IMPLICATIONS OF FREQUENT HIGH INTENSITY FIRE ON THE LONG-TERM STABILITY OF OAK BARRENS, WOODLANDS, AND SAVANNAS

Wayne K. Clatterbuck and Rebecca L. Stratton Rollins

Abstract—A study was initiated in 1963 to evaluate the stand dynamics associated with three fire frequency treatments (annual burning, 5-year periodic burning, and fire exclusion) on a pyric oak (*Quercus* spp.)-dominated site in south-central Tennessee. Controlled burns were conducted during the dormant season. The experimental design was a randomized block, blocked on location, with three replications of the three treatments. The purpose of this paper is to report on the overstory structural vegetation changes that accompany these burning treatments after 54 years. Overstory number of stems and basal area of the two burning treatments have gradually diminished through time and with little to no ingrowth. Presently, the overstory of both fire frequency treatments consists of sparsely populated, individual trees with <18 square feet per acre of basal area. Most of these trees are decrepit with fire scars and decay jeopardizing their longevity. Annual burns promoted an oak savanna-like structure dominated by herbaceous vegetation. The 5-year periodic burns promoted woody vegetation, which typically was top-killed and resprouted after each burn. The fire exclusion treatment had a closed overstory with basal areas greater than 78 square feet per acre and little midstory or understory. Our results suggest high intensity, small-scale, frequent fires in pyric oak systems do not support oak ingrowth and would be relatively unstable communities. To allow oak ingrowth to occur, land managers should cease burning for a greater period of time or conduct lower intensity burns.

INTRODUCTION

The stand structure and composition of many former oak barrens, woodlands, and savannas were shaped by frequent fire regimes from both natural and anthropogenic sources (Peterson and Reich 2001). With the advent of fire suppression, these open vegetation communities have diminished and are quite rare (Dey and others 2017, Noss 2013). Interest in the use of frequent prescribed burning to restore these pyric oak structures has increased (Keyser and others 2016). Typically, with frequent burning, a diverse herbaceous understory of grasses and forbs develops with sparse, open overstories of scattered trees or groups of trees. A midstory canopy layer is usually absent or limited (Burger and others 2016).

A topic not addressed well in the literature is the impact of frequent burning damage on overstory trees and the resulting long-term sustainability implications of these systems. To address this topic, we capitalize on a University of Tennessee 54-year long-term fire frequency and stand dynamics research study and evaluated the impact of frequent, high intensity fire on the present condition of overstory trees and ingrowth for an oak barrens site in Tennessee (DeSelm 1994).

METHODS

Study Site

The study was initiated in 1963 and is located at 35°30’N: 86°15’W on the Interior Low Plateau Province of the Eastern Highland Rim in middle Tennessee on the University of Tennessee Forest Resources Research and Education Center (FRREC) in Franklin County, near Tullahoma, TN. Although the Eastern Highland Rim is typically characterized as more rolling with hills and valleys, the Interior Low Plateau Province on the eastern edge of the Rim is an undulating flat plain derived from loess-derived soils with a fragipan that inhibits water movement (Fenneman 1938). Soils are mapped as the Dickson series (fine-silty, siliceous, thermic Glossic Fragiudults with slopes of 0 to 2 percent (USDA NRCS 2001). These soils are usually excessively dry during late summer and have a perched water table during late winter. The study site is on Landtype 12 (Broad Silty Uplands) of Smalley’s (1983) site classification of the Eastern Highland Rim. The climate is characterized by long, moderately hot summers and short, mild winters (Thornthwaite 1948). Annual average monthly temperatures range from 40 °F in December and January to 77 °F in July and August. Annual monthly precipitation ranges from 5.4 inches per month December–March, 4.4 inches per month April–July, and 3.5 inches per month

Author information: Wayne K. Clatterbuck, Professor, Department of Forestry, Wildlife & Fisheries, University of Tennessee, Knoxville, TN 37996-4563; Rebecca L. Stratton Rollins, Gulf Region R&D Coordinator, Rayonier, Lufkin, TX 75901.

