EFFECTS OF LANDSCAPE POSITION AND SEASON OF BURN ON FIRE TEMPERATURE IN SOUTHERN OHIO'S MIXED OAK FORESTS

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Abstract—The use of fire to maintain and restore oak (*Quercus* spp.) ecosystems is becoming an increasingly accepted silvicultural tool; however, specific management recommendations have been slow to develop as past studies have shown mixed results. By examining fire temperature in response to landscape position and season of burn, we attempted to offer increased insight into the use of prescribed fire to effectively regenerate oak. Prescribed burns were performed in 2004 in two oak forests that encompassed 96 and 170 ha. One forest was burned late-March and the other was burned early-November. Eight areas that represented the four aspects and two slope positions (upper and lower) were marked out within each forest and replicated. Fire temperature was measured using temperature-sensitive paint applied to aluminum tags (pyrometer) at three different heights above the forest floor. Six pyrometers were placed in each area, providing a total of 192 sets of temperature/height data. Pre-burn fuel conditions were characterized around each temperature gauge. Temperature readings as indicated by temperature-sensitive paint were recorded immediately after each burn. Fall burns were significantly hotter than spring burns at all aspects and slope positions. This same trend was recorded at the different height readings, indicating longer flame lengths during the fall burn. This paper discusses how fire reacts to landscape position and season of burn, and how these factors may be used to more successfully implement prescribed fire for oak management objectives.

INTRODUCTION

Over the past fifty years many stands once dominated by oak have been slowly replaced by more mesophytic species, especially red maple (*Acer rubrum*) (Heiligmann and Norland 1985, Lorimer 1993). These declining oak-dominated, second-growth forests of today are believed to have originated after years of widespread, high intensity fires swept through old-growth logging slash. However, the historical disturbance regime also consisted of more frequent, low intensity fire (Brose and others 2001), ignited naturally by lighting, but mainly by indigenous peoples and early settlers (Kimmerer and Lake 2001). It seems inevitable that without replicating this historical fire regime, oaks will continue to decline because of the increasing difficulty in regenerating the genus (Clark 1993).

In recent years the use of prescribed fire as a means to maintain or restore oak forests has gained attention as studies have indicated the potential effectiveness of this management tool (Arthur and others 1998, Brose and others 1999). The ubiquitous nature of oak regeneration failure throughout its eastern range requires that an equally universal management technique must be developed and implemented if forest managers are to maintain and restore oak forests. Although it seems clear that fire can increase oak regeneration success, the analysis of more specific data about fire will increase its effectiveness as a management tool. For instance, if higher fire intensity, of which temperature is large part, is more effective in promoting oak regeneration, then detailed knowledge about fire temperature variability across a multitude of landscape positions would be very useful. The objective of this study was to examine how fire temperature is affected by landscape position, aspect, and season of burn. These results are the first phase of a continuing study that will evaluate the differential sprouting response of oak and red maple following fire.

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SITE DESCRIPTION

The two study sites are located 24 km apart in the unglaciated hill country of southern Ohio. The regional topography is characterized by deeply dissected terrain of the Allegheny Plateau, which creates a gradient of moisture regimes and subsequent microclimates across the landscape. Forest composition and structure consist primarily of mixed-oak, sawtimber size stands. Both sites are located within Ohio state forests with similar geologic, topographic, and climatic characteristics, and accordingly, very similar vegetation.

The spring burn site is a 96 ha tract located in Richland Furnace State Forest (39°10'N, 82°36'W), in Jackson County, Ohio. Soils consist mainly of deep, well drained to moderately well drained silt loams of the Rigley-Rarden-Clymer association, formed in colluvium and residuum from sandstone and shale. The climate of Jackson County is characterized by mean annual precipitation of 105.36 cm and a mean annual temperature of 11°C. Average daily maximum and minimum temperatures in January are 4.3°C and -5.7°C respectively, and average daily maximum and minimum temperatures in July are 30°C and 15.5°C respectively (United States Department of Agriculture 1985).

The fall burn site is a 170 ha tract located in Tar Hollow State Forest (39°22'N, 82°45'W), in Ross County, Ohio. Soils in this area are deep to very deep, moderately well drained to well drained soils of Cruze-Shelocta-Brownville association, derived from shale, siltstone, and sandstone. The climate of Ross County is characterized by mean annual precipitation of 98.50 cm with a fairly even annual distribution. The mean annual temperature is 11.6°C, with January average daily maximum and minimum temperatures being 3.7°C and -7.7°C respectively, and July average daily maximum and minimum temperatures being 30°C and 16.8°C respectively (United States Department of Agriculture 2003).

