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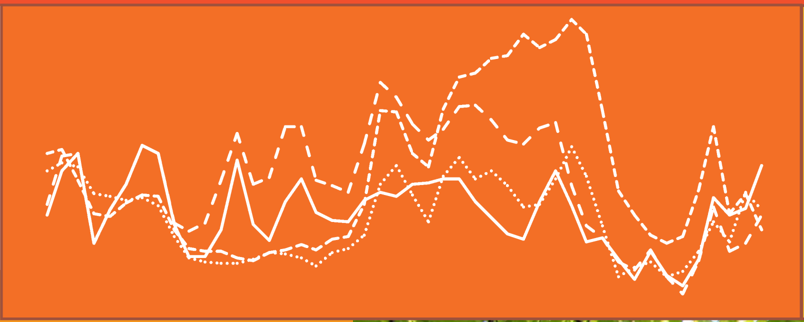
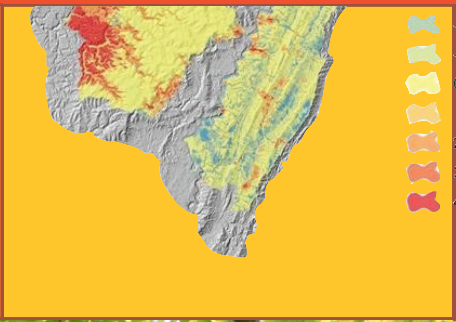
Oak Symposium: Sustaining Oak Forests in the 21st Century through Science-based Management

October 24-26, 2017
Knoxville Hilton Hotel
Knoxville, TN





Forest Service
Southern Research Station
e-General Technical Report SRS-237, March 2019

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March 2019

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Asheville, NC 28804

www.srs.fs.usda.gov

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Abstract

The 2017 Oak Symposium was convened in Knoxville, TN, to share knowledge on state-of-the-art management and research to improve sustainability of the upland oak resource in the Eastern United States. The symposium featured 33 invited speakers, an audience discussion period, a field trip, and 21 offered posters. Speakers addressed topics including the history of silviculture, fire, and research; current status of the oak resource; emerging economic markets; forest health; silviculture for climate change; artificial regeneration; wildlife habitat management; approaches to secure natural advanced oak regeneration; prescribed burning to promote oak regeneration; and management of woodland habitat. Presenters represented various organizations from non-governmental organizations, Federal agencies, State agencies, universities, and industry.

Keywords: Climate change, economic markets, oak woodlands, prescribed fire, regeneration, silviculture, wildlife.

Preface

Significant progress has been made in research and oak management since the mid-20th century, but knowledge of prescriptions to regenerate, sustain, and conserve oak forests is still lacking. The first comprehensive meeting on oak silviculture and management was held in 1971 in Morgantown, WV; it addressed problems with securing oak regeneration, multiple use management, and wood products and utilization [White, D.E. and Roach, B.A. (co-chairmen), Oak Symposium Proceedings. Northeastern Forest Experiment Station, USDA Forest Service]. In 1979, a regional meeting was held at Purdue University that concentrated primarily on the oak regeneration problem [Holt, H.A. and Fisher, B.C. (editors), John S. Wright Forestry Conference: Regenerating Oaks in Upland Hardwood Forests. Purdue Research Foundation]. A meeting was held in 1992 in Knoxville, TN [Loftis, D.L. and McGee, C.E. (editors), Oak Regeneration: Serious Problems, Practical Recommendations. Southeastern Forest Experiment Station, USDA Forest Service, General Technical Report SE-84] that synthesized knowledge and approaches to problems and opportunities associated with regenerating oak. The most recent symposium was held in 2002 in Fayetteville, AR [Spetich, M.A. (editor), Upland Oak Ecology Symposium: History, Current Conditions, and Sustainability. Southern Research Station, USDA Forest Service, General Technical Report SRS-73] that addressed silviculture to regenerate oak, oak decline, wildlife ecology, and forest health. The 2017 Oak Symposium was developed to continue these technology transfer efforts and to share knowledge on state-of-the-art management and research to improve sustainability of the upland oak resource in the Eastern United States. The symposium was hosted by The University of Tennessee (UT), Department of Forestry, Wildlife, and Fisheries, and featured 33 invited speakers, an audience discussion period, and a poster session. Topics addressed included emerging economic markets, silviculture for climate change, artificial regeneration, wildlife habitat management, approaches to secure natural advanced oak regeneration, and prescribed burning to promote oak and to create woodland habitat. A field trip was offered that showcased collaborative research between the UT Forest Resources AgResearch and Education Center, the UT Department of Forestry, Wildlife, and Fisheries, and the USDA Forest Service, Southern Research Station.

Acknowledgments

The committee would like to thank personnel with the Department of Forestry, Wildlife, and Fisheries at The University of Tennessee and the Departmental staff for assistance with hosting this event and coordinating the field trip: Keith Belli, Department Head; David Buckley, Professor; Josh Granger, Post-doctoral Research Associate; John Johnson, Research Specialist III; Scott Schlarbaum, Professor; Ami Sharp, Research Associate II; Alison Shimer, Graduate Student; and Miriam Wright, Administrative Specialist. Sandra Baker and Monica Schwalbach, Secretary and Assistant Station Director, respectively, with the Southern Research Station, USDA Forest Service, provided valuable support with navigating meetings management for the Forest Service. Kevin Hoyt and Martin Schubert, Director and Cumberland Forest Manager, respectively, with The University of Tennessee's Forest Resources AgResearch and Education Center, provided logistical support for the field trip. We would like the thank the staff with the Knoxville Hilton, particularly Dustin Gibson and Tracy O'Connor, and the UT Conference Center, particularly Jessica Swett, for their assistance in registration, meeting arrangements, lodging, and logistics. Nancy Bastin, Office Automation Clerk, Southern Research Station, USDA Forest Service, provided invaluable assistance in editing and formatting papers for the proceedings. We would like to thank the sponsors, field trip hosts, and moderators listed below for their contributions to this meeting.

Sponsors

The Department of Forestry, Wildlife, and Fisheries, The University of Tennessee (fwf.tennessee.edu)

UT AgResearch, Institute of Agriculture, The University of Tennessee (agresearch.tennessee.edu)

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The Forestland Group (forestlandgroup.com)

The Kentucky-Tennessee Society of American Foresters (ktsaf.org)

The Forest Stewards Guild (forestguild.org)

Appalachian Hardwood Manufacturers, Inc. (appalachianhardwood.org)

Tennessee Wildlife Resources Agency (tnwildlife.org)

Mountain Lakes Chapter, Alabama Division, Society of American Foresters

Field Trip Hosts

(Thursday, October 26)

The University of Tennessee: David Buckley, Professor; Josh Granger, Post-doctoral Research Associate; and Scott Schlarbaum, Professor.

Forest Resources AgResearch and Education Center: Kevin Hoyt and Martin Schubert, Director and Cumberland Forest Manager, respectively.

Southern Research Station, USDA Forest Service: Stacy L. Clark, Research Forester.

Moderators

▯ Tuesday, October 24

General Session morning: Stacy L. Clark, Research Forester, Southern Research Station, USDA Forest Service

General Session afternoon: Callie J. Schweitzer, Research Forester, Southern Research Station, USDA Forest Service

Concurrent **Session 1, Adaptive Silviculture for Climate Change**: Sunshine Brosi, Associate Professor, Department of Biology, Frostburg State University

Concurrent **Session 2, Shelterwood Methods for Oak Regeneration**: Ken Smith, Professor and Assistant Dean, Integrated Program in the Environment, The University of the South

▯ Wednesday, October 25

General Session morning: Thomas Schuler, Project Leader, Northern Research Station, USDA Forest Service

Concurrent **Session 3, Prescribed Fire in Oak Forests**: Brian Izbicki, Master's Student, Department of Forestry, Mississippi State University

Concurrent **Session 4, Artificial Regeneration**: David Buckley, Professor, Department of Forestry, Wildlife, and Fisheries, The University of Tennessee

Concurrent **Session 5, Wood Products and Economic Markets**: Matt Bumgardner, Research Forest Products Technologist, Northern Research Station, USDA Forest Service

Concurrent **Session 6, Silviculture to Restore Oak Woodlands**: Daniel C. Dey, Project Leader and Research Forester, Northern Research Station, USDA Forest Service

Concurrent **Session 7, Stand Improvement**: Josh Granger, Post-doctoral Research Associate, Department of Forestry, Wildlife, and Fisheries, The University of Tennessee

Concurrent **Session 8, Early Successional Wildlife Habitat**: Emily Hockman, Ph.D. candidate, Department of Forestry, Wildlife, and Fisheries, The University of Tennessee

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Morning moderator:

Stacy L. Clark
USDA Forest Service, Southern Research Station

Afternoon moderator:

Callie J. Schweitzer
USDA Forest Service, Southern Research Station

WHAT DO WE KNOW ABOUT OAKS?
KEYSTONES OF OAK SILVICULTURE

Wayne K. Clatterbuck

INTRODUCTION

A wealth of information about the silviculture, management, and utilization of oaks (*Quercus* spp.) is available in many research papers and symposia. The first symposium dedicated to oaks was held at West Virginia University in 1971 (Northeastern Forest Experiment Station 1971) in response to five oak presentations given at the Division of Silviculture session at the Society of American Foresters (SAF) Annual Meeting in Philadelphia, PA in October 1968 (Northeastern Forest Experiment Station 1970) when SAF attendees expressed an interest in a more comprehensive conference on oak silviculture. Three other oak symposia have been held since: in 1979 at Purdue University as part of the John S. Wright Forestry Conference focusing on regeneration (Holt and Fischer 1979), in 1992 at The University of Tennessee also focusing on oak regeneration (Loftis and McGee 1993), and in 2002 in Fayetteville, AR focusing on upland oak ecology (Spetich 2004). The 19 Biennial Southern Silvicultural Research Conferences and the 20 Central Hardwood Forest Conferences have a majority of their hardwood research presentations centering on oak. There are many other various regional symposia, conferences, and compendiums on oaks (e.g., Brose and others 2008, Ffolliott and others 1992, Johnson 1985, USDA Forest Service 1980). Peer-reviewed journal articles are also abundant concerning oak regeneration, growth and development, management alternatives, and utilization. However, even with the plethora of materials and resources available about oaks, many questions remain. This fifth Oak Symposium (present conference) returning to The University of Tennessee (2017) provides a framework of what is known about the biology and management of upland oaks and the concerns that research should continue to address within present contexts of oak ecology and ecosystems, forest health, economics, climate change, wildlife habitat, and prescribed burning.

This review of oak silviculture is a compendium of my own research as well as reflections of conversations with other researchers and forest practitioners alike. My Extension position has allowed me to observe on-the-ground practices, markets, and costs associated with hardwood (oak) silviculture and management as well as values and attitudes of private forest owners and stand prescriptionsß implemented on public lands. Associations with several mentors, including Dr. John Hodges at Mississippi State University; Drs. C.E. (Gene) McGee, Glendon Smalley, and David Loftis at the Southern and Southeastern Forest Experiment Stations (now merged into the Southern Research Station); and Dr. Ed Buckner at the University of Tennessee, as well as many silviculturists at universities across the country, have greatly influenced my knowledge and perspectives of oak ecosystems.

Past and present research about oak species is summarized, and what is known and not known and the opportunities or priorities for future research and management to successfully manage oak development and environments from regeneration through harvest are discussed in this review.

WORKING WITH OAKS IS PARADOXICAL

According to Oxford Dictionaries (2017), paradox is defined as "a statement or proposition which, despite sound (or apparently sound) reasoning from acceptable premises, leads to a conclusion that seems logically unacceptable or self-contradictory." Various practitioners, landowners, and researchers for a period of years have noted the numerous paradoxes that arise when working with oaks. Although these statements (and their numerical estimates) about oaks and the oak resource cannot be attributed to any one person or literature reference as the original source, these

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

assertions have a degree of truth associated with them as well as aggravation in addressing some of the difficulties related to oak management. Working with oaks can be both exhilarating and exasperating!

1. More money is spent each year controlling or eradicating oak where it is unwanted than is spent on oak silviculture.
2. Although oak is widely distributed and of great abundance, a major research problem is the difficulty associated with replacing existing oak stands with future oak stands.
3. High-quality oaks command high prices. Yet, for a high proportion of typical oak stands, there is not a market for abundant low-quality or low-grade oaks.
4. Oaks are widely perceived to be long-lived, but more than 99 percent of the natural oak population dies before it is 5 years old.
5. Oaks vary in their ecological requirements and their productive potential, yet little is known on how to predict the quality or quantity of mast crops. Many silvicultural recommendations made to favor wildlife may actually reduce acorn production potential.
6. The best growth and yield models and volume tables for upland oaks are still those in the Schnur (1937) publication.
7. Hundreds of thousands of oaks are planted each year, but few attain maturity, become merchantable for wood products, or bear acorns.
8. Timber buyers reduce their stumpage offers by 20 percent or more if there are indications of burning in hardwood stands. Meanwhile, veneer buyers, as a rule, will not buy stumpage from stands with evidence of burning.
9. Production of high-grade hardwood timber was not present in quantity until wildfire control programs were implemented in the 1940s and 1950s.
10. Typically, 20 percent of the hardwood species produce 90 percent of the hardwood revenue and within such trees, 90 percent of the value is in the butt (first) log.

Oak practitioners from the science, management, and economic spectrums contend with a range of frustrations about this popular taxon. The paradox of managing oaks begins with their biology. Potential solutions to oak management and regeneration will stem from further understanding of oak biology, especially as compared to other associated species.

SPECIES-SITE RELATIONSHIPS

Unlike many forests that are composed of few species, oak forests are composed of many species, both oak and non-oak. For oak species, the myriad of different species that each grows with and the variety of sites where each occurs (xeric, mesic, hydric, and transitions) make regeneration and growth of oaks extremely complex and variable. Different oak species regenerate and grow at different rates on different sites. Therefore, silviculture should focus on the requirements of each oak species rather than the broad oak genus. The specificity in the management and culture of oak species goes well beyond the two subgenuses: *Erythrobalanu*s (red oaks) and *Leucobalanus* (white oaks). Typically each species within each subgenus will respond differently to silvicultural treatments based on the biology/ecology of the species and the site conditions.

These highly variable species-site relationships concerning oak regeneration and management are much more pronounced in Tennessee, the area where I work, than most Eastern States. The landscapes range from the Blue Ridge Mountains in the east to the Mississippi Alluvial Plain in the west (fig. 1). The Forest Service research installations that perform or have performed oak research applicable to Tennessee are many, usually keyed to different physiographic areas. Oak response to practices that may be applicable or suitable for one physiographic region such as the Western Highland Rim is quite different than at higher elevations that are less dissected like the Cumberland Plateau or more dissected such as the Blue Ridge Mountains.

Although the native ranges of white oak (*Q. alba*) and northern red oak (*Q. rubra*) are quite ubiquitous on the landscape covering all States east of the Mississippi River and States that border the western edge of the river (Burns and Honkala 1990), the sites, vegetation, disturbance histories, and climates are quite variable resulting in different oak growth responses. With the widespread occurrence of oak in the Eastern United States, management is often keyed to the least common denominator or a mentality where similar prescriptions will yield similar results. However, the diverse landscape that oaks occupy usually results in much greater unpredictability and inconsistencies based on the wide combinations of biotic and abiotic factors. Often site evaluation is either not performed or misinterpreted yielding unfortunate outcomes. Site evaluation is becoming a lost art, particularly with the wide variability of oak species, each with distinctive environmental settings and constraints. The challenge is to determine oak response to these environmental gradients (Arthur and others 2012).

Oaks, with their conservative growth strategy, regenerate well on lower quality, drier, more xeric upland sites where they does not compete with faster-growing species. Root growth is emphasized during the seedling stage which may be a survival mechanism on more xeric sites, but conversely on more mesic sites, height growth is diminished allowing faster growing competitor species to overwhelm the oak (Dickson and others 1990, Rebbeck and others 2011). However, between these two site

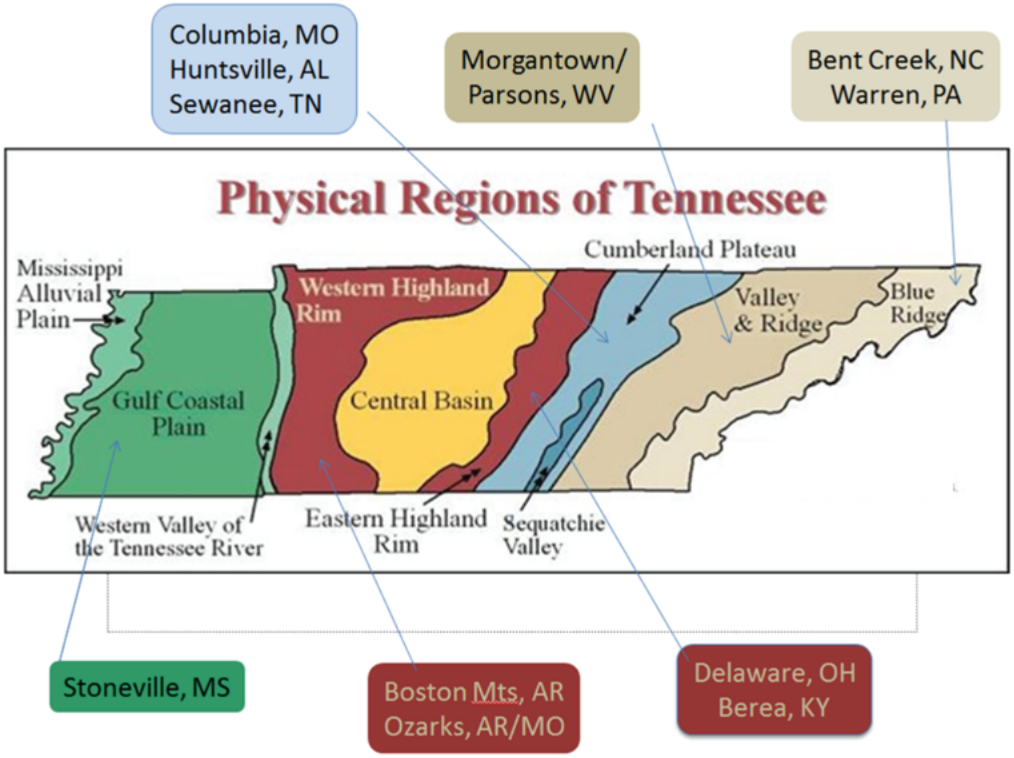

Figure 1—Physical regions of Tennessee and past and present U.S. Department of Agriculture Forest Service locations responsible for research associated with those regions (maps adapted from Miller 1974).

extremes, both oak and competitor species can co-exist (estimated site index between 65 to 75 feet for oak at 50 years). On these “average” sites, the growth of oaks is enhanced somewhat from the xeric sites and the growth of faster growing competitor species is reduced. If oaks are desired, sites should be chosen that encourage the biological requirements of oaks as opposed to the competing species (Hodges and Gardiner 1993).

Site productivity is difficult to judge on many eastern hardwood sites. Stands have been disturbed repeatedly through indiscriminant cutting, burning, and grazing as well as natural disturbances such as climatic events resulting in stands that are poorly stocked with an undesirable species mix and trees that are defective with poor form and stem injuries. Desirable growing stock is not present or poorly represented with erratic degrees of stocking, structure, and age. The trees in the stand are not representative of growth potential and previous communities and thus are not good candidates for a direct measure of site index or site productivity. In lieu of direct estimations of site productivity, landforms or landtypes have been incorporated as spatial synthesizers integrating physiography (geographic setting, geology, and topography), soil, and climate to potential vegetation in indirectly assessing site productivity (Baker and Broadfoot 1979, McNab and others 2007, Smalley 1986). Ultimately, species grow where they can compete successfully and tolerate local conditions, not necessarily where they grow best. Matching species, sites, and environmental gradients is instrumental for hardwood (and oak) management with the wide array of sites and species present. Sites are also dynamic and change based on pedogenesis, vegetation succession, and disturbances through processes such as deposition, erosion, drainage alterations, and climate variability which impact species-site relationships.

NATURAL REGENERATION

The majority of oak research has been investigations into some aspect of oak natural regeneration. However, a few steadfast standards are apparent. Oaks can regenerate from seed, sprouts, and advance reproduction (seedling in place). Typically, new oak germinants shunt energy into root growth and are outcompeted by existing competitor species. Oak sprouts, although fast growing with their existing root system, are too few in number to establish a viable oak stand. Advance reproduction is more effective in regenerating oak since a root system is already established and leaves and shoots are more developed.

Pioneering studies by Sander (1972, Sander and others 1976) suggest that advance reproduction of oak with sufficient numbers and size (generally ≥4 feet tall) is necessary to successfully regenerate oak. This advance oak reproduction should be present before the harvest cut. Otherwise, shade-tolerant species such as maple (*Acer* spp.) and beech (*Fagus* spp.) that are present in the understory and midstory and intolerant species from seed such as yellow-poplar (*Liriodendron tulipifera*) and cherry (*Prunus* spp.) will outgrow and supplant small oak reproduction (<2 feet tall) or germinating acorns. Typically, oaks with their intermediate light tolerance are favored in partial light conditions and on drier, xeric sites, whereas tolerant species are more abundant with more limited light or closed canopies on mesic sites and decline on xeric sites. Intolerants prefer open canopies and greater sunlight on mesic sites (Hodges and Gardiner 1993).

The number of large oak seedlings recommended to be present at harvest depends on management objectives for the number of mature oaks desired in the future stand. The common guideline of 100 to 200 large oak seedlings as advance reproduction per acre (Stringer 2016) is sufficient to have 40 to 60 mature oaks per acre at maturity (Clatterbuck and Hodges 1988). These general recommendations should be taken into consideration with existing stand and environmental conditions that vary widely within the oak range. Modifications to these guidelines should be considered based on differences in site productivity, management goals for species composition and stand structure, abundance of competing species, and external influences such as herbivory (Dey 2014).

Unfortunately, many stands suitable for harvest have not been disturbed or managed for many years resulting in closed canopies and dense midstories and understories of shade-tolerant species. These environmental conditions restrain establishment and development of advance oak reproduction which has intermediate light tolerance. The harvest of these oak-dominated stands without adequate oak advance reproduction usually shifts future composition to non-oak species. Hodges (1989) states "the answer to the question of how to ensure adequate oak regeneration . . . is not the development of some radically new method of cutting, but recognition that all cutting operations in the stand, from the very first, should have as some of their objectives creation of an environment, largely light conditions, favorable for oak regeneration . . . and furthermore . . . ensure that cuttings occur frequently enough to maintain growth of oak regeneration." However, the scarcity of markets for small-diameter trees in many hardwood areas has inhibited thinnings and other intermediate treatments that can promote advance reproduction. With the absence of these operations and other disturbances such as fire, grazing, weather-related occurrences, and insect and disease infestations, closed canopies are prevalent for extended time periods prohibiting advance oak reproduction.

The key to establishing and developing advance oak reproduction for natural regeneration is in the regulation of sunlight reaching the forest floor. Too much or too little light can deter advance reproduction promoting other species rather than oak. Many studies have agreed that 20 to 30 percent of full sunlight is necessary for developing competitive oak seedlings (Dillaway and Stringer 2006, Gardiner and Hodges 1998, Gottschalk 1994, Lhotka and Lowenstein 2009, Lorimer and others 1994, Phares 1971). These light levels can be attained through several practices that have been or continue to be studied: shelterwood, midstory removal, expanding gap, and variable overstory retention as well as opening sizes.

The shelterwood regeneration method favors species with intermediate light tolerance such as oaks. However, there is a fine line in practice to promote oak species as discussed previously. Too much light or too little light will promote species other than oaks. The shelterwood method for oak regeneration is primarily used to encourage the development of large seedlings from existing smaller ones, so that they will be able to successfully compete with other vegetation when the overstory is removed (Loftis 1990a, 1990b). A caveat with the shelterwood method is that advance oak reproduction must be present and cultured to a larger size by regulating the amount of light. If advance oak reproduction is not present, the method should not be implemented until advanced reproduction is present, usually following a bumper seed year, and environmental conditions are favorable for acorn germination. The environmental conditions for germination (primarily moisture and seedbed receptivity) and good acorn crops that exceed predation do not occur regularly such that establishment of advance reproduction may take several to many years (Burns and Honkala 1990, Dey 2014).

Partial or diffuse light levels that are beneficial to oak advance reproduction and discourage other vegetation can be achieved through midstory removal. This practice is often used in stands that have a dense midstory layer composed of tolerant species. Removal of the midstory layer allows more penetration of diffused sunlight through the canopy, increasing the amount of light for the oak seedlings. Midstory removal is commonly practiced with shelterwoods and small openings (0.5 to 1 acre) to develop greater size of small existing oak advance reproduction (Loftis 1990b, Stringer 2006).

Likewise, light conditions that promote greater size of oak reproduction can be implemented through varying the size of openings (light received within the opening) and edge effects of openings, often referred to as expanding gap or femelschlag (Kern and others 2017, Lhotka and Stringer 2013). Midstory control is used

in conjunction with varying opening sizes to increase light penetration within and on the edge of the opening. Different opening sizes provide different light intensities and durations supporting different suites of species, parallel to species light tolerances. Small, individual tree openings support tolerant species, large openings support intolerant species, and intermediate openings favor more intermediate species (Lhotka 2013). The edge of the opening receives light from the opening. With midstory removal within the opening and from the edge outward (expanding gap), additional light is available (Craig and others 2014). Although research into expanding gap and various gap and opening sizes are in their infancy, investigations evaluating these partial light concepts to favor oaks are continuing in efforts to provide more definitive management guidelines for regenerating oak in partial light matrices.

Even when oak regeneration is ample, oaks have a difficult time emerging into the overstory. The “oak bottleneck” occurs when mature oaks and oak seedlings are numerous in the overstory and understory, respectively, but oak saplings are scarce in the midstory such that there is little potential of oak ingrowth into the overstory (Dey 2014, Signell and others 2005). Nowacki and Abrams (2008) suggested that long-term forest mesophication due to fire suppression may be promoting more vigorous, fire-tolerant species rather than oak. However, the same bottleneck is also occurring on moist sites without a burning history in absence of disturbances. Research is beginning to investigate the bottleneck problem. Crop tree release (Miller and others 2007) at an early stage of development before or at canopy closure may be one solution.

In summary, advance oak reproduction of adequate size and number is necessary for regeneration. Oaks regenerate well on average to poor productivity sites (sub-mesic to xeric) where competition from faster growing species is less. On the better sites, the issue is that even though oak advanced regeneration of sufficient size and number is present, faster growing species tend to supplant and overwhelm oaks (bottleneck effect) before they reach the overstory. Regulation of the sunlight is necessary to promote oaks and discourage other vegetation. Regeneration of oak must be planned several years before the harvest cut for advanced reproduction of oak to develop and become a component of the next stand. Stands should be entered and disturbed more frequently to create light conditions for growth and development of advance regeneration. Typically these measures can be attained on lands that are continually managed, but do not occur on unmanaged lands where disturbances are infrequent and closed canopies are maintained for an indefinite period. Natural regeneration of oak is a process and not an event. Merely harvesting an oak stand without oak advance regeneration will yield a future stand of non-oaks. Advance regeneration should be established and cultured to larger sizes. With this process, oak regeneration can also be interpreted as disturbance-dependent to allow for the establishment and growth of advance reproduction well before the harvest and advance growth-dependent in that advance reproduction should be of sufficient size and number to successfully compete with other species following the final harvest. Additional disturbances through release treatments are necessary to ensure that oak stems do not bottleneck and emerge into the overstory.

ARTIFICIAL REGENERATION

Planting is an alternative for oak regeneration when advance oak reproduction is not present. Oaks can be planted in reforestation or afforestation efforts or as enrichment or supplemental planting when natural oak reproduction is judged to be insufficient to meet regeneration goals. Unfortunately, there have been many more oak planting failures than successes. Planting failure can be nursery and planting related with poor quality seedlings, poor nursery practices from the nursery bed to the planting vendor, or poor planting techniques. However, as expressed earlier, many failures are also from inferior site preparation to control competing species as well as incorrect species-site associations where sites are better suited for growth of other species rather than oaks, or inattention to sunlight relationships that favor oaks rather than other species.

Planting oaks is usually more successful on the better sites (bottomlands, stream valleys and drains, and on lower slopes) where soil moisture is not as limiting. Alternatively, oaks planted on convex surfaces and drier sites where soil moisture holding capacity is poor are not as successful. Natural regeneration is a better option on these sites if a seed source is available.

The condition of planted seedlings is critical for a successful oak planting. Some controversy exists around whether to plant small or large seedlings. Larger seedlings are more difficult to plant and usually more expensive. The question is whether these larger seedlings have a greater probability of success for survival and growth than smaller seedlings. Trees/seedlings try to keep a balanced ratio between the aboveground stems and leaves and the root system (Perry 1982). Seedlings grow well in the nursery where growth components (water and nutrients) are generously provided and competition is controlled. However, once seedlings are lifted from the nursery, usually more than half of the seedling’s root system is not retained which stresses the seedling (Watson 1994). With the diminutive root system, the aboveground portion of the seedling is also affected. The outplanted seedling either is stimulated to regenerate more roots quickly to sustain the top, or the top partially dies back, or both so that the shoots and the roots re-establish equilibrium. After planting, height growth is minimal during the first growing season allowing competitor species to have a growth advantage which can adversely impact the oak seedling. At this time, there is no definitive agreement or peer-reviewed, oak-specific study on whether planting small or large seedlings is more successful.

Although containerized seedlings or plugs have a complete root system when transplanted, the container has limited root and medium volume. Because of restricted root development, most container seedlings are watered frequently during growth and before transplanting creating a hospitable rooting environment. Soil environments on submesic to xeric sites are moisture-limited and are often detrimental to survival of planted seedlings. After planting, the differences in water potentials between the favorable container medium and the native, usually poorer soil will either take water away from the container medium causing water deficits, or draw water into the container medium causing saturation and limiting oxygen to the roots. At either extreme, water uptake is limited and influences seedling growth and survival. Seedlings must compensate between the favorable growing environment in the container medium and the much harsher soil conditions (usually more moisture-limited) at planting sites. These differing water potentials between controlled and planting environments as well as differences in soil substrates (container vs. field) can affect seedling growth and performance.

Another unresolved component of oak seedling quality from nurseries is the impact of top-clipping seedlings to regulate seedling size making them easier to plant and perhaps increasing the root collar diameter of the seedling, e.g., make the seedling stouter. The question is whether top-clipping apical leaders of the seedling has an influence on seedling performance once outplanted. Clipping may influence growth hormones causing multiple leaders to emerge rather than a single shoot with apical dominance and greater height growth. This disruption of overall height growth may concede height advantages to competing vegetation. Again, oak-specific research has not taken place to address whether top-clipping is physiologically beneficial or not to overall outplanting performance. Top-clipping certainly limits seedling size making the seedling easier to lift, handle, and pack by the nursery before outplanting, but seedling performance is unknown.

Seedlings, whether produced in nurseries or in containers, are usually grown in full sunlight, and then transplanted to partial light conditions, especially in enrichment or supplemental plantings. The impact of these different light regimes on seedling performance is not known and is not referenced well in the literature (McGee 1975, 1986). Further research on seedling size, use of top-clipping, use of bare-root or container seedlings, and light regimes are warranted to improve planted seedling performance and survival so oaks can become viable components of the future stand.

PRESCRIBED FIRE

Burning in hardwood forests is more in vogue today than at any time since fire suppression policies were implemented in the 1940s. Five recent conferences have been held about the role of fire in eastern oak forests and the impacts on people, resources, vegetation, and landscapes (Dey and others 2012, Dickinson 2006, Hutchinson 2009, Varner and others 2016, Yaussy 2000).

Prescribed fire is a silvicultural tool commonly implemented for site preparation for natural or artificial regeneration, fuel reduction, enhancing wildlife habitat, perpetuating fire-dependent species, improving site access and appearance, and providing early successional vegetation structure (Wade and Lunsford 1989). Prescribed burning has environmental impacts on vegetation, soil, water, air, wildlife, and visual appeal. Burning for successful oak regeneration remains challenging with both benefits and detriments to vegetation and sites (Arthur and others 2012, Brose and others 2013).

Prescribed burning to improve wildlife habitat in upland hardwood forests is a subject of this conference, has been thoroughly reviewed (Harper and others 2016), and is not further discussed in this paper. Fire is a component of savanna and woodland systems that have diminished with fire suppression (Dey and others 2017, Keyser and others 2016). One of the concerns with repeated burning in these pyric systems is high-intensity, small-scale, frequent fires do not support oak ingrowth and result in relatively unstable communities (Clatterbuck and Stratton Rollins 2018, Knapp and others 2015). To allow oak ingrowth to occur, land managers should cease burning for a greater period of time or conduct lower intensity burns. With repeated burns, the overstory trees are decrepit with fire scars and decay, and their numbers diminish with time and each burn. The consequence of one longer burning interval to allow ingrowth will shift vegetation to more woody species and less herbaceous vegetation.

The primary disadvantage of burning in standing trees when developing oak reproduction is the potential of damage to tree boles. Most hardwoods are highly susceptible to butt rot, especially from the *Armillaria* root fungus. Even a low-intensity burn with small fire scars will result in greater susceptibility to butt rot. The risk is even greater with repeated burning. The results of burning are often erratic with varying fuels, temperatures,

and durations. Small-diameter trees with thinner bark are much more susceptible to stem damage and topkill, but many will resprout with their root systems. Stem damage from fire reduces sawtimber value. Many of the older trees present today with fire scars were damaged when trees were young.

Wildfires that burned regularly 80 to 100 years ago have been hypothesized as one factor that contributed to the oak forests that are present today (Van Lear and Watt 1993). Prescribed fire could be used to simulate the environmental conditions that favored the growth of oak seedlings amongst the growth of competitors. Other factors that could have contributed to the environmental conditions that promoted oaks are grazing, loss of American chestnut (*Castanea dentata*), and indiscriminant logging. These disturbances (and probably others) jointly created an environment, primarily species composition and stand structures, which is different from the environmental conditions present in forests today.

The remaining discussion concerning oak regeneration assessments with prescribed fire is based on my perspectives of species relationships for various site productivities.

Burning for oak regeneration on lower quality, poor productivity sites [Site Index (SI) <65 feet for oak] is not necessary because oak already proliferates in both the overstory and in the understory. Oak competition is fairly sparse on these sites. Prescribed burning may be appropriate for other purposes such has wildlife habitat but not for oak regeneration that is already in place. On the better, more mesic hardwood sites (SI >80 feet), burning is difficult and rarely occurs. These better sites in cove hardwood areas, lower slopes, and near stream valleys and floodplains are usually too moist throughout the year to ignite and carry a fire. Typically, faster growing species will dominate on these sites. Burning for the purpose of regenerating oak on these higher productivity sites is not realistic. The best opportunity for burning to benefit oak regeneration is on the average or mediocre site productivities (SI 65 to 80 feet) that encompass a narrow range of site productivities but entail hundreds of thousands of acres of forest land in eastern forests. Advance oak reproduction of sufficient number and size must be present because burning will not create oak regeneration. Burning can also damage and decrease the value of standing trees, if present.

Fire is a blunt tool that is difficult to characterize due to variable weather conditions, fuels, vegetation, and moisture. Research with burning is problematic to replicate because different areas tend to have varying conditions (weather, substrate/soils, vegetation, fuels) that will impact the burn and cause different effects. With most burns, small oak reproduction is as likely to be killed as perpetuated. A successful prescription that favors oaks selectively at the expense of other species is easier said than done. Much of the information that we have is anecdotal or observational at one point in time and has not been verified or replicated by long-term research to the degree that oak regeneration prescriptions using fire predictably result in overstories composed of oaks. There is much more we need to understand about these ecosystems and the ecology of the species involved as suggested by Arthur and others (2012). Some of the fire variables that will influence success include fire properties such as duration, residence time, rate of spread, frequency, intensity, and season and timing of burning; fuel properties such as type, amount, size, and moistures; and susceptibility of species based on size and age.

There has been much discussion about whether repeated burning would selectively favor oaks compared to other species (Arthur and others 2015, Hutchinson and others 2012, Keyser and others 2017). In theory, repeated burning would tend to gradually reduce the sprouting ability of some species (progressively reducing root reserves until they no longer sprout) and perhaps enhance those species (primarily oaks) that may be better adapted to burning through their resprouting ability. Although oaks can be influenced by repeated burns (either positively or negatively), perhaps the more pertinent question is whether a landowner can afford to lose 8 to 10 years of growth by burning three or more times attempting to structure the vegetation for a greater oak component. Repeated burning can degrade and decrease the value of standing trees (Marschall and others 2014, Yaussy and Waldrop 2010). Research has indicated that just one burn is not enough to favor oak over other species. Most all hardwood species will sprout when damaged and stressed! Repeated burns increase the chance of damage to residual trees.

Burning in hardwoods for purposes of regeneration is difficult! Fuels vary based on the species and stand structure present. Intensity of the fire is difficult to regulate. Prescribed fire on slopes is very tricky. Fires will not start or carry on moist lower slopes and stream valleys. Fires are tough to control on upper slopes and ridges where fuels are drier and often directed by gusty, inconsistent winds. A program of prescribed burning should not be undertaken without a full appreciation of the purpose, difficulty, and risks/liabilities involved with each burn. Although there are many proponents of burning to regenerate oak, many uncertainties are present. Care should be taken to ensure that prescriptions using fire are successful for both meeting oak regeneration objectives and increasing the probability for oaks to emerge into the overstory in mixed-species stands. More research and definitive answers to the following questions are necessary to successfully implement prescribed burning as a practice to manage and regenerate oaks:

1. How can fire be used to develop sufficient size and number of oak advance reproduction?
2. What is a feasible oak regeneration prescription using fire considering that most competitors sprout?
3. How can stands of mature hardwoods or immature stands of developing hardwoods be burned without damaging crop trees?

TAKE HOME SUMMARIES

- Know your species, both oak and non-oak. Know your sites. Evaluate species-site relationships to favor oaks.
- Advance reproduction is necessary to regenerate oak. How to implement partial light conditions (at least 20 to 30 percent available light) relies on the skill of the silviculturist. Several methods are available: shelterwood, midstory removal, expanding gap, and variable overstory retention as well as opening sizes.
- Oaks are disturbance-dependent and advance growth-dependent. Regenerating oak is a process and not an event. Growth of competing species often displaces the development of oak (bottleneck effect) before oaks are able to emerge into the overstory.
- Prescriptions to successfully regenerate oak using prescribed fire are largely unknown, untested and unpredictable. An intensive regeneration survey is necessary before the harvest and the burn to evaluate the impacts on oaks in conjunction with other species. Most all hardwood species resprout. Several factors influence burning properties including fire duration, residence time, rate of spread, frequency, air temperature, intensity, and season and timing of the burn as well as type, amount, size and moisture content of the fuels, and individual species' tolerances to burning. Many of these properties and combinations are difficult to prescribe and implement consistently for desired effects. Each fire has different impacts on vegetation.
- Most research has been oak-centric. More focus should be given to oak ecosystem dynamics, particularly other species and site characteristics than relying on an oak-only mentality, especially when implementing practices/treatments in mixed-species stands.

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THE PLACE OF OAK TREES IN FORESTS OF THE UNITED STATES— A BRIEF SUMMARY OF FOREST INVENTORY DATA

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Extended abstract—Oaks (*Quercus*) can be found growing in the Americas, Europe, Asia, and Africa. About 600 species have been identified worldwide (Oswalt and Olson, 2016). Native to the Northern Hemisphere, oaks are found from the cold latitudes of North America to the tropics in Asia and the Americas. In North America, oaks are widely distributed and found in both the Western and Eastern United States, with only two species (chinkapin (*Q. muehlenbergii* Engelm.) and bur oak (*Q. macrocarpa* Michx.)) common to both regions. Oak species richness (the number of oak species) in the Eastern United States is highest in the South near the shared borders of Alabama, Florida, and Georgia and declines as you travel north and west. Using data from the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) program, the distribution and importance of oaks across the United States (U.S.) are explored and summarized.

The FIA database is a long-term record of information on U.S. forest resources based on field samples distributed across the landscape. The forest inventory conducted by FIA is a year-round effort to collect and disseminate information and statistics on the extent, condition, status, and trends of forest resources across all ownerships (Oswalt and others 2014). Fixed-area plots were installed in locations with accessible forest land cover (see Bechtold and Patterson 2005 for detailed discussion of the annual FIA program). Field crews collected data on >300 variables, including land ownership, forest type, tree species, tree size, tree condition, and other site attributes (e.g., slope, aspect, disturbance, land use) (Oswalt and others 2014). Plot intensity for field collected data was approximately one plot for every 6,000 acres (2 400 ha) of land (approximately 130,000 forested plots nationally).

Data were assembled from the Forest Service FIA database (FIADB) version 1.7.2.00 in August 2017. Over 300,000 plots were pulled from the FIADB that included approximately 150,000 forested plots and approximately 55,000 plots with oak represented (at least 1 stem with 1 inch DBH or greater) in the sampled trees. Data from the Caribbean and Pacific islands were not included in the analysis. Data assembled represented the most recent inventory (10-year remeasurement cycle in the West and 5-7 year cycle in the East).

According to recent data, over 765 million acres of forest land (not including low productivity woodland) exist in the United States, of which about 62 percent are in private holdings (supported by Oswalt and others 2014). Located within the over 750 million acres of forest land in the United States, 377 different unique tree species (see www.fia.fs.fed.us/library/field-guides-methods-proc/index.php for FIA tree definition and lists of sampled species) and 51 different species belonging to *Quercus* were recorded. In fact, the *Quercus* genus is represented by a greater number of unique species than any other genera in the FIA database (excluding island inventories). However, oaks fall behind Pinus with respect to total number of estimated stems growing in forests of the continental United States. In total, there is an estimated 43 billion oak stems (1 inch DBH or greater) growing across the United States which represents about 11 percent of the total U.S. tree population. White oak (*Q. alba* L.) represented 19 percent of all oak biomass, the most of all oaks, while Oglethorpe oak (*Q. oglethorpensis* Duncan) represented the least (<0.001 percent of all oak biomass).

A total of 150 different forest communities or FIA forest types were recorded across the continental United States. Oak was a primary component of 28 different forest types. The white oak–red oak–hickory type was the most common recorded (7 percent of total forest land area. NOTE: loblolly pine (*Pinus taeda* L.) represented the most common forest type with nearly 8 percent of total forest land area). The mixed oak–pine type of longleaf pine oak currently occupies the least area (0.01 percent of total forest land area).

Oaks are an important component of U.S. forests, particularly in the eastern half of the country. Oak tree species play and important role in the ecology and economy of the forests they are found within and the surrounding

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

areas. It is imperative that these communities be monitored over time to understand the landscapes they exist in and to better understand how these communities are changing. The FIA program is unique in that consistent data is collected across the United States to facilitate such monitoring.

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THE ADAPTIVE SILVICULTURE FOR CLIMATE CHANGE PROJECT: A SCIENTIST–MANAGER PARTNERSHIP

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Extended abstract—Forest managers in the United States face many challenges to sustaining critical ecosystems, including observed and projected climatic changes that require implementation of climate-adaptive strategies. However, there is a lack of on-the-ground forest adaptation research to help managers determine what adaptation measures or tactics might be effective in preparing local forest ecosystems to deal with climate change, which can create challenges in translating these concepts into operational silvicultural prescriptions specific for individual forest types that vary in structure, composition, and function (Kemp and others 2015). The Adaptive Silviculture for Climate Change (ASCC) project responds to these barriers by providing a multi-region network of replicated operational-scale research sites testing ecosystem-specific climate change adaptation treatments across a gradient of adaptive approaches. Here we describe the ASCC project along with two of the research sites and provide ideas for how these concepts might apply to oak forests.

The ASCC project utilizes a decision-making framework (Swanston and others 2016) and manager–scientist partnerships to co-design locally relevant treatments and research questions. The study is designed to test broad, conceptual adaptation concepts appropriate to the management of public and private lands (Joyce and others 2009, sensu Millar and others 2007). The adaptation options occupy a continuum of management goals related to desired levels of change:

1) resistance—maintaining relatively unchanged conditions over time;
2) resilience—allowing some change in current conditions but encouraging an eventual return to reference conditions; and
3) transition—actively facilitating change to encourage adaptive responses.

A consistent study design (e.g., size and replication of treatments, monitoring approach, etc.) has been implemented across distinct ecosystem types, allowing scientists and managers to leverage a shared approach to further reveal trends and measure the efficacy of adaptive management strategies across the ASCC network (Janowiak and others 2014, Nagel and others 2017, Swanston and others 2016).

There are currently five sites that make up the National ASCC Network:

1) the Cutfoot Experimental Forest site on the Chippewa National Forest in Minnesota;
2) the Flathead National Forest/Coram Experimental Forest site in northwest Montana;
3) the Joseph W. Jones Ecological Research Center site on the southeastern coastal plain in Georgia;
4) the San Juan National Forest site in southwest Colorado; and
5) Dartmouth's Second College Grant site in New Hampshire.

At each site, we used an interactive workshop process where local managers and scientists determined management objectives to meet desired future conditions (DFCs) and developed an array of silvicultural treatments that correspond to each of the adaptation options of resistance, resilience, and transition.

The Cutfoot Experimental Forest was the first ASCC site to be developed. Scientists and managers assessed the current condition of the red pine-dominated forest (overly dense, history of fire exclusion) and examined ecosystem vulnerability information, including Tree Atlas and LANDIS II projections (Handler and others 2014), as well as expert opinions to inform the development of adaptation strategies. Based on the DFCs for the site, the

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

resistance strategy for the Cutfoot ASCC site includes maintaining red pine (*Pinus resinosa* Ait.) dominance and increasing soil moisture availability through density management. The resilience strategy includes maintaining red pine dominance while also increasing the presence of future-adapted native species over time. Finally, the site's transition strategy is aimed at actively facilitating change including increasing future-adapted native and novel species to gradually become more abundant than red pine.

The Joseph W. Jones Ecological Research Center, a fire-maintained, pine-dominated site with a competitive component of oak and other hardwoods, is located on the southeastern coastal plain in Georgia. The site hosts a diverse range of ecological communities, including open-canopy longleaf pine (*Pinus palustris* Mill.) and mixed pine-hardwood forests that have a highly diverse herbaceous groundcover of global ecological significance. Based on climate change projections and DFCs for the site, the team created a resistance strategy that enhances the dominance of longleaf pine and optimizes fire behavior by eliminating oaks and off-site pines. The resilience strategy maintains response diversity by retaining drought-tolerant oaks, removing the water-profligate mesic oaks, and lightly thinning longleaf pine. The transition strategy aims to diminish vulnerability to drought by reducing longleaf pine basal area by 40 percent, eliminating all but the most highly drought-adapted oaks in the overstory, creating a multi-aged, multi-cohort structure by planting drought-tolerant, fire facilitating oaks (i.e., turkey oak, *Quercus laevis* Walter), and planting warm season C_4 grasses to help carry fire in the grass-dominated understory. All treatments are scheduled to receive prescribed burning every two years.

Future climate change has the potential to significantly impact disturbance dynamics and species response of oak forests. Historical and dendrochronological records indicate a strong relationship between drought years and oak decline (Dwyer and others 1995, Jenkins and Pallardy 1995). As droughts are projected to increase in duration and aerial extent (Mishra and others 2010), oak decline could become an even larger problem for species in the red oak group across the Missouri Ozarks, especially for older trees on marginal sites. Oak decline could be exacerbated by other stressors: insect defoliation may increase with rising temperatures, and red oak species may already be stressed due to a decline in habitat suitability as projected by tree species models. As these species decline, new opportunities could open up for other species that are better adapted to projected climate, such as pine and white oak species (Brandt and others 2014). Utilizing ecosystem vulnerability information will be key to promoting resilient ecosystems into the future, with the ASCC study potentially informing climate-adaptive management decisions.

As we move into a future where it is easy to become overwhelmed by the uncertainty and the high potential for loss and change, it is imperative that scientists and managers work together to create innovative solutions and new alternatives for adaptive management. The interactive process of the ASCC study allows the network to directly address numerous barriers natural resource managers face when it comes to developing adaptive management strategies for climate change, which can in turn be applied more broadly and be replicated by others working to sustain a variety of ecosystem types into the future.

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IMPACTS OF OAK DECLINE, GYPSY MOTH, AND NATIVE SPRING DEFOLIATORS ON THE OAK RESOURCE IN VIRGINIA

Christopher Asaro and Lori A. Chamberlin

Abstract—The oak-hickory and oak-pine forest types dominate much of the southern landscape. In the Blue-Ridge and Appalachian Mountains of western Virginia, oak as a percentage of total forest volume can be as high as 60 percent. Much of this forest type is represented by older aged cohorts with little potential for oak regeneration to replace declining codominants. Oak decline is a prevalent natural phenomenon across the landscape, brought about by aging cohorts growing on poor sites, and exacerbated by inciting factors such as recurring drought and insect defoliation events. In Virginia, the gypsy moth (*Lymantria dispar* L.) has been the primary spring defoliator of oaks since the mid-1980s, although outbreak populations have been moderated since the mid-1990s by the gypsy moth fungus, *Entomophaga maimaiga*. In addition, several native defoliators have produced periodic outbreaks since the 1950s, particularly the fall cankerworm. The fall cankerworm (*Alsophila pometaria*) is the most common native defoliator of Virginia's oaks, producing outbreaks somewhere in the State about every 5 years for the last 65 years or so. According to detailed historical records, these outbreaks seem to be getting worse in terms of acres impacted by defoliation. Other native defoliators have also had periodic outbreaks over this time period, albeit less frequently than the fall cankerworm. These include the forest tent caterpillar (*Malacasoma disstria*), variable oakleaf caterpillar (*Lochmaeus manteo*), linden looper (*Erannis tiliaria*), oak leaf tier (*Croesia semipurpurana*), and half-winged geometer (*Phigalia titea*). Collectively, these insects produce recurring stresses on the oak resource that, in concert with periodic drought stress, could significantly exacerbate ongoing decline and punctuate mortality events.

INTRODUCTION

The oak-hickory and oak-pine forest types collectively represent a major proportion of total forest area across much of the southern region of the United States, particularly across the Southern Appalachians, Cumberland Plateau, and portions of the Piedmont (Conner and Hartsell 2002). Oak (*Quercus* spp.) is an essential resource in these regions, representing a major proportion of many forest canopies. These trees provide high-quality wood products and an essential food source for many wildlife species via regular acorn (mast) crops. Furthermore, with over 30 species across the Southern United States, many of which become large and/or relatively long-lived, oaks significantly improve forest biodiversity. Indeed, over 500 species of Lepidoptera (moths and butterflies) feed on oak leaves as caterpillars, which are a major food source for most resident and migrant bird species as well as other animals (Tallamy and Shropshire 2009).

Unfortunately, the long-term health and condition of the oak resource may be under threat in some regions. Canopy oaks are increasingly in older age cohorts (80+ years), which inevitably results in accelerating rates of decline and mortality (Oak and others 1996, 2016). In addition, more punctuated mortality events can be triggered by environmental conditions such as drought or defoliation (Manion 1991). In concert, many oak-dominant forests lack sufficient oak regeneration to replace mature trees as they die off (Dey 2014, Rose 2008). The low regeneration potential of oak across many landscapes is due to a multitude of factors such as: 1) competition with more shade-tolerant species in dense understories, such as red maple (*Acer rubrum*) or blackgum (*Nyssa sylvatica*); 2) competition with more shade-intolerant species in open stands, such as birch (*Betula* spp.) or tulip poplar (*Liriodendron tulipifera*); 3) lack of appropriate management (prescribed burning, selection thinning) and/or conditions ideal for oak survival, such as intermediate light levels in the understory; and 4) heavy pressure from deer browse (McShea and others 2007, Woodall and others 2010). Currently, annual volume increment of most major oak species is either slowly increasing or static (Miles 2014), but these trends are expected to reverse as growth rates of aging tree cohorts begin to slow down and

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

mortality rates increase. A lack of regeneration in many areas means oak-dominant canopies will not replace themselves over time without appropriate management.

OAK DECLINE

Due to the abundance and aging cohort of oaks in the Southern Appalachians, oak decline is a prevalent condition across this landscape. Decline is broadly defined as a gradual failure in health of a forest, stand, or tree resulting from a combination of biotic and abiotic factors in which no single agent is responsible. In some cases, the key factors associated with decline are unknown or difficult to determine; in other cases decline is fairly predictable and can be thought of as a mechanism of succession, especially in older, senescent stands. Oak decline falls into the latter category. Symptoms of declines can include reduced growth, foliage tufting, epicormic branching, small or chlorotic leaves, twig and branch dieback, asymmetrical crowns, premature fall coloration in hardwoods, degeneration of roots and mycorrhizae, and depletion of food reserves (Manion 1991).

The decline process can be separated into 3 phases, based on Paul Manion's forest decline concept (Manion 1991): 1) predisposing factors, 2) inciting factors, and 3) contributing factors. Predisposing factors are typically associated with site characteristics – poor soils with low fertility or moisture holding capacity, aspect and elevations that expose trees to challenging environmental extremes, and vegetative composition. The age of the trees is also a predisposing factor. As the term implies, trees facing these conditions are 'predisposed' to later health problems. Inciting factors can be one-time or multiple, repeated disturbances, biotic or abiotic, that can further weaken trees and accelerate the decline process. Examples of inciting factors can include drought, late frost, and insect and disease outbreaks. This discussion will focus on gypsy moth (*Lymantria dispar* L.) and other insect defoliators as major inciting factors in the oak decline process in Virginia. Finally, contributing factors are typically biotic agents that, once established in the tree, lead directly to mortality. Contributing factors are normally ubiquitous and non-aggressive insects or pathogens that are only able to exploit trees that are in a weakened condition. Examples of contributing factors to oak decline are various wood boring insects such as two-lined chestnut borer (*Agrilus bilineatus*) and red oak borer (*Enaphalodes rufulus*), ambrosia beetles, carpenterworms, and fungi such as *Armillaria* root disease and *Hypoxylon* canker. The latter pathogens are found in most hardwood forests where they fester for many years without causing problems, but can be 'released' when trees are under stress. Drought conditions are the most common stress on the landscape, and the visible appearance of hypoxylon canker on hardwood stems is a reliable indicator of drought stress (Oak and others 1996, Starkey and Oak 1989). Oaks make up as much as 56 percent of the forest volume in the northwestern parts of Virginia, and from 18–35 percent of the resource in other areas (Miles 2014). With the decline of aging cohorts of oaks and associated stressors being a prevalent force, the majority of trees dying across the Commonwealth are oaks.

Tree species in the red oak group may be more vulnerable to decline compared to the white oak group. In part, this may be due to red oaks' greater abundance on poor, rocky soils at higher elevations (Oak and others 2016, Spetich and others 2016). Red oaks also differ significantly in wood structure compared to white oaks in that they lack tyloses, which are bladder-like extensions of parenchyma cells that project themselves into adjacent wood vessels. By essentially 'plugging' the pits in between wood cells, tyloses help limit water loss and also facilitate the compartmentalization of decay in trees in response to injury and pathogen invasion. Thus, red oaks as a group can generally be said to be less drought-resistant and more susceptible to pathogen invasion compared to white oaks (Oak and others 1996).

SPRING DEFOLIATORS

Our focus is on gypsy moth, fall cankerworm, and other spring defoliators that utilize oak species as major hosts. Gypsy moth, as an invasive species, is the most problematic since repeated, severe defoliation events over successive years are more common than with native defoliators who have a co-evolved natural enemy complex in place that reacts more quickly to outbreak populations of its prey with a strong density-dependent response. However, several other native defoliators periodically reach outbreak populations and can cause significant damage to the oak resource (Asaro and Chamberlin 2015). These include the fall cankerworm (*Alsophila pometaria*), forest tent caterpillar (*Malacasoma disstria*), variable oakleaf caterpillar (*Lochmaeus manteo*), linden looper (*Erannis tiliaria*), half-winged geometer (*Phigalia titea*), and oak leaf tier (*Croesia semipurpurana*). All these defoliators feed during the spring, which is the most damaging time of year for trees to lose leaf tissue (Coulson and Witter 1984). Refoliation depletes a tree's nutritional and energy reserves which compromise other necessities such as chemical defense and energy storage. However, it would be more energetically expensive for trees to lose leaves early in the growing season and not replace them, foregoing photosynthesis for most of the season. By contrast, trees that lose leaf tissue during the second half of the growing season have already begun storing energy reserves via photosynthesis, and will often not expend vital energy reserves putting out a new crop of leaves prior to fall (Houston and others 1981). The pivot point that determines if a tree will leaf out again after being defoliated depends on the tree species and other physiological conditions. From an evolutionary standpoint, spring defoliation allows these insects to exploit newly emergent oak leaves when tannin content is at its lowest. Tannins interfere with efficient digestion and absorption of vital nutrients, so by avoiding them, these insects experience increased nutritional gain and fecundity. This is thought to be the primary reason that many spring defoliators exhibit eruptive population dynamics compared to those that feed later in the growing season (Bernays 1981, Feeny 1970, Feeny and Bostock 1968).

We summarized the outbreak activity of all spring defoliators of oak since 1953 in Virginia utilizing records from quarterly and annual reports by forest health specialists within the Virginia Department of Forestry. Where outbreak maps were absent, we used narrative descriptions of approximate areas and acres defoliated if sufficient detail was provided to reconstruct the event spatially and temporally. Additional details on data collection methodology are provided in Asaro and Chamberlin (2015).

