TREE MORTALITY FOLLOWING A DROUGHT-YEAR LIGHTNING IGNITION IN THE OUACHITA MOUNTAINS, ARKANSAS: 2 YEARS POSTBURN

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Abstract—Increasingly, fire managers are using natural ignitions in conjunction with prescribed burns to restore and maintain fire-adapted ecosystems. Increased fuel loading from fire suppression and increasing drought indices associated with climate change, however, may cause natural ignitions to burn with greater intensity and severity. Managers must weigh risk factors versus benefits before allowing a lightning ignition to burn under these conditions. During the severe drought of 2011, the Ouachita National Forest had more lightning ignitions than any year in recorded history. While most were fully suppressed, one lightning ignition occurred in a particularly remote and rugged location that made suppression difficult and unsafe. Managers decided to use "less than full suppression" techniques and allowed this fire to burn within a designated containment area (~700 ha). Given the drought conditions, there was concern that significant overstory mortality would occur. We installed 32 randomly placed 10-m-radius circular plots directly after the fire in three community types: hardwood forest, pine-oak forest, and pine plantation. We identified and measured all trees ≥2.5 cm diameter at breast height (dbh) and determined scorch height and percentage, char height, and live or dead status. Plots were remeasured 1 and 2 years postburn to determine mortality. Overstory (>15.0 cm dbh) and midstory (≤15.0 cm dbh) stem densities were reduced significantly 1 year postburn by 5 and 64 percent respectively, but not significantly between 1 year postburn and 2 years postburn. The long-term outlook for the Southern Region includes hotter and drier conditions. This study provides resource managers with information on tree mortality following a lightning ignition during a drought in the High Peak area of the southeastern United States, and will allow more informed decisions to be made on the necessity of suppressing wildfires versus using them to restore and maintain forest structure and composition.

INTRODUCTION

Lightning ignitions occur at times of the year when plant and animal communities have evolved to survive fire (Frost 1998) and, in theory, these ignitions should better restore and maintain fire-adapted ecosystems than prescribed fire (Knapp and others 2009). Increasingly, fire managers are considering the use of natural ignitions, in combination with prescribed burns, to restore and maintain fire-adapted ecosystems (Cohen and others 2007). Due to the buildup of surface fuels from years of fire suppression and increasing drought indices associated with climate change, however, natural ignitions can have greater intensity and severity than occurred in the historical fire regime. As part of this buildup in fuels, ladder fuels can increase the chance of a destructive crown fire (Agee and Skinner 2005) and smoldering duff around tree trunks can cause root or basal cambial damage, especially to mature trees (Jenkins and others 2011, Varner and others 2005, Varner and others 2007, Varner and others 2009). Finally, fire-caused injury to drought-stressed trees can make them more susceptible to insects and disease outbreaks (Fettig and others 2010).

During the summer of 2011, the Ouachita National Forest (ONF) in Arkansas experienced a severe drought during which the Palmer Drought Severity Index (Palmer 1965) was -2.3 and the Keetch Byrum Drought Index (Keetch and Byram 1968) was over 700 (table 1). In conjunction with the drought, a series of thunderstorms produced many lightning ignitions on ridges in the central part of the Ouachita Mountains; in fact, more lightning ignitions were reported than any previous year in recorded history. Although most of these ignitions were managed with full suppression, one occurred in a remote and rugged area near High Peak on the Caddo-Womble Ranger District. Previous wildfires in this area had proved challenging to suppress. In the interest of

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Table 1—Fire weather indices during the High Peak Wildfire, Ouachita National Forest, Arkansas, 2011

Index	Mean	Range
Maximum temperature	40 °C (104 °F)	36–43 °C (97–110 °F)
Minimum relative humidity	27%	18–36%
10-hour fuel moisture	7	5–11
Keetch Byram Drought Index	705	670–725

firefighter safety given the rugged terrain and extreme heat—and with the opportunity to allow this natural ignition to potentially reduce stem densities and move stands towards the desired future conditions—ONF staff decided to use "less than full suppression" techniques, whereby the fire was allowed to burn naturally within a contained area. The High Peak Wildfire burned nearly 607 ha of the 729-ha designated containment area between 29 July and 11 August 2011. Heat and drought indices were extreme during this time (table 1).