SAMPLE DESIGN

This study was the first phase of a continuing study that will evaluate the differential sprouting response of oak and red maple following fire. Because the overall objective was to evaluate the response of individual sample trees to fire, the experimental design consisted accordingly of individual observations surrounding those sample trees.

Prior to the burns at each site, two areas were identified that represent northeast (NE) (360°-90°), southeast (SE) (90°-180°), southwest (SW) (180°-270°), and northwest (NW) (270°-360°) aspects. In addition, two areas were chosen at each aspect that represent slope position: upper and lower. These landscape positions were defined with the upper slope being the upper 33 percent of the slope and lower slope being the lower 33 percent of the slope. The two sample areas in each aspect and slope position were placed in different locations within each site for replication. This provided for the following sample design:

(2 areas) X (4 aspects) X (2 slope positions) X (2 sites) = 32 areas

Fire temperature measurement was achieved by placing six pyrometers throughout each area. With six temperature gauges at 32 areas, the following sample size was achieved:

N = (6 pyrometers) X (32 areas) = 192

Each pyrometer then became the center of a circular 0.005 hectare plot for purposes of characterizing fuel. This characterization was performed by placing fuel into fuel-type categories defined as: (1) coarse woody debris being small to large logs, (2) fine woody debris being twig, branch and bark material, (3) woody vegetation, and (4) herbaceous vegetation. The percent coverage of each of these fuel types on each plot was determined by ocular estimation and recorded. The litter depth was defined as the depth to mineral soil, and was measured at the base of each pyrometer.

The temperature gauges consisted of three aluminum tags painted with temperature-sensitive paint (Tempilaq®), and attached to a metal pin that was then inserted into the ground (Blankenship and Arthur

1999, Boerner and others 2000, Cole and others 1992). The three aluminum tags were attached to each pin at 0 cm, 20 cm, and 40 cm above the ground. On each tag, 10 temperature-sensitive paints were applied, each with a different melting point from 79°C to 538°C, as a means to record the fire temperature at different heights. The aluminum tags were then covered with aluminum foil to protect the paint from moisture, ash, and charring damage. Soon after the burns were completed, the aluminum tags were collected, and the temperature indicated by the melted paint was recorded.

Fire Implementation

The Ohio Division of Forestry conducted both the spring and fall burns with the dual intention of reducing fuel, in accordance with the national fire plan, and to promote oak regeneration. Both burn areas were fully enclosed by either roads or bulldozed fire lines. Ignition consisted of first backfiring a buffer or blackline of approximately 30 m around the perimeter of the burn area. The interior of the burn compartment was then lit using both manual and aerial internal ignitions.

The spring burn in Richland Furnace State Forest was conducted at approximately 10:00 a.m. on March 26, 2004. Weather conditions were partly cloudy with a relative humidity and air temperature of 46 percent and 21°C respectively, and southwesterly winds of 14.5 km per hour. The fall burn at Tar Hollow State Forest was implemented at approximately 10:00 a.m. on November 10, 2004. Weather conditions were partly cloudy with a relative humidity and air temperature of 35 percent and 16°C respectively, and southwesterly winds of 7.9 km per hour. Fuel moisture levels were not measured prior to the fires; however both sites had recently received light precipitation.

RESULTS

The prescribed fires burned both sites almost completely, leaving only small patches of each area unburned. However, due to these unburned areas several samples were discarded, reducing the spring burn sample size from 96 to 92, and the fall burn sample size from 96 to 90.

Fuel characterization yielded fairly homogeneous pre-burn fuel levels between the spring and fall sites (table 1). Litter depths across sites did not differ significantly, with a spring site depth of 4.5202 cm and a fall site depth of 4.5159 cm. Similarly, little difference was measured in the fuel-type categories across the two sites with coarse, woody and herbaceous fuels not differing significantly; however, a significant difference was found between mean fine woody debris percentages, with a spring site mean of 9.7917 percent cover and a fall site mean of 12.604 percent cover.

