SOME FIRST-YEAR WILDFIRE EFFECTS ON TREE AND STAND CHARACTERISTICS ON THE CUMBERLAND FOREST, TENNESSEE

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Abstract—The summer and early fall of 2016 were characterized by an extended period of drought in Tennessee with as little as 3.8 inches of precipitation from August 1 through November 28. Subsequently, the fall fire season was exceptional in numbers of fires, the intensity with which they burned, and the severity of their impacts. One such wildfire burned 500 acres on the University of Tennessee's Cumberland Forest near Coalfield, TN, in late November. A study comparing the impact of this wildfire on the burned forest with the adjacent forest was initiated the following June. In the unburned forest, 3.5 percent of trees were estimated as recent mortality (<1 year old mortality) at the time of plot establishment. First-year results in the burn area indicated 87.6 percent of measured trees sustained some damage and 14 percent were top-killed by the fire. Chestnut oak (*Quercus montana*), the most common tree (*n* = 135), experienced 8.1 percent aboveground mortality, followed by yellow-poplar (*Liriodendron tulipifera*, *n* = 47) with 12.8 percent, and red maple (*Acer rubrum*, *n* = 125) with 16.8 percent. Mean scorch height was 2.95 feet, 2.05 feet, and 2.04 feet for these species, respectively. Basal burn was 76.1 percent, 68.0 percent, 46.0 percent for chestnut oak, red maple, and yellow-poplar, respectively. Red maple located in plots categorized as burned by high-severity fire experienced 37.2 percent top-kill and another 39.5 percent were experiencing significant decline by the end of the first growing season. Plots with 15-year-old legacy shortleaf pine (*Pinus echinata*) stumps had a mean fire severity of 3.7 (1-5 scale: low to high severity); plots without stumps had a mean fire severity of 2.8.

INTRODUCTION

Major wildfire events are often perceived as a western phenomenon because of the prevailing weather conditions and fuel types that make dramatic, large-scale, high-severity fires a relatively common occurrence. This frequency allows ample opportunity to investigate the ecological impacts of these stand-replacing events on western forests. For example, numerous reports spanning more than 60 years document ponderosa pine (*Pinus ponderosa*) mortality in high-severity burn areas and subsequent natural regeneration shortfalls rangewide (Ffolliot and others 2008, Lynch 1959, McHugh and Kolb 2003, Pearson 1950, Schmidt 1988, Schubert 1974).

While major mixed-severity wildfires can occur in the hardwood forests of the Eastern United States, regional climatic conditions are typically less favorable for major conflagrations. Additionally, fuel types and structure generally lend themselves to less dramatic surface fires of variable intensity and lower severity. The resulting lack of major wildfires in the Eastern United States has led to a dearth of literature on the effects of high-severity wildfire in this region. For example, the authors are aware of only one published source looking at postfire mortality in high- and low-severity fires of upland hardwoods of Virginia (Regelbrugge and Smith 1994). Most literature on fire in the East reports on effects of prescribed fire such as in the synthesis of fire-oak literature by Brose and others (2014).

However, there may be problems with inferring wildfire impacts from prescribed fire effects. For instance, major wildfires generally occur outside the prescriptive windows allowed by State permitting agencies. As such, not only would fuel moisture typically be lower at these times but soil moisture would be as well, especially during extended dry periods. Both points are important to consider as lower fuel moisture would contribute to higher burn intensity (all other factors being equal). With depressed soil moisture during extended dry periods, trees become stressed as xylem sap water pressure is decreased throughout its conductive tissue. As a result, these trees may be less capable of convective dissipation of heat by distributive movement of heated sap water (Michaletz and others 2012) and therefore potentially more susceptible to cambial necrosis, historically accepted as the cause of tree mortality

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(Dickinson and Johnson 2004). But the above decrease in sap pressure and susceptibility to heating has also been shown to cause xylem conduit deformation and transport cavitation (Lodge and others 2018, Michaletz and others 2012, Midgley and others 2011). This cavitation and deformation could contribute to the likelihood of top-kill from fire.

