0.19m^2)clip plot located at the end of the fuel transect. Collected fuels were dried at 60^{o}C to a constant weight and reported on a dry weight basis.

Prescribed Fire Data Collection

Flame Height

Prescribed fire behavior was measured at 3 randomly chosen fire behavior plots out of the 15 fuel sampling points within each stand. In order to objectively determine flame length, two measures were recorded at each fire behavior plot. First, flame height was recorded by an array of passive flame height sensors calibrated for use in the Central Hardwood Region (Kolaks et al. 2004). Second, trained observers used visual aids to determine flame-tilt angle as the fire front passed through the flame height sensor arrays. Flame-tilt angle, which is combined with flame height to derive flame length, can be measured at a greater distance by fewer observers than direct observation of flame length (Ryan 1981). Average flame lengths were derived by averaging flame heights indicated by each individual sensor within a plot (array) (Kolaks et al. 2004) and applying the corresponding flame-tilt angle (Ryan 1981). Estimated maximum flame length was derived using the tallest flame height recorded by a sensor array and applying the flame tilt angle. Utilizing these methods eliminated a large component of variation imposed via human observations by removing subjectivity and perception discrepancies.

Rate of Spread

Prescribed fire rate of spread was measured using rate of spread clocks. Rate of spread clocks were constructed from digital sport watches (Blank et al. 1983, Kolaks et al. 2005). The clocks were modified with a solder trigger and the entire clock assembly fit into a plastic housing that was buried at each fire behavior plot. The solder trigger remained above the soil; the trigger was activated when the flaming front passed over the solder trigger, melting the trigger and turning the clock on. Five rate of spread clocks were located in each fire behavior plot, one at plot center and the others 50 ft (15.24m) in each cardinal or sub-cardinal (NE, SW, etc.) direction, depending on the locations of fire spread obstructions such as logs and rock outcroppings. If three rate of spread clocks were activated prescribed fire rate and direction of spread was calculated (Simard et al.

1984). Using five clocks provided backup in case one or two clocks failed to operate properly.

Unfortunately, only a fraction of the rate of spread clocks worked properly. Over two-thirds of the clocks endured cold temperatures and precipitation for several days after the burn due to circumstances beyond our control. Clocks recovered immediately after the burn worked properly and provided good data. Rate of spread clock data was not sufficient enough for statistical analysis. Given that the fireline intensity can be determined by two methods, and that the two methods are correlated with each other (Byram 1959, Nelson 1986), estimates of rate of spread were derived by dividing fireline intensity by energy released by 1-hour woody and litter fuels (Equation 1). It was assumed that only litter and 1-hour woody fuels were consumed by flaming front.

Equation 1. Calculation of fireline intensity into estimated rate of spread.
Given that I = HWR (Byram 1959),

$$R = I / HW$$

Where:
I = fire line intensity (Btu/ft/sec)
H = low heat combustion (8039.56 Btu/lb)
W = weight of fuel consumed (1-hour woody and litter in pounds)
R = rate of spread (ft/min)

Fire Weather Monitoring

Prescribed fire weather was measured and recorded every fifteen minutes with an automated weather station. Parameters measured include eye level wind speed and direction, 10-hour fuel moisture and temperature, relative humidity (RH), and air temperature. The station was placed on a ridge upwind and adjacent to the sites under the leafless canopy. One, 100, and 1000-hour fuel moistures were calculated using data from two additional automated weather stations, in close proximity to the study sites (9 and 15 miles away), that experienced similar weather patterns.

Data Analysis

An ANOVA model was developed to include the three replicate sites, three aspect classes, and four treatment levels. Using SAS, PROC GLM and PROC MIXED were used to test for differences between pre- and post-treatment fuel plant community characteristics such as species richness, diversity, and evenness.

Fuel data analysis was conducted on the following fuel categories: litter, 1-hour, 10-hour, 100-hour, all fuel < ¼inches (litter and 1-hour fuel), all fuel <3inches (litter, 1-hour, 10-hour, and 100-hour), 1000-hour solid, 1000-hour rotten, total fuel load, fuel height, litter depth, and duff depth. Fire behavior data analysis was conducted on total energy released, flame length, heat per unit area, and rate of spread. ANOVA was used to determine if fuel loading and fire behavior differences were due to treatment and/or aspect. Data were analyzed using the PROC 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 for fuel loading analysis, but a p-value of 0.10 or less was considered signigicant for fire behavior data analysis. A p-value of 0.10 was used for fire behavior analysis because we did not include weather factors or slope as explanatory variables, and because of fire behavior's variable nature.

