RETENTION TREE SURVIVAL TRENDS IN BURNED AND UNBURNED AREAS MANAGED USING THE IRREGULAR SHELTERWOOD METHOD

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Abstract—Survival of individual stems selected as retention trees in irregular shelterwoods is important as these stems are expected to remain for 20 percent or longer of the subsequent rotation. In mountainous terrain where windstorms may occur regularly and prescribed fire may be utilized to improve regeneration composition, survival of retention trees becomes less certain. An upland, mixed hardwood stand in Morgan County, Tennessee, received an irregular shelterwood harvest and a burn or no-burn treatment between 2014 and 2016. Retention tree assessments were made 3.5 years post-harvest and 2.5 years post-burn to allow for delayed individual stem mortality to occur. Results indicated greater mortality of retention trees in the burn treatment, but no differences in slope positions across treatments. Windthrow mortality ranged from 4.0 to 7.6 percent across all slope positions in the two treatments. Red oak species (*Quercus* spp., Section *Lobatae*) and conifer species had a higher probability of mortality than the yellow-poplar (*Liriodendron tulipifera*) reference group. Managers should select desirable retention trees that avoid possible tree mortality and damage from logging and prescribed burns when implementing irregular shelterwoods in aging hardwood stands.

INTRODUCTION

The irregular shelterwood, or shelterwood with reserves, regeneration method is a two-age or uneven-aged regeneration method where individual or groups of trees are left on site (Ashton and Kelty 2018). Typically, an average basal area from 10 to 40 square feet per acre is left in retention trees, and these trees are expected to remain for at least 20 percent of the subsequent rotation or longer (Johnson and others 1998, Nyland 2007). This method is used to retain trees on site that have the potential to increase in value, produce seed, create variable vegetation structure for wildlife, enhance structural diversity, and provide intermediate shade conditions for regenerating stems (Johnson and others 2009, Nyland 2007). Aesthetics may also be improved over clearcutting on highly visible sites such as mountainous terrain. Windthrow is a concern with this regeneration method, especially in mountainous terrain where slopes and ridges are exposed regularly to high winds.

Prescribed fire has been documented as a viable treatment in uncut stands and oak (*Quercus* spp.) shelterwoods to promote oak regeneration and establishment when oak seedlings and saplings are present (Barnes and Van Lear 1998, Brose and others 1999, Van Lear and Brose 2002). Information on overstory tree survival and condition following such burns is limited. Stands that have not been burned in many years, or stands that have an abundance of woody fuels following a shelterwood harvest are more likely to burn more intensely and have adverse effects on overstory trees that are intended to remain for an extended period of time as retention trees. Minimal information is available on retention tree survival on sites in the Cumberland Plateau or Cumberland Mountains physiographic regions following irregular shelterwood harvests where prescribed burning may or may not be utilized.

OBJECTIVES

The objectives of this study were to (1) monitor survival and mortality of reserve trees following an irregular shelterwood harvest in areas with and without prescribed burning, (2) compare retention tree survival across three slope positions in burned and unburned areas, and (3) assess reserve tree survival probability differences by species group and diameter class in burned and unburned areas.

METHODS

Study Site

The study site was located on a 76-acre property owned by the University of Tennessee, Forest Resources Research and Education Center in Morgan County, Tennessee (36.053955° N, -84.435428° W). This site was located on western and northwestern flanks as well as ridgetop positions of Little Brushy Mountain,