GYPSY MOTH OUTBREAK HISTORY IN VIRGINIA

The gypsy moth was introduced into Massachusetts in 1869 and has been spreading south and west ever since (Liebhold and others 1989). Adult moths reached northern Virginia in the late 1960s, but the first major defoliation wasn't reported until 1984 (Davidson and others 2001). As of 2018, gypsy moth has infested most of the State, with only extreme southwest Virginia escaping major defoliation to date. The outbreak history of gypsy moth in Virginia spans the years 1984–2017 and can be broken out into four major periods separated by years with non-damaging populations (fig. 1): 1) 1984–1995 – the initial wave, 2) 2000–2003, 3) 2005–2009 and 4) 2015–the present. The initial wave of gypsy moth had the most devastating impact, resulting in a cumulative total of 4.3 million acres of heavy defoliation across much of northern Virginia over 12 years. In 1996, the sudden appearance and first known epizootic of the gypsy moth fungus (*Entomophaga maimaiga*) occurred, crashing the population abruptly (Asaro and Chamberlin 2015, Hajek 1995). *Entomophaga maimaiga* is not density dependent (as are the gypsy moth virus and other natural enemies) so therefore does not change the cyclical nature of gypsy moth populations (Allstadt and others 2013, Liebhold and others 2013). However, the fungus is more active and impactful during wet spring weather, where rain splash can disperse fungal spores from infected larvae to other actively feeding larvae (Hajek 1999, Reilly and others 2014). This is perhaps why subsequent gypsy moth outbreak periods never reached the severity of the initial wave – the 2000–2003 period impacted 644,000 cumulative acres, the 2005–2009 period 234,000 acres, and the current period from 2015 to the present <50,000 acres so far (fig. 1). Successive years of very dry spring weather can lead to more significant outbreaks once again, but this has not occurred in Virginia since 2008.

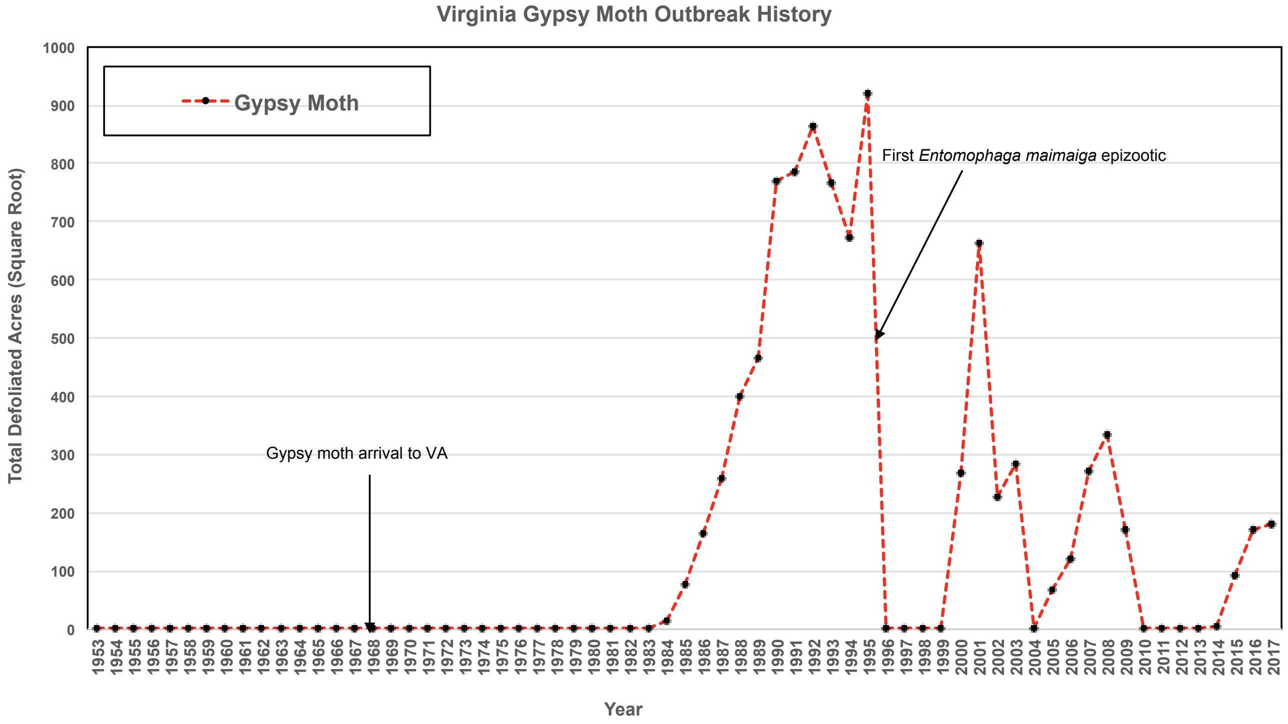

Figure 1—Outbreak history of gypsy moth in Virginia expressed in terms of annual defoliated acres by year. Note: values for total defoliated acres were square-root transformed so that extreme highs and lows are visible on the same graph.

Nonetheless, the impact of all this cumulative defoliation by gypsy moth has been significant, particularly along the Blue Ridge and Appalachian mountain chains spanning down the western spine of Virginia. Many locations experiencing successive years of heavy to severe defoliation were on Federal lands such as the George Washington National Forest and Shenandoah National Park. The signs of past gypsy moth outbreaks can still be seen in these areas today, with standing dead oak trees that persist for years littered across the landscape (Asaro and Chamberlin 2015). Although gypsy moth can feed on hundreds of different species of trees and shrubs,[1] oaks are most preferred and, where they are abundant, most likely to suffer mortality compared to other species (Liebhold and others 1994). These same areas were already major centers of oak decline prior to the arrival of gypsy moth due to a combination of high oak volumes, maturing stands, and high-elevation sites where trees grow in challenging conditions (poor, drought-prone soils and high exposure to climatic extremes) (Oak and others 1996). Waves of drought and gypsy moth defoliation have exacerbated oak decline where it was already occurring. Some of the poorest sites along ridges are typically the hardest hit, although species like chestnut oak that are highly competitive on these poor sites are likely to successfully regenerate. In contrast, more mesic sites on lower slopes and coves, when defoliated, can suffer losses to higher value species such as white (*Q. alba*) and northern red (*Q. rubra*) oaks. Oaks are less competitive on more mesic sites without appropriate levels of disturbance or management. In addition, nonnative invasive plants are increasingly invading and overtaking sites when sudden canopy losses increase light levels to the understory (Asaro and Chamberlin 2015). Finally, heavy deer browse in many areas can often prohibit the establishment of oak seedlings and saplings, even if other conditions for oak regeneration are favorable (McShea and others 2007). Therefore, without intervention, many locations seeing rapid loss of mature oak canopy will likely transition to other forest types dominated by species such red maple, tulip poplar, or sweet birch (*B. lenta*). As gypsy moth inevitably advances southward along the Appalachian Mountains, and westward across Tennessee, Kentucky, and into the Ozark Mountains of Missouri and Arkansas, similar ecological shifts in oak species abundance may be anticipated (Spetich and others 2016).

OUTBREAK HISTORY OF FALL CANKERWORM AND OTHER NATIVE DEFOLIATORS

The fall cankerworm, so named due to the fall activity of adult moths, has been the most common native defoliator of oak across Virginia over the last 60 years (see footnote 1, Asaro and Chamberlin 2015). Adult females are wingless, and upon emerging from pupation sites in the ground, will climb up the tree to mate. Egg masses are placed on bark surfaces of the main stem, branches, and twigs during the late fall or winter months. Fall cankerworm caterpillars hatch in early spring during or just after bud-break, earlier than gypsy moth (Drooz 1985). Outbreak populations in Virginia have been occurring somewhere in the State approximately every 5 years since the 1950s (fig. 2, Asaro and Chamberlin 2015). If we assume that historical records are reasonably accurate as to acres impacted, then outbreaks appear to be getting worse since 1980 compared to the previous 30 years (fig. 2). Although natural enemies, including an egg parasitoid, are effective in suppressing outbreak populations within a year or two (Butler 1990, Fedde 1980), substantially more acres appear to be defoliated with each new outbreak (fig. 2). For example, since 2002, fall cankerworm has defoliated more cumulative acres (almost 600,000) than the gypsy moth (365,000). The reasons for this trend are unclear, and much more research on population dynamics of this defoliator is warranted. Recurring populations within the same general areas are a hallmark of this pest, perhaps due to the limited ability of the flightless female moths to disburse long distances. Fall cankerworm can also be a recurring, persistent problem in urban areas such as Charlotte, NC, Richmond, VA, and the Washington, DC suburbs in northern Virginia (Ciesla and Asaro 2013).

Long-term impacts to the oak resource are generally considered minor due to the short-term nature of most fall cankerworm outbreaks (1–2 years), compared to gypsy moth (3–5 years). Like gypsy moth, fall cankerworm has a very broad host range but prefers oaks where they are abundant (Ciesla and Asaro 2013). However, near complete defoliation of oaks over 2 years is not uncommon among ridgetop environments and more mesic habitats. These disturbances, when combined with older age cohorts, severe drought events, and ongoing oak decline can lead to significant canopy loss, although the degree to which this occurs has not been properly documented (Crow and Hicks 1990). Similar arguments can be made for other native defoliators of oak in Virginia. Although major outbreaks of forest tent caterpillar, linden looper, variable oak leaf caterpillar, oak leaf tier, and half-winged geometer have been much less frequent than fall cankerworm over the last 60 years (fig. 2, Asaro and Chamberlin 2015), one or two severe oak defoliation events at the right place and time can theoretically precipitate significant canopy loss. For example, two major outbreaks of the variable oakleaf

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[1] Asaro, C. 2005-2014. Forest health review. Virginia Department of Forestry, Charlottesville, VA. http://www.dof.virginia.gov/infopubs/index.htm.

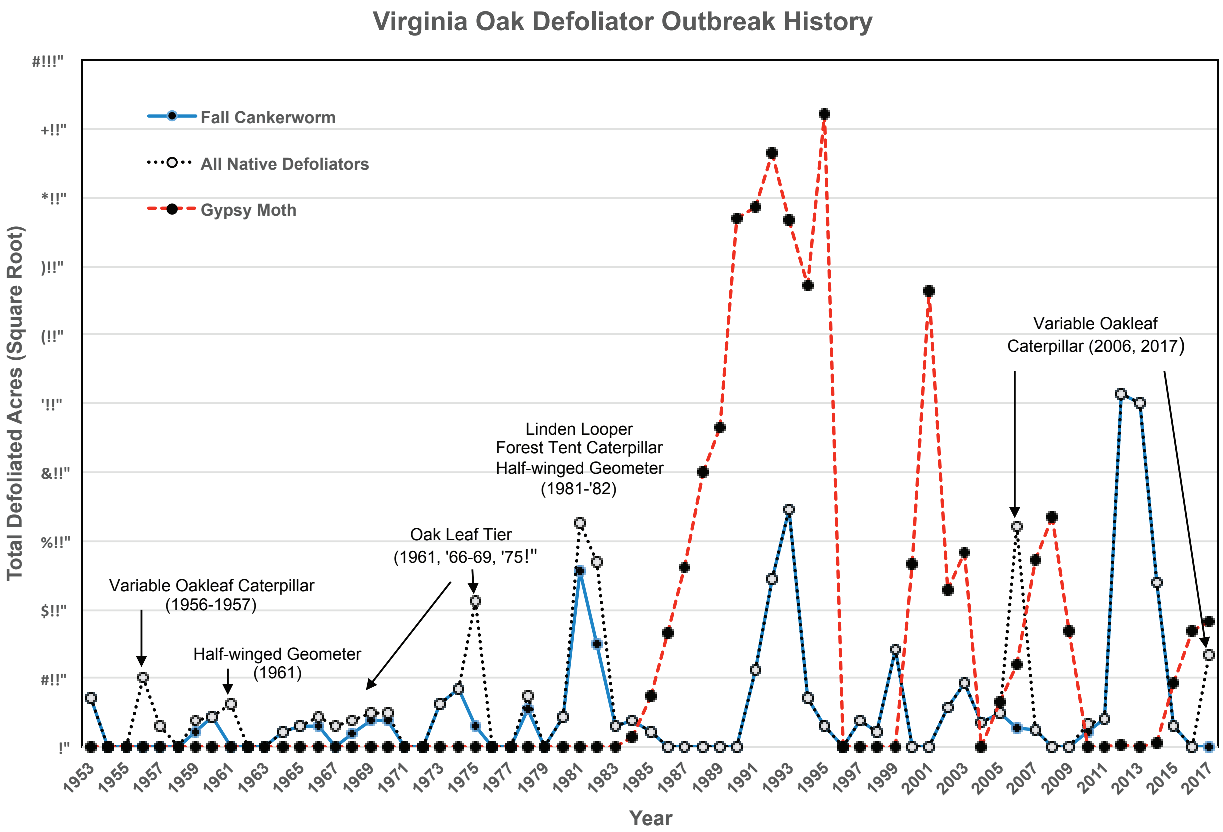

Figure 2—Outbreak histories for several major spring defoliators of oak forests in Virginia expressed in terms of annual defoliated acres. The solid (blue) line represents annual fall cankerworm defoliation, the dashed (red) line represents annual gypsy moth defoliation, and the dotted (black) line represents a combination of annual defoliation by all native defoliators, including fall cankerworm. Several other important species are highlighted above areas of peak activity. Note: values for total defoliated acres were square-root transformed so that extreme highs and lows are visible on the same graph.

caterpillar,[2] which has a strong preference for white oak and has two generations per year, have occurred across many forested areas around Richmond in 2006 and 2017 (fig. 2, see footnote 1). In between those events, across the same area, a historic fall cankerworm outbreak occurred from 2012–2014 impacting over 250,000 acres for 2 successive years (fig. 2, Asaro and Chamberlin 2015). Although oak mortality following these defoliation events has been poorly documented, such concerns may be warranted given the overall condition of the oak resource, as described previously.

CONCLUSIONS

Beyond the impacts to Virginia's oaks by the gypsy moth, the frequency and severity of native defoliator outbreaks on this resource may be unappreciated. It seems probable that all of these defoliators, combined with other stressors, will continue to exacerbate oak decline in many areas, although more research to quantify defoliator impacts is needed. It's also worth continuing to monitor native defoliator outbreaks, especially if they are becoming more frequent, extensive, and severe over time. According to U.S. Forest Service Forest Inventory and Analysis data, oak volumes in Virginia continue to increase due to the abundance of maturing and mature age cohorts. However, this trend is expected to level off and then decline as mature trees continue to die off, and the potential for recruitment of oak seedlings/saplings into the canopy seems to be diminishing in many areas. Long term, this could have significant implications for forest biodiversity since oaks generally increase the diversity of insect fauna (moth caterpillars), birds, and wildlife dependent on regular mast crops. The prevalence of nonnative invasive plants and high deer populations across Virginia mean that there may be fewer opportunities for oaks to regenerate successfully even if the right balance of favorable disturbance or silvicultural prescriptions exist.

Across the Appalachians, chestnut blight eliminated the most common hardwood species during the early 20th century, which suddenly provided an ideal opportunity

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[2] Chamberlin, L.A. 2016-2018. Forest health review. Virginia Department of Forestry, Charlottesville, VA. http://www.dof.virginia.gov/infopubs/index.htm.

for oaks, which were already prevalent, to increase in dominance (McCormick and Platt 1980, Woods and Shanks 1959). It may be that oaks in some areas are simply too abundant to be sustainable and that spring defoliators that prefer oaks are likewise more prone to outbreaks. Where unsustainable oak volumes currently exist, defoliation events in concert with other stressors associated with decline will inevitably act as a 'correction mechanism,' and new forest assemblages with less oak will be the result.

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THE OAK TIMBER BASE AND MARKET: PAST, PRESENT, AND FUTURE

William G. Luppold

Abstract—Since 1992, the oaks (*Quercus* spp.) have accounted for a third of the eastern hardwood growing stock volume, but oak poletimber volume has declined from 27 percent of total hardwood poletimber volume in 1992 to 23 percent in 2012 with most of this change occurring since 2002. This decline is a precursor to a reduction in oak sawtimber volume in the future in the absence of successful timber management efforts to avert it. The decline in oak poletimber volume initially occurred concurrently with a decline in consumption and price of higher grade hardwood lumber and a historic reduction in the margins between lumber and stumpage prices. These declines in price margins appear to be a market aberration since margins recovered to prerecession levels by 2017. The greatest value for oak and most other hardwood species is associated with aesthetic attributes which are influenced by the rate and consistency of tree growth, bole clarity, and wood color. Desirable attributes may take 75 years to develop. The extended period of time it takes oak to mature combined with the price risk due to market variability and changing fashion trends makes the time value of money a barrier to oak management. An understanding of economic factors that influence hardwood markets should be embodied in the development of timber management plans. Successful oak regeneration could be promoted as a part of hardwood sustainability certification, thereby transferring the management costs to the current customers of hardwood products.

INTRODUCTION

In 2012, oak species (*Quercus* spp.) accounted for 34 percent of eastern hardwood growing stock (Oswalt and others 2014). This percentage has remained unchanged since 1992 (Powell and others 1993). What has changed is the proportional volume of oak poletimber [5 to 10.9 inches diameter at breast height (dbh)] which has declined from 27 percent in 1992 to 23 percent in 2012 (Oswalt and others 2014, Smith and others 2004). Nearly all this change has occurred since 2002. The decline in poletimber volume of oak species since 1992 is a precursor to reduced oak sawtimber volume in the coming decades. This decline has been predicted for decades, and management plans have been developed to prevent it but apparently not implemented on the scale necessary to avert it.

A major barrier in the implementation of timber management plans for oak is the length of time it takes for trees to grow to a merchantable size (Barton and Schmelz 1986) and the opportunity cost of the money required to accomplish silvicultural activities if it were invested in endeavors other than timber management. Another factor is that hardwood markets, the ultimate force affecting when trees are harvested and their value, may not be fully understood or integrated into management plans. It is important to recognize that the market factors that influence successful implementation of hardwood management can differ from those prescribed for softwood management.

This paper examines the oak resource, the major markets for this resource, and economic and financial barriers to oak management. Changes in the oak inventory will be examined relative to changes in the eastern hardwood timber base. This is followed by an examination of changes in the most important market for hardwood timber, lumber and related sawn products, and the importance of oak species in this market. Included in this analysis is a discussion of some important aspects of hardwood lumber and stumpage prices. Next, the market and financial aspects of successfully managed timberland is compared and contrasted for southern yellow pine versus the oaks. The last section summarizes important aspects of hardwood markets that may be useful to understand and incorporate into oak management plans.

CHANGES IN THE OAK TIMBER BASE

The eastern hardwood resource can be examined in terms of species groups with the oaks comprising four of these groups (table 1). The select white oak group is primarily composed of white oak (*Q. alba*), bur oak (*Q. macrocarpa*), and chinkapin oak *(Q. muehlenbergii*)

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

while the most important select red oaks on a volumetric basis are northern red (*Q. rubra* L.) and cherrybark oak (*Q. falcata* var. *pagodifolia*). The most important species contained in the other white oak group are chestnut oak (*Q. prinus*) and post oak (*Q. stellata*). The other red oak group is the largest of the oak species groups in terms of total volume with the most important species being black oak (*Q. velutina*), water oak (*Q. nigra*), scarlet oak (*Q. coccinea*), southern red oak (*Q. falcata* var. *falcate*), willow oak (Q. *phellos*), and laurel oak (*Q. laurifolia*). In addition to the oak groups, other important hardwood species groups include hard maple [primarily sugar maple (*Acer saccharum*)], soft maple [primarily red maple (*A. rubrum*) and silver maple (*A. saccharinum*)], sweetgum (*Liquidambar styraciflua*), ash [primarily white ash (*Fraxinus americana* L.) and green ash (*F. pennsylvanica* Marsh)], yellow-poplar (*Liriodendron tulipifera* L.), and the hickories (*Carya* spp.)

Changes in the volume of growing stock between 2002 and 2012 for the major eastern species groups are shown in table 1. A common trend exhibited in all species groups is either slow increases or net declines in the volume of poletimber-size trees with the most pronounced declines occurring in the oak species groups. This decline is a result of long-term regeneration issues associated with oak species (Lorimer 1993). An associated trend is the relatively small net volume increase of mid-size (11–16.9 inches dbh) select white oak, select red oak, and other red oak. The combination of negative net growth of poletimber and low net growth of mid-size trees (11–16.9 inches dbh) means that relatively fewer oak trees will be transitioning to the larger size class in the future. This suggests that past forest management efforts have not been successful and proactive management options should be considered to increase the survival of the remaining small-diameter trees to avert even larger decreases in future oak inventory – if only to enable future mast production.

MAJOR MARKETS FOR HARDWOOD LUMBER AND RELATED PRODUCTS

The most important markets for higher quality hardwood timber in terms of value are lumber and related products. The major domestic market for hardwood lumber can be separated into four major sectors (table 2). Hardwood lumber consumption in the furniture sector was traditionally dominated by the wood household industry with lesser volumes consumed by the wood office/commercial and institution furniture manufacturers. These industries are influenced by style and fashion considerations that cause the demand for different species and groups of species to vary over time. The construction and remodeling sector includes kitchen cabinets, millwork (doors, windows, molding, etc.), and wood flooring. Fashion consideration also influences species selection in construction products. Most lumber used in the furniture and construction sectors is higher grade product sawn from higher quality logs. However, lower grade hardwood lumber can be used in the production of strip flooring.

Pallets and crossties are the most important industrial markets (Luppold and Bumgardner 2016). While sawn material used for industrial application must be sound, it can have knots and blemishes and is produced predominantly from the cants (log centers) of higher quality logs or lower quality roundwood. Hardwood lumber and related sawn products are also used in the production of other goods including whiskey barrels, handles, gun stocks, solid guitar bodies and necks, decorative boxes, and toys.

Table 1—Net change in eastern hardwood growing stock volume by major species group and diameter category, 2002 to 2012, in million cubic feet

Species group	Total net change	5 to 10.9 inches	11 to 16.9 inches	17 inches and larger
Total hardwood	59,018	-9,108	24,526	43,596
Select white oak	6,255	-1,334	2,365	5,224
Select red oak	5,186	-1,159	903	5,443
Other white oak	3,721	-1,036	2,072	2,687
Other red oak	5,636	-1,771	1,014	6,392
Hickory	4,517	-183	2,581	2,117
Hard maple	4,647	208	3,031	1,406
Soft maple	8,509	195	5,067	3,247
Sweetgum	1,792	-235	637	1,393
Ash	4,995	543	2,254	2,199
Yellow-poplar	9,194	347	1,786	7,058

Sources: Smith and others (2004), Oswalt and others (2014).

Traditionally the largest domestic consumers of hardwood lumber have been the fashion-influenced furniture and construction sectors (table 2). In the early part of the 21st century, wood household furniture production was displaced by imports (Luppold and Bumgardner 2016). In 2006, home construction started to decline preceding the Great Recession of 2008 and 2009. The industrial sector was not nearly as affected by this series of events. As a result, the proportion of lumber used in the fashion-related sectors declined from 56 percent in 1999 to 39 percent in 2009. This change in relative demand caused prices of higher and mid-grade hardwood lumber to fall to historically low levels (fig. 1).

Another market for hardwood lumber that has been increasingly important is exports (table 3). Lumber exports can range in quality but tend to be skewed to the higher grades (Luppold and Bumgardner 2013). In 1991, exports accounted for about 8 percent of the total hardwood lumber consumption volume and about 16 percent of higher grade lumber sales on a volume basis. While hardwood lumber exports declined during the Great Recession, they surpassed prerecession levels by 2011, and in 2017, 40 percent of the higher grade hardwood lumber manufactured in the United States was exported.

HOW DO OAKS FIT IN THE CURRENT MARKET?

Oak species accounted for 41 percent of the eastern hardwood lumber production in 2010 (U.S. Census Bureau 2011) and is consumed by every domestic sector. However, the most important domestic user of appearance lumber today is the wood flooring industry,

Table 2—Total domestic hardwood consumption and consumption by the furniture, construction and remodeling, industrial, and all other sectors for selected years, in million board feet

Year	Total domestic consumption	Furniture	Construction and remodeling	Industrial	Other
1982	8,136	2,480	1,441	3,342	873
1991	10,001	2,578	2,524	3,952	946
1999	12,011	2,677	4,009	4,578	747
2004	10,728	1,608	4,036	4,408	676
2006	10,696	1,323	4,063	4,614	696
2008	8,901	996	2,929	4,367	609
2009	6,884	619	2,036	3,707	521
2011	6,982	537	2,156	3,703	587
2015	8,061	575	2,587	4,032	866

Sources: Luppold and Bumgardner (2008, 2016).

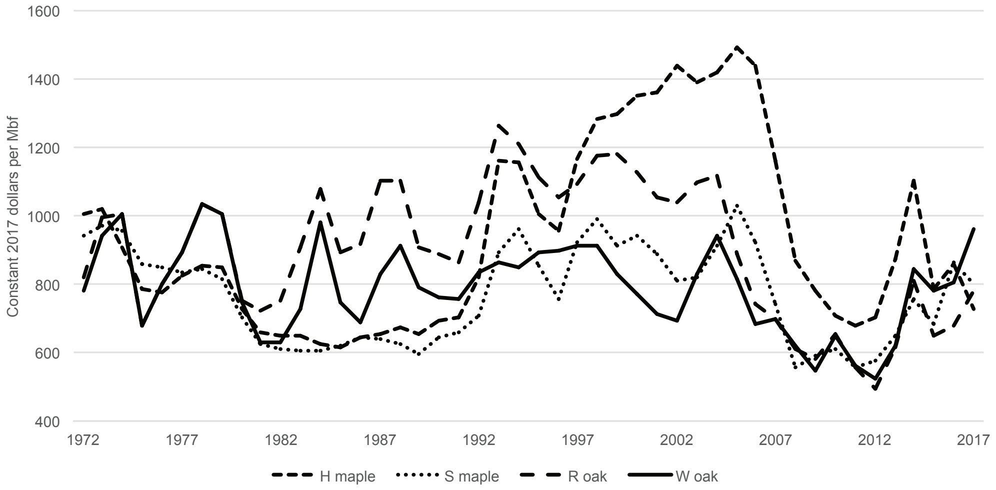

Figure 1—Inflation-adjusted prices of number 1 common Appalachian hard maple, soft maple, red oak, and white oak, 1972 to 2017. (Developed from HMR 1971 to 2017; U.S. Department of Labor 2018).

Table 3—U.S. hardwood lumber exports, the proportion of exports to total consumption plus exports, and the proportion of exports to appearance consumption plus exports for select years from 1991 to 2017

Year	U.S. hardwood lumber exports	Proportion of exports to total estimated consumption plus exports	Proportion of exports to appearance consumption plus exports
	million board feet	*percent*	*percent*
1991	882	8	16
1999	1,183	9	16
2002	1,172	10	17
2006	1,323	11	21
2009	801	10	25
2014	1,653	17	37
2017	1,875	20	40

Source: Luppold and Bumgardner (2016), updated to 2017.

and the dominant species used by this industry are red and white oak. Oak species are preferred by crosstie manufactures because of their durability. White and bur oak are the species used in whiskey barrel production.

In 2017, the oaks accounted for nearly 44 percent of exports with red oak exports being nearly twice as high as white oak exports (U.S. Department of Agriculture 2018). The major export markets for red oak are East Asia (China and Vietnam) and North America (Canada and Mexico) while the white oak export market is more diffuse with Europe being the most important regional market. The oaks also account for nearly 40 percent of log exports on a volume basis with red oak exports being nearly three times higher than white oak.

SOME IMPORTANT ASPECTS OF HARDWOOD LUMBER AND STUMPAGE PRICE

While lumber prices of most hardwood species have fluctuated over the last several decades because of fashion considerations (Luppold and Prestemon 2003) there is no discernable trend (fig. 1). By contrast, hardwood stumpage prices have been trending upward since the early 1970s with the exception of the declines associated with the Great Recession (fig. 2). The declines in stumpage prices during the Great Recession were unusual because stumpage prices since 1970 have been less sensitive to economic downturns than lumber prices yet correlated with lumber prices during periods of economic expansion (Luppold and others 2014). Since 2011, stumpage prices and the margin between stumpage and lumber prices reached or exceeded prerecession levels by 2017. But, will stumpage prices increase more than lumber prices in the future?

In competitive markets, economic gains at higher market levels (such as cost saving technology or better marketing) eventually accrue to the base resource. This is especially true when owners of the resource do not have to sell at any given time due to spoilage. In the case of hardwood timber this causes stumpage prices to be less sensitive downward (Luppold and others 1998). Additionally, hardwood trees normally increase in value if left to grow.

As timber becomes larger, natural defects including knots are overgrown resulting in higher prices per board foot. The exact relationship between increased value and tree size is difficult to quantify because there are numerous factors influencing value (Wiedenbeck and others 2004). These factors can be termed the four Cs of hardwood timber and log value. The most important factor is bole quality and resulting log *clarity* (Rast and others 1973, Wiedenbeck and others 2004). Another factor is ring *count*; tighter ring count (slower growth) is especially important for veneer logs (Wiedenbeck and others 2004) and white oak stave logs. Related to ring count is ring *consistency* which also can be termed texture consistency. The last factor is *color* which varies by subspecies and also can be affected by genetics, soils, and other site-specific factors.

Another aspect to timber value is that logs of different oak species have different lumber grade yields as a result of physiological factors including the propensity to self-prune (table 4). Northern red oak logs have greater yields of high- and mid-grade lumber than black oak or white oak logs of the same grade. Chestnut oak has a relatively poor grade yield because of the volume of wormy material associated with this species (Hanks and others 1980).

The relative yields of the different grades of hardwood logs and the increased sawing cost associated with smaller diameter logs is reflected in the Ohio log price data shown in table 5. Importantly, low-grade logs have a similar value regardless of species while higher quality

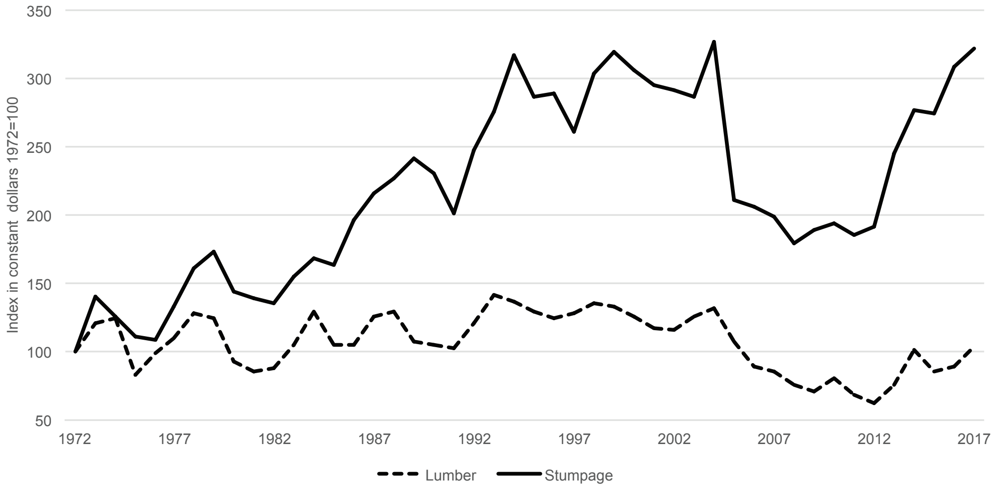

Figure 2—Deflated price indexes for composite oak stumpage and lumber price, 1972 to 2017, with associated weight of 70 percent for red oak and 30 percent for white oak. (Developed from: OWSP and OSUE 2018; HMR 1972 to 2017; USDL 2018).

Table 4—Percentage yield of high-grade (FAS, Sel, and 1F), mid-grade (1C and worm hole no defect FAS, 1C, Sel, and 1F), and low-grade (grades 2A and below and sound wormy) lumber for Forest Service log grade 1, 2, and 3 of black oak, northern red oak, chestnut oak, and white oak

Species	Log grade	High-grade lumber	Mid-grade lumber	Low-grade lumber
Black oak	Grade 1	38.4	31.1	30.5
	Grade 2	12.6	29.5	57.9
	Grade 3	5.3	18.9	75.8
Northern red oak	Grade 1	49.0	28.3	22.7
	Grade 2	22.0	34.5	43.5
	Grade 3	7.0	22.3	70.7
Chestnut oak	Grade 1	15.0	50.3	34.7
	Grade 2	6.5	39.1	54.4
	Grade 3	1.1	21.4	77.5
White oak	Grade 1	33.7	31.1	35.2
	Grade 2	12.2	27.9	59.9
	Grade 3	3.7	17.2	79.1

Source: Developed form Hanks and others (1980).

Table 5—Prices (dollars per thousand board feet) of prime, number 1 common, number 2 common, and blocking grade sawlogs per thousand board feet (Doyle Scale) in Ohio

	White oak	Red oak	Hard maple	Black cherry	Hickory	Yellow-poplar
Prime	1,183	739	1,038	865	575	585
No. 1 com.	675	568	558	493	425	372
No. 2 com.	372	339	317	311	288	289
Blocking	220	198	198	198	215	206

Source: OWSP and OSUE (2018).

sawlogs can be 3 to 5 time more valuable than low-quality logs (table 5). The difference in the interspecies value of higher grade logs are mainly the result of fashion considerations but also are influenced by yield of higher grade lumber.

MARKET AND FINANCIAL FACTORS OF SOUTHERN YELLOW PINE VERSUS OAK MANAGEMENT

Southern yellow pine plantations are predominantly artificially regenerated even-age stands that are normally planted, thinned, and harvested within a finite timeframe of 25 years or less. The end markets (pulpwood/chips, sawlogs, and bark) are understood prior to planting. The trees that are harvested are true commodities, identical to one another in form and value, and normally transported to mills in tree length or chip form. The financial returns of pine plantations are relatively easy to project although these projections are not always met. Pine plantations normally have the same ownership through the entire planting-to-harvest cycle, but even when ownership is transferred, the value of the plantation can be projected over the remaining life of the stand. Additionally, the value of the roundwood harvested during the thinning process has the same per-pound value in the pulpwood and bark markets as the roundwood harvested in the final clearcut.

The oaks are normally found in naturally regenerated uneven-age multi-species stands and, except in the case of a clearcut, there is no finite beginning or end of life of these stands. A high proportion of these stands has been repeatedly disturbed by seemingly random markets and natural processes making each stand somewhat unique but definable in terms of composition, structure, and site index. The length of time it takes most oak species to transition from sapling to merchantability may be as short as 50 years but can exceed 75 years. In higher quality stands, individual trees can have considerably different values and the logs harvested from these stands can be sold individually or as finite groups with specific attributes. There also is a high degree of natural (nonhuman-induced) mortality within hardwood stands which declines as surviving trees become greater in diameter.

Hardwood trees become considerably more valuable once they reach merchantable size. However, there is no unique specification of what is merchantable size because of spatial and temporal market factors. While the end markets for oaks and other long-lived hardwood species are somewhat understood, they have and probably will continue to change over time, introducing another element of temporal risk in the investment equation. Some of this temporal uncertainty is the result of cyclical fashion and style changes. Another factor is change that occurs in domestic and international personal income growth. The greatest factor contributing to the domestic decline in higher grade hardwood lumber consumption between 2008 and 2017 has been low economic growth and associated stagnate if not negative change in real income.

The most important contributor to the value of hardwoods is the human aesthetic and emotional connection with wood (Song and Zhao 2012, Tsunetsugu and others 2007). Traditionally, the best logs for aesthetic applications have the clarity, ring count, ring count consistency and color and associated attributes discussed by Wiedenbeck and others (2004). The fashion aspects can be temporal in any given culture but in a world market of multiple cultures it may be less important because fashion trends in one country may not transition to another.

DISCUSSION AND CONCLUSIONS

The greatest barrier to hardwood management appears to be the opportunity cost of the money required to finance forestry activities if that money were invested in other, higher yielding endeavors which is associated with the time value of money. When expecting an annual return of 4 percent compounded monthly, an investment of $1,000 would have to net $2,700 in 25 years, $7,360 in 50 years, and $20,000 in 75 years. A basic concept in risk theory is the greater the uncertainty, the higher the required rate of return. Doubling the interest rate to 8 percent requires a return of $7,300 in 25 years, $53,900 in 50 years, and $395,000 in 75 years for the same $1,000 investment.

As indicated in figure 2, oak stumpage prices have increased at about 6.1 percent per year in nominal terms and an acceptable 2.5 percent in real (inflation-adjusted rate) terms. Still, pine management seems considerably more attractive than long-term hardwood management because of the shorter duration of these investments (25 years or less) and lower risk. Since the greatest value of higher quality hardwood trees occurs only after they reach merchantable size, there is little or no market for roundwood resulting from prescribed thinning or improvement cuts. Attempts to circumvent the time-value-of-money problem in hardwoods by developing trees with faster growth rates ignores the importance of the apparent linking of hardwood attributes (e.g., color, species) and the human aesthetic and emotional connection with wood associated with ring count and ring consistency attributes. However, while the time-value-of-money argument may be a good explanation for why hardwood management has not taken place, it is less relevant given the aging of the oak timber base (table 1).

Today, nearly all the net growth of oak species is in large-diameter trees. While the life of these trees can be extended through fire and disease prevention, there is little that can be done to improve their quality. The

portions of the timber base that appear to have the greatest investment opportunity in the next 25 years are mid-size trees and poletimber. Still, any active management on these trees including the removal of invasive vegetation and cull material or intermediate cuts of larger trees must be examined on a cost-return basis. The potential consequence of root damage and associated damage-induced heartwood should also be considered in susceptible species groups which include the maples, ashes, and yellow-poplar. Cost and return considerations over a relatively short period are especially important for attracting high-net-worth individuals considering timber investment as part of their retirement portfolio.

Oak regeneration cannot be easily promoted as a standalone product but may be sold as a coproduct in combination with harvesting/timber stand improvement. Early stand intervention may also be economically feasible as demonstrated by Siry and others (2004). Even when the cost of encouraging oak regeneration during the harvesting process cannot be justified using time-value-of-money equations, it may be justified to the investor as “doing the right thing” if the perceived costs are acceptable (e.g., conservation financing). In this cost-revenue analysis all institutional structures such as tax law, inheritance tax, and direct or indirect subsidies should be included. Still, there will not be a one-size-fits-all solution for hardwood or oak management but rather several strategies that can be expanded or contracted so as to adapt to forest structure, composition, site index, and location of individual stands. Other variables that have to be considered are the objectives of the investors, who because of tax laws, have become timber management organizations, real estate investment trusts, or high-net-worth individuals.

Another way of covering the cost of better management is to include it as part of the attributes associated in the price of roundwood sold, which is a central concept behind forest certification. Having oak regeneration as a direct component of the timber certification process would pass the cost of regeneration to the final consumer of lumber and related products. However, while the market for hardwood lumber and related products over the past decade did not provide much opportunity to market the idea of oak management as part of the harvesting cost, the growth in the domestic and world economies since early 2017 may provide a greater opportunity to promote oak regeneration.

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SESSION 1:

Adaptive Silviculture for Climate Change

Moderator:

Sunshine Brosi
Frostburg State University

ADAPTING OAK MANAGEMENT IN AN AGE OF ONGOING MESOPHICATION BUT WARMING CLIMATE

**Louis R. Iverson, Matthew P. Peters, Stephen N. Matthews, Anantha Prasad,
Todd Hutchinson, Jarel Bartig, Joanne Rebbeck, Dan Yaussy,
Susan Stout, and Greg Nowacki**

Abstract—Rising temperatures and variable precipitation events leading to droughts and floods will likely increase in frequency. We present climate models with bracketed scenarios of daily temperature and precipitation from 1980 to 2099 showing increasing heat and drought for much of the country throughout this century. We then model and map potential changes in suitable habitat for ~130 tree species (10 x 10 km to 20 x 20 km) in the Eastern United States. Potential adaptability to changing climate was evaluated by literature assessment of biological and disturbance traits. Overall, trends show many species with shrinking habitat suitability but also several drought-tolerant species (especially oaks) with increased habitat. However, current oak regeneration is often poor - hence management assistance is needed to ensure an ongoing, thriving oak component. Long-term research in Ohio has shown that prescribed fire and thinning can provide a successful path for oak regeneration, depending on the moisture regime within the landscape. These data-informed models of oak regeneration highlight potential sites for oak regeneration across a 17-county region in southeastern Ohio. Silvicultural treatments promoting future increasers (e.g., oak) and finding refugia for decreasers can then be devised as a means to adapt to the changing climate.

INTRODUCTION

Oaks (*Quercus* spp.) have long been a foundational genus across much of Eastern United States (Hanberry and Nowacki 2016), but oak regeneration has been shown to be a problem across its distribution for many decades, and this problem continues to grow despite research and management attempts to decelerate it (Hutchinson and others 2012, Johnson and others 2009, Loftis 2004). Trends in Ohio, for instance, show a leveling out of oak volume, especially white oak (*Q. alba*), which is being harvested at a rate exceeding growth, as compared to a rapid rise in the maples (*Acer* spp.), which are increasing at a rate that is nearly four times their harvest rate (Widmann and others 2014). This is due to 'mesophication' of the landscape because of closed overstory canopies with insufficient light reaching the forest floor for adequate oak regeneration (Nowacki and Abrams 2008). Oaks provide a plethora of ecosystem services, so that sustaining the biodiversity, cultural, aesthetic, and economic services provided by oaks is highly desired by society.

There is now a robust body of research, including that reported in this volume, which identifies effective silvicultural treatments to increase the probability of successful oak regeneration. Prescribed fire, partial harvesting, herbicide application, and herbivore exclusion can all improve oak regeneration if applied at the right time, at the right place and at the right frequency and/or intensity (Brose and others 2008, Iverson and others 2017, Johnson and others 2009). For example, research into the treatments necessary to

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

achieve successful oak-hickory (*Carya* spp.) regeneration has been underway in Ohio since 1995 (Hutchinson and others 2005, 2012; Iverson and others 2008a; Sutherland and Hutchinson 2003), and has shown that a combination of removing mid- to upper story trees and repeated prescribed fire has the best potential to promote oak-hickory regeneration, but most successfully on drier ridges and southwest-facing sites. So when appropriate conditions are met (e.g., drier positions with advance oak regeneration), these 'zones of investment' for silvicultural treatment priority have been shown to increase the regeneration capacity for oaks. In contrast, areas not meeting criteria for the 'zones of investment' (e.g., mesic sites with little or no oak advance regeneration) are ill suited for silvicultural treatments aimed at oak regeneration based on limited available resources. A goal of this paper is to present a method to identify appropriate 'zones of investment' across southeastern Ohio where oak regeneration may be most successful per unit of effort and resources.

Meanwhile, the climate is warming, primarily caused by human-derived inputs of greenhouse gases (Wuebbles and others 2017), with heat, drought, and wildfire projected to increase in coming decades (Clark and others 2016, Matthews and others 2018, Wehner and others 2017). These conditions are expected to favor most oaks and hickories because they are physiologically more competitive under such conditions (Brose and others 2014, Butler and others 2015, Iverson and others 2017). It is therefore incumbent upon society and forest managers to work to sustain oaks and hickories so that adequate supplies of propagules, safe sites, and migration corridors are available into the future. A second goal of this paper is to present outputs of modeling efforts to identify the species that may do better or worse in coming decades under climate projections.

METHODS

Assessment of Climate Change Ongoing Now and Into the Future

We used several datasets of estimates of daily temperature and precipitation from 1980 to 2099 to evaluate past and potential future trends in climate indices related to biotic activity across the conterminous United States (Matthews and others 2018). These data allowed us to calculate, for four 30-year periods [1980–2009 (recent past), 2010–2039, 2040–2069, 2070–2099], four indices related to climate: Plant Hardiness Zones, Growing Degree Days, Heat Zones, and Cumulative Drought Severity Index. To explore the potential variation in projected changes of these climate patterns, we evaluated each metric under two scenarios, or 'bookends,' of projected climate change. These used, at the low end of potential change, a representative concentration pathway (RCP) 4.5 storyline of relatively rapid reduction of greenhouse gasses with peak emissions ~2040 (Moss and others 2008), combined with a general circulation model (GCM) with a relatively low sensitivity to carbon dioxide (CO_2). For the higher end of potential change, we used a model more sensitive to CO_2 with the RCP 8.5 storyline of continuing our current emissions path throughout this century. Unfortunately, global CO_2 levels have been tracking RCP 8.5 much more closely than RCP 4.5 levels in the time since these scenarios were generated in 2008 (Peters and others 2013). See Matthews and others (2018) for details on methods and results for the conterminous United States, but to demonstrate potential changes in conditions for tree success in the eastern forests, we here provide selected data on Heat Zones (the average number of days when maximum temperature exceeds 30 °C, averaged across the 30 years) and Cumulative Drought Severity Index (a weighted value derived from the occurrence and intensity of monthly drought events accumulated over 30 years (Peters and others 2014, 2015) for the Eastern United States, as they pertain to the eastern oak-prevalent geographies.

Modeling Potential Changes in Tree Species with the Changing Climate

The past climate has influenced species habitats for trees, as will future climates. Our group has been modeling, using the DISTRIB model, the potential change in suitable habitats under a changing climate for over 20 years, resulting in a number of publications (Iverson and Prasad 1998; Iverson and others 2008b, 2011), regional assessments (Brandt and others 2014, 2017, Butler and others 2015), and multiple updates to a Climate Change Atlas website (www.nrs.fs.fed.us/atlas). An update to the modeling was recently completed, and selected data are reported here. We use 45 environmental variables, including climate variables mentioned above, in combination with Forest Inventory and Analysis (FIA) inventory data (www.fia.fs.fed.us) to create a statistical model, DISTRIB II, projecting current and potential future suitable habitats in 30-year intervals throughout this century. A full explanation of the new modeling procedures and outcomes is in process and will be reported on the web site and future publications.

Besides the potential change in suitable habitats, the possible migration within those habitats has also been an ongoing investigation by our group, using the SHIFT model (Iverson and others 1999, 2004a, 2004b; Prasad and others 2013, 2016), and provides a basis for understanding the large lag time between the change in suitable habitats and the possible natural colonization in future decades based on historical migration rates.

Since models are unable to capture all aspects of potential change, we scored each of 134 species via literature- derived indications of 9 biological traits and 12 disturbance traits related to the capability to deal with climate change; these modification factors form the basis of the estimate of adaptability for each species (Iverson and others 2011, Matthews and others 2011).

For purposes of display and summarization, we report outputs of DISTRIB II and SHIFT by 1- by 1-degree grid, in this case for a portion of southeastern Ohio that encompasses the Athens District of the Wayne National Forest. This is an area bounded by 39-40° N latitude and 82-83° W longitude. The output includes estimates of species abundance (based on number of stems and basal area) both now and at century's end, the potential changes in habitat at low and high emissions, scores of adaptability, model reliability, and capability. The capability rating combines previously mentioned variables to assess the species' ability to cope with a changing climate, so that a species is ranked with a very good, good, fair, poor, very poor, lost, new habitat, or unknown capability, based on its current abundance within this 1- by 1-degree grid.

Assessment of Landtypes for Oak-Hickory Investment

To enable relatively large-scale treatments with limited resources, a mapping exercise was used to identify 'zones of investment' for oak-hickory restoration; a Geographic Information System (GIS) was used to rank every 10- by 10-m pixel across a 17-county region of southeastern Ohio into six landtype phases via derivatives of topography. The six landtype phases were further collapsed into three landtypes: Dry Oak forest (lovingly nicknamed 'Oaky-doaky sites'), Dry-mesic Mixed Oak Hardwood forest, and Rolling Bottomland Mixed Hardwood forest. See Iverson and others (2018) for details. For purposes of demonstration, we report a summary for the same 1- by 1-degree grid as reported above.

SILVAH is a decision-support system which enables forest managers to select appropriate silvicultural prescriptions based on multiple, small plot inventories from stands of interest (Brose and others 2008). SILVAH-based plot data are now routinely collected by State and Federal agencies in southeastern Ohio, and thus can be used in conjunction with the landtype mapping to assess potentials for oak-hickory restoration on particular parcels of land. As described in Iverson and others 2018, a GIS-based tool is available to summarize both the areas of landtypes (or landtype phases) within a user-specified area, and the SILVAH-derived statistics of species abundance in the under- and overstory.

RESULTS AND DISCUSSION

Changes in Heat and Drought

An analysis of potential trends in the Heat Zones and the Cumulative Drought Severity Index (CDSI) shows the potential for large changes, depending on the choice humans make relative to curbing emissions (fig. 1) (Matthews and others 2018). For example, in Midwestern States, under the high level of emissions, an average additional 95 days exceeding 30 °C are projected; in contrast, under low emissions, only 42 additional days are projected (Matthews and others 2018). With CDSI, again there is a large contrast of overall drought between low and high levels of emissions (fig. 1). Even under low emissions, however, there are projected increases in heat and drought which would have significant impacts on the biota of the region, including potential conditions which allow oaks and hickories to be more competitive against the more mesophytic species. Nonetheless in the meantime, the oaks and hickories are losing status relative to the maples such that near-heroic efforts need to be undertaken to sustain them into the near future so that sufficient propagules will be present should conditions turn to favor the oaks and hickories in the later decades of this century.

Changes in Tree Suitable Habitat

Suitable habitats for tree species are reported for the 1- by 1-degree grid bounded by 39-40^{o} N and 82-83^{o} W, a portion of southeastern Ohio (and of the 17-county study area) that encompasses the Athens District of the Wayne National Forest (tables 1 and 2). This area shows a total of 78 species, with 67 species present now and 68 species with habitat projected to be suitable at the end of this century. We also score the species for their current abundance, based on the FIA data-derived sum of importance in the 1- by 1-degree grid; it showed 18 abundant species led by red maple (*A. rubrum*), sugar maple (*A. saccharum*), yellow-poplar (*Liriodendron tulipifera*), sassafras (*Sassafras albidum*), white oak, and black cherry (*Prunus serotina*); 34 common species; and 15 rare species in the area (including 3 with some evidence for the species in the area but too rare for an acceptable model to be generated). Of the species present currently, 24 are projected to lose substantial habitat (large or very large decreaser) and another 17 to lose some habitat (small decreaser) if the climate changes according to the high emissions projection. On the other hand, one species is projected to gain substantial habitat and seven gain some habitat under high emissions (table 2). In addition, 15 species are projected to remain with about equivalent habitat, while 8 species not presently in the area (according to FIA plots) could gain habitat, and 5 species present currently could see their suitable habitat eliminated. Under low emissions, the projected changes are somewhat dampened, but still substantial (table 2).

By combining several attributes of the species and their modeled outputs, we also present an overall capability rating for the species, within that particular grid, to cope with a changing climate under a high level of

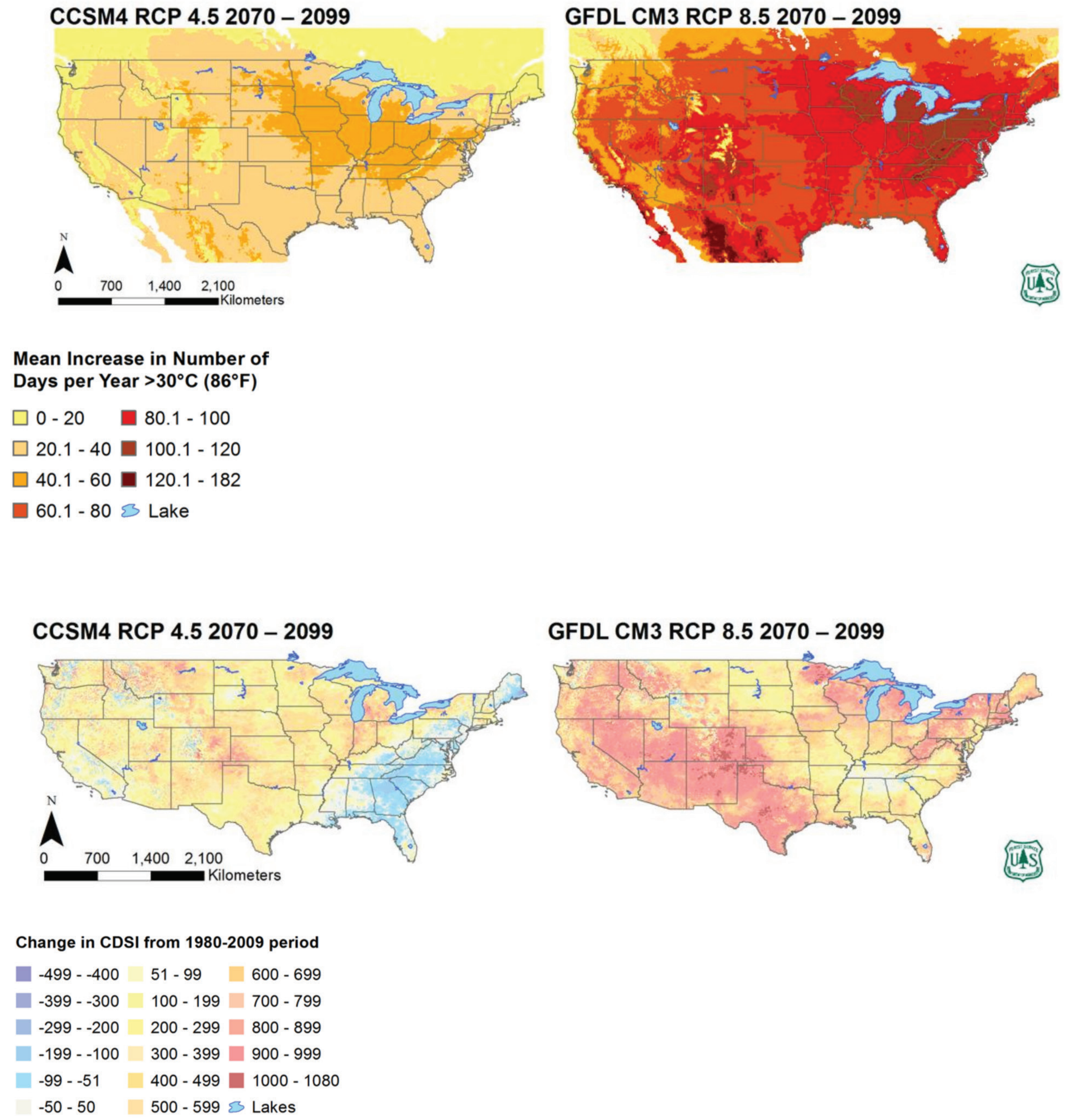

Figure 1—Change in Heat Zones (HZ) and Cumulative Drought Severity Index (CDSI) for the Eastern United States (oak-hickory-dominated regions) projected from current (1980–2009) to end of century (2070–2099) according to low and high emissions scenarios.

Table 1—Estimates of tree species characteristics for the 1- by 1-degree grid, 82°W 39°N, in southeastern Ohio

Common_Name	Scientific_Name	FIA code	Mod Rel	Pct Area	FIAi	FIAsum
White oak	*Quercus alba*	802	High	86.4	6.07	256.63
Black oak	*Quercus velutina*	837	High	85.34	4.53	148.56
Mockernut hickory	*Carya tomentosa*	409	Medium	49.79	3.08	67.91
Blackgum	*Nyssa sylvatica*	693	Medium	61.23	2.55	63.74
Red maple	*Acer rubrum*	316	High	88.33	10.69	491.06
Yellow-poplar	*Liriodendron tulipifera*	621	High	79.15	10.89	452.47
Chestnut oak	*Quercus prinus*	832	High	35.8	9.24	179.07
Sourwood	*Oxydendrum arboreum*	711	High	41.14	3.71	79.48
Sugar maple	*Acer saccharum*	318	High	100	12.33	484.73
Post oak	*Quercus stellata*	835	High	2.71	4.65	2.14
Northern red oak	*Quercus rubra*	833	Medium	91.18	4.03	112.49
American beech	*Fagus grandifolia*	531	High	81.47	4.87	139.14
Shortleaf pine	*Pinus echinata*	110	High	0	0.53	0.38
Red mulberry	*Morus rubra*	682	Low	3.14	0.59	0.42
Slippery elm	*Ulmus rubra*	975	Low	74.52	4.71	124.87
Bitternut hickory	*Carya cordiformis*	402	Low	56.84	3.35	56.25
Common persimmon	*Diospyros virginiana*	521	Low	7.3	1.56	9.55
Green ash	*Fraxinus pennsylvanica*	544	Low	24.28	2.5	19.03
Bigtooth aspen	*Populus grandidentata*	743	Medium	50.11	4.16	106.64
Boxelder	*Acer negundo*	313	Medium	35.42	12.43	69.48
American elm	*Ulmus americana*	972	Medium	90.6	7.5	203.78
White ash	*Fraxinus americana*	541	Medium	97.88	6.16	182.12
Pignut hickory	*Carya glabra*	403	Medium	76.91	3.04	91.27
Hackberry	*Celtis occidentalis*	462	Medium	22.67	2.85	18.11
Osage-orange	*Maclura pomifera*	641	Medium	8.62	4.11	10.85
Sassafras	*Sassafras albidum*	931	Medium	81.15	6.27	261.41
Shagbark hickory	*Carya ovata*	407	Medium	80.97	4.62	144.4
Black locust	*Robinia psuedoacacia*	901	Medium	76.18	5.84	141.48
Eastern red cedar	*Juniperus virginiana*	68	Medium	0	1.19	0.01
Virginia pine	*Pinus virginiana*	132	High	24.72	5.26	60.99
Scarlet oak	*Quercus coccinea*	806	High	31	3.42	51.74
Pitch pine	*Pinus rigida*	126	High	8.38	4.15	27.49
Sweetgum	*Liquidambar styraciflua*	611	High	5.24	13.63	15.48
Silver maple	*Acer saccharinum*	317	Low	8.54	23.21	49.57
River birch	*Betula nigra*	373	Low	4.17	9.65	27.39
Pawpaw	*Asimina triloba*	367	Low	10.79	2.58	26.83
Eastern hophornbeam	*Ostrya virginiana*	701	Low	11.18	2.16	14.34
Black walnut	*Juglans nigra*	602	Low	73.2	3.86	67.06
Sycamore	*Platanus occidentalis*	731	Low	45.66	3.83	66.78

continued

Mod Rel = model reliability; Pct Area = percent of the 1- by 1-degree grid occupied; FIAi = average importance value of the species when present); FIAsum = sum of the importance value for the entire grid.