Results and Discussion

Vegetation Data

Overstory

Prior to fuel reduction treatments all study plots were fully stocked stands dominated by oak and hickory species. Pre-treatment tree density ranged from 241.6 to 485.5 trees/acre with a mean of 357.4 trees/acre. Pretreatment basal area ranged from 79.5 to 146.2 ft^2/acre (7.4 to 13.7 m^2/ha) with a mean of 107.4 ft^2/acre (10.0 m^2/ha) (McMurry et al. 2007). Pretreatment stand stocking ranged from 71.5 to 129.2 percent with protected slopes having the highest stocking (Table 2). The thinning treatment removed on average 101.8 trees/acre and 57.7 ft^2/acre. The thinning operation reduced stand stocking by an average of 59.1 percent.

Prior to the thinning treatment the overstory across all plots contained the same dominant species: hickory (*Carya* spp.), flowering dogwood (*Cornus florida*), white oak (*Quercus alba*), black oak (*Quercus velutina*), and black gum (*Nyssa sylvatica*). After the thinning treatment the relative basal area of shortleaf pine (*Pinus echinata*), scarlet oak (*Quercus coccinea*), and post oak (*Quercus stellata*) increased and these species had a greater proportional abundance post-thinning (McMurry et al. 2007). Post oak and shortleaf pine were retained during thinning operations on ridges and exposed slopes, because they are fire tolerant and they tend to occur on ridges and exposed slopes. On protected slopes hickories, flowering dogwood, and black gum were favored for removal. These species were removed during thinning operations because they are fire intolerant and they have a high occurrence on protected slopes.

Ground Flora

Prior to fuel reduction treatments species richness ranged from 20 to 91 with a mean of 36.5. Post-treatment species richness ranged from 28 to 87 with a mean of 36.8 (McMurry et al. 2007). The ANOVA model for species richness showed no significant difference due to treatment, and most of the variability in richness was due to differences among replicate blocks. Richness was significantly greater on exposed slopes compared to protected slopes (p=0.0437).

Pre-treatment Shannon diversity indices ranged from 2.0 to 3.5 with a mean of 2.5 and were significantly different between blocks and aspect classes (McMurry et al. 2007). Post-treatment Shannon diversity indices ranged from 2.1 to 3.5 with a mean of 2.6. The thin and prescribed fire treatment had the highest diversity and was followed by the prescribed fire treatment, thin only treatment, and control. Mean diversity values were

Table 2. Mean pre- and post-treatment tree density and basal area by block, aspect, and treatment (Data from McMurry et al. 2007).

Site, Aspect, and Treatment	Pre-treatment		Post-treatment	
	Trees/Acre	Basal Area (ft^2/acre)	Trees/Acre	Basal Area (ft^2/acre)
Block 1	341	105	187	77
Block 2	380	109	174	70
Block 3	351	108	208	78
Protected Slope	367.4	110.4	184.1	76.2
Ridge	348.9	105.8	188.3	75.8
Exposed Slope	356.1	105.9	196.2	73.6
Control	350.6	107.3	329.0	107.9
Burn	333.2	94.3	246.9	89.3
Thin	338.3	112.3	94.7	54.0
Thin and Burn	370.7	105.1	60.0	39.7

significantly lower on protected control sites and protected thin only sites (McMurry et al. 2007). Evenness differed significantly pre-treatment across aspect classes. Protected aspects had a significantly lower evenness than ridge plots (p=0.0308) and exposed plots (p=0.0244).

All fuel reduction treatments significantly reduced ground flora abundance on every aspect class. Aspect class seemed to buffer treatments as ridges were less affected than both protected and exposed aspect classes. Thinning had a lower impact on ground flora than prescribed fire and thin and prescribed fire treatments. Annual forbs increased with the prescribed fire only and the thin and prescribed fire treatment. The results of the ground flora work showed the immediate post treatment effects. The results of vegetation data analysis suggested that there was a significant interaction among all treatments with aspect class. The fuel demonstration sites were treated with a second prescribed fire in 2005 and overstory and ground flora data were collected after the second prescribed fire. In the future collaborators on this project will analyze the effects of the second prescribed fire on vegetation response.