Kirschman, Julia E., comp. 2018. Proceedings of the 19th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS- 234. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 444 p.

August–November with a monthly low of 2.5 inches in October. Total average annual precipitation is 53 inches (Smalley 1983).

The area had a long history of low intensity, frequent fires for agriculture and grazing from Native American culture through European settlement. Other more modern sources of fire, prior to University acquisition of the property, included wildfires from an adjacent large U.S. Army military complex (presently Arnold Air Force Base or Arnold Engineering Development Center) that used fire for clearing the area for training and maneuvers during World War II, wildfires resulting from a primary north-south railroad line adjacent to the property, and wildfires from adjacent farmers and landowners who burned for agriculture and grazing (DeSelm and others 1991).

Known as the 'oak barrens,' the subclimax pyric community is characterized as a sparse overstory with basal areas from 5 to 20 square feet, little to no midstory, and an open grass and forb understory (Delcourt 1979, DeSelm 1994). At study inception in 1963, the forest was understocked and degraded due to previous (pre-1950) frequent fires, poor previous management practices (primarily high-grading), and overgrazing (Stratton 2007). The forest structure was at the early stages of a two-aged forest. The initial forest condition was a sparse, mature overstory of approximately 80-year-old oaks with approximately 20 square feet per acre average basal area and 20 trees per acre. Basal area of the midstory [5 to 11 inches diameter breast height (DBH) at 4.5 feet] was approximately 30 square feet per acre with 100 trees per acre. Nearly 100 percent of the midstory stems were oak species. Total stand basal area (overstory and midstory) was approximately 50 square feet per acre (Nichols 1971). The study area was in the stand initiation phase (Oliver and Larson 1996) with the understory composed of the same woody species present today. The present overstory is primarily oak species including post oak (*Q. stellata*), southern red oak (*Q. falcata*), scarlet oak (*Q. coccinea*), and blackjack oak (*Q. marilandica*). Other species include hickories (*Carya* spp.) and blackgum (*Nyssa sylvatica*). Willow oak (*Q. phellos*), water oak (*Q. nigra*), and red maple (*Acer rubrum*) occur along the first-order stream which divides the study sites. Two age classes currently represent the overstory trees: an older age class for white oaks, primarily post oak at an estimated 120 to 150 years old and a slightly younger age class for the red oaks from 80 to 100 years old. Site index for upland oaks averages 70 feet at 50 years (Smalley 1983).

Study design

Nine 1.8-acre rectangular (200 x 400 feet) plots were established, three plots of each treatment: annual burn, 5-year periodic burn, and control (no burns). The original study design was a randomized block, blocked on location with three replications of the three treatments. Controlled burns (henceforth burns) were conducted during the dormant season from late February to early April when burning conditions were favorable. A plowed fire line separated each plot. Each plot was burned individually in a ring pattern. Each burn was distributed evenly across the plot, but as a result of the fire ring pattern, the intensity of the fire was greater in the center than the edge of the plot. The annual treatments started in 1963, and 5-year periodic treatments started in 1964. A tornado went through the study area in March 2011 disrupting the continuity of the annual burn regimes for 2 years. According to FRREC records, the annual burn plots have been burned 50 times in 54 years and the 5-year periodic burn plots have been burned 11 times.

Sampling

The 2016 data collected for this report were obtained after the fourth growing season of the last 5-year periodic burn regime. Each treatment plot was bisected lengthwise with a line transect where 1/10-acre measurement plots were located at one-chain intervals yielding five measurement plots (15 total plots per treatment). The sampled area represented 0.5 acres of the 1.8-acre treatment plot or a sampling intensity of about 28 percent. Only stems >2 inches DBH were measured. Species, DBH, and fire damage of the bole were recorded. Bole fire damage was observed on the lower 2 feet of the bole and classified as superficial, moderate, or severe. All the stems received some superficial charring in the burn plots. Superficial damage was classified as fully intact bark completely encircling the bole and the cambium was not visually damaged. Moderate bole damage classification was that a fire scar had occurred and no visible wood decay was evident. Severe bole damage was that wood decay was visible inside the tree beyond the cambium.