NOTE: The asterisk (*) denotes percent of area with at least a 5-percent probability of colonization.

[a] For the “new habitat” species, the migration potential is based on the SHIFT model’s estimate of the percent of area with at least five percent probability of colonization within 100 years.

Table 1—(continued) Estimates of tree species characteristics for the 1- by 1-degree grid, 82°W 39°N, in southeastern Ohio

Common_Name	Scientific_Name	FIA code	Mod Rel	Pct Area	FIAi	FIAsum
American hornbeam	*Carpinus caroliniana*	391	Low	8.38	1.09	19
Eastern redbud	*Cercis canadensis*	471	Low	12.56	1.66	15.71
Ohio buckeye	*Aesculus glabra*	331	Low	12.9	1.71	13.39
Honeylocust	*Gleditsia triacanthos*	552	Low	18.21	3.81	12.69
Eastern cottonwood	*Populus deltoides*	742	Low	3.71	2.87	10.19
Shingle oak	*Quercus imbricaria*	817	Medium	4.18	1.76	7.48
Bur oak	*Quercus macrocarpa*	823	Medium	0	0.41	0.09
Black cherry	*Prunus serotina*	762	Medium	99.68	7.29	223.73
Flowering dogwood	*Cornus florida*	491	Medium	49.09	2.11	63.8
Chinkapin oak	*Quercus muehlenbergii*	826	Medium	1.05	4.08	5.8
Quaking aspen	*Populus tremuloides*	746	High	2.09	2.73	3.88
Red spruce	*Picea rubens*	97	High	7.33	0.88	0.63
Sweet birch	*Betula lenta*	372	High	6.28	3.66	15.61
Yellow buckeye	*Aesculus octandra*	332	Low	15.88	4.69	51.84
Pin oak	*Quercus palustris*	830	Low	2.62	13.71	6.09
Black maple	*Acer nigrum*	314	Low	0.32	1	2.07
Black willow	*Salix nigra*	922	Low	2.09	4.83	6.84
Serviceberry	*Amelanchier* sp.	356	Low	3.47	1.89	4.45
Shellbark hickory	*Carya laciniosa*	405	Low	1.69	3.65	4.2
Red pine	*Pinus resinosa*	125	Medium	1.02	11.01	7.63
Eastern white pine	*Pinus strobus*	129	High	15.01	11.16	74.71
Eastern hemlock	*Tsuga canadensis*	261	High	5.24	6.3	22.42
Butternut	*Juglans cinerea*	601	Low	7.3	0.86	3.15
Cucumbertree	*Magnolia acuminata*	651	Low	2.74	0.85	1.21
American basswood	*Tilia americana*	951	Medium	9.36	2.77	16.97
Yellow birch	*Betula alleghaniensis*	371	High	0.32	0	0
Bluejack oak	*Quercus incana*	842	Low	0	0	0
Striped maple	*Acer pensylvanicum*	315	Medium	2.31	0	0
Chokecherry	*Prunus virginiana*	763	Unacc	2.43	1.21	2
Northern catalpa	*Catalpa speciosa*	452	Unacc	0.32	0.83	0.18
Wild plum	*Prunus americana*	766	Unacc	0.01	4.56	0.03
Migration Potential[a]						
Loblolly pine	*Pinus taeda*	131	High	1.05	0	9.7*
Black hickory	*Carya texana*	408	High	0	0	0*
Water oak	*Quercus nigra*	827	High	0	0	0*
Pecan	*Carya illinoensis*	404	Low	0	0	0*
Winged elm	*Ulmus alata*	971	Medium	0	0	0.36*
Southern red oak	*Quercus falcata* var. *falcata*	812	Medium	0	0	26.6*
Sugarberry	*Celtis laevigata*	461	Medium	0	0	7.0*
Blackjack oak	*Quercus marilandica*	824	Medium	0	0	0.01*

Mod Rel = model reliability; Pct Area = percent of the 1- by 1-degree grid occupied; FIAi = average importance value of the species when present); FIAsum = sum of the importance value for the entire grid.

NOTE: The asterisk (*) denotes percent of area with at least a 5-percent probability of colonization.

[a] For the “new habitat” species, the migration potential is based on the SHIFT model’s estimate of the percent of area with at least five percent probability of colonization within 100 years.

Table 2—Estimates of tree species characteristics for the 1- by 1-degree grid, 82°W 39°N, in southeastern Ohio

Common_Name	ChngCl45	ChngCl85	Adapt	Abundance	Capability
White oak	No change	No change	6.1	Abundant	Very good
Black oak	Sm. inc.	Sm. inc.	4.9	Abundant	Very good
Mockernut hickory	Sm. inc.	Sm. inc.	5.4	Common	Very good
Blackgum	No change	Sm. inc.	5.9	Common	Very good
Red maple	Lg. dec.	Lg. dec.	8.5	Abundant	Good
Yellow-poplar	Lg. dec.	Lg. dec.	5.3	Abundant	Good
Chestnut oak	Lg. dec.	Lg. dec.	6.1	Abundant	Good
Sourwood	Sm. dec.	Lg. dec.	6.9	Abundant	Good
Sugar maple	Sm. dec.	Sm. dec.	5.8	Abundant	Good
Post oak	No change	Sm. inc.	5.7	Rare	Good
Northern red oak	No change	No change	5.4	Abundant	Good
American beech	Sm. dec.	Lg. dec.	3.6	Abundant	Fair
Shortleaf pine	Sm. inc.	Sm. inc.	3.6	Rare	Fair
Red mulberry	Lg. inc.	Lg. inc.	4.7	Rare	Fair
Slippery elm	No change	No change	4.8	Abundant	Fair
Bitternut hickory	No change	No change	5.6	Common	Fair
Common persimmon	No change	No change	5.8	Common	Fair
Green ash	Sm. inc.	Sm. inc.	4	Common	Fair
Bigtooth aspen	Lg. dec.	Lg. dec.	5.1	Abundant	Fair
Boxelder	Sm. dec.	Lg. dec.	7.4	Common	Fair
American elm	No change	No change	4	Abundant	Fair
White ash	No change	No change	2.7	Abundant	Fair
Pignut hickory	No change	No change	4.7	Abundant	Fair
Hackberry	No change	No change	5.7	Common	Fair
Osage-orange	No change	No change	6.3	Common	Fair
Sassafras	Sm. dec.	Sm. dec.	4.2	Abundant	Fair
Shagbark hickory	Sm. dec.	Sm. dec.	4.4	Abundant	Fair
Black locust	Sm. dec.	Sm. dec.	3.8	Abundant	Fair
Eastern red cedar	Sm. inc.	Sm. inc.	3.9	Rare	Fair
Virginia pine	Sm. dec.	Lg. dec.	3.8	Common	Poor
Scarlet oak	Sm. dec.	Lg. dec.	4.6	Common	Poor
Pitch pine	Sm. dec.	Lg. dec.	3.8	Common	Poor
Sweetgum	Sm. dec.	Sm. dec.	4.1	Common	Poor
Silver maple	Sm. dec.	Lg. dec.	5.6	Common	Poor
River birch	Sm. dec.	Lg. dec.	3.7	Common	Poor
Pawpaw	Lg. dec.	Lg. dec.	3.7	Common	Poor
Eastern hophornbeam	Lg. dec.	Lg. dec.	6.4	Common	Poor
Black walnut	No change	No change	4	Common	Poor
Sycamore	No change	No change	4.8	Common	Poor

continued

ChngCl45 and ChngCl85 = change classes for low and high emissions, respectively; Adapt = the adaptability of the species to a changing climate; Capability = score for potential of the species to cope with the RCP 8.5 climate at end of century within this 1- by 1-degree grid.

Table 2—(continued) Estimates of tree species characteristics for the 1- by 1-degree grid, 82°W 39°N, in southeastern Ohio

Common_Name	ChngCl45	ChngCl85	Adapt	Abundance	Capability
American hornbeam	Sm. dec.	Sm. dec.	5.1	Common	Poor
Eastern redbud	Sm. dec.	Sm. dec.	4.9	Common	Poor
Ohio buckeye	Sm. dec.	Sm. dec.	3.5	Common	Poor
Honeylocust	No change	Sm. dec.	5.5	Common	Poor
Eastern cottonwood	No change	Sm. dec.	3.9	Common	Poor
Shingle oak	No change	No change	4.9	Common	Poor
Bur oak	No change	No change	6.4	Rare	Poor
Black cherry	Sm. dec.	Sm. dec.	3	Abundant	Poor
Flowering dogwood	Sm. dec.	Sm. dec.	5	Common	Poor
Chinkapin oak	Sm. dec.	Sm. dec.	4.8	Common	Poor
Quaking aspen	Lg. dec.	Lg. dec.	4.7	Rare	Very poor
Red spruce	No change	No change	2.9	Rare	Very poor
Sweet birch	Sm. dec.	Sm. dec.	3.2	Common	Very poor
Yellow buckeye	Lg. dec.	Lg. dec.	3.1	Common	Very poor
Pin oak	Sm. dec.	Lg. dec.	2.8	Common	Very poor
Black maple	Lg. dec.	Lg. dec.	5.2	Rare	Very poor
Black willow	Sm. dec.	Sm. dec.	2.8	Common	Very poor
Serviceberry	Sm. dec.	Sm. dec.	4.8	Rare	Very poor
Shellbark hickory	Sm. dec.	Sm. dec.	3.7	Rare	Very poor
Red pine	Lg. dec.	Lg. dec.	3	Common	Very poor
Eastern white pine	Very Lg. dec.	Very Lg. dec.	3.3	Common	Lost
Eastern hemlock	Very Lg. dec.	Very Lg. dec.	2.7	Common	Lost
Butternut	Very Lg. dec.	Very Lg. dec.	2.3	Rare	Lost
Cucumbertree	Very Lg. dec.	Very Lg. dec.	3.6	Rare	Lost
American basswood	Very Lg. dec.	Very Lg. dec.	4.6	Common	Lost
Yellow birch	Unknown	Unknown	3.4	Absent	Unknown
Bluejack oak	Unknown	Unknown	4.8	Absent	Unknown
Striped maple	Unknown	Unknown	5.1	Absent	Unknown
Chokecherry	Unknown	Unknown	3.8	Rare	Unknown
Northern catalpa	Unknown	Unknown	4.2	Rare	Unknown
Wild plum	Unknown	Unknown	3.9	Rare	Unknown
Migration Potential[a]					
Loblolly pine	New habitat	New habitat	3.4	Absent	New habitat
Black hickory	New habitat	New habitat	4.1	Absent	New habitat
Water oak	New habitat	New habitat	3.7	Absent	New habitat
Pecan	New habitat	New habitat	2.2	Absent	New habitat
Winged elm	New habitat	New habitat	3.6	Absent	New habitat
Southern red oak	New habitat	New habitat	5.3	Absent	New habitat
Sugarberry	New habitat	New habitat	4.6	Absent	New habitat
Blackjack oak	New habitat	New habitat	5.6	Absent	New habitat

ChngCl45 and ChngCl85 = change classes for low and high emissions, respectively; Adapt = the adaptability of the species to a changing climate; Capability = score for potential of the species to cope with the RCP 8.5 climate at end of century within this 1- by 1-degree grid.

emissions. Four species attained the very good rating, three of which are oaks or hickories: white and black oak (*Q. velutina*), mockernut hickory (*C. tomentosa*), and blackgum (*Nyssa sylvatica*) (table 2). An additional seven species rated good, including three additional oak species: yellow-poplar, chestnut oak (*Q. prinus*), sourwood (*Oxydendrum arboretum*), sugar maple, post oak (*Q. stellata*), northern red oak (*Q. rubra*), and eastern white pine (*Pinus strobus*). These are species with high levels of abundance currently, projected to gain or at least remain stable in habitat, and well adapted to drought and other disturbances expected in the coming decades. Beyond those, 18 species rated fair, 20 poor, 10 very poor, 5 lost, 8 new habitat, and 6 unknown. Thus, according to this analysis, even though more species are expected to have new habitat appear (8) than disappear (5), at least 30 of the species present now are expected to have a reduction in their capability status by 2100.

For the eight species projected to gain newly suitable habitat by the end of century, we can use the results from SHIFT to evaluate the likelihood of that new habitat getting colonized. SHIFT can be visualized as the likelihood of propagules from current occupied cells colonizing unoccupied cells. The likelihood is based on post-glacial migration estimates (Prasad and others 2013) and depends on the abundance in the current cells and the habitat quality of the colonizing cells, and decays rapidly with distance, simulating long-distance seed-dispersal phenomenon. Thus, if the new habitat is a long distance from current occupied cells, especially if not highly abundant, the potential for migration into the 1- by 1-degree grid is severely compromised. In this study region, three species would have virtually no chance of being naturally colonized [water oak (*Q. nigra*), black hickory (*C. texana*), pecan (*C. illinoensis*)], another two with very little likelihood [winged elm (*Ulmus alata*) and blackjack oak (*Q. marilandica*)], and only three [southern red oak (*Q. falcata* var. *falcata*), loblolly pine (*Pinus taeda*), and sugarberry (*Celtis laevigata*)] would have a decent probability of colonizing into the region naturally (table 1). Of course, the species could be moved artificially to circumvent the limitations of natural migration; in this case perhaps selecting those species with new suitable habitat and some likelihood of colonization could be seen as the most likely for long-term successful establishment of new species to occupy the area.

Assessment of Landtypes for Oak-Hickory Investment

Of the 71.6 percent of the study area 1- by 1-degree grid that was analyzed for landtypes, 39 percent was classed as Dry Oak (DO, or 'oaky-doaky'), 28 percent as Dry-mesic Mixed Oak Hardwoods (DMMOH), and 32 percent as Rolling Bottomland Mixed Hardwoods (RBMH) (fig. 2). This area reveals a complex intermingling of the landtypes within this dissected landscape, [see also Iverson and others 2018 for high resolution images]. The DO areas can be considered the most suitable for silvicultural investment into promoting oaks and hickories; these investments include several approaches to increase light to the forest floor and the competitiveness of oaks and hickories, such as thinning, prescribed fire, herbiciding the competing species, or a combination thereof (Brose and others 2008). Land managers can use the maps, the data extraction tool, and the resulting statistics to target their silvicultural investments in an age of limited staff and financial resources.

CONCLUSIONS

In this brief summary paper, we outline several thrusts of research aimed at assisting land managers for both short- and long-term forest management. With the summaries of climate projections, we aim to portray the range of possible future growing conditions, pointing out potential future heat and drought conditions and the large differences projected between low and high emissions during this century (i.e., the choices humans make regarding curbing emissions). Next, we evaluate and tabulate the potential changes in tree species habitats for 78 species associated with one 1- by 1-degree grid in southeastern Ohio, according to the potential future climatic conditions previously described. We further assess the capability of the species to cope with the changing climate, in which only 11 of the 78 species are classed with a 'good' or 'very good' capability, in comparison to 30 species with 'poor' or 'very poor' capability to cope. We also evaluate the eight species shown to have new suitable habitat appearing in the area by 2100, and show that only three of the eight (southern red oak, loblolly pine, and sugarberry) are modeled to have a reasonable chance of naturally migrating to the area within 100 years. Notably, southern red oak and sugarberry have been found in southeastern Ohio but not yet recorded within FIA plots (thus our models), and they are likely to increase in prominence in the future. Finally, we mapped much of southeastern Ohio into three landtypes and six landtype phases for each of five subsections across southeastern Ohio for a total of 15 landtypes and 19 landtype phases. One landtype group, the Dry Oak forest landtype, is most suitable for investing in silvicultural treatments such as prescribed fire, thinning, or herbicides to promote oaks and hickories. Those species projected most favorably under these analyses include white oak, black oak, mockernut hickory, chestnut oak, post oak, northern red oak, and, gauging for the future, southern red oak; each of these species scored as viable species capable of coping with the hotter and physiologically drier future climate.

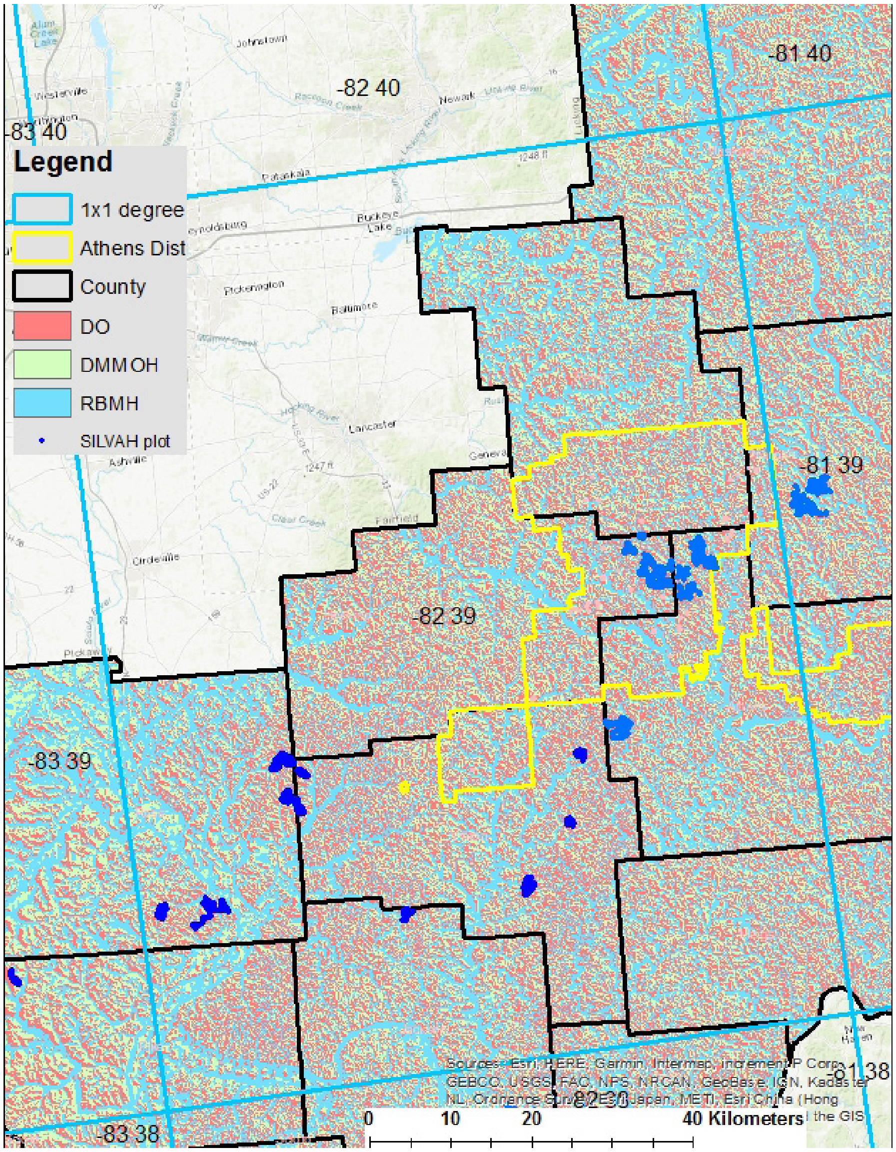

Figure 2—Landtypes for much of the 1- by 1-degree grid, 82°W 39°N, in southern Ohio. Also shown is the boundary of the Athens District of the Wayne National Forest, county lines, and locations of SILVAH plots.

ACKNOWLEDGMENTS

The authors are indebted to multiple field personnel who collected data to make this paper possible: FIA crews, State and Federal crews in Ohio, and Northern Research Station personnel on the Vinton Furnace State Forest.

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IDENTIFYING AND ADDRESSING VULNERABILITIES OF OAK ECOSYSTEMS

Patricia Butler-Leopold, Leslie A. Brandt, Stephen D. Handler, Maria K. Janowiak, Patricia D. Shannon, and Chris W. Swanston

Extended abstract—The Climate Change Response Framework (CCRF 2014) was developed to provide a collaborative approach to supporting adaptation decisions in natural resource management that accommodate diverse management goals, ecosystem types, and organizational structures. An essential element of the CCRF is the Adaptation Workbook—a five-step adaptation-planning process that helps land managers consider climate change in their management and planning (Swanston and others 2016). A key resource for the Adaptation Workbook is a menu of adaptation strategies and approaches that represent a continuum of adaptation concepts ranging from resistance (preventing ecosystem change), resilience (enhancing ecosystem capacity to recover to its original state after disturbance), and transition (intentionally accommodating change to help ecosystems adapt). To date, more than 250 adaptation demonstration projects have been developed throughout the Midwestern and Northeastern United States using the Adaptation Workbook and menu of adaptation strategies. These projects serve as examples of how land managers have integrated climate considerations into planning at scales where management decisions are made and actions are implemented (CCRF 2014, Ontl and others 2018). Here, we focus on three adaptation demonstration projects in oak-dominated forests in the Central Hardwoods region.

“Collaborative Oak Management in Southeast Ohio” brought together forest managers and resource specialists from the Wayne National Forest and Ohio Division of Forestry. A team from each organization considered climate change in separate vegetation management projects using the Adaptation Workbook process; teams first completed each step for their project area before both teams then worked together to identify commonalities among the two areas. In step one, teams identified common management goals for the two areas: create early successional habitat for wildlife; improve forest health; and restore oak-hickory forest on the landscape. In step 2, teams identified common impacts and vulnerabilities among the two areas. Vulnerability to climate change under a range of future climate scenarios was previously assessed for 18 forest ecosystems in the Central Hardwoods and Central Appalachians regions (Brandt and others 2014, Butler and others 2015). A negative impact is potential increases in invasive species and disease (i.e., oak wilt), and a positive impact is potential increases in suitable habitat for native oak and pine species. In step 3, these impacts were evaluated on their ability to create challenges or opportunities to meeting management goals and objectives. An opportunity is to use shelterwood regeneration treatments in mature oak stands, followed by site preparation to promote natural regeneration of oak and hickory species as maple becomes less competitive in a warming climate. In step 4, teams used the menu of adaptation strategies to identify adaptation actions for oak-hickory management, including actions to match prescribed burn windows to environmental conditions and stages of oak development; reduce tree density in overcrowded stands; encourage future-adapted species by underplanting with shortleaf pine (or pitch pine); and managing the northward expansion of southern red oak. The exact timing and application of these broad strategies are expected to vary based on ownership and site conditions. In step 5, teams identified monitoring metrics to evaluate progress toward meeting management goals and objectives. For example, the number of acres and stocking level of oak seedlings and saplings may indicate trends in oak and associated species.

“Improving Bottomland Hardwood Forest” (Ducks Unlimited, Inc. 2017) brought together a team from Ducks Unlimited, the National Wild Turkey Federation, and State and Federal partners to complete an adaptation workbook on the Mississippi River and Cache River Bottoms of southern Illinois and Patoka River Bottoms of southwestern Indiana. Step 1 management goals were to: maintain hydrology in bottomland forests during

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

severe and variable flood regimes; enhance natural regeneration of flood-tolerant oaks and hickories via thinning and prescribed burning; and restore bottomland forests at higher elevation sites previously converted to farmland. Step 2 impacts for the project area included increasing severity and number of heavy precipitation events, increases in runoff and peak streamflow during winter and spring, and increases in flood magnitude and frequency. Step 3 challenges were associated with changes in vegetative species composition (i.e., habitat for migratory waterfowl during fall migration) driven by spring flooding and subsequent soil erosion, and dry periods during the summer. Step 3 opportunities included potential for improved conditions for prescribed fire in the fall, which could help regenerate oak and control invasive species; favorable conditions for pin oak, which provides a key food source to migratory waterfowl; and potential increases in overwintering waterfowl that historically migrated further south. Step 4 adaptation actions included efforts to increase productive wintering habitat for waterfowl; diversify species composition and genetic stock of species used for reforestation; and take advantage of dry periods to conduct controlled burns. Step 5 monitoring metrics to gauge the successful advancement of bottomland oaks included oak regeneration success, effects of upgrades to water management structures, and floral diversity.

“Restoring Jerktail Mountain Woodland” (Jerktail Mountain 2018) brought together a team from L-A-D Foundation’s Pioneer Forest and the National Park Service’s Ozark National Scenic Riverways to enhance the adaptive capacity of woodland ecosystems in southern Missouri. Step 1 management goals are to: reduce woody species encroachment; restore and maintain the woodland ecosystem; and enhance adaptive capacity to cope with a range of future climates. Step 2 impacts include mean annual temperature increases ranging from 2 to 7 °F; increased precipitation in winter and spring and declines in summer; and increased wildfire frequency and severity. Step 3 opportunities are projected increases in suitable habitat for shortleaf pine and post oak. Step 3 challenges are projected summer stress on black oak and scarlet oak; encroachment of eastern redcedar; and potential increases in fire intensity beyond this system’s tolerance. Step 4 adaptation actions included methods to restore fire to fire-dependent systems; favor native species expected to cope with a range future climates; and allow for areas of natural regeneration after disturbance. Step 5 monitoring metrics included pre- and post-burn species richness.

Although described briefly here, these examples highlight a diversity of adaptation options for managers that address anticipated climate impacts, as well as a variety of management goals and objectives for oak-hickory management and restoration in a changing climate.

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SESSION 2:

Shelterwood Methods for Oak Regeneration

Moderator:

Ken Smith
The University of the South

RECRUITING OAK USING MIDSTORY HERBICIDE SHELTERWOOD PRESCRIPTIONS IN CUMBERLAND PLATEAU FORESTS IN ALABAMA, TENNESSEE, AND KENTUCKY

Callie J. Schweitzer

Abstract—I examined the implementation of a midstory herbicide treatment as the first phase in a two-phase shelterwood prescription in upland hardwood stands in Alabama, Tennessee, and Kentucky. The initial prescription for all three sites was similar: use herbicide to reduce the density of the midstory, allowing increased light to the established oak (*Quercus* spp.) reproduction. The goal was to increase understory light to at least 20 percent of full sun to promote oak seedling growth and recruitment over other species. Light was increased, but ephemeral and not to the 20-percent full sun goal. Densities of large oak seedlings [>4 feet in height up to 1.5 inches diameter at breast height (dbh)] increased only on the Kentucky site, which had the most advance oak reproduction of all three sites prior to treatment. Response of competitors, including shade-tolerant sugar maple (*Acer saccharum* Marsh.), intolerant yellow-poplar (*Liriodendron tulipifera* L.), and ubiquitous red maple (*A. rubrum* L.), also responded. Treating small stems (<1 inch dbh) and other tending treatments prior to overstory may be warranted to maintain oak.

INTRODUCTION

The idea of applying the two-phase shelterwood method to recruit oak (*Quercus* spp.) reproduction into larger, competitive size classes, followed by release, is not new. In the southern upland hardwood forests, one original mention of using shelterwood prescriptions came as a result of Frothingham's (1917) study, from which he concluded that total clearing or clearing with reserves was needed for an immediate start in the shape of stocked stands of desirable species composition. He recognized the need to control light to recruit oaks into competitive positons, and recommended thinning where white oak (*Q. alba* L.) was found overtopped by black (*Q. velutina* Lamark) and scarlet oak (*Q. coccinea* Muench.). Shelterwood cutting and selection cutting were also considered, but little thought was given to present or future management of young growth or to the reproduction status and composition. From this study came the origins of managing for desired species by altering light regimes.

For researchers who have devoted careers to studying oak, an original and fundamental reference is work conducted by Clarence Korstian (1927). His earliest work was a cooperative project between the U.S. Department of Agriculture Forest Service Appalachian Forest Experiment Station and the School of Forestry at Yale. He began by saying ". . . there is little information available upon the seed and seedling characteristics of the American oaks" (p. 7). Research by both the Forest Service Appalachian and Northeastern Forest Experiment Stations indicated that American chestnut [*Castanea dentata* (Marsh.) Borkh.] was being replaced by stands more highly stocked with various species of oak (Korstian and Stickel 1927, Leffelman and Hawley 1925). Korstian (1927) recommended natural reproduction of oak by partial harvesting or a two- or three-cut shelterwood method. His conclusions were complemented by those of Leffelman and Hawley (1925), whose work in Connecticut hardwoods also concluded that the desired reproduction (oaks) originates prior to the regeneration harvest, and was assisted in its development under shelterwood prescriptions.

Downs and McQuilkin (1944), in a seminal paper, focused on defining silviculture prescriptions for sustaining oak stands using 'quantitative evidence,' with emphasis on the reproduction cohort. Seeding habits, seed fate, and the amount of seed needed for adequate restocking were quantified for northern red (*Q. rubra* L.), black, scarlet, white, and chestnut oak (*Q. prinus* L.), and cutting methods were described to enhance seedling growth. They found that some form of partial cutting benefited oak reproduction as litter and canopy cover retarded acorn desiccation, partial shade lent to sapling recruitment, and oak seed sources from

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

trees with healthy, well-developed crowns were plentiful. They referenced partial-cutting systems, including shelterwood and selective cutting.

In 1961, Carvell and Tryon detailed the response of oak under various environmental factors in an inclusive examination of influences to oak regeneration (Carvell and Tryon 1961). They showed that oak reproduction was best on drier sites and thus more easily maintained on those sites as opposed to moister exposures, in which myriad factors increased the competition for light, including more competition from herbaceous vegetation, shrubs, and tolerant tree species, and denser overhead canopies. The amount of sunlight in the understory was the driving factor in oak seedling abundance and subsequent recruitment into the larger size classes. They concluded that the ability of oak reproduction to persist was more related to environmental conditions than its ability to become established, as overstory seed sources were abundant and understory conditions were not retarding germination. Finally, they suggested a series of thinnings during the last years of a stand's rotation to get light to the small seedlings, allowing those seedlings to grow into a more competitive position, prior to overstory removal.

Tall (4.5 feet in height) oak reproduction was shown to have a high potential to compete successfully in a new stand (Sander 1972). To grow seedlings into larger size classes, Sander (1979) prescribed a shelterwood system in which the overstory density was reduced to not <60 percent, and understory stems larger than the oaks were selectively herbicided, followed by a 10-year growth period. Overstory removal was to be done when the stand had 430 stems per acre (SPA) of oak >4.5 feet tall (Sander 1979). In shelterwood prescriptions examined by McGee (1975) and Loftis (1983), the first cut to residual basal areas of 66 square feet per acre or 33 square feet per acre, followed 15 years later by all overstory stem removal, resulted in the same species composition as clearcutting. Loftis (1983) suggested an initial phase I reduction of density to be minimal to prevent high sunlight levels and stimulation of yellow-poplar (*Liriodendron tulipifera* L.) germination and growth, coupled with an herbicide treatment targeting midstory stratum trees to prevent their resprouting after final harvest. A combination of the shelterwood method with site preparation to control understory competition and allow oak to grow before complete overstory removal was also proposed (Johnson and others 1989). Essentially this work evolved into the two-phase shelterwood prescription, in which 20 percent of the basal area is reduced from below using herbicides 10 years prior to final harvest, to enhance growth of oak over other woody competitors (Dey 1996, Kass and Boyette 1998, Loftis 1990a, Lorimer and others 1994, Parker and Dey 2008, Schlesinger and others 1993, Schuler and Miller 1995).

Recruiting oak in the regeneration process has become the focus of much oak-hardwood silviculture. In upland hardwood systems in the eastern United States, there remains sufficient seed source (sexually mature oak trees) to provide seed for germination and establishment. The challenge now is to introduce a series of disturbances that will favor environmental conditions, especially light, conducive to oak growth response, over competing trees. This is essentially the shelterwood prescription touted to regenerate oaks that is still under examination today (Brose and others 2008; Craig and others 2014; Hutchinson and others 2016; Janzen and Hodges 1987; Lockhart and others 2000; Loftis 1990b; Miller and others 2014, 2017; Parrott and others 2012; Schweitzer and Dey 2011, 2017) and that was first proposed by Leffelman and Hawley (1925) and Korstian (1927).

I examined the implementation of the midstory herbicide as the first phase in a two-phase shelterwood in upland hardwood stands in Alabama, Tennessee, and Kentucky. The initial prescription for all three sites was similar: use herbicide to reduce the density of the midstory, allowing increased light to the established oak reproduction. The goal was to recruit the small oak reproduction into larger sizes classes enhancing their competitive status at the time of residual overstory removal. This paper reviews the initial response of the reproduction for all three sites, gives response following phase II for the Alabama sites, and details changes in the prescription for both the Tennessee and Kentucky sites based on preliminary results.

SITES AND METHODS

All three study locations were within the Cumberland Plateau section of the Appalachian Plateaus physiographic province (Fenneman 1938), and each site had three to six replications, with stand sizes from 10 to 36 acres. All sites had replicated control stands. The Alabama study was conducted in mature upland hardwood forested sites located at the southern end of the mid-Cumberland Plateau in northeastern Jackson County, AL, on State lands managed by the Alabama Department of Natural Resources and Conservation. The area was classed into the Cliff section of the Cumberland Plateau in the Mixed Mesophytic Forest region by Braun (1950) and the Eastern Broadleaf Forest (Oceanic) province and Northern Cumberland Plateau section by Bailey (1995). The area is characterized by steep slopes dissecting the plateau surface and draining to the Tennessee River. Stands were located on the escarpment between 1,245 and 1,667 feet elevation. Upland oak site index was 75 to 80 feet, and yellow-poplar site index was 100 feet (base age 50 years) (Smalley 1982). Soils are shallow to deep, stony and gravelly loam or clay, well-drained, and formed in colluvium from those on the plateau top (Smalley 1982). Climate of the region is temperate with mild winters and moderately hot summers; mean annual temperature is 55 °F, and mean annual precipitation is 59 inches (Smalley 1982).

The midstory-herbicide shelterwood prescription was implemented in two phases. The phase I goal was to retain 75 percent of the basal area by removing midstory stems. In 2001, the stands were treated using an herbicide (Arsenal®, active ingredient imazapyr) by means of the tree injection technique to deaden the midstory. Rates of application were within the range recommended by the manufacturer. Aqueous solutions were made in the laboratory, and then trees received application via waist-level hatchet wounds using a small, handheld sprayer. One incision was made per 3 inches of diameter, and each incision received approximately 0.15 fluid ounce of solution. Herbicide treatments were completed in autumn 2001, before leaf fall. The goal was to minimize the creation of overstory canopy gaps while removing 25 percent of the basal area in the stand midstory. All injected trees were in lower canopy positions [diameter at breast height (dbh) range of 1.5 to 10.5 inches; average dbh of treated stems was 2.9 inches], reducing the creation of canopy gaps.

Stands on average had 120.6 square feet per acre of basal area and 320 stems per acre for all stems >1.5 inches dbh. Canopies were dominated by oaks (black, northern red, white, and chestnut), yellow-poplar, hickories (*Carya* spp.), and sugar maple (*Acer saccharum* Marsh.), with a lesser proportion of ash (*Fraxinus* spp.) and blackgum (*Nyssa sylvatica* Marsh.) (Schweitzer and Dey 2011). Depending on the site, dogwood (*Cornus florida* L.), sourwood (*Oxydendrum arboreum* DC.), Carolina buckthorn (*Rhamnus caroliniana* Walt.), and eastern redbud (*Cercis canadensis* L.) were common understory species. Herbicide was applied to 202 SPA of trees ≥1.5–10.5 inches dbh. Basal area removed in this treatment was 19.4 square feet per acre, or 16.1 percent of the total. Nine species were targeted in the herbicide treatment. *A. rubrum* L. was the primary species for removal (56 SPA treated), followed by sugar maple (53 SPA treated) and blackgum (40 SPA treated).

Phase II was implemented in 2010 after eight growing seasons. Phase II was the release or final harvest. Merchantable trees, primarily those ≥5.5 inches dbh, were removed through chainsaw felling and grapple skidding (Schweitzer and Dey 2017).

The Tennessee study site was located on the mid-Cumberland Plateau in Grundy County, in southern Tennessee, on private timber industry lands managed by Stevenson Land Company. The elevation of the site is approximately 1,279–1,804 feet above sea level. The site is just east of the Eastern Highland rim in a true plateau with strongly dissected margins (Smalley 1982), and in the Cliff section of Mixed Mesophytic Forest region (Braun 1950). The site index is 75–80 feet for upland oak and 100 feet for yellow-poplar (Smalley 1982). Soil is deep and well drained, consisting of 30–75 percent rocky slopes on the escarpment and classified as Bouldin series, a stony loam formed in colluviums weathered from interbedded sandstone, siltstone, and shale (U.S. Department of Agriculture Natural Resources Conservation Service 2007). The climate is characterized by long, hot summers while winters are mild and short (Smalley 1982). The average date of last freeze is in mid-April, and the average date of the first freeze occurs in mid- to late October. The annual precipitation average is approximately 50 inches.

Midstory trees (1.0–11.0 inches dbh) were deadened using a triclopyr herbicide solution (Garlon® 3A) injected using the hack and squirt method. Rates and application instructions were as described by the label: the herbicide was diluted with water and applied at 0.03 ounce (1 ml) per cut, with one cut per inch of diameter. The initial treatment in 2008 did not kill targeted midstory trees and was successfully reapplied in the fall/winter of 2009. Small stems (1.0–1.5 inches dbh) were severed or scraped with a hatchet and the cut surface treated.

The dominant overstory trees at the site include yellow-poplar, sugar maple, white oak, pignut hickory (*Carya glabra* Sweet), and northern red oak (Cantrell and others 2013). The stands on average had a basal area of 119.7 square feet per acre and a density of 306 SPA (trees >1.5 inches dbh). Herbicided trees totaled 207 SPA, averaging 3.6 inches dbh. After treatment, there were 182 residual SPA; deadened basal area totaled 12.3 square feet per acre. The majority of the treated trees were sugar maple (89 SPA), followed by 8 SPA of blackgum, 5 SPA of red maple, and 5 SPA of basswood (*Tilia glabra* Vent.). Remaining treated stems (2 or 3 SPA) were beech (*Fagus grandifolia* Ehrh.), black locust (*Robinia pseudoacacia* L.), eastern red bud, flowering dogwood, pignut hickory, red hickory (*C. ovalis* Sarg.), sassafras [*Sassafras albidum* (Nutt.) Nees.], and red maple.

The Kentucky study area is located on the Cold Hill Area of the London Ranger District of the Daniel Boone National Forest (DBNF), under federal jurisdiction. The treatment stands are described by Smalley (1986) as the Rugged Eastern Area of the Northern Cumberland Plateau, with mixed oak and oak-hickory forest communities mingled with mixed mesophytic forests (Braun 1950). All treatment stands were located on broad ridges. Soils on the study sites are predominantly silt loams belonging to the Latham, Shelocta, and Whitley soil series (Smalley 1986). Site indices for upland oaks are 50–65 feet on subxeric sites (McNab and others 2002, Smalley 1986). Treatment stands were relatively similar prior to treatment and uniform within stand boundaries, and are best described as upland hardwood forests dominated by oak species. The stands have been subjected to various silvicultural treatments, including harvesting and prescribed burning, since the National Forest acquired the land, but the stands are representative of fully stocked upland hardwood forests on the Cumberland Plateau.

An herbicide was used to remove the midstory, with treatment applied between October 2008 and March 2009. Undesirable tree species <3 inches dbh were treated with a thin line basal bark treatment using triclopyr ester (Garlon® 4). Trees >3 inches dbh in the midstories and understories were treated with a stem injection method using triclopyr amine (Garlon® 3A). Application rates followed labeling directions.

The forest type on the study sites predominantly comprised white oak, scarlet oak, black oak, and red maple. For all stems with dbh ≥1.5 inches, basal area changed from 100.0 square feet per acre pretreatment to 85.8 square feet per acre posttreatment, and SPA changed from 333 pretreatment to 139 posttreatment. We herbicide-treated, on average, 176 SPA that had an average dbh of 3.0 inches and a range of dbh of 1.6 to 9.1 inches. Of the 176 SPA treated with herbicide, 106 were red maple, 13 were yellow-poplar, and the rest included blackgum, sourwood, sassafras, bigleaf magnolia (*Magnolia macrophylla* Michx.), and serviceberry [*Amelanchier aborea* (Michx. f. Fern.)]. The residual stands comprised primarily oaks, hickories, and red maple, with a lesser component of shortleaf pine (*Pinus echinata* Mill.), yellow-poplar, sourwood, and flowering dogwood (Schweitzer and others 2011).

Field Techniques

Prior to treatment, measurement plots were systematically located in each treatment area. Plot centers were permanently marked with a 2-foot piece of reinforcing steel, and GPS coordinates were recorded. Using the plot center, all trees were monumented (distance and azimuth measured and recorded from plot center, each tree tagged with a numbered aluminum tag) and species and dbh recorded. Each site differed slightly with regard to overstory and midstory survey plot size, but all plots were fixed radius circular plots. The Alabama site had concentric plots of 0.2 acre for overstory (>5.6 inches dbh) and 0.025 acre for midstory (≥1.5 inches dbh). The Tennessee site's overstory plots were 0.125 acre and midstory plots were 0.02 acre; plots were also concentric. The Kentucky site used one 0.1-acre plot for both overstory and midstory trees. For the reproduction, all woody vegetation was sampled on 0.01-acre circular plots, located at plot center for Alabama and Tennessee sites, and offset 14 feet from plot center in Kentucky. All reproduction was tallied by species by 1-foot height classes up to 4.5 feet tall; large seedlings were recorded as those >4.5 feet tall up to 1.5 inches dbh. Trees >1.5 inches dbh were tallied by diameter. Reproduction tallies were truncated at 25 for each species on each plot.

To determine how much of full sunlight was penetrating the canopy and reaching the seedling layer through the residual stand structure, I measured photosynthetically active radiation (μmol m^{-2}s^{-1}) in the understory and compared those values to measurements taken simultaneously in full sunlight. I used two AccuPar Linear Par Ceptometers, Model PAR-80 (Decagon Devices Inc., Pullman, WA). Measurements with one ceptometer were taken at 4.5 feet above the forest floor at each plot center and along transects equally dissecting each plot. Measurements with the second ceptometer were taken in completely open conditions adjacent to each stand. By matching two simultaneous readings, I could take into account some variation caused by changes in cloud cover. Canopy cover was estimated using a hand-held spherical densitometer, with five measurements obtained at each plot, one 10 feet from plot center in each cardinal direction and one at plot center.

RESULTS

Canopy Cover and Understory Light

Canopy cover for the Alabama site was 99.8 percent pretreatment, and slowly declined to 94.0 percent eight growing seasons posttreatment (fig. 1). The percent of full sunlight reaching the forest floor was not measured pretreatment for this site; however, in the first two growing seasons posttreatment, the measured light was 16.7 and 17.1 percent, compared to 8 and 6.4 percent for control stands. By the third growing season, understory light was 6.2 percent, and ranged from 6.2 to 10.0 percent during the next 5 years of measurement. These same trends, with an initial but ephemeral increase in light coupled with a slight decrease in canopy cover, were also found for the Tennessee and Kentucky sites (fig. 1). Light measurements on the Kentucky site for the control stands showed that light was <5 percent of full ambient light under these closed canopies (Grayson and others 2012).

Reproduction Composition and Structure

On the Alabama site, the reproduction cohort had 32 species and averaged 9,214 SPA (table 1). Seventy-six percent of the stems were ≤1 foot tall, 19 percent were >1 foot to 4.5 feet tall, and 4 percent were >4.5 feet tall-1.5 inches dbh. For all reproduction sizes, 22.1 percent were sugar maple, 19.5 percent were oaks [black, chinkapin (*Q. muehlenbergii* Englem.), chestnut, northern red, white], 9.4 percent were red maple, 4 percent were hickories [mockernut (*C. tomentosa* Nutt.), red, shagbark (*C. ovata* K. Koch.)], 2.9 percent were ash, and 1 percent were yellow-poplar. The 46 percent of species in the other category included future canopy species such as beech, blackgum, cucumber tree (*M. acuminata* L.),

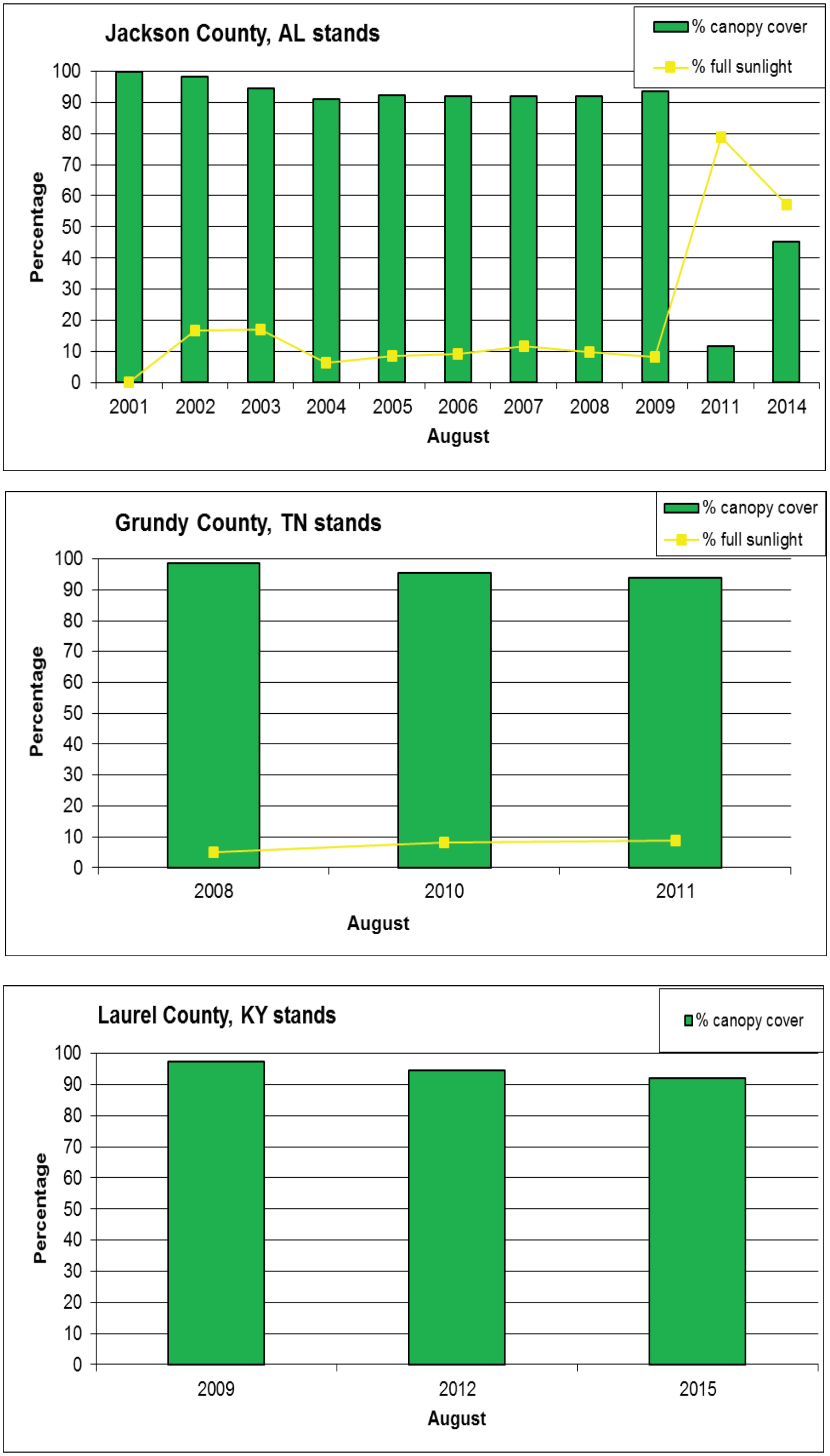

Figure 1—Percent canopy cover and understory light measured in August for three sites subjected to a midstory herbicide shelterwood treatment; no light was recorded for the Kentucky site. The first bar for each graph represents pretreatment levels.

Table 1—Stems per acre of reproduction by species and size class for pretreatment (pre) and 5 years following a midstory herbicide shelterwood treatment (post) for stands in Jackson County, AL

	<1 ft		1–4.5 ft		4.5 ft–1.5 in dbh		Total	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
All spp.	7,038	6,319	1,776	3,352	400	729	9,214	10,400
Oak spp.	1,524	748	29	105	0	0	1,552	852
Yellow-poplar	52	943	14	524	0	43	67	1,510
Ash	181	724	33	119	14	10	229	852
Hickory spp.	333	295	24	24	5	5	362	324
Sugar maple	1,486	1,495	290	429	110	133	1,886	2,057
Red maple	805	881	52	138	10	10	867	1,029
Other spp.	2,657	1,233	1,333	2,014	262	529	4,252	3,776

sassafras, and sourwood, and midstory stratum species including blackhaw (*Viburnum prunifolium* L.), Carolina buckthorn, eastern hophornbeam (*Ostrya virginiana* K. Koch.), eastern redbud, flowering dogwood, *Viburnum* species, and *Vaccinium* species. These species dominated all size classes and were 65–78 percent of the >1-foot tallies. Pretreatment oaks were 1,524 SPA, and 21.7 percent of these oaks were in the <1-foot-tall height class. There were 29 SPA of oak in the >1-foot to ≤2-feet size class, and none in any other size class. On the Alabama sites, sugar maple reproduction was prevalent in all size classes, with 1,486 SPA in the <1-foot size class, 290 SPA in the >1-foot to 4.5-feet class, and 110 SPA >4.5 feet tall up to 1.5 inches dbh (table 1).

After five growing seasons post-midstory herbicide, the shift in the reproduction cohort was pronounced, and for most species there was recruitment into larger size classes (table 1). Yellow-poplar had the largest increase of 1,443 SPA, representing a 13 percent change in the proportion of the total density. All size classes of yellow-poplar accrued seedlings and represented 14.5 percent of the regeneration cohort. Ash seedlings also increased to 8.2 percent of the cohort, and SPA increased in all size classes. Sugar maple seedlings continued to comprise a significant component of the seedling pool, representing 9.8 percent of the total seedling density and 18 percent of the largest size class. Sugar maple seedlings in the >3–4.5-feet size class declined by 33 SPA, as these stems recruited into the next and largest size class, which increased from 110 to 133 SPA. Oak seedling densities declined by 700 SPA; the majority of this loss was in the <1-foot-tall size class, and there was recruitment of oak into the >1-foot to ≤2-feet and >2-feet to ≤3-feet size classes. No oak recruited into the largest size class.

Phase II on the Alabama site was implemented in 2010 after eight growing seasons. Phase II was the release or final harvest. Merchantable trees, primarily those ≥5.5 inches dbh, were removed through chainsaw felling and grapple skidding. After the harvest, the stands had 14.5 square feet per acre of basal area and 19 SPA. Four years after the final harvest, the species composition of larger stems in the stands was scant; only two species, eastern redbud and ash, provided any structure for stems >1.5 inches. The species of residual stems after the final harvest were red hickory, beech, ash, black cherry (*Prunus serotina* Ehrh.), and black locust. The red hickory was the largest diameter tallied at 11.5 inches dbh; the other stems were all ≤4.0 inches dbh. Four years after the final harvest, total oak densities were 914 SPA. Thirty-three percent of total oak stems were in the largest size class, which represented a change from none before treatment to 300 SPA following four growing seasons after the final harvest. In 2014, yellow-poplar had the greatest number of SPA in the largest seedling size class at 995 SPA. In 2009, just prior to overstory removal, there were 500 SPA of yellow-poplar, with a gradient of stems across the seedling size classes; 42 percent were in the ≤1-foot-tall size class, 37 percent were >1 foot to ≤2 feet tall, 12 percent were >2 feet to ≤3 feet tall, and 9 percent were >3 feet to ≤1.5 inches dbh. In 2014, we found no differences for yellow-poplar tallies between the midstory shelterwood treatment and the clearcut (cut in 2010 also). In the clearcut, 75 percent of the total 2,376 SPA of yellow-poplar were in the largest seedling size class, and in shelterwood, 50 percent of the 1,986 SPA were in the largest size class (Schweitzer and Dey 2017).

Reproduction species richness for the Tennessee location included 41 species; oaks included black, chinkapin, chestnut, northern red, scarlet, and white oak. Hickories included bitternut (*C. cordiformis* K. Koch.), pignut, red, shagbark, and mockernut, and the site had similar ‘other’ canopy species and midstory species to the Alabama site. The reproduction in the

Tennessee stands was dominated by sugar maple, which represented 29.9 percent of the cohort. Sugar maple densities were 2,639 SPA, with 1,291 <1 foot tall, 437 ≥1 foot tall to 4.5 feet tall, and 369 SPA 4.5 feet tall to 1.5 inches dbh (table 2). There were few stems in the larger size classes of any other species except those grouped in the other category. Ash seedling densities totaled 1,007, with the majority in the smallest size class (863 SPA), 134 SPA >1 foot to 4.5 feet tall, and 10 SPA in the largest size class. Oaks were greatest in the smallest size class at 646 SPA, with 60 SPA >1 foot to ≤3 feet tall. There were no oaks in the larger seedling size classes.

After only two growing seasons, the largest change in the portion of total seedling densities by species was for yellow-poplar, which increased 3.1 percent. Yellow-poplar densities increased from 27 to 324 SPA, with the largest increase in the smallest size class (from 3 SPA pretreatment to 297 posttreatment) and a concurrent increase from 5 to 12 SPA in the largest size class (table 2). The reproduction cohort remained dominated by sugar maple, which increased by 1,304 SPA in the smallest size class, but decreased by 259 SPA in the largest size class. Oak total seedling densities declined from 706 to 608 SPA; however only the smallest sizes declined, with recruitment of these stems into larger size classes. Oak seedling classes >3 feet to 4.5 feet tall and 4.5 feet-1.5 inches dbh each had 3 SPA accrual.

Stands on the DBNF in Kentucky had 38 species tallied in the understory, with 6 oaks [white, scarlet, southern red (*Q. falcata* Michx.), chestnut, northern red, and black] and 2 hickories (pignut and mockernut). The regeneration cohort was dominated by red maple (3,957 SPA, 31.2 percent of the total) and oaks (2,753 SPA, 21.5 percent of the total). Red maple seedlings were dominant across all size classes (table 3). Oak

Table 2—Stems per acre of reproduction by species and size class for pretreatment (pre) and 2 years following a midstory herbicide shelterwood treatment (post) for stands in Grundy County, TN

	<1 ft		1–4.5 ft		4.5 ft-1.5 in dbh		Total	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
All spp.	4,798	5,860	1,642	2,953	633	359	7,027	9,172
Oak spp.	646	543	60	62	0	3	706	608
Yellow-poplar	3	297	18	15	5	12	27	324
Ash	863	1,027	134	220	10	22	1,007	1,269
Hickory spp.	426	554	50	65	2	2	478	621
Sugar maple	1,291	1,595	438	1,189	369	110	2,098	2,894
Red maple	140	180	60	167	2	0	202	347
Other spp.	1,428	1,663	965	1,234	245	210	2,639	3,108

Table 3—Stems per acre of reproduction by species and size class for pretreatment (pre) and 5 years following a midstory herbicide shelterwood treatment (post) for stands in Laurel County, TN

	<1 ft		1–4.5 ft		4.5 ft–1.5 in dbh		Total	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
All spp.	7,973	17,060	3,633	0	1,080	2,428	12,687	26,111
Oak spp.	2,077	2,821	613	556	43	163	2,733	4,179
Yellow-poplar	200	77	120	3,260	67	117	387	256
Ash	27	17	13	63	3	10	43	47
Hickory spp.	467	456	447	20	120	220	1,033	1,232
Sugar maple	0	0	0	1,528	0	0	0	0
Red maple	2,187	11,245	1,277	0	493	1,375	3,957	15,881
Other spp.	3,017	2,444	1,163	6,623	353	543	4,533	4,515

seedlings were highest in the smallest size class (2,077 SPA), but oaks were well distributed across all seedling size classes, and there were 614 SPA of oaks >1 foot to 4.5 feet tall and 43 SPA in the largest size class. Hickory reproduction was 8 percent of the cohort, with seedlings distributed among all size classes. Ash seedlings were scant and small, and there was no sugar maple on this site.

After five growing seasons, red maple seedlings increased by 29.6 percent, with an increase of 882 SPA in the largest size class. Red maple seedlings dominated all size classes and doubled or more in their densities in each size class (table 3). The remaining non-oak and oak groups also increased (table 3). Oaks increased across all size classes, and recruitment of oak into the largest seedling sizes was 120 SPA, resulting in a total of 163 SPA of large oak seedlings; the next largest size, >3 feet to 4.5 feet tall, also increased, from 37 to 180 SPA. Yellow-poplar seedling densities declined across all sizes, and hickories increased across all sizes, with the greatest increase for hickories in the largest seedling sizes.