Fuel Loading Data

Pre-Treatment Fuel Loading

Fuel loading by timelag categories did not substantially vary between aspects, except for 1000-hour solid fuels. 1000-hour solid fuels were significantly greater (p=0.007) on protected slopes when compared to both ridges and exposed slopes. On average there was a progression of increasing total fuel load from exposed, to ridge, and finally to protected slopes (Kolaks 2004; Figure 3). Litter, 1, 10, 100-hour, 1000-hour rotten, and the sum of all fuels < 3.0 in did not vary greatly between aspects (Figure 2 and Table 3). However, some patterns, though not statistically significant, in fuel loading by aspect class were worth noting. Fuel loading patterns of note occurred between exposed slopes and ridges in 10-hour fuels, exposed and protected slopes in total fuel loading (p=0.070),

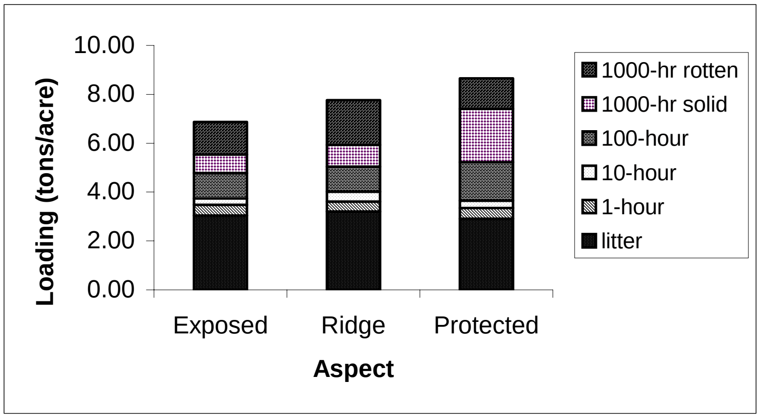

Figure 2. Fuel loading by size class and aspect (Kolaks 2004).

Table 3. Pre-treatment fuel loading and vertical structure by size class and aspect (Kolaks 2004).

		Fuel Loading (tons/acre)							Vertical Structure (feet)		
		Litter	1-hour	10-hour	100-hour	1000-hour Solid*	1000-hour Rotten	**Total**	Fuel Height	Litter Depth	Duff Depth
Block 1	E	3.06	0.44	0.17	0.96	0.44	1.55	**6.61**	0.21	0.20	0.029
	R	2.76	0.39	0.32	1.01	0.56	4.44	**9.99**	0.24	0.22	0.045
	P	2.85	0.43	0.24	1.18	2.39	1.99	**9.08**	0.25	0.22	0.048
Block 2	E	3.38	0.54	0.40	1.25	0.57	1.54	**7.56**	0.20	0.19	0.070
	R	3.51	0.46	0.41	1.00	0.96	0.43	**6.71**	0.20	0.19	0.066
	P	2.89	0.51	0.45	1.56	2.73	0.43	**8.57**	0.22	0.21	0.078
Block 3	E	2.61	0.39	0.24	0.86	1.25	0.96	**6.32**	0.21	0.19	0.038
	R	3.30	0.37	0.47	1.07	1.18	0.61	**7.00**	0.32	0.26	0.069
	P	3.01	0.34	0.22	1.91	1.39	1.31	**8.24**	0.27	0.26	0.054

* significant difference among aspect found only in 1000-hour solid(p=0.007).

E = Exposed, R = Ridge, P = Protected

between exposed and protected slopes (p=0.059) as well as exposed slopes and ridges (p=0.081) in fuel height, and exposed and protected slopes in litter depth (p=0.059) (Figure 2 and Table 3). Because finer fuels primarily drive fire behavior, particularly rate-of-spread, total fuel loading probably is not the best indicator of potential fire behavior (Davis 1959, Brown 1970, Brown and Davis 1973, Anderson and Brown 1987).