The pyrometers indicated a significantly higher temperature in the fall burn than in the spring (table 2). The average total temperature, which consisted of all samples combined, was 117°C for the spring burn and 167°C for fall burn. This difference between burns was similar when temperatures were examined at

Table 1—Mean fuel characteristics of two forest sites in southern Ohio used in this study

	Burn season (site)	
Fuel characteristics	Spring	Fall
Litter depth (cm)	4.52 a	4.52 a
Coarse woody debris cover (percent)	8.23 a	9.48 a
Fine woody debris cover (percent)	9.79 a	12.60 b
Woody vegetation (percent)	25.26 a	23.65 a
Herbaceous vegetation (percent)	13.81 a	12.53 a

Means followed by the same small case letter are not significantly different across sites (Duncan's MRT, p = 0.05).

Table 2—Mean fire temperatures by burning season of two forest sites in southern Ohio used in this study

	Burn season (site)			
Temperature/location	N	Spring	N	Fall
		°C		*°C*
Average total temperature	92	117 a	90	167 b
Average temperature at 0 cm	92	176 a	90	233 b
Average temperature at 20 cm	92	107 a	90	166 b
Average temperature at 40 cm	92	68 a	90	101 b

N = sample size.
Means followed by the same small case letter are not significantly different across sites (Duncan's MRT, $p = 0.05$).

the three temperature height locations. Mean ground level temperatures for spring versus fall burns were 176°C and 233°C, mean temperatures at 20 cm were 107°C and 166°C, and mean temperatures at 40 cm were 68°C and 101°C respectively. The significantly higher temperatures recorded at 40 cm during the fall burn indicate that fall burn flame heights were greater. These higher flame heights were also confirmed by observing higher scorch heights on surrounding trees. Fire temperature and height were found to have a negative relationship at both the spring and fall burn sites, with ground level temperatures being the highest and the 40 cm temperatures being the lowest.

The fall burn also resulted in higher temperatures when measurements were further evaluated by aspect, height, and burn season (table 3). For each temperature location: total average temperature, average temperatures at 0 cm, average temperature at 20 cm, and average temperature at 40 cm, the NE and NW aspects were slightly higher for the fall burn than for the spring burn; however SE and SW aspects were all significantly higher for the fall burn. In addition to burning hotter, the fall burn had a more variable temperature range than the spring burn, with average total spring temperatures ranging from 89°C to 141°C, a difference of only 52°C, while average total fall temperatures ranged from 96°C to 207°C, a difference of 111°C. For both burns the SE aspects achieved the highest temperatures for all temperature locations, except for the 20 cm location during the fall burn where the SW aspect temperatures were highest. SW aspects showed the second highest temperatures across both sites, NW aspects were the third highest, and NE aspects indicated the lowest temperatures.

Fire temperatures were higher on upper slope positions for both spring and fall burns (table 4). Spring burn values across all temperature height locations were higher on upper slope positions than lower slope positions, with the average total temperature ranging from 103°C on lower slopes to 132°C on upper slopes, a difference of 29°C; however only the difference at the 0 cm temperature location was found to be significant. Fall burn values across all temperature locations were significantly higher on upper slopes than lower slopes, with the average total temperature ranging from 103°C on lower slopes to 199°C on upper slopes, a difference of 96°C. Temperature differences between season of burn were higher across both slope positions and all temperature locations for the fall burn. Upper slope positions for the fall burn were significantly higher than upper slope positions for the spring burn across all temperature locations. Lower slope position temperatures were higher for the fall burn, with the exception of the 20 cm temperature location, but these differences were not significant.

Mean temperature values grouped according to slope position and aspect show significantly higher fall burn temperatures (table 5). The mean temperatures also duplicate the positive relationship between slope elevation and temperature, as in table 4. Upper slopes with SE and SW aspects achieved the highest

Table 3—Mean fire temperatures by burning season and aspect of two forest sites in southern Ohio used in this study

		Burn season (site)			
Temperature/location	Aspect	N	Spring	N	Fall
			°C		*°C*
Average total temperature	NE	29	89 aA	22	96 aA
	SE	29	141 bA	22	207 aB
	SW	11	124 abA	24	203 aB
	NW	21	120 abA	25	155 bA
Average temperature at 0 cm	NE	29	156 aA	21	165 aA
	SE	29	207 aA	22	278 bB
	SW	11	169 aA	24	257 bB
	NW	21	165 aA	25	227 bB
Average temperature at 20 cm	NE	29	77 aA	21	95 aA
	SE	29	125 aA	22	198 bB
	SW	11	125 aA	24	207 bB
	NW	21	113 aA	25	158 bA
Average temperature at 40 cm	NE	29	35 aA	21	29 aA
	SE	29	89 aA	22	145 bB
	SW	11	79 aA	24	144 bB
	NW	21	80 aA	25	81 cA

N = sample size.
Means followed by the same small case letter are not significantly different across aspects; means followed by the same uppercase letter are not significantly different between burn seasons (Duncan's MRT, p = 0.05).

temperatures for both spring and fall burns, while lower slopes with NW and NE aspects experienced lowest temperatures.