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which is near the southern terminus of the Cumberland Mountains Physiographic Province (Smalley 1984). Elevations ranged from 1,280 to 1,840 feet. Parent materials consisted of shale and siltstone, while soil series included the Gilpin-Boulin-Petros complex with varying percent slopes (USDA NRCS 2017, Wilson and others 1956). These soils were rocky silt loams, loams, and clay loams, and depth to bedrock ranged from 25 to 43 inches. Site indexes for shortleaf pine (*Pinus echinata*) and black oak (*Quercus velutina*) were 60 feet at base age 50 years and 90 feet (base age 50 years) for yellow-poplar (*Liriodendron tulipifera*) (Beck 1962, Martin 1966, Olson 1959, USDA NRCS 2017). The mean annual temperature was 55.9° F, and the region averaged 54 inches of precipitation annually with autumn as the driest season (NOAA 2017). The site had remained relatively undisturbed since the university conducted a stand improvement harvest in 1949 on a portion of the stand, except for cyclical southern pine beetle (*Dendroctonus frontalis*) outbreaks, which reduced the shortleaf and Virginia pine (*P. virginiana*) components across the stand. The most recent bark beetle outbreak occurred from 1999 through 2002 across the State (Cassidy 2004).

Vegetation on the site prior to harvest operations consisted mostly of mixed species upland hardwoods. Common overstory species included black oak, white oak (*Q. alba*), scarlet oak *(Q. coccinea*), chestnut oak (*Q. montana*), mockernut hickory (*Carya tomentosa*), yellow-poplar, and red maple (*Acer rubrum*). Common midstory and understory species included sourwood (*Oxydendrum arboreum*), sassafras (*Sassafras albidum*), blackgum (*Nyssa sylvatica*), serviceberry (*Amelanchier arborea*), eastern white pine (*P. strobus*), and mountain laurel (*Kalmia latifolia*). The site averaged 7,108 board feet per acre sawtimber (Doyle log rule form class 78). A commercial harvest began in October 2014 and was completed in April 2015.

Plot Layout and Measurements

Retention trees were marked during summer 2014 prior to the beginning of harvest operations. Oak and hickory species as well as shortleaf pine were preferred retention trees (with less desirable species such as sourwood and sassafras marked when those species were not present) so that approximately 15-20 square feet per acre basal area would remain following the harvest. Individual stems with at least intermediate crown classes, healthy appearance (no sign of stem or crown damage as well as crown dieback), and diameters between 4 and 14 inches were targeted as retention trees. Harvest occurred in fall of 2015. The site averaged 1,550 board feet per acre (Doyle log rule form classes 78 and 80) and 67 square feet per acre of basal area following the harvest as many marked take trees were left by the logging crew (table 1). Access to some areas of the stand was limited by steep topography, and wet weather during the winter of 2014-2015 prevented work from occurring for days at a time. The logging crew had to be off the site by April 1, 2015 for planting. During summer 2015, 300 variable-radius plots (10-factor prism) were established at random throughout the study site. All trees were identified to species and measured for diameter at breast height (d.b.h.). In addition, slope position and elevation were recorded at each plot location. Three slope position classifications were devised to characterize plot elevations: lower slope (1,280 to 1,380 feet), middle slope (1,380 to 1,670 feet), and upper slope (1,670 to 1,840 feet) positions.

Table 1—Pre- and post-harvest basal area, sawtimber volume, and pulpwood weight averages per acre for the irregular shelterwood study located in Morgan County, Tennessee

Timing	Basal area	Sawtimber	Pulpwood
	per acre	*vol per acre*	*tons per acre*
Pre-harvest	97	7,100	22.6
Post-harvest	67	1,550	20.6

Burn treatments were completed over 3 days during March 2016. Fuel loadings were variable across the burn areas due to the partial logging operation, but were most represented by Anderson's (1982) fuel model 11 for light slash. Due to the steep topography of the site, burns were first ignited as backing fires from higher elevation positions and allowed to burn down slope before flanking fires were ignited. The burns had 100 percent coverage and 32.4 acres of the 76 total acres were burned. Weather conditions for each of the 3 burning days are presented in table 2.