Post-Thinning Fuel Loading

Commercial thinning reduced litter weight, all fuel < ¼ 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 < ¼ 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 (p=0.009 and 0.025, respectively) and all fuel < 3 in (p=0.008 and 0.008, respectively) categories. Fuel height increases were also significantly higher (p=0.040) on protected slopes as opposed to exposed slopes. Though not significant, the differences between exposed slopes and ridges in 1-hour (p=0.054) and 10-hour fuel loading (p=0.093) are noteworthy.

Table 4. Fuel loading differences in tons/acre as result of commercial thinning (Kolaks 2004). Negative values indicated post-thinning fuel loading was less than pre-treatment fuel loading, therefore thinning operations removed fuel.

	Fuel loading (tons/acre)									Vertical structure (in)		
							1000-hour			Fuel	Litter	Duff
	Litter	1-hour	10-hour	100-hour	< 1/4 in	< 3 in	Solid	Rotten	Total	Height	Depth	Depth
E	-0.7a	0.4ab	0.4a	1.4a	-0.37a	1.4a	13.1a	1.5a	14.6a	9.1ab	-0.9a	-0.20a
R	-0.2a	0.7a	0.8a	3.8b	0.42a	4.5b	13.3a	1.2a	18.3a	9.8a	-1.1a	0.1a
P	-0.7a	0.7ac	0.7a	3.3b	-0.02a	4.5b	13.3a	1.6a	19.6a	12.8ac	-1.0a	-0.3a

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

Different letters within columns indicate significant (α=0.05) difference.

Reduction in litter weight, litter depth, and duff depth was most likely the result of the mechanical harvesting operation (rubber-tire skidder). The dragging of logs by a skidder moved litter and duff laterally across the landscape, redistributing fuel. 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.

Fuel Loading Post-Prescribed Fire

Consumption:

For the most part, all burns were conducted within prescription. Prescribed fire operations were initiated within prescription parameters but after ignition operations were completed the relative humidity dropped below prescription during some of the prescribed fire treatments. Weather and 10-hour fuel moisture were taken by an on-site automated weather station. One, 100, and 1000-hour fuel moistures were calculated using data from 2 automated weather stations that experienced similar weather patterns located in relatively close proximity (9 and 15 miles).

Prescribed burning reduced fuel loading and vertical structure in all categories in both thinned and unthinned treatments (Table 5 and 6). Fuel consumption decreased as timelag size class increased (Table 5 and 6). Consumption did not significantly vary among aspects for either treatment. However, the data suggest that a greater proportion

Table 5. Consumption of fuel for the prescribed fire-only treatment by aspect (Kolaks 2004). Data within table were calculated using the following equation pre-prescribed fire fuel loading – post-prescribed fire fuel loading.

	Fuel Loading (tons/acre)									Vertical Structure (in)		
							1000-hour			Fuel	Litter	Duff
Aspect[1]	Litter	1-hour	10-hour	100-hour	< ¼ in	< 3 in	Solid	Rotten	Total	Height	Depth	Depth
E	2.9a	0.3a	0.2a	0.3a	3.2a	3.7a	0.1a	0.5a	3.9a	2.4a	2.1a	0.3a
Percent	**99**	**60**	**45**	**35**	**93**	**78**	**30**	**60**	**67**	**91**	**98**	**45**
R	3.0a	0.2a	0.1a	0.1a	3.2a	3.6a	0.1a	0.2a	3.5a	2.8a	1.9a	0.3a
Percent	**97**	**48**	**19**	**16**	**92**	**79**	**12**	**9**	**49**	**91**	**97**	**35**
P	2.5a	0.3a	0.1a	0.3a	2.8a	3.0a	0.1a	1.1a	3.5a	2.5a	2.0a	0.2a
Percent	**96**	**27**	**16**	**19**	**89**	**62**	**37**	**41**	**47**	**90**	**96**	**27**

[1]Aspects: E=exposed, R=ridge, P=protected
Different letters within a column designate significant (α=0.05) difference.

Table 6. Consumption of fuel by aspect for the thin-prescribed fire treatment aspect (Kolaks 2004). Data within table were calculated using the following equation pre-prescribed fire fuel loading – post-prescribed fire fuel loading.