DISCUSSION

The midstory oak shelterwood prescription is predicated on altering light in the understory to create conditions more conducive to oak growth and subsequent recruitment into larger seedling size classes over other co-occurring species. For most stands, where oak remains in the overstory, oak reproduction exists, although it is small in stature and low in density. Because sites differ greatly in their understory species composition, primarily due to inherent site characteristics and past stand disturbance regimes, the response of the oak, coupled with the concurrent response of competing woody vegetation, will differ. Oak is easier to regenerate on xeric than mesic sites (Carvell and Tryon 1961, Weitzman and Trimble 1957), and the range of light conditions favorable to oak seedling growth is narrower on mesic sites (Hodges and Gardiner 1993).

It has been well-established that light is the primary driver in the oak recruitment conundrum, and that an increase in understory light up to at least 20 percent of full sunlight is imperative. This is the minimum level and was a goal for these studies because of the concern over stimulating yellow-poplar with any increase in light. Kramer and Decker (1944) and Ferrell (1953) were early reporters of the need to increase light in the understory to promote oak; their collective recommendations were to increase light up to one-third of full sunlight. Suggestions to increase light during the last years of rotation were made by Downs and McQuilken (1944), Weitzman and Trimble (1957), Scholz and DeVriend (1957), Tryon and Carvell (1958), and McGee (1975). Light availability in studies of midstory removal at phase I of a shelterwood prescription have been reported at 10–20 percent of full sun (Dey and others 2012, Lhotka and Loewenstein 2009, Lorimer and others 1994, Miller and others 2004, Schweitzer and Dey 2011). Gottschalk (1985) identified the optimal range of light to grow understory oak at 40-percent reduction of basal area with an increased understory light of 20 percent, with a caveat of caution that the use of a midstory shelterwood was not promising to favor oak over black cherry and red maple. Ostrom and Loewenstein (2006) removed the midstory in a mesic Piedmont forest in Georgia and found that light only increased to 10 percent of full sunlight, and midstory removal in a bottomland hardwood forest in Missouri increased light to 15 percent (Motsinger and others 2010). In Kentucky, understory light evaluated immediately after midstory herbicide treatment was 10 percent of full light, and was 14 percent 7 years later (Parrott and others 2012). Also in Kentucky, a removal of 20 percent of the basal area from below in an upland hardwood stand resulted in an increase of light from 4 to 18.5 percent of full sunlight (Craig and others 2014).

The challenge is altering light enough to stimulate growth, but not so much that shade-intolerant, or other, species respond more favorably than oak. This response is dependent on the species composition and competitive status within each stand.

Deadening the midstory allowed an ephemeral increase in light to the understory. Overstory canopy cover was not changed, but growing space was created in the midstory stratum. On the Alabama site, competition was from shade-intolerant yellow-poplar, which came in as new seedlings, and shade-intolerant sugar maple. The response of yellow-poplar to high light conditions was one driver behind using a midstory shelterwood to promote oak (Beck and Hooper 1986; Loftis 1978, 1983, 1990a). Because the understory sugar maple that was <1.5 inches dbh was not treated, these residual stems took full advantage of the opened growing space and quickly occupied the midstory (Schweitzer and Dey 2015). Hutchinson and others (2016) also found that lack of herbicide treatment for small shade-tolerant species (blackgum and sourwood) resulted in their impediment to oak response. This compensatory increase in the larger size class of sugar maple, or other shade-tolerant species, contributed to the competition for light in the understory. As with Hutchinson and others' study (2016) germination and establishment of yellow-poplar seedlings also occurred, but on the Alabama site by the 9th growing season, they began to decline from a high of 18 percent of the total reproduction cohort to 4 percent. Tolerant sugar maple soon shaded out less tolerant ash and yellow-poplar seedlings (Sander and Williamson 1957) and increased most under heavy crown cover (Hannah 1991). However, there were 40 SPA of large yellow-poplar seedlings at the time of overstory removal. Prior to overstory removal in phase II, there were

250 SPA of sugar maple in the largest size class and only 7 oaks. The competition from both yellow-poplar and sugar maple most likely deterred oak from recruiting into greater numbers into the largest size class (Schweitzer and Dey 2016).

The Tennessee study was implemented after the Alabama site, and the prescription was slightly altered to treat more of the smaller understory sugar maple. Tweaking the prescription to target the smaller sugar maple (1–3 inches dbh) may facilitate a less transient light response as these trees would be removed and thus unable to occupy any newly created growing space. On productive sites, however, caution is needed as this may enhance germination and growth of yellow-poplar. On these productive sites, light levels in the understory may not be high enough to sustain the yellow-poplar, but their competitiveness under these conditions must be considered. Although the increase in understory light was small, recruitment into larger size classes was found for all species, and sugar maple once again dominated the reproduction cohort. This dense population of sugar maple will essentially shade the understory and prevent the recruitment of oak into larger sizes.

In Kentucky, the sites were slightly different, located more on xeric, broad ridges. These sites had the greatest potential for recruiting oak because of lower site quality (Carvell and Tryon 1961) and high densities of oak reproduction. The treatment did not increase light above a threshold 20 percent of full sunlight level (Grayson and others 2012). However, there was an increase in the density and proportion of larger seedlings for oak, hickory, and red maple. Other studies on similar sites in Kentucky have found that red maple can be competitive with oaks after some disturbance (Arthur and others 1997, Lhotka 2012, Tift and Fajvan 1999), and Parrott and others (2012) found red maple comprised 57 percent of the reproduction stems and were most abundant in larger size classes 7 years after a midstory treatment. In order to maintain the stocking of oak, the Kentucky study stands will receive a site preparation herbicide treatment prior to overstory removal (Clatterbuck and Armel 2011, Hutchinson and others 2016). A shelterwood with reserves regeneration harvest retaining 10 to 15 square feet per acre basal area is scheduled for phase II. Pre-harvest site preparation via herbicide treatment of the red maple stems will be implemented 2 years prior to the harvest. Herbicide (imazapyr) will be applied to the cut surface of red maple stems using a backpack sprayer or spray bottles.

CONCLUSION

Regeneration success cannot be determined until after the parent stand has been removed. Under most stand conditions, oak reproduction lacks adequacy in size and number, and intense manipulation will be required to recruit oak into larger size classes and promote the highest probability of retaining oak dominance in the next stand. Competition and differential growth rates among species in mixed species stands drive future stand composition. The theory of shade tolerance predicts that growth of species with differing tolerances must intersect at some point of moderate light intensity. The midstory shelterwood prescription using herbicide to deaden midstory trees is predicated on finding this optimal point. Removing trees from the lower (mid) canopy layers as the first phase will provide favorable light conditions to grow and recruit oak into larger sizes. Timing this treatment with a good acorn crop increases the potential for recruitment. Consideration of lingering small shade-tolerant species must be done and if a threat of their recruitment is present, those small stems should be also be treated along with midstory stems. Depending on site conditions and species composition, a 5- to 10-year growth response period should be allowed, reproduction status assessed, and a cleaning of undesirable stems performed if warranted. The number and size of desirable oak stems are dependent on site and ownership goals, but error given towards larger and more being better. A final overstory removal to release oak is imperative to complete the process.

ACKNOWLEDGMENTS

This work was made possible through partnerships and many devoted people, including Ryan Sisk and Matt Zirbel with the Southern Research Station, Greg Janzen with the Stevenson Land Company, and Robbie Sitzlar and Paul Finke with the National Forest System. Thanks to Kyle Cunningham and Brian Lockhart for their considerate review comments.

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EFFECTIVENESS OF HERBICIDE AND FIRE TO FAVOR OAK REGENERATION IN OHIO SHELTERWOOD STANDS

Todd F. Hutchinson and Joanne Rebbeck

Extended abstract—Poor oak regeneration is a major problem throughout much of the Central Hardwoods region, as shade-tolerant species have become abundant in the midstory and understory of mature oak stands. Low light levels reduce the survival of oak seedlings and prevent the accumulation of larger oak advance reproduction. To address this issue, we initiated a study in southern Ohio to document the response of oak and other tree regeneration to shelterwood harvest, herbicide, and prescribed fire.

Four study sites were established in 2005, each with four 20-acre treatment units. Among sites, tree basal area averaged 96–126 square feet per acre, of which 74–85 percent was oak-hickory. The entire area of each site received a commercial shelterwood cut (50 percent BA reduction) in 2005 or 2006. The treatments were 1) Control (C), 2) Herbicide (H), 3) Burn (B) and 4) Herbicide + Burn (HB). The H treatment was an autumn stem-injection of all non-oak-hickory trees >2 inches DBH with glyphosate (54 percent active ingredient), prior to the shelterwood harvest (SWH). Burns were conducted in early April in 2012 or 2013, 5 to 7 years after SWH; flame lengths were mostly 1–3 feet in length.

Twelve plots (25.4 feet radius) were established per treatment unit to sample vegetation. Pretreatment tree regeneration (large seedlings 1 to 4.4 feet tall and saplings 4.5 feet tall to 3.9-inches DBH) was sampled in 2005 (year 0). Regeneration (saplings only) was recorded again in 2010 (year 5), 4 or 5 years after the SWH. Finally, saplings were sampled in 2015 (year 10), 9 or 10 years after the SWH and 3 or 4 years after the burns. Species were classified into five groups that made up >97 percent of stems: 1) oak-hickory, 2) sassafras, 3) red maple, 4) other-tolerant (all other shade-tolerant species, of which blackgum and sourwood were most abundant), and 5) poplar-aspen-cherry (yellow-poplar, bigtooth aspen, black cherry, shade-intolerant species that established from seed after SWH).

In year 0 (pre-treatment), red maple and other-tolerants made up 88 percent of the 630 saplings per acre. Among large seedlings, the most abundant species/group was sassafras (31 percent of stems), followed by oak-hickory (23 percent), other-tolerants (22 percent), and red maple (21 percent).

After the SWH, sprouts from stumps >3 inches basal diameter of non-oak-hickory trees were abundant in units not treated with herbicide; red maple occurred at the greatest densities, followed by blackgum and sourwood. The herbicide greatly reduced the density of stump sprouts of the treated species, with the exception of red maple. Stump sprouts of treated species other than red maple were 83 percent less abundant in treated units, while red maple density was only 38 percent lower on herbicide-treated units.

By year 5, a dense sapling layer, averaging 2811 stems per acre, had developed. Across treatments, the most abundant group was poplar-aspen-cherry (26 percent of saplings), followed by other-tolerant (23 percent), red maple (22 percent), oak-hickory (19 percent), and sassafras (9 percent) (fig. 1). Analyses showed no significant herbicide effect on the relative abundance of regeneration for any group (Hutchinson and others 2016). The relative abundance of oak-hickory, red maple, and other-tolerants did not change significantly from year 0 to year 5; i.e., there was also no “harvest” effect on relative abundance. There was, however, a significant increase of poplar-aspen-cherry and a significant decrease in sassafras.

One year prior to the prescribed fires, a subset of saplings (oak-hickory, red maple, blackgum, yellow-poplar, sassafras) were tagged in order to quantify rates of mortality after fire. Nearly all stems were topkilled, but all species had very low mortality rates (<10 percent) after fire with the exception of yellow-poplar, for which 53 percent of topkilled saplings failed to resprout.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

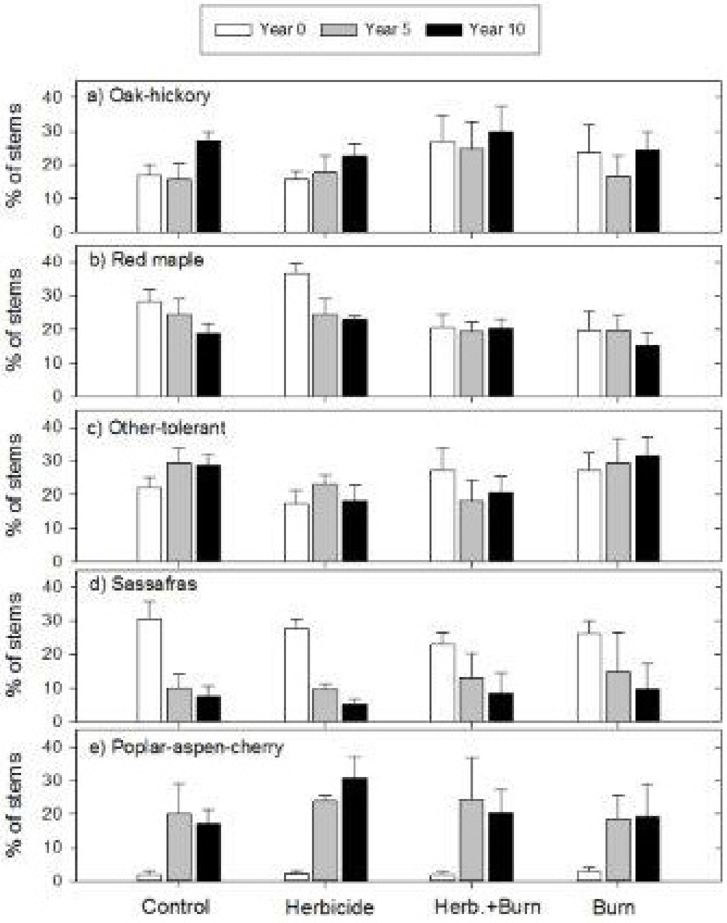

Figure 1—Mean (± 1 standard error) relative abundance of tree regeneration for species/groups in years 1, 5, and 10, among four treatments in Ohio shelterwood stands. Note: the Control treatment was a shelterwood harvest with no additional treatment.

By year 10, 3 or 4 years after the burns, mean sapling density across treatments had increased to 4288 stems per acre. On the B and HB treatments, the relative abundance of species/groups showed very minor changes after fire (fig. 1). Surprisingly, this was true even for the poplar-aspen-cherry group, in which we documented greater rates of post-burn mortality for yellow-poplar. The average relative abundance of oak-hickory in the sapling layer in year 10 was quite similar among treatments, ranging from 23 percent on H to 30 percent on HB; oak-hickory exhibited modest increases in relative abundance on all treatments from year 5 to year 10.

Our results indicate that the relative abundance of oak-hickory regeneration changed very little from year 0 to year 10, across all treatments (fig. 1). This was also the case for red maple and the other-tolerant group. By contrast, there was a large increase, across all treatments, in the relative abundance of poplar-aspen-cherry, as these species established from seed and grew rapidly after the SWH. There was a concomitant decrease in sassafras in all treatments after the SWH.

Why were the impacts of the herbicide and prescribed fire treatments, which were designed to favor oak-hickory regeneration, so limited in this study? Two factors limited the effects of herbicide. First, prior to treatment, all stands had high densities of shade-tolerant saplings that were below the 2.5 inches DBH threshold for herbicide treatment. These cut or damaged untreated saplings sprouted prolifically after the SWH. Second, glyphosate was not very effective on red maple, which was the most abundant species in the midstory. With regard to fire, it appeared that two factors limited its effectiveness to favor oak-hickory. First, the study plan proposed to conduct spring growing-season burns, which have been shown to greatly favor oaks over competitors that leaf out earlier. However, we were unable to conduct growing season burns because of Ohio regulations related to state-endangered animal species. Second, the prescribed fires were likely conducted too long (5–7 years) after the SWH. By that time, the non-oak saplings were large and resprouted vigorously, as did the oak-hickory saplings, after being topkilled in the dormant-season burns.

These preliminary results suggest that oak-hickory will remain a significant component of these stands, but with much reduced dominance in the future. In hindsight, a more gradual approach of reducing stand density to develop competitive oak regeneration, via a non-commercial preparatory cut or prescribed fire, prior to the heavy SWH, would be more likely to increase the competitive position of oak-hickory regeneration after the SHW.

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Hutchinson, T.F.; Rebbeck, J.; Stout, S. 2016. The devil is in the small dense saplings: A midstory herbicide treatment has limited effects on short-term regeneration outcomes in oak shelterwood stands. Forest Ecology and Management. 372: 189-198.

APPLICATION OF MIDSTORY REMOVAL TO ENHANCE OAK REGENERATION POTENTIAL WITHIN UNIFORM AND IRREGULAR SHELTERWOOD SYSTEMS

John M. Lhotka, Jeffrey W. Stringer, Jared M. Craig, and Clinton P. Patterson

Extended abstract—Shelterwoods are recommended in the Central Hardwood Forest Region (CHFR) due to the intermediate shade tolerance and advance reproduction dependence of the region's primary oak (*Quercus*) species. Due to the widespread development of subordinate canopies dominated by shade-tolerant species, midstory removal is a typical component of oak shelterwood systems within the CHFR. This work presents the effect of midstory removal on light availability and seedling development when applied following uniform and expanding-gap shelterwoods. Leveraged studies were completed on the Berea College Forest (Madison County, KY) and occurred on intermediate quality sites (upland oak site index ranged from 22 to 24 m) associated with the western edge of the Northern Cumberland Plateau ecological section.

The first study documented the effect of midstory removal on the survival and growth of natural advance reproduction and underplanted white oak (*Quercus alba* L.), northern red oak (*Quercus rubra* L.), and black oak (*Quercus velutina* Lam.) (Craig and others 2014). The response of the predominant shade-tolerant competitor, red maple (*Acer rubrum* L.), was also evaluated. After six growing seasons, relative height and groundline diameter (GLD) growth of all oak species were significantly greater in the midstory removal treatment than in the control but did not differ between reproduction types. Survival of oak advance reproduction was high (>96 percent) and was not affected by midstory removal. However, underplanted oaks had significantly lower survival (47–70 percent) than the oak advance reproduction. While midstory removal significantly increased six-year relative height growth of red maple, the treatment did not affect red maple's relative GLD growth or percent survival. Six-year total height of red maple was similar to all but one of the oak reproduction types evaluated; only natural white oak reproduction was significantly shorter than red maple in the midstory removal treatment. In addition to quantifying seedling responses, we found that the midstory removal treatment altered canopy structure by maintaining a greater height to the forest canopy and a lower canopy closure than the control six years after treatment. Understory light data collected in the seventh growing season showed that average light transmittance in the control and midstory removal treatments were 2.9 percent and 18.5 percent of full sunlight, respectively. While the mean light transmittance value was more than five times greater following midstory removal, no significant difference was present between treatments (*P-value* = 0.055).

The second study examined an expanding-gap shelterwood with and without midstory removal as a preparatory cutting around the silvicultural gaps (Patterson 2017). The study incorporated 12 experimental units established in the spring of 2012 and consisting of a 60-m diameter gap plus a 30-m perimeter zone; forming a 120-m diameter "gap array." The experimental units were randomly assigned two treatments: gap harvest with complete midstory removal in the perimeter zone around a gap, and gap harvest with undisturbed control around the perimeter of the gap. Six transects were laid out like spokes on a wheel within each gap array for the purpose of recording light transmittance and seedling development along the spatial extent that extended from the gap edge to the outer margin of the gap array. Light transmittance was measured during summer 2013 within two hours of solar noon on cloudless days. GLD measurements of the underplanted white oak seedlings were recorded initially in spring 2013 and were remeasured after two growing seasons. Light transmittance and underplanted seedling data collected within the 30-m wide zone around the perimeter of each gap were aggregated into five, 6-m distance from gap edge categories for analysis. Effects of the two experimental factors, midstory removal treatment and distance from gap edge, on light transmittance and seedling GLD growth was tested using an ANOVA model. Second year results from this gap-based study indicated that midstory removal treatment and the distance relative to gap edge affected understory light availability and GLD growth of underplanted oak. Light transmittance was significantly higher (*P-value* = 0.005) in the midstory removal treatment (15.4 percent) than

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

in the control (10.5 percent). Light transmittance directly adjacent to the gap (i.e., 0- to 6-m distance category) was nearly twice as high (25.6 percent) as transmittance in the other four distance categories (6.3 percent to 13.7 percent) occurring further away from the gap edge. Two-year GLD growth by underplanted white oak was significantly higher (p = 0.012) in the midstory removal treatment (1.0 mm) than in the control (0.8 mm). Mean GLD growth was significantly greater within the 0- to 6-m distance category (1.2 mm) than it was in distance categories occurring more than 12 m from the gap edge.

Together these studies support midstory removal as a silvicultural approach for oak whether the shelterwood is applied uniformly across a stand or implemented using principles of gap-based silviculture to increase structural complexity and microclimate heterogeneity. Midstory removal enhanced light availability primarily by increasing canopy heights and improved growth of natural and underplanted oaks, though the practice was also shown to increase height growth of shade-tolerant competitors. Data suggest that light availability may be greater following midstory removal in the gap-edge environment than following the treatment in a uniform shelterwood. While midstory removal enhanced light and seedling growth beyond gap margins, it did not appear to increase the spatial extent of a gap's influence on edge environment.

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General Session

Moderator:

Thomas Schuler

USDA Forest Service, Northern Research Station

PRESCRIBED FIRE EFFECTS ON WILDLIFE IN EASTERN OAK ECOSYSTEMS

Craig A. Harper, W. Mark Ford, Marcus A. Lashley,
Christopher E. Moorman, and Michael C. Stambaugh

Extended abstract—Fire is being prescribed and used increasingly in eastern oak ecosystems to promote open forest conditions (e.g., oak woodlands and savannas) that enhance habitat for wildlife (Brose and others 2014, Harper and Keyser 2016, USDA Forest Service 2015). Recent research has provided a better understanding of the effects of fire on wildlife in the Central Hardwoods and Appalachian regions. Recently, a comprehensive review summarizing research on fire effects on wildlife in these regions was completed with prescriptive recommendations for burning for various wildlife species and guilds (Harper and others 2016).

Managers sometimes are unclear as to why they are burning. Too often, objectives are ambiguous. Furthermore, motivation to burn is often limited without the ability to predict the values, benefits, and costs. "Burning is good for wildlife" is commonly stated. However, effects of fire vary greatly by fire conditions and among wildlife species, and not all species benefit from fire (Rush and others 2012). The notion that "fire is good for wildlife" is just as false as it is true. Because of the diverse requirements of wildlife species that occur in the region, species of interest should be identified in the management plan to ensure fire is implemented in a way that enhances conditions for focal species. Furthermore, for those species that may benefit from fire, how fire is implemented and the resulting fire effects determine whether and the extent to which fire is beneficial or detrimental. Explicit reasoning for how fire will benefit the species should be articulated.

The primary effects of burning on wildlife are indirect (Smith 2000). Fire alters plant structure and composition, which affect habitat quality through food and cover availability. Indirect effects are influenced by fire frequency, fire intensity, and season of burning. Unless fire intensity is great enough to reduce canopy closure, then additional canopy reduction treatments (mechanical or chemical) that allow a minimum of 20 percent of full sunlight to reach the forest floor will be necessary to realize a meaningful understory vegetation response (McCord and others 2014). Low-intensity fire following regeneration harvests, various thinnings, and improvement cuts can be used to enhance food and cover for wildlife without damaging trees retained in the overstory (Lashley and others 2011). Canopy removal without repeated fire commonly stimulates increased woody stem density, which may be desirable for some species, but not for others (Bakermans and others 2012, Kendrick and others 2015, Semlitsch and others 2009, Vander Yacht and others 2016). Oak savanna and oak woodland restoration efforts typically retain 5–30 percent and 30–80 percent overstory coverage, respectively, and require relatively frequent fire (≤ 3- to 6-year mean fire return interval) to provide habitat for species that require more open structure and maintain groundcover dominated by herbaceous species (Nelson 2005; Stambaugh and others 2016; Vander Yacht and others 2017a, 2017b).

A fire-return interval of 2–6 years in forests with partial canopy cover benefits a variety of wildlife species, depending on site and objectives, by providing diverse understory structure for nesting and cover, and increased browse, forage, insect abundance, and soft mast (Chitwood and others 2017, Greenberg and others 2013, Lashley and others 2011, McCord and others 2014), but see Lashley and others (2017). Within this range of fire frequency, shorter return intervals maintain shorter understory structure with more visibility, whereas longer intervals maintain taller understory structure and less visibility, which can influence use by different wildlife species (Ford and others 2016, Greenberg and others 2013, Lashley and others 2015a).

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

Periodic burning during the early growing season (April–May) has not led to compositional change from periodic burning during the dormant season in the Central Hardwoods and Appalachian regions; woody sprouts continue to dominate response (McCord and others 2014). Burning during the latter portion of the growing season (August–October) provides additional burn days, provides increased heterogeneity of cover, may alter composition with increased forb coverage and reduced woody resprouting, expands availability of high-quality forage, and alleviates concerns with burning during reproductive periods of most wildlife species (Gruchy and others 2009; Harper and others 2016; Lashley and others 2015b; Nanney and others, in press; Weir and Scasta 2017). Regardless, repeated burning over time usually is necessary to affect considerable change in vegetation composition (Knapp and others 2015).

Direct effects of prescribed fire on wildlife (injury/death) are relatively rare and largely associated with timing, intensity, and firing technique (Ford and others 1999, Howey and Roosenburg 2013). In particular, several snake species and eastern box turtles (*Terrapene carolina*) are most vulnerable soon after emerging from hibernacula because they are relatively lethargic at that time. Burning early in the growing season would be least desirable where these animals are of concern (Beaupre and Douglas 2012). Nonetheless, there is no indication that prescribed fire in eastern oak ecosystems is leading to reduced populations of any wildlife species (Greenberg and others 2018a), including taxa of conservation concern, such as Indiana bat (*Myotis sodalis*) or northern long-eared bat (*M. septentrionalis*), which are ESA-listed species. Alternatively, there is indication prescribed fire has enhanced conditions for foraging and roosting for these and other bat species (Johnson and others 2010, Silvis and others 2015, Womack and others 2013). Prescribed fire outside the maternal colony period, May through early August, can be implemented to reduce midstory clutter (improving bat foraging conditions) and create snag availability (provide roost sites) with no direct effects (Austin and others 2018).

Burning consumes leaf litter and leads to relatively dry microsite conditions for several months following fire, which is not favorable for some wildlife, including ovenbird (Seiurus aurocapilla; Rush and others 2012), shrews (Matthews and others 2009), or woodland salamanders (Plethodontidae; O'Donnell and others 2015), but is favorable to other species, including various lizards and snakes (Greenberg and others 2018a, 2018b; Matthews and others 2010), supporting the need to articulate objectives prior to burning. However, when burning is allowed to follow environmental patterns, such as being more frequent on south- and west-facing slopes and less frequent in more mesic and productive sites (where woodland salamanders are concentrated), then concern of negatively impacting salamander populations is alleviated (Moorman and others 2011).

We contend a lack of fire in the Central Hardwoods and Appalachian regions is a limiting factor for increased landscape heterogeneity and biological diversity. The lack of fire-mediated communities limits the abundance of many wildlife species, including at-risk species as well as iconic game species. Applying fire on ecologically appropriate sites and at the appropriate scales will help achieve objectives related to wildlife conservation and ecosystem restoration in these regions.

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EMERGING NEEDS FOR OAK MANAGEMENT AND RESEARCH

Stacy L. Clark, Callie J. Schweitzer, and David Todd

A facilitated audience discussion on emerging needs for oak management and research at the Oak Symposium revealed several interrelated themes. The audience identified needs that fell into three primary categories:

- Applying research;
- Adoption of existing knowledge and technology; and
- Infrastructure/available markets.

Research needs are broad, due to large species' ranges, and specific, due to lack of studies on particular research questions. Extrapolation of research results across multiple geographical ranges is difficult. A single management prescription to regenerate and recruit oak is desired by managers, but is probably unrealistic; however, single prescriptions have been adopted across a wide geographic range. For example, a shelterwood-burn technique (Brose 2010) tested in the Piedmont is currently being applied on many public and some private lands throughout the Eastern United States without concurrent support from research in other areas. Conversely, other research needs (e.g., use of fire, planting, thinning) in the Piedmont is largely lacking. Artificial regeneration research developed in the Ozarks/Boston Mountains (Johnson and others 1986, Spetich and others 2002) has been largely adopted throughout the Eastern United States even though site quality and competition will drastically differ in forests to the east and south. The long-term nature of forestry research further exacerbates difficulties in transferring research results into real-world prescriptions. Rarely do silvicultural studies have results past the stem exclusion stage of forest development.

Specific research gaps exist on relationships between site quality and management. While it is well understood that lower site quality yield better oak regeneration and recruitment (see Chapter 4 Johnson and others 2002), there is a specific lack of research on efficacy of specific management practices across a range of productivity levels (e.g., site index). Oak silviculture should be 'finer-tuned' to identify stands where oaks can dominate, timber returns can be realized, and management inputs to promote oak (e.g., fire, herbicide, planting) do not exceed revenue. In other words, where will managers get the best return on their investment?

A major research need currently exists for growth and yield models in oak stands. Comparisons among existing growth and yield models have not been adequately conducted, and models of ingrowth are virtually non-existent (see Chapter 10 in Johnson and others 2002). The most commonly used growth and yield tables in oak stands are limited to even-aged stands that are normally stocked (i.e., near 100 percent stocking) (Gingrich 1971, Schnur 1937). Model use and validation rely largely on expert knowledge of forest conditions.

Large knowledge gaps exist on prescribed burning in oak stands. Impacts to timber quality and economics from prescribed fire is not well understood. The inherent variability in fire use and behavior restricts research results from specific studies being applied broadly. Studies that capture the full gamut of stand management, species characterization, and fire ecology are largely lacking (but see Iverson and others 2008). Managers need to be able to incorporate knowledge of past stand disturbances, including fire, into silvicultural

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

prescriptions and better understand when and how to apply prescribed burning to meet management and restoration goals.

Perhaps the most difficult aspect of oak research is the transfer and adoption of research results to the field. The most widespread problem is the continual use of high grading or diameter-limit harvesting on private forest lands. Forestry was founded on sound principles to improve tree growth, and thereby tree health, but degradation of forests through high-grading is probably the most widespread ‘management’ technique historically and currently used in eastern hardwood forests (Nyland 1992). A specific question arose as to how to persuade landowners to conduct silvicultural practices that do not include high-grading. The transfer of information on prescribed fire could be used as a model, as this is being conducted somewhat successfully to both public and private landowners using a variety of public-private partnerships, consortia, and State vendor programs.

Lack of available markets for poor quality (i.e., non-commercial) wood products inhibits sound forest management (Nyland 1992). The biofuel market offers one alternative, but this is largely driven by policy (both nationally and internationally) that is not well understood, studied, and is ever changing (Abt and others 2012). Infrastructure for biofuels is currently largely restricted to predominately softwood regions in the South (Abt and others 2014). Current efforts to subsidize alternative wood markets to private industries are underway (USDA 2018). The lag time between policy changes that fund these initiatives and impacts on the ground is a problem for landowners wishing to invest in alternative markets. Pulpwood markets are also not consistently available across the region, and are not subsidized similarly to biofuels.

On public lands, lack of management is negatively affecting habitat conditions for certain wildlife (e.g., golden-winged warbler), forest health, and timber revenue streams. This in turn, leads to loss of infrastructure that further degrade future management operations. For example, reduction in logging operations will lead to loss of available loggers and sawmills, making future timber sales difficult to implement. There is currently more timber lost on national forests from natural mortality than from timber extraction (Hartsell and Connor 2013). Forest certification and Collaborative Forest Landscape Restoration (CFLR) programs may help increase management by engaging participation from private citizens’ groups with the hopes of decreasing litigation (Urgenson and others, 2017).

An additional concern was raised that does not fit into one of the three aforementioned categories. The creation of savannas or woodlands through harvesting or thinning and repeated fire has been an emerging focus for conservationists in recent decades. Multi-purpose management is a goal, but savanna/woodland management itself has been largely framed in a silviculture context (i.e., to promote oak regeneration). Specific habitat creation (e.g., stand structure, vegetation composition of both woody plants and grasses) can also be achieved using standard silviculture practices such as even-aged management and thinning while improving forest health (Clark and Schweitzer 2016). Repeated prescribed burning has been used to promote oak regeneration, but it can also be used to create a specific habitat to meet goals of restoration or improvement of wildlife habitat.

The facilitated discussion with the audience at the Oak Symposium probably served to raise more questions than answers, but specific recommendations did emerge:

- Research should be more refined to specific site productivity levels. A ‘one size fits all’ approach is probably not feasible to regenerate and sustain the oak resource we currently have.
- The lack of subsidies for management and/or diverse and available markets for forest products on private lands is a problem in achieving forest management goals. In particular, the removal of lower quality wood products is a consistent need.
- New markets are emerging for biofuels, but these may not be sustainable as they are dependent on policies that are not necessarily stable.
- Growth and yield models need to be better developed and tested, specifically for ingrowth.
- The lack of management expectations on public lands, particularly Federal lands, could be improved with use of third-party review/forest certification and CFLR programs.
- Forest management to create savannas or woodlands should be focused not just on the regeneration process, but on creation of specific habitat conditions for wildlife or restoration of historical conditions.

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SESSION 3:

Prescribed Fire in Oak Forests

Moderator:

Brian Izbicki

Mississippi State University

PRESCRIBED FIRE, OAK REGENERATION, AND FUTURE FOREST FLAMMABILITY

**Heather D. Alexander, Mary Arthur, Marcus Lashley,
Courtney Siegert, Brian Izbicki, and Emily Babl**

Extended abstract—Prescribed fire is a common management tool applied to upland oak (*Quercus*) forests of the Central Hardwoods and southern Appalachian Regions to promote oak regeneration. Increased use of prescribed fire is largely driven by paleoecological and dendrochonological evidence showing fire and upland oaks co-occurred across the landscape, morphological and physiological traits suggesting oaks are fire-adapted, and increased dominance of shade-tolerant "mesophytes" following fire suppression. To assess whether fire restoration to these forests could improve oak regeneration, we implemented several studies across the region to evaluate the:

1) Impacts of single vs. multiple dormant-season burns on understory light conditions and tree seedling growth and survival;
2) Effects of a period of fire cessation following multiple burns;
3) Interacting role of fire season and mammalian herbivory on re-sprout success of top-killed trees; and
4) Variability in tree bark, canopy, and leaf litter traits that could influence future forest flammability through changes in fuel characteristics.

In two separate studies, we examined the impacts of prescribed fire treatment (unburned, single, and multiple) on oak and mesophyte regeneration. In the first study, we measured regeneration density in response to prescribed fires in areas with and without natural canopy gaps. We found that single fires increased red maple (*Acer rubrum* L.) sapling ($\geq$ 1.5, < 4 m height) density 10-fold, while multiple fires reduced red maple large seedling density ($\geq$ 0.5, < 1.5 m height) and increased white oak (*Quercus alba* L.) large seedling density. However, canopy gaps did not accentuate prescribed fire trends, likely because gaps were too small (111–522 m^2) to substantially alter light, or because they occurred too many years prior to fire treatment. In the second study, we monitored the impacts of prescribed fire on stand structure and composition, canopy cover, and regeneration growth. We found that single and multiple fires did not alter canopy cover, overstory stems, or seedling density. Single fires reduced American beech (*Fagus grandifolia* Ehrh.) saplings approximately 40 percent but had no impacts on red maple and oak species saplings. Seedling growth of all species increased after single and multiple fires; however, prescribed fire failed to improve competitive status of oaks because oak growth was similar to mesophytes.

Our work has also examined the effects of multiple burns after a period of fire cessation. For example, where regeneration was measured 5–7 years after frequent and less frequent burning, there was some indication that oak and hickory (*Carya*) regeneration increased relative to competitors, primarily in the sites burned less frequently. In another study where midstory stems were measured after a fire-free interval of approximately 10 years following sites burned four times, burned treatments had significantly lower red maple relative stem density and increased relative stem density of oaks compared to earlier measurements. In contrast, on sites with continued absence of fire, the relative stem density of midstory (10–20 cm dbh) red maple increased, and relative density of oak stems decreased. These findings support the idea that fire-free periods, and not burning alone, strongly influence the abundance and species composition of tree species regeneration. Significant changes in stand structure and species composition may require time to unfold, as subsequent canopy disturbances differentially impact burned and unburned sites.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

Our research also suggests that matching fire phenology (i.e., timing of burn) with natural fire seasons may be essential to promote oak regeneration indirectly through a shared herbivore. That is, when fires occur during the lightning season (i.e., June), a resource pulse in resprouting vegetation attracts white-tailed deer (*Odocoileus virginiana*) during the extreme nutritional stress of lactation and antler growth. Preliminary results indicate the resource pulse is far greater in magnitude in common mesophytes than oaks, and herbivore preference shifts strongly to mesophytes. Coupling the attraction of deer to recently burned areas with the shift in preference appears to exert strong top-down control of mesophyte regeneration, which may allow oaks to indirectly outcompete mesophytes. Our data indicate that fires in the traditional anthropogenic fire phenology (i.e., March) result in a resource pulse that co-occurs with green-up, a time when high-quality forage is abundant, weakening attraction to the area, the shift in preference, and ultimately, top-down control. In fact, mesophytes obtained the same height with or without deer herbivory following March top-kill, whereas June top-killed trees were twice the height by the end of the growing season when deer were excluded. Two growing seasons after the June top-kill, a majority of regenerating stems either died or were still trapped in the understory by herbivory.

Finally, our research indicates that the presence of mesophytes may reduce the flammability of upland oak forests through their canopy, bark, and leaf litter traits, which may dampen prescribed fire effectiveness as an oak regeneration tool. For example, some mesophytes, such as American beech (*Fagus grandifolia* Ehrh.), red maple, and sugar maple (*Acer saccharum* Marshall.), have greater canopy depth and slower rates of bark thickening as trees reach larger overstory sizes (20–60 cm dbh) compared to oaks, which may allow these trees to reduce understory light and generate more stemflow. Coupled with greater leaf area, American beech also had 30-percent lower understory light levels when compared to chestnut oak (*Q. montana*) and white oak, which may foster the growth of shade-tolerant seedlings in their understory and contribute to a cooler and moister microclimate. We also discovered that mesophytes may alter litter distribution; the understory of American beech, red maple, and sugar maple had 18-percent less oak leaf litter when compared to the understory of upland oaks. Because these mesophytes also have smaller, thinner, and less curly leaf litter with faster decomposition rates, higher proportions of their quickly decomposing, less flammable litter may reduce fuel loads and lead to an overall reduction in flammability.

Thus far, these findings suggest that:
1) Multiple dormant-season burns marginally improve oak regeneration;
2) A fire-free period following multiple burns is needed for oaks to reach competitive size classes;
3) Growing-season burns may enhance oak regeneration by increasing herbivory on mesophytes; and
4) Mesophytes may suppress future forest flammability by reducing fuel loads and increasing fuel moisture.

THE FUNDAMENTALS OF RELEASE BURNING IN MIXED OAK FORESTS WITH EMPHASIS ON THE SHELTERWOOD-BURN TECHNIQUE

Patrick H. Brose and Todd F. Hutchinson

Abstract—Release burning is the term used to describe prescribed fire conducted in the mid- to latter stages of the oak (*Quercus* spp.) regeneration process to promote the dominance of oak reproduction. In this context, the fire exploits differences in resource allocation (roots versus stems) between oak seedlings and those of other hardwoods to free the oaks from excessive competition. Fire seasonality and fire intensity strongly influence release burning outcomes with hot fires conducted in late spring being most beneficial for promoting oak dominance. However, release burning must be used wisely as it can produce unintended consequences regarding whitetail deer (*Odocoileus virginianus*) browsing, damage to overstory trees, invasive species, and smoke impacts.

INTRODUCTION

To correctly use prescribed fire in oak (*Quercus* spp.) forests, one must first understand the oak regeneration process and its relationship to fire (Arthur and others 2012, Johnson and others 2009). The oak regeneration process is the procedure by which mature oaks are replaced by their progeny. It consists of three phases (acorn production, establishment of new oak seedlings, and development of those seedlings into competitive-sized individuals) and an event – an adequate, timely release (Johnson and others 2009, Loftis 2004). The oak regeneration process usually spans a decade or more due to the sporadic occurrence of large acorn crops and the emphasis on root development by young oak seedlings. Oaks typically have heavy masting events every 5 to 10 years depending on species and location (Burns and Honkala 1990). Acorn crops are subject to numerous environmental factors that can slow this phase of the regeneration process or delay it entirely until the next mast year (Arthur and others 2012, Johnson and others 2009). For example, diseases, insects, and weather can ruin acorns before they fall from the trees or, once on the ground, acorns can be destroyed by these same factors or consumed by wildlife. Once an oak seedling cohort forms, these seedlings grow slowly for several years as energy is focused on root system development if adequate resources, especially light, are sufficient for oak seedling survival and growth. Like plentiful acorn crops, the root development phase of the regeneration process can be slowed, stalled, or forced to begin again due to numerous environmental factors. Pre-eminent among these are the amount of understory shade, whitetail deer (*Odocoileus virginianus*) browsing, and the amount and composition of competing vegetation (Brose 2011a, 2011b; Miller and others 2014). Eventually, if the oak reproduction becomes large enough to successfully compete on that site, it can be released by overstory harvests. Because of all these factors, the oak regeneration process is excruciatingly slow, typically lasting 10 to 25 years (Carvell and Tryon 1961, Clark and Watt 1971, Sander 1972).

The first steps of using prescribed fire in oak forest management are to decide what type of future oak forest is desired and determine where the prospective stand is in the oak regeneration process. The desired future condition is dictated by the management objectives while the current condition is ascertained by an inventory. The inventory is an absolute necessity for determining whether oak-stand replacement is feasible or worth pursuing. The inventory can be a simple walk-through evaluation by a forester experienced with local conditions, or a more comprehensive, systematic assessment such as those done in conjunction with prescriptive expert systems like SILVAH (Brose and others 2008), or some other type of forest inventory that falls between these two extremes. Regardless of the degree of complexity of the inventory, it must provide basic information on overstory, understory, and regeneration conditions to determine the oak regeneration potential, as well as to identify potential obstacles to forest renewal and sustainability of oak. Only after an inventory reveals where the stand is in the

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

oak regeneration process can the correct type of fire be prescribed and coordinated with other silvicultural practices to meet the management objectives.

There are three types of prescribed fire that are appropriate in oak ecosystems. They are: (1) seedbed preparation burning, (2) release burning, and (3) ecological restoration burning. Because other presenters at this symposium covered seedbed preparation burning and ecological restoration, this paper focuses on release burning and provides guidelines on how to conduct this type of prescribed fire and also presents pitfalls that can negate the desired outcome of the prescribed burn.

RELEASE BURNING

This type of prescribed fire occurs in oak stands nearing the end of the oak regeneration process, where an abundance of large oak advance reproduction is present. There are two types of stands suitable for release burning: those undergoing a shelterwood sequence to promote further development of oak advance reproduction and those that have just been regenerated via a final harvest (fig. 1). Both have the same two characteristics: oak reproduction that is still viable despite being overtopped by taller competing regeneration of mesophytic hardwoods. Oak reproduction suitable for prescribed burning will typically be >1 foot tall with root collar diameters of at least 0.5-inch diameter (Brose and Van Lear 2004). Density of such oaks needs to range from several hundred to several thousand stems per acre with the larger densities needed on high-quality sites. Adequate oak density at this stage also varies by management objectives for future oak stocking at maturity. It also depends on the ability to do additional treatments at critical stand developmental stages such as crop tree release at canopy closure. Spatial distribution or stocking of the oak reproduction needs to be widespread throughout the stand so that at least 50 percent of the inventory plots contain this viable oak reproduction. On better quality sites, reproduction of the competing mesophytic hardwoods will often outnumber (by several thousand stems) and overtop (by several feet) the oak reproduction. When oak shelterwoods and final harvest stands have these two characteristics, they are candidate stands for prescribed burning to release the oak from competition. It should be noted that if vigorous oak reproduction is not overtopped and outnumbered by mesophytic hardwoods, then release burning is not necessary. However, this situation may only occur on low-quality sites.

The Shelterwood-Burn Technique

Correctly implementing the shelterwood-burn technique (Brose and others 1999a, 1999b) is more than simply applying fire to a partially cut oak stand. The proper application of the technique actually begins before the shelterwood harvest, while the stand is still uncut or has had a low/midstory shade reduction treatment. The first step addresses two questions: (1) is there enough oak reproduction at this time to proceed with a regeneration sequence given the future oak stocking goal, site quality, and obstacles to stand renewal, and (2) will the stand be able to be burned in approximately 5 years (fig. 2)? If the first question is answered negatively, then you must wait to implement the shelterwood-burn technique until there is an adequate density of oak reproduction or institute underplanting to reach the desired density of oak reproduction (Dey and Parker 1997a, 1997b; Johnson and others 2009). You may also consider the appropriateness of implementing a seedbed preparation burn (Brose and others 2014, Schuler and others 2013). If the second one is answered negatively, then you must make alternative regeneration plans such as using the Loftis shelterwood method, which is largely a removal of the midstory and overstory trees in the lower crown classes by mechanical or chemical methods

Figure 1—Shelterwood stands (left) and newly regenerated stands (right) are appropriate for release burning. (photo by Patrick Brose, USDA Forest Service)

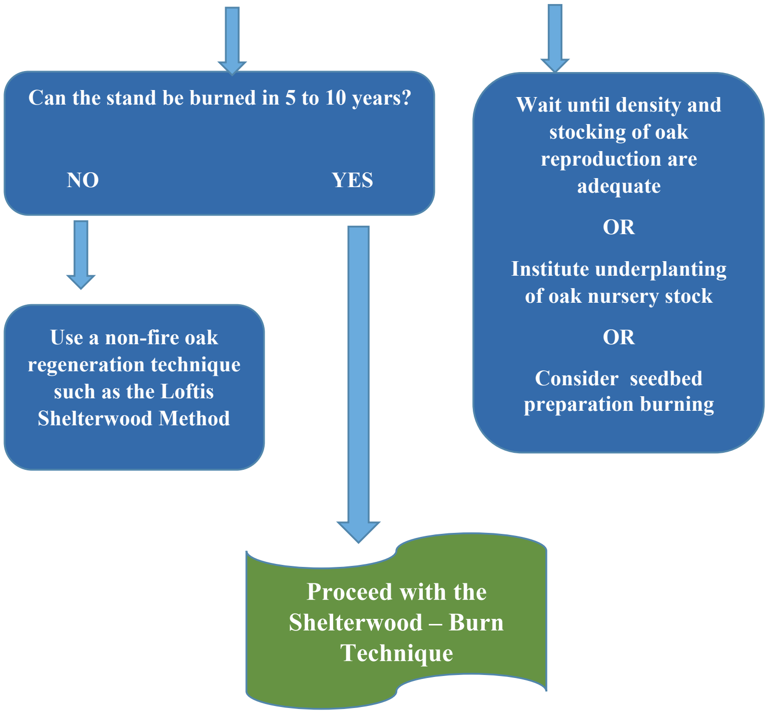

Figure 2—Decision-tree flowchart illustrating the questions that must be answered before implementing the shelterwood-burn technique. (photo by Patrick Brose, USDA Forest Service)

to promote the growth of the abundant but small oak advance reproduction (Loftis 1990). If both questions are answered positively, then proceed with the technique by planning and conducting the first removal cut of a two-stage shelterwood sequence.

The purpose of the first removal cut is to create the understory light conditions to promote rapid root development of the oak reproduction while not causing rapid height growth of the competing mesophytic regeneration (fig. 3, Brose 2011a). Because fire will be used in a few years, planning and conducting this harvest require some extra attention. First, lay out the access roads and skid trails so they can double as fire control lines in the future. This will expedite the preparation for the prescribed fire, decreasing one of its costs. Second, create a 50-percent open canopy by harvesting the low-quality stems, undesirable species, and some financially mature trees. This is more than a commercial harvest. It is necessary to remove unmerchantable overstory trees in the lower crown classes and any midstory trees to achieve this level of light. Fell unmerchantable trees and larger saplings, especially those >3 inches diameter at breast height (dbh), because they have higher probabilities of surviving a low-intensity fire intact. The cut stems have a high likelihood of sprouting, but the sprouts will be susceptible to topkill in a subsequent burn. Alternatively, the midstory and noncommercial trees can be stem injected with herbicides (Kochenderfer and others 2012).

Figure 3—Eight-year-old chestnut oak seedlings grown in shelterwoods of varying residual relative densities. Those on the left were in 70- to 90-percent relative density while those on the right were in 20- to 50-percent relative density. (photo by Patrick Brose, USDA Forest Service)

In terms of basal area, the residual will range from 50 to 80 square feet per acre with the higher residual levels being left on the better quality sites. The ideal leave trees are healthy, vigorous, high-quality oaks that are approximately 15 to 17 inches dbh. Trees of this diameter will increase substantially in size and value over the next 5 to 10 years, especially if they move from Grade 2 sawlogs to Grade 1 (Hanks 1976, Miller and others 1986) and will resist the formation of epicormics branches (Miller and Stringer 2004). It is unlikely that there will be enough ideal oaks per acre to meet the residual basal area guideline so other trees will have to be kept as leave trees, but be sure not to keep any undesirable species that are prolific seed producers such as black birch (*Betula lenta* L.) and yellow-poplar (*Liriodendron tulipifera* L.). Finally, manage the slash to protect the residual crop trees. The harvest will create concentrations of slash and such “fuel jackpots” within 10 feet of the bases of residual crop trees will create and hold an intense fire that will likely damage or kill them (Brose and Van Lear 1999). Be sure the logging contract stipulates that directional felling is used to prevent placing tree tops near the bases of residual crop trees or such slash is removed as part of the harvesting operation (Brose 2009b).

The first removal cut is followed by a multi-year waiting period of 4 to 7 years. This period is important for several reasons. First and foremost, this is when the oak reproduction develops root systems, a necessary precursor to the ability to vigorously sprout post-fire (Brose 2008, 2011a; Brose and Van Lear 2004). The wait also allows the seed bank in the forest floor to germinate, at least in part (Schuler and others 2010). The resultant flush of new reproduction probably will contain some seedlings that are potential long-term competitors to oak such as black birch and yellow-poplar. As new seedlings, these are virtually defenseless against a prescribed fire. Additionally, this wait allows the fuel bed to develop as the logging slash settles and dries and leaf litter accumulates from the residual canopy trees. Finally, the waiting period allows the residual crop trees to increase in volume and value, making the upcoming final harvest more profitable. Leave the stand undisturbed until the oak seedlings have root collars at least 0.50-inch diameter and are shorter than the competing mesophytic hardwood reproduction by 2 or more feet. These conditions will usually develop within 4 to 7 years, depending on site quality.

The purpose of the prescribed fire is to select for the oak seedlings and against the mesophytic hardwood reproduction based on the difference in resource allocation strategies between the two species groups – oaks concentrating resources on root development and mesophytic hardwoods on stems and branches. To do this, a hot spring burn is the optimal combination of fire intensity and season-of-burn for maximum benefit to the oak seedlings (Brose 2010, Brose and Van Lear 1998, Brose and others 1999a). Because such a fire will occur in an oak shelterwood, careful planning is essential. First, use Fuel Model 06 or 10 to represent the fuel loadings of oak shelterwoods in predicting expected fire behavior (Anderson 1982, Brose 2009a). Second, identify the residual crop trees in danger of fire damage due to logging slash close to their bases and take preventative measures to protect them (Brose 2010). Third, strive to burn at the ideal time in the spring season when the mesophytic hardwood reproduction has expanded leaves at least 50 percent, but the oak seedlings still have closed buds and the overstory is still dormant. This “sweet spot” varies by location and elevation from year to year. For example, this optimal burn window generally occurs in southern Ohio in late April, but is in mid-May in northern Pennsylvania. An extended winter or early spring will delay or move forward this window in the calendar as well as shorten or extend its duration. Finally, prescribe a hot surface fire. Flame lengths need to be at least 2 feet with rates of spread ranging from 3 to 7 feet per minute (fig. 4). Although this combination of fire intensity and season-of-burn has consistently produced excellent results in shifting the composition of the regeneration pool towards oak, burning outside the hot mid-spring window will also benefit oak but to a lesser degree (Brose 2010, Brose and others 2014). Cooler fires and those conducted earlier in the spring will provide less control of competing mesophytic hardwoods, and burns done after leaf expansion of the oak reproduction will reduce survival and decrease post-fire height growth.

When done properly, the shelterwood-burn technique will provide several benefits to the oak reproduction (Brose 2010, Brose and Van Lear 1998, Brose and others 1999a, Fenwick and others 2016). Well-timed surface burns will kill more mesophytic hardwood regeneration than oak reproduction, thereby increasing the relative abundance of oak in the advance regeneration pool (fig. 5). Sprouting oaks will improve in stem form and rate of height growth. Nutrients stored in the leaf litter and slash will be released back into the forest floor for subsequent use by the sprouting oaks (Blankenship and Arthur 1999, Boerner 2000). The ectomycorrhizae in the forest floor will be stimulated (Stottlemyer and others 2013). Berry-producing shrubs such as blueberry (*Vaccinium* spp.), huckleberry (*Gaylusscia* spp.), and blackberry (*Rubus* spp.) will be reinvigorated or germinate from seed stored in the forest floor. Besides the food benefit to wildlife, blackberry may help in development of oak sprouts as it slows the height growth of mesophytic hardwood seedlings (Donoso and Nyland 2006). It also provides an alternative supply of browse for deer and hiding cover for oak reproduction, potentially reducing deer browsing pressure on oaks.

Figure 4—A moderate-intensity spring fire in central Virginia. Flame lengths are 2 and 4 feet, (photo by Patrick Brose, USDA Forest Service)

Figure 5—The same stand shown in figure 4 but several weeks later. The dead saplings are yellow-poplar and red maple while the green sprouts are oak and hickory. The relative abundance of oak and hickory increased from 10 to 70 percent in the regeneration pool, and this dominance continued as the new stand grew into saplings. (photo by Patrick Brose, USDA Forest Service)

Based on our collective experience, we see six common mistakes committed by land managers implementing the shelterwood-burn technique. They are:

1. Making the first removal cut before adequate oak seedlings are established.
2. Not creating at least 50 percent open canopy with the first removal cut.
3. Not preventing slash accumulations near the bases of residual crop trees or not mitigating this situation prior to burning.
4. Not waiting long enough for the oak reproduction to develop roots and be overtopped by competing mesophytic hardwood regeneration.
5. Burning earlier in the spring than is recommended.
6. Not conducting a moderate- to high-intensity fire.

Committing any of these mistakes will likely necessitate additional prescribed fires or other silvicultural treatments to regenerate oak and avoid undesirable results at the end of the regeneration process.

The shelterwood-burn technique does have some drawbacks. The residual crop trees are at risk for fire damage and mortality (Brose and Van Lear 1999, Wiedenbeck and others 2017). This risk is real as well as perceived. Even though a veneer-quality oak is not damaged by the fire, potential buyers may pay less money for it because of the threat of staining. Larger red oaks (>11 inches dbh) scarred by fire can lose up to 10 percent of value in the butt log within 15 years of burning (Marschall and others 2014). The fire will kill small oak reproduction that has not yet developed large enough root systems necessary for vigorous post-fire sprouting (Miller and others 2017). If native and nonnative invasive plant species are in the burn unit, they may expand in coverage or they may seed in from adjoining areas (Rebbeck 2012). Deer are attracted to burned areas because the sprouting hardwoods are especially palatable and nutritious. Mid-spring prescribed fires are probably disruptive to ground-nesting birds such as ruffed grouse (*Bonasa umbellus*), wild turkey (*Meleagris gallopavo*), and several species of neotropical songbirds and are potentially lethal to herpetofauna just emerging from winter hibernation (Beaupre and Douglas 2012). Indeed, in some States or within some agencies, burning in the mid-spring period is not permitted due to endangered species regulations.

Post-Harvest Burning

One approach to mitigating the fire damage risk to crop trees in the shelterwood-burn technique is to conduct the final removal harvest before implementing the burn. This alternative is called post-harvest burning (and mimics the early-20th-century disturbance regime that produced many of the current oak stands (Hutchinson and others 2008). If more time is needed for oak seedlings to get bigger before burning, the overstory harvest itself may provide a short-term release of the oak reproduction. Therefore, burning may be delayed for 1 to 3 years depending on site quality, and should be done before the height of the woody competition exceeds the oak reproduction by >2 feet and average stem dbh increases to >3 inches. Post-harvest burning has much in common with the shelterwood-burn technique. Both have the same objectives and prerequisites. Post-harvest burning should be done in mid-spring and strive for the same fire intensity as in the shelterwood-burn methods. One difference is in planning. Post-harvest burning has considerably higher fuel loads, 30 to 40 tons per acre, so AFM 12 should be used in place of AFM-06 or 10 (Brose 2009a). Anticipate flame lengths in excess of 5 feet (10 to 15 feet is not unusual) and a large smoke column and plan accordingly for containment resources and smoke dispersal strategies. Post-harvest burning is not common in the scientific literature, but the existing publications indicate that the oaks in the regeneration pool are benefitted by fire at the end of the regeneration process (Carvell and Maxey 1969, McGee 1980, Ward and Brose 2004, Ward and Stephens 1989). Recent research confirms the findings of these studies (fig. 6, Brose 2013).

