Coproducing Science on Prescribed Fire, Thinning, and Vegetation Dynamics on a National Forest in Alabama

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Southeastern forests are no strangers to fire. Historically, frequent fire was prevalent across the landscape (Guyette and others 2012; Lafon and others 2017). Today, however, wildfire affects southeastern upland hardwood forests only to a limited extent due to effective fire suppression.

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(An exception of note was in 2016, when the Great Smoky Mountains National Park experienced a 17,000-acre wildfire near Gatlinburg, TN, killing 14 people and causing $500 million in damage.) Most fires are quickly suppressed; human-ignited wildfires are normally small in area, driven by climate, terrain, and vegetation.

This loss of fire from the southern region is a relatively recent phenomenon, beginning in about the 1950s. It has resulted in forest changes that are not always considered desirable due to loss of native biodiversity, decline in quality of wildlife habitat, and escalating problems in regenerating oak and pine species.

FIRE USE IN SOUTHEASTERN HARDWOODS

It is an understatement to declare that the type of fire, fire behavior, and response of vegetation after fire in southeastern upland hardwood forests differ from fire and vegetation dynamics in western mixed-conifer and southeastern pine forests. Upland hardwood forest managers throughout the Southeastern United States, including those on the

William B. Bankhead National Forest (BNF) in north-central Alabama, are increasingly interested in the use of fire for a variety of management goals. In terms of planning, prescription, and implementation, however, they are challenged on how to use fire as a forest management tool to obtain desired future forest conditions. Strategies, approaches, methods, and tools in fire management from other regions and forest types are not necessarily directly applicable to upland southern hardwood forests. The role of prescribed fire in upland hardwood forests is understudied relative to other regions. Prescribed fire in upland hardwood forests is being used and examined for its ability to achieve three main objectives: fuel reduction, ecosystem restoration, and sustaining oak forests.

Prescribed fire in hardwood systems is often used in some "restoration" capacity because of wildfire's demise in the Nation's forest and grassland systems due to the success of the national Smokey Bear campaign in preventing forest fires and, by extension, in validating fire exclusion. The suppression of wildland fire across the Nation resulted in the loss of a fundamental forest process, a type of disturbance that needs to be restored to counter the loss of native biodiversity, the degradation of wildlife habitat, the failure of desired tree species to regenerate, the decline in forest and landscape resilience, and the unique role of fire in catalyzing the disruption of forest processes. Understanding the feedback system of fire, whereby vegetation influences flammability and fire effects and fire effects influence future vegetation, is paramount in using fire in a restoration capacity (Mitchell and others 2009; Tiribelli and others 2018).

Managers are using prescribed fire in upland hardwood or mixed hardwood/pine systems to move the stands towards some specific species composition and structure. A common goal is to create conditions conducive to recruiting oak (*Quercus* spp.) into more competitive understory positions, with heightened probabilities to dominate in future stands (Arthur and others 2015; Brose and others 2013; Hutchinson and others 2012; McEwan and others 2011; Schweitzer and others 2016). Currently, the predominate use of prescribed fires in the Southeastern United States is for site preparation and for postplanting competition control of oaks and other hardwoods in the management of loblolly (*Pinus taeda*), shortleaf (*P. echinata*), and longleaf pine (*P. palustris*) forests (Hiers and others 2014). Fire also contributes to the restoration of native grasses and forbs in these systems as well as in oak woodlands.

The oak-fire hypothesis proposes that prescribed fire in upland hardwoods can be used to promote species such as oaks over other hardwood species (Arthur and others 2012). However, questions abound regarding this hypothesis and what it means for practical on-the-ground management incorporating prescribed fire, especially given that the genus *Quercus* contains species with disparate responses to fire regimes. The partnership of research and management is foundational to identifying research problems in forestry and to developing practical science-based solutions to problems of high priority to forest managers.

Many managers in the Southeast use prescribed fire in either pine or hardwood systems as a part of integrated management plans. In this article, we discuss a project involving researchers and managers in examining the use of fire as a management tool on the BNF, a good example of coproduced science. We also provide some summary observations from this large-scale, long-term study, after years of research and management related to fire and fuels on the BNF, about restoring fire as a process and changing the reproduction cohort.

Restoring the historic disturbance regime, which included fire, is paramount to successful restoration of healthy and resilient hardwood forests.

COPRODUCTION OF SCIENCE

Administrative constraints, social influences on management decisions, and imperfect transfer of knowledge from researchers to forest managers limit the adoption of prescribed fire in southeastern upland hardwood forests. The authors were fortunate to partner with the BNF, located in north-central Alabama, at the nexus of a newly approved forest plan and the need for study of active management, including prescribed fire (Schweitzer and others 2008). While developing the forest plan, scientists and managers exchanged ideas; engaged in discussions; held field exploration events; and copresented to the public the ideas, current state of knowledge, and potential researchable questions in the proposed management program.