	Fuel Loading (tons/ acre)									Vertical Structure (in)		
							1000-hour			Fuel	Litter	Duff
Aspect[1]	Litter	1-hour	10-hour	100-hour	< 1/4 in	< 3 in	Solid	Rotten	Total	Height	Depth	Depth
E	2.8a	0.5a	0.4a	0.1a	3.3a	4.6a	1.7a	1.0a	6.0a	7.0a	1.9a	0.30a
Percent	**100**	**56**	**53**	**5**	**89**	**66**	**12**	**51**	**28**	**50**	**98**	**38**
R	2.7a	0.9a	1.0a	1.6a	3.6a	6.1a	0.7a	.05a	7.2a	6.4a	2.0a	1.0a
Percent	**97**	**75**	**66**	**30**	**91**	**57**	**5**	**3**	**27**	**41**	**93**	**68**
P	3.0a	1.0a	0.6a	1.1a	3.9a	5.6a	1.3a	1.0a	6.6a	8.0a	2.1a	0.40a
Percent	**100**	**73**	**57**	**26**	**91**	**58**	**7**	**39**	**24**	**43**	**99**	**45**

[1]Aspects: E=exposed, R=ridge, P=protected
Different letters within a column indicate significant (α=0.05) difference

of consumption occurred on exposed slopes in 1, 10, and 100-hour timelag classes than on ridges and protected slopes (Kolaks 2004).

In all cases nearly 100 percent of litter was consumed. Litter was responsible for the consumption of about 90 percent of all fuel < ¼ 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.

100-hour, 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). Prescribed fire-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 result while fire behavior on the ridges was mostly only wind driven. However, this effect was not observed in the burn-thin treatment (Kolaks 2004).

There were no post-burn significant differences among aspects in all categories of the prescribed fire-only treatment (Table 7). Several categories exhibited post-prescribed fire differences between aspects in the burn-thin treatment (Table 7) including 100-hour between exposed and both protected slopes (p=0.023) and ridges (p=0.005), all fuel < 3 in between exposed and both protected slopes (p=0.031) and ridges (p=0.007), fuel height between exposed and protected slopes (p=0.014), and litter depth between ridges and both exposed and protected slopes (p=0.001 for both). 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 7). These differences are almost identical to those observed after thinning (Table 3). However, burning also produced a near significant difference in total fuel loading (p=0.083) between exposed and protected slopes, not observed pre-burn.

Fuel height was greater on protected slopes compared to exposed slopes after burning in the thinning treatment. Although not indicated in post-thinning data, litter depth on ridges was greater than both protected and exposed slopes after the burn (Table 7). 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 prescribed fire-only and thin-prescribed fire treatments in litter, 1-hour, all fuel < ¼ in, 1000-hour rotten, litter depth, and duff depth categories following the prescribed fire (Table 7). This is not surprising considering that many of the same categories were not significantly different from pre- to post-thinning conditions (Table 3).

Table 7. Post-treatment fuel loading by aspect for prescribed fire-only and thin-prescribed fire treatments.

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

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

Different letters within a column indicate significant (α=0.05) difference

*Differences between treatments significant (α=0.05) for category

Prescribed Fire Behavior

Average Flame Length

Prescribed fire operations were initiated within prescription parameters but after ignition operations were completed the relative humidity dropped below prescription during some of the prescribed fire treatments. Aspect had a significant impact average flame length, a p-value of 0.10 or less was considered significant for fire behavior data analysis due to the variable nature of these data. In general average flame length was greater on the slopes than on ridges with exposed slopes having significantly greater flame lengths than ridges and protected slopes (p=0.010 and 0.083, respectively; Table 8). Average flame length was also significantly different among aspects within the burn/thin treatment with exposed slopes being significantly greater than ridges and protected slopes (p=0.012 and 0.064, respectively; Kolaks 2004). However, despite similar differences between aspects in the burn-only treatment, high variability masked any potential difference. Average flame length was greater for the burn/thin treatment compared to the burn-only treatment, albeit not significant.

Table 8. Average flame (in) length by aspect/treatment unit (Kolaks 2004).

	Aspect			Treatment
Treatment	Exposed	Ridge	Protected	Average
Prescribed fire	23.0a A	11.8a A	17.8a A	17.5A
Thin/prescribed fire*	33.8a A	13.9b A	20.6b A	22.7A
Aspect Average	28.4a	12.9b	19.17b	

Different letters indicate significant difference within a row, lower case or column, upper case.