Given the severe drought, some Forest Service personnel were concerned that the fire might cause excessive timber damage and mortality. Varner and others (2005) found that reintroducing fire into long-unburned longleaf pine (*Pinus palustris* Mill.) stands resulted in excessive (>50 percent) overstory pine mortality. This mortality may have resulted from smoldering duff around the bases of trees causing root and basal cambial damage, as mortality was positively correlated with decreasing duff moisture in these forests (Varner and others 2007). Overstory pine mortality in these studies, however, occurred following spring burns. As leaves begin to emerge in the spring, transpiration occurs, with water pulled through feeder roots to the new leaves. This causes duff moisture content to drop suddenly, leaving many feeder roots in the duff to be heated and killed by a smoldering fire. Knapp and others (2009) noted that in the summer, when the duff is dry, feeder roots have moved deeper in the soil; hence, duff consumption may not translate to tree mortality at this time of year. Many other factors, however, could also contribute to tree mortality, including fuel loading (Prichard and Kennedy 2012), crown damage due to scorch and/or consumption (Saveland and Neuenschwander 1990, Wyant and others 1986), and fire intensity (Prichard and Kennedy 2012, Regelbrugge and Conrad 1993).

Tree mortality has been studied in relation to wildfire (Regelbrugge and Conrad 1993), prescribed fire (Swezy and Agee 1991), and drought (Elliott and Swank 1994), but no studies have examined tree mortality in the Ozark-Ouachita Highlands in relation to lightning-ignited fire during a severe drought. The High Peak Wildfire provided a unique opportunity to document the combined effects of wildfire and drought on tree mortality. The objective of this research was to examine tree mortality following the High Peak Wildfire over a 2-year period. The Ouachita National Forest Plan indicates that a response to "unplanned, natural ignitions may include fire use, which is managing the ignition to accomplish specific resource management objectives in predefined areas" (Ouachita National Forest 2005). One of those objectives is fire fighter safety and another is returning fire to its historical role in defining forest structure and composition. Although we cannot attribute tree mortality directly to the fire because our data did not include unburned areas for comparison, we present results from a case study on tree mortality following naturally ignited fires under extreme drought conditions in the High Peak area.

METHODS

Study Site

The ONF is located in the Ouachita Mountain Ecoregion (Ouachita Ecoregional Assessment Team 2003) of western Arkansas and eastern Oklahoma. Ridges are underlain by Pennsylvania and Mississippi sandstone and shale valleys with clayey colluviums and covered with pine, pine-oak (*Quercus* L. spp.), and oak woodlands and forests (U.S. Department of Agriculture, Forest Service 1999). We conducted our study in the central part of the Ouachita Mountain Ecoregion on the Caddo-Womble Ranger District of the ONF at the High Peak Wildfire.

Data Collection

We randomly generated 50 points within the High Peak Wildfire containment area. We visited each point directly after the fire and installed rebar at the center of a 10-m-radius circular plot in burned areas (32 plots). Due to time constraints and lack of personnel, plots were not established in unburned areas at this time. Therefore, we were unable to distinguish between mortality caused by the wildfire and mortality due to other factors (e.g., drought).

The percentage of area burned per plot was assessed using ocular estimation. Ground-level burn severity was assessed using a rating system from 1 to 5, where: 5 =

unburned, 4 = scorched (litter partially blackened but wood and leaf structures unchanged), 3 = lightly burned (litter charred to partially consumed and upper duff may be slightly charred), 2 = moderately burned (litter mostly to entirely consumed and duff deeply charred), and 1 = heavily burned (litter and duff completely burned leaving fine white ash and mineral soil visibly altered).

On each plot, we identified and measured the diameter at breast height (dbh) of all trees ≥2.5 cm dbh and determined scorch height, percentage of crown volume scorched, char height, and live or dead status. Char is defined as the blackening of the boles of trees, whereas scorch is leaf mortality caused by radiant or convection heat. Since we were unable to collect preburn data, we used immediate postburn conditions to reconstruct the preburn composition of live versus dead trees. We assumed trees with scorched leaves were alive preburn. We classified trees >15 cm dbh as overstory and trees ≤15 cm as midstory. Based upon species composition, sites were classified into three forest types: hardwood, pine-oak, and pine plantation. Hardwood forests were dominated by white oak (*Quercus alba* L.), hickory (*Carya* L. spp.), blackgum (*Nyssa sylvatica* Marshall), and northern red oak (*Quercus rubra* L.); pine-oak forests were dominated by shortleaf pine (*Pinus echinata* Mill.), white oak, hickory, northern red oak, and red maple (*Acer rubrum* L.); and pine plantation by loblolly pine (*Pinus taeda* L.) All plots were remeasured 1 and 2 years postburn to determine mortality and changes in tree composition.