Researchers worked with the BNF staff to design a large-scale, long-term study aligned with the treatments approved through the Forest Health and Restoration Project (USDA Forest Service 2003, 2004). The northern portion of the BNF was designated for upland hardwood, hardwood/pine, or oak woodlands restoration. It covers approximately 110,000 acres (44,000 ha), of which 1,898 acres (759 ha) were included in our study. In essence, we used the Forest Health and Restoration Project's parameters of thinning (with a residual basal area ranging from 75 to 50 square feet per acre) and prescribed fire (with a return interval ranging from 3 to 9 years) to plan and implement a study with a randomized complete block design with a 3-by-3 factorial treatment arrangement and four replications of each treatment (see Schweitzer and others (2016) for study details). We are using these tools to move mixed pine/hardwood forests towards forests that are more hardwood dominated.

Stands were delineated by BNF staff, and reconnaissance visits with staff and researchers allowed selection of stands that met pretreatment criteria for study in that stands had similar disturbance histories and species compositions. A significant amount of coordination and communication among managers and researchers allowed not only the successful implementation of this study but also continued research over 16 years.

Each year, the BNF prescribe-burns between 18,000 and 22,000 acres (7,200–8,800 ha) of its 157,000 acres (62,800 ha) that are outside wilderness areas by burning nearly every day that meets exacting prescription parameters, from November through May. Maintaining any specific burn block on an exact schedule is exceptionally difficult.* Much commendation is to be given to Kerry Clark, the fire management officer on the BNF, who has been instrumental in implementing a total of 86 prescribed burns on schedule since 2006. While management and research is done at the stand level, prescribed fire is done at the landscape scale, and burn sizes ranged from 150 to 3,000 acres (60–1,200 ha). The "research burns" were embedded within a larger burn plan on the BNF; accordingly, although we reported results at a stand level, we must keep in mind the broader impacts occurring at the landscape scale.

Our study on the BNF is a true Forest Service partnership between the National Forest System and Research and Development. The BNF held all responsibility for treatment implementation, and researchers held all responsibility for completing the research. For example, we installed fire temperature monitoring equipment prior to each burn, which required flexibility and responsiveness to complete installation in the morning before each fire. Understanding by all parties allowed for acceptance of no burn situations after equipment installation and altering of initial ignition sites to allow for installation completion.

PRESCRIBED FIRE AND FUELS IN HARDWOODS

Southeastern pine forests have long been managed using prescribed fire. In these systems, intensive management in silviculture prescriptions includes, for example, a stand that is removed in a single harvest, which is followed by site preparation done mechanically with drum rollers and choppers, chemically with herbicides, or through prescribed fire. At times, more than one of these practices is used. Once the site is clear, pine seedlings (*Pinus taeda, P. echinata,* or *P. palustris*) are planted at given spaces; the pine quickly obtains some height growth, and prescribed fire is used to reduce any competition, which consists of volunteer herbaceous vegetation and hardwoods.

Typical dormant season fire on the Bankhead National Forest in Alabama. Photo: Callie Schweitzer, USDA Forest Service.

We are using thinning and burning tools to move mixed pine/hardwood forests towards forests that are more hardwood dominated.

Because the pines have amplified growth compared to the volunteer hardwood stems in these stands, the larger stemmed pines are relatively unaffected by the dormant-season fires that top-kill small woody stems and reduce any accumulated surface fuels. Pines are more fire resistant than hardwoods due to early thick bark production, and shortleaf and longleaf pine are especially fire adapted. Most understory hardwood stems will sprout following a single fire, and additional fires will be needed to control hardwood competition. Maximum fire temperatures are higher under pines than under oaks, and those higher temperatures differentially contribute to oak attrition (Williamson and Black 1981). It takes multiple fires to remove the hardwoods, until eventually the pines have a sufficient early height growth advantage over the hardwood sprouts and other competing stems that fire is no longer needed. Depending on site conditions and landowner objectives, additional fires may be used as a tending treatment to clear out the underbrush during midrotation.

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Although the intensive silviculture used to manage pine plantations has been well established by researchers and managers over the years and significant advances have been made in longleaf pine management, the ecology and role of fire in pine plantations is not transferable to hardwood systems. Prescribed fire in southeastern hardwood forests is nascent in its use by managers; moreover, the potential for use throughout the southeastern hardwood region is substantial, and our need for research is great.

Most prescribed fires are executed during the dormant season of January, February, and March, based on experience, resource allocation commitments, and burning priorities in different forest types as well as on meeting many burn parameter prescriptions to manage fire behavior, fire effects, and smoke dispersion. Collectively, managers and researchers desire an improved understanding of the ability of treatments to reduce fuel hazards, provide ecological benefits, and validate fire behavior and effects models.