The summer and early fall of 2016 was characterized by an extended period of drought in Tennessee. Subsequently, the regional fall fire season was exceptional in number of fires, the intensity with which they burned, and the severity of their effects. A notable example was the 17,000-acre Chimney Tops 2 wildfire that burned into Gatlinburg, TN, at the end of November. At the same time as the Chimney Tops 2 wildfire, the Little Brushy wildfire burned 500 acres on the University of Tennessee's Cumberland Forest near Coalfield, TN. Beginning in June 2017, a study was begun using a paired stand approach investigating the impacts of this fire on the burned area in comparison to 500 acres of adjacent unburned but drought-impacted stands. This paper reports on some of the first-year findings.

MATERIALS AND METHODS

Location and Drought Conditions

The University of Tennessee's Cumberland Forest is located in Morgan County, TN. Particularly, the wildfire burned on Little Brushy Mountain located on the southernmost ridge of the Cumberland Mountain level III ecoregion (Griffith and others 1998). This elongated highland ridge runs east and west with a base elevation of under 1300 feet, a high point over 2100 feet, and is underlain by horizontal Pennsylvanian rocks of the Pottsville series. These strata are composed of fine-grained sandstone layers alternating with beds of shale, siltstone and coal (Wilson and others 1956). The wildfires extended from near the base of both the north and south sides and over the top of the mountain ridge (fig. 1).

Forests of this region are characterized as Appalachian mixed mesophytic with a highly diverse species composition. Past disturbance included mining and

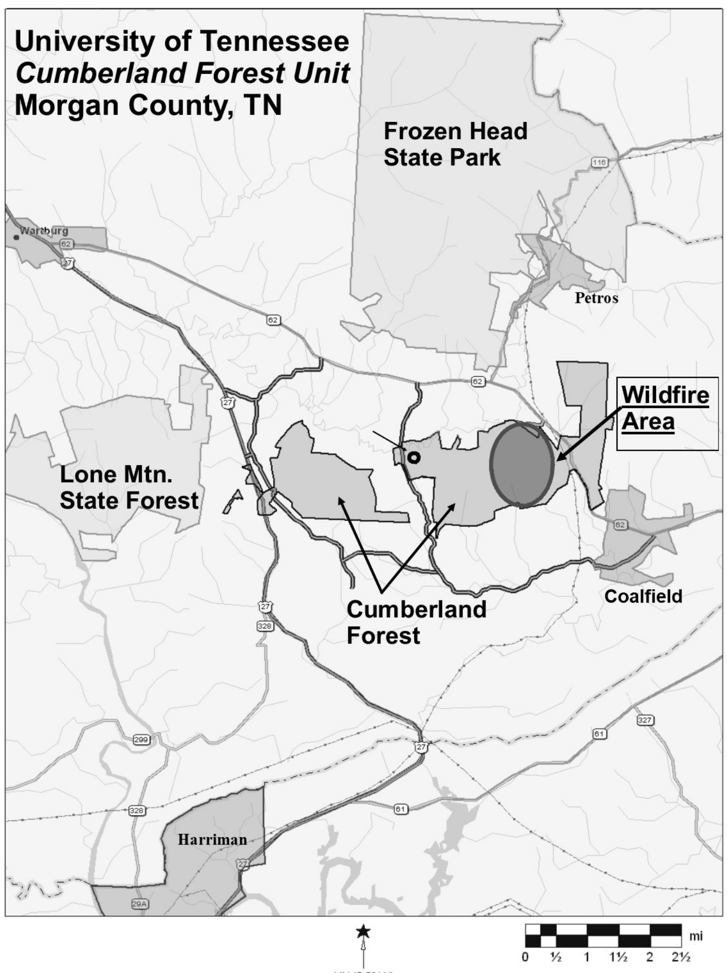

Figure 1—General location map of the University of Tennessee, Forest Resources Research and Education Center's Cumberland Forest Unit in Morgan County, TN, with the wildfire area highlighted.

extensive high-grading prior to University ownership in 1936. Some contour mining persisted through 1964 and pine afforestation trials were conducted on mined and cutover lands. Wildfire occurred regularly on the property prior to 1950 (Kring 1950). Subsequently, the area experienced little to no widespread disturbance until a southern pine beetle epidemic removed the overstory pine component from 1999-2002. One 53-acre clearcut regeneration harvest was conducted in the area in 2011.