Retention tree plots were re-located and assessed during fall 2018 approximately 3.5 years post-harvest and 2.5 years post-burn to allow for possible delayed mortality to occur. While personnel limitations and time restraints prevented all plots from being redone, 154 of the original 300 plots were randomly selected and re-measured, with approximately 50 plots located at each slope position. Seventy-four plots were located in the burn treatment and 80 were in the no burn treatment. All retention trees were measured and assessed for d.b.h., stem damage (living trees only), and probable cause of mortality was noted for stems that were recorded as alive during the pre-burn inventory. In burn treatment plots, bark blackening or scorch greater than 10 feet up the tree bole as well as evidence of crown and root scorch were used as indicators for heat-related mortality. Bole blackening or scorch was defined as black discoloration on fissures and ridges of bark as well as noticeable pitting, consumption, or removal of bark on the bole (Loomis 1973). For hardwood species such as oaks and hickories, scorch more than 10 feet high on the bole of stems with a d.b.h. between 5 and

Table 2—Weather variables by date for the burn treatment for the irregular shelterwood study located in Morgan County, Tennessee

Date	Time	Temperature	Relative humidity	Wind speed	Wind direction	KBDI
		degrees F	*percent*	*miles per hour*		
March 17, 2016	5:00-7:00 PM	65-70	14-18	6.9-8.1	W	<300
March 18, 2016	12:00-7:00 PM	64-70	18-23	0.0-8.1	Variable	<300
March 20, 2016	1:30-5:30 PM	71-76	22-29	5.8-11.5	SSE-SSW	<300

KBDI = Keetch-Byrum Drought Index.

16 inches is associated with a probability of mortality exceeding 50 percent (Loomis 1973). If a tree had both visible stem and/or root scorch and was windthrown, the cause of mortality was classified as both. Stems that were topkilled but had resprouted were tallied as alive. In no-burn treatment areas, stems with obvious signs of windthrow mortality (uprooted and/or broken stem) were noted as wind-related mortality. Stems in both treatment areas that were dead but did not have any obvious wind or heat related damage were classified as other for the mortality cause. Trees that were damaged but still alive were classified as damaged.

Statistical Analyses

Percentage of stem deaths by windthrow, fire, both, or other causes as well as stem damage (live trees) were reported by treatment (*n* = 1,029 stems assessed). Retention tree survival (both those marked as retention trees prior to harvest and those that were left by the logging crew) was analyzed using analysis of variance (ANOVA) as a two-way factorial treatment design. Treatment (burn or no burn) and slope position (low, middle, or high) were fixed factors, while plot was considered a random factor. Fisher's protected least significant difference test was used for all pairwise comparisons of least-squares means to detect survival differences in treatments and slope positions. The binomial distribution was used for all survival analyses. ANOVA analyses were conducted in SAS© 9.4 using the Proc Mixed procedure (Littell and others 2006).

Multiple logistic regression was used to assess residual tree mortality probability by species group, diameter class, and treatment using Proc Logistic and the logit link function in SAS© 9.4. All statistical tests were conducted at an $\alpha = 0.05$ significance level. Species groups for the regression analysis included blackgum, conifers (eastern white pine, and eastern hemlock (*Tsuga canadensis*)), yellow-poplar, white oaks (white and chestnut oak), red oaks (northern red oak (*Q. rubra*), black oak, and scarlet oak), red maple, and other hardwoods (sourwood, hickory spp., sugar maple (*Acer saccharum*), sweetgum (*Liquidambar styraciflua*), American beech (*Fagus grandifolia*), sassafras, and black birch (*Betula lenta*)).

RESULTS

The number of stems 2 inches or greater pre-burn averaged 239 trees per acre while 2.5 years post-burn the site averaged 161 trees per acre. Basal area per acre pre-burn averaged 67.5 square feet per acre and was reduced to 51.4 square feet per acre 2.5 years post burn. The burn reduced the number of trees per acre in the 2-inch and greater diameter class by 32.7 percent and basal area per acre was reduced by 23.8 percent. Nearly 30 percent of the trees that were assessed in the burn treatment areas were killed by heat-related causes, and 5.6 percent of stems had damage (table 3). Wind-related mortality was the leading cause of death in the no-burn treatment, while fewer stems had damage than the burn treatment. The red oak and the other hardwood species groups had the most wind-related mortality across all

Table 3—Number and percent of dead stems by mortality causal factor and treatment 3.5 years post-harvest and 2.5 years post-burn for the irregular shelterwood study located in Morgan County, Tennessee