Eight 15.24-m planar intercepts (Brown 1974) were established randomly in the burn unit and measured preburn and immediately postburn to determine average fuel consumption on the burn. These transects were not associated with the 32 plots being used to assess tree mortality. We tallied preburn and postburn dead and down woody fuel that bisected each planar intercept. In the first 1.83 m of the planar intercept, we tallied 1- and 10-hour woody fuels (≤0.64 cm and 0.65-2.54 cm diameter, respectively). In the first 3.66 m of the planar intercept, we tallied 100-hour fuels (2.55-7.62 cm diameter). For logs (>7.62 cm diameter), we recorded diameter, decay class, and species type (hardwood or pine) along the entire 15.24-m transect. We sampled depth of litter and duff (to the nearest 0.25 cm) in an exposed profile using a trowel and ruler at 10 points along each planar intercept preburn and postburn.

Analyses

We first calculated frequency of species found in plots (percentage of plot where species occurred). We then calculated the density (live stems/ha) of trees per plot. Because plots were measured more than once and data were not normally distributed, we used generalized estimating equations (GEE) to model the effects of time since burn on live-stem density. The GEE model is an extension of the generalized linear model to longitudinal data analysis using quasi-likelihood estimation (Liang and Zeger 1986, Zeger and Liang 1986). The GEE models used a Poisson distribution and an exchangeable correlation structure (Littell and others 2002). Contrasts and Wald chi-square statistics were used to compare preburn and 1- and 2-year postburn live-stem densities.

RESULTS

White oak and shortleaf pine were the most frequently found overstory species in hardwood and pine-oak forest plots, found on 75 and 50 percent of preburn plots, respectively (table 2). Loblolly pine was the dominant species in pine plantations. Of all overstory frequencies, northern red oak frequency was the most reduced (table 2). The most frequent midstory species in preburn plots were red maple, blackgum, white oak, mockernut hickory (*Carya tomentosa* (Poir) Nutt.), and black cherry (*Prunus serotina* Ehrh.) (table 3). The frequency of all midstory species declined between preburn and 2 years postburn, but the frequency of common serviceberry [*Amelanchier arborea* (Michx. f.) Fernald], northern red oak, black cherry, flowering dogwood (*Cornus florida* L.), sweetgum (*Liquidambar styraciflua* L.), and red maple was reduced over 50 percent.

Total fuel loading was reduced from 22.0 t/ha to 13.7 t/ha. Litter was reduced from 7.2 to 2.5 t/ha (3.9 cm to 1 cm), duff was reduced from 6.9 to 5.2 t/ha (1.2 cm to 0.9 cm), and woody fuels were reduced from 7.8 to 6.1 t/ha. Note that while many logs were observed to be consumed during the High Peak Wildfire, no logs were measured in planar intercepts. Thus, this estimate of woody fuel consumption is most certainly an underestimation. Average char height was 0.20, 0.31, and 0.42 m and average scorch height was 4.51, 4.12, and 6.60 m in the hardwood forest, pine-oak forest, and pine plantation, respectively (table 4). Overstory scorch was 15, 18, and 34 percent in the hardwood forest, pine-oak forest and pine plantation, respectively. Plot area burned ranged from 76 percent in the hardwood forests to 86 percent in the pine-oak forest to 99 percent in the pine plantation. Plots in all communities burned with a moderate severity (table 4).

Across all forest types, the density of living stems was reduced 51 percent from preburn to 1 year postburn ($p < 0.05$) but only 2 percent from 1 year postburn to 2 years postburn ($p > 0.05$) (fig. 1). Midstory stem density was significantly reduced between preburn and 1 year postburn (64 percent, $p < 0.0001$) but not significantly between 1 year postburn and 2 years postburn (3 percent, $p = 0.1435$). Overstory stem density was significantly reduced from preburn to 1 year postburn (5 percent, $p = 0.0382$) but not significantly from 1 year postburn to 2 years postburn (1 percent, $p = 0.5095$) (fig. 1).