A somewhat different approach to post-harvest burning is the fell-and-burn technique (Abercrombie and Sims 1986, Phillips and Abercrombie 1987). This method originated in the southern Appalachian Mountains and upper Piedmont regions in the 1980s to regenerate or create pine-oak stands on low-quality sites (fig. 7). As the name suggests, this technique is a multi-step process. First, all the merchantable trees of the existing stand are harvested. This is generally done in the winter. In the following spring, once the leaves are well- to fully developed, all the non-merchantable stems are felled. Once their foliage is cured and their twigs and small branches dry, the site is broadcast burned. This prescribed burn is conducted during the first summer following harvesting and slashing and after the hardwood stumps have sprouted, but within 1 to 2 days after a soaking rain. This fire reduces the fuel loading, slows the height growth of oak and other hardwood sprouts, and prepares the site for the final step – planting of pine (*Pinus* spp.) seedlings. This planting takes place during the following winter and the pines are planted at a fairly wide spacing (15 x 15 feet or greater). The preferred pine species varies by locale – loblolly (*Pinus taeda* L.) in the Piedmont, shortleaf (*P. echinata* Mill.) in the Ozarks, and pitch (*P. rigida* Mill.) and eastern white (*P. strobus* L.) in the Appalachians. Long-term research of this technique shows that the pine seedlings initially lag behind the hardwood sprouts in height growth, but become dominant by year 7 to 10 (Waldrop 1997). By

Figure 6—A 5-year-old post-harvest burn stand in northern Pennsylvania. Post-harvest burning appears to create new, oak-dominated stands much like the shelterwood-burn technique. (photo by Patrick Brose, USDA Forest Service)

Figure 7—A young mixed oak-pine forest in western South Carolina created by the fell-and-burn technique. Note the diversity of tree species as indicated by their different fall colors. (photo by Thomas Waldrop, USDA Forest Service)

year 20, this method results in a mixed-species stand dominated by two species groups: oaks and pines (Waldrop and Mohr 2012).

CONCLUSION

Using prescribed fire as a silvicultural tool, where timber values are expected to be retained, requires more consideration than returning fire as an ecological component to a forest. Oak reproduction must be assessed before using fire. Burn prescriptions must mesh with silvicultural prescriptions. Common mistakes must be avoided. However, if the guidelines presented here are followed and the common mistakes avoided, prescribed fire can be successful in the oak reproduction process.

ACKNOWLEDGMENTS

These guidelines are a synthesis of the authors' considerable experience in prescribed burning, fire-oak research, and countless stimulating conversations on the subject matter with numerous colleagues and other professional foresters over the years. Chief among these colleagues is David Van Lear, retired professor of forestry from Clemson University and Patrick Brose's doctoral advisor, who formulated many of the key points presented in this paper. The authors thank the organizers of this Oak Symposium for the invitation to attend and speak on using fire to regenerate mixed-oak forests. The authors also thank Greg Nowacki and Melissa Thomas-Van Gundy who graciously reviewed an earlier draft of this paper and provided many comments that improved clarity and conciseness.

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INFERRING FIRE REGIMES FROM DATA YOU MAY ALREADY HAVE: ASSESSING LANDFIRE FIRE REGIME MAPS USING LOCAL PRODUCTS

Melissa A. Thomas-Van Gundy

Extended abstract—The determination of fire regime and condition class on federally owned land is needed for prescribed and wildland fire management. Determining historic fire regimes for large areas can be difficult without fire-scar records from old-growth forests or sediment charcoal from paleoecological sites. Large-scale efforts to map fire regimes have been made incorporating fire ecology of tree species to assign fire regimes (Nowacki and Abrams 2008), fire scars from dendrochronology studies (Guyette and others 2006), and climate and chemistry (Guyette and others 2012). Early nationwide maps incorporated many lines of evidence to map the role of fire in forested ecosystems. Frost (1998) compiled fire histories from across the contiguous United States and, combined with landform characteristics, created a map of pre-European settlement fire regimes. Using current and potential vegetation, ecological regions, and expert opinion, Schmidt and others (2002) mapped historical natural fire regimes for the contiguous United States at a coarse resolution.

To help identify areas where prescribed burning is appropriate for restoration purposes, two local mapping products were created for the Monongahela National Forest. The first used the fire ecology of current and potential vegetation to map fire-adapted vegetation and directly convert this to fire regime groups (FRG) (Thomas-Van Gundy and others 2007). The second used witness trees from early land surveys to create a continuous surface depicting percentages of pyrophilic tree species (Thomas-Van Gundy and Nowacki 2013). Cells with pyrophilic percentages of 60–100 were assigned to FRG I, those with 40–60 percent pyrophilic species were assigned to FGR III, and cells of 0–40 percent pyrophilic were assigned to FRG V. Fire regime groups derived from both mapping products were compared to LANDFIRE (LANDFIRE 2013) fire regime groups for assessment and comparison.

The cell-by-cell comparison of the rule-based map and LANDFIRE showed that the two versions of FRGs agree on about 57 percent of the Monongahela National Forest. Most of the departures (about 36 percent of the area) were positive 2 or 4 meaning the rule-based map FRGs were greater than LANDFIRE; about 8 percent of the area was in departures of negative 2 or 4.

Creating FRGs from the witness tree-based map resulted in about 30 percent of the study area classified as FR I, about 14 percent as FR III, and about 56 percent as FR V (fig. 1). The fire regime groups inferred from the witness tree data matched LANDFIRE on about 61 percent of the area. Departures from LANDFIRE from the witness tree-based map were more evenly distributed above and below zero (compared to departures between LANDFIRE and the rule-based map) with about 22 percent of the area with a difference of positive 2 or 4 and about 17 percent in negative 2 or 4 differences.

The grids resulting from these calculations spatially depict where the agreements and departures occur. All three versions of FRGs for the study area identify the higher elevations in the mountainous center of the study area as an area of low fire frequency. The influence of subsection boundaries is more obvious in the LANDFIRE estimation of FRG and was a main contributor to departures from the two locally derived maps.

The mapped differences between the two locally derived FRGs and LANDFIRE FRGs are a useful starting point for detailed, site-specific reviews for project planning. The methods described here are applicable to other landscapes and should be useful for others trying to define areas to restore fire-adapted vegetation. Managers should not limit themselves to one product—witness trees, historical records, potential natural vegetation mapping, fire scars, responses to prescribed fire—all can inform options for restoring fire as a disturbance regime.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

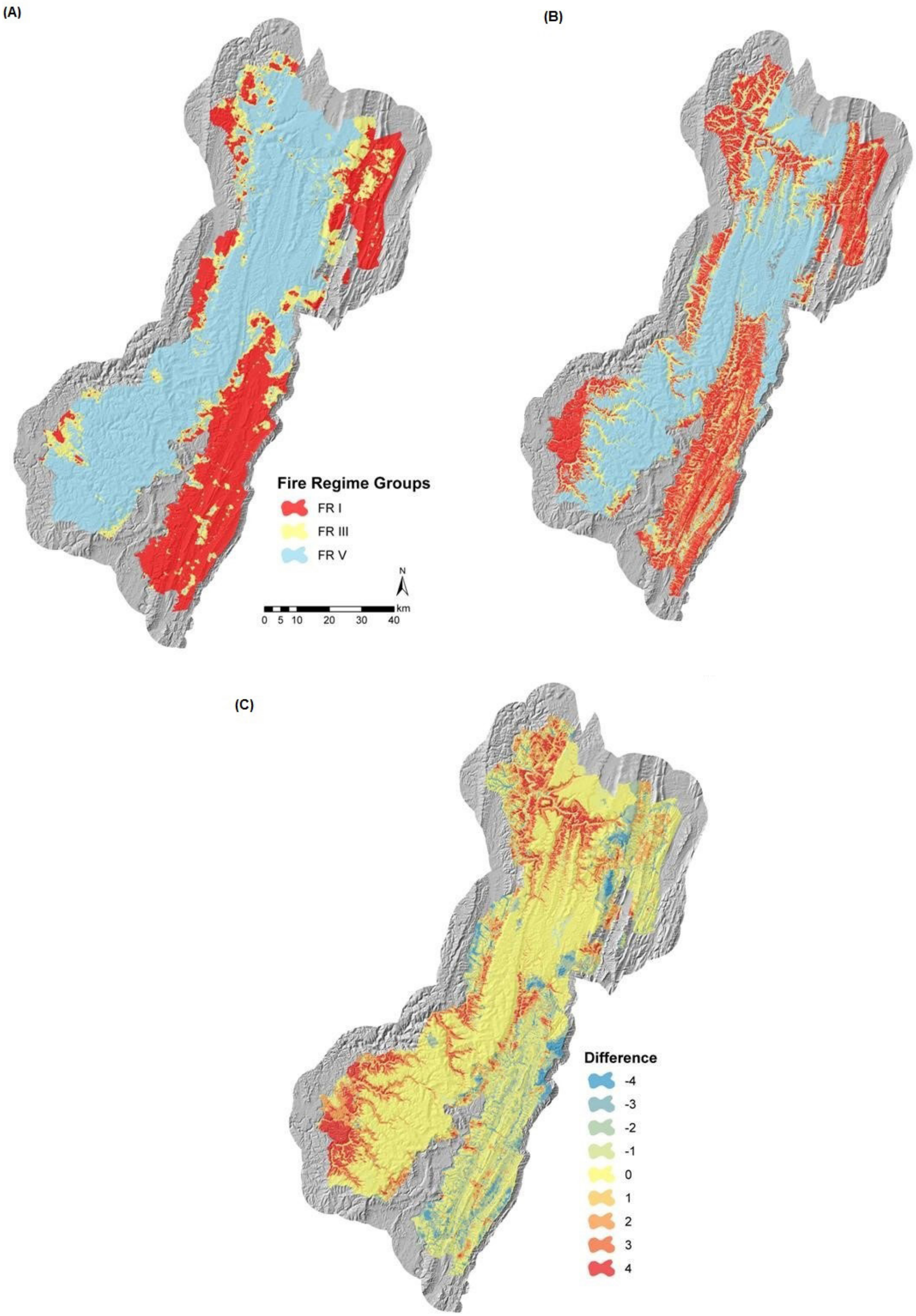

Figure 1—Fire regime group maps derived from (A) the witness tree-based map (Thomas-Van Gundy and Nowacki 2013), (B) LANDFIRE, and (C) the difference between them.

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SESSION 4:

Artificial Regeneration

Moderator:

David Buckley
The University of Tennessee

ARTIFICIAL REGENERATION IN THE SOUTHERN APPALACHIANS

Stacy L. Clark and Scott E. Schlarbaum

Abstract—Reforestation of upland oak species on productive forest sites in the Southern Appalachian region will require different prescriptions than in other regions where yellow-poplar (*Liriodendron tulipifera* L.) is not a primary competitor. We present results from three studies on highly productive sites [site index, base age 50, for northern red oak (*Quercus rubra*) ranged from 78 to 98 feet] that represented a broad range of residual basal areas and competition control methods. In all studies, we used seedlings produced using the most advanced bare-root nursery protocols currently available (averaging 1.6 to 3.6 feet in height). Seven to 10 years after harvest, approximately 15 percent of planted seedlings were in canopy positions where recruitment into the overstory was probable, and recruitment capabilities were similar at all three study sites despite differences in site conditions and silvicultural prescriptions. Assuming a planting density of 300 trees per acre, a recruitment density of approximately 50 trees per acre would be expected. After 10 years, trees were capable of attaining 20 to 26 feet in height and averaged 9 to 10 feet for the two oldest plantings. The study that received the most targeted competition control treatment and the largest seedlings had a significant positive relationship between seedling height at the time of planting and recruitment density. Variability in silvicultural treatments, genetics, and site conditions probably masked this relationship for the other studies. We recommend planting high-quality seedlings from a diverse genetic mixture and targeted herbicide competition control to improve recruitment success rates of planted oak seedlings.

INTRODUCTION

Forest resources are increasingly pressured in the United States by land conversion, invasive and exotic plants and disease, and climate change. Human population is increasing while forest lands have remained stable over the last 100 years (Oswalt and Smith 2014), requiring improved production of natural resources. Domestication of plants and animals has improved efficiency for food and timber commodities on a per-area basis, but hardwoods remain largely undomesticated, particularly oak (*Quercus* L.) species. Tree improvement and research on artificial regeneration of upland oak species have been limited to primarily northern red oak (*Q. rubra* L.) and white oak (*Q. alba* L.), which have high economic and ecological values. Oaks in general are difficult to improve, however, due to inherent slow growth, relatively high intraspecies variability, and limited long-term resources to sustain research and development programs (Beineke 1979, Schlarbaum 2000).

Managers require practical prescriptions with predictable outcomes to regenerate oak naturally or artificially, particularly on private land in the Southern Appalachian region. While research has improved our understanding of requirements for regenerating oak, successful regeneration is rarely achieved in practice due to high cost or lengthy time required for implementation. From the 1970s to the 2000s, practical recommendations for planting oak were developed and tested in the Ozark and Boston Mountain region (Spetich and others 2002, Weigel and Johnson 2000) and in the Northeastern United States (Zaczek and Steiner 2011). Research focused on seedling quality and physiology, stock types, and silvicultural prescriptions for competition control and browse protection (Dey and others 2008). However, recommendations derived from this research were largely outside the Southern Appalachian region where fast-growing, shade-intolerant species, like yellow-poplar (*Liriodendron tulipifera* L.), compete with planted oaks.

Approximately 25 years ago, advancements in artificial regeneration in the Southern Appalachians were made through two primary processes: development and maturation of seed orchards that provided a basis for multi-year research projects from pedigreed sources (Schlarbaum and others 1994), and development of nursery prescriptions that improved seedling quality (Kormanik and others 1994). Since that time, the U.S. Department of Agriculture Forest Service, Southern Research Station (formerly Southeastern Forest

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

Experiment Station) and Southern Region, and The University of Tennessee's Tree Improvement Program have cooperated on research and development of northern red oak. A primary goal of this effort was to conduct research to provide practical recommendations to enrich sites that were experiencing natural regeneration failures through the planting of high-quality oaks.

As a result of this cooperation, the objectives of this research were to:

1) present general performance metrics (survival, growth, and recruitment capability) of seedlings grown using advanced nursery prescriptions and planted on high-quality sites in the Southern Appalachians; and

2) determine if an easily identifiable seedling quality metric (height) can be used to predict recruitment capability.

Our goal has been to provide practical recommendations to artificially regenerate upland oak (primarily northern red oak) on moderate to productive sites in the Southern Appalachian region. Three research projects are presented (from youngest to oldest) where successful enrichment of northern red oak looks promising.

METHODS

Specific site descriptions are briefly described below in the results section. Experimental material consisted of putative half-sibling progeny from open-pollinated mother trees in the wild or in a seed orchard on the Cherokee National Forest (Schlarbaum and others 1994). Acorns were sown at a density of six per square foot in state commercial tree nurseries in Bryomville, GA, or Delano, TN, and subsequent seedlings were grown for 1 year using advanced nursery protocols to maximize overall seedling size (Kormanik and others 1994). Seedlings were lifted from the nursery using a Fobro$^{\text{TM}}$ machine lifter that undercut seedlings (10–12 inches) and loosened soil around the roots. Seedlings were manually removed from the nursery beds, roots sprayed with a hydrogel slurry solution to prevent desiccation, and placed in poly-coated paper tree bags in cold storage until planted in March. Trees were planted on a 10- by 10-foot or 12- by 12-foot spacing using a planting bar (Jim Gem® KBC) modified to be 12 inches in width and length to accommodate relatively large root systems.

Seedling height measurements were collected during the dormant season at the time of planting and in 2016 or 2017, depending on study. For all studies, a planted tree was determined to be 'free to grow' if the terminal bud of the planted seedling was not directly overtopped by stems or leaves from competing trees in the understory or midstory canopy layer. For study 3, a planted tree was determined to have 'understory dominance' if it was at least 80 percent of the height of the tallest understory competitor occurring within a 4.3-foot-radius plot around the planted seedling (adapted from Spetich and others 2002). Understory describes trees >1 foot in height and <1.5 inches in diameter at breast height (DBH), and midstory describes trees 1.5 to 5.4 inches DBH. Free-to-grow and dominance data were collected in the late growing season of 2016 or 2017, depending on study.

The studies were originally established to test various treatments including family, seedling grade, and root pruning treatments, and these treatment effects have been previously reported (Clark and others 2015, 2016). Raw means and associated standard deviations for the entire seedling population were computed for each study. Trees were considered capable of successful recruitment to the canopy if they were greater than the mean height of planted seedlings for the site, and were free to grow in the understory and midstory. A recruitment density was calculated by multiplying the fraction of trees capable of recruiting to the canopy by 302, which represents a planting density of a 12- by 12-foot spacing. Logistic regression analysis was performed separately for each study using SAS® 9.3 software (SAS Institute Inc. 2011) to predict recruitment capability from seedling height at planting. Linearity assumptions of the predictor variable were tested, and assumptions were not violated for any study. Hosmer and Lemeshow goodness of fit tests were conducted, and all models were determined to adequately fit the data. An associated *P*-value of 0.05 was used to indicate significance of the Wald chi-square value, where larger Wald chi-square values indicate a stronger relationship between the height predictor variable and recruitment capability.

RESULTS

Study 1. Shelterwood-Burn, Cold Mountain Game Lands, NC (ca. 2010)

Seedlings (n = 252) were planted in three stands (n = 84 in each stand) treated with a shelterwood with reserve harvest, resulting in a two-age stand (Clark and others 2016, Westby-Gibson and others 2017). Site index (base age 50) for northern red oak ranged from 78 to 98 feet, and residual basal area was 30 to 39 square feet per acre. The stands were treated with a prescribed fire in March after their fifth (one stand) or sixth (two stands) growing season. Pre-burn data represented 5- or 6-year post-planting data, depending on stand, and post-burn data represented 7-year post-planting data for all trees. Trees averaged 3.4 feet in height at the time of planting, ranging from 1.3 to 6.2 feet. The stand that was burned in year 5 was low severity (i.e., 11 percent of trees affected), but the two stands burned in year 6 had moderate severity fires (i.e., 90 percent of trees affected). Prior to the burn, survival was 87 percent and height was 7.5 feet. After burning, survival was reduced

by 5 percent and height by 1.6 feet, on average. After seven growing seasons, trees could reach over 17 feet in height, and 75 and 64 percent of trees were free to grow in the understory and midstory, respectively (table 1). Forty-seven trees per acre (15 percent of total planted) were considered to be capable of successful recruitment. Recruitment capability at age 7 was positively related to nursery seedling height, but this relationship was bordering on significance (Wald chi-square value = 3.60; *P*-value = 0.06). The relationship between nursery seedling height and recruitment capability increased at an increasing rate according to the logistic regression analysis (fig. 1).

Study 2. Thinning, White County, TN (ca. 2008)

Seedlings (n = 252) were planted on a site that was thinned from below to a residual basal area of 60 square feet per acre. Site index (base age 50) for northern red oak was 85 feet. A mechanical release was implemented 6 years after planting that included cutting stems <1.5 inches DBH [excluding other oaks, hickory (*Carya* Nutt.), dogwood (*Cornus florida* L.), or cherry (*Prunus serotina* Ehrhart)] that were directly overtopping the planted seedling. Seedlings were 1.6 feet at the time of planting, ranging from 0.7 to 4.1 feet. After 10 growing seasons, survival and average height were 67 percent and 9.2 feet, respectively (table 1). The tallest tree was

Table 1—Means (standard deviations) of performance metrics for three northern red oak plantings 7 or 10 years after planting

	Study 1 (age 7)	Study 2 (age 10)	Study 3 (age 10)
Survival	83 (37)	67 (47)	57 (50)
Average height (feet)	5.9 (4.5)	9.2 (4.8)	9.9 (5.6)
Maximum height (feet)	17.8	20.3	25.8
Understory dominance (percent)	--	--	68 (47)
FTG in understory (percent)	75 (43)	64 (48)	73 (44)
FTG in midstory (percent)	64 (48)	55 (50)	48 (50)
Recruitment density (trees per acre)[a]	47	54	45

FTG = free to grow.

NOTE: Data for understory dominance were not collected at Studies 1 and 2.

[a] Recruitment density was based on planting 302 trees per acre.

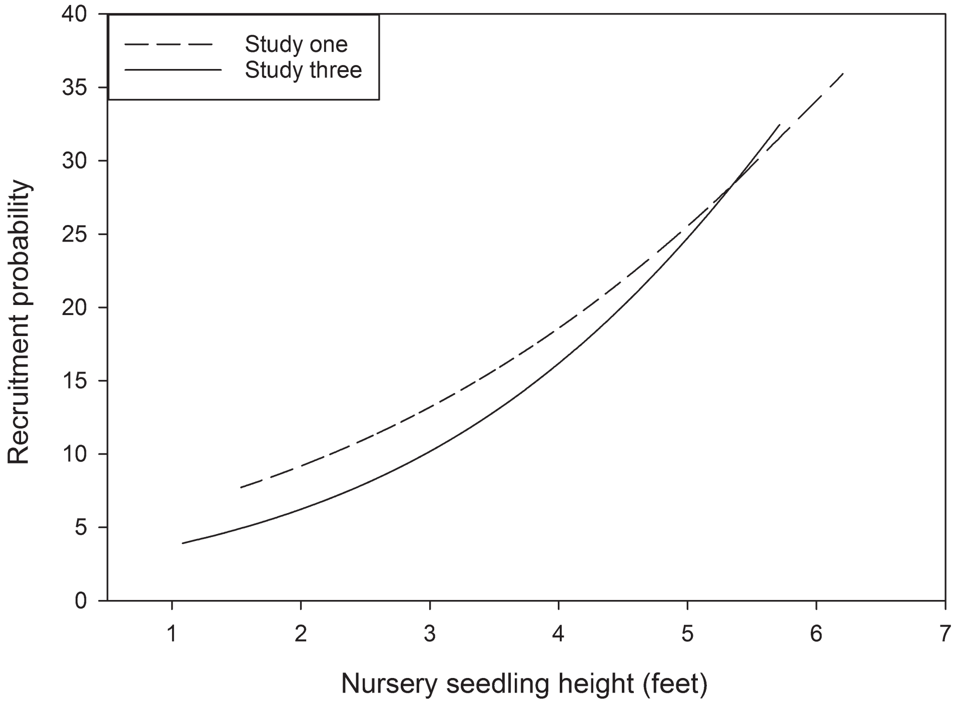

Figure 1—Probability of canopy recruitment at year 10 based on nursery seedling height for northern red oak seedlings planted in a thinning (study 1) and a two-age retention stand (study 3).

20.3 feet tall, and 64 and 55 percent of trees were free to grow in the understory and midstory, respectively. Approximately 54 trees per acre (18 percent of total planted) were considered to be capable of successful recruitment. Recruitment capability was positively related to nursery seedling height, but this relationship was not significant (Wald chi-square value = 1.91; *P*-value = 0.17).

Study 3. Two-Age Retention Harvest, North Cumberland Wildlife Management Area, TN (ca. 2007)

Seedlings (n = 292) were planted in a shelterwood with reserve harvest resulting in a two-age stand (Clark and others 2015). Site index (base age 50) for upland oaks was 82 feet, and residual basal area was 56 square feet per acre. Seedlings were released from competition using a triclopyr herbicide mix applied as a basal bark spray 5 years after planting. Seedlings averaged 3.6 feet tall at the time of planting, ranging from 1.1 to 5.7 feet. After 10 years, survival was 57 percent, and trees averaged 9.9 feet in height (table 1). The tallest tree was 25.8 feet tall. Sixty-eight percent of trees attained dominance in the understory, and 48 percent of stems were free to grow in the midstory. Approximately 44 trees per acre (15 percent of total planted) were considered to be capable of successful recruitment. Recruitment capability was significantly related to nursery seedling height (Wald chi-square value = 8.13; *P*-value = 0.0043). The relationship between nursery seedling height and recruitment capability increased at an increasing rate according to the logistic regression analysis (fig. 1).

DISCUSSION

Successful oak recruitment on productive sites requires the presence of tall advanced reproduction (i.e., 3 to 4 feet tall) prior to overstory canopy removal (Loftis 1983). Silvicultural prescriptions, including artificial regeneration, necessary to obtain advanced reproduction must be balanced with practical considerations (e.g., costs, time) to improve efficacy of treatments (Spetich and others 2009). In practice, many managers desire a simple ‘plant and walk away’ approach to restore or enrich an upland oak stand that is transferable across multiple site types and silvicultural prescriptions. Planting relatively tall seedlings, as conducted in our studies, resulted in similar recruitment success densities across sites despite variability in silvicultural prescriptions and site conditions. Compared to natural regeneration methods, planting eliminated the need to coordinate silvicultural treatments with acorn crops and shortened the time necessary to obtain tall natural regeneration, which can take up to 10 years if herbicide is applied prior to harvest (Loftis 1990) or 3 or 4 years if burning is applied after the harvest (Brose 2010). Our results showed that 45 to 57 stems per acre of oak out of a planting density of 302 per acre were in positions favorable for recruitment approximately 10 years after harvest with minimal competition control. The recruitment density and success rate (ranging from 15 to 18 percent of planted seedlings) may appear insufficient, but could be enhanced with additional forest management practices such as crop tree release or pre-harvest competition control (Johnson and others 1989, Miller and others 2007). In 10-year-old stands, approximately 800 codominant or dominant trees per acre will be present, and approximately 80 per acre will be considered ‘crop trees’ capable of remaining competitive and responding to future management (Miller and others 2007); thus, the results indicate planted seedlings could potentially constitute 60 to 70 percent of a stand’s crop tree population at age 10.

We expected to find a stronger relationship between recruitment capabilities and nursery seedling height, but our results did show positive relationships in all three studies, albeit not always significant. Studies 1 and 3 yielded similar predictions of recruitment success using nursery seedling height (fig. 1). While our goal was to test a seedling characteristic commonly used during grading in commercial nurseries, we suspect that other physiological or morphological parameters may have had better correlations to recruitment success. The tallest seedlings (i.e., >4 feet) may have had dieback related to unbalanced root:shoot ratio (Struve and others 2000), which weakens relationships between recruitment capability and seedling height at planting. Additionally, most of our studies incorporated treatments or practices (e.g., root pruning, genetic family, burning) that may have masked effects of seedling size on field performance. Each study was subject to varying forms of wildlife damage (e.g., deer browsing) and drought (study 3; Clark and others 2015), and seedling quality also varied. Study 3 had the strongest relationship (largest Wald chi-square value and lowest *P*-value) between nursery seedling height and recruitment capability, and this study held genetics constant by using seedlings from one genetic family, used the most targeted competition control, and had the largest seedlings at the time of planting (Clark and others 2015). These results provide some anecdotal evidence that the use of high-quality (i.e., tall) bare-root seedlings may be most effective when coupled with herbicide competition control, as suggested by previous research (Kormanik and others 2002, Weigel and Johnson 2000). However, empirical research is needed to quantify relationships between herbicide treatments and seedling quality of larger sized seedlings.

Some form of competition control will be beneficial for artificial regeneration (Dey and others 2008), but timing and method of application need further study. The mechanical release in study 2 was largely ineffective due to aggressive resprouting of competition. The prescribed fire effects on competition in study 1 has not yet been quantified, but observations to date indicate the effects were highly variable within the sites and not reliable for control of faster growing shade-intolerant species. While targeted herbicide competition control was not used on most of our studies due to constraints by landowners or lack of resources, it would have almost certainly improved recruitment densities and will probably be necessary when residual basal area is low (Weigel and Johnson 2000, Zaczek and Steiner 2011). Lack of competition control is typical for many management situations and will result in lower success rates, particularly for stands with low residual basal area. Oak is difficult to regenerate without some form of competition control, and we are currently investigating the most efficacious methods in other studies on productive sites in the Southern Appalachians.

These results indicate that approximately 15 percent of seedlings will be successful across a diversity of silvicultural prescriptions and site conditions due to planting tall nursery seedlings that were produced using the most advanced nursery protocols available (Kormanik and others 1994). Planting seedlings with mean heights of 3 to 4 feet and large root systems will improve competitive ability and reduce deer browsing effects across many stocking densities or competition control treatments (Dey and others 2008). Genetics will also affect nursery and outplanting performance (Clark and others 2016). Thus, relatively tall nursery seedlings from a diverse genetic mixture should be used for reforestation.

ACKNOWLEDGMENTS

The authors would like to thank numerous staff with The University of Tennessee Tree Improvement Program and the U.S. Department of Agriculture Forest Service Southern Research Station for assistance with planting and data collection including: David Griffin, Jason Hogan, John Johnson, Tracy Powers, Ami Sharp, and Ryan Sisk. We also thank managers with the Tennessee Wildlife Resources Agency, including Joe Elkins, Justin Walters, Lucas Hadden, and Wes Tilley, and with the North Carolina Wildlife Resources Commission including Ryan Jacobs and Dean Simon (retired). Rebecca Tuuk of the Shafer-Tuuk Tree Farm, LLC, and Trisha Johnson with The Nature Conservancy provided access and assistance for research on the study site in White County, TN. David Buckley and David Mercker, both with The University of Tennessee, provided reviews that improved this manuscript.

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DEVELOPING A SYSTEM FOR ARTIFICIAL REGENERATION OF FINE HARDWOOD SPECIES AND MANAGEMENT TO MATURITY ON THE AMES PLANTATION

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Abstract—An integrated agenda for hardwood research has been developed at the Ames Plantation over the last 3 decades that will produce locally adapted, genetically improved seedlings for incorporation into an experimental silvicultural system that yields commercially viable trees. Components include: establishment of hardwood seedling seed orchards with 22 species, the use of seedlings from these orchards for stand enrichment and reforestation in natural stands leading to precision forestry experiments, and crop tree enhancement treatments at mid-rotation to increase growth of successful trees. This long-term agenda will allow for better control of species composition in complex hardwood systems by using robust seedlings established in naturally regenerating stands. The Ames Hardwood Laboratory currently has over 25,000 trees and 40.5 ha of fenced orchards included in the three phases of the project: Hardwood Seed Orchards, Artificial Regeneration Enrichment, and Crop Tree Management.

INTRODUCTION

Planted seedlings established in naturally regenerating stands often fail due to poor seedling quality combined with the impact of aggressive herbaceous and woody competition (Johnson and Krinard 1985, Lay and others 1997, McGee and Loftis 1986). Desired species such as northern red oak (*Quercus rubra* L.) and cherrybark oak (*Q. pagoda* Raf.) are often displaced by fast-growing species such as sycamore (*Platanus occidentalis* L.), yellow-poplar (*Liriodendron tulipifera* L.), maple (*Acer* L. species), and sweetgum (*Liquidambar styraciflua* L.). Consequently, mature stands are often dominated by less desired and less valuable species.

Natural regeneration is routinely employed to initiate hardwood stands. Methods vary across a range of treatment intensities to establish a desirable suite of species. However, establishing a suitable mix and amount of advance regeneration can be difficult, and its development following release is often hard to predict (Loftis 1990, Sander 1972). This can be particularly true on the best sites, where undesirable competition is quick to respond to full sunlight (Dey and others 2008, Kellison 1993, Lorimer 1993). Once stand composition is established, it will affect a range of objectives for the remainder of the rotation, including values associated with timber, wildlife, and aesthetics.

Throughout human history, domestication of crop and animal species has occurred to meet societal needs, largely as a result of population increase and a need to be more productive on limited land bases (cf. Gepts and others 2012). This has proven true with forest tree species in the United States, as shown by the genetic and cultural improvement of certain coniferous species, e.g., loblolly pine (*Pinus taeda* L.) and Douglas-fir (*Pseudotsuga menziesii* Mirb. Franco) (Byam and others 2005, Silen 1978, cf. Wheeler and others 2015). In contrast, research and development efforts to domesticate highly desirable hardwood species have been minimal, with the possible exception of black walnut (*Juglans nigra* L). Additionally, research focusing on early seedling growth of high-quality hardwood seedlings in the highly competitive, naturally regenerating systems following mature hardwood harvests has been limited (Clark and others 2015, 2016; Pinchot and others 2015, 2018)

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

For the last 3 decades, research has been conducted on the Ames Plantation, to develop an integrated research agenda, from seed to harvest, to ensure the continuing presence of fine hardwood species at adequate stocking levels and to enhance their growth. The research has three primary areas:

- Development of hardwood seedling seed orchards
- Artificial regeneration to enrich naturally developing stands
- Crop tree enhancement at mid-rotation

Until recently, each research area has proceeded independently. The advent of significant seed production in some of the Margaret Finley Shackelford Seed Orchards and growth of species enrichment studies have enabled integration among the research areas. This paper briefly describes the current research and plans for the future.

METHODS

Location

The Ames Plantation is a 7487-ha University of Tennessee Research and Education Center located in western Tennessee, situated on the upper Mississippi Embayment. The plantation is characterized by low rolling hills, loess deposits, and rich bottomlands associated with the North Fork of the Wolf River, a tributary to the Mississippi River. The property is about 80.5 km east of Memphis, TN.

There are 5463 ha of forested land on the property, situated on a wide diversity of sites, ranging across the riparian zones and bottomlands along the North Fork of the Wolf River to rich loess farmlands to increasingly more xeric uplands, with some occurring on highly eroded, sandy slopes. Accordingly, there are a number of forest types occurring on the property and at a scale to be regionally representative. This diversity provides a unique opportunity to establish hardwood orchards and test silvicultural treatments on the same land base, where species and sites can be well-matched.

Hardwood Seed Orchards

Past hardwood tree improvement programs at land grant universities and the Tennessee Valley Authority were often discontinued before seed production occurred in materials from the first generation of genetic testing (Schlarbaum 2000, Wheeler and others 2015). Most of these programs were initiated in the 1950s and 1960s and discontinued when the program leader retired and federal formula funds became stagnated. The lack of seed production, an endpoint in tree improvement research, caused administrations to question further investment and contributed to the demise of tree improvement programs through hiring of scientists that were involved in more basic research.

The University of Tennessee's Tree Improvement Program was founded in 1959 by Professor Eyvind Thor (Thor 1976) and continued by the second author. In response to some of the reasons for closures of other tree improvement programs (Schlarbaum 2000), a seedling seed orchard approach was implemented in 1999 on the Ames Plantation. Hardwood plantations using pedigreed seedlings were established on Ames Plantation. These ranged across a number of species but were focused largely on oak. All plantings supported genetic testing of individual mother trees. Based on selection criteria, including form and acorn production, they were thinned at the earliest possible date to create seedling seed orchards. With one exception, this approach followed the methodology of LaFarge and Lewis (1987), who created a seedling seed orchard from a northern red oak progeny test. An additional characteristic, aside from growth and spacing, was taken into consideration when retaining trees: fruiting data. All genetic tests were observed for seed production, as there are genetic differences in reproduction maturation among genetic families. In addition to the conversion of genetic tests through the seedling seed orchard approach, other approaches were used to create seed orchards with species that did not lend well to orchard development through genetic testing (table 1).

Stand Enrichment Using Artificial Regeneration

Planting of high-quality (*sensu* Kormanik and others 1994), characterized, pedigreed hardwood seedlings on sites with suitable species associations began in 2002 with a 1,250-seedling northern red oak study. The origin of the seedlings was a 28-year-old northern red oak seedling seed orchard on the Ames Plantation. Since that time, a number of similar studies have been established.

For this paper, a bottomland study was selected as an example. The research was established in 2006 and consisted of high-quality, pedigreed seedlings from two species: cherrybark oak and swamp chestnut oak (*Q. michauxii* Nutt.). The acorns were planted at the Georgia Forestry Commission's Flint River Nursery in the 2005 autumn. The resulting seedlings were grown according to fertilization and irrigation protocols developed by Kormanik and others (1994). The 1-0 seedlings were undercut at approximately 20.3 cm and lifted in February, 2006. The best seedlings in each family (i.e., tallest and greatest root collar diameter) were selected for planting. The lateral roots were clipped to 15.2 cm from the taproot to facilitate planting, while the taproot was not clipped. Each seedling received a tag with individual numbers to maintain pedigree and identity. The seedlings were stored in a cooler until transportation to the Ames Plantation for planting.

Planting occurred during the winter of 2006–2007 on five bottomland sites, each approximately 1 ha in size. Soil

Table 1—Summary of the Margaret Finley Hardwood Seed Orchards on the Ames Plantation

Species	Common name	Year established	Type	Seed production
Querus rubra L.	Northern red oak	1972	SSO	Yes
Q. rubra L.	Northern red oak	2004	2nd Gen SSO	Yes
Q. rubra L.	Northern red oak	2013	PT	No
Q. alba L.	White oak	1972	SSO	Yes
Q. alba L.	White oak	1985	PT	No
Q. alba L.	White oak	2001	2nd Gen SSO	Yes
Q. alba L.	White oak	2003/2005/2007	PT	Yes
Q. pagoda Raf.	Cherrybark oak	1983	SSO	Yes
Q. pagoda Raf.	Cherrybark oak	2003/2006	SSO	No
Q. phellos L.	Willow oak	2003	SSO	No
Q. nigra L.	Water oak	2003	SSO	Yes
Q. macrocrarpa Michx.	Bur oak	2003/2005	PT	Yes
Q. bicolor Willd.	Swamp white oak	2006	PT	Yes
Q. shumardii Buckley	Shumard oak	2003/2006	PT	No
Q. palustris Muechh.	Pin oak	2003/2006/2007	SSO/PT	No
Q. lyrata Walter	Overcup oak	2003/2006	PT	No
Q. stellata Wangenhs.	Post oak	2007	PT	No
Q. falcata Michx.	Southern red oak	2003/2013	SSO/PT	No
Q. michauxii Nutt.	Swamp chestnut oak	2003	PT	No
Prunus virginiana Marshall	American plum	2016	CLO	No
Diospyrous virginiana L.	Persimmon	2005	PT	Yes
Carya illinoinensis (Wangenh.) K. Koch	Pecan	2013	PT	No
Ilex opaca Aiton	American holly	2011	WL/SSO	Yes
Q. velutina Lam.	Black oak	2003	SSO	No
Q. texana Buckley	Nuttall oak	2003	PT	No
Juglans nigra L.	Black walnut	2007	PT	No
Q. muehlenbergii Engelm.	Chinquapin oak	2005	SSO/CLO	No
Q. margaretta (Ashe) Small	Small sand post oak	Continuous	CON	No

Abbreviations for type: PT= progeny test; SSO = seedling seed orchard; CLO = clonal seed orchard; WL = wildlings; 2nd Gen = 2nd Generation; CON = conservation planting.

series were predominated by Falaya and Collins, both somewhat poorly drained, recently deposited, silt/sand alluvium. Each site was occupied by a mature stand of mixed bottomland hardwood species, including the study species, but largely predominated by sweetgum. Prior to planting, all merchantable timber, non-merchantable trees, and tops were removed from the site. The seedlings were planted on a 3.05- by 3.05-m spacing in an incomplete block, within complete block, using split, split plots, taking into consideration species and multiple seed sources. They were planted with a modified, i.e., widened at the blade, KBC bar. There were no release treatments following planting.

Height and diamter growth were periodically assessed. In 2016, all seedlings were measured and assigned a crown classification using methodology developed by Meadows and others (2001). Position assessments were assigned as shown in table 2.

Table 2—Numerical rating system for assigning a crown class based on crown characteristics as adapted from Meadows and others (2001)

Crown characteristics	Points
Direct sunlight from above	0–10
Direct sunlight from the sides	0–10
Crown balance	1–4
Relative crown size	1–4
Crown class assigned	Total ranking (2–28 points)
Dominant	24–28 points
Codominant	17–23 points
Intermediate	10–16 points
Suppressed	2–9 points

Using a more subjective and rigorous estimation, trees in the dominant and codominant classes were assigned a "free-to-grow" status if they had gained an obvious commanding crown position and could be reasonably envisioned to occupy the mature stand. Growth analyses were conducted using mixed model analyses of variance, and chi-square analysis was used for crown class separation with Chi Square. A *p*-value of ≤ 0.05 was selected to indicate significant differences.

Crop Tree Management

In 1993, a naturally occurring, 40-year-old, well-stocked upland hardwood stand, dominated by white oak (*Q. alba* L.), was selected for fertilization, release, and combination treatments. The stand was divided into twenty 0.4-ha randomized, complete, blocks. Thirty-six cells were established on each block in a 10.7- by 10.7- m grid. The best tree was chosen inside that grid and where possible, a white oak was chosen. Of 720 cells, 653 cells were filled with a suitable crop tree, with 445 containing white oak.

Three treatments were applied:

1) Fertilization applied at rate of 68 kg of available nitrogen per 0.4 ha, and phosphorous, applied as triple super phosphate, at a rate of 13.6 kg per 0.4 kg

2) Release based on at least three sides of the crown freed from immediate competition

3) Combination of both treatments

In 2003, 10 years after treatments were applied, the study was re-measured.

RESULTS

Hardwood Seed Orchards

Seeding seed orchard or genetic tests intended for conversion to seedling seed orchards of 22 hardwood species have been created since 1999 on the Ames Plantation and are now collectively referred to as the Margaret Finley Shackelford Hardwood Seed Orchards. The Shackelford Orchards encompass species important for timber production, wildlife habitat, and mast production, and a variety of species that can inhabit very wet sites [e.g., overcup oak (*Q. lyrata* Walter)] to dry site species [e.g., southern red oak (*Q. falcata* Michx.)], reflecting the site diversity of the western Tennessee area. Some of the Shackelford Orchards are now producing enough acorns for species enrichment plantings, reforestation on a landscape scale, and precision forestry studies (table 2). The seed orchards are located on various sites that match the silvics of each species and encompass 40.5 ha, surrounded by electric fences to protect the trees from deer herbivory and seed predation.

As the genetic tests are converted to orchards, selections are made for traits important to both timber and acorn production. For example, the water oak (*Q. nigra* L.) orchard contains some trees that produce relatively small acorns, e.g., 0.64 cm in diameter, preferred by wild turkey (*Meleagris gallopavo* L.) (cf. Minser and others 1995), and small enough for consumption by bobwhite quail (*Colinus virginianus* L.). In addition, observations of acorn retention in the water oak orchard have revealed a subset of trees that delay dropping acorns until late January and early February, thereby extending the availability of relatively fresh mast.

Grafting of either wildlife or timber selections, depending on the orchard species, will occur with establishment of a grafted orchard at another location. Following establishment of the grafted orchard, those selections will be cut from the mother orchard, resulting in two orchards, one for timber production and one wildlife-oriented, from the original genetic test.

Stand Enrichment Using Artificial Regeneration

At the end of the 11th growing season, 1,036 cherrybark oaks and 997 of the swamp chestnut oaks were alive, and survival rates (88 percent and 84 percent, respectively) were significantly different. Cherrybark oak height growth averaged 7.4 m and was statistically different than swamp chestnut oak height growth (5.8 m). Average height for both species over the course of the study is shown in figure 1.

Crop Tree Enhancement

Average 10-year diameter growth in the respective treatments was: control (5.0 cm), fertilize (5.8 cm), release (7.9 cm), and combination treatment (9.1 cm), which were statistically different from each other (Twillmann 2004).

In a more striking contrast, 10-year volume growth was: control [1.12 m^3 (487 board feet)], fertilize [1.76 m^3 (746 board feet)], release [2.02 m^3 (858 board feet)], and combination [3.27 m^3 (1,385 board feet)]. Modeling indicated significant differences among treatments were maintained for grade 1 lumber to the 80-year mark (fig. 2).

DISCUSSION

Hardwood Seed Orchards

The development of hardwood seedling seed orchards that will produce locally adapted, genetically improved seed for western Tennessee, northern Mississippi, and eastern Arkansas will serve this area for decades to come. Forestry operations in western Tennessee and associated areas will have an opportunity to incorporate seedlings originating from the orchards to enrich

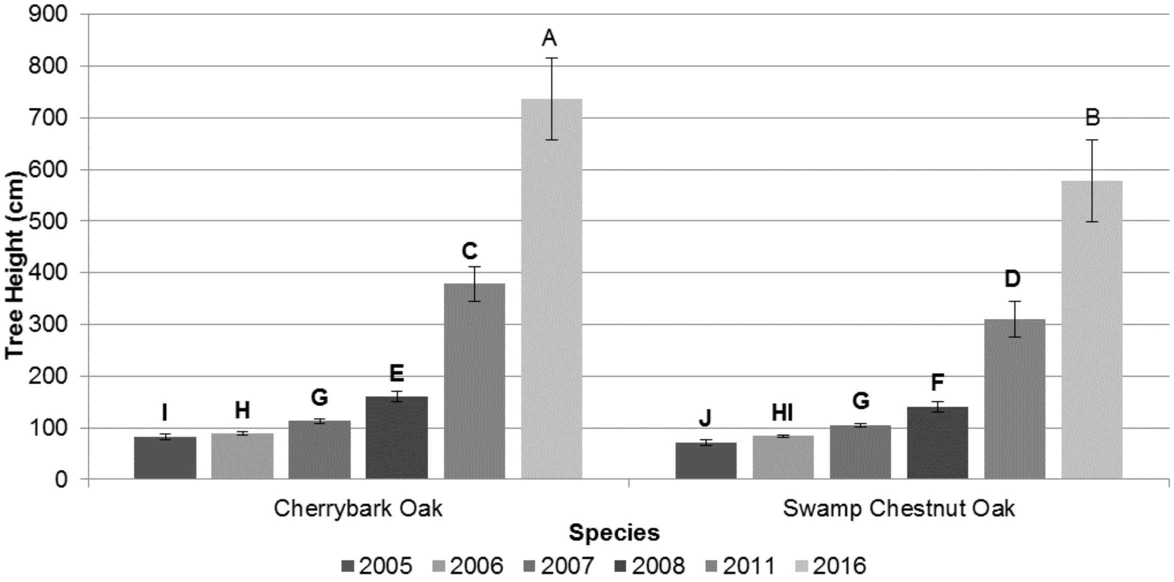

Figure 1—Height growth of cherrybark and swamp chestnut oak, over five sites at the Ames Plantation. Out of the original 2,387 planted trees, a total of 830 trees had achieved either a dominant or codominant crown class, and about 80 percent of these were evaluated as being free-to-grow (53 percent cherrybark oak and 28 percent swamp chestnut oak). Some cherrybark oaks exceeded 12 m in height and 11 cm diameter at breast height.

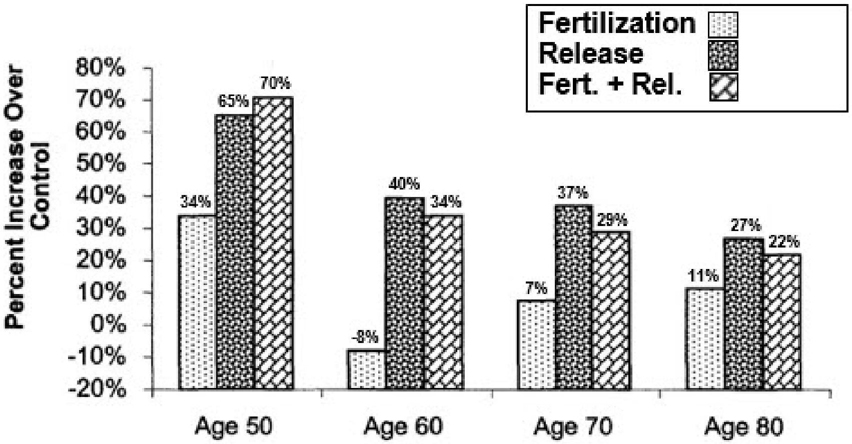

Figure 2—Model showing maintenance of grade 1 sawtimber 40 years beyond Crop Tree Enhancement treatments on the Ames Plantation (Twillmann 2004).

selected species following different types of harvests or to fill natural forest gaps and openings. Additionally, landscape-level restoration with mixed species of appropriate seed source will be readily possible following natural disasters such as tornados or for creating new forests on former marginal agricultural fields.

The Shackelford orchards will provide the Ames Plantation and associated scientists with unique opportunities to initiate a variety of forestry and wildlife studies using pedigreed seedlings from either a single or a mixture of species, depending on the study objective(s). Highly characterized pedigreed orchard-origin seedlings will be used in species enhancement and precision forestry studies and for genetic studies in post-harvest and open field conditions. Evaluation of pedigreed seedlings in such studies will allow for actual genetic gain to be calculated for the seed orchards, as well as for orchard refinement to maximize gain. The orchards themselves will contribute to hardwood seed orchard management protocols, as well as to a better understanding of reproductive biology of hardwood species. Experimental and practical use of orchard-derived seedlings will provide for state-of-the-art forestry field days and workshops, as well as unique learning opportunities for undergraduate and graduate students. Aside from research implications, Shackelford orchard seedlings will be routinely integrated into Ames Plantation forestry operations. The availability of seedlings with appropriate seed source, genetically improved for specific uses and of sufficient quality to withstand the challenges of field planting without post-planting management, will allow Ames Plantation managers to plan land use with more precision.

Stand Enrichment Using Artificial Regeneration

The results of this study are very encouraging for stand enrichment with specific species though planting. Partial or complete planting failure is prohibitively expensive to landowners. If the regeneration phase of a hardwood stand does not develop as planned, it represents a long-term failure, given the relatively long rotations in hardwood stands grown for sawtimber. In this study, about half of all surviving cherrybark oaks and a quarter of the swamp chestnut oaks have achieved dominant or codominant classes. For both species combined, there were 189 planted trees per ha (76 planted trees per acre) having a crown position rated as free-to-grow. Even within the justifiable uncertainties of juvenile:mature correlations, this number of 11-year-old successful trees supports a reasonable prediction for a mature stand having a much larger component of oak than what is naturally occurring (i.e., a stand dominated by sycamore and sweetgum). If only 95 oaks per ha persist to maturity it would very closely match the number chosen for the crop tree enhancement work at 89 trees per ha (36 trees per acre), and the planted trees would occupy about half of the upper canopy.

Although it is tempting to envision using species enhancement to produce essentially oak plantations, that is not a desired outcome of this research. Evaluation of these studies is focused on the objective of having enough artificially established trees present at maturity to impact stand diversity in such way to add value, in terms of timber income, wildlife support, ecological integrity, and aesthetics. It is a concept best envisioned as species enrichment of the developing stand.

Crop Tree Management

A number of studies have reported the value of fertilization and release treatments on mid-rotation hardwood stands (Kochenderfer and others 2001; LeDoux and Miller 2008; Miller 2000; Miller and Stringer 2004; Miller and others 2007; Perkey and others 1993, 2011). Our study is still ongoing, and the results shown here are only a portion of a range of similar work strongly suggesting that selection of a subset of the best trees at mid-rotation in a natural stand and using fertilization and/or release can significantly increase growth.

Intuitively, there is a strong inference that selection of the best trees in the species enhancement experiments at some point(s) in the mid-rotation for crop tree enhancement could accelerate growth. Correspondingly, this would accomplish two things:

1) Rotation would be shortened; and

2) The stand would be dominated with a consciously chosen component.

SUMMARY

The integration of seed orchard products, enrichment plantings, and crop tree management at the Ames Plantation is directed toward a rotation-length set of silvicultural treatments to improve naturally forming hardwood stands, allowing the ability to address global markets, impact of invasive pests, ecosystem services, societal needs, wildlife populations, and ecological parameters on a more precise level than natural regeneration systems can regularly provide. Additionally, this system has potential to enable a more agile response to changing weather patterns and associated shifts in site classifications.

The integration of these three areas of research forms a basis for forest design, similar in concept to plantation management, but tremendously more complex when species:site relationships and the vertical structuring of the forest by shade tolerance are considered, in reference to a central goal to improve composition but also maintain diversity. It is a silvicultural system of enrichment where the composition of the mature stand is significantly impacted in the initial stages of regeneration by embedding a domesticated component into the naturally forming matrix and, at mid-rotation, selecting a portion of the successful trees to favor with release and/or fertilization treatments.

Over time, this system will become more refined as further experimentation with greater precision in experimental materials and site characterization will yield more information on interactions among pedigree, site, and silvicultural protocols. The system lends itself well for experiments that provide information pertinent to seed orchard refinements as well as exploring new approaches to hardwood management, especially where forest diversity might be, to a reasonable extent, designed with the injection of pedigreed, artificial regeneration into naturally developing systems. Through practical use of this system, we believe the Ames Plantation forests can become a prototype for the blending of natural and domesticated hardwood forests. It is a system applied over the life of the stand and, with targeted objectives, has similarities to precision agriculture. In consideration of the experimental and practical aspects of this effort, along with the increasing scale of the project, we have decided to refer to it as the "Ames Plantation Hardwood Laboratory."

ACKNOWLEDGMENTS

The authors thank the Margaret Finley Shackelford Charitable Trust for supporting hardwood seed orchard development and precision forestry research on the Ames Plantation and, in particular, recognizing the foresight of the past and present Trust Advisors, Mr. Paul Calame, Mrs. Nancy Smith, Mr. Carlyle Blakeney, Mr. Orma Smith, and Mr. Clayton Stanley, for taking a leap of faith in recommending and continuing funding for this work. The authors are also indebted to the Trustees of the Hobart Ames Foundation for providing labor, housing, and equipment and dedicating the enormous land and forest resources required to develop a Hardwood Laboratory.

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ARTIFICAL REGENERATION ON THE NORTH CUMBERLAND WILDLIFE MANAGEMENT AREA IN TENNESSEE

Joe Elkins

Extended abstract—The primary objective of the Tennessee Wildlife Resources Agency (TWRA) forest management program is to create and maintain a healthy forest with a diversity of wildlife habitats. This goal is accomplished through a variety of silvicultural treatments which include forest regeneration, forest thinning, prescribed burning, and artificial regeneration. One challenge faced by TWRA and many land managers is the lack of oak regeneration and the loss of the oak component in regenerated stands. Artificial oak regeneration is one technique the Tennessee Wildlife Resources Agency is exploring to restore or enrich the oak component of harvested stands.

Forest inventory is the first step in creating a management plan and is the basis for silvicultural decisions. From this inventory we determine species composition, size class, basal area, trees per acre, site index, and forest health. One unique aspect of the TWRA forest management program is that we look to regenerate stands that exhibit the worst qualities such as low stocking, poor species composition, wild fire damage, and evidence of past high grading. By regenerating these stands we can produce quality early successional forest habitat for wildlife while improving forest stand quality. The problem occurs when trying to determine the best means of regeneration that will produce a stand with at least a component of oak species. Lack of oak regeneration often prohibits a silvicultural clear cut. Lack of preferred canopy trees rules out a shelterwood harvest. The lack of manpower and funding make it impossible to enter these stands repeatedly for multiple intermediate treatments.

In an attempt to address these concerns TWRA began using artificial oak regeneration. Beginning in 2006, 18 forest stands consisting of 265 acres on upland hardwood sites have been planted post-harvest with various oak species. Seedlings used were grown from local seed source and species were selected based on existing composition of surrounding stands. Seedlings were graded at the nursery prior to shipment. Planting was supervised by TWRA foresters and conducted by professional contract planters. Plantings were conducted as part of different regeneration methods such as silvicultural clear cut and shelterwood. Post planting survival checks were conducted within a year of planting with an average survival of 85 percent. Further data will be collected as part of the normal compartment reentry schedule every 10 years.

As the earliest plantings have begun to be re-inventoried, the results seem promising. In these stands the goal of establishing at least a component of oak species in stands with little to no oak regeneration has been accomplished. As more stands mature to the point of reentry, we will have a better idea of the overall success. The intent of the program was not research. The goal was to be a working example of how artificial oak regeneration may have a place on a working forest.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

SESSION 5:

Wood Products and Economic Markets

Moderator:

Matt Bumgardner
USDA Forest Service, Northern Research Station

OVERVIEW OF OAK MARKETS AND MARKETING

Matthew Bumgardner

Abstract—The height of oak popularity in the U.S. marketplace came in the early 1990s as the furniture and cabinet industries made use of large quantities of oak in their designs, especially red oak. This familiarity has led to a consumer awareness for oak that surpasses other commercial hardwood species. More recently, however, oak's position in many U.S. fashion-based markets has waned (flooring being an exception), and oak log and lumber exports have surged. Exports of U.S. red oak lumber alone surpassed 520 million board feet in 2017, which was a record for any species exported from the United States. Over 70 percent of current U.S. red oak lumber exports go to China while export markets for white oak are more diverse. Industrial markets such as pallets and railway ties also have been critical for oak utilization, especially after the Great Recession and associated housing market decline.

INTRODUCTION

Red oak (*Quercus* spp. subgenus *Erythrobalanus* but primarily northern red oak or *Q. rubra*) is the leading species of hardwood lumber derived from eastern hardwood forests on a volume basis, and white oak (subgenus *Leucobalanus* but primarily *Q. alba*) is close to yellow-poplar (*Liriodendron tulipifera*) as the next most important species produced in the United States (U.S. Census Bureau 2009). However, there have been changes in oak markets in recent years, and the users of oak products also have changed. The objective of this paper is to provide an overview of these changes in oak markets and discuss some of the implications for oak management and use in the future. The focus will be on lumber and the secondary products manufactured from oak lumber.

OAKS IN THE U.S. MARKETPLACE

The height of oak popularity in the U.S. marketplace came in the early 1990s as the furniture and cabinet industries made use of large quantities of oak in their designs, especially red oak. For example, showings of oak at the High Point Furniture Market peaked around 1990 when 30 percent of the furniture groups shown were oak (Luppold and Bumgardner 2007). This percentage had declined to 15 percent by 2005 as other species increased in popularity. Oak also has been shown to comprise a relatively small percentage of showings at more recent High Point Furniture Markets, with red oak constituting <5 percent of dining room showings and white oak <7 percent of the bedroom showings in the spring of 2014 (Appalachian Hardwood Manufacturers, Inc. 2014).

The relatively recent widespread use of and exposure to oak seem to have led to familiarity among consumers, as awareness of oak seems to surpass other hardwood species. For example, research has shown that consumers are most able to identify oak among several other commonly used species. In a study of consumers interviewed at two home shows in the Pacific Northwest (Seattle and Portland), 60 percent correctly identified a red oak wood sample. However, species knowledge dropped sharply after oak with just 18 percent correctly identifying cherry (*Prunus serotina*) and 15 percent correctly identifying hard maple (*Acer saccahrum*) (Bumgardner and others 2007). In another study of consumers interviewed at several furniture stores and trade shows in Wisconsin (Madison and Milwaukee), it was similarly found that red oak was correctly identified nearly 50 percent of the time, which was just higher than walnut (*Juglans nigra*) and nearly 30 percentage points higher than both cherry and hard maple (Bowe and Bumgardner 2004). Others also have found that oak was relatively more easy for consumers to identify than other hardwoods (Swearingen and others 1998).