Treatment	Total trees, pretreatment	Mortality factor: Heat related	Wind	Other	Heat and wind	Damage
		% of stems				*% of stems*
Burn	478	143 (29.9)	19 (4.0)	4 (0.8)	9 (1.8)	27 (5.6)
Unburned	551	15 (2.7)[a]	42 (7.6)	17 (3.1)	2 (0.03)[a]	17 (3.1)
All	1029	158 (14.5)	61 (5.6)	21 (1.9)	11 (1.0)	44 (4.0)

[a] Fire escaped containment lines briefly during the March 18, 2016 burn.

treatments, while blackgum, yellow-poplar, and conifer species group all had relatively minor wind-related mortality (table 4).

Treatment and slope position did not interact to affect residual stem survival (p = 0.94). Residual stems in the unburned treatment had significantly greater survival rates than those located in the burn treatment (85.3 ± 3.9 SE percent and 64.9 ± 3.8 percent, respectively, p = 0.004). No statistical differences in retention tree survival were observed for slope position (p = 0.14). Retention tree survival averaged 79.4 ± 2.8 percent, 78.6 ± 2.9 percent, and 66.4 ± 3.9 percent for lower, middle, and upper slope positions, respectively. Average survival rates ranged from 90.3 ± 2.0 percent on lower slope positions of the no burn treatment, to 55.3 ± 4.4 percent on upper slope positions of the burn treatment (fig. 1).

Table 4—Percent windthrow by species across both treatments for the irregular shelterwood study located in Morgan County, Tennessee

Species	Windthrow
	percent
Blackgum	2.9
Conifers	0.0
Other hardwoods	6.9
Red oaks	11.2
Red maple	5.8
White oaks	5.1
Yellow-poplar	2.9

The logistic regression analysis revealed that species group and treatment were both significant factors in the odds of mortality (table 5). The main effects model analysis revealed that red oaks (p = 0.02) and conifer species (p = 0.01), as well as the stems in the burn treatment (p < 0.0001), had a significantly greater probability of mortality than the reference species, yellow-poplar (table 6).

When the maximum likelihood estimates were converted to odds ratios, the odds of mortality for the conifer and red oak groups were 2.1 and 1.7 times greater, respectively, than the odds for the reference group yellow-poplar. The odds of mortality for stems in the burn treatment were 1.9 times greater than the odds for stems in the no-burn treatment.

DISCUSSION AND MANAGEMENT IMPLICATIONS

Retention tree mortality rates were increased by a single prescribed burn in this study. Stem density and basal area were reduced by the burn post-harvest. Burn treatment retention trees were less likely to experience wind-related mortality than no-burn treatment stems, but small and declining stems in the burn treatment were most likely killed by heat-related effects before windthrow mortality could occur. Vascular cambium and fine root damage are primary modes of decline in hardwoods and the degree of damage is affected by fire intensity (Regelbrugge and Smith 1994). Individual hardwood tree mortality in burn areas can be explained by a complex of variables including peak burn temperature, flame residence time, tree vigor, and bark thickness (Hare 1961, Yaussy and Waldrop