Greater average flame lengths occurred on exposed slopes than ridges or protected slopes despite exposed slopes having significantly less fuel loading in the 100-hour or less timelag category. This could be attributed to drier fuels due to solar exposure or a southerly wind may have created a more pronounced difference between exposed and protected slopes.

Despite random and relatively unbiased sampling, average flame lengths in thinned stands did not accurately reflect the average across the entire stand. Passive flame height sensors could not be installed through logging slash. Rather, average flame lengths more accurately depict the areas between slash piles as the thinning influenced them. Trained observers visually estimated flame lengths off of slash piles. Estimates included average and maximum flame lengths. In general, flame lengths from slash averaged 14 ft with maximum flame lengths of 50 ft being not uncommon.

Rate of Spread

Rate of spread was back calculated from fireline intensity. Based on observations during the prescribed fires and the limited clock data, it is safe to assume that actual rate of spread lies between the two rate of spread estimation techniques (back calculation of Nelson's and Byram's fireline intensities) (Table 9). Albeit not significant, overall trends indicated that rate of spread was 3 to 4 times greater on the slopes than on the ridges. Significant differences only existed in the thin-prescribed fire treatment between exposed slopes and ridges as well as exposed and protected slopes (p=0.015 and 0.076, respectively (Nelson) and p=0.021 and 0.081, respectively (Byram; Table 9). Rate of spread also appeared to be slightly faster in thin-prescribed fire stands than in prescribed fire-only stands. Though this difference was not significant, it can be attributed to the longer flame lengths in burn-thin stands and may not reflect an actual increase in rate of spread (Kolaks 2004). As mentioned before, the differences between exposed and protected slopes may have been more pronounced given a southerly wind.

Table 9. Rate of spread(ft/min) derived from both fireline intensity methods by aspect/treatment unit (Kolaks 2004).

	Aspect						Treatment Average	
	Exposed		Ridge		Protected			
Treatment	Nelson	Byram	Nelson	Byram	Nelson	Byram	Nelson	Byram
Prescribed fire	3.09a A	1.59a A	0.76a A	0.36a A	2.14a A	1.08a A	2.00A	1.01A
Thin/prescribed fire	6.37a B	3.48a B	1.14b A	0.56b A	2.89b A	1.56b A	3.47A	1.87A
Aspect Average	4.5ab	2.53ab	0.95ac	0.46ac	2.51a	1.31a		

Different letters indicate significant difference within a row lowercase, or column, uppercase.

Conclusion

The data collected on these fuel demonstration sites was the first project in the Missouri Ozarks to combine detailed fuel and vegetation data with detailed fire behavior data. The results from the fuel reduction demonstration areas showed that aspect had a significant affect on vegetation patterns and prescribed fire flame lengths and influenced fuel loading and prescribed fire rate of spread, though differences were not statistically significant. The influence of aspect on vegetation, fuels, and fire behavior was anticipated and incorporated into the design of this project. Fuel reduction treatments also had an effect on ground flora richness. Ground flora responded to thin and prescribed fire and prescribed fire only treatments resulting in an increase in species richness. The thinning only treatment increased species richness but not to the same extent as fire. It appeared that aspect and fuel reduction treatments interact. With the ability to continue monitoring these fuel reduction demonstration sites we will hopefully begin to understand how this interaction affects vegetation patterns in the short and long term.

The fuel reduction treatments had an affect on fuel loading. Thinning operations increased total fuel loading and fuel loading in the 10-hour, 100-hour, and 1000-hour solid fuel timelag classes. The thinning operation added fuel to the fuel bed but it did not evenly distribute the fuel. The thinning operation resulted in fuel jack pots. The prescribed fire treatment did reduce fuel loading, as was expected. Prescribed fire did not significantly reduce fuel loading in the 100-hour and 1000-hour fuel classes. These results indicate that after one prescribed fire treatment these larger fuels were not significantly affected. .

The results of fuel reduction treatments showed that thinning and prescribed fire have an affect on vegetation and fuels. The fuel treatment demonstration areas were treated with a second prescribed fire in the spring of 2005. Fuels and vegetation data were collected in association with this second prescribed fire treatment, and these data are currently being analyzed. The affects of the fuel reduction treatments on these sites may be seen for a long time. All data collection points were permanently marked and will enable future resampling to track the trajectory of the changes to both vegetation and fuels. The changes that we have seen on these demonstration sites represent only the beginning.