Researchers lack site-specific data related to fuel loading in upland hardwood or hardwood/pine forests in the Southeast, although load inputs and consumption algorithms are paramount to the accuracy of many fire effects models. Because we were interested in stand-level fuel dynamics and the surface fuel components most closely related to the vegetation response, we quantified these surface fuels by collecting fuel samples immediately before and immediately after prescribed fire in replicated treatment stands on the BNF. Five burns at 3-year return intervals have been conducted; for most treatments, we collected surface fuels and duff. For control stands (no thinning and no burning), we collected fuels only at the same time as preburn data collection. Stands were thinned once, either to a residual basal area of 75 square feet per acre (light thin) or 50 square feet per acre (heavy thin). Surface fuel samples were processed in the laboratory, sorted by component, and dried to get load weight. Components included 10-hour fuels, 1-hour fuels, duff, leaves/needles, fruit, and bark.

Thinning initially increased the loading of fine fuels, duff, and bark (fig. 1), but that increase was not evident 3 years after the first prescribed fire. Most components decreased slightly after each fire, and the overall trend of forest floor fuels was decline, including in the control stands. Fruit loading during this time was the most variable (fig. 1), with hardwood masting and fire-induced cone drop from pines contributing much to this. Unfortunately, we did not sort the fruits by species, so these are only inferences based on field observations.

Fire and thinning on the BNF were done as intermediate stand disturbances. The distribution, type, and amount of fuels we examined were consistent, over time,