Oak also holds a distinct perceptional space. Blomgren (1965) noted that oak had the most specific-species image among the consumers he studied in a perception-based study. More recently, consumers have been shown to perceive oak as warm, expensive, durable, sustainable, and stately (Bowe and Bumgardner 2004). However, a study based on a different population, college students, revealed slightly different results. In that study (Bumgardner and Bowe 2002), word-based perceptions of oak were formal, warm, expensive,

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

and stately. However, appearance-based perceptions were casual, cold, inexpensive, and modest. Thus, it was concluded that oak held a positive "reputation" that outweighed its actual appearance among college students.

There are implications to the above findings for oak promotion and marketing. Perhaps the biggest one is that oak has a more positive perception in word than in actual appearance, but this effect is greater among younger people than adults. For adults, there was less difference between word-based and appearance-based perceptions, and oak was generally viewed favorably. This could correspond to adults' observed greater ability to correctly identify oak wood samples than college students—oak has a more positive reputation among college students, but this changes when it is viewed, while adults know oak and generally view it favorably. Perhaps there is a generational component to this trend given the popularity of oak in the 1990s. It also reinforces the notion that hardwoods used in appearance-based applications ultimately are a fashion product that can go into and out of favor at different points in time. Although oak's position in many U.S. fashion-based markets has waned of late, red and white oak are leading species used in solid wood flooring production (Hardwood Market Report 2018).

Industrial markets such as pallets, railway ties, furniture framing, and board road/timber mats also are critical for oak utilization, and this was especially true after the Great Recession and associated housing market decline. In these markets, fashion and consumer income are less important than trends in the overall economy and functionality. Red oak in particular is useful in railway tie production due to its relative treatability. A recent study showed the importance of industrial markets (defined as pallets and railway ties) to the hardwood industry. In 2009, industrial uses accounted for 54 percent of domestic consumption (excluding exports), up from 43 percent in 2006 and 38 percent in 1999 (Luppold and Bumgardner 2016a). Industrial manufacturing sectors also were the first to recover from the recession in terms of employment. Employment in the pallet sector began to improve on an annual basis in 2011, while the cabinet and millwork sectors did not show an increasing trend in employment until 2013 (Luppold and Bumgardner 2016b). This suggests that industrial markets were associated more with the overall economy, while appearance-based hardwood markets were related more to housing and remodeling that lagged in recovery.

OAK EXPORTS

Although use of oak has declined in many U.S. appearance-based markets, oak log and lumber exports have surged. Overall exports of U.S. hardwood lumber (all species) reached record highs for both volume (1.9 billion board feet) and value ($2.6 billion) in 2017 (table 1). Much of this exported lumber is mid-to higher grade material destined for use in appearance-based applications, although some white oak exports are used in wine and whiskey barrels. Exports of U.S. red oak lumber alone surpassed 520 million board feet (MMBF) in 2017, which was a record for any individual hardwood species exported from the United States. The year 2017 also was a record year for U.S. red oak log exports (USDA Foreign Agricultural Service 2018). Table 1 shows the top five hardwood lumber species exported in 2017 by volume and value. The oaks accounted for 44 percent of the export volume and 48 percent of the export value. Although these percentages for oak have been larger in the past (e.g., oak as a percent of total volume was nearly 59 percent in 1990), the volume of oak lumber exported was 1.7 times higher in 2017 than in 1990 (USDA Foreign Agricultural Service 2018).

Table 1—Top five U.S. hardwood lumber export species by volume and value in 2017[a, b]

Species	Volume	Rank	Value	Rank
	million board feet		*million $*	
Red oak	521	1	757	1
Yellow-poplar	321	2	290	3
White oak	303	3	509	2
Ash	185	4	281	4
Walnut	91	5	258	5
Total of all species[c]	1,885	—	2,640	—

[a] Eastern species only; western red alder (*Alnus rubra*) was the fifth largest export species by volume in 2017 (94 MMBF).

[b] Data source: USDA Foreign Agricultural Service (2018).

[c] Including species not shown in the top five.

— = Not applicable.

Most of the red oak lumber exported from the United States goes to China, and this percentage has been increasing in recent years. As shown in table 2, over 73 percent of red oak lumber exports went to China in 2017, up from 28 percent in 2009 (USDA Foreign Agricultural Service 2018). Red oak exports to China were approaching 400 MMBF in 2017. Export markets for U.S. white oak lumber are more diverse, with 38 percent going to China in 2017, which was the leading market. However, even for white oak, China's share of the export market was 31 percent in 2016, meaning that China's share increased by 7 percentage points in just 1 year. Other major markets for U.S. white oak lumber exports include the United Kingdom, Vietnam, Canada, and Spain, which collectively accounted for over 32 percent of the volume in 2017.

CONCLUSION

In the early 1990s, oak was the leading species for use in the domestic furniture and related industries, and oak maintains a positive perception among many consumers today. The popularity of oak in appearance-based applications in the United States has declined in recent years, however, while oak log and lumber exports have increased. One implication is that consumer perceptions and acceptance of oak in other global economies is becoming increasingly important to oak marketing. In the United States, industrial and flooring markets for oak remain strong, as well as specialty uses such as barrels. Additionally, the fashion aspect of the furniture and related industries suggests that oak could cycle into increased popularity again in the United States in the future. For example, the popularity of solid oak flooring keeps oak in view in many homes. Red and white oak are leading lumber species produced from U.S. hardwood forests. Thus it remains critical to industry and forest managers alike to develop silvicultural systems that encourage oak regeneration and survival.

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Table 2—Red oak lumber exports to major trading partners and China's share of the total, 2009–2017[a]

Year	China	Canada	Mexico	Rest of world	China share
	------------------------- *MMBF*			------------------------------	*percent*
2009	40.5	65.7	14.3	21.5	28.5
2010	63.5	81.7	14.5	29.4	33.6
2011	106.5	69.1	16.8	34.3	47.0
2012	126.2	75.6	18.4	29.2	50.6
2013	190.6	69.3	25.3	30.9	60.3
2014	227.0	79.2	22.7	35.8	62.2
2015	244.2	69.5	22.6	39.3	65.0
2016	310.0	70.7	21.7	40.0	70.1
2017	383.9	72.9	20.0	44.7	73.6

[a] Data source: USDA Foreign Agricultural Service (2018).

CONSIDERATIONS IN THE UTILIZATION OF OAK

Brian H. Bond

Abstract—The commercial groupings of red and white oak make up the majority of timber in the central hardwood region. Getting the highest value during utilization is important for the management of forests, forest landowners, and the regional economy; therefore, understanding the limitations of the raw material and proper handling and processing is critical. This paper focuses on a description of material limitations, such as: mineral stain, bacterial infection, and why differences in price exist for the "same" material. Utilization considerations, such as reducing log yard degrade, phytosanitation requirements for log shipments overseas, longer drying times, drying methods used, and difficulty with checking will also be discussed.

INTRODUCTION

In the central hardwood region, the commercial groupings of red and white oak make up the majority of timber, and getting the highest value during utilization is important for the management of forests, forest landowners, and the regional economy. Nationwide, it is estimated that red and white oak account for 41 percent of all hardwood lumber produced (U.S. Census Bureau 2011). The oaks are a preferred species for products ranging from furniture, cabinets, millwork, caskets, and flooring to industrial products such as railroad ties, mine timbers, pallets, blocking, and industrial and truck flooring. Both species are well suited to secondary products as they tend to machine well, process well, and glue, stain, and finish well. They are typically straight grained and steam bend well (Cassens 2007).

Achieving the highest value requires an understanding of the limitations of the raw material, proper handling methods, and processing. Raw material variability and processing inconsistencies can limit the value recovered. Examples of raw material variability include: density/specific gravity, anatomy, and growth site and location. Taking a closer look at the two groupings of oak will help to understand some of the variability of the species.

DEFINING OAK AND LIMITATIONS

In the forest industry, oaks are commonly classified into two categories: red oak and white oak. These classifications are commercial classifications based on similarity of the anatomical properties of the tree and wood. Multiple species fall into each commercial category, for example, there are 17 species considered in the red oak commercial classification. An example of eight red oak species and their properties are listed in table 1. The variability is reflected in stumpage prices paid for timber sales that have higher proportions of one or another of the species in a species group. For example, for a given log size, diameter, and number of clear faces, scarlet oak often is valued lower than other species in the red oak grouping. In the white oak grouping, chestnut oak is not accepted for barrel stave production due to its lack of consistent tyloses. Interestingly, once sawn, scarlet oak will be mixed with the lumber produced from other species and sold as red oak lumber, and chestnut oak will be sold intermixed with white oak lumber.

The variability within each of the two species groups is further exemplified by the differences in the value given to the lumber based on the location where it was grown which can influence average growth rates (Shmulsky and Jones 2011), species composition, and perceived quality. The value of lumber for the same commercial grouping is shown in price reports to vary by its production region; three common price categories for lumber produced for red and white oak are Appalachian, Northern, and Southern (Hardwood Market Report 2017).

Other material limitations for the red oak group include the presence/absence and percentage of material that includes mineral stain or bacterial infection. Both of these defects reduce the value of the raw material and the quality of the lumber produced. They can also influence the quality of the lumber when it is processed through drying operations.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

Mineral Stain

Mineral streak/stain in red oak is a common visual defect. The dark discolorations of undetermined origin may be present in a portion of a growth ring or in small patchy clusters either within the sapwood, heartwood, or both. These areas reduce the value of both logs and lumber. Log buyers often deduct a log with mineral stain by one log grade, and veneer buyers will often entirely avoid logs with mineral stain, even when all four faces are clear of knots and other defects. While mineral streak is not considered a lumber grade defect in National Hardwood Lumber grading rules, it is often considered a defect by the purchaser. Many purchasers will specify that mineral stain is to be considered a defect in the purchase order. Mineral stain is also commonly considered a defect in export markets. This defect is associated with increased tool wear when machining and increased checking when drying (Sachs and others 1966). Mineral stain in the finished product is often considered undesirable and of lower quality and value. In one study, approximately 25 percent of #1 Common and 33 percent of #2 Common oak flooring was determined to be downgraded because of mineral stains and streaks (Bulgrin 1965).

A tool to help foresters predict where mineral stain would occur in red oak would allow for better value estimation of timber stands. Work to develop such a tool was conducted in the Appalachian Mountains of Virginia and West Virginia. Researchers focused on geographic and growth site factors selected through a literature search and a survey of foresters who purchased stands for harvesting. Then, the presence and severity of mineral stain in red oak were sampled at eight locations and correlated to growth site variables collected in the field and derived from spatial datasets (table 2). A statistical model was developed to predict mineral stain presence, which determined that elevation, slope angle, solar radiation, flow accumulation (hydrologic analyses), and cardinal direction contributed the most to the presence or absence of mineral stain in red oak for the sites studied. The values of the model coefficients suggested that the probability of staining was highest when the tree is on a relatively flat part of the ground, which receives more water and little sunlight to evaporate the moisture. Although the model did explain a large amount of the variation in the presence/absence of mineral stain, it was clear that some important variables were not included or that some variables measured did not contain enough contrast to provide a clearer picture of their contribution (Bond and Resler 2012).

Bacterial Infection

Another site-related defect that can reduce the quality and value of red oaks is the presence of bacterial infection. An anaerobic bacterium known as *Clostridium* spp. can enter the living tree through the roots, slowly moving up the log over time (Ward and Groom 1983).

The bacteria are most commonly found in the butt log of a tree, the log which usually has the highest volume, quality, and value wood material. Wood that is

Table 1—An example of eight species considered in the red oak commercial classification and four important properties (specific gravity, modulus of rupture, modulus of elasticity, hardness) (Ross 2010)

	SG^a	MOR^b	MOE^c	Hardness
		lb/in^2	*x 106 lb/in*^{2}	*lbs*
Black	0.61	13,900	13.7	1,210
Cherrybark	0.68	18,100	18.3	1,480
Laurel	0.63	12,600	11.8	1,210
Northern red	0.63	14,300	14.5	1,290
Pin	0.63	14,000	14.8	1,510
Scarlet	0.67	17,400	20.5	1,400
Southern red	0.59	10,900	9.4	1,060
Water	0.63	15,400	21.5	1,190

[a] SG = specific gravity.

[b] MOR = modulus of rupture.

[c] MOE = modulus of elasticity.

Table 2—Field and GIS-derived variables measured in Bond and Resler's (2012) study of mineral stain in red oak (variables written in bold font were found to be significant)

Field- or GIS-derived	Variable
Field	Longitude/latitude
Field (GPS)	**Elevation**
Field	Visual damage
GIS	**Cardinal direction**
Field	Age of tree
Field	Calcium (Ca)
Field	pH
Field	Potassium (K)
Field	Phosphorus (P)
Field	Zinc (Zn)
Field	Magnesium (Mg)
Field	Copper (Cu)
Field	Iron (Fe)
Field	**Slope angle**
GIS	**Flow accumulation**
GIS	**Solar radiation**

bacterially infected often contains large amounts of ring shake thus reducing the value of logs and lumber. When lumber containing the bacterial infection is processed, if often has a higher incidence of honey comb, surface checks, and pockets of wood with higher moisture contents (Ward and Groom 1983). While there are methods that can identify the presence of bacterially infected wood, none are commercially practical for the commercial forester or wood processor to use in a production environment. The techniques that have shown promise for bacterial infection detection include stress wave analysis, near-infrared spectroscopy (NIR), and laser fluorescence (Murdoch 1992). Extremely high moisture content, strong odor, and the presence of ring shake have been associated with bacterial infection but have not proven effective for commercial sorting of infected material.

Export Limitations

A large volume of oak is exported in log form (table 3), and understanding the limitations for exporting this material is also important for its utilization. Red and white oak logs are required to be sterilized/fumigated at the port of exit to prevent the transport of insects or other biological organisms. The most common method of sterilization/fumigation is the treatment of containers with methyl bromide at the port of exit. Methyl bromide is considered an ozone-depleting substance, and the Environmental Protection Agency has established site-specific usage restrictions and is providing incentives to develop alternatives to its use. The long-term goal is to eliminate its use (EPA 2017). Sterilization/fumigation requirements have been developed by the U.S. Department of Agriculture and are available in the Treatment Manual (USDA 2016). The standards vary for different species and types of biological organisms being addressed. The problem with fumigation as the currently accepted method for sterilization is that the cost of methyl bromide is increasing as its allowable uses are scaled back. Also, the treatment times are typically long (72 hours) and limited by temperature (must be above 4.44 °C).

While heat treatment standards exist as an alternative, the time period required to heat a log to the required temperatures are excessive with standard conventional heating methods, which use convection to apply heat to the log surface. There are currently no commercial applications of heat sterilization of logs. However, a method using vacuum/steam heating has recently been developed and can treat logs effectively, meeting the current standards in less than a 24-hour time period. Treatment times are dependent on the size of the log, the species, and the treatment standard required. The vacuum/steam treatment has been shown to be effective meeting the 56 °C/30-minute sterilization requirement for logs 46 to 53 cm (small-end diameter) using an initial vacuum of 200 mmHg, with a temperature of 90 °C applied over 24 hours; no adverse effect on the quality or yield of veneer produced occurred (Chen and others 2017). The same equipment has demonstrated its effectiveness on oak wilt, meeting the 56 °C/30-minute treatment standard and the 60 °C/60-minute standard at 2-inch depth with an initial vacuum of 100 mmHG. The average treatment time to 56 °C/30 minutes was 6.4 hours, and the average treatment time to 60 °C/60 minutes was 8.2 hours (White and Chen 2016). This new treatment method creates an opportunity for not only lower cost treatment of oak logs for export but also shorter treatment times.

Drying

Oak lumber must be dried before use in secondary products. Both red and white oak are relatively dense and have wide wood rays. These two characteristics require a slower drying process with a reduced rate of moisture content loss per day relative to other North American hardwood species. Drying too fast results in high drying stresses due to the large moisture content gradient that can form as a result of slow moisture transfer, in part, due to its high density. The wide wood rays result in lower strength perpendicular to grain in the tangential plane of reference. The combination results in a propensity to split on the ends and to surface check, at the wood ray, when dried at too high a rate. Therefore, oak must be dried slowly, resulting in higher cost of drying. Kiln drying times for 4/4 red oak lumber that is put into the kiln directly after being sawn are commonly 28–35 days (table 4) (Denig and others 2000). The kiln drying times can be shortened by air drying or pre-drying, both of which still require that large inventories be carried to fill the kilns as they cycle, adding to the cost of drying.

A potential solution to overcome the longer drying times for the oaks is the use of vacuum drying. Vacuum drying can significantly reduce the drying time, drying costs, and potential for defects. Depending on the vacuum technology used, drying times for 4/4 red oak can be reduced from 28–35 days to 3 to 9 days (Brenes-Angulo

Table 3—Log exports from the United States in 2011 (Luppold and Bumgardner 2013)

Species	Volume	Number of logs	Number of 40-foot containers
Red oak	223,000 m^3	300,000	6,700
White oak	229,000 m^3	305,000	6,700

Table 4—Drying times for 4/4 and 8/4 red oak using conventional drying methods versus vacuum

Species and thickness	Conventional kiln drying time (green condition)	Vacuum (dependent on technology)
Red oak 4/4	28–35 days	3–9 days
Red oak 8/4	46–53 days	4–6 days

and others 2015). One of the drawbacks to industry acceptance of vacuum kilns is the high cost of the kiln and limited capacity compared to conventional dry kilns. However, research based on the use of this technology in flooring production has demonstrated the high initial capital cost can be offset by a lumber drying inventory reduction, from 52 to 58 percent. The work-in-process inventory could also be reduced up to 50 percent. Most importantly, a company's lead time, the time from the placement of an order to shipment, could be reduced 78–90 percent (Brenes-Angulo and others 2015). The operational costs of drying were estimated to not be significantly different between vacuum and conventional drying technology (Brenes-Angulo and others 2017). It should be noted that the conventional drying technology compared was air drying for 30 days and then kiln drying to the target moisture content. Not only has research demonstrated the ability of vacuum drying to be used on a large commercial scale for 4/4 hardwood lumber, but as of 2017 two large commercial secondary processing operations, a large national flooring company and a cabinet company, have begun to implement the technology to meet specific species production requirements.

SUMMARY

Understanding the limitations of a particular species is important to understanding the value of the material and the markets that utilize the material. In this paper, I have tried to demonstrate how variations in red and white oak influence their value and processing. While difficulties associated with their utilization exist, I have also tried to present some technologies that have been or are being developed to overcome these limitations and thus assure a bright future for oaks' continued utilization and value.

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SESSION 6:

Silviculture to Restore Oak Woodlands

Moderator:

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APPLIED HISTORICAL ECOLOGY: BRINGING PERSPECTIVE AND QUESTIONS ABOUT OAK WOODLAND ECOLOGY AND MANAGEMENT

Michael C. Stambaugh, Daniel C. Dey, and Benjamin O. Knapp

Extended abstract—Prior to and during Euro-American settlement (EAS), the structure and composition of many forest communities throughout the United States were mediated by frequent and recurring fires. A major ecological consequence of 19th- to 20th-century era of fire suppression has been the alteration of these fire regimes, often resulting in increased woody vegetation density (Nowacki and Abrams 2008). Another major consequence has been that little cultural or experiential knowledge about the ecology and management of these fire-mediated communities was preserved or passed down to future generations. Thus, reliable and long-term information is needed to understand the past to better manage natural resources into the future.

A model for how to address these information needs lies within the discipline of applied historical ecology. Applied historical ecology is the use of long-term information in natural resource management (Allen and others 1998, Swetnam and others 1999). Applied historical ecology draws on multiple information sources such as natural archives, forest inventories, and remote sensing. Long records from natural archives provide a unique contribution to ecological understanding because they significantly lengthen temporal scales of observations, thus enhancing the ability to identify features such as slow changing processes (e.g., decadal variability in moisture regimes) and infrequent, yet ecologically important events (e.g., a high severity fire).

Applied historical ecology is often erroneously simplified as aiming to identify and promote restoring some past condition. Rather, the discipline aims to identify the range of past conditions and, from this, improve the ability to set achievable and sustainable management goals. Interest in applied historical ecology has increased in recent decades, especially as a result of forest restoration and ecosystem management directives. Although an alternative to applied historical ecology could be conducting long-term experiments, in many cases, decision-making related to managing natural resources cannot afford the time lag or replication investment required to obtain results.

Management of oak woodlands in the Central United States is an excellent subject for discussing the value of applied historical ecology. Oak woodlands were historically a fire-mediated forest structure that existed throughout North America. Oak woodlands are characterized as highly variable forest communities with a canopy of trees ranging from 30 to 100 percent closure with a sparse understory (or midstory) and a dense ground flora rich in forbs, grasses, and sedges (Nelson 2005). The historical ecology of oak woodlands in the Eastern United States is poorly understood. Further, scientists and managers have begun to recognize complex ecological and social challenges to managing woodlands with fire as they have commercial (e.g., harvesting) and non-commercial (e.g., decreased fire risk, biodiversity) values that can be conflicting.

In the Eastern United States, current understanding of the applied historical ecology of oak woodlands fits well within the current historical narrative and modern day conditions. It has been recognized that transition of closed-canopy forests to more open structured, fire-mediated woodlands has the potential to affect many taxa (Guyette and Kabrick 2002). From an ecological standpoint, these transitions in taxa are often considered positive since woodland management practices (e.g., prescribed burning, harvesting) often increase abundance of native disturbance-dependent, early-successional species, including many oaks. In the Eastern United States, restoration treatments applied to closed-canopy forests on sites of historical oak woodlands often result in significant increases in native plant diversity (e.g., from suppressed plants, seedbanks, and dormant rhizomes), including species of conservation concern.

Many different questions related to managing for woodlands in the Central United States are well-suited for an applied historical ecology approach. Some questions require a general understanding of the deep past while others benefit from also having a detailed understanding of present conditions and ecological relationships. For

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

the past, many questions remain as to the spatial extent of woodlands, how they changed in structure, and to what extent they were of anthropogenic construct. For example, in the Missouri Ozarks, most forested areas increased in tree density from mid-19th-century land surveys to present (Hanberry and others 2014). Although the greater historical extent of woodland conditions across the Eastern United States is not well known, many other regions were observed and/or given place names that emphasized woodland or savanna conditions such as the Cross Timbers ecoregion, The Big Barrens of Kentucky, and The Barrens of Tennessee. Even the current abundance of some tree species, including oaks (e.g., *Quercus stellata, Q. marilandica, Q. macrocarpa*), implies that more open canopy conditions must have occurred to perpetuate their historical existence considering that they largely fail to regenerate as more closed-canopy conditions advance.

Long-term forest and fire history data have improved knowledge of woodland ecology and will likely continue to influence interpretation of other data sources by putting them in greater temporal context. For example, in many locations, the timing of the General Land Office (GLO) surveys corresponded with the beginning of EAS. In many eastern U.S. forests, the historical ecology information from fire scar history records shows that the period during EAS corresponded to increased fire frequency and decreased fire severity from previous times. In some cases, fires during EAS were more frequent than any other time in the last 400 years. This culmination of data sources begs the question: What were the effects of this altered EAS period fire regime, and how does this timing correspond with the timing of GLO information?

Many modern day questions directly related to management practices can also be addressed by applied historical ecology. For example, a region-wide concern for oak forests is the apparent lack of oak regeneration and recruitment in locations currently dominated by an oak overstory. Outstanding, yet seemingly basic questions related to the ecology and management of oak woodlands include: In the past, did oak woodlands always exist in open-canopy conditions, or did they begin as forests that then underwent tree density reductions? Were oak woodlands predominantly even-aged, uneven-aged, or mixed? Is the disturbance regime that favors oak regeneration the same that is needed to favor its successful recruitment and survival?

In the future, as more and new demands are placed on natural resources, it will be important to revisit the relevance of historical conditions to future management. In the future, likely questions addressed by applied historical ecology include: Is there any evidence that what is desired today has existed in the past? If so: What disturbance regimes and ecological processes made this possible, and will this be feasible through management given modern day constraints? An example of this scenario is that, although frequent fire may have been important in the past, future smoke emission standards could be exceeded with the level of burning required to manage for woodland conditions. In this way, applied historical ecology may be extremely valuable to setting achievable and sustainable management goals.

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SILVICULTURE TO RESTORE OAK WOODLANDS AND SAVANNAS

Daniel C. Dey, Benjamin O. Knapp, and Michael C. Stambaugh

Abstract—We present a perspective on how to approach developing silvicultural prescriptions for restoring oak woodlands and savannas. A large degree of success depends on selecting appropriate sites for restoration. We discuss historical landscape ecology, fire history, detecting legacies of woodland/savanna structure, and models of historical vegetation surveys. Ultimately, site selection for restoration is determined by integrated management goals and objectives. We discuss silvicultural practices for restoration including prescribed burning and thinning by mechanical or chemical methods or timber harvesting. We provide an overview of fire effects on vegetation and stress how the timing and sequencing of the various practices can be used flexibly depending on site restrictions, initial vegetation condition, and threats such as invasive species. We review various fire regime attributes that managers can control in moving the vegetation toward the desired future condition. We conclude by giving a perspective on developing the restoration prescription using a holistic, integrated resource management approach.

INTRODUCTION

Oak savannas and woodlands were once significantly more prominent on eastern landscapes in the United States and Canada. Since European settlement, their loss has decreased landscape diversity and resilience, and diminished our ability to conserve and sustain native biodiversity and promote ecosystem/landscape productivity and health. We lack silvicultural strategies, prescriptions, and tools to restore these natural communities. However, we have a strong foundation in hardwood forest silviculture that we may draw upon to develop plans for restoring oak woodlands and savannas. In addition, a strong understanding of oak woodland and savanna ecology forms the critical basis for developing the silviculture needed to manage these systems. This paper discusses silviculture strategies, practices, and tools for restoration of oak natural communities including (1) positioning restoration on the landscape, (2) developing the silvicultural prescription—available practices, and (3) the restoration prescription—setting the quantitative targets.

POSITIONING RESTORATION ON THE LANDSCAPE

Landform, Topography, and Soils

Landscape patterns of oak forests, woodlands, and savannas and prairies resulted, in part, directly from the physical characteristics of landform, geology, soils, and topography, and indirectly by the effect of the landscape on disturbance regimes (Anderson and others 1999, Batek and others 1999, Nigh and Schroeder 2002, Stambaugh and Guyette 2008). Important environmental and physical site variables that influence species distribution and natural community type can be identified through landscape modeling with spatially explicit historic vegetation information (e.g., Bolliger and others 2004; Hanberry and others 2012, 2014a, 2014b, 2014c). For example, oak species that are typical of woodlands and savannas were more likely to occur on increasingly xeric sites as defined by variables such as elevation, slope, parent material, wetness index, and solar radiation in the Missouri Ozarks according to Hanberry and others (2012), who modeled species occurrence and community tree structure using General Land Office (GLO) witness tree survey data. Managers can also use vegetation and ecological classifications developed by ecologists who have reconstructed or modelled the location and extent of historic vegetation types for States and physiographic regions (e.g., Anderson and others 1999, Curtis 1959, Nigh and Schroeder 2002, Schroeder 1982).

Tree density and canopy cover may be limited on sites that are seasonally flooded (e.g., oak flatwoods) and droughty where (1) soils are shallow in depth, or where rooting volume is limited by the presence of claypans and fragipans, (2) soils are coarse textured and extremely well-drained such as those derived from sandstones,

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

and (3) soils have high rock content that limits water holding capacity and increases internal drainage. All of these soil-site features may restrict the development of forests and promote woodland and savanna communities as defined by Nelson (2010). Collectively, these site characteristics often increase the likelihood of droughts that limit tree development and fires that can create oak woodlands and savannas. Certain oak species such as post oak (*Quercus stellata*), white oak (*Q. alba*), bur oak (*Q. macrocarpa*), and chinkapin oak (*Q. muehlenbergii*) were dominant overstory trees in these systems and on these sites because of their adaptations to fire and drought, ability to resist wood decay, and longevity (Abrams 1990, Bahari and others 1985). Given a set of physical site characteristics, the nature of the fire regime would then determine the outcome, i.e., whether oak forests, woodlands, or savannas formed.

Topography/landform influences various attributes of a fire regime including fire frequency and size (fig. 1). Frequent fires—sometimes annual fires—were characteristic of the once extensive prairies in the Eastern United States (Anderson 2006, Transeau 1935). In the past, prairies occurred most often on level to gently rolling terrain (e.g., <4 percent slope) where fires could spread rapidly and extensively. As topography becomes more dissected, topographic roughness increases, and fire frequency and size decrease (Guyette and others 2006, Stambaugh and Guyette 2008). Prairies transition into savannas as the topography becomes gently rolling and headwater drainage ways begin to form. Steeply dissected topography creates landscapes that have more natural barriers to fire spread such as waterways and protected mesic north-to-east slopes, which either physically oppose the advance of fire,

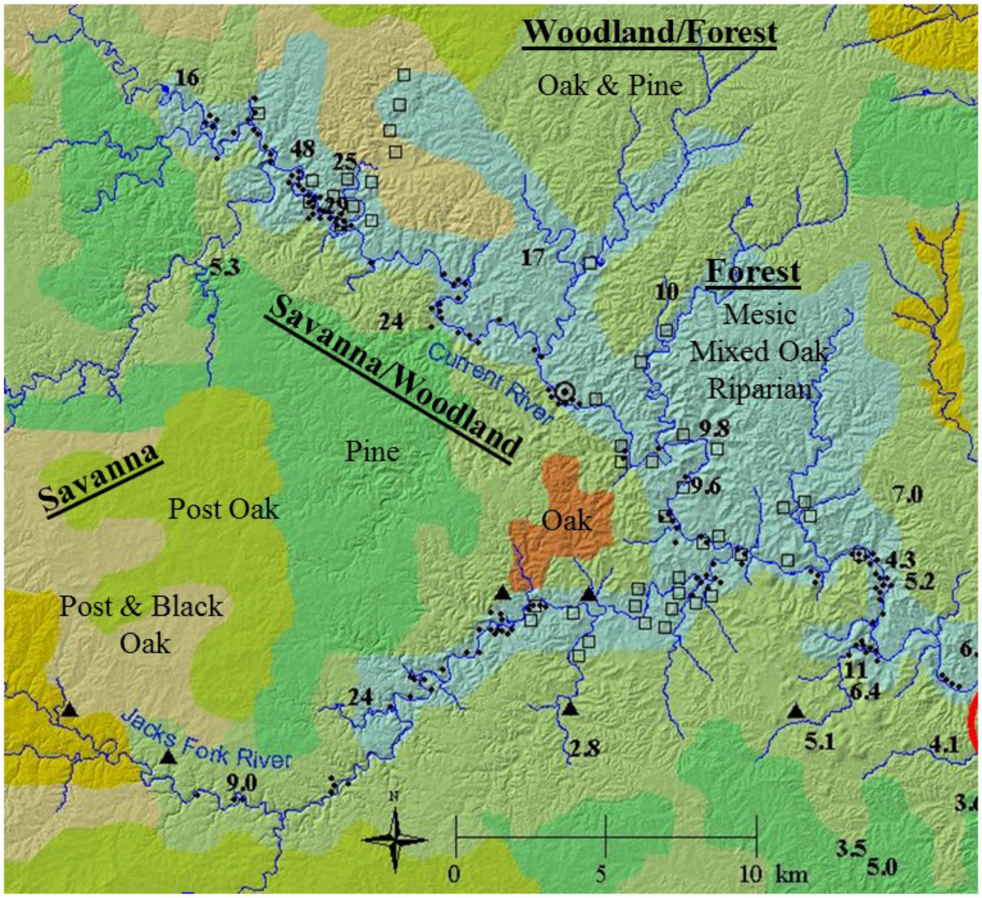

Figure 1—Topography had a strong influence on fire frequency and size before the fire suppression era. In plains and relatively flat terrain, fires were more frequent and larger in size resulting in prairie, or oak-pine savanna and open woodlands. In more severely dissected terrain, fire frequency and size were reduced due to the increase in natural fire breaks in the form of streams and north-east aspects that were less conducive to burning. Oak-pine woodlands were a dominant type on moderately dissected terrain. On the leeward side of major waterways, fires burned relatively infrequently, and mesic forests were able to develop. This example from the upper Current River watershed in the Missouri Ozarks illustrates the interaction of fire and topography that resulted in distinct, spatially explicit patterns in tree composition and structure (based on Batek and others 1999).

or modify fire weather, fuel dynamics (e.g., continuity, loading and moisture), and site hydrology to restrict fire spread. Although fires can burn rapidly and more intensely up exposed, xeric, south-west slopes, the rate of fire spread—especially that of low-intensity backfires—is reduced on north-east slopes due to cooler and moister conditions, increased fuel moisture, changes in fuel loading and flammability, and increased tree density among other factors. With less frequent fire on protected and mesic sites, trees increase in dominance and density, and forests develop complex vertical structure with the formation of a midstory canopy and shrub/tree understory while the more flammable grasses and heliotrophic forbs are greatly diminished. Litter from the more shade-tolerant trees and shrubs has relatively low flammability; forms a compact, flat fuel structure; and decomposes quickly. These conditions act to reduce the probability of fire ignition, the fire intensity, and the rate of spread. This mesophication that occurs in the absence of fire, or in areas of infrequent fire, creates a positive feedback that promotes succession and forest development toward more fire-resistant conditions (Nowacki and Abrams 2008). In heavily dissected terrain, oak woodlands prevailed and true forests formed on mesic aspects and lower toe-slope positions, and on the leeward side of major natural fire barriers such as rivers and lakes.

Historic Legacies in Vegetation Composition and Structure

Stand structure and characteristics of individual trees may indicate previous savanna or woodland conditions. The presence of large “wolf” trees with low and wide spreading crowns and large lateral branches indicates that previously the trees had grown in the open in low-density savannas or open woodlands. Sometimes these trees are also surrounded by dense thickets of smaller diameter saplings or pole-sized trees that invaded the savanna or woodland following fire suppression. Oaks often dominate the initial recruitment of trees in savannas and woodlands during an extended fire-free period following a long-term history of frequent fire (Stambaugh and others 2014). Encroachment of mesophytic tree species such as red maple requires longer periods of fire suppression (Fei and Steiner 2007, Johnson and others 2009, Nowacki and Abrams 2008). Final confirmation of natural community location on the landscape may be gained by a study of historic photos or journals that provide anecdotal information on local natural community types and composition and insights on fire history and land use practices to better understand vegetation change since European settlement.

Remnant ground flora may indicate more open woodland and savanna conditions once occurred in the past. Many public and non-profit conservation organizations have published lists of indicator plant species for natural communities that can be used to identify sites that once were savanna or woodland, and still have the potential to respond well to silvicultural restoration practices (e.g., Bader 2001, Farrington 2010, Packard and Mutel 1997). Floristic inventory of the candidate restoration area can reveal the presence and coverage of desired indicator species, which indicates the site’s potential to respond well naturally to the reintroduction of fire and reduction of tree density. Ecological indices developed by plant ecologists such as floristic quality index and coefficient of conservatism can be used to identify those sites that have the capacity to recover through natural regeneration of the ground flora following restoration practices (Swink and Wilhelm 1994, Taft and others 1997), and to anticipate ahead of time the need for supplemental artificial regeneration of desired ground flora to meet management objectives on degraded sites. Knowledge of land use history is useful for considering how degraded sites may be. Severely degraded sites are those that were cultivated annually or overgrazed, and allowed to erode severely. They are of low floristic quality having lost native seed bank and remnant vegetation, and are dominated by weedy, invasive exotic or native-generalist species. Historical photos or local journals provide anecdotal insights on historical conditions and land uses.

Knowledge of Local Fire History

Knowledge of local fire history can provide insight on the occurrence of savannas, woodlands, and forests. Site-specific fire histories are increasingly being developed throughout eastern North America (e.g., Brose and others 2013a; Guyette and Spetich 2003; Guyette and others 2003; Hoss and others 2008; Stambaugh and others 2006a, 2011). A landscape model predicting historic fire frequency for the continental United States has been produced by Guyette and others (2012) and is a useful guide for areas that lack local fire history data. Annual and biennial fire regimes are more closely associated with prairies and savannas (Anderson and others 1999, Anderson 2006, Nelson 2010). Less frequent mean fire return intervals favor woodland (>5 years) and forest (>10 years) development. Fire histories provide a wealth of information on past fire regimes such as variation in fire occurrence at a given site, which is equally important as average fire frequency. Infrequent but extended fire-free periods of from 10 to 30 years are needed to permit recruitment of tree saplings into the overstory to replace the overstory (Arthur and others 2012, Dey 2014). Infrequent high-severity fires are capable of killing much of the overstory and provide regeneration and recruitment opportunities, or fundamentally change oak natural communities from one type to another. Variation in fire seasonality results in higher plant diversity in the long term. Frequent fire regimes that lack variability in fire-free periods trend toward producing savanna or prairie communities

because they suppress tree recruitment into the overstory and as overstory tree mortality occurs then stand density decreases.

Management Goals and Objectives

Forestry organizations, agencies, and industries usually develop a hierarchy of plans and prescriptions to guide management at the forest level (e.g., MTNF 2005, OSFNF 2005), project level (e.g., MTNF 2015), and stand level (e.g., Wisconsin DNR 2013). They often use a synthesis of the above mentioned criteria in setting forest, management unit, and stand goals and objectives. However, selection of areas and sites for oak woodland and savanna restoration also considers the character of modern-day landscapes, priority needs for wildlife habitat, landscape and stand resilience goals, forest health risks and threats, rural community sustainability, and demands for goods and services from the public. Hence, sites may be designated for restoration regardless of historic patterns, disturbances, and processes.

DEVELOPING THE SILVICULTURAL PRESCRIPTION – AVAILABLE PRACTICES

In the absence of fire, savannas and woodlands become forests, and many landscapes have come to be dominated by mature forests of similar composition. Forests today have two to three times more trees than former woodlands and savannas did in the early 1800s (e.g., Hanberry and others 2012, 2014b, 2014c). The most common starting condition in areas designated for savanna or woodland restoration is the mature forest state. In mature oak forests in Eastern North America there is an absence or lack of large oak advance reproduction, and the ground flora is sparse, being dominated by woody species and shade-tolerant forbs, with low diversity. Light levels in the understory are extremely low, often inhibiting survival and growth of all but the most shade-tolerant species (Dey 2014). This forest condition provides habitat that favors wildlife species associated with complex forest structure.

In the absence of an invasive species problem (see below for further discussion), an initial silvicultural objective is to reduce stand density. This can be achieved in a number of ways using timber harvesting, prescribed fire, mechanical cutting and girdling, or herbicide application, or a combination of these practices. There are several sources that can be used to set a reasonable range in stand structure metrics that define desired future conditions at intermediate stages in restoration, or endpoint conditions that represent the beginning of the maintenance phase in sustainable natural community management. In some areas, models of historic natural communities at specified historic times can be used to guide setting of quantitative ranges in tree density, size, stocking, and canopy cover (e.g., table 1). Alternatively, matrices can be developed by experts based on ecological principles and knowledge that define key attributes of the range of natural communities (e.g., table 2).

Prescribed Fire Effects on Vegetation

Since fire was instrumental in creating and sustaining oak savannas and woodlands historically, it is natural to think about reintroducing fire by prescribed burning to begin restoration. Prescribed fire is often conducted in winter and spring seasons, when it burns with low intensity and severity. These types of fires are capable of killing or topkilling hardwood stems that are <4–6 inches diameter at breast height (dbh) and thereby begin the process of reducing stand density (Arthur and others 2012, Dey and others 2017). The midstory canopy in mature forests can be diminished or eliminated by one or more low-intensity dormant season fires (fig. 2) (Dey and Hartman 2005; Fan and Dey 2014; Hutchinson and others 2005a; Knapp and others 2015, 2017). Removal of the hardwood midstory canopy increases light levels to about 15 percent of full sunlight depending on the composition of the overstory, i.e., northern hardwood vs. oak vs. pine, with light levels being highest under pine overstories (Lockhart and others 2000, Lorimer and others 1994, Motsinger and others 2010, Ostrom

Table 1—Setting structural targets for oak woodlands and savannas using historical conditions[a] in the Missouri Ozarks

Natural community[b]	Density *trees per acre*		Dbh *in*	Basal area ft^2*/ac*		Stocking *percent*		Canopy cover *percent*	
	avg	range	avg	avg	range	avg	range	avg	range
Savanna	33	23–44	14	35	22–44	25	16–30	51	38–60
Open woodland	54	34–87	13	61	39–87	41	30–55	66	50–80
Closed woodland	81	53–100	14	100	78–126	64	55–75	81	74–87

[a] Estimates are based on models of witness trees from General Land Office surveys done in the early 1800s.

[b] Natural communities were defined as: savanna—10 to 30% stocking, 20 to 40 tpa; open woodland—30 to 55% stocking, 40 to 71 tpa; closed woodland—55 to 75% stocking, 71 to 101 tpa; forest—≥75% stocking, ≥101 tpa (based on Hanberry and others 2014b).

Table 2—Quantitative attributes defining desired conditions for natural community types on the Mark Twain National Forest, Missouri Ozarks (MTNF 2005)

	Overstory trees		Shrubs	Ground cover layer	
Natural community types	Tree canopy *percent*	Basal area *ft^2/ac*	Shrub layer *percent*	Ground organic layer	Ground cover *percent*
Prairie	<10	NA	<10	Scattered grasses, sedges, and forbs	90–100
Savanna	20–40	40–60	50	Scattered grasses, sedges, and forbs; 60–80% leaf litter cover	30–50
Open woodland	40–70	40–70	20–40	Scattered grasses, sedges, and forbs; 30–50% leaf litter cover	30–40
Closed woodland	70–90	80–100	5–10	Scattered sparse grasses, sedges, and forbs; 100% leaf litter cover	20–30
Upland forest	90–100	80–100	50% in 2-acre openings/wind gaps; <5 % elsewhere	Moderately deep leaf litter; sparse ground cover	<30
Bottomland forest	90–100	90–100	Multi-layered; uneven-age; few gaps	Deep leaf litter; ephemeral herbs	50–70
Fen	<10	NA	Variable	Shallow marly to deep muck	90–100
All glade types	<20	NA	<40	Sparse to dense thatch of grasses; mineral soil sometimes exposed	30–90 grasses dominant

Figure 2—Low-intensity prescribed fires done in the spring (March to April) are effective in eliminating or significantly reducing density of the hardwood midstory in mature oak forests in the Missouri Ozarks (A). Annual fires (B) or periodic fires (every 2–3 years) (C) over 10 years can topkill saplings that form the midstory and inhibit redevelopment of the midstory by causing mortality of understory stems and repeated topkilling of survivors. Overstory density is relatively unaffected by these burning regimes, and growth of hardwood sprouts is reduced by shade of the closed-overstory canopy. (photographs courtesy of Daniel C. Dey, USDA Forest Service)

and Loewenstein 2006). This improves environmental conditions for oak regeneration development and increases ground flora diversity and coverage, but further increases in light levels are often needed to achieve desired future conditions in both tree regeneration and ground flora (Dey 2014, Hutchinson 2006, Kinkead and others 2017). However, an incremental approach and deliberate progress toward the final desired condition may be prudent when transitioning from a forest condition with aggressive competing tree species such as yellow-poplar (*Liriodendron tulipifera* L.), sweet birch (*Betula lenta* L.), and aspen (*Populus* spp.), or disturbance-adapted invasive species. Low-intensity fires have little effect on overstory mortality (Fan and Dey 2014, Fry 2008, Horney and others 2002, Hutchinson and others 2005a).

Oak reproduction is generally favored over other hardwood species in a regime of frequent fire (Brose and others 2013b). Oak seedling and sapling sprouts can grow and increase root mass with adequate light under a regime of frequent fires, i.e., every 2 to 5 years (Brose 2008, Brose and others 2013a, Dey and Parker 1997, Rebbeck and others 2011). However, young and small-diameter oaks are vulnerable to mortality when subjected to low-intensity, dormant season prescribed burns (Johnson 1974). Survival of oak advance reproduction is relatively high (80 to 90 percent) after only one fire regardless of species, but mortality among oak species varies with repeated fires, and scarlet oak is one of the most fire-sensitive species (Dey and Hartman 2005). Differential mortality rates between oak and its competitors in a frequent fire regime give oak a competitive advantage over time (Brose and others 2013b, Dey and Hartman 2005).

Acorns are recalcitrant seed and must maintain high moisture content to remain viable (Korstian 1927). Seed lying on the forest floor or mixed in litter is vulnerable to desiccation over the winter, especially in regions without permanent snow cover. Some leaf cover (e.g., 1 to 2 inches) helps to maintain moisture content in acorns located beneath the litter and in contact with mineral soil, but deep litter (>2 inches) can reduce germination and seedling establishment (Barrett 1931). Prescribed fire is an effective tool for reducing leaf litter depth but must be applied periodically (e.g., <4 years) to consume additional litter input and maintain optimal litter depth (Barrett 1931, Stambaugh and others 2006b). Fire conducted before acorn drop and in forests with little to no oak advance reproduction can reduce leaf litter, midstory density, understory height structure, and canopy coverage, and begin to manage competitor seed in the forest seed bank (Schuler and others 2010). Repeated fire is important in controlling seed bank and young germinants of competing or undesirable species (Schuler and others 2010). Once a good acorn crop is on the ground, fire should be delayed until oak seedlings are well-established (e.g., for 2 to 3 years) because fire can kill 70 percent or more of the acorn crop (Auchmoody and Smith 1993, Greenberg and others 2012). Sufficient light in the understory promotes oak seedling development and shortens the time that fire should be avoided to minimize mortality in small oak advance reproduction.

In addition to using fire to restore and maintain the woody structure of savanna ecosystems, the restoration of fire as a disturbance that shapes the ground flora community is important. Fire may increase ground flora diversity and promote its development by breaking chemical or thermal seed dormancy, thus increasing germination in some species (Hutchinson 2006). Fire may improve establishment of herbaceous plants by reducing thick litter layers that act as a physical barrier to seedling establishment by inhibiting roots from reaching mineral soil, or emerging shoots growing beneath litter from reaching the light of day. Litter removal elevates soil temperature that promotes germination and early seedling growth. Fire releases nutrients when litter is consumed, which promotes plant growth. It also increases available light for herbaceous plants by top killing woody trees, shrubs, and vines. Fire frequency, season, intensity and other attributes of the fire regime can be set by the manager, and various combinations of these attributes can dramatically direct plant dominance and community succession.

The use of prescribed fire alone in mature forests generally increases herbaceous species coverage, richness, and diversity, but improvements are small in magnitude due to the shade from a closed-canopy overstory (Lettow and others 2014; Ralston and Cook 2013; Taft 2003, 2005). These improvements in the ground flora are also ephemeral unless burning is repeated to control the sprouting and regrowth of trees and shrubs in the understory (Abrahamson and Abrahamson 1996, Bowles and others 2007, Glasgow and Matlack 2007, Kuddes-Fischer and Arthur 2002, Vander Yacht and others 2017). It may take 20 to 40 years of annual burning to eliminate most of the understory woody species (Knapp and others 2015, Waldrop and others 1992). Each woody and herbaceous species is unique, but some generalities in how functional groups of plants respond to changes in the fire regime are worth noting. Annual fires increase grass dominance, and biennial fires promote forb species richness and cover, especially in open environments such as prairies, savannas, and open woodlands (Anderson and others 1999, Burton and others 2010, Haywood and others 2001, Nelson 2010, Peterson and others 2007). Fires separated by 3 to 5 years or longer favor trees, shrubs, and vines (Briggs and others 2002, Burton and others 2010, Haywood 2009, Peterson and others 2007). Ground flora diversity is relatively lower in prairies where tallgrasses can dominate or in forests where woody species are the major competitors than in savannas and open woodlands where there is the greatest heterogeneity in environmental conditions that support high plant diversity (Haywood 2009, Peterson and others 2007, Peterson and Reich 2008, Towne and Kemp 2003).

Controlling the season of burning can help promote specific plant functional groups. Burning in the spring (March to April) favors warm season grasses and forbs; may promote flowering and biomass production of late summer flowering species; and diminishes survival, growth, and vigor of cool season grasses and forbs (Copeland and others 2002, Glen-Lewin and others 1990, Howe 1994, Peterson and Reich 2008, Taft 2003, Towne and Kemp 2003). Promoting the dominance of warm season grasses may actually decrease total plant diversity due to the ability of warm season grasses to suppress all subdominant vegetation (Biondini and others 1989, Copeland and others 2002). Compared to winter or spring fires, summer burns (mid-July to early August) can increase cool season grass and forb diversity, cover, and density; reduce to a greater extent woody trees, shrubs, and vines; and increase perennials that are able to flower before the summer burn (Haywood and others 2001, Haywood

2009, Howe 1994, Nelson 2010, Waldrop and others 1992). Summer burns done during a time when warm season grasses are actively growing can reduce their dominance, thus releasing subdominant vegetation and increasing total species richness (Biondini and others 1989). The outcomes of fall (September to October) fires are somewhat inconsistent but show a tendency to decrease cool season exotic grasses; reduce woody cover; increase perennial forb cover; and either increase or have no effect on warm and cool season grasses and forbs (Biodini and others 1989, Bowles and others 2007, Copeland and others 2002, Howe 1994, Towne and Kemp 2003, Weir and Scasta 2017). Dormant season (December to February) fires have the least impact on herbaceous or woody species, even when repeated for decades (Haywood 2009, Hutchinson 2006, Waldrop and others 1992, Weir and Scasta 2017). Consistency in application of prescribed fire tends to create homogeneity in the vegetation community. Therefore it can be beneficial to vary the frequency, intensity and season of burning to sustain plant species diversity and provide a variety of habitats for wildlife, insects, pollinators, and other taxa (Hiers and others 2000, Howe 1994, Nelson 2010, Peterson and Reich 2008). An important factor that governs the initial response of ground flora to burning is the abundance of propagules in the seed and bud bank. These may be diminished on sites degraded from decades of agricultural land use or from years under heavy forest shade and deep litter (Ralston and Cook 2013). Restoration of severely degraded sites may require artificial regeneration of the ground flora by seeding and planting (e.g., Packard and Mutel 1997).

Prescribed Fire, Woody Structure, and Ground Flora Interactions

Heavy tree canopy cover is a major limiting factor contributing to low diversity and productivity of ground flora (i.e., grasses, forbs, and legumes) (Peterson and Reich 2008, Ratajczak and others 2012, Vander Yacht and others 2017, Zenner and others 2006). Application of low-intensity dormant season fires is effective at creating closed-woodland structure (Hutchinson and others 2005a, Knapp and others 2017, Waldrop and others 1992), but other practices are needed to create open-woodland and savanna structure and promote their ground flora. Increasing fire intensity to produce moderate to high-severity fires is generally not the preferred method for reducing overstory density. Thinning by herbicide or mechanical methods or harvesting using a modified shelterwood system is preferred for managing stand density, regulating tree density in time and space, controlling species composition, and receiving income from timber sales. The shelterwood system is flexible to accommodate incremental adjustments to tree density and stocking, can be used to achieve a wide range of final desired tree density and stocking, and can be applied as an irregular or uniform pattern to create heterogeneity in structure. The application of the shelterwood method in restoration of woodlands and savannas differs from the traditional forestry application in that the final shelterwood is retained for the long term in restoration, and is removed once adequate desirable regeneration is secured when timber goals are a priority. The details of how tree structure and fire are managed depend largely on desired future conditions of the ground flora, and the prescription is modified by initial stand conditions, physical environment, site quality, presence of invasive species, initial floristic composition and structure, and the physiology and ecology of key indicator native flora.

Thinning the overstory to reduce its density (i.e., removing larger diameter trees that are resistant to fire treatments) often increases herbaceous richness and coverage by increasing light levels at the forest floor (Hutchinson 2006, Kinkead and others 2017, Waldrop and others 2008, Zenner and others 2006). Retaining a moderate-density overstory may benefit cool season grasses, sedges, and shade-tolerant forbs, but any tree cover inhibits warm season prairie grasses and forbs that thrive best in the open (Peterson and others 2007). The increasing species richness and coverage in the ground flora are accelerated when stand basal area is held <60 square feet per acre, which is below B-level stocking (i.e., where growing space is unoccupied by trees and thus available to ground flora in treeless openings) (fig. 3) (Vander Yacht and others 2017). However, these gains in ground flora restoration are ephemeral, because an abundance of woody sprouts can rapidly form a dense midstory that shades out the ground flora once again. Thinning or harvesting trees in a way that leaves a variable-density overstory maximizes heterogeneity and increases diversity (Peterson and others 2007, Peterson and Reich 2008, Vander Yacht and others 2017). Thinning alone is no surrogate for fire when it comes to other ecosystem processes and functions such as nutrient cycling, litter dynamics, plant regeneration and competition, and community development (Hutchinson 2006, Phillips and Waldrop 2008). Restoration of a healthy, productive, diverse ground flora community can be accelerated by thinning the overstory from below and implementing prescribed burning, which provides substantial increases in cover, species richness, diversity, and plant productivity compared to burning or thinning alone. Repeated burning is effective in preventing the dominance of sprouting trees and shrubs after harvesting (Hutchinson and others 2005b, Kinkead and others 2017, Lettow and others 2014, Waldrop and others 2008).

There are treatments that can precede harvesting or be done in conjunction with harvesting to reduce density, limit dominance of tree and shrub sprouts, or control an invasive species problem. Reducing the regeneration potential of undesirable competing vegetation before

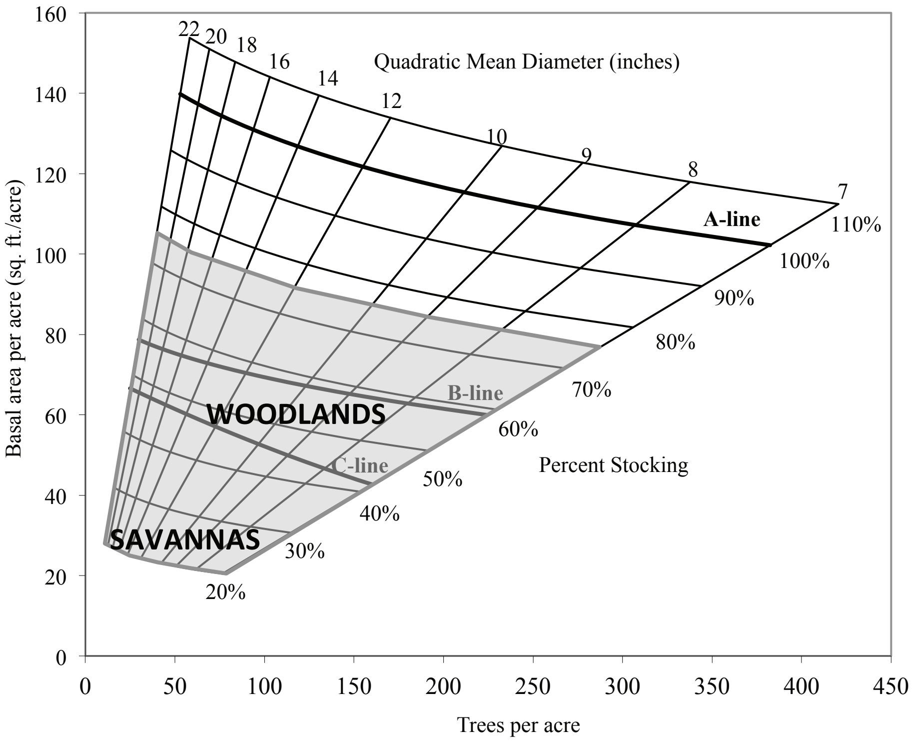

Figure 3—Stocking (Gingrich 1967) for woodlands and savannas (shaded area). Stocking in woodlands is maintained between 30 and 75 percent. Closed woodlands are maintained above the B-line, and open woodlands are maintained between 30 percent stocking and the B-line. Savannas are maintained at stocking levels <30 percent. For regenerating woodlands, stocking is reduced below 30 percent stocking. Stocking in savannas is low enough to permit recruitment anytime there is a sufficiently long fire-free period (based on Hanberry and others 2014b).

thinning or harvesting the overstory takes advantage of overstory shade to reduce response and vigor of undesirable vegetation. Combinations of fire, herbicide, and mechanical practices (e.g., cutting, scarification, and mastication) can be used to minimize the response of undesirable vegetation after overstory harvest. Maintaining higher levels of overstory canopy cover (e.g., >70 percent) or density (e.g., >60 square feet per acre) can suppress the growth of woody sprouts or invasive species in the understory through shading (Dey and Hartman 2005, Kinkead and others 2017), but this would also delay the restoration of savanna ground flora, which requires more sunlight. In the end, rapid reduction of the overstory to meet long-term structure objectives for woodlands and savannas promotes the greatest response in ground flora (Zenner and others 2006). A chart has been developed that is useful for managing stand density to produce desired crown cover in upland oak savannas depending on overstory tree size and density (Law and others 1994). Models have been developed that are useful for estimating available light in the understory from overstory crown cover, density, basal area, or stocking for upland oak-hickory forests in the Missouri Ozarks (Blizzard and others 2013, Dey and others 2017). These can be used to manage stand density to provide light levels necessary to promote desirable ground flora.