From August 1 through November 28, 2016, only 3.8 inches of precipitation were recorded at the Cumberland Forest's weather station (normal 4-month mean precipitation at this site through November is 17.4 inches (Logan and others 1990)). The drought by the end of November 2016 (according to the Standardized Precipitation-Evapotranspiration Index (SPEI)) was of near-record severity (fig. 2). The 1000-hour fuel moisture was a record minimum value of 15 percent on November 22 (USDI 2017). On November 23, wildfire was reported on the Cumberland Forest and burned through November 28.

Plot Design

In the summer of 2017, 30 0.10-acre, fixed-radius permanent plots were established in the 500-acre wildfire area and 30 plots were placed in adjacent unburned forest on an 860-foot by 860-foot grid. Each plot had a 0.01-acre, nested revegetation circular micro-plot located at 90 degrees and 18.6 feet from plot center.

Plot Measurement Variables

Plot center was marked with a heavy gauge iron pin. Plot level parameters collected included slope (percent), aspect (degrees), overstory crown density (percent) using a densiometer, shortleaf pine (*Pinus echinata*) stump hole presence (True/False), and plot burn severity (0-5; 0 = unburned, 1 = surface fire (<5 percent replacement of upper canopy layer from top-kill), 2 = low severity fire (6-25 percent top-kill), 3 = moderate/mixed severity fire (26-75 percent top-kill), 4 = high severity fire (76-95 percent top-kill), and 5 = replacement fire (>95 percent top-kill)). These burn severity categories followed a hybrid of LANDFIRE fire severity classes (LANDFIRE 2013) and the Fire Effects Information System term definitions (USDA FS 2020) and the authors' additional upper- and lower-end delineations. These modifications