Stand structural data and understory composition data were collected at different intervals for each burning treatment from earlier study reports and are available from DeSelm and others (1991), Nichols (1971), and Stratton (2007). This study reports only on the presence and condition of overstory trees after 54 years of different burning regimes.

RESULTS

Mean basal area of both annual burn (18.1 square feet per acre) and periodic 5-year burn (13.9 square feet per acre) treatments decreased from approximately 50 square feet per acre during the 54-year period since study inception in 1963 (table 1). Basal area of the control treatment increased from 50 square feet per acre to 78.7 square feet per acre in the absence of fire. The mean number of trees >2 inches DBH also decreased from an average of 120 trees per acre to 25.3 trees per acre in the annual burn treatment and to 15.3 trees

Table 1—Mean basal area, number of trees, and diameter (DBHa) of trees >2 inches in diameter with standard errors for each treatment after 54 years for the long-term prescribed fire study in the Tennessee Oak Barrens, Tullahoma, TN[b]

Treatment	Mean basal area (std error)	Mean number of trees (std error)	DBH of tree of mean basal area
	-----*ft²/acre*-----	-----*trees/acre*-----	------*inches*------
Annual burn	18.1 (3.2)	25.3 (4.4)	11.4
Periodic 5-yr burn	13.9 (2.8)	15.3 (3.4)	12.9
Control (no burn)[c]	78.7 (5.2)	---	---

--- = Data not collected.

[a] DBH = diameter breast height at 4.5 feet.

[b] Based on fifteen 0.1-acre plots per treatment.

Table 2—Bole damage classification for each tallied tree for each burn treatment and both treatments combined after 54 years for the long-term prescribed fire study in the Tennessee Oak Barrens, Tullahoma, TN

Bole damage classification	Annual burn	Periodic 5-yr burn	Combined treatments
Superficial	2 (5%)	0	2 (3%)
Moderate	9 (22%)	5 (22%)	14 (22%)
Severe	29 (73%)	18 (78%)	47 (75%)
Total	40	23	63

per acre in the periodic burn treatment (table 1). The diameters of trees in both burn treatments ranged from 7 to 18 inches with a tree diameter of mean basal area of 11 to 13 inches (table 1). The burn treatments had very few trees with diameters between 2 and 6 inches DBH.

The lower boles of all sample trees for both burning treatments combined (n=63 trees) incurred fire damage from the regimes of repeated burning (table 2). More than 74 percent of the tree boles were classified as severe with wood decay visible. Moderate damage was observed on 22 percent of the sample trees. Only two trees had superficial damage; both were in the annual burn treatment. Both of these trees were located in wet depressions where fire intensity was less severe. None of the trees in the control plots had any visible fire damage.

DISCUSSION

With the burning regimes imposed in this study, the basal area and number of overstory trees gradually decreased throughout the 54 years. The gradual decrease in the overstory can be attributed to three sources: (1) bole damage and structural decay associated with the repeated burning, (2) blowdown from the 2011 tornado, and (3) tree senescence. The burn treatments accelerated the mortality rate as evidenced by the overall decrease in total basal area of the burn plots and the increased total basal area of the control plots, both before and after the tornado event. All of the overstory trees sampled in the burn treatments were damaged by the fires with 74 percent of them classified as severe damage with internal wood decay (table 2). The 2011 tornado caused an increase in down woody debris and uprooting of some overstory trees; however, we did not quantify the amount or proportion in this study. Saturated soils from storms just prior to the tornado followed by 111–135 mile-per-hour winds (EF 2 tornado) (Edwards 2017) caused some trees in the control and burning treatments to uproot and blow over. The impact of the tornado winds appeared to be patchy across the study area with no tree blowdowns in several of the treatment plots. A few dead, standing trees also were observed in the treatment plots after the tornado. Many of the older trees were 80+ years at study inception in 1963, which would put them in excess of 130 years of age and in the later range of their life cycles, especially the red oaks. The longevity of oaks in the red oak family is much less than those in the white oak family (Dey and Schweitzer 2015, Johnson and others 2009).