Table 2—Frequency of predominant overstory species (>8%) found in preburn and 2-year postburn plots on the High Peak Wildfire, Ouachita National Forest, Arkansas, 2011-2013

Common name	Scientific name	% Frequency	
		Preburn	Year 2
White oak	*Quercus alba* L.	75	72
Shortleaf pine	*Pinus echinata* Mill.	50	47
Northern red oak	*Quercus rubra* L.	41	25
Blackgum	*Nyssa sylvatica* Marshall	28	22
Mockernut hickory	*Carya tomentosa* (Poir) Nutt.	25	25
Black hickory	*Carya texana* Buckley	22	22
Loblolly pine	*Pinus taeda* L.	22	22
Red maple	*Acer rubrum* L.	19	13
Sweetgum	*Liquidambar styraciflua* L.	16	16
Black oak	*Quercus velutina* Lam.	13	16
Post oak	*Quercus stellata* Wangenh.	9	6
Black cherry	*Prunus serotina* Ehrh.	9	6

Table 3—Frequency of predominant midstory species (>30%) found in preburn and 2-year postburn plots on the High Peak Wildfire, Ouachita National Forest, Arkansas, 2011-2013

Common name	Scientific name	% Frequency	
		Preburn	Year 2
Red maple	*Acer rubrum* L.	78	38
Blackgum	*Nyssa sylvatica* Marshall	72	47
White oak	*Quercus alba* L.	72	44
Mockernut hickory	*Carya tomentosa* (Poir) Nutt.	69	38
Black cherry	*Prunus serotina* Ehrh.	69	25
Black hickory	*Carya texana* Buckley	56	41
Northern red oak	*Quercus rubra* L.	56	19
Winged elm	*Ulmus alata* Michx.	50	28
Flowering dogwood	*Cornus florida* L.	44	16
Shortleaf pine	*Pinus echinata* Mill.	38	28
Common serviceberry	*Amelanchier arborea* (Michx. f.) Fernald	34	9
Sweetgum	*Liquidambar styraciflua* L.	34	16
Hophornbeam	*Ostrya virginiana* (Mill.) K. Koch	34	25
Black oak	*Quercus velutina* Lam.	31	19

Table 4—Burn intensity and severity ratings for different forest types on the High Peak Wildfire, Ouachita National Forest, Arkansas, 2011

Burn variable	Hardwood (n = 9)		Pine-oak (n = 18)		Pine plantation (n = 5)		Total (n = 32)	
	-mean-	--SE--	-mean-	--SE--	-mean-	--SE--	-mean-	--SE--
Char height (m)	0.20	0.06	0.31	0.04	0.42	0.16	0.30	0.04
Scorch height (m)	4.51	0.98	4.12	0.44	6.60	1.17	4.62	0.42
Scorch (%)	46	10	54	5	58	10	52	4
Overstory scorch (%)	15	4	18	4	34	12	19	3
Plot area burned (%)	76	13	86	5	99	1	85	5
Severity rating (1-5)[a]	2.8	0.3	2.9	0.1	2.9	0.1	2.9	0.1
Total mortality (%)	42	9	47	6	49	8	46	4

[a] Burn severity: 1= high; 5 = unburned.
SE = Standard error.

Overstory density was higher in the pine plantations preburn and 2 years postburn (940 and 933 stems/ha) than both the hardwood community (307 and 267 stems/ha) and pine-oak community (379 and 355 stems/ha) (fig. 2). By forest type, overstory density was reduced 13, 6, and <1 percent 2 years postburn in the hardwood forest, pine-oak forest, and pine plantation, respectively, but none of the overstory reductions were significant ($p > 0.05$) (fig. 2). Preburn midstory density was higher in the pine plantations than hardwood and pine-oak communities (2247 versus 1459 and 1405 stems/ha, respectively), but similar to hardwood and pine-oak communities 2 years postburn (613 versus 704 and 440 stems/ha respectively) (fig. 3). By forest type, midstory density was significantly reduced from preburn to year 2 postburn by 52 ($p = 0.0245$), 69 ($p < 0.0001$), and 73 ($p = 0.0001$) percent in the hardwood forest, pine-oak forest, and pine plantation, respectively (fig. 3).