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Appendix A. Products resulting from JFSP Project # 00-2-04

Proposed	Delivered	Status
Publication	Stevenson, A.P., R.M. Muzika, and R.P. Guyette. 2008 Fire Scars and tree vigor following proscribed fires in Missouri Ozark upland forests.	In Progress. Estimated Completion: Spring 2008
Publications	McMurry, E.R., Muzika, R-M, Loewenstein, E.F., Grabner, K.W., and Hartman, G.W. 2007. Initial effects of prescribed burning and thinning on plant communities in the southeast Missouri Ozarks. pp. 241-249. *In:* Proceedings, 15th Central Hardwood Forest Conference. Buckley, D.S. and Clatterbuck, W.K. (eds.). General Technical Report SRS-101. USDA Forest Service, Southern Research Station. 770p.	Done
Publication	Stambaugh, M.C., Guyette, R.P., Grabner, K.W., and Kolaks, J.2006. Understanding Ozark forest litter variability through a synthesis of accumulation rates and fire events. In: Andrews, Patricia L.; Butler, Bret W.,comps. Fuels Management—How to Measure Success: Conference Proceedings. 2006 28-30 March; Portland, OR. Proceedings RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research	Done
Publications	Kolaks, J.; Grabner, K.;Hartman, G.;Cutter, B.; and Loewenstein, E.. 2005. An updated ROS clock. Fire Management Today 65(4):24-25.	Done
Publications	Kolaks, J., B.E. Cutter, E.F. Loewenstein, K.W. Grabner, G.W. Hartman, and J.M. Kabrick. (In press) The effect of thinning and aspect on fire behavior in the central hardwood region. *In:* Proceedings of the 23rd Tall Timbers Fire Ecology Conference; Fire in grassland and shrubland ecosystems. October 17-20, 2005, Bartlesville, OK.	In Press

Publications	Kolaks, J.K.; Cutter, B.E.; Loewenstein, E.F.; Grabner, K.W.; Hartman, G.W.; and Kabrick, J.M. 2004 The effect of thinning and prescribed fire on fuel loading in the central hardwood region of Missouri. p. 168-178 *In:* Proceedings. 14th Central Hardwood Forest Conference, March 16-19; Wooster, OH. Yaussy, D.A.; Hix, D.M.; Long, R.P.; Goebel, P.C. (eds.). Gen. Tech. Rep. NE-316. Newtown Square, PA: U.S. Department of Agriculture. Forest Service. Northeastern Research Station. 539 p.	Done
Publication	Hartman, G. 2004. Where there's fuel, there could be fire. Missouri Conservationist 65(3):19-23	Done
Publications	Loewenstein, Edward F., Grabner, Keith W., Hartman, George W., and McMurry, Erin R. 2003. Integrating fuel and forest management: developing prescriptions for the central hardwoods region. pp. 101-104. *In*: Proceedings, Thirteenth Central Hardwood Forest conference; VanSambeek, J.W.; Dawson, J.O.; Ponder, F., Jr.; Loewenstein, E.F.; Fralish, J.S. (eds). 2002 April 1-3; Urbana, IL. Gen. Tech. Rep. NC-234. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 565 p.	Done
Publication	Jenkins, J.L. 2003. Keep one foot in the black. Article in MU Graduate Student Research Matters. A publication of the University of Missouri. (http://gradschool.missouri.edu/about-us/initiatives/matters/research-matters.pdf)	Done
Publication	Loewenstein, E.F. 2001. Fire in the hills: Landmark study of fuel loading in the Ozarks. North Central Research Station News, April/May/June. Pp:1-2.	
Long Powerpoint	Kabrick, J.M., Dey, D.C.,	Done