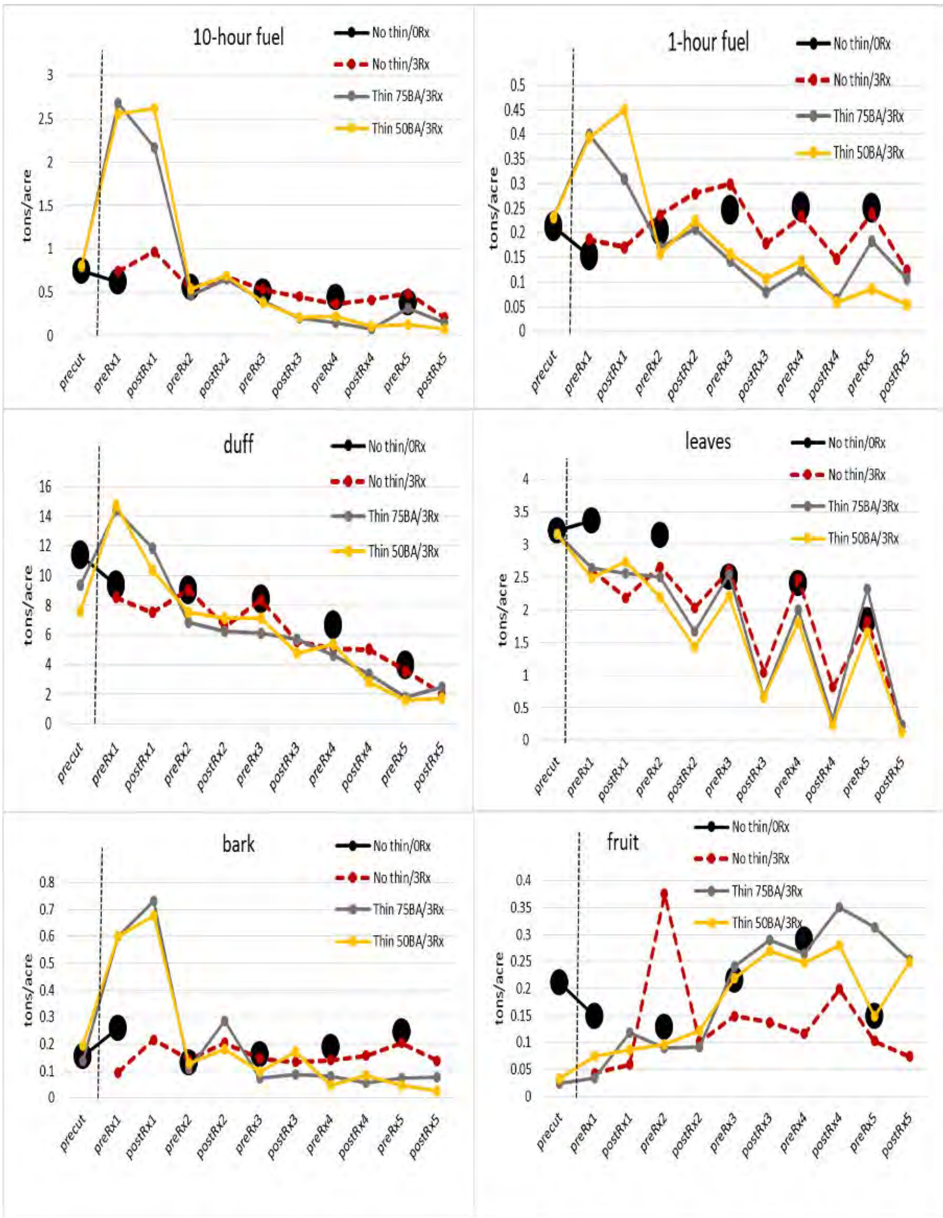

Figure 1—*Fuel loading from oven-dried field samples collected prior to and immediately after prescribed burns on the Bankhead National Forest in Alabama. All burns were conducted in the dormant season and were on a 3-year return interval. Treatments were: no thin/0Rx = control (no thin and no burns); no thin/3Rx = no thin and three burns; thin 75 BA/3Rx = thin to a residual basal area of 75 square feet per acre and three burns; thin 50 BA/3Rx= thin to a residual basal area of 50 square feet per acre and three burns. The dashed line indicates the time of the thinning. The control data, represented by a point, were collected only prior to scheduled burns on the other treatments, and point size is for demonstration purposes only. The timelag between pre- and postdata collection for a given fire is 1 to 3 months; the time lag between fires is 3 years.*

with those of natural decomposition processes, as demonstrated by the control (Graham and McCarthy 2006). Although the data were collected neither to quantify all fuels nor to model fire behavior, we have an opportunity to make some general inferences.

Estimates of fuel loading and consumption lack validation in upland hardwoods and mixed pine/hardwood systems, and there are no published data on fuel loads and consumption for the BNF. If models are being used to make management decisions, such as burning acreage and timing allowable given compliance with air quality standards, then we need parameter validation with local fuel loading and cover type.

For southeastern hardwoods, the testing of inputs is limited. Prichard and others (2014) found that the First Order Fire Effects Model (FOFEM) predictions for woody fuel, litter, and duff consumption should be improved for hardwood forests in Kentucky and Virginia. Reid and others (2012) found that FOFEM default litter fuel loads in oldfield pine communities were less than observed loads and that duff loads were greater than observed. In mixed oak/pine stands in Arkansas, Daniels and others (2016) used default preburn fuel loads and found FOFEM litter and duff estimates to be greater than field estimates.

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In general, our measured consumption of 33 percent for litter was low compared to other reported values for mixed hardwoods, although ranges are reported from 50 to 93 percent across sites (Clinton and others 1998; Prichard and others 2014; Reid and others 2012; Scholl and Waldrop 1999; Sullivan and others 2003). We did not consider impacts on larger fuels, but we plan to correlate fuel loading by components to estimate values obtained through field transects (Brown 1974), a more commonly applied technique for estimating fuels than fine fuel collection.

RESTORING THE PROCESS OF FIRE IN HARDWOODS

Managing hardwood systems is nothing like managing southern pines. For one, our southeastern hardwood stands may have 40 species in dominant or codominant positions, with 5 to 20 of commercial or wildlife value. The lack of fire and other disturbances in hardwoods has resulted in stand compositional and structural changes, often referred to as mesophication (Nowacki and Adams 2008). In essence, the lack of disturbance has altered the understory environment; without disturbance and the resultant increase in light penetration through the canopy, the understory is no longer subjected to periodic xeric conditions, which contributes to a change in the regeneration cohort from oak dominance to dominance by red maple (*Acer rubrum*) or other less xeric and less fire-tolerant species. Restoring the historic disturbance regime, which included fire, is paramount to successful restoration of healthy and resilient hardwood forests. Restoring the process of fire will require managers to develop a prescribed fire regime in which the process outcomes meet the goals of creating the environment needed to move our stands towards desired future composition. After 86 prescribed fires, the BNF has successfully restored fire to these systems.

Prescribed burning was conducted during the dormant season (January through March) using backing fires and strip head fires to ensure that only surface fire occurred. Immediately prior to each fire, we installed six to eight HOBO data recorders (HOBO U12 Series Dataloggers from Onset Computer Corporation in Cape Cod, MA)

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connected to a temperature probe (an HOBO TCP6-K12 Probe Thermocouple Sensor from the same corporation) at each vegetation sampling plot (30 to 48 probes per stand). Installation was based on the design of Iverson and others (2004). Ignition type included hand strip firing at approximately 26-foot (8-m) intervals and aerial ignition for six fires; all others were ignited by hand strip firing along ridgetops, allowing the fire to burn downslope. All study burns were included as part of a larger target burn area on the BNF, and burn areas ranged from 150 to 3,000 acres (60–1,200 ha). Absolute maximum fire temperatures ranged from 2 °F (on January 27, 2007) to 575.4 °F (on March 16, 2013). On average, the maximum temperature was 203.9 °F (with a standard deviation of 145.1 °F) for the first burn, 253.8 °F (with a standard deviation of 130.3 °F) for the second burn, and 407.1 °F (with a standard deviation of 165.4 °F) for the third burn.