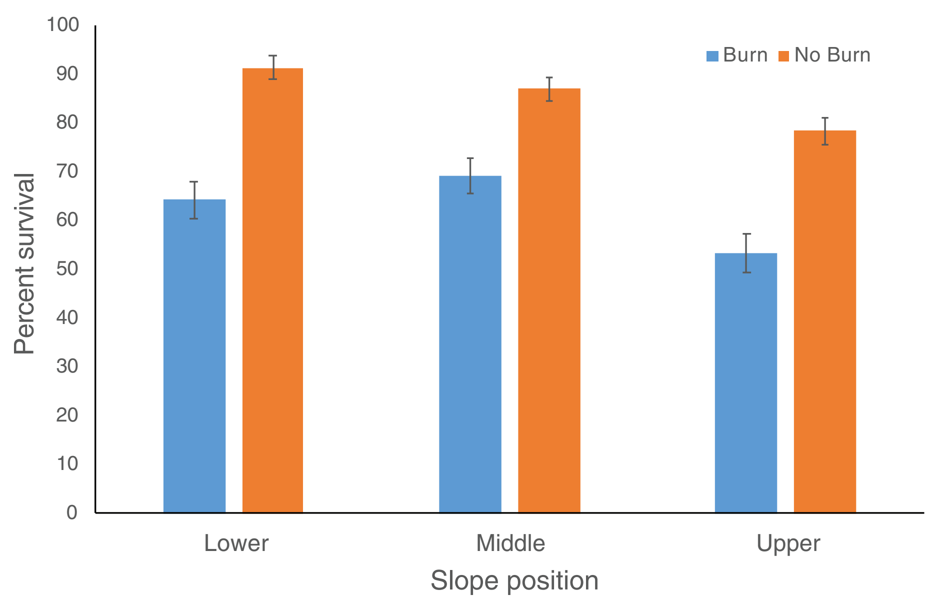

Figure 1—Residual tree average survival rate and standard error for the treatment by slope position interaction for the irregular shelterwood study located in Morgan County, Tennessee (p = 0.94).

Table 5—Type III fixed effects results for the logistic regression analysis for the irregular shelterwood study located in Morgan County, Tennessee

Effect	DF	Wald chi-Square	Pr>ChiSq
Species	6	21.3515	0.0016
d.b.h.	1	0.3667	0.5448
Treatment	1	60.3787	<0.0001

d.b.h. = diameter at breast height.

Table 6—Maximum likelihood estimates for the irregular shelterwood study located in Morgan County, Tennessee

Parameter		DF	Estimate	Standard error	Wald chi-Square	Pr>ChiSq
Intercept		1	-1.2006	0.2166	30.7215	<0.0001
Species	Blackgum	1	-0.4545	0.4105	1.2259	0.2682
Species	Conifers	1	0.7458	0.3061	5.9377	0.0148
Species	Other hardwoods	1	0.1161	0.2951	0.1548	0.6940
Species	Red maple	1	0.2927	0.1681	3.0324	0.0816
Species	Red oaks	1	0.5169	0.2135	5.8593	0.0155
Species	White oaks	1	-0.3051	0.1912	2.5458	0.1106
d.b.h.		1	-0.0093	0.0154	0.3667	0.5448
Treatment	Burn or no	1	0.6214	0.0800	60.3797	<0.0001

d.b.h. = diameter at breast height.

2010). Some stems in both treatments were affected by logging damage and most likely by the development of secondary agents of decline such as *Phytophthora* and *Armillaria* though these factors were not addressed in this study (Yaussy and Waldrop 2010).

Slope position did not significantly affect retention tree survival. Increased windthrow is often a concern at upper slope positions and ridge lines with two-age or irregular shelterwood stands in mountainous terrain (Stringer 2006). This site had approximately 560 feet in elevation change from lower slope positions to higher slope positions, but was partially protected from prevailing weather systems by another section of Little Brushy Mountain. Past research has demonstrated that prevailing winds that blow perpendicular to hill crests cause wind speeds to increase from lower slope positions to higher slope positions (Ruel 1995). This along with similar prescribed fire ignition patterns and weather conditions across the site may provide some explanation as to why similar retention tree survival rates occurred across slope positions in this study. The lack of significance in the treatment x slope position interaction term suggests that the effects of prescribed fire in irregular shelterwood stands are independent of slope position. This finding may encourage use of prescribed fire as a management tool to alter regenerating species composition in irregular shelterwood stands in similar terrain.