The periodic burn treatment plots had fewer overstory trees than the annual treatment plots (table 1). The 5 years of growth between periodic burns resulted in greater fire intensity due to greater accumulation of fuels. The ring fire pattern would have also increased the intensity of the burn in the center of the plot. The fuels buildup in the annual treatments was much less than the periodic treatment as a result of fire frequency. The differences in fuel buildup and resulting fire intensity differences created more intense fires in the 5-year periodic treatment, which accelerated tree damage and mortality.

The annual burning regime created a barrens or savanna structure with few or no woody stems in the understory (Stratton 2007). The periodic 5-year burn regime created a woody shrublike structure. The burning regime results are similar to that reported by Knapp and others (2015) in Missouri. The striking impact of these treatments is that few stems became ingrowth or tree recruitment for the overstory. None of the sample trees in either of the burn treatments were between 2 and 7 inches DBH. We did observe a few stems on the margin of the periodic burn treatment that could be future ingrowth, but intensity of burns on the margin of the plots was less than the center of the plots. Upon closer observation of these stems, they did incur fire scars from previous burns that could jeopardize their recruitment into the overstory.

The fire behavior and fire effects associated with the small scale of these plots, the implementation of the ring pattern for the burning treatments, and constant fire frequency regimes are quite different from the fire behavior and fire effects that would occur on larger scales. Large-scale burning results in more variable fire behavior and effects from differing amounts and distribution of fuels as well as other stand, weather, and topographic variables (Stambaugh and others 2016). Although it is impossible to separate the effects of the scale of the ring pattern, some broader fire implications are evident and would occur regardless of scale. Some stems escape burning coverage to become future ingrowth, especially in surface depressions or near riparian areas where soil moisture is greater. However, these conditions also tend to accumulate fuels which potentially create more intense future burns that would damage trees. Burning damage, whether from one or repeated fires, increases the potential mortality of overstory trees. Recruitment and ingrowth may prove challenging regardless of scale, particularly if fire intensity is not managed.

Under fire regimes imposed in this study, fire frequency and intensity are impeding ingrowth and therefore not replacing these senescent overstory trees. If a sparse overstory is desired for the future and ingrowth is not occurring, we recommend omitting fire from the area for a longer time interval to allow stems to become large enough to survive burning and/or decrease fire intensity (Dey and others 2017, Knapp and others 2015). Although the length of time required to allow ingrowth into the overstory is unknown (Arthur and others 2012), that time period will be a function of fire intensity, build-up of fuels present, and the diameter of stems to survive the subsequent burning events. Instituting a longer burn interval until ingrowth occurs will promote more woody growth which will alter the community structure during that interval. The desired community structure can then be restored once more frequent burning is reinitiated. A different fire frequency regime or burn pattern(s) may be necessary and periodically adjusted to achieve desired results.

Frequent, high intensity burning to sustain barrens, woodlands, and savanna structures neither maintains the existing overstory stems nor promotes recruitment or ingrowth of young stems into the canopy. The stability of the overstory is at risk because of frequent, high intensity burning regimes that tend to damage these trees. The accumulation of damage from repeated fires gradually increases stem mortality and diminishes tree longevity. To promote trees to the overstory, burning should cease until ingrowth from existing stems is large enough to survive future burns. However, fire scars and decay associated with prescribed burning will always be a factor in the perpetuation and longevity of the sparse overstory in these systems suggesting that these disturbance-dependent communities may be more transitional and less enduring over time.

ACKNOWLEDGMENTS

Appreciation is expressed to the staff at the University of Tennessee, Forest Resources Research and Education Center for assisting with data collection and maintenance of the study area and retaining records for the long-term research.

LITERATURE CITED

Arthur, M.A.; Alexander, H.D.; Dey, D.C. [and others]. 2012. Refining the oak-fire hypothesis for management of oak-dominated forests in the eastern United States. Journal of Forestry. 110: 257–266.