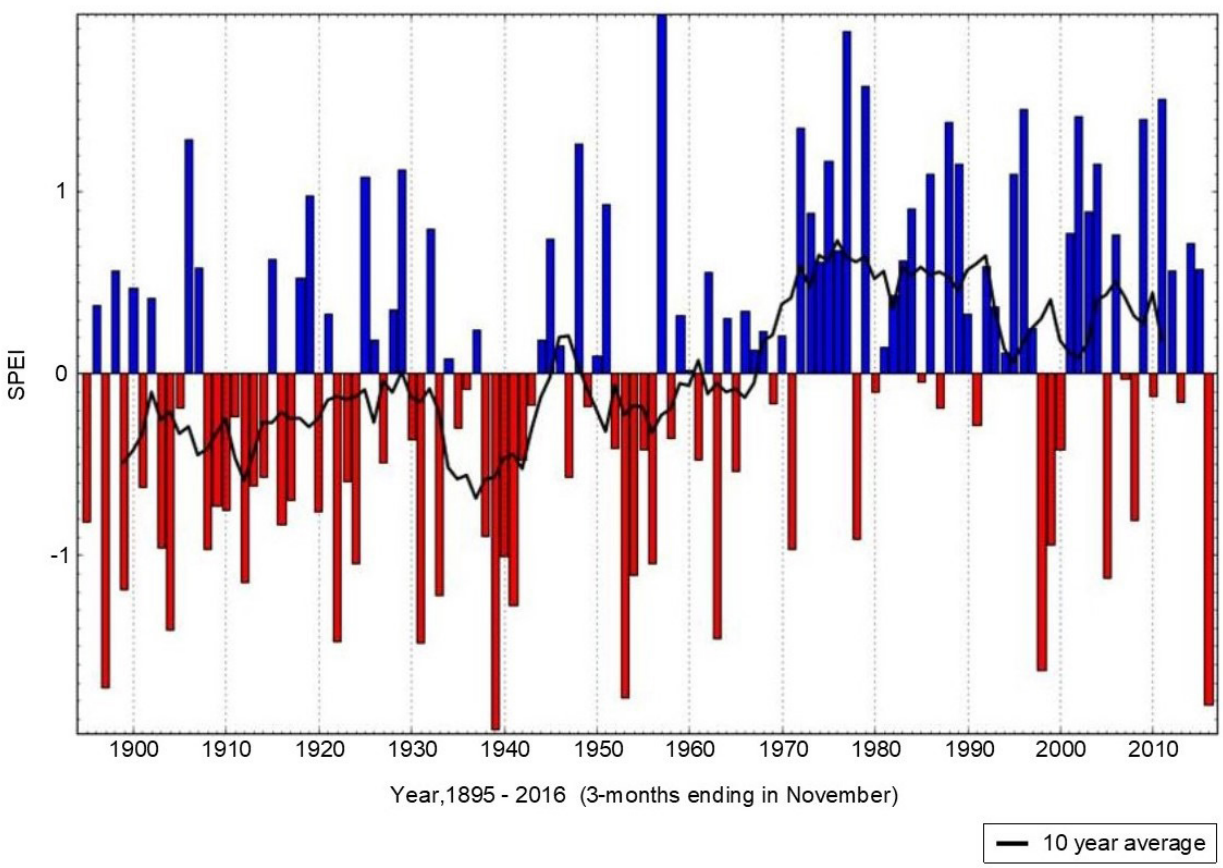

Figure 2—Standardized Precipitation-Evapotransporation Index (SPEI) for Tennessee. SPEI is a multiscalar drought index (Beguería and others 2014) which, in this case, used data sourced from the Western Regional Climate Center (https://wrcc.dri.edu/). Bars extending below 0 indicate annual moisture deficiency with the 2016 bar representing 11-month negative surpassed only by 1939.

were made to accommodate the paired unburned area of the study (0 = unburned) and to distinguish them from plots that may have experienced only partial burns on the lower end of the scale (1 = surface fire). The inclusion of the upper-scale category, the stand-replacement burn severity (index class 5), allowed for a finer-grain data capture of extreme fire effects achieved by these wildfire conditions in contrast to fire behavior under normal prescribed fire conditions in the Eastern United States.

Tree Variables

Each stem 5 inches or greater in diameter at breast height (d.b.h.) in the 0.10-acre plot was tagged with a uniquely numbered aluminum tag attached near the base-facing plot center. In the case of multiple sprouts, each individual stem (ramet) was measured and recorded distinctly and the clump (genet) was numbered. The tree species was identified, and d.b.h. (inches and tenths) and total height (feet) were measured and recorded. A TruPulse® laser clinometer was used to measure tree height. Crown class was noted (1-5; 1 = dominant, 2 = codominant, 3 = intermediate, 4 = suppressed, 5 = dead). Mortality rank was given on a 1-3 scale (1 = assumed survival, 2 = significant decline, 3 = dead). In unburned plots, mortality was estimated to be >3 years old, about 2 years old, and <2 years old at measurement. Physical characteristics such as remaining presence of attached dead leaves, enduring fine twigs, and presence and quantity of intact bark were used as most recent mortality indicators. Acknowledgement of general fire damage (True/False) was noted on burn plots and specifically, scorch height was recorded (feet and tenths) as well as the percentage of the circumference of the base that was burned. Finally, acknowledgement of burned out shortleaf pine stump holes within 10 feet of the tree was noted (True/False).

Micro-Plot Variables

In the micro-plot, seedlings taller than 1 foot but less than 1 inch in d.b.h. were tallied. Height and d.b.h. for saplings between 1 inch and 5 inches in d.b.h. were measured and recorded. Finally, percent cover was estimated and categorized (vines, grasses, shrubs, forbs).

Analysis

The wildfire effects on plot and tree variables were analyzed using the Real Statistics Resource Pack software Release 6.8 (Zaiontz 2020) with supplementary graphics generated by R package '*ggplot2*' (R Core Team 2017, Wickham 2016).

For the plot-level data, we investigated the relationships between shortleaf pine stump presence and burn severity and slope. After verifying normal distribution of the data with Shapiro-Wilk's test, we used 2-sample t-tests to look for differences between burn severity and slope of plots with stumps present and absent.