MANAGEMENT IMPLICATIONS AND CONCLUSIONS

Fire intensity has been shown to be one of the key factors in encouraging competitive oak regeneration (Arthur and others 1998, Brose and others 1999), with oak regeneration success often displaying a positive relationship with fire intensity. Because landscape position, season of burn and fuel characteristics can determine fire intensity, more knowledge about these interactions could help to fine-tune the use of prescribed fire as a management tool.

Other studies have suggested that spring burns are most effective in achieving medium to high intensity burns (Brose and others 1999), due to the occurrence of more days with favorable weather conditions such as high temperature, low humidity, and sunshine. Our findings at Richland Furnace and Tar Hollow, however, showed that higher fire intensity was reached during the fall burn. With weather conditions, fuel quantities, and site characteristics being similar between the spring and fall burns studied here, the more intense fall burn can perhaps be explained by the superior quality of leaf litter in the fall burn. Leaves had freshly fallen prior to the November fire, whereas by spring much of the fall litter would be expected to degrade somewhat. However, contrary to expectations, the results showed nearly identical litter depths at the two sites, suggesting that leaf litter quality rather than leaf litter quantity influenced fire temperature.

Table 4—Mean fire temperatures by burning season and slope position of two forest sites in southern Ohio used in this study

Temperature/location	Slope position	Burn season (site)			
		N	Spring	N	Fall
			°C		*°C*
Average total temperature	Upper	43	132 aA	46	199 aB
	Lower	47	103 aA	46	103 bA
Average temperature at 0 cm	Upper	43	198 aA	46	198 aB
	Lower	47	156 bA	46	156 bA
Average temperature at 20 cm	Upper	43	119 aA	46	119 aB
	Lower	47	96 aA	46	96 bB
Average temperature at 40 cm	Upper	43	79 aA	46	79 aB
	Lower	47	58 aA	46	58 bA

N = sample size.
Means followed by the same small case letter are not significantly different across slope positions; means followed by the same uppercase letter are not significantly different between burn seasons (Duncan's MRT, $p = 0.05$).

Fall burns may also be preferable to spring burns for oak regeneration due to differences in post-burn nutrient utilization by trees. The historical forest conditions in which oak remained dominant are thought to have been nitrogen limiting, and through chronic atmospheric deposition, species with higher nitrogen requirements can now outcompete oak (Boerner and Brinkman 2003). These competitors are likely to receive a surge of recycled nutrients after a spring burn to facilitate vigorous sprouting. However, after a fall burn, many of these nutrients would be lost to leaching and runoff while the trees are dormant. Boerner and Brinkman also state that when mean fire temperatures exceed 200°C, direct volatilization of nitrogen becomes significant, which would also help to favor oak because of its adaptation to poorer site conditions. This volatilization would have been greater during the fall burn where temperatures frequently reached or exceeded 200°C, while during the spring burn 200°C was rarely reached.

Our results also clearly show that fire intensity is directly related to slope position and aspect. Measurements on the upper slopes of both spring and fall sites displayed higher temperatures than on lower slopes. Measurements on SE and SW aspects showed significantly higher temperatures than on NW and NE slopes across both sites. This relationship between aspect and fire temperature has important management implications if achieving moderate to high intensity fire is the goal. Because oak regeneration success, or oak competition failure, has been shown to increase with fire intensity (Arthur and others 1998, Brose and others 1999), then it may only be practical to maintain or restore oak on the SE and SW aspects where fire intensity will be high enough to have the desired effect. On NW and NE aspects where fire intensity is likely to be low, repeated burns or alternative silvicultural treatments may be necessary to promote oak. Historically, oak may have been able to dominate these productive, mesic sites due to a more frequent and intense fire regime which, due to safety precautions, today's forest managers are unable to duplicate with prescribed fire.