Nonnative invasive species (NNIS) are increasingly a threat to oak management and restoration (Kurtz 2013, Miller and others 2013, Oswalt and Oswalt 2011). No longer are they merely a problem in urban areas; they are rapidly expanding into rural forest lands. Many of the more common and problematic NNIS prosper in open environments and are adapted to fire. Thus, prescriptions to sustain or restore oak forests, woodlands, and savannas that use regeneration methods such as the group selection, clearcut, shelterwood, or seed tree in combination with prescribed burning can potentially promote the rapid colonization and invasion by NNIS (Phillips and others 2013, Rebbeck 2012).

Fire can promote NNIS colonization and spread, or it can be a useful method for control, depending on the timing and severity of fire and the phenology, physiology, mode of reproduction, and ecology of the invading NNIS (DiTomaso and others 2006, Huebner 2006, Miller and others 2013, Rebbeck 2012, Zouhar and others 2008).

Nonnative invasive species often have traits that help them prosper in a post-fire environment. The ability to self-pollinate allows them to reproduce in low-density or sparse populations. Some species are prolific seed producers, and seed can be dispersed by the wind or birds, or both, which maximizes the number of seeds disseminated for opportunistic colonization of ephemerally favorable sites. The seed of some NNIS can remain viable in the seed bank for years or decades. Thus, seed can accumulate to densities far exceeding those of annual crops and remain ready for release by a future disturbance. Chemically or thermally induced seed dormancy ensures that germination is likely to occur after a fire when the post-fire environment is favorable for establishment and early growth. Reproductive structures such as rhizomes, caudices, bulbs, corms, and root crown buds are commonly buried in mineral soil or located under moist duff and, hence, protected from fire injury. Thus, after a fire, NNIS are immediately onsite and capable of rapid vegetative growth when resources are most available. Rapid early growth is characteristic of many NNIS as they are adapted to high-light environments following moderate- to high-severity disturbances. This promotes early dominance and acquisition of resources for development toward maturity and completion of their life cycle.

Monitoring for early detection of NNIS is key to controlling invasive populations when they are still small. Aggressive eradication at this stage is necessary to avoid the development of an expensive problem that can thwart other management goals. Nonnative invasive species monitoring and control are essential elements of contemporary sustainable management programs. A prudent approach to NNIS control is to deal with threats before initiating major disturbances such as overstory harvesting that may accelerate expansion and dominance of the NNIS. Early treatment of existing NNIS in and around a management unit takes advantage of overstory shade that can help limit the response of shade-intolerant NNIS. Complications arise when considering NNIS control treatment impacts on desired native flora, because an important control strategy is to promote the establishment and dominance of native species, thereby increasing the competitive pressure on NNIS.

Fire can be used alone or in combination with other practices to control some NNIS. The timing and severity of fires are key to controlling NNIS and determine the fate of native species as well. The easiest NNIS to control are annuals that produce seed after the fire season, whose seed is readily exposed directly to fire's flames and does not persist in the seed bank. Late spring to early summer fires are most likely to control NNIS annuals that set seed later in the summer. Biennial and perennial NNIS are more difficult to control. Severe fires are needed to kill reproductive structures in organic or mineral soil layers. Few NNIS are controlled with a single fire. It takes consecutive, repeated fires to stop seed production by killing existing individuals and to eliminate plants that arise from the seed bank or from vegetative structures, which often are stimulated by the initial fire. Scheduling fires several years apart only allows NNIS to add seed to the seed bank, or build energy reserves in belowground structures.

Burning followed by herbicide application can be an effective control method (DiTomaso and others 2006). The fire kills current vegetation, stimulates germination, converts large plants into small, concentrated sprout clumps through topkill and sprouting, and removes debris that facilitates herbicide application. Herbicides can be effective at killing plants that sprout prolifically from large underground bud banks and stored energy reserves. The succulent growth of seedling sprouts and germinants readily absorbs herbicides, increasing their efficacy. Fire effects on native species must also be considered in planning prescribed fire regimes to ensure they are not adversely impacted and that their response to fire is vigorous. Dominance of native species after fire can help to suppress NNIS establishment or recovery.

THE RESTORATION PRESCRIPTION – SETTING THE QUANTITATIVE TARGETS

There are several elements that guide the development of silvicultural prescriptions for restoration. Vegetation compositional and structural targets are good for defining forests, woodlands, and savannas. Both woody and ground flora are important because they play an essential role in the development of the natural community, its functioning, and its diversity potential, and production of ecological, economic, and social goods and services. Vegetation composition and structure are good for setting quantitative intermediate and final end targets in the silvicultural prescription that aid in selection and sequencing of practices to transform the initial state into the desired future condition (Dey and Schweitzer 2014). The initial vegetation structure and composition determine the initial stages and activities that are needed to achieve the desired future condition. The divergence of the initial state from the desired future state influences the extent of the restoration period. Site productivity influences the rate of change in vegetation, and hence, the scope of practices, their timing, and the investment in energy (both financial and all other resources and capital, including the human) needed to manage for the desired composition and structure in vegetation. Invasive species, troublesome herbivores, and insect and disease threats are modifiers in the prescription process.

Compositional and structural targets can be quantified using: (1) analysis and modeling of historical vegetation surveys, (2) inventory of high quality modern examples, (3) ecophysiology requirements of the desired indicator and competing species, and (4) wildlife habitat objectives. Ground flora targets are formed from a list of natural community indicator species and quantified through the use of conservation goals to increase diversity, coverage, floristic quality index, and coefficient of conservatism. The structure (vertical and horizontal) of vegetation can be quantified using common metrics derived from field surveys and inventories and models that define the relationship among the suite of structural variables that influence the environment, physical resources, and competitive dynamics. Modes of reproduction of desired species and their key competitors influence the choice of silvicultural practices and their sequencing. Threats from invasive plant species require special consideration in the prescription process. Developing a successful silvicultural prescription for restoration requires a holistic approach that integrates the key components in a dynamic system over the entire period that starts with the initial condition and ends with the final desired future condition, and entry into the sustainable, maintenance phase of management.

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PRACTICAL CONSIDERATIONS FOR LONG-TERM MAINTENANCE OF OAK WOODLANDS

Benjamin O. Knapp, Michael C. Stambaugh, and Daniel C. Dey

Extended abstract—Managing oak (*Quercus* spp.) woodlands has become an increasing common objective across many areas within the Eastern United States. Oak woodlands have been variously defined, primarily by characteristics of structure (e.g., relatively open canopies, low abundance of midstory trees, and abundant herbaceous ground flora), composition (e.g., fire-tolerant species and woodland indicator ground flora), and disturbance (e.g., fire regime) (Hanberry and others 2014a, Kabrick and others 2014, Nelson 2005). Mounting evidence of the historical prevalence and contemporary reduction in oak woodlands has contributed to interest in restoration efforts (Hanberry and others 2014b, Nuzzo 1986). Given the legacies of land use (e.g., historical logging and more recent fire suppression/exclusion) that have led to contemporary conditions, woodland management is often described in terms of 'restoration' and 'maintenance' phases (Dey and others 2016). The restoration phase uses silvicultural thinning and prescribed burning to reach structural targets and enhance the ground flora community (Kinkead and others 2013, Laatsch and Anderson 2000, Vander Yacht and others 2017). The maintenance phase usually requires repeated prescribed burning in order to reduce encroachment by woody vegetation and favor herbaceous ground flora (Dey and others 2016). Recently, there have been experimental and operational examples of successful woodland restoration and maintenance over relatively short time periods. Over the long-term, woodland management is resource-intensive because repeated management action (e.g., prescribed burning) is required for continued maintenance.

We discuss several considerations for long-term oak woodland management, presenting expected effects of repeated prescribed burning and suggesting recommendations to reduce undesirable outcomes. In some cases, challenges for woodland maintenance derive from interest in retaining relatively static conditions through time (e.g., an open stand structure/habitat) by suppressing dynamic processes (e.g., forest succession or stand dynamics).

Forest dynamics—Several long-term considerations relate to the effects of repeated prescribed burning on processes of forest stand dynamics. The woodland restoration phase commonly uses thinning to initially reduce stand density to meet structural criteria for woodlands (Dey and others 2016, Kabrick and others 2014), which often corresponds to stocking near or below the B-line of the Gingrich stocking chart (Gingrich 1967). At this level of stocking, growing space is available for new trees to establish and grow; thus, maintaining oak woodland structure includes sustained effort to suppress tree regeneration from dominating the midstory layer. The rate at which regenerating trees develop is related to stand density but also site productivity, suggesting that greater effort may be required to maintain woodland structure on higher quality sites. Although individual fires of low intensity may have limited effects on canopy tree mortality, repeated burning over long time periods was found to favor fire-tolerant post oak (*Quercus stellata*) almost exclusively due to canopy attrition of other hardwood species in oak woodlands of the Missouri Ozarks (Huddle and Pallardy 1996, Knapp and others 2015). Maintaining woodland structure through repeated prescribed burning may accelerate hardwood canopy mortality of fire-sensitive species and prohibit regeneration and recruitment of new trees, effectively suspending succession from occurring (Knapp and others 2016).

Plant diversity and conservation value—Increasing light to the forest floor and reducing the thickness of the litter layer allow the development of dense, species-rich ground flora (Hiers and others 2007, Veldman and others 2014). Repeated prescribed burning maintains these conditions, with long-term studies demonstrating the importance of frequent fire for ground flora diversity in woodland ecosystems (Brockway and Lewis 1997, Knapp and others 2015). In the Missouri Ozarks, frequent burning for 16 years at the landscape scale increased the abundance and conservation value of the ground flora (Maginel 2015). However, strength of the effect varied by site characteristics, with greater response observed on exposed sites than on protected sites. These results highlight the importance of considering appropriateness of the edaphic conditions for the potential for woodland

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

restoration. Moreover, ground flora species vary in their resource requirements (Peterson and others 2007) and response to specific aspects of fire regime, such as fire season. Thus, evidence suggests that long-term woodland maintenance supports diverse ground flora communities, although nuances of woodland management practice likely modify community responses.

Wildlife habitat—Wildlife species often respond to structural and compositional characteristics of ecosystems, and oak woodlands provide unique and important habitats. The habitats maintained by woodland management commonly meet the needs of some but not all species within taxonomic groups, such as early successional bird species (Vander Yacht and others 2016) or bat species that favor open forests (Starbuck and others 2014). Maintaining woodlands across a landscape of diverse habitats, including closed canopy forests and other early successional conditions, offers variability to satisfy a wider range of habitat needs.

Timber value—The value of standing timber in woodland ecosystems may be reduced by repeated burning. Wounds from fire can lead to rot and value loss of wood products, although the rate and magnitude of value loss varies by species; individual tree characteristics such as size, age, or vigor; and fire behavior. Time since fire and scar size are important because wound tissue that is located on external portions of the bole may be removed during slabbing (Marschall and others 2011). However, maintaining frequent burning when hardwoods are small would likely result in wounds and internal defects that last throughout the rotation. Repeated burning over the long term also affects stumpage value through stand composition and structure. Long-term burning of Missouri Ozark woodlands shifted composition to post oak, a low value species, and reduced the abundance of red oak species of higher value (Knapp and others 2017). Unexpected changes in market value may create uncertainty in long-term economic projections, however, and extending rotation ages of canopy trees may allow individuals to gain value through continued growth.

Tree regeneration—Long-term woodland maintenance will eventually require replacement of canopy trees (Dey and others 2016). Repeated burning at frequent intervals can allow oak sprouts to persist but prohibits recruitment from occurring (Knapp and others 2016). Oak recruitment may require fire-free periods ranging from 10 to 30 years, depending on site productivity and species (Arthur and others 2012). The development of a recruiting midstory cohort and accumulation of forest floor would alter the character of the ecosystem, reducing ground flora density and appearance of the structure. However, once the regenerating cohort reaches around 5 inches dbh, many stems would likely survive reintroduction of frequent fire. Kabrick and others (2014) suggest an area-regulation approach for woodland regeneration, in which fire is removed from woodland stands during a prescribed regeneration period. For objectives of regenerating and recruiting oaks while retaining open woodland structure with frequent fire, more intensive efforts may be needed to protect individuals or small groups of stems from top-kill by fire.

Ecosystem resistance/resilience—Plant species associated with oak woodlands are commonly well-adapted to dry conditions, indicating potential for adaptability for possible future climate extremes. In Missouri, mixing shortleaf pine (*Pinus echinata*) with oak was found to increase estimated compatibility to future climate scenarios (Kabrick and others 2017). Diversifying fire-tolerant tree species within woodlands may provide buffers against future disturbance. In addition, woodland restoration treatments commonly favor retaining large canopy trees, found to increase stand vigor and resistance to drought impacts in a woodland restoration study in Kentucky (Clark and Schweitzer 2016).

The decision to initiate oak woodland management requires consideration of short-term restoration treatment needs but also commitment to long-term management outcomes. On most sites, repeated prescribed burning is necessary to maintain open conditions, diverse ground flora communities, and associated wildlife habitats. Repeated prescribed burning costs time and money, however, and may reduce future timber value. Specific consideration should be given to canopy tree replacement, especially if canopy trees are not highly fire-tolerant. Targeting appropriate ecological sites and canopy species for frequent fire woodland management can reduce required management inputs and likely result in more favorable outcomes.

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SESSION 7:

Stand Improvement

Moderator:

Josh Granger
The University of Tennessee

MANUAL HERBICIDE APPLICATION METHODS FOR MANAGING VEGETATION IN APPALACHIAN HARDWOOD FORESTS

Jeff Kochenderfer

Extended abstract—Controlling undesirable vegetation is a major component of any silvicultural system involving the management of oaks. It has long been recognized that controlling understory and midstory layers of competing vegetation before harvest and timely release after harvest are critical to successfully regenerating and retaining oaks in future stands. Herbicides are a very versatile, cost-effective tool that can be used in a variety of ways to help manage forest vegetation. Manual herbicide application methods reviewed here are well suited for the small forest ownerships in the rugged Appalachians, where the use of mechanical methods and prescribed burning are often limited by steep terrain and fragmented ownerships. Some herbicide treatment methods also have the advantage of being very target-specific, especially when treatments are restricted to species different from those considered desirable. The effects of herbicide treatments on interfering vegetation can last for several years thereby providing slower growing seedlings like oak (*Quercus* spp.) species time to develop and become competitive. Four commonly used manual herbicide application methods used are reviewed here:

- Stem injection,
- Basal spray,
- Cut-stump, and
- Foliar spray

Recommendations on which herbicides to use, rates of application, and timing are also discussed.

Stem injection involves cutting incisions though the bark of a treated tree using a hatchet with a ground-down narrow blade 1.75 inches wide. While leaving the blade in the incision, twist the hatchet slightly to open the incision, and squirt the herbicide solution directly into the incision on the cambium layer of the tree. A plastic spray bottle or a gunjet herbicide gun attached to a backpack sprayer is often used to dispense the herbicide. Make one incision per inch of DBH (diameter at breast height) evenly spaced around the tree; spacing between incisions should not exceed 1.5 inches. Squirt approximately 1.5 milliliters of herbicide solution in each incision. A 50-percent solution of Garlon® 3A (active ingredient triclopyr) or glyphosate product (41.0-percent a.i.), in a water carrier is recommended for stem injection. When treating maple (*Acer* spp.) species, a 6-percent solution Arsenal® (active ingredient imazapyr) mixed with water is recommended. The glyphosate and Arsenal® treatments should not be used to control competing trees closer than 5 feet of the same species as crop trees or to competing stump sprouts originating from the same stump as crop trees. Stem injection treatments are best applied when trees are in full leaf (June 1–November 1), and avoid periods of heavy sap flow (January–April). Chemical stem injection treatments are often used in crop tree release treatments and to control cull trees in order to increase the future value of Appalachian hardwood stands.

Stem injection treatments are usually not recommended for stems less than 1 inch DBH. A similar cut-surface treatment that can be used to treat small stems is the cut-stub treatment. Dense understories of shade-tolerant species develop naturally in Appalachian forest stands and respond rapidly to overstory disturbance such as cutting. In some stands, a larger percentage of these stems are <1 inch DBH in size. Stems 6 feet tall to 1 inch DBH are bent over and completely severed about 2 feet above the ground and the cut-surface sprayed with the same herbicide concentrations recommended for the regular stem injection treatment. A Swedish brush ax works better on these small stems than the hatchet recommended for injecting larger stems. Incisions can also be made on scattered larger stems up to 6–8 inches DBH with this ax permitting them to be injected in the conventional manner.

Basal spraying is a manual application method where herbicide is mixed with an oil carrier and applied using a backpack sprayer to the lower 12–15 inches of the treated stem. A 10-percent solution of Garlon® 4 (active ingredient triclopyr) mixed with an oil carrier is recommended. Basal spraying works best on thin-barked species, such as American beech (*Fagus gradifolia* Ehrh.), birch (*Betula* spp.), and maple less than 6 inches DBH. It normally costs more than tree injection or cut-stump treatments, and triclopyr, the active ingredient in Garlon® 4,

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

is not readily translocated to attached root sprouts. Apply the herbicide solution completely around the stem until it begins to run off. This treatment is especially effective on tall shrubs like autumn olive (*Elaeagnus umbellata* Thrunb.) and witch hazel (*Hamamelis virginiana* L.) which are difficult to inject or foliar spray. This treatment can be applied at any time of the year, if the stems are dry.

The cut-stump treatment is a target specific application method applied to the outer 2 inches of tree stumps using a backpack sprayer to control stump sprouting and to disperse herbicide to attached root sprouts. Some herbicide transmission may also occur through intraspecific root grafts of the same species. The cut-stump treatment enables large numbers of small stems to be controlled by treating one large stem. It can be used in site preparation treatments to control understories of interfering vegetation. The cut-stump treatment is very cost effective when used in conjunction with mechanized feller-buncher harvesting operations because it is not necessary to cut the stems, stumps are usually more exposed, and access is easier, especially after whole-tree harvesting operations. It is similar to stem injection in that the herbicide is being applied directly to the cambial layer of the treated trees; however, this treatment will control a much higher percentage of root sprouts on trees like American beech, blackgum (*Nyssa sylvatica* March.), sassafras (S*assafras albidum* Nutt.) than stem injection. Research has demonstrated that treatment efficacy around individual beech stumps was strongly correlated with stump size; as stump diameter increased, so did the effective range of root sprout control. Use a 50-percent solution of glyphosate (41.0-percent a.i.) or a 6-percent solution of Arsenal® and a surfactant in a water carrier. Treat stumps as soon as possible after cutting, but research has demonstrated that this treatment can be effective up to 4 days after cutting in the central Appalachians. This treatment is best applied from June 1 to November 1 and avoid heavy sap periods (January–April).

Manual supplication methods can be used to foliar spray around individually protected plants (e.g., planted seedlings), clumps of undesirable plants, or to broadcast spray areas of interfering plants like fern beds. Herbicide solutions are usually applied using a backpack sprayer to completely wet the foliage of target plants. A 2-percent solution of glyphosate or 1-percent solution of Arsenal® AC (active ingredient imazapyr) are recommended. Add a non-ionic surfactant to the solution if the herbicide being used does not already have one. Adding 0.25 ounces of Oust® XP (active ingredient sulfometuron-methyl) per 3 gallons of solution when controlling herbaceous weeds and grass adds longevity to treatments. Foliar treatments can be applied after full leaf-out until leaves begin to change color in the fall. The foliage should be dry when sprayed, and a 2-hour rain free period is recommended after spraying.

REHABILITATION OF POORLY STOCKED STANDS USING A MICROSTAND APPROACH

Jeffrey S. Ward

Abstract—Nearly one-quarter of upland oak forests in the Eastern United States are poorly stocked, often as the result of high-grading or repeated diameter-limit harvests. Returning poorly stocked stands to their economic and ecosystem services potential will require innovative rehabilitation practices that are cost-neutral at a minimum. One approach developed for northern hardwoods in Quebec was to recognize that poorly stocked stands are a conglomerate of stand types at the microstand scale (~0.1 acre) and to assign unique treatments to each microstand type. In 2012, we initiated research at five study areas in Connecticut to examine rehabilitation of poorly stocked stands. Rather than a single prescription for the entire stand, we used the decision tree approach to assign treatments at the microstand scale to account for the irregular, spatially patchy structure typical of high-graded stands. The treatment prescriptions incorporated earlier research showing that crop tree release can greatly increase diameter growth and survival, together with timber stand improvement, for the several microstand types commonly found in poorly stocked stands: poletimber, two-aged, sapling, or regeneration. On untreated control plots, 4-year basal area growth of unacceptable growing stock (UGS) was 60 percent greater than for acceptable growing stock (AGS). In contrast, AGS basal area growth was more than double that of UGS on treated plots. Crop tree release on treated plots increased 4-year diameter growth of sapling and pole crop trees, doubling growth of upland oaks. A microstand approach has potential where a commercial biomass market exists or for landowners cutting their own firewood.

INTRODUCTION

Across much of the 133 million acres of oak-hickory forest in the Eastern United States, poorly stocked stands are a common problem—occupying >32 million acres in the region (Miles 2018). In addition, there are another 57 million acres with medium stocking that are potentially one high-grade harvest away from becoming poorly stocked. Oak forests that are not fully stocked are especially at risk of "exploitive and unsustainable timber harvesting [high-grading]" that can create poorly stocked forests (Schuler and McGill 2007). Please note that descriptive terms for stocking levels in this paper follow Forest Inventory and Analysis standards (Arner and others 2003): poorly stocked (<35 percent stocking), medium stocked (35–59 percent), and fully stocked (60–99 percent). Poorly stocked stands are nearly synonymous with "degraded" stands as described by Clatterbuck (2006), and the terms will be used interchangeably throughout.

Poorly stocked stands rarely develop on publicly managed lands and other professionally managed forests except following severe weather, repeated defoliations, or wildfire. While the majority of privately owned, family forest land is held for non-financial amenities such as scenic beauty or protecting nature, there is a much higher risk of poorly stocked stands developing on family forests as the majority have not received professional consultation (Butler 2008). Recent studies have reported that 60 percent of harvests in Kentucky were high-grades (Stringer 2008), and high-grading was the most common practice in West Virginia (Fajvan and others 1998, Luppold and Alderman 2007). High-grading is also a problem in Massachusetts (Catanzaro and D'Amato 2006), Mississippi (Ezell 2011), Pennsylvania (Egan and others 2001), and New York (Munsell and others 2009, Tabolt and Smallidge 1999). Diameter-limit harvesting mandated by law in Ontario has led, in some cases, to high-graded stands (Schwan and Elliot 2010).

Hardwood silviculture demonstration plots established in the early 1950s suggested that diameter-limit cutting reduces the quality of trees in the residual stand, creates irregular stands that are logistically more difficult to manage, and increases the time between commercially feasible harvests (Blum and Filip 1963). These predictions have proven to be prescient. In West Virginia, 37 percent of poletimber trees were damaged following a 30-cm (12-inch) diameter-limit harvest (Fajvan and others

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

2002). Diameter-limit cutting increased 30-year volume growth for white oak poletimber, but development of persistent epicormic branches degraded log quality (Miller and others 2011). Repeated diameter-limit cutting lead to a decrease in the proportion of grade 1 buttlogs in West Virginia (Brown and others 2018).

Confirming the predictions of Blum and Filip (1963), it was reported that diameter-limit cutting “provides no control of spacing, and so results in a clumpy stand with clearcut and partially-cut areas interspersed with overly-dense areas” (Trimble 1971). Diameter-limit harvests resulted in an irregular stand structure of gaps and residual canopy (Grushecky and Fajvan 1999). The last prediction of Blum and Filip (1963) was that diameter-limit cuts would increase intervals between harvests. Nearly half of harvests were so heavy (i.e., high-grading) that no sawtimber harvests would be possible for decades in both West Virginia (Fajvan and others 1998) and upstate New York (Munsell and others 2009). There was insufficient volume for an economically viable harvest 14–17 years after an 11-inch high-grade cut in Connecticut (Ward and others 2005).

While there are suggested guidelines for rehabilitating poorly stocked stands, research has been limited to studies in southern pine and hardwoods in Arkansas (Baker and Shelton 1998, Montgomery and others 2006) and a recently begun study in mixed hardwood-conifer stands of northern Maine. Suggested approaches have focused on stand-level treatments, i.e., having a single prescription for an area several acres or larger (Clatterbuck 2006, Ezell 2011). This one-prescription-fits-all approach, unless the stand is uncharacteristically homogeneous for a poorly stocked stand, will result in inappropriate treatment for some of the stand and will likely be unacceptable to many landowners with <100 acres. A different approach is the innovative decision tree model developed for northern hardwoods in Quebec (Lussier and Meek 2014). Their method recognizes that a variety of silvicultural prescriptions will be required to optimally manage poorly stocked stands. The Canadian model evaluates microstands (0.03 ha, ~0.1 acre) and assigns each microstand to one of four microtypes. Each microtype is then assigned a unique prescription which is implemented by the harvester.

After myriad discussions with other foresters, a thorough literature search, and a half-day meeting with Connecticut Department of Energy and Environmental Protection – Division of Forestry field staff; the consensus was that most poorly stocked stands in southern New England had highly irregular structures that could be placed in four types at the microstand scale: (1) areas with sufficient poletimber (diameters ≥5 inches) to develop into a fully stocked stands, (2) areas with sufficient sapling density (diameters between 1–5 inches) of desirable species, (3) areas with some poletimber that could be developed into a two-aged stand, and (4) all other areas where regeneration should be released or initiated. This last microstand type includes a variety of initial conditions such as beech thickets or clumps of cull trees and is not covered in this paper. These observations suggested that a decision tree model might be appropriate for poorly stocked stands in the region (fig. 1). A combination of crop tree release (CTR) and timber stand improvement (TSI) could be used for the first three microstand conditions in the previous paragraph.

Earlier research has shown that for most species, CTR increases survival and diameter growth across a wide range of diameters (Miller and others 2007, Schuler 2006, Voorhis 1990, Ward 2017). Relative to area-wide thinning, the rationale for CTR is easy to explain as assisting selected trees to thrive and is straightforward to implement for family forest owners. This low-intensity, minimal- or no-cost approach could be implemented on family forests by owners harvesting firewood and, in some cases, removing cull trees and releasing a limited number of saplings to promote desired stems. Alternatively, it could be implemented on larger parcels by recognizing the effective work radius of mechanized harvesters in approximately 0.1 acre as has been done in Quebec (Lussier and Meek 2014). This system would eschew converting stands to a homogeneous standard, but recognize the high-graded stands are a heterogeneous mix of initial conditions, and would apply a set of criteria to create a stand with several distinct structures. In concept, the treated stand would be similar to a stand after several cutting cycles using small group selection.

The objective of this study was to evaluate the potential of a microstand approach to rehabilitate poorly stocked stands. Specific objectives were: (1) determine if this approach could be used to shift allocation of stand growth from low-value to high-value trees, and (2) examine whether the diameter-growth response to treatments differed among species.

METHODS

Study Areas

Five study areas were established in 2012 in poorly stocked stands in western and central Connecticut with low-quality trees (table 1). Two of the areas (Ehlich, Bass Road) had been high-graded before being donated to local land trusts. One area (Rebekah) had been high-graded during a temporary change in management oversight. Two areas were poorly stocked because of a predominance of low-quality red maple/dying ash (Bantam) or American beech (Guilford). Stand histories prior to high-grading were not known. To minimize risk of selecting target trees that would form epicormic branches following treatment, study areas were where the last harvest had been in 2006 or earlier.

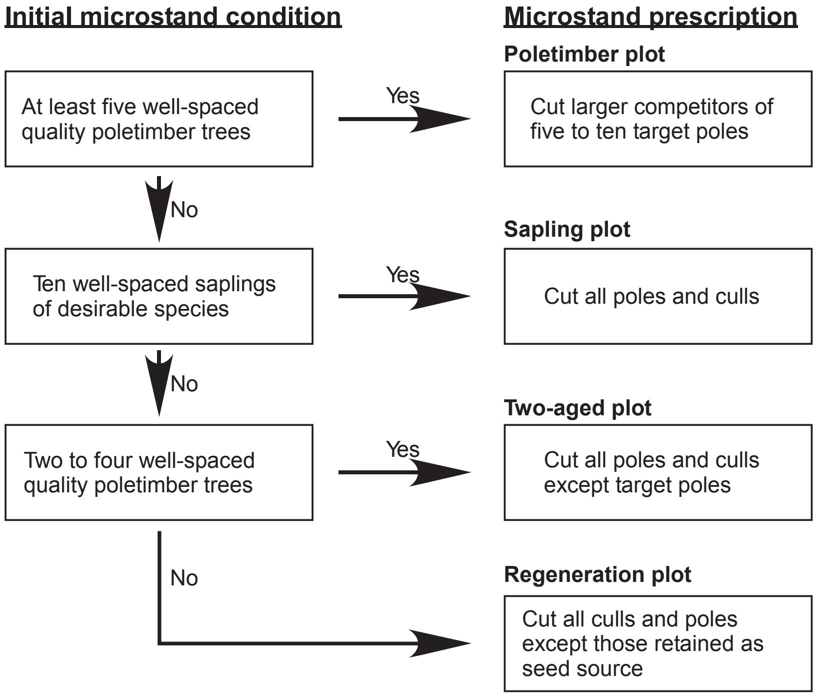

Figure1—Decision tree for microstand rehabilitation prescriptions of poorly stocked stands.

Table 1—Initial mean (standard error) tree characteristics by study area in a southern New England rehabilitation study

Study area	Diameter *inches*	Total height[a]	Pulpwood height[a]	Sawlog height[a]	Buttlog grade	Sample size AGS/UGS	Density (n/acre)
Poletimber (5.0–10.0-inch diameter)							
Ehlich	6.8 (0.2)	38.1 (1.1)	22.2 (1.2)	—	4.0 (0.1)	6/79	47.8
Guilford	7.5 (0.1)	53.8 (1.1)	33.0 (1.2)	—	3.4 (0.1)	33/95	71.9
Bass Road	7.4 (0.1)	52.4 (1.2)	29.9 (1.1)	—	3.7 (0.1)	31/105	76.4
Rebekah	7.5 (0.1)	52.5 (0.8)	31.6 (0.7)	—	3.7 (0.0)	90/272	130.8
Bantam	8.0 (0.2)	57.5 (1.6)	39.1 (1.5)	—	4.1 (0.1)	1/79	89.9
All poletimber	7.4 (0.1)	51.7 (0.5)	31.3 (0.5)	—	3.8 (0.0)	161/630	87.9
Sawtimber (≥10.6-inch diameter)							
Ehlich	15.8 (0.5)	73.7 (8.1)	53.4 (1.8)	29.8 (1.5)	3.7 (0.1)	12/53	36.5
Guilford	14.3 (0.3)	75.0 (1.2)	56.3 (1.1)	32.5 (1.0)	2.7 (0.1)	84/26	61.8
Bass Road	14.0 (0.4)	75.0 (1.3)	53.5 (1.1)	26.0 (1.1)	3.5 (0.1)	33/53	48.3
Rebekah	13.2 (0.2)	71.3 (1.0)	53.5 (0.9)	27.3 (0.8)	2.9 (0.1)	91/102	69.7
Bantam	13.8 (0.4)	72.8 (1.2)	54.1 (1.0)	22.9 (1.2)	3.9 (0.1)	2/64	74.2
All sawtimber	13.9 (0.1)	73.2 (1.1)	54.2 (0.5)	27.9 (0.5)	3.2 (0.1)	222/298	57.8
Combined	10.0 (0.1)	60.2 (0.6)	40.4 (0.5)	27.9 (0.3)	3.6 (0.0)	383/928	145.8

[a] Heights were measured to nearest foot.

Soils were stony to extremely stony, fine sandy loam Typic Dystrudepts and Oxyaquic Dystrudepts derived from gneiss, schist, and granite glacial melt-out and lodgment tills, respectively. Elevations ranged from 590 to 1050 feet above mean sea level. The area is in the northern temperate climate zone. Mean monthly temperature ranged from 27 °F in January to 73 °F in July with an average of 176 frost-free days per year. Average annual precipitation was 46 inches per year, evenly distributed over all months.

Experimental Design and Measurements

Study areas had nine (Bantam), eighteen (Guilford, Ehlich, Bass Road), or twenty-eight (Rebekah) 65.6- by 65.6-foot (~0.1 acre) plots. Except at Rebekah, plots were arranged in a 3- by 3-plot contiguous block to form a square, i.e., each 197- by 197-foot block had nine plots. Because high-grading at Rebekah was proximate to the network of permanent logging roads, there was a 2- by 5-block, a 3- by 3-block, and three 3- by 1-blocks. Within each plot, a tree identification number and diameter measurement height of all stems [diameter at breast height (DBH) >4.9 inches] were permanently marked with paint. Species, stem diameter (at 4.5 feet aboveground), and crown class were recorded for each tree. Each tree was also classified as acceptable growing stock (AGS) or unacceptable growing stock (UGS). While metric units were used for all field measurements, values reported here are in English units for analysis and to facilitate communication with target audiences of practicing foresters and landowners.

After initial measurements were completed, each plot was evaluated and categorized as one of four microstand classes based on initial conditions: poletimber, two-aged, sapling, or regeneration (fig. 1). Poletimber plots had at least five well-spaced AGS poletimber trees – equivalent to a minimum of 50 trees per acre. Two-aged plots had two to four well-spaced AGS poletimber trees. Sapling plots had at least 10 well-spaced saplings (diameters between 0.8–4.9 inches) of desirable species (e.g., oak, white pine) with good form. The last microstand class, regeneration, did not have sufficient sapling or poles to create a fully stocked future stand.

After each plot was assigned to one of the four initial microstand classes, plots were randomly designated as either control (no management) or treated (active management) with two treated plots for every control. The four treatments applied differed by microstand class. On the poletimber plots, five to ten AGS poletimber trees (diameter >4.9 inches) on each plot were given a four-sided crown release (complete crop tree). The AGS poletimber trees in the two-aged plots were given a four-sided release, and any AGS saplings not in direct competition were also given a CTR. On the sapling plots, all poles were cut and the 10 sapling crop trees were given a four-sided release. For the regeneration plots, all poles except those retained as seed trees were cut to either release seedlings of desirable species (seedling) or to prepare site for planting (initiate). Results for the regeneration microstand plots are not reported here.

To simulate operational implementation in low-value stands, target and cut stems were not designated prior to actual treatment. As this was a research study with random treatment allocation, harvesters entered each plot knowing the prescription goal, but made their own determination as to which stems were crop trees following defined criteria (table 2). To ensure quality control of target stem selection, harvesters were guided

Table 2—Criteria for crop tree selection[a]

Species (in order of preference)
Oak, sugar maple, black cherry, eastern white pine, yellow-poplar, birch, hickory, red maple, aspen. Species preference will depend on site quality and landowner objectives, and requires judgment of an experienced forester.
Buttlog characteristics
Minimum height of 16 feet (5 m) to first major fork, no branches with diameters >2 inches (5 cm), no live epicormic branches, lean <10 percent, sweep <6 inches (15 cm), no crook, no more than one seam, no exposed wood (catface) wider than 2 inches, no cankers or gum. No seams or exposed wood was acceptable for red maple or aspen because these species poorly compartmentalize decay.
Crown characteristics
Live crown equal to a minimum of 30 percent of total height, crown dieback <20 percent, free-to-grow before or after release, no broken branches with diameters >5 inches, no major forks below 33 feet (10 m) with included bark, no persistent insect or disease. Presence of a fork below 33 feet that did not have included bark was acceptable fo saplings.

[a] Criteria for defining a quality crop tree will vary depending on landowner objectives, but will usually include the characteristics we selected.

by a licensed Connecticut Certified Forester. After cutting was completed, the degree of canopy openness for all residual stems was assessed by the number of sides free of competition. As is typical in high-graded and poorly stocked stands, many stems not intentionally released, even in untreated control plots, nevertheless had one or more sides free of competition from prior harvests. Diameters of all live trees were measured during the dormant season for the following 4 years. Mortality was also recorded when appropriate.

Data Analysis

Six species groups were included in the analysis: upland oaks (*Quercus rubra*, *Q. alba*, *Q. velutina*, *Q. coccinea*, *Q. montana*), maple (*Acer rubrum*, *A. saccharum*), birch (*Betula lenta, B. alleghaniensis*), hickory (*Carya* spp.), conifer (*Tsuga canadensis*, *Pinus strobus*), and other major species (*Fraxinus americana*, *Fagus americana*, *Tilia americana*, *Betula papyrifera*, *Prunus serotina*, *Ulmus americana*, *Ostrya virginiana*). Species are listed in the order of importance within each species group and species fewer than five stems are not listed. Species-specific stocking provided by each tree was determined following procedures in Arner and others (2003).

To determine effects of level of release on tree diameter growth, all crop trees were assigned a release class after treatment. Trees with three or four sides free of competition were classified as fully released, regardless if the release was from treatment during this study or from the prior high-grading. Trees with one or two sides free were classified as partially released and those with no sides free of competition were classified as not released.

Repeated measures analysis of variance (ANOVA) was used to examine basal area growth of AGS and UGS stems. Years since cutting was the within-subjects factor, with study area, microstand classification, and treatment as between-subject factors. Reported P-values are those after applying the conservative Greenhouse-Geisser Epsilon correction for deviations from compound symmetry, i.e., non-sphericity (Hand and Crowder 1996). To examine how treatments influenced AGS vs. UGS basal area growth, a multifactor ANOVA with study area, microstand classification, treatment, and crossed effects was used. While full models and subsets were examined, only the most parsimonious model with the lowest Akaike Information Criterion (AIC) is presented (Hosmer and others 2013). Tukey's HSD test was used to test differences of sprout heights among treatments. Differences were considered significant at $P < 0.05$.

For each species group, repeated measures ANOVA was used to examine treatment effects on 4-year diameter growth. Years since cutting was the within-subjects factor, with study area, release category, and AGS/UGS as between-subject factors. Reported P-values are those after applying the conservative Greenhouse-Geisser Epsilon correction for deviations from compound symmetry, i.e., non-sphericity (Hand and Crowder 1996). When repeated measures ANOVA indicated a factor effect, a multiway ANOVA was used to determine if cumulative diameter growth differed between factor levels. While full models and subsets were examined, only the most parsimonious model with the lowest AIC is presented (Hosmer and others 2013). Tukey's HSD test was used to test differences of sprout heights among treatments. Differences were considered significant at $P < 0.05$. The same procedures were used to examine influence of release on sapling diameter growth.

RESULTS AND DISCUSSION

Stand Response

As is typical of many high-graded stands, total stocking and stocking of AGS varied greatly at the microstand (~0.1 acre) scale (fig. 2). Unacceptable growing stock stocking was higher than AGS stocking on over 70 percent of plots examined. Two of the stands (Ehlich and Bantam) had no plots with medium AGS stocking or better, and Bass Road only had 22 percent of plots with medium AGS stocking. While stocking of AGS on the Rebekah and Guilford stands ranged from fully to poorly stocked, only 11 and 33 percent of plots, respectively, had full AGS stocking. Both stands had more plots with poor stocking of AGS than full stocking. We found stocking levels were highly irregular within these poorly stocked stands as has been reported in West Virginia (Grushecky and Fajvan 1999, Trimble 1971), New York (Nyland 2006), and Quebec (Lussier and Meek 2014). The patchy distribution of trees in poorly stocked stands, especially those that had been high-graded has long been recognized as an impediment to developing a stand prescription (Blum and Filip 1963).

The treatments prescribed to shift growth onto higher quality residual stems had an immediate impact on the relative proportion of UGS to AGS stocking (fig. 3). Unacceptable growing stock stems initially accounted for 50 percent or more of plot stocking, but only 29 and 22 percent after management implementation on the poletimber and two-aged plots, respectively. Treatment also reduced UGS basal area on sapling plots when trees competing with quality saplings were removed. It should be noted that some UGS stems that did not compete with crop trees were left to provide structure for wildlife per all landowner's objectives.

Unacceptable growing stock basal area growth was greater than for AGS on both poletimber and two-aged plots during the 4 years after initial treatment (table 3). In contrast, basal area growth of AGS was greater than for UGS on treated plots. In general, AGS basal area growth was constant for a given microstand class regardless of

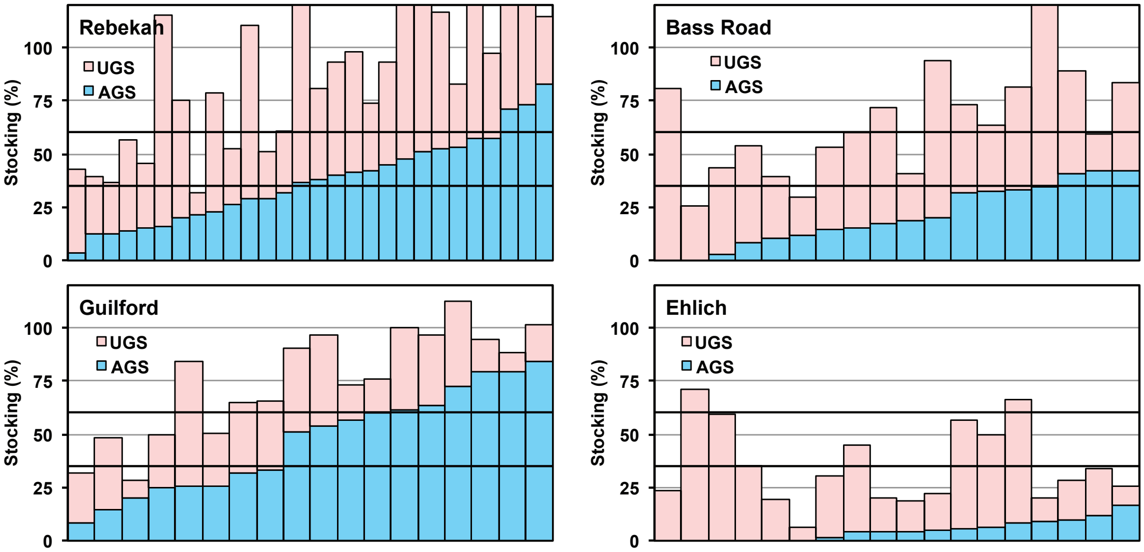

Figure 2—Stocking (percent) of acceptable growing stock (AGS) and unacceptable growing stock (UGS) among microstands (~0.1-acre plots) on study areas. Horizontal lines indicate minimal levels for medium-stocked (35 percent) and fully stocked (60 percent) stands. Values for Bantam are not shown as UGS stocking averaged 64 percent, seven plots had no AGS, one plot had 3 percent AGS stocking, and one plot had 11 percent AGS stocking.

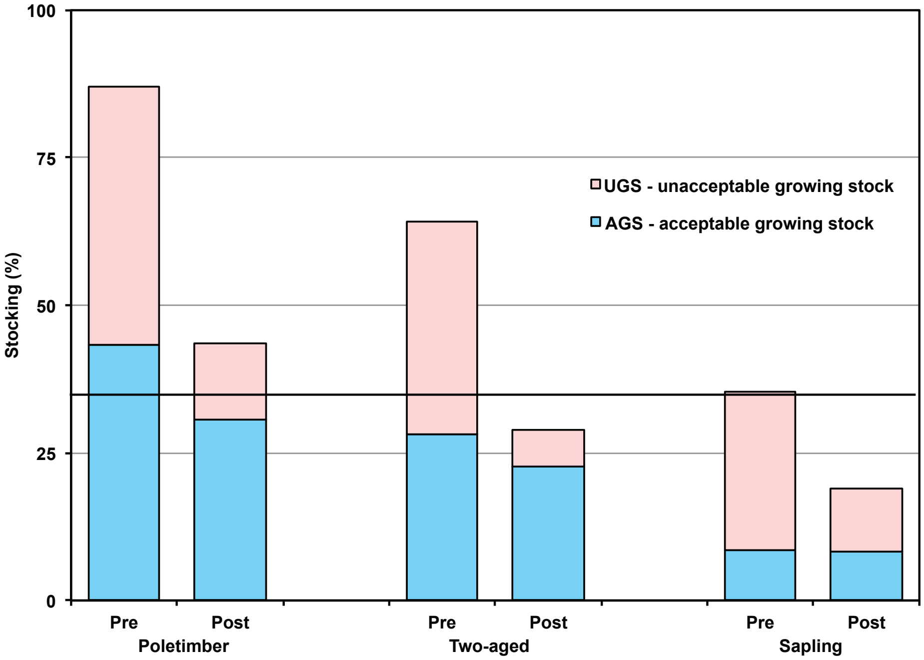

Figure 3—Mean initial (Pre) and post treatment (Post) stocking (percent) of acceptable growing stock (AGS) and unacceptable growing stock (UGS) by microstand classification.

Table 3—Mean (standard error) 4-year basal area growth (square feet per acre) of acceptable and unacceptable growing stock by microstand classification and subsequent treatment

Microstand type	Acceptable growing stock Mean (SE)[a]		N	Unacceptable growing stock Mean (SE)[a]		N	AGS/UGS *P*-value[b]
Two-aged (treated)	3.4 (1.3)	a	12	1.0 (1.0)	c	7	0.385
Two-aged (uncut control)	4.7 (1.4)	a	6	7.0 (1.0)	a	6	0.148
Poletimber (treated)	4.3 (1.2)	a	19	3.7 (0.8)	bc	18	0.594
Poletimber (uncut control)	3.8 (1.2)	a	11	4.3 (0.8)	ab	12	0.303
All plots (treated)	4.0 (0.5)	a	44	1.8 (0.6)	a	44	0.007
All plots (uncut control)	3.8 (0.7)	a	22	6.1 (0.6)	b	26	0.007

[a] Column values with same letter were not significantly different.
[b] AGS/UGS is P-value comparison within a row.

treatment, while UGS basal area growth was reduced following treatments that removed a large proportion of UGS stems.

Plots that had some residual basal area showed a dramatic shift in allocation of basal area growth from predominately on UGS stems on untreated plots to predominately on AGS stems on treated plots. A full-model repeated measures ANOVA indicated that AGS basal area growth over the 4-year period was independent of year × initial microstand classification ($F = 0.26$, d.f. = 4,168, $P_{GG} = 0.667$, where P_{GG} is after Greenhouse-Geisser Epsilon correction), year × treatment ($F = 0.25$, d.f. = 4,168, $P_{GG} = 0.680$), and year × microstand classification × treatment interactions ($F = 0.91$, d.f. = 4,168, $P_{GG} = 0.367$); i.e., AGS basal area growth did not differ among microstand classification, treatment, or their interactions. In contrast, UGS basal area growth was not independent of year × treatment ($F = 8.99$, d.f. = 4,148, $P_{GG} < 0.001$) and year × microstand × treatment interactions ($F = 4.85$, d.f. = 4,148, $P_{GG} = 0.016$), but was independent of year × microstand classification ($F = 0.60$, d.f. = 4,148, $P_{GG} = 0.518$). Standard ANOVA found that UGS basal area growth did not differ between poletimber and two-aged microstands ($F = 0.39$, d.f. = 1,37, $P = 0.534$), but did differ by treatment (uncut vs. treated) ($F = 10.3$, d.f. = 1,37, $P = 0.003$) and microstand × treatment interaction ($F = 7.26$, d.f. = 2,37, $P = 0.011$). A parsimonious model without initial condition had a lower AIC_c, and least square means from that analysis are presented in table 3.

Surprisingly, there may be regional differences in the long-term response of stands to high-grading and diameter-limit cuts. Relative to uncut and shelterwood stands in Connecticut, 15-year volume growth after high-grade harvests was depressed by >80 percent, and most volume was on grade 3 or cull trees (Ward and others 2005). Because practically all residual AGS trees in a high-graded stand are small, as are most following a diameter-limit cut, it will probably be a couple of decades or longer before a commercial harvest is feasible in northern New England (Leak 1996).

In contrast, volume growth was higher with repeated diameter-limit harvest than uncut control over 50 years in West Virginia (Schuler 2004). However, it should be noted that many of the stands in that study were on relatively high site indices with cutting return intervals of 15 or 20 years (Schuler 2004). Good long-term growth was also reported after high-grading in another West Virginia study, but it was recommended that diameter-limit harvests be accompanied by improvement cutting and release of trees smaller than commercial thresholds (Smith and Lamson 1977); i.e., proactive rehabilitation conducted simultaneously with the harvest. Basal area growth following high-grading that included removal of cull trees averaged 2.3 square feet per acre per year in West Virginia, similar to growth rates following a 16-inch diameter cut (Hutnik 1958). A rehabilitation cut that removed UGS and cull trees doubled stand volume over an 8-year period in Illinois (Plass and Greth 1959).

Tree and Sapling Response

Unacceptable growing stock class trees predominated in both poletimber and sawtimber size classes, 80 and 57 percent, respectively (table 1). Buttlog grades were poor as would be expected in these stands, with poletimber trees having an average potential buttlog grade of 3.8 and sawtimber trees an average buttlog grade of 3.6. Unfortunately, diameter growth for both low-quality (UGS) and better quality (AGS) trees did not differ. Repeated measures ANOVA found 4-year diameter growth was independent of year × AGS/UGS classification for all species groups ($P_{GG} = 0.054–0.859$). Diameter growth was not independent of year × release class (none, partial, full) for any species group, ranging from $F = 4.2$, d.f. = 8,412, $P_{GG} = 0.023$ for conifers to $F = 18.0$, d.f. = 8,564, $P_{GG} < 0.0001$ for birches. Two-factor ANOVA (study area, release class) indicated that fully released trees grew faster than those not released, except for the other species group (table 4). Full release more than doubled diameter growth of oaks, maples, and conifers. Partial release increased mean diameters of all species groups except hickory.

Sapling diameter growth was improved by full canopy release for the three species groups examined (table 5). Repeated measures ANOVA found 4-year diameter growth of oak saplings was independent of year × initial crown class ($F = 1.6$, d.f. = 3,96, $P_{GG} = 0.216$), but not year × release ($F = 6.9$, d.f. = 3,96, $P_{GG} = 0.002$). Four-year diameter growth of white pine ($F = 40.9$, d.f. = 3,111, $P_{GG} < 0.001$) and birch saplings ($F = 17.2$, d.f. = 3,261, $P_{GG} < 0.001$) was not independent of year × release. Two-factor ANOVA (initial crown class, release class) indicated that fully released trees grew faster than those not released for all species. Diameter growth of white pine and birch, but not oak, was greater for saplings that were initially in the upper canopy than for intermediate saplings.

The positive response of both trees and saplings to CTR on poorly stocked stands suggests that forest managers and landowners can shift growth onto stems that have the potential to develop into quality trees. Prior crop tree research examined the response of trees in even-aged stands and focused on releasing higher quality stems. While unknown, it is probable that a large proportion of residual trees on the high-graded study areas were weak codominants or in the intermediate crown class prior to harvest. The increased diameter growth exhibited by all species following CTR suggests lower canopy trees have not necessarily stagnated, but can respond to release. Overtopped white oaks released from competition by a diameter-limit harvest and removal of adjacent trees grew 80 percent more over 30 years than similar trees in an adjacent uncut stand (Miller and others 2011).

At least 10 years will be required to determine if these treatments resulted in a permanent increase of stand growth allocated to AGS without causing a loss of buttlog grade due to increased epicormic branching on released trees (Miller and others 2011) or development of large branches of the buttlog of saplings. The UGS trees that we left for wildlife habitat or as a seed source on sapling and regeneration microstands will have to be carried through until at least the first commercial thinning to avoid damaging the smaller cohort during logging. The UGS trees we left, primarily white pine and birch, typically do not develop wide-spreading crowns.

Table 4—Mean (standard error) 4-year diameter growth (inches) of trees (>4.9 inches in diameter) by degree of tree crown release: non-competitive crowns on all four sides, partial-competitive crowns on two or three sides, full-crown free of competition on three or four sides

		------------------Release classification------------------						
Species group	*P*-value[a]	None		Partial		Full		N
Oak	<0.001	0.53 (0.02)	a	0.84 (0.02)	b	1.08 (0.02)	c	141
Hickory	0.004	0.46 (0.02)	a	0.53 (0.03)	a	0.75 (0.02)	b	64
Maple	<0.001	0.37 (0.02)	a	0.69 (0.02)	b	0.99 (0.03)	c	198
Birch	<0.001	0.65 (0.03)	a	0.86 (0.02)	b	1.20 (0.03)	c	147
Conifer	0.002	0.47 (0.04)	a	0.70 (0.03)	b	1.05 (0.05)	b	108
Other	<0.001	0.52 (0.02)	a	0.85 (0.03)	b	0.60 (0.03)	ab	106

[a] Row values with the same letter were not significantly different.

Table 5—Mean (standard error) 4-year diameter growth (inches) of saplings (diameters between 0.8 and 4.9 inches) by whether stems had full or no canopy release from other saplings

		--------------Canopy release---------------				Sample size	
Species	*P*-value[a]	None		Full		None	Full
Oak	0.001	0.31 (0.15)	a	0.95 (0.10)	b	11	24
White pine	<0.001	1.14 (0.12)	a	1.59 (0.12)	b	13	28
Birch	<0.001	0.92 (0.10)	a	1.39 (0.06)	b	24	66

[a] Row values with the same letter were not significantly different.

Therefore, it is unknown if the residual UGS trees will suppress sapling growth as was observed with oak reserve trees in West Virginia (Miller and others 2006).

The extensive expanse of poorly stocked or potentially poorly stocked forests in the Eastern United States has serious ramifications on the ability of forests to provide critical economic and ecological services. While there are sound silvicultural and practical administrative reasons for treating a poorly stocked stand as one unit, any recommendation to initiate a regeneration cut by removing all larger stems is unlikely to be implemented on a significant proportion of many family forests – the very forests that are most susceptible to high-grading disguised as a diameter-limit or ‘selection’ harvest. This study suggests that the microstand approach developed in Quebec by Lussier and Meek (2014) may be a practicable in poorly stocked stands in southern New England and probably throughout much of eastern hardwood forest when prescriptions are tailored to local species and stand conditions.

ACKNOWLEDGMENTS

We would like to thank technicians J.P. Barsky and M.R. Short and seasonals J. Cantoni, A. Massa, G. Cerne, A. Ellison, K. Nagy, and A. Simpson for their help with plot establishment and data collection. This research was made possible with in-kind help provided by Town of Guilford; Rebekah’s Hill Flora and Fauna Preservation Society, LLC; Weantinoge Heritage Land Trust, Inc.; the White Memorial Foundation; and the Winchester Land Trust. This material is based upon work that was supported by the National Institute of Food and Agriculture, McIntire-Stennis Project CONH-578 (Accession No. 229098).

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SESSION 8:

Early Successional Wildlife Habitat

Moderator:

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WILDLIFE RESPONSE TO OAK ECOSYSTEM RESTORATION

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Charles Kwit, and Mike Stambaugh**

Extended abstract—The eastern oak (*Quercus*) forest ecosystem once included extensive open-canopy and early successional communities (i.e., woodlands and savannahs) that had been maintained by frequent natural and anthropogenic fires (Burhans and others 2016). However, beginning in the early 20th century and continuing until the present, fire regimes have been dramatically altered resulting in the almost complete elimination of such communities and substantial degradation of remnants. Consequently, associated wildlife populations have also experienced pronounced declines.

Within a long-term, field experiment conducted at three sites (Catoosa Wildlife Management Area and Land Between the Lakes National Recreation Area, both in TN, and Green River Game Lands in NC), we explored responses of breeding birds and forest bats to community restoration treatments, including canopy reduction to woodland (60 square feet per acre residual BA) and savannah (30 square feet per acre residual BA) targets and prescribed fire (March and October). Treatments were assigned under a randomized block design with a total of five replicates across all three locations. We documented breeding bird responses using point counts visited three times annually, 2010–2016, and nest searching and monitoring for two focal species, red-headed woodpecker (RHWO; *Melanerpes erythrocephalus*) and prairie warbler (PRAW; *Setophaga discolor*), 2015–2016. Forest bat activity was monitored through passive acoustic arrays that detected echolocation calls of feeding bats, 2013–2014. We estimated occupancy (multiple season, robust design in Program MARK) and abundance (N-mixture model in Program Unmarked); nest success was estimated using Program MARK. We used repeated measures (sample period and year), mixed-model regressions to compare bat activity and availability of insect prey among treatments.

Occupancy of breeding birds was strongly influenced by key measures of structure (Vander Yacht and others 2016). Seven of the 10 early-successional avian species we evaluated responded positively to decreased live basal area (LBA), while three species showed no significant trend. Among ten late-successional avian species examined, two (hooded warbler [HOWA; *Setophaga citrina*] and ovenbird [OVEN; *Seiurus aurocapilla*]) showed a negative trend in response to decreased LBA, one a positive quadratic relationship, and seven no relationship. A similar pattern was observed with respect to percent herbaceous groundcover with six early successional species showing a positive relationship with herbaceous ground cover and four species having no trend; among late successional species, the same two species (HOWA and OVEN) had negative relationships, while eight species demonstrated no trend in relation to herbaceous ground cover. Associations with midstory density were weaker and less consistent, perhaps due to the ubiquitous woody cover (primarily red maple [*Acer rubrum*]) in this strata during the restoration process.

Avian abundance was also influenced by LBA and herbaceous ground cover, but unlike occupancy, midstory density was positively related to abundance for five early successional species with a less pronounced and variable influence on late successional species (Henderson 2017). For all early successional species with a relationship between abundance and LBA (n = 5), that relationship was positive. Furthermore, six late

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

successional species were sensitive to reduced LBA, but in every case, abundances increased with some level of disturbance with peak abundances occurring between 45 and 75 square feet per acre. This pattern indicated some level of disturbance-dependence for these late successional species. For herbaceous ground cover, we found fewer species' abundance being influenced, but the thresholds (approximately 20-percent cover) were very similar to that observed with occupancy. As expected, the relationships for abundance were less pronounced and more gradual than occupancy in all cases.