Red oak was one of the species groups identified as having a greater probability of mortality than yellow-poplar. This result has been noted with other studies in upland hardwood stands that had previously had fire excluded for many years (Regelbrugge and Smith 1994, Yaussy and Waldrop 2010). Decline of mature red oak stems may have been one of the main factors resulting in their greater probability of mortality. Red oaks such as scarlet and black oak tend not to live as long on average as white oaks and some other upland hardwood associates such as yellow-poplar (Stringer 2006). Red oaks also develop decay fungi regularly, especially scarlet oak and black oak (the two most common mature red oak species on this site) (Berry 1969). The other conifer species group also had a higher probability of mortality than the reference group (yellow-poplar). Eastern white pine and eastern hemlock are very susceptible to fire, especially smaller diameter stems, due to thin bark that provides minimal heat insulation. Older and larger stems are moderately susceptible to fire due to thicker bark compared to younger stems (Godman and Lancaster 1990, Wendel and Smith 1990).

Windthrow has been identified as a concern for retention trees in irregular shelterwood harvests. Local climate, tree age, species, and vigor all affect windthrow rates in these stands (Nyland 2007). Exposed slopes and landscape positions magnify windthrow concerns (Stringer 2006). Windthrow rates for mature, overstory stems vary by species, and shade-tolerant species tend to be more wind firm than shade-intolerant species (Canham and others 2001). Greater likelihood of windthrow was observed for upper slope and ridge landscape positions in a two-age deferment harvest study in Kentucky (Stringer 2006). The Kentucky study documented a similar to slightly greater windthrow rate range (7 to 10 percent) than this study. A similar shelterwood study in the Ouachita Mountains of Arkansas where favored retention trees were white oaks, hickories, and red oaks found a lower windthrow mortality rate (0.3 percent) than this study (Starkey and Guldin 2004). Based on results from this study and Stringer (2006), upland hardwood stands located in the Cumberland Plateau and Cumberland Mountains regions that receive the first cut of an irregular shelterwood are at more risk for mortality than undisturbed stands where the average annual mortality rate for average-sized, mature stems has been reported as 0.5 percent per year (Lorimer 1989).

The irregular shelterwood regeneration method can be implemented to maintain desirable residual stems on site which may fulfill multiple management objectives (Johnson and others 1998, Johnson and others 2009, Nyland 2007). Species, tree age, size, health, and topographic position should be considered collectively in the selection of retention trees for an irregular shelterwood in aging hardwood stands, especially with logging and burning operations. Red oak species, eastern white pine, eastern hemlock, and species with thin bark should be avoided as retention trees unless composition and structure prescriptions necessitate them. Favorable retention trees should include more fire-tolerant and longer-lived species such as white oaks (Dey and Hartman 2005). During logging, directional felling and concentrating tops away from retention trees may decrease heat-related mortality if prescribed burning is utilized (Wade and others 2000). Tree mortality and damage can be minimized with careful assessment and selection of retention trees when logging and prescribed burns are conducted in irregular shelterwood applications.

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LITERATURE CITED

Anderson, H.E. 1982. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

Ashton, M.S.; Kelty, M.J. 2018. The practice of silviculture: applied forest ecology. Hoboken, NJ: John Wiley and Sons. 758 p.

Barnes, T.A.; Van Lear, D.H. 1998. Prescribed fire effects on advanced regeneration in mixed hardwood stands. Southern Journal of Applied Forestry. 22(3): 138-142.

Beck, D.E. 1962. Yellow-poplar site index curves. Res. Note SE-180. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 2 p.

Berry, F.H. 1969. Decay in upland oak stands of Kentucky. Res Pap. NE-126. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 16 p.

Brose, P.; Van Lear, D.; Cooper, R. 1999. Using shelterwood harvests and prescribed fire to regenerate oak stands on productive upland sites. Forest Ecology and Management. 113 (2-3): 125-141.

Canham, C.D.; Papaik, M.J.; Latty, E.F. 2001. Interspecific variation in susceptibility to windthrow as a function of tree size and storm severity for northern temperate tree species. Canadian Journal of Forest Research. 31: 1-10.

Cassidy, P.D. 2004. Dynamics and development of shortleaf pine east Tennessee. Ph.D. Dissertation. Knoxville, TN: University of Tennessee. 99 p.

Dey, D.C.; G. Hartman. 2005. Returning fire to the Ozark Highland forest ecosystems: effects on advance regeneration. Forest Ecology and Management. 217: 37-53.