DISCUSSION

Stem density of woody plants in the Ozark-Ouachita Highlands was historically much lower than it is today (Spetich 2004). Chapman and others (2006) compared stem density of woody plants on the Sylamore Experimental Forest in northern Arkansas and found overstory stem density (≥14.1 cm dbh) increased from 124 stems/ha to 344 stems/ha between 1934 and 2002, while midstory stem density (4.1–14.0 cm) increased from 240 stems/ha to 688 stems/ha. Using the General Land Office data from the 19th century, Foti (2004) found historical stem densities of 121 stems/ha and 112 stems/ha in the Boston Mountains and Ozark Highlands, respectively. Preburn stem density of overstory and midstory canopy layers on High Peak was higher than historical conditions in all three community types (figs. 2, 3).

High stem density, often a result of fire suppression, can make stands more susceptible to insect outbreaks (Schowalter and others 1981) and high-intensity fire (Agee and Skinner 2005) or, in some cases, less susceptible to fire (Nowacki and Abrams 2008). Prescribed fire management objectives often include a reduction in midstory stems, an increase in herbaceous plant diversity, improved wildlife habitat, improved health and vigor of overstory trees, and restoration of historical forest composition and structure (Andre and others 2009, Guldin and others 2004). Attaining these objectives is possible with prescribed fire, but sometimes requires several burns or mechanical treatments (e.g., thinning) because prescribed burns are conducted under conservative burn prescriptions (Knapp and others 2009, Waldrop and others 2010). Lightning fires, on the other hand, usually occur during drought conditions when prescribed burns would typically be avoided. Thus, these fires may provide an avenue for attaining management objectives more efficiently.

Following the High Peak Wildfire, which ignited from a lightning strike during drought conditions, midstory and overstory densities were significantly reduced between preburn and 1 year postburn. Overstory mortality 1 year postburn was higher than typical background mortality (Clark and others 2008, Klos and others 2009), but mortality from 1 to 2 years postburn was not significant. Overstory density in hardwood and pine-oak forests was reduced to 267 and 356 stems/ha, respectively, moving them closer to historical stand structures. At the same time, pine plantations experienced little mortality and retained an overstory density of 933 stems/ha. The reduced competition as a result of midstory stem density reduction may benefit growth rates of

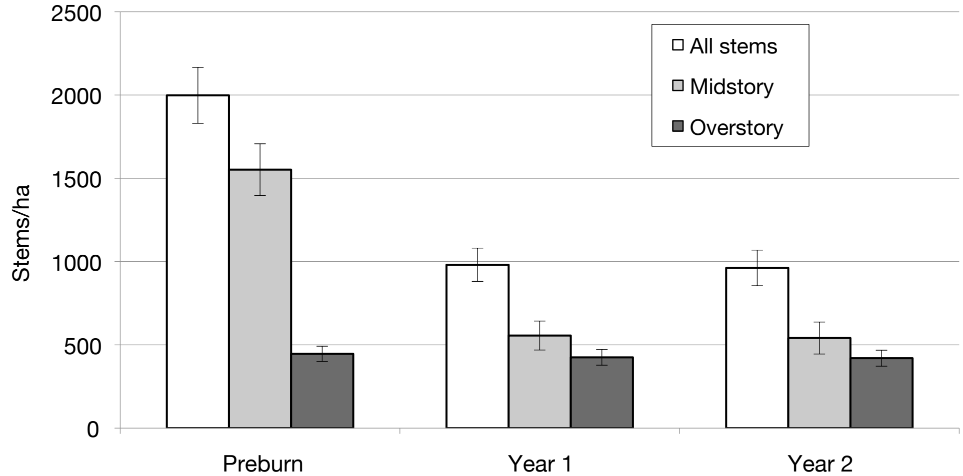

Figure 1—Density of total, midstory, and overstory stems from preburn to 2 years postburn on plots on the High Peak Wildfire in Arkansas, 2011-2013 (bars represent ±1 standard error). There was significant decline between preburn and 1 year postburn but not between 1 year and 2 years postburn in all stems, midstory, and overstory.