We restricted our tree-level analyses to red maple (*Acer rubrum*), yellow-poplar (*Liriodendron tulipifera*), and chestnut oak (*Quercus montana*). Tree species differences in normally distributed variables (mortality) were investigated with one-way analysis of variance followed by pairwise t-tests. Differences among tree species for variables not normally distributed (mortality index, scorch height, base burn, and burn severity) were explored with nonparametric Kruskal-Wallis tests, followed by pairwise Mann-Whitney exact tests.

The unburned plot data were used in this analysis only as a contrasting reference to fire induced top-kill. It is recognized that this unburned mortality likely represents a process of tree decline in their entirety (above- and belowground) and over a period of time rather than the crown replacement more prevalent in this disturbance event. Only recent mortality in the unburned plots (estimated dead <2 years) was used for comparison.

RESULTS

Plot Variables

Every plot established in the wildfire area had been burned through, confirming the almost complete coverage of the fire within the 500-acre area. Percent slope for the plots ranged from a low of 4 percent to a high of 65 percent with two-thirds having slopes greater than 31 percent. Aspect did not appear to influence burn severity except potentially in the lowest severity class (1) where only two plots were north-by-northwest facing (336 and 344 degrees). Distribution of plot burn severity (1-5) had a bell shape slightly weighted to the severe end with a third of the plots ranked at a 3 and 23 percent ranked both as 2 and 4. Thirteen percent of the plots experienced high severity fire.

Plots with burned-out shortleaf pine stumps (n = 12) had a mean burn severity of 3.7. Plots without stumps (n = 18) had a mean severity of 2.8 and similar variance ($F_{11,17\,=}$ 1.281, $p < 0.345$). This significant difference ($p < 0.033$) in mean severity might be due in part to the historical occurrence of shortleaf pine in areas topographically predisposed to more extreme fire behavior; mean aspect of plots with shortleaf pine was 197.3 degrees and 216.5 degrees without shortleaf pine. However, 13 of the 18 plots with historical shortleaf pine absent had a northerly aspect (270 – 360 degrees; 0 – 90 degrees). Ten of the 12 plots with legacy shortleaf pine stumps had a southerly aspect (>90 and < 270 degrees). Average slope for plots without legacy shortleaf pine was 40 percent and were not significantly different ($p < 0.247$) from plots with stumps (32 percent) and similar variance ($F_{11,17\,=}$ 0.785, $p < 0.317$).

Tree Variables

The three most prevalent species in the burn area were chestnut oak (31.3 percent; *n*=135), red maple (29.0 percent; *n*=125) and yellow-poplar (10.9 percent; *n*=47) (table 1). Mean tree d.b.h. of these species ranged from 14.4 inches for yellow-poplar and 13.5 inches for chestnut oak to 8.5 inches for red maple. Fire damage was observed on 87.6 percent of all trees measured in the wildfire area. Fourteen percent of all trees were recorded as top-killed during the first growing season after the fire. Only 3.5 percent of measured trees were estimated to have died within 1 year in the adjacent unburned forest. Chestnut oak, yellow-poplar, and red maple experienced 8.1 percent, 12.8 percent, and 16.8 percent mortality. The means of the ranks of the three species mortality index significantly differed between groups ($p < 0.002$; $\alpha = 0.05$). Chestnut oak mortality index value was 1.27 and similar to yellow-poplar's 1.47 ($p = 0.140$). Red maple mortality index was 1.56, significantly higher than chestnut oaks ($p = 0.005$) but not yellow-poplar ($p < 0.556$). The index value accounted for trees experiencing dramatic aboveground die-back, but were not top-killed.

Mean scorch height among the three species were 2.95 feet for chestnut oak, 2.04 feet for red maple, and 2.05 feet for yellow-poplar. There were significant differences in the means of the ranks of scorch heights among the three species ($p < 0.001$). Chestnut oak scorch height was greater than both red maple ($p < 0.001$) and yellow poplar ($p < 0.001$). Red maple and yellow poplar were similar ($p < 0.113$). Maximum scorch heights for the three species were 12 feet, 20 feet, and 13.5 feet respectively. Chestnut oak experienced significantly greater base burn damage (76.1 percent) than both yellow-poplar (46.0 percent) ($p <0.001$) but not red maple (68.0 percent) ($p = 0.463$) (ranked base burn group differences p = 0.001). Red maple and yellow-poplar base burn damage was significantly different ($p = 0.003$). The interaction of scorch height to base burn only became positively correlated above 75 percent basal burn (fig. 3).