Late successional species sensitive to disturbances associated with restoration treatments, OVEN and HOWA, are species that nest or forage in leaf litter. Early successional species were almost completely absent from controls leading to reduced species richness in these stands. Indeed, a composite index based on Partners In Flight conservation assessment scores indicated that the greatest cumulative conservation benefit for breeding birds occurred at lower LBA and greater levels of herbaceous ground cover.

Nests for both PRAW and RHWO were absent from our undisturbed control stands (Henderson 2017). Prairie warblers selected nest sites (n = 105) with greater herbaceous groundcover, although this did not influence nest survival. Our estimate of nest survival over both years was 20.7 percent but showed a strong year effect, being quite low (6.8 percent) in the breeding season immediately after burning but comparable to other studies one year post-fire (32.5 percent). Given the pattern we observed for abundance over time (a strong biennial cycle with lows linked to burning years and highs occurring one year post-burning) with this species, we believe that the reduced vegetation cover in burn years is a plausible explanation for the reduced nest success the year of the burn. Red-headed woodpeckers selected for pine snags for nest cavities (n = 47) and had very high nest survival rates, among the highest reported (84.1 percent). Furthermore, we did not find any support for any habitat covariates or for a year effect in our survival models. Collectively, our results suggest that habitat in our study area may have been near optimal for this species.

Forest bat activity for all taxa was greater in disturbed sites, especially stands reduced to savannah target basal areas, than in controls (Cox and others 2016). Activity was also greater for larger bodied species with lower call frequencies that are adapted to fly and forage in open conditions. Myotis species (4.74 percent of all classified detections) did not differ among our treatments. We found no evidence insect prey abundance or biomass influenced activity of bats, suggesting stand structure was more important than prey availability in determining habitat use by bats in woodlands and savannahs.

Woodland and savannah restoration treatments involving canopy reduction and re-introduction of prescribed fire benefited early successional wildlife in oak forest ecosystems and did not appear to negatively impact most species associated with later seral stages. Indeed, with the exception of two species (OVEN and HOWA), we did not observe consistent or substantial detriment to any wildlife taxon. On the other hand, many species of high conservation priority responded positively to the treatments we examined. Furthermore, woodlands and savannahs restore a long missing community to eastern oak ecosystems, one with substantial biodiversity and conservation value.

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FOREST MANAGEMENT FOR GOLDEN-WINGED AND CERULEAN WARBLERS—LESSONS LEARNED FROM FOREST MANAGEMENT EXPERIMENTS

David A. Buehler, Douglas W. Raybuck, Justin A. Lehman, Patrick D. Keyser, Than J. Boves, and Jeffrey L. Larkin

Extended abstract—Golden-winged Warbler (*Vermivora chrysoptera*) and Cerulean Warbler (*Setophaga cerulea*) are two of the most rapidly declining forest songbird species that occur in oak-dominated forests in eastern North America. Both species are considered species of national conservation concern by the U.S. Fish and Wildlife Service (USFWS 2008) and are listed as endangered, threatened, or in need of management by most States throughout their breeding range (Roth and others 2012, Wood and others 2013). Both species occupy large forested landscapes but generally nest at opposite ends of the successional spectrum with Golden-winged Warbler preferring young forests for nesting and Cerulean Warblers preferring mature forests for nesting. Comprehensive, science-based management strategies have been developed for both species individually (Roth and others 2012, Wood and others 2013). Because the two species are sympatric throughout much of their Appalachian Mountains range, holistic, forest-wide management approaches are needed to allow for the strategic management of forested landscapes to meet the life history requirements of both species simultaneously.

Management opportunities focused where both species co-occur have been discussed previously in general terms (Hamel and others 2005). Recently, we conducted two forest management experiments on the North Cumberland Mountains Wildlife Management Area in eastern Tennessee specifically focused on these two species where they co-occur to identify their response to various forest management prescriptions and to identify how to optimize management of both species on the same managed forest landscape. The Cerulean Warbler forest management experiment implemented in 2007 involved two replicates of four treatments: control–unharvested (~30 m^2/ha basal area), light harvest (~25 m^2/ha residual basal area), intermediate harvest (~17 m^2/ha residual basal area), and heavy harvest (~7.5 m^2/ha residual basal area) (Boves and others 2013)2013. The Golden-winged Warbler experiment involved three replicates of four treatments implemented by clearcutting mature hardwood forest stands in 2010 (control), followed by combinations of prescribed burning and/or herbicide treatments of stump sprouts in 2012 (Lehman 2017). In both experiments, we monitored experimental stands for 1–2 years prior to treatments to establish baseline conditions, and we monitored stands for 3–4 years post-treatment. We monitored territory densities with spot-mapping, habitat selection, and nest survival on both studies; we monitored post-fledging survival and habitat selection via radio telemetry on the Golden-winged Warbler experiment. We evaluated results from Raybuck (2016) from Pennsylvania to infer how Cerulean Warblers use similar forest conditions during the post-fledging period.

Cerulean Warbler territory occupancy occurred across the entire range of treatments, with the greatest positive density response occurring in intermediate and heavy harvest treatments, whereas densities on controls (no harvest) actually declined. In contrast, nest survival was greatest in the controls, and generally declined with harvest (Boves and others 2013)2013. Golden-winged Warbler territory occupancy occurred across all four treatments post-harvest, although the greatest densities occurred in stands with prescribed burning and/or herbicide treatments. We detected no differences in nest survival among treatments, although sample sizes were limited and statistical power was low (Lehman 2017).

Post-fledging habitat selection differed from nesting habitat selection for both Cerulean Warblers in Pennsylvania (Raybuck 2016) and Golden-winged Warblers (Lehman 2017). For Ceruleans, fledglings occupied forest stands with trees of lesser diameters and greater midstory cover. Fledglings moved >1600 m from the nest over the first

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

30 days post-fledging (Raybuck 2016). Golden-winged Warbler fledglings occupied forest stands with greater shrub/sapling cover and lesser herbaceous cover, although paradoxically, fledgling survival was negatively linked to shrub/sapling cover. Fledglings used all cover types, occurring in generally older-aged stands than nests occurred in, although generally not in mature, closed-canopy forest. Golden-winged fledglings moved extensively across the landscape, averaging >400 m per day after 2 weeks post-fledging (Lehman 2017).

Combining the forest management experiment results for territory occupancy and density, nest and post-fledging survival, and habitat selection for both species, some clear conclusions emerge (fig. 1). First, nest-site selection by Golden-winged Warblers and Cerulean Warblers occurs over a fairly broad range of forest stand conditions, ranging from 2.5–10.0 m^2/ha basal area for Golden-winged Warblers to 7.5–30+ m^2/ha for Cerulean Warblers. Interestingly, there is a region of overlap (7.5–10.0 m^2/ha) in which both species can actually co-occur nesting. Secondly, the optimal conditions for nest survival are much more restrictive for both species, occurring in the lower end of the basal area range for Golden-winged Warblers (2.5 m^2/ha) and in the upper end of the basal area range for Cerulean Warblers (>25 m^2/ha). Finally, in the case of both species, post-fledging habitat use differed significantly from nesting habitat use. Golden-winged Warblers used forest stands with well-developed shrub/sapling layers, whereas Cerulean Warblers used forest stands that were smaller in diameter with greater midstory cover than forest stand conditions at nest sites. Although we did not monitor Golden-winged Warbler and Cerulean Warbler fledglings via telemetry on the same sites, presumably both species of fledglings could co-occur in the same stand conditions.

Given what we have learned from these forest management experiments, we have developed the following management considerations to promote the goal of supporting both of these high-priority species. First, both species require hardwood forest-dominated landscapes, generally >70 percent forest cover within 10 km, to establish breeding territories in the first place. Second, because the nesting habitat requirements for both species are at opposite ends of the successional spectrum, because nesting habitat differs from post-fledging habitat, and because fledglings move over such a large area, both species require a dynamic forest landscape with the juxtaposition of a diversity of age classes and structural conditions. Third, sustainable timber harvest is the most likely tool to provide the diversity of forest age classes and structural conditions required to meet the nesting and post-fledging habitat requirements of these species. Finally, it is possible to manage for viable populations of both species on the same forest landscape with strategic forest management planning. Managing to optimize full season productivity of both species will require the balancing of the provision of quality nesting habitat with the provision of adjacent quality post-fledging habitat (Streby and others 2014).

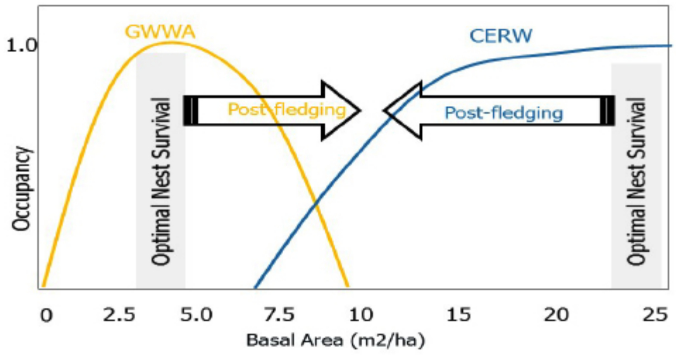

Figure 1—Territory occupancy, nest survival, and post-fledging survival and habitat use for Golden-winged Warblers and Cerulean Warblers on the North Cumberland Mountains Wildlife Management Area, Tennessee.

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HERPETOFAUNAL RESPONSES TO FOREST MANAGEMENT: A SYNOPSIS OF FINDINGS IN OAK-HARDWOOD RESTORATION FOREST STANDS

William B. Sutton, Yong Wang, and Callie J. Schweitzer

Extended abstract—Globally, biodiversity declines have occurred at alarming rates across a wide array of taxa. Amphibians and reptiles (known collectively as herpetofauna), represent two taxa that have declined considerably over the past three decades. A variety of stressors, including landscape change, habitat destruction, emerging pathogens, illegal collection, and climate change all contribute synergistically to impact herpetofaunal populations. Of these threats, habitat alteration and destruction represent acute stressors that have increased concomitantly with the rise in global human population. Habitat alteration includes a variety of natural and anthropogenic sources of disturbance. Forest management represents a significant form of habitat disturbance that often impacts large portions of the landscape; however, forest management practices involve a variety of vegetation management techniques that can be tailored to mimic regional disturbance regimes. In addition, forest management can be used in a restoration context to restore ecosystem function and forest structure. Our current study evaluated the ecological impacts of forest restoration in pine-dominated forests in the William B. Bankhead National Forest (BNF) located in Lawrence, Winston, and Franklin counties of northwest Alabama. The over-arching goal of the larger project was to evaluate the efficacy of forest management (thinning and prescribed burning) to restore upland loblolly pine (*Pinus taeda*) dominated stands to historical hardwood (*Quercus* and *Carya*) conditions.

Experimental design consisted of a randomized block design and included six total treatments consisting of control (no thin and no burn), burn, light thin (17 m^2/ha residual basal area [BA]), heavy thin (11 m^2/ha residual BA), light thin and burn, and heavy thin and burn. Each treatment was replicated three times across the landscape for a total of 18 treatments with each stand approximately 9 ha in size. Herein, we report the impacts of the thinning and prescribed burning on herpetofaunal populations. We used a variety of techniques to evaluate herpetofaunal response to forest management, including drift fences equipped with box traps and pitfall traps (detailed in Sutton and others 2010) and artificial cover objects (Sutton 2010). In addition, we used radiotelemetry to monitor the spatial ecology and habitat use of the copperhead (*Agkistrodon contortrix*) in a subsample of stands. We employed radiotelemetry as a means to evaluate the impacts of forest management at a larger spatial scale than what would be revealed by drift fences alone. We monitored each forest stand for 1 year prior to management implementation and for 2 years post-management.

Over the 4-year study period, we captured a total of 2,643 individuals of 47 species (27 reptiles and 20 amphibians) over 3,132 trap nights. Collectively, we found that reptiles (specifically lizards and large-bodied snakes) were impacted by forest management compared to other reptile species (Sutton and others 2013, 2014). Specifically, the Green Anole (*Anolis carolinensis*), which was the most abundant lizard captured during the study (n = 261), increased up to two seasons post-treatment with abundance correlated with increased temperatures in thinned stands (fig. 1A). Eastern Fence Lizard (*Sceloporus undulatus*) counts increased primarily during the second season post-treatment primarily in thin and burn stands. Conversely, Little Brown Skink (*Scincella lateralis*) counts decreased post-treatment in all treated stands; we found that stands with greatest counts also had relatively greater litter depths (fig. 1A). Two other species, the Five-lined Skink (*Plestiodon fasciatus*) and Broad-headed Skink (*Plestiodon lateralis*), did not directly respond to forest management; however, *P. fasciatus* relative abundance was greater in forest stands with greater coarse woody debris cover (fig. 1A). In reference to snake responses to forest management, *A. contortrix* was the most abundant snake captured during the study (n = 178); however, we documented no clear impact of management on counts of this species (fig. 1B). The Black Racer (*Coluber constrictor*) and Black Kingsnake (*Lampropeltis nigra*) tended to increase in thin-only stands during the second year post-treatment (fig. 1B). Amphibians did not show a clear response to forest management, but pond-breeding species, such as the Marbled Salamander (*Ambystoma opacum*), Eastern

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

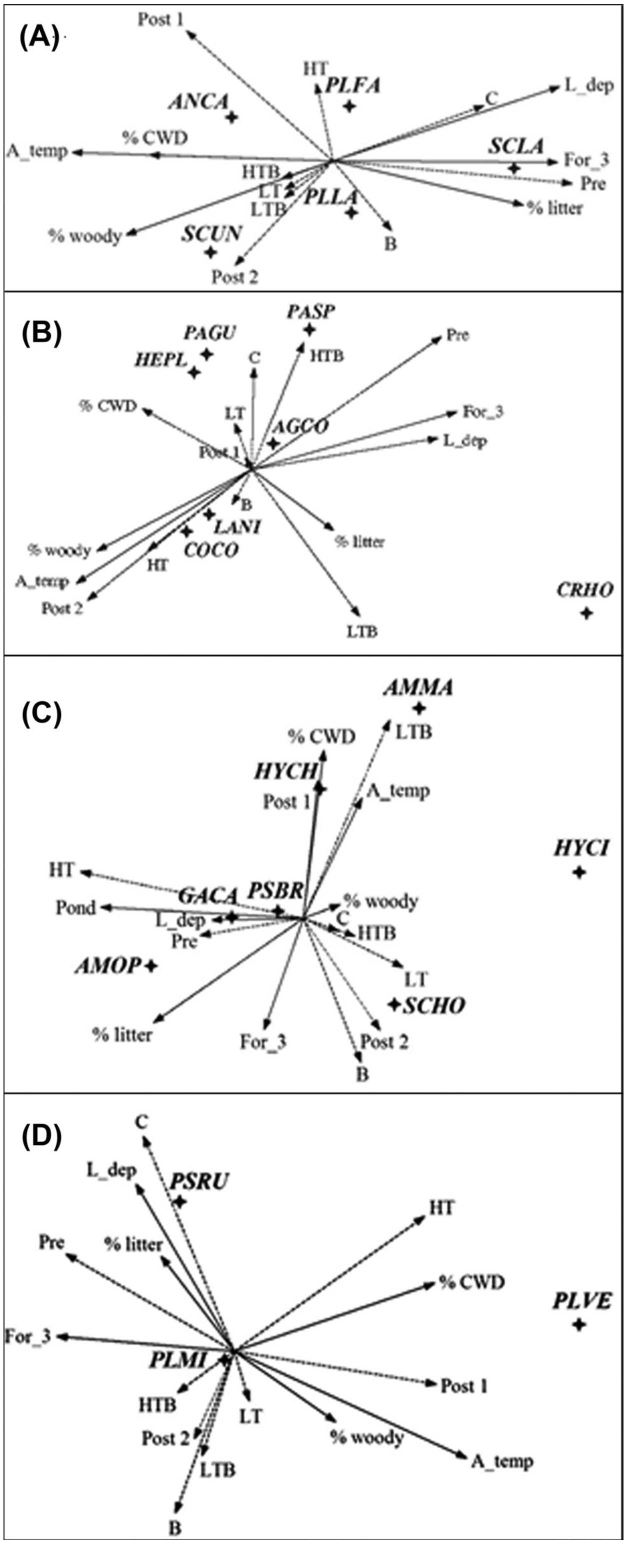

Figure 1—Ordination results displaying microhabitat, management, and yearly effects on lizards (A), medium- and large-bodied snakes (B), pond-breeding amphibians (C), and terrestrial salamanders (D) to forest management. Please refer to Sutton and others (2013) for further details related to these figures.

Narrow-mouthed Toad (*Gastrophryne carolinensis*), and Mountain Chorus Frog (*Pseudacris brachyphona*), tended to occur in forest stands that occurred in close proximity to temporary ponds (fig. 1C). The Eastern Spadefoot (*Scaphiopus holbrookii*) increased in abundance in thin-only stands primarily during the second year post-treatment (fig. 1C). We did not detect impacts of forest management on terrestrial salamanders, but found that the Red Salamander (*Pseudotriton ruber*) was primarily associated with unmanaged (control) stands (fig. 1D).

Results from our radiotelemetry work revealed that *A. contortrix* selected microhabitats with relatively greater litter depth and coarse woody debris cover compared to randomly available microhabitats (Sutton and others 2017). Although home range estimates were nearly three times larger for male *A. contortrix* compared to gravid female snakes, we did not observe differences in home range size between snakes in thin and unthinned stands (Sutton and others. 2017). At the landscape spatial scale, male snakes selected hard edge (e.g., road edges and field edges) habitats at a greater frequency than what was available and avoided pine forest and soft edge habitats; gravid female snakes did not select macrohabitats differently from what was available, but occurred most commonly in thinned stands (Sutton and others 2017). Overall, we found that forest management had negligible impacts on amphibians and had a more pronounced impact on reptiles. Lizards and large-bodied colubrid snakes generally increased in relative abundance after management, but considerable species-specific responses were observed, and these nuances should be considered prior to implementation of forest management operations in similar systems. As our study reports short-term responses of herpetofauna to prescribed burning and thinning, monitoring should be continued to understand longer term impacts of management on herpetofauna in pine-hardwood forests of the Southeastern United States.

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Field Trip

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INTERCROPPING OAKS AND PINES

Joshua J. Granger and David S. Buckley

Extended abstract—Work in northern Michigan pine plantations and oak plantings in the 1990s (Buckley and others 1998) suggested that oak seedlings may have better growth and survival when grown in pine shelterwoods than hardwood shelterwoods, and when intercropped with pine seedlings in mixed-species plantings. In 2000, loblolly pine (*Pinus taeda* L.) seedlings were inter-planted between northern red oak (*Quercus rubra* L.) seedlings in the same rows as a part of a larger study investigating the effects of oak seedling quality, planting practices, and competition control on the performance of outplanted oaks in Tennessee (Buckley 2002). Over the next 10 years, height growth of small- and medium-size class northern red oak nursery seedlings was significantly greater when grown with loblolly pine, but signs of diminishing apical dominance in the overtopped oaks generated several new questions concerning:

1) The optimum time for releasing the oaks from competition with the pines;
2) The growth of different pine species relative to the growth of intercropped oaks;
3) The performance of different oak species when intercropped with pine; and
4) The effects of different spatial arrangements of intercropped oaks and pines.

A replicated study with a randomized complete block design was established in 2014 to address several of these questions. Specific objectives were to:

1) Quantify and compare the growth and survival of oak and pine seedlings when intercropped and planted alone;
2) Document the performance of different oak and pine species combinations;
3) Determine the effects of oak seedling size on performance; and
4) Investigate the effects of different spatial arrangements on seedling performance.

Three 22- by 146-m blocks were established parallel to the contour in three recently clearcut areas having predominantly northeastern, eastern, and southern aspects. Stump sprouts and first-year seedlings of competitors were sprayed with glyphosate in late summer, 2013.

Ten treatments were assigned at random to ten 0.03-ha plots within each block:

1) White oak (*Quercus alba* L.) planted alone on a 2.44- by 2.44-m spacing;
2) Loblolly pine planted alone on a 2.44- by 2.44-m spacing;
3) Shortleaf pine (*Pinus echinata* Mill.) planted alone on a 2.44- by 2.44-m spacing;
4) Eastern white pine (*Pinus strobus* L.) planted alone on a 2.44- by 2.44-m spacing;
5) White oak planted on a 2.44- by 2.44-m spacing with a loblolly pine planted 0.31 m away from each oak;
6) White oak planted on a 2.44- by 2.44-m spacing with a shortleaf pine planted 0.31 m away from each oak;
7) White oak planted on a 2.44- by 2.44-m spacing with an eastern white pine planted 0.31 m away from each oak;
8) White oak planted on a 2.44- by 2.44-m spacing with loblolly pines planted in alternating rows 1.74 m away from each oak;
9) White oak planted on a 2.44- by 2.44-m spacing with shortleaf pines planted in alternating rows 1.74 m away from each oak; and
10) White oak planted on a 2.44- by 2.44-m spacing with eastern white pines planted in alternating rows 1.74 m away from each oak.

All oak and pine seedlings planted were 1-0, bare-root nursery seedlings purchased from the Tennessee Department of Agriculture, Division of Forestry State tree nursery in Delano, TN. Two grades of white oak were planted: standard seedlings and large diameter seedlings. All seedlings were planted in March, 2014. Blackberry (*Rubus* sp.) and hardwood competitors have been removed periodically since 2014 with a brushcutter and lopping shears.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

After three growing seasons, there were no significant differences in the height of loblolly pine, shortleaf pine, or eastern white pine seedlings whether planted alone or planted within 0.31 m or 1.74 m of planted white oaks. It should be noted that interactions between oaks and pines spaced 1.74 m apart in the alternating row treatments were likely to be minimal at this point in the development of the plantings. The treatments involving 0.31-m spacings were included to force interactions between oaks and pines early on, but the heights of pines planted in these treatments were not significantly different from those planted alone. Mean heights of loblolly, shortleaf, and eastern white pines were approximately 1.5, 0.9, and 0.8 m, respectively, after three growing seasons.

Similar to the pines, there were no significant differences in the heights of white oak whether planted alone or intercropped with any of the pines at the 0.31- or 1.74-m spacings (fig. 1). Again, it is unlikely that important interactions occurred between oaks and pines in the treatments with 1.74-m spacings. The lowest mean height for white oak occurred in the shortleaf pine intercropping treatment with 0.31-m spacings (fig. 1), but no differences were statistically significant.

These third-year results suggest no significant positive or negative effects of intercropping on the oaks and pines planted. Long-term monitoring of these treatments is planned as interactions between these species are likely to intensify over time as the planted trees continue to develop. Whether intercropped pines will eventually have positive impacts on oak seedling growth and survival remains to be seen, but the results to date suggest that oaks and pines may be compatible in mixed-species plantings. Interest in oak-pine mixtures exists on the part of private landowners, and the potential benefits of intercropping different species in forest plantations (Burton and others 1992, Hartley 2002, Kelty 2006) are worth exploring.

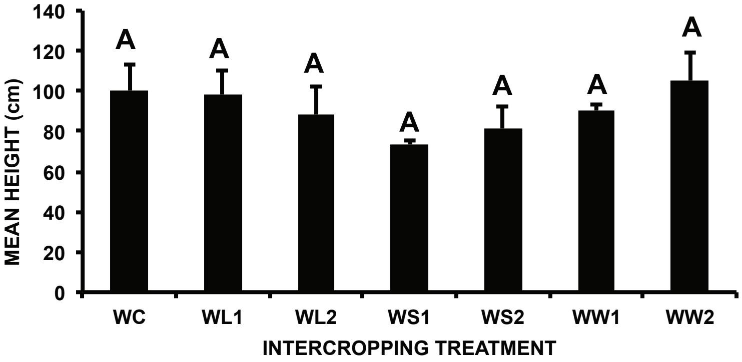

Figure 1—Mean third-year height of white oak seedlings by treatment. WC = white oak control, WL1 = white oak intercropped with loblolly pine at 0.31-m spacing, WL2 = white oak intercropped with loblolly pine at 1.74-m spacing, WS1 = white oak intercropped with shortleaf pine at 0.31-m spacing, WS2 = white oak intercropped with shortleaf pine at 1.74-m spacing, WW1 = white oak intercropped with eastern white pine at 0.31-m spacing, and WW2 = white oak intercropped with eastern white pine at 1.74-m spacing. Means with the same letter are not significantly different. Error bars represent one standard error.

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Poster Session

BROWSE RATES OF PLANTED OAK ON A RECLAIMED MINE

Matthew Aldrovandi and Jennifer Franklin

Abstract—Horseshoe Mountain, a former mine site reclaimed in the 1990s, located in Claiborne County, TN, was planted in the late fall and winter of 2014 with white oak (*Quercus alba*), northern red oak (*Q. rubra*), southern red oak (*Q. falcata*), pin oak (*Q. palustris*), and chinkapin oak (*Q. muehlenbergii).* Prior to tree planting, soil compaction was relieved and then four different ground cover treatments (wildlife promoting, unpalatable to wildlife, herbicided, and control) were applied over three replicates (12 macroplots total; an area of about 23 acres). Sixty permanent FIA-style plots (24 feet radius) were installed in summer 2015 within the macroplots; all trees within the plots were measured for height, root collar diameter, vigor, and browse. Subsequent measurements were recorded twice a year until 2017; vegetation surveys were conducted on the same schedule. The probability of browse was found to be statistically significant in relation to the height of oaks in 2015. In the height class from 0.1-1.0 foot, 30 percent of 91 oaks were browsed; in the 1.1-2.0 feet height class, 29 percent of 253 oaks were browsed; in the 2.1-3.0 feet height class, 52 percent of 218 oaks were browsed; in the 3.1-4.0 feet height class, 52 percent of 23 oaks were browsed. When broken down by species, it was found that 40 percent of 113 *Q. muehlenbergii*, 38 percent of 269 *Q. rubra*, 38 percent of 113 *Q. palustris*, 48 percent of 25 *Q. falcata*, and 37 percent of 65 *Q. alba* were browsed.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

SPECIES-SPECIFIC MECHANISMS CONTRIBUTING TO THE MESOPHICATION OF UPLAND OAK STANDS IN THE ABSENCE OF FIRE

**Emily K. Babl, Heather D. Alexander, Courtney M. Siegert,
John L. Willis, and Andrew I. Berry**

Abstract—Upland oak forests of the Eastern United States are shifting dominance towards shade-tolerant, fire-intolerant species (i.e., mesophytes). This shift is hypothesized to lead to mesophication, a process where mesophytes create cool, moist understories, reducing flammability and promoting their own proliferation at the expense of pyrophytic, shade intolerant oaks. There are few empirical studies identifying mechanisms of mesophication, and these studies have yet to explore potential mesophytes other than red maple *(Acer rubrum*). To address this issue, we sampled four hypothesized mesophytes: red maple, sugar maple (*A saccharum*)*,* pignut hickory (*Carya glabra*)*,* and American beech (*Fagus grandifolia*) and two upland oak species, white oak (*Quercus alba*) and chestnut oak (*Q. montana*) across a gradient of diameter at breast height (dbh) sizes (20–60 cm) in western Kentucky. We quantified canopy, bark, and leaf litter traits that may lead to differences in forest floor flammability among upland oaks and mesophytes. Preliminary results showed that mesophytes had thinner and smoother bark than upland oaks and increased canopy volume to stem volume ratio, which could decrease forest floor flammability. Initial results from a decomposition bag study indicated that maple leaf litter had 37 percent mass loss after 6 months, with 32 percent, 22 percent, and 14 percent mass loss occurring in hickory, oak, and American beech litter, respectively. Delineating potential mechanisms by which mesophytes could alter forest flammability through their bark, canopy, and leaf litter traits is essential for understanding community stability and exploring options to successfully manage for conservation of upland oak forests before restoration is prohibitively expensive.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

MIXED-SEVERITY WILDFIRE PROMOTES OAK SAPLING RECRUITMENT AND UNDERSTORY SPECIES RICHNESS ON THE CUMBERLAND PLATEAU, KENTUCKY

Devin E. Black, Zachary W. Poynter, Mary A. Arthur, Wendy Leuenberger,
Claudia A. Cotton, David D. Taylor, and Beth A. Blankenship

Abstract—Wildland fires of natural and anthropogenic origin were once more prevalent in the oak-dominated forests of the Southern Appalachian Region than they are today. In the absence of periodic fire, forest structure and species composition have shifted within many Appalachian forests. In response, forest managers have used prescribed fire to create diversified habitats, restore open stand structure, and enhance the recruitment of desired species, with varied success. As an indirect and unplanned "management tool", mixed-severity wildfire remains largely unstudied, yet may effectively promote targeted species and structural changes in forests. A wildfire within an upland-oak forest in eastern Kentucky provided a rare chance to assess forest recovery across a gradient of fire severity. Nearly 6 years following the wildfire, we found greater net recruitment of oak and pine saplings (2-10 cm diameter at breast height) on moderate and high fire severity sites compared to low severity sites; recruitment of mesophytic competitor species was unaffected by fire severity. Additionally, we found that both relative stem density of oak saplings and species richness of non-woody understory species were positively associated with fire severity. Though not desirable due to complications for control, human safety, and property protection, this wildfire study illustrated the ecologically beneficial effects of mixed-severity fire, inadvertently accomplishing management objectives focused on creating a mosaic of habitats with varied openness and species diversity, and promoting the recruitment of desired tree species, elusive outcomes using prescribed fire alone.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

CULTURAL RESOURCES PLANTINGS OF WHITE OAK FOR CHEROKEE BASKETRY

Brenna R. Bohn, Sunshine L. Brosi, Bryan W. Whitmore,
Ami Sharp, and Scott E. Schlarbaum

Abstract—White oak trees (*Quercus alba*) are declining in the eastern forests due to high rates of mesophyte invasion due to fire suppression and overpopulation of deer. White oak is vitally important in the Southern Appalachians for wood products, food for wildlife, and as a cultural resource for Cherokee basket making. From a Cherokee cultural perspective, a challenge is to produce certain wood properties important to artisans for basket making. These properties are usually found in slow growing white oaks in the forest understory. We evaluated an 11-year old white oak progeny test, planted on the Qualla Boundary in North Carolina using a variety of tree shelter sizes to increase apical dominance and limit branching. Overall survival was 65.6 percent and was significantly impacted by initial seedling height (*P-value* = 0.045) and number of first-order lateral roots (*P-value* < 0.001). The tallest 3 m shelter had the lowest survival (47 percent). While seedlings in the 2.3 m shelters had 55 percent survival, seedlings in the 1.8 m (76 percent) and the 1.5 m shelters had the highest survival (81 percent). Survival across open-pollinated half-sibling genetic families lines ranged from 31 percent to 81 percent (*P-value* = 0.008). Average height was 5.4 m (max 9.3 m) and the average root-collar diameter was 10.7 cm (max 22.3 cm). Cherokee basket makers determined most white oaks were too fast growing to be desirable for baskets. Additional plantings on more xeric sites at various densities may provide the cultural resources needs for the Cherokee.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

DELPHI EXPERT OPINION SURVEY TO ASSESS THREATS TO OAKS IN THE EASTERN UNITED STATES

**Ellen V. Crocker, Anna O. Conrad, Xiaoshu Li, Billy Thomas,
Thomas Ochuodho, and C. Dana Nelson**

Abstract—Oaks are important fixtures of many Eastern United States forests, providing both ecological and economic benefits. While regeneration is a major issue impacting oaks currently, biotic (e.g., pests and pathogens) and abiotic (e.g., abnormal weather and climate change) stressors, may also threaten oaks in this region. The goal of our Delphi expert opinion survey is to identify the most significant threats (biotic and abiotic) to oaks in the Eastern United States (as defined by the eastern and southern regions of the U.S. Forest Service), and to gauge the potential impact of these threats on oaks. To accomplish this, we initiated a three-part Delphi expert opinion survey. The iterative Delphi approach is useful for evaluating consensus (or lack thereof) among experts on a specific topic. In the course of this survey series, we asked experts to identify current and future biotic and abiotic threats to oaks, and then based on expert opinions, gauged the current and potential impact of these threats by asking a series of questions concerning, for example, their spatial and temporal manifestation. Data collected as part of this Delphi survey series will be used to support subsequent analyses aimed at assessing the economic impact of these threats, and may be useful for prioritizing the management of these threats within the Eastern United States.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

TREESNAP: A CITIZEN SCIENCE TOOL TO HELP OUR FORESTS

Bradford J. Condon, Ellen V. Crocker, Abdullah Almsaeed, Albert G. Abbott, C. Dana Nelson, and Margaret Staton

Abstract—We created TreeSnap, a mobile app available for iOS and Android that connects interested citizens with tree breeding programs to help fight forest threats through both awareness and research. TreeSnap integrates the outreach and education efforts of different tree breeding groups. The mobile app combines reporting for multiple tree species in a single place with an intuitive and convenient interface, while the web database provides an easy way for scientists to analyze the collected data. Our goal is that scientists will gain data on trees to use in research programs while the public will become more engaged in and informed about forest health. Currently, restoration tree breeding programs each have their own portals and requirements for submitting potential trees for inclusion in breeding programs. TreeSnap provides a more unified gateway for members of the public to submit information to scientists. The app is designed to easily incorporate more trees as we build new collaborations. Similarly, each tree submission type is customizable, which allows us to ask different questions for each tree, providing the relevant information to scientific partners. TreeSnap prompts users to take photos of trees and answer questions specified by each tree-breeding program while collecting GPS coordinates. Meanwhile, the web app allows participants to view, track, and edit their submissions, and will serve as a learning resource. For scientists, the web app provides a single location for tracking and curating submissions, contacting participants with questions, and working collaboratively to visit and sample trees of interest.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

SURVIVAL, CAUSE-SPECIFIC MORTALITY, AND SPATIAL ECOLOGY OF WHITE-TAILED DEER IN THE NORTH GEORGIA MOUNTAINS

Gino J. D'Angelo, Adam C. Edge, Cheyenne J. Yates, Andrew R. Little,
Charlie H. Killmaster, Kristina L. Johannsen, David A. Osborn, and Karl V. Miller

Abstract—Acorn abundance in the Southern Appalachians has been shown to be an important driver of white-tailed deer (*Odocoileus virginianus*) populations. Reductions in timber harvests on National forests in recent years has resulted in increased coverage of mature forests and little early successional habitat. The Georgia Department of Natural Resources (DNR) documented an 85 percent decline in the harvest of male white-tailed deer from 1979-2015 on eight Wildlife Management Areas (WMAs) in the North Georgia Mountains. DNR substantially reduced opportunities to harvest female deer, but populations continued to decline. As densities decreased, the condition of deer improved, suggesting that habitat conditions have not caused declines in fecundity. Therefore, factors other than acorn availability may be driving declines in these populations. Simultaneously, predator populations increased in northern Georgia, including black bears (*Ursus americanus*) and coyotes (*Canis latrans*). Therefore, insufficient recruitment of fawns due to predation is suspected as a reason for population declines. In January 2018, we are initiating a study in the north Georgia Mountains to investigate: (1) survival and cause-specific mortality of deer fawns, (2) home ranges and habitat selection of deer, and (3) influence of mast on space-use by deer. We will GPS-collar 30 adult does per year for 3 years on WMAs, and capture and radio-collar their fawns. We will investigate habitat selection and cause-specific mortality of adults and neonates. Understanding the potential influences of deer habitat use on population vital rates would improve management of deer populations and their habitats to aid population recovery.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

TWENTY-FIVE YEARS OF OAK-MAST SURVEYS AND ALLEGHENY WOODRAT POPULATIONS IN WESTERN MARYLAND

Erica S. Duda, Sunshine L. Brosi, A.J. Dayton,
Dan J. Feller, and Rande Brown

Abstract—Allegheny woodrats (*Neotoma magister*) occur on rocky outcrops, cliffs, and caves in oak-dominated forests where they play an important role dispersing fruits and nuts and altering vegetation. The decline of the Allegheny woodrat corresponds with the loss of *Castanea dentata* (Marshall) Borkh., and currently acorns from oak (*Quercus* spp.) are their most important food source. Since 1991, acorn production and extant woodrat populations have been monitored in western Maryland in the Appalachian Plateau, eastern Ridge & Valley, and Blue Ridge physiographic regions. Mean number of acorns per branch were recorded from the same 10 trees from white oak (*Lepidobalanus*) and black oak (*Erythrobalanus*) groups within each region. Woodrat populations were monitored using two consecutive night mark-recapture techniques. On the Appalachian Plateau, bumper crops of black oak acorns were followed by an increase in woodrat captures 75 percent of the time. Mast failures were followed by sharp declines in woodrat captures 100 percent of the time. In the eastern Ridge and Valley region, there have been no bumper crops and limited fair-good years for white oaks as well as sharp declines in woodrat captures. In the Blue Ridge, there have been limited bumper mast events of white oaks, but fair-good years were followed by an increase in woodrat captures 100 percent of the time (R = 0.575, *P-value* = 0.05). Additional factors influencing the woodrat may include habitat fragmentation, gypsy moth defoliation, and raccoon roundworm. Allegheny woodrat population numbers may improve with supplemental planting of mast species less impacted by gypsy moth.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

TWENTY-FIVE-YEAR EFFECTS OF CUTTING AND PRESCRIBED FIRE ON NORTHERN RED OAK REGENERATION IN MICHIGAN OAK AND PINE STANDS

**Joshua J. Granger, David S. Buckley, Terry L. Sharik, John M. Zobel,
William W. DeBord, Jason P. Hartman, Jason G. Henning,
Tara L. Keyser, and Jordan M. Marshall**

Abstract—Reviews of likely causes of the oak regeneration problem in the 1980s and 1990s stimulated several studies designed to test different methods of reducing competition between oaks and other hardwoods. A study involving multiple overstory and understory treatments was established in 1991 in Michigan oak stands and red pine plantations to test the hypotheses that (1) northern red oak regeneration would be more successful in pine than oak stands, and (2) removal of competitors would enhance northern red oak seedling performance. Late spring prescribed fires were implemented in 2002 and 2008 to investigate their effectiveness in controlling understory red maple. Planted northern red oak performance and natural regeneration of oak and red maple have been documented since 1991. A subset of planted seedlings has been protected against deer browsing since planting. Results suggest partial removal of competitors enhances oak seedling performance, whereas complete removal greatly increases mortality from browsing and frost. Although the stature of many red maple stems was reduced, red maple abundance increased and oak abundance decreased after the two fires. The timing of the fires likely reduced their impact on red maple. Greater growth and survival of planted oaks occurred in the pine stands, provided they were protected from browsing. Based on these results, the most viable technique for regenerating oak in the study region may include protecting oak seedlings from deer in 25 percent canopy cover shelterwoods in pine plantations. Opportunities exist for developing systems involving alternating rotations and mixtures of oak and pine species.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

DENDROECOLOGICAL ANALYSIS OF CONTINUED *QUERCUS* DOMINANCE ON EDAPHICALLY EXTREME SOUTHEASTERN SLOPES OF THE ALLEGHANY FRONT

Karen J. Heeter and Sunshine L. Brosi

Abstract—The Allegheny Front escarpment forms the boundary between the Ridge and Valley to the east and the Allegheny Plateau to the west. Peaks including Mount Porte Crayon in West Virginia (1,450 m), Blue Knob in Pennsylvania (882 m), and the focal area of this study, Dans Mountain (882 m) in western Maryland. Dans Mountain contains infertile, xeric habitats due to thin weathered soils on southeastern-facing convex slopes. These edaphically extreme situations also occur in the interior low plateau of Kentucky, Tennessee, and Indiana on bluff tops and narrow ridges including the Knobstone Escarpment. These fire-adapted communities have been dominated by *Quercus* and *Pinus* since the demise of *Castanea dentata.* The *Quercus* component providing essential mast for Allegheny woodrats (*Neotoma magister*) and contributes to the complex canopy structures for northern long-eared bat (*Myotis septentrionalis*) and Appalachian cottontail (*Sylvilagus obscurus*). Unlike other *Quercus*-dominated sites, old-growth forests on Dans Mountain, have adequate oak regeneration based on SILVAH 7 (primarily *prinus*, *rubra,* and *alba*) and have escaped the typical encroachment of *Acer.* Our study presents the recruitment dates, species compositions and densities, fire histories and deer densities that have resulted in continued oak-domination even on sites impacted by gypsy moth (*Lymantria dispar dispar*). We suggest additional fire management and active measures to reduce deer densities to continue the suppression of *Acer* on these unique and often overlooked ecosystems.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

TWO IMAGE CLASSIFICATION OPTIONS FOR QUANTIFYING EASTERN REDCEDAR (*JUNIPERUS VIRGINIANA*) ENCROACHMENT INTO THE CROSS TIMBERS REGION

**Daniel L. Hoff, Rodney E. Will, Chris B. Zou, John R. Weir,
Mark S. Gregory, and Nathan D. Lillie**

Abstract—Encroachment of eastern redcedar (ERC) (*Juniperus virginiana*) into the *Quercus*-dominated Cross Timbers region of the Southern Great Plains is an ongoing management issue that affects ecosystem services and wildfire risk. The location and density of ERC canopy in the forest understory and midstory and in forest gaps are important information for fire managers seeking to estimate the behavior of fires or anticipate resources and attack methods needed to contain wildland fires. We compared a supervised classification method of 3-band (RGB) imagery taken from Google Earth and an unsupervised isocluster classification of multispectral RGB + Near Infrared imagery augmented with an NDVI and texture layer to identify the canopy of ERC on 124 forested field plots located in the Cross Timbers forest matrix of Pawnee and Payne Counties, OK, USA. The 3-band imagery detected approximately 50 percent of the canopy area ($R^2 = 0.78$, n = 124):

$$ACA = 1.95 \times CCA + 13.01$$

where

ACA= Actual Canopy Area (m2)
CCA=Classified Canopy Area (m2)

The multispectral imagery identified a greater proportion of ERC canopy area (95 percent) but had higher variance, particularly for plots with less ERC canopy area ($R^2 = 0.43$, n = 124):

$$ACA = 1.05 \times CCA + 19.62$$

Both of these techniques can be used throughout the Cross Timbers region to identify the best locations for fuels reduction treatments, such as mastication or prescribed fire, to reduce wildfire risk and potential property damage.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

UPLAND OAK REGENERATION RESPONSE TO PRESCRIBED FIRE AND CANOPY GAP DISTURBANCES

Brian J. Izbicki, Heather D. Alexander, Brent R. Frey,
Ryan W. McEwan, and Andrew I. Berry

Abstract—In the Central Hardwood and southern Appalachian regions, fire suppression contributes to oak (*Quercus*) regeneration failure and compositional shifts toward more shade-tolerant fire-sensitive species. Prescribed fire may maintain upland oak ecosystems by removing competing species and increasing understory light; however, the most appropriate fire regimes to meet these objectives have yet to be identified. In Kentucky, single and multiple (2x, 3x) prescribed fires were implemented over 3- and 5-year periods. Each growing season, canopy cover, annual growth, height, and basal diameter were quantified for oak (*Q. alba, Q. coccinea, Q montana, Q. rubra, Q. velutina*), hickory (*Carya glabra, C. tomentosa*), and competing red maple (*Acer rubrum*) and American beech (*Fagus grandifolia*) seedlings in three burned and two unburned plots at six treatment sites. Tree regeneration within canopy gaps of varying age and size within both burned and unburned areas was also quantified to identify gap influences on regeneration dynamics of oaks and competing species. Thus far, results suggest single fires are ineffective at promoting oak growth, while multiple fires have modest positive impacts on oak growth relative to competing species. This difference may be because single fires had no impact on canopy cover, whereas multiple fires caused approximately 5 percent reduction in canopy cover. Canopy gap data suggest gaps influence species composition and stand dynamics, with larger gaps having greater oak dominance than smaller gaps. This study could demonstrate how prescribed fire can help maintain upland oak ecosystems and determine future dynamics of upland forests with continued fire suppression.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

ON THE ORIGIN(S) OF *DIPLODIA CORTICOLA*: CAUSAL AGENT OF COSMOPOLITAN CANKER DISEASE OF *QUERCUS* SPP.

Danielle K.H. Martin, Cameron M. Stauder, Richard M. Turcotte, Isabel A. Munck, Srdjan G. Aćimović, and Matthew T. Kasson

Abstract—*Diplodia corticola* (*Dc*) has emerged as an important canker pathogen of oaks in the United States with introductions to Maine, Massachusetts, West Virginia, Florida, and California since 2010. In 2014, symptomatic red oaks (*Quercus rubra*) were observed in Seneca State Forest (SSF), WV, exhibiting premature leaf drop with associated branch dieback, bleeding cankers, and mortality. Wood plugs were sampled from canker margins, and a dominant fungus was identified molecularly as *Diplodia corticola* using the fungal barcoding gene (ITS). Two WV *Dc* isolates, one ME isolate, and one MA isolate were used to confirm pathogenicity on red oak seedlings. By 8 weeks post-inoculation, all inoculated seedlings had cankers while controls remained canker-free. Combined canker area means for WV *Dc* isolates were significantly larger (*P-value* < 0.05, 4.8 cm^2) than the controls (0.2 cm^2). All sampled *Dc*-inoculated stems showed vascular streaks and occlusions, while controls remained asymptomatic. Combined means for WV *Dc* isolates showed longer streaking (*P-value* < 0.05, 23.6 cm) than the controls (0.0 cm). Isolations of *Dc* from 80 percent of cankers and 25 percent of symptomatic vascular tissues across all *Dc* treatments confirmed pathogenicity of *Dc*. Due to the synchronous nature of outbreaks among geographically distinct disease epicenters in the United States following similar outbreaks in Europe, questions regarding the origin of these various *Dc* introductions have been raised. Phylogenetic analyses and mating type assays are currently being conducted to further explore these relationships and determine if global decline of oaks by *D. corticola* can be attributed to an invasive pathogen.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

ASSESSING CHANGE IN HARDWOOD FORESTS OF THE WAYNE NATIONAL FOREST, SOUTHEASTERN OHIO

**Stephen N. Matthews, David M. Hix, James D. Palus,
Erin E. Andrew, P. Charles Goebel, and Donald Radcliffe**

Abstract—Many forest ecosystems of the unglaciated Allegheny Plateau of southeastern Ohio are undergoing a conversion from oak–hickory (*Quercus–Carya*) species to future dominance by mesophytic species (e.g., *Acer rubrum*). We examined the changes in tagged trees that were measured on permanent plots during 1992- 1993 on the Athens Unit of the Wayne National Forest. In 2016, we relocated 102 plots to measure the same tagged trees. Tagged, or witness, trees were the two living trees [diameter at breast height (DBH) ≥ 10.1 cm] closest to the plot center, and along with DBH, we recorded the direction and distance of each tree from plot center. On returning to the plots, we relocated each tree; we searched for the remnants of the tree if it was missing. There had been no harvesting on the plots; therefore, we believe the missing witness trees had fallen and decayed. Twenty-three species were represented as witness trees. *Quercus alba* was the most common across all plots; *Acer saccharum* and *Fagus grandifolia* (the second and third most common species) were concentrated on mesic northeast-facing slope Ecological Land Type (ELT). Nearly 80 percent of the trees were still alive; about half of the mortality occurred on mesic ELTs. Growth varied considerably by species with *Quercus rubra* having the largest median increase in DBH. Among the ELTs, dry southwest slope ELTs had the smallest increase in DBH. These data capture the current dominance of oak in the overstory and reflect the initiation of change across a diverse landscape.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

METHODS TO TAME *AILANTHUS* IN MIXED OAK FORESTS, WHAT WORKS: PRESCRIBED FIRE, HERBICIDES, OR BIOLOGICAL CONTROL?

Joanne Rebbeck, Todd Hutchinson, Louis Iverson, Matthew Peters, and Joan Jolliff

Abstract—Just as oaks can thrive in disturbed forests, so can non-natives trees like *Ailanthus*. Proactive land management integrates control strategies at a landscape level to minimize the spread of nonnatives. Unfortunately, current control recommendations for *Ailanthus* are inconsistent and often ineffective. Over the last several years, we have conducted studies to quantify the impacts of silvicultural practices on *Ailanthus* populations within mixed oak forest landscapes. We analyzed the presence and abundance of Ailanthus across the landscape in relation to prescribed fire, timber harvest, and stand structure. We found that recent timber harvest activity (< 25 years) was the best predictor of Ailanthus presence. In other words, we found that fall stem-injections of *imazapyr* herbicide (6 percent a.i.) were 100 percent effective in killing *Ailanthus* trees and saplings compared to a winter herbicide treatment followed by a prescribed fire (86 percent decrease), or prescribed fire alone (10 percent increase). Post-burn, *Ailanthus* germinants and sprouts from top-killed saplings and trees were poor competitors with faster growing post-fire woody regeneration as forest floor shading increased over subsequent years. More recently, we began testing a native fungus *Verticillium nonalfalfae*, as a biological control agent for *Ailanthus*. After two growing seasons, 78 percent of inoculated trees were either dead or 90-100 percent defoliated. Studies are ongoing to develop biocontrol methodologies, continue non-target risk assessments and study post-inoculation fungal spread. The goal is develop integrated recommendations for cost-effective control of *Ailanthus* in Appalachian forests.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

RED MAPLE SPROUTING CLUMPS DOMINATE OAKS AFTER THINNING AND BURNING

Callie J. Schweitzer, Yong Wang, and Daniel C. Dey

Abstract—We studied the response of the regeneration cohort under various prescriptions aimed at restoring hardwood dominance in existing 50-year old pine-hardwood mixed woods on the William B. Bankhead National Forest in north central Alabama. We evaluated various prescriptions combining thinning of pine followed by prescribed burning using a randomized complete block design with a three-by-three factorial treatment arrangement and four replications of each treatment. Treatments were combinations of three residual basal areas (heavy thin, 50 square feet per acre; light thin, 75 square feet per acre; and untreated control) with three burn frequencies (burns once every 3 years; burns once every 9 years, and unburned control). Stands were thinned June through December, and burned January through March. We examined the sprouting dynamics of the reproduction cohort in response to these disturbances. The number of clumps of sprouts for oak and red maple, as well as the number of sprouts per clump, increased for both species with infrequent and frequent fire. The majority of red maple sprouts were in the largest size class, while the majority of oak sprouts were half as tall as the red maple. Repeated fire coupled with heavy thinning appear to be eliminating red maple from the sapling-midstory stratum, but recruitment seems inevitable due to the sprouting response of the juvenile cohort.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

VALUE AND STATUS OF STATE-AND-TRANSITION MODELS FOR OAK SYSTEMS: APPALACHIANS AND CENTRAL HARDWOOD REGIONS

James Smith, Randy Swaty, Kori Blankenship, Sarah Hagen, Kimberly Hall, Jeannie Patton, and Katherine Medlock

Abstract—Quantitative state-and-transition ecosystem models, representing both current and historic time periods, are available for key oak ecosystems in the Central Hardwood and Appalachian regions. These models, originally developed by the LANDFIRE program and modified locally, extensively describe these ecosystems, document and define succession classes, key disturbance rates and pathways, and often highlight areas where more information is needed. Numerous applications, such as the Cherokee National Forest North Zone Plan and the Great Smoky Mountains National Park Landscape Conservation Forecasting project illustrate the values of these models and descriptions to the natural resource management and conservation communities. Over the past 2 years, the TNC LANDFIRE Team led an update and revision process based on the original suite of products with the goal of updating, correcting and improving the efficiency of every model and description. Over that period every LANDFIRE state-and-transition model was made available to any individual willing to participate. Thousands of review products were downloaded and hundreds of expert reviews were received and considered for inclusion. The review and revision process is now complete and revised and updated Biophysical Settings (BpS) quantitative models and descriptions will be available later in 2018.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

OAK DECLINE—WHAT WE KNOW TODAY AND WHAT TO DO ABOUT IT

Martin A. Spetich, Zhaofei Fan, Hong S. He, Wen J. Wang, Michael K. Crosby, and Stephen R. Shifley

Abstract—Oak decline was the focus of the last Oak Symposium in 2002. Since then, in the Ozark Highlands and considering the red oak group alone, more than 60 percent of the forest has been severely impacted by oak decline. This is a synthesis of our past 15 years of research into oak decline. Our methods included inventories and/or modeling at seedling, forest stand, landscape, and regional scales. Within 1 year of decline onset, a stand scale study showed the number of standing dead northern red oak (*Quercus rubra* L.) trees increased by 55 percent (*P-value* = 0.029). Within the Ozark Highlands, 3.6 million ha of the red oak group [(*Quercus* Section *Lobatae*): includes northern red oak (*Q. rubra* L.), black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), blackjack oak (*Q. marilandica* Munchh.) and southern red oak (*Q. falcate* Michx.)], 0.4 million ha of white oak (e.g., *Quercus alba* L., *Quercus stellata*) and 0.28 million ha of non-oak group forests had severe decline between 2006 to 2010. While model simulations across a 0.43-million ha area of the Ozark National Forest through the next century predict reduction of potential oak decline sites from 45 percent to 20 percent if historic fire frequencies are re-established. However, simulations by harvesting alone resulted in only a 3-percent reduction of high risk sites over doing nothing. Based on the combined results of these studies, our recommendations to reduce the impact of oak decline within oak decline susceptible forests include managing physiological age of susceptible trees, favoring decline resistant species, and prescribed fire.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

THE USE OF FIRE AND THINNING TO PROMOTE OAK REGENERATION ON PRIVATE PROPERTY IN THE SOUTHERN CUMBERLAND PLATEAU

C. Ken Smith, Ellie Fowler, Nate Wilson,
Nicole Nunley, and Victoria Schnaufer

Abstract—Oak regeneration and recruitment of oak seedlings into the sapling stage is a major goal for many land managers in the Southeastern United States. Over the past 7 years and on three sites, we have attempted to restore forest stands that were partially planted in loblolly pine (*Pinus taeda*) and eastern white pine (*P. strobus*) in the 1960s back to oak dominated stands. The primary objectives of this work were to examine the effectiveness of thinning and fire in the restoration of the native hardwood component, particularly with regard to our primary oak species (*Quercus alba, Q. montana, Q. velutina, Q. coccinea*), to integrate undergraduate students into the management process (inventory, tree marking, prescribed fire), to create long-term research sites for student projects, and to create habitat diversity in a matrix of closed upland forest. After basal area reductions ranging from 21-60 percent and three fires, oak seedling densities increased from pre-treatment densities that ranged from 2000–9000 seedlings per ha to 8000–54 000 per ha two growing seasons after the third fire. After the third fire, mean litter depths ranged from 0.4 to 1.2 cm, with no statistical differences for litter and O Horizon depth among the three sites (*P-value* > 0.15). Browse of oak seedlings has been light with *Vaccinium spp*., *Smilax spp*., *Sassafras albidum* and *Nyssa sylvatica* the preferred species. We noted that logging technology and the resulting slash distribution greatly influenced the intensity and spread of the first fire at each site.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

UPLAND OAK AND MESOPHYTE SEEDLING MORPHOLOGICAL TRAITS IN RESPONSE TO PRESCRIBED FIRE

Evangelin Von Boeckman, Heather D. Alexander,
Brian Izbicki, and Emily Babl

Abstract—Morphological traits of upland oak (*Quercus*) seedlings are a direct expression of resource allocation, and fire is believed to alter resource allocation. There have been few studies in upland oak forests that identify a relationship between above- and below-ground traits of seedlings in response to fire. The objective of this study was to quantify species distribution of resources to various structural components, and whether oaks or shade-tolerant, fire sensitive species (i.e., mesophytes) differ. To address this issue, we chose seven species in Kentucky, which included upland oaks (*Q. alba, Q. coccinea, and Q. montana*) and hypothesized mesophytes (*Acer rubrum, A. saccharum, Carya glabra,* and *Fagus grandifolia*) that were sampled in various fire treatments (unburned,1x, 2x, and 3x burned). In the field, environmental variables such as canopy cover and soil organic layer depth and seedling traits such as height, basal diameter, and root collar were measured before seedling harvest; lab procedures included measurement of specific leaf area, leaf thickness, and nitrogen content to understand photosynthetic capabilities, along with the development of allometric equations for linking above- and below-ground traits. We hypothesized oak species will allocate more resources to below-ground structures with increased fire treatments compared to mesophytes due to oaks' physiological and morphological traits to withstand fire. This research could contribute to the further understanding of oak regeneration response to prescribed fire and the pattern of resource allocation between oaks and mesophytes.

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Citation for proceedings: Clark, Stacy L.; Schweitzer, Callie J., eds. 2019. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 192 p.

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The 2017 Oak Symposium was convened in Knoxville, TN, to share knowledge on state-of-the-art management and research to improve sustainability of the upland oak resource in the Eastern United States. The symposium featured 33 invited speakers, an audience discussion period, a field trip, and 21 offered posters. Speakers addressed topics including the history of silviculture, fire, and research; current status of the oak resource; emerging economic markets; forest health; silviculture for climate change; artificial regeneration; wildlife habitat management; approaches to secure natural advanced oak regeneration; prescribed burning to promote oak regeneration; and management of woodland habitat. Presenters represented various organizations from non-governmental organizations, Federal agencies, State agencies, universities, and industry.

Keywords: Climate change, economic markets, oak woodlands, prescribed fire, regeneration, silviculture, wildlife.

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