CHANGING THE REPRODUCTION COHORT

Almost all hardwoods will sprout if their aboveground growth is removed, and sprouting in seedlings promotes their survival under a variety of stressful conditions. Thus, most hardwood seedlings, when subjected to a fire that removes their aboveground portion, will sprout. Both time and temperature influence this response; in general, the thermal death point for mesophytic plants lies between 122 °F and 131 °F (Hare 1961). The premise used to support prescribed fire is that juvenile oaks are more tolerant to fire due to their physiological propensities: they store carbohydrates belowground as a priority over aboveground growth, and the area around the root collar has an abundance of dormant buds that are often located in the soil, where they are better insulated from fires (Tredici 2001). Single fires do not often turn the competitive tables in oaks' favor, but frequent fires eventually increase oaks' ability to dominate over other reproduction.

Fire behavior greatly influences any resulting sprouting response: hotter, slower moving fires with longer residence time have a greater effect in killing juvenile hardwoods. Prescribed fires in hardwood systems are mostly during the dormant season; they have slow spread rates and somewhat cooler temperatures. However, the minimal thermal death temperature was met on all prescribed fires under study on the BNF. Some involved with restoration in these systems have suggested burning during different seasons to alter fire behavior (to have hotter fires, for example); however, prescription parameters and resource limitations, as well as a lack of sufficient scientific studies detailing vegetation response in hardwood systems, make the possibility of implementing their recommendations tenuous.

The Nation's ability to sustain southeastern oak systems faces enormous challenges (Clark and Schweitzer 2019). Oak reproduction is advance-growth dependent, with greater densities and larger seedlings resulting in the highest probabilities of oak recruiting into larger size classes. Oak reproduction comes from new germinates (acorns) and sprouts from both seedlings and larger trees. Because forest overstories remain dominated by oak, acorn production and germination are not a challenge. The challenge is creating the conditions that encourage small advance-reproduction stems to grow into larger size classes without stimulating competition from the surrounding woody vegetation. Can managers use fire to get oaks through this bottleneck by changing understory conditions? Using fire to manipulate the understory in hardwood systems, with the goal of enhancing oak recruitment into larger size classes, has been reported with disparate results (Arthur and others 2015; Brose and others 2013; Hutchinson and others 2012; McEwan and others 2011).

We have reported on the initial results of reproduction and stand dynamics on the BNF (Schweitzer and others 2008, Schweitzer and Wang 2013, Schweitzer and others 2016; Schweitzer and others 2019). As we continue with these studies, we have noticed an interesting response with regard to sprouting and competition between oak and red maple, the major competitor to oak on the BNF. We examined stands that were thinned or not and had three dormant-season fires at a 3-year return interval and a control with no thinning and no fire. After three prescribed fires, midstory stem density was reduced and overstory mortality was not affected. The reproduction was dominated by sprouts (see Schweitzer and others 2016). The number of clumps, defined as a seedling sprout assemblage with two or more stems, increased over time in all stands, but this increase was three to four times greater in stands that had three fires compared to the controls (fig. 2). There were more seedling sprouts in all treatments, with red maple densities greater than oak densities in all prescribed fire treatments (fig. 2); moreover, the red maple sprouts shielded from fire were in the largest size class for red maple sprouts under the thinning-and-three-fires prescription (fig. 2).

As we continue to burn these stands, we are observing that red maple seedling sprouts are dominating the regeneration cohort. Moreover, many of the red maple clumps have 10 to 15 sprouts, with subsequent fires affecting only the outermost sprouts, which serve as sentinels, protecting the innermost sprouts. The reproduction "fire trap" for red maple may be defeated by this unique sprouting defense, while smaller and less sprout-dense oak continue to be completely top-killed. Red maple is obtaining a competitive advantage over oak in that the unburned protected sprouts are gaining more height growth over the oak sprouts.

As part of the study, we will continue to burn these stands; however, if the management goal is to regenerate oak on these sites, we would suggest removing fire and treating the clumps of red maple sprouts with herbicide. The open midstory