Table 1—Occurrence (*n*), percent mortality, mortality index value, scorch height, base burn, and burn severity by species

Species	*n*	Mortality	Mortality index	Scorch height	Base burn	Burn severity
		percent		*feet*	*percent*	
Red maple	125	16.8	1.56 ± 0.8 b	2.04 ± 2.9 a	68.0 ± 38.2 b	3.6 ± 1.2 b
Yellow-poplar	47	12.8	1.47 ± 0.7 b	2.05 ± 3.1 a	46.0 ± 47.2 a	2.6 ± 1.5 a
Chestnut oak	135	8.1	1.27 ± 0.6 a	2.95 ± 2.8 b	76.1 ± 28.8 b	3.5 ± 1.1 b

Means (± standard deviation) in mortality index, base burn, and burn severity columns followed by the same letter are not significantly different ($p < 0.05$).

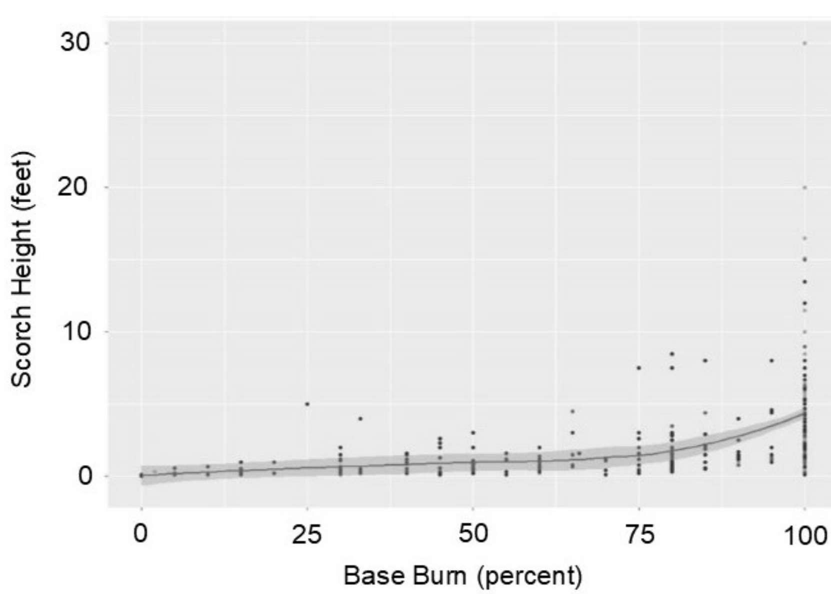

Figure 3—Correlation of scorch height (feet) by basal burn (percent). Increasingly positive correlation of scorch height begins past 75 percent basal burn.

Chestnut oak and red maple were fairly evenly distributed across burn severities while yellow-poplar was heavily skewed in numbers of occurrences in the low-severity plots. High-severity fire impacted every yellow-poplar with 42.9 percent mortality and the remaining 57.1 percent in decline. Red maple mortality was 37.2 percent with another 39.5 percent in decline. Chestnut oak mortality was 6.6 percent with another 33.3 percent in decline. (table 2).

DISCUSSION

Chestnut oak was the most prevalent species in the burn area. Surprisingly, it had the highest percentage of basal burn damage but had the lowest mortality rate. This corresponded with a significantly higher burn severity index measure than yellow-poplar, indicating its occurrence in areas with greater fire effects. Although previously existing fire scars were not measured as part of this study, given the age of the chestnut oak and frequency of historical fires known to have been common on the property prior to the 1950s (Kring 1950), it is likely that old fire scars also inflated the basal burning reported in this study. The ability of chestnut oak to compartmentalize damage explains how it remained on site despite previous scarring and corresponded with these mortality results.