Table 5—Mean fire temperatures grouped according to slope position and aspect by burning season for two forest sites in southern Ohio used in this study

Temperature/location	Slope position	Aspect	N	Burn season (site) Spring	N	Fall
				°C		*°C*
Average total temperature	Upper	NE	16	91 aA	13	135 aA
		SE	13	175 aB	9	223 bB
		SW	3	115 aAB	13	229 bB
		NW	11	146 aAB	11	219 bB
	Lower	NE	13	87 aA	8	33 aA
		SE	16	112 aA	13	196 bB
		SW	8	128 aA	11	172 aB
		NW	10	91 aA	14	105 aC
Average temperature at 0 cm	Upper	NE	16	184 aA	13	219 aA
		SE	13	228 aA	9	297 bB
		SW	3	186 aA	13	290 bB
		NW	11	187 aA	11	290 bB
	Lower	NE	13	121 aA	8	78 aA
		SE	16	191 aA	13	264 bB
		SW	8	163 aA	11	218 aB
		NW	10	142 aA	14	177 aB
Average temperature at 20 cm	Upper	NE	16	72 aA	13	130 aA
		SE	13	166 aB	9	217 aB
		SW	3	79 aA	13	228 bB
		NW	11	144 aAB	11	226 bB
	Lower	NE	13	84 aA	8	40 aA
		SE	16	92 aA	13	184 bB
		SW	8	142 aA	11	183 aB
		NW	10	79 aA	14	105 aA
Average temperature at 40 cm	Upper	NE	16	18 aA	13	58 aA
		SE	13	132 aB	9	155 aB
		SW	3	79 aB	13	169 aB
		NW	11	107 aAB	11	141 aB
	Lower	NE	13	56 aA	8	0
		SE	16	54 aA	13	138 bB
		SW	8	79 aA	11	114 aB
		NW	10	33 aA	14	50 aA

N = sample size.
Means followed by the same small case letter are not significantly different across aspects within slope positions; means followed by the same uppercase letter are not significantly different between burn seasons (Duncan's MRT, $p = 0.05$).

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LITERATURE CITED

Arthur, M.A.; Paratley, R.D.; Blankenship, B.A. 1998. Single and repeated fires affect survival and regeneration of woody and herbaceous species in an oak-pine forest. Journal of the Torrey Botanical Society. 125:225-236.

Blankenship, B.A.; Arthur, M.A. 1999. Prescribed fire affects eastern white pine recruitment and survival on eastern Kentucky ridgetops. Southern Journal of Applied Forestry. 23:144-150.

Boerner, R.E.; Brinkman, J.A. 2003. Fire frequency and soil enzyme activity in southern Ohio oak-hickory forests. Applied Soil Ecology. 23:137-146.

Boerner, R.E.; Morris, S.J. 2000. Spatial variability in soil nitrogen dynamics after prescribed burning in Ohio mixed-oak forests. Landscape Ecology. 15:425-439.

Brose, P.; Schuler, T.; Van Lear, D. [and others]. 2001. Bringing fire back: the changing regimes of the Appalachian mixed-oak forests. Journal of Forestry. 99:30-35.

Brose, P.H.; Van Lear, D.H.; Cooper, R.D. 1999. Using shelterwood harvests and prescribed fire to regenerate oak stands on productive upland sites. Forest Ecology and Management. 113:125-141.

Clark, B.F. 1993. An historical perspective of oak regeneration. In: Oak regeneration: Serious problems, practical recommendations. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 3-13.

Cole, K.L.; Klick, K.F.; Pavlovic, N.B. 1992. Fire temperature monitoring during experimental burns at Indiana Dunes National Lakeshore. Natural Areas Journal. 12:177-183.

Heiligmann, R.B.; Norland, E.R. 1985. 28-year-old reproduction on five cutting practices in upland oak. Northern Journal of Applied Forestry. 2:17-22.

Kimmerer, R.W.; Lake, F.K. 2001. The role of indigenous burning in land management. Journal of Forestry. 99:36-41.

Lorimer, C.G. 1993. Causes of the oak regeneration problem. In: Oak regeneration: Serious problems, practical recommendations. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 14-39.

United States Department of Agriculture, Soil Conservation Service. 1985. Soil survey of Jackson County, Ohio. Washington, D.C. The Service. 159 p.

United States Department of Agriculture, Soil Conservation Service. 2003. Soil survey of Ross County, Ohio. Washington, D.C. The Service. 307 p.