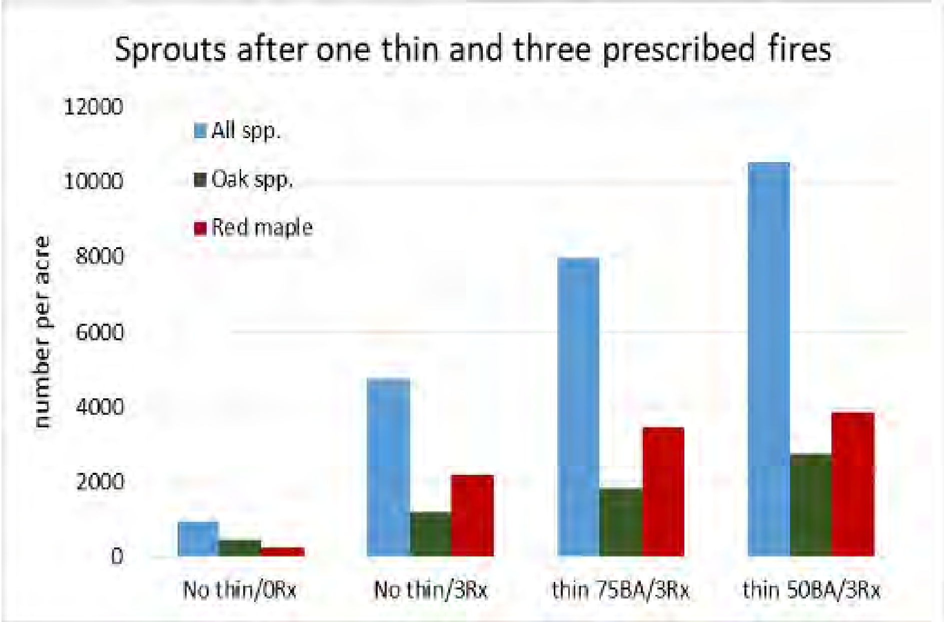

Figure 2—*Reproduction vegetation structures for woody species after one thinning and three prescribed burns on the Bankhead National Forest in Alabama. Reproduction tallied was all stems from 0 to 4.5 feet (0–1.4 m) tall and up to 1.5 inches (3.8 cm) in diameter at breast height. Clumps were enumerated as a reproductive structure with two or more stems, and sprouts were counted as those stems. All burns were conducted in the dormant season and were on a 3-year return interval. Treatments were: no thin/0Rx = control (no thin and no burns); no thin/3Rx = no thin and three burns; thin 75 BA/3Rx = thin to a residual basal area of 75 square feet per acre and three burns; and thin 50 BA/3Rx = thin to a residual basal area of 50 square feet per acre and three burns.*

conditions should enhance recruitment of oak into larger size classes, at which time the overstory can be removed. Alternative fire regimes need to be tested, including hotter fires, more frequent fires, and growing-season fires. Benefit and cost analysis also needs to be made for restoration scenarios using prescribed fire in combination with other management practices and schedules that meet specific management challenges, such as competition from red maple sprouts.

Stand development processes, especially the recruitment stage for oak, must be incorporated into silvicultural prescriptions. Interactions between fire and the resulting species composition and structure are governing intermediate stand development on the BNF, such as the prolific sprouting of red maple. Legacies of past fire suppression and the status of contemporary forests may have increased the density of fire-intolerant hardwood structures, such as fecund sprouting stocks of red maple.

Some have postulated that the leaves of mesic species such as red maple are not as flammable as those of oaks, which also drives the fuel ecology (Nowacki and Abrams 2008). The density of red maple in the understory has increased, potentially altering the concentration of red maple leaf litter. At the same time, our fire temperatures have increased with subsequent burns. This disparity in the vegetation/fuel feedback system is intriguing. Low to moderate fuel loads in these systems will limit the potential for catastrophic wildfires, but restoring fire to these systems is fundamental to restoration goals.

While we did not discuss the effects that fire may be having on residual tree quality, mortality, and timber value (Schweitzer and others 2019; Dey and others 2020, in this issue), the complex feedback between fire, fuels, and vegetation and the long-term rotation length in these systems must be considered (Dey and Schweitzer 2018). Without fire, these forests are moving away from a predominately oak composition; but how to favor oak is not exactly known in terms of the prescriptions that are most effective and efficient, both ecologically and economically. Fire does have a role to play in the restoration and sustainability of southeastern oak forests.

Red maple sprouts with dead "sentinels" (the outermost sprouts, killed by prescribed fire) and live stems on the Bankhead National Forest in Alabama. Photo: Callie Schweitzer, USDA Forest Service.

Red maple clumps and sprouts after three prescribed fires on the Bankhead National Forest in Alabama. Photo: Callie Schweitzer, USDA Forest Service.

COPRODUCING NEEDED SCIENCE

This study exemplifies the ability of managers and researchers to design and implement long-term, stand-level studies to answer questions germane to forest types and restoration goals in forest management plans. Under tight operational tempos, we succeeded in carrying out treatments and collecting data. Meeting specific management goals while relying on prescribed fire can be tenuous, but it can be done.

Researchers and managers have much to learn about fire behavior in southeastern hardwood systems as well as about assessing response under conditions of variable habitat and structural complexity. Managers should consider alternatives to prescribed fire because natural and anthropomorphic restrictions seem to be limiting the number of days on which they can burn. They also must consider the consequences of not reaching desired

Along the way, we demonstrated that coproducing science isn't really that daunting.

outcomes with the fire tool.

We used the template of this study to add to existing research, such as research on the response of the herbaceous community (Barefoot and others 2019; Willison and others 2018); on herpetofauna (Sutton and others 2017); and on birds (Wick and others 2013). These other studies responded to a need by the BNF to establish desired future conditions for multiple uses, goods, and services. Studies at this scale, both spatially and temporally, are essential in producing the science most needed by managers.