Yellow-poplar followed the pattern reported by Nelson and others (1933) of being more resistant to basal damage than chestnut oak. Despite this resistance, mortality of poplar was greater than chestnut oak. When wildfire-caused mortality was exclusively considered, red maple had the highest number of stems top-killed. Initial top-kill and significant decline estimations of red maple may be overstated, however, as continued visitation to the plots revealed heavily damaged stems but many with full crowns persisting at the end of the second growing season. This may be indicative of a high tolerance for stem damage as a result of its diffuse-porous stem architecture that would prevent or prolong decline and mortality. Yellow-poplar had the highest rate of top-kill in areas of mixed/moderate, high, and replacement severity fires. Regelbrugge and Smith (1994) reported scorch height accounting for 93 percent of the variation in fire-killed basal area and 96 percent of variation in tree number measured 2 years after a wildfire in Virginia. Interestingly, scorch heights measured in this study were similar for the three most prevalent species. Yellow-poplar's frequency in low-severity plots should have low scorch heights reported and in fact there was a significantly lower mean basal burn percentage then chestnut oak.

Variability in scorch height for yellow-poplar may be attributed to topographical features and their effects on fire behavior. More specifically, this is indicative of

Table 2—Species occurrence (*n*), percent of total species population, percent mortality, and significant decline by burn severity class and percent of plots in burn class

Burn severity class	Plots in burn class	Species	Occurrence		Mortality	In decline
	percent		*n*	*percent*	*percent*	*percent*
1	6.6	CHO	0	0.0	-	-
		REM	6	4.8	-	-
		YEP	19	40.4	10.5	5.3
2	23.3	CHO	30	22.2	6.7	13.3
		REM	16	12.8	12.5	12.5
		YEP	2	4.3	-	-
3	33.3	CHO	44	32.6	2.3	-
		REM	45	36.0	4.4	8.9
		YEP	14	29.9	14.3	-
4	23.3	CHO	31	22.9	12.9	12.9
		REM	15	12.0	6.7	20.0
		YEP	5	10.7	20.0	60.0
5	13.3	CHO	30	22.2	6.6	33.3
		REM	43	34.4	37.2	39.5
		YEP	7	14.9	42.9	57.1

CHO = chestnut oak, REM = red maple, YEP = yellow-poplar a “chimney effect” on fire behavior impacting yellow-poplar occupying narrow drains on upland sites. These steep, narrow topographical features which are typically mesic sites with a thick duff layer and coarse woody debris under normal conditions, dried under the drought conditions experienced in 2016. The three sides of these features can funnel air upslope much like a chimney, creating strong convective currents and cross radiation between the three sides, concentrating the fires heat and preheating the existing heavy fuels. This environment may have created high flame fronts that scorched yellow-poplar as the fire burned uphill in drains occupied by these trees, compensating for the yellow-poplar that experienced little fire behavior at the low-severity plots.

CONCLUSIONS

These data may be too early to accurately determine top-kill and correlate mortality to an indicator variable(s) like scorch height or basal burn. Repeated measures are needed to track any shift in successional trajectories as caused by the fire. The large percentages of declining trees, especially yellow-poplar, may indicate ongoing mortality for the next few years. Mature yellow-poplar appeared more susceptible to mortality in the drought-fueled fall wildfire than red maple. Based on these preliminary results, wildfire effects may vary primarily by species in a mature upland eastern hardwood forest.

LITERATURE CITED

Beguería, S.; Vicente-Serrano, S.M.; Reig, F.; Latorre, B. 2014. Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. International Journal of Climatology. 34(10): 3001-3023.

Brose, P.H.; Dey, D.C.; Waldrop, T.A. 2014. The fire–oak literature of eastern North America: synthesis and guidelines. Gen. Tech. Rep. NRS-135. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 98 p.

Dickinson, M.B.; Johnson, E.A. 2004. Temperature-dependent rate models of vascular cambium cell mortality. Canadian Journal of Forest Research. 34: 546-559.

Ffolliott, P.F.; Stropki, C.L.; Neary, D.G. 2008. Historical wildfire impacts on ponderosa pine tree overstories: An Arizona case study. Res. Pap. RMRS-RP-75. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 20 p.