Godman, R.M.; Lancaster, K. 1990. *Tsuga canadensis* (L.) Carr. Eastern hemlock. In: Burns, R.M.; Honkala, B.H., tech. coords. Silvics of North America. Vol. 1. Conifers. Agric. Handbook 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 604-612.

Hare, R.C. 1961. Heat effects on living plants. Occas. Pap. 183. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 32 p.

Johnson, J.E.; Miller, G.W.; Baumgras, J.E. 1998. Assessment of residual stand quality and regeneration following shelterwood cutting in central Appalachian hardwoods. Northern Journal of Applied Forestry. 15(4): 203-210.

Johnson, P.S.; Shifley, S.R.; Rogers, R. 2009. The ecology and silviculture of oaks. 2^{nd} ed. Cambridge, MA: CAB International. 580 p.

Littell, R.C.; Milliken, G.A.; Stroup, W.W. [and others]. 2006. SAS for mixed models. 2^{nd} ed. Cary, NC: SAS Institute Inc. 814 p.

Loomis, R.M. 1973. Estimating fire-caused mortality and injury in oak-hickory forests. Res. Pap. NC-94. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 9 p.

Lorimer, C.G. 1989. Relative effects of small and large disturbances on temperate hardwood forest structure. Ecology. 70(3): 565-567.

Martin, W.M., III. 1966. Some relationships of vegetation to soil and site factors on Wilson Mountain, Morgan County, Tennessee. M.S. Thesis. Knoxville, TN: University of Tennessee. 134 p.

National Oceanic and Atmospheric Administration [NOAA]. 2017. Summary of monthly normal 1981-2010 for Lancing 6 NW, TN US GHCND: USC00405040. www.ncdc.noaa.gov/cdo-web/datasets/ [date accessed: April 11, 2017].

Nyland, R.D. 2007. Silviculture: concepts and applications. 2nd ed. Long Grove, IL: Waveland Press. 682 p.

Olson, D.J. 1959. Site index curves for upland oak in the Southeast. Res Note SO-125. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 2 p.

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.

Ruel, J.C. 1995. Understanding windthrow: silvicultural implications. The Forestry Chronicle. 71(4): 434-445.

Smalley, G.W. 1984. Classification and evaluation of forest sites in the Cumberland Mountains. Gen. Tech. Rep. SO-50. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 84 p.

Starkey, D.A.; Guldin, J.M. 2004. Crown health of reserve hardwood trees following reproduction cutting in the Ouachita Mountains. In: Guldin, J.M., tech. comp. 2004. Ouachita and Ozark Mountains symposium: ecosystem management research. Gen. Tech. Rep. SRS-74. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 92-97.

Stringer, J. 2006. Two-age system and deferment harvests. Extension Publ. SP676. Knoxville, TN: University of Tennessee, Agricultural Extension Service. 12 p.

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2017. Web soil survey. https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm. [date accessed: April 11, 2017]

Van Lear, D.H.; Brose, P.H. 2002. Fire and oak management. In: McShea, W.J.; Heavy, W.M., eds. Oak forest ecosystems: ecology and management for wildlife. Baltimore, MD: John Hopkins University Press: 269-279.

Wade, D.D.; Brock, B.L.; Brose, P.H. [and others]. 2000. Fire in eastern ecosystems. In: Brown, J.K.; Smith, J.K., eds. Wildland fire in ecosystems: effects of fire on flora. Gen. Tech. Rep. RMRS-42-vol. 2. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 53-96.

Wendel, G.W.; Smith, H.C. 1990. *Pinus strobus* L. Eastern white pine. In: Burns, R.M.; Honkala, B.H., tech. coords. Silvics of North America. Vol. 1. Conifers. Agric. Handbook 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 476-488.

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

Yaussy, D.A.; Waldrop, T.A. 2010. Delayed mortality of eastern hardwoods after prescribed fire. In: Stanturf, J.A. ed. Proceedings of the 14th biennial southern silvicultural research conference. Gen. Tech Rep. SRS-121. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 609-612.