At a broad scale, land managers have increased the heterogeneity of forest structure and fuels across thousands of acres. Repeated fires are changing the composition of midstory and understory species. Although it is a mantra among researchers, we do need more data to move our understanding forward. Few replicated studies exist at this scale that are examining stand-level responses to repeated fires.

The response of the red maple clumps, with their protective sentinels, will be tested on future fires. At some point, fire will have to be removed from these stands to allow the reproduction cohort to develop. At that time, our understanding of the fuels and the feedback regulating vegetation dynamics will be more complete. To date, researchers and managers together have accomplished the objectives put forth in the forest plan: we have introduced disturbances that are moving these stands towards upland hardwood dominance; we have influenced surface fuels and reduced hazardous fuel conditions; and we have restored the process of fire to these systems. And along the way, we demonstrated that coproducing science isn't really that daunting.

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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 of the Eastern United States. Journal of Forestry. 110: 257–266.

Arthur, M.A.; Blankenship, B.A.; Schorgendorfer, A. 2015. Changes in stand structure and tree vigor with repeated prescribed fire in an Appalachian hardwood forest. Forest Ecology and Management. 340: 46–61.

Barefoot, C.; Willson, K.; Hart, J. [and others]. 2019. Effects of thinning and prescribed fire frequency on ground flora in mixed *Pinus*-hardwood stands. Forest Ecology and Management. 432: 729–740.

Brose, P.H.; Dey, D.C.; Phillips, R.J.; Waldrop, T.A. 2013. A meta-analysis of the fire-oak hypothesis: Does prescribed burning promote oak reproduction in eastern North America? Forest Science. 59: 322–334.

Brown, J.K. 1974. Handbook for inventorying downed woody material. Gen. Tech. Rep. INT–GTR–16. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station. 24 p.

Fire does have a role to play in the restoration and sustainability of southeastern oak forests.

Clark, S.; Schweitzer, C. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS–GTR–237. Asheville, NC: USDA Forest Service, Southern Research Station. 192 p.

Clinton, B.D.; Vose, J.M.; Swank, W.T. [and others]. 1998. Fuel consumption and fire characteristics during understory burning in a mixed white pine-hardwood stand in the Southern Appalachians. Res. Pap. SRS–RP–12. Asheville, NC: USDA Forest Service, Southern Research Station. 8 p.

Daniels, V.L.; Perry, R.W.; Koerth, N.E.; Guldin, J.M. 2016. Evaluation of FOFEM fuel loads and consumption estimates in pine-oak forests and woodlands of the Ouachita Mountains in Arkansas, USA. Forest Science. 62: 307–315.

Dey, D.C.; Schweitzer, C.J. 2018. A review of the dynamics of prescribed fire, tree mortality, and injury in managing oak natural communities to minimize economic loss in North America. Forests. 9: 461. DOI: 10.3390/f9080461.

Dey, D.C.; Stambaugh, M.; Schweitzer, C. 2020. Learning to live with fire: managing the impacts of prescribed burning on eastern hardwood value. Fire Management Today. 78(3): 51–59.

Graham, J.B.; McCarthy, B.C. 2006. Forest floor fuel dynamics in mixed-oak forests of south-eastern Ohio. International Journal of Wildland Fire. 15: 479–488.

Guyette, R.P.; Stambaugh, M.C.; Dey, D.C. [and others]. 2012. Predicting fire frequency with chemistry and climate. Ecosystems. 15(2): 322–335.

Hare, R.C. 1961. Heat effects on living plants. Occasional Pap. 183. New Orleans, LA: USDA Forest Service, Southern Forest Experiment Station. 32 p.

Hiers, J.K.; Walters, J.R.; Mitchell, R.J. [and others]. 2014. Ecological value of retaining pyrophytic oaks in longleaf pine ecosystems. Journal of Wildlife Management. 78: 1–11.

Hutchinson, T.F.; Yaussy, D.A.; Long, R.P. [and others]. 2012. Long-term (13-year) effects of repeated prescribed fires on stand structure and tree regeneration in mixed-oak forests. Forest Ecology and Management. 286: 87–100.

Iverson, L.R.; Yaussy, D.A.; J. Rebbeck, J. [and others]. 2004. A comparison of thermocouples and temperature paints to monitor spatial and temporal characteristics of landscape-scale prescribed fires. International Journal of Wildland Fire. 13: 311–322.

Lafon, G.W.; Naito, A.T.; Grissino-Mayer, H.D. [and others]. 2017. Fire history of the Appalachian region: a review and synthesis. Gen. Tech. Rep. SRS–GTR–219. Asheville, NC: USDA Forest Service, Southern

Research Station. 108 p.

McEwan, R.W.; Dyer, J.M.; Pederson, N. 2011. Multiple interacting ecosystem drivers: toward an encompassing hypothesis of oak forest dynamics across eastern North America. Ecography. 34: 244–256.