Griffith, G.; Omernik, J.; Azevedo, S. 1998. Ecoregions of Tennessee. Washington, DC: U.S. Environmental Protection Agency. ftp://newftp.epa.gov/EPADataCommons/ORD/Ecoregions/tn/tn_eco_lg.pdf. [date accessed: April 13, 2017].

Kring, J. 1950. Report of initial timber sale, University of Tennessee lands, Morgan County. Knoxville, TN: University of Tennessee, Agricultural Experiment Station. 4 p.

LANDFIRE. 2013. Forest vegetation simulator disturbance database. U.S. Department of Agriculture, Forest Service, and U.S. Department of the Interior. https://www.landfire.gov/lf_fvs.php. [date accessed: March 25, 2020].

Lodge, A.G.; Dickinson, M.B.; Kavanagh, K.I. 2018. Xylem heating increases vulnerability to cavitation in longleaf pine. Environmental Research Letters. 13: 055007. 8 p.

Logan, J.L.; Mueller, M.A.; Evans, R.M. [and others]. 1990. Climate summary 1957-1989, Cumberland Forestry Experiment Station, Morgan County, Joyner, Tennessee. Res. Rep. 90-26. Knoxville, TN: University of Tennessee, Agricultural Experiment Station. 13 p.

Lynch, D.W. 1959. Effects of a wildfire on mortality and growth of young ponderosa pine trees. Res. Note No. 66. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p.

McHugh, C.W.; Kolb, T.E. 2003. Ponderosa pine mortality following fire in northern Arizona. International Journal of Wildland Fire. 12: 7-22.

Michaletz, S.T.; Johnson, E.A.; Tyree, M.T. 2012. Moving beyond the cambium necrosis hypothesis of post-fire tree mortality: cavitation and deformation of xylem in forest fires. New Phytologist. 194: 254-263.

Midgley, J.J.; Kruger, L.M.; Skelton, R. 2011. How do fires kill plants? The hydraulic death hypothesis and Cape Proteaceae “fire resisters.” South African Journal of Botany. 77(2): 381-386.

Nelson, R.M.; Sims, I.H.; Abell, M.S. 1933. Basal fire wounds on some southern Appalachian hardwoods. Journal of Forestry. 31(7): 829-837.

Pearson, G.A. 1950. Management of ponderosa pine in the Southwest as developed by research and experimental practice. Agric. Monogr. No. 6. U.S. Department of Agriculture, Forest Service. 114 p.

R Core Team. 2017. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/. [date accessed: March 9, 2019].

Regelbrugge, J.C.; Smith, D.W. 1994. Postfire tree mortality in relation to wildfire severity in mixed oak forests in the Blue Ridge of Virginia. Northern Journal of Applied Forestry. 11(3): 90-97.

Schmidt, W.C., comp. 1988. Proceedings—future forests of the Mountain West: a stand culture symposium. Gen. Tech. Rep. INT-243. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 402 p.

Schubert, G.H. 1974. Silviculture of southwestern ponderosa pine: the status of our knowledge. Res. Pap. RM-123 Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 80 p.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2020. Fire Effects Information System glossary. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory. https://www.fs.fed.us/database/feis/glossary.html [date accessed: March 25, 2020].

U.S. Department of the Interior [USDI]. 2017. Chimney Tops 2 Fire review: individual fire review report. Washington, DC: U.S. Department of the Interior, National Park Service, Division of Fire and Aviation. 115 p. https://www.wildfirelessons.net/viewdocument/chimney-tops-2-fire-review-2017. [date accessed: May 05, 2020].

Wickham, H. 2016. ggplot2: elegant graphics for data analysis. https://ggplot2.tidyverse.org. [date accessed: March 9, 2019].

Wilson, C.W., Jr.; Jewell, J.W.; Luther, E.T. 1956. Pennsylvanian geology of the Cumberland Plateau. Nashville, TN: Tennessee Department of Conservation, Division of Geology. 21 p.

Zaiontz, C. 2020. Real statistics using Excel. http://www.real-statistics.com/. [date accessed: May 5, 2020].