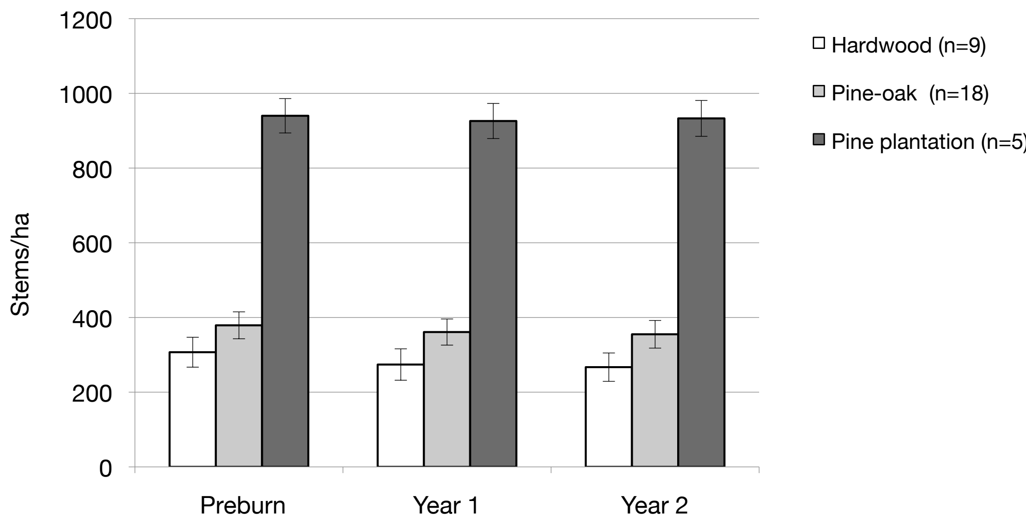

Figure 2—Overstory stem density by community type from preburn to 2 years postburn on plots on the High Peak Wildfire in Arkansas, 2011-2013 (bars represent ±1 standard error). There was no significant decline postburn in any overstory community.

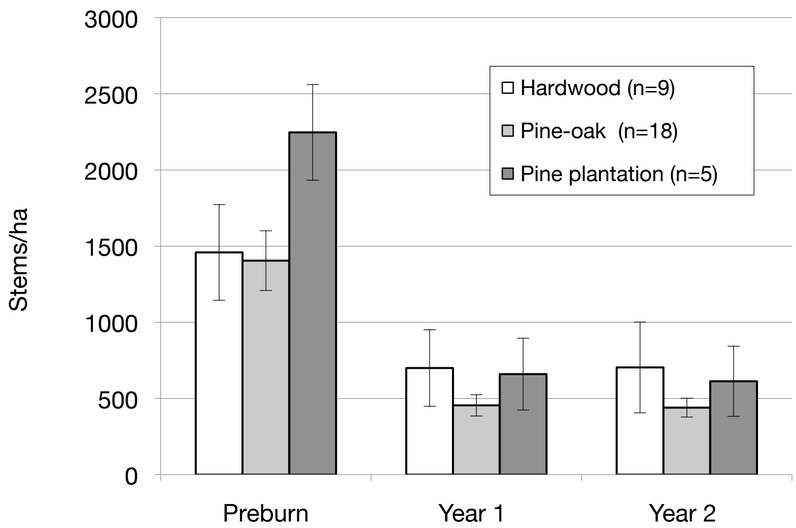

Figure 3—Midstory stem density by community type from preburn to 2 years postburn on plots on the High Peak Wildfire in Arkansas, 2011-2013 (bars represent ±1 standard error). There was significant decline between preburn and 1 year postburn but not between 1 year and 2 years postburn in hardwood, pine-oak and pine plantation communities.

overstory trees and allow for increased understory diversity (Masters and others 1998). Thinning of both the midstory and overstory could ultimately make the forest less susceptible to disease and insect outbreaks (Schowalter and others 1981). In conclusion, based upon the degree of mortality observed relative to historical stand densities, this fire assisted the ONF in reaching its resource management objectives.

The reduction in density we observed after the High Peak Wildfire has led other fire managers on the Ouachita National Forest to use "less than full suppression" tactics with other wildfires [Raspberry Mountain Wildfire, Caddo-Womble Ranger District (RD), 2012; Rough Branch Wildfire, Oklahoma RD, 2013; and Pipeline Wildfire, Jessieville-Winona-Fourche RD, 2013]. We will remeasure plots on the High Peak Wildfire 5 years postburn to document potential delayed mortality. Ultimately, we hope to expand this research to other areas and include control plots, thus enabling us to make mortality predictions in areas beyond the area of the High Peak Wildfire.

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