Mitchell, R.J.; Hiers, J.K.; O'Brien, J.; Starr, G. 2009. Ecological forestry in the Southeast: understanding the ecology of fuels. Journal of Forestry. 107: 391–397.

Nowacki, G.J.; Abrams, M.D. 2008. The demise of fire and the mesophication of forests in the Eastern United States. BioScience. 58: 123–138.

Prichard, S.J.; Karau, E.C.; Ottmar, R.D. [and others]. 2014. Evaluation of the CONSUME and FOFEM fuel consumption models in pine and mixed hardwood forests of the Eastern United States. Canadian Journal of Forest Research. 44: 784–795.

Reid, A.M.; Robertson, K.M.; Hmielowski, T.L. 2012. Predicting litter and live herb fuel consumption during prescribed fires in native and old-field upland pine communities of the Southeastern United States. Canadian Journal of Forest Research. 42: 1611–1622.

Scholl, E.R.; Waldrop, T.A. 1999. Photos for estimating fuel loadings before and after prescribed burning in the Upper Coastal Plain of the Southeast. Gen. Tech. Rep. SRS–GTR–26. Asheville, NC: USDA Forest Service, Southern Research Station. 29 p.

Schweitzer, C.J.; Wang, Y. 2013. Overstory tree status following thinning and burning treatments in mixed pine-hardwood stands on the William B. Bankhead National Forest, Alabama. In: Guldin, J.M., ed. Proceedings of the 15th Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS–GTR–175. Asheville, NC: USDA Forest Service, Southern Research Station: 57–63.

Schweitzer, C.J.; Clark, S.L.; Gaines, P. [and others]. 2008. Integrating land and resource management plans and applied large-scale research on two national forests. In: Deal, R.L., tech. ed. Integrated restoration of forested ecosystems to achieve multiresource benefits. Gen. Tech. Rep. PNW–GTR–733. Portland, OR: USDA Forest Service, Pacific Northwest Experiment Station: 127–134.

Schweitzer, C.J.; Dey, D.C.; Wang, Y. 2016. Hardwood-pine mixedwoods stand dynamics following thinning and prescribed burning. Fire Ecology. 12: 85–104.

Schweitzer, C.J.; Dey, D.; Wang, Y. 2018. Overstory tree mortality and wounding after thinning and prescribed fire in mixed pine-hardwood stands. In: Kirschman, J.E.; Johnsen K., comps. Proceedings of the 19th Biennial Southern Silviculture Research Conference. e-Gen. Tech. Rep. SRS–GTR–234. Asheville, NC: USDA Forest Service, Southern Research Station: 337–346.

Schweitzer, C.J.; Dey, D.C.; Wang, Y. 2019. White oak *(Quercus alba)* response to thinning and prescribed fire in northcentral Alabama mixed pine–hardwood systems. Forest Science. 65: 758–766.

Sullivan, B.T.; Fettig, C.J.; Otrosina, W.J. [and others]. 2003. Association between severity of prescribed burns and subsequent activity of conifer-infesting beetles in stands of longleaf pine. Forest Ecology and Management. 185: 327–340.

Sutton, W.; Wang, Y.; McClure, C; Schweitzer, C. 2017. Spatial ecology and multi-scale habitat selection of the copperhead (*Agkistrodon contortrix*) in a managed forest landscape. Forest Ecology and Management. 391: 469–481.

Tiribelli, F.; Kitzberger, T.; Morales, J.M. 2018. Changes in vegetation structure and fuel characteristics along post-fire succession promote alternative stable states and positive fire-vegetation feedbacks. Journal of Vegetation Science. 29: 147–156.

Tredici, P.D. 2001. Sprouting in temperate trees: a morphological and ecological review. The Botanical Review. 67: 121–140.

USDA Forest Service. 2003. Final environmental impact statement, forest health and restoration project. Management Bulletin R8–MB 110B. Atlanta, GA: USDA Forest Service, Southern Region. 352 p.

USDA Forest Service. 2004. Revised land and resource management plan: National Forests in Alabama. Management Bulletin R8–MB 112A. Atlanta, GA: USDA Forest Service, Southern Region. 330 p.

Wick, J.; Wang, Y.; Schweitzer, C. 2013. Immediate effect of burning and logging treatments on the avian community at Bankhead National Forest of northern Alabama. In: Guldin, J.M., ed. Proceedings of the 15th Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS–GTR–175. Asheville, NC: USDA Forest Service, Southern Research Station: 33–37.

Williamson, G.B.; Black, E.M. 1981. High temperatures of forest fires under pines as a selective advantage over oaks. Nature. 293: 643–644.

Willson, K.; Barefoot, C.; Hart, J. [and others]. 2018. Temporal patterns of ground flora response to fire in thinned *Pinus-Quercus* stands. Canadian Journal of Forest Research. 48: 1–13.