Burger, G.; Keyser, P.D.; Vander Yacht, A.L. 2016. Ecology and management of oak woodlands and savannahs. Publication PB 1812. Knoxville, TN: University of Tennessee Extension. 8 p.

Delcourt, H.R. 1979. Late quaternary vegetation of the Eastern Highland Rim and adjacent Cumberland Plateau of Tennessee. Ecological Monographs. 49: 255–280.

DeSelm, H.R. 1994. Tennessee barrens. Castanea. 59(3): 214–225

DeSelm, H.R.; Clebsch, E.E.C.; Rennie, J.C. 1991. Effects of 27 years of prescribed fire on an oak forest and its soils in middle Tennessee. In: Coleman, C.C.; Neary, D.G., eds. Proceedings, 6th biennial southern silvicultural research conference. Gen. Tech. Rep. SE-70. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station: 409–417.

Dey, D.C.; Kabrick, J.M.; Schweitzer, C.J. 2017. Silviculture to restore oak savannas and woodlands. Journal of Forestry. 115(3): 202–211.

Dey, D.C.; Schweitzer, C.J. 2015. Timing fire to minimize damage in managing oak ecosystems. In: Holley, A.G.; Connor, K.F.; Haywood, J.D., eds. Proceedings of the 17th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-203. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 143–153.

Edwards, R. 2017 (updated). The online tornado FAQ. National Oceanic and Atmospheric Administration, Storm Prediction Center. http://www.spc.noaa.gov/faq/tornado/index.html. [Date accessed May 8, 2017].

Fenneman, N.E. 1938. Physiography of Eastern United States. New York: McGraw-Hill. 691 p.

Johnson, P.S.; Shifley, S.R.; Rogers, R. 2009. The ecology and silviculture of oaks. New York: CABI Publishing, 2nd edition. 580 p.

Keyser, P.D.; Harper, C.A.; Anderson, M.; Vander Yacht, A. 2016. How do I manage for woodlands and savannahs? In: Keyser, P.D.; Fearer, T.; Harper, C.A., eds. Managing oak forests in the eastern United States. Boca Raton, FL: CRC Press: 223–245.

Knapp, B.O.; Stephan, K.; Hubbart, J.A. 2015. Structure and composition of an oak-hickory forest after over 60 years of repeated prescribed burning in Missouri, U.S.A. Forest Ecology and Management. 344: 95–109.

Nichols, G.M. 1971. Effects of annual and periodic fires in a hardwood forest on the Eastern Highland Rim. Knoxville, TN: University of Tennessee. 121 p. M.S. thesis.

Noss, R.F. 2013. Forgotten grasslands of the South: Natural history and conservation. Washington, DC: Island Press. 317 p.

Oliver, C.D.; Larson, B.C. 1996. Forest stand dynamics, update edition. New York: John Wiley. 520 p.

Peterson, D.W.; Reich, P.B. 2001. Prescribed fire in oak savanna: fire frequency effects on stand structure and dynamics. Ecological Applications. 11: 914–927.

Smalley, G.W. 1983. Classification and evaluation for forest sites on the Eastern Highland Rim and Pennyroyal. Gen. Tech. Rep. SO-43. New Orleans, LA: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 123 p.

Stambaugh, M.C.; Guyette, J.M.; Marschall, J.M.; Dey, D.C. 2016. Scale dependence of oak woodland historical fire intervals: Contrasting The Barrens of Tennessee and Cross Timbers of Oklahoma, USA. Fire Ecology. 12(2): 65–84.

Stratton, R.L. 2007. Effects of long-term winter prescribed fire on forest stand dynamics, small mammal populations, and habitat demographics in a Tennessee Oak Barrens. Knoxville, TN: University of Tennessee. 90 p. M.S. thesis.

Thornthwaite, C.W. 1948. An approach toward rational classification of climate. American Geographical Society. 38(1): 55–94.

U.S. Department of Agriculture, Natural Resources Conservation Service, National Cooperative Soil Survey [USDA NRCS]. 2001. Dickson series. https://soilseries.sc.egov.usda.gov/OSD_Docs/D/DICKSON.html. [Date accessed: February 26, 2017].