Presentation	Loewenstein, E.F. 2007. Integrating ecology into management: Silvicultural tools for restoring and managing oak woodlands in the Ozark Highlands. (invited presentation) Society of American Foresters National Convention. October 23-27, 2007, Portland, OR.	
Short Powerpoint Presentation	McMurry, E.R., Muzika, R-M, Loewenstein, E.F., Grabner, K.W., and Hartman, G.W. 2007. Initial effects of prescribed burning and thinning on plant communities in the southeast Missouri Ozarks. pp. 241-249. *In:* Proceedings, 15th Central Hardwood Forest Conference. (20min)	Done
Short Powerpoint Presentation	Kolaks, J., B.E. Cutter, E.F. Loewenstein, K.W. Grabner, G.W. Hartman, and J.M. Kabrick. (In press) The effect of thinning and aspect on fire behavior in the central hardwood region. 23rd Tall Timbers Fire Ecology Conference; Fire in grassland and shrubland ecosystems. October 17-20, 2005, Bartlesville, OK.(20min)	Done
Short Powerpoint Presentation	Kolaks, J.K.; Cutter, B.E.; Loewenstein, E.F.; Grabner, K.W.; Hartman, G.W.; and Kabrick, J.M. 2004 The effect of thinning and prescribed fire on fuel loading in the central hardwood region of Missouri. p. 168-178 *In:* Proceedings. 14th Central Hardwood Forest Conference, March 16-19; Wooster, OH. (20min)	Done
Short Powerpoint Talk	McMurry, E.R., Muzika, R-M., Loewenstein, E.R., Grabner, K.W., and Hartman G. 2003. Plant Community Response to Prescribed Fire and Thinning in the Southeast Missouri Ozarks. Paper presented at the 2d International Fire Ecology and Fire Management Congress. November 16-20, 2003, Orlando, FL. (20min)	Done
Poster	Immediate effects of prescribed burning and thinning on plant	Done

	communities in the southeast Missouri Ozarks. Poster presented at the 2005 Missouri Natural Resources Conference. February 2-4, 2005, Osage Beach, MO	
Poster	Integrating fuel and forest management: developing prescriptions for the central hardwoods forest region. Poster presented at the AU Earth Day celebration sponsored by the AU Environmental Institute, April 21, 2003.	Done
Poster	Integrating fuel and forest management: developing prescriptions for the central hardwoods forest region. Poster presented at the JFSP Principle Investigators Workshop. Phoenix, AZ, March 10-13, 2003.	Done
Poster	Integrating fuel and forest management, developing prescriptions for the Central Hardwoods Region. Poster presented at the U.S. Geological Survey Third Wildland Fire Science Workshop, November 12-15, 2002 Denver, CO.	Done
Poster	Integrating fuel and forest management, developing prescriptions for the Central Hardwoods Region. Poster presented at the 13th Central Hardwoods Forest Conference. April 1-3, 2002, Champaign, IL.	Done
Poster	Integrating fuel and forest management, developing prescriptions for the Central Hardwoods Region. Poster presented at the 2002 Missouri Natural Resources Conference. January 30 – February 1, 2002, Osage Beach, MO.	Done
Poster	Integrating fuel and forest management, developing prescriptions for the Central Hardwoods Region. Poster presented at the 2001 Joint Fire Science Program, principal investigators workshop. October 2 – 4, 2001, San Antonio, TX.	Done

Master's Thesis	Kolaks J.K., 2004. Fuel loading and fire behavior in the Missouri Ozarks of the Central Hardwood Region. University of Missouri M.S. Thesis 115p.	Done
Master's Thesis	McMurry, E.R. Effects of Prescribed Burning and Thinning on Plant Communities of the Southeast Missouri Ozarks. University of Missouri M.S. Thesis.	In Progress Estimated Completion: Spring 2008
Tours/Site Visits	Hartman, G. and Grabner, K. Estimating wildland fuels training. Fall 2001	Done
Tours/Site Visits	Morris, M. Prescribed fire training for the Ellington work crew-Missouri Department of Conservation. Spring 2003	Done
Tours/Site Visits	Morris, M. Prescribed fire training for the Ellington work crew-Missouri Department of Conservation. Spring 2003	Done
Tours/Site Visits	Kolaks, J.J. Site tour for Jason Jenkins information specialist for the University of Missouri School of Agriculture department of Agricultural Journalism. 2003	Done
Tours/Site Visits	Kolaks, J.J. Estimating wildland fuels training for the Missouri Department of Conservation Forest Field Station wildland fuels sampling crew. January 2005	Done
Tours/Site Visits	Kolaks, J.J. Estimating wildland fuels training for the Missouri Department of Conservation Forest Field Station wildland fuels sampling crew. January 2006	Done