USDA FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

Southern Research Station | General Technical Report SRS-278 | October 2024

The International Oak Symposium: Science-Based Management for Dynamic Oak Forests

October 7–10, 2024
Knoxville Hilton Hotel,
Knoxville, Tennessee, USA

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October 2024
https://doi.org/10.2737/SRS-GTR-278

Forest Service
Research & Development
Southern Research Station
General Technical Report SRS-278

Southern Research Station
200 W.T. Weaver Blvd.
Asheville, NC 28804
https://research.fs.usda.gov/srs

The International Oak Symposium: Science-Based Management for Dynamic Oak Forests

October 7–10, 2024
Knoxville Hilton Hotel, Knoxville, Tennessee, USA

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Christine Martens, Stacy Clark, and Callie Schweitzer

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School of Natural Resources, The University of Tennessee
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ABSTRACT

The 2024 *International Oak Symposium* is an inaugural meeting in Knoxville, TN, USA and represents the first international symposium addressing broad ecological and forestry issues of the genus *Quercus* (oak) ever held in the United States. The symposium provides opportunities and platforms to exchange information and build collaborations around the best available science and technology on oak ecology and management for a global audience. The meeting provides innovative and progressive formats, such as panel discussions, field tours, receptions, surveys, and question and answer sessions to deliver and exchange information and foster collaborations between researchers and practitioners. Attendees chose one of three field tours that will showcase: 1) multidisciplinary research by the U.S. Department of Agriculture, Forest Service and The University of Tennessee Institute of Agriculture; 2) Indigenous and western ecological knowledge and cultural history of the Great Smoky Mountains National Park; or 3) prescribed fire and silviculture at the Catoosa Wildlife Management Area. The symposium features 13 invited plenary session speakers from North America and Europe and approximately 100 offered oral presentations and posters from four continents. Presentations address an array of topics: climate change impacts and climate-smart forestry; woodland restoration; genetics, genomics, and tree improvement; prescribed fire efficacy; emerging economic markets including carbon; forest health; and silvicultural applications for natural and artificial regeneration. Two common themes

identified at the symposium are: 1) the difficulty and barriers that impede the delivery and application of the best available science to land managers, and 2) the need for active management while facing uncertainty. Presenters represent various organizations from nongovernmental organizations, Federal agencies, State agencies, research centers, universities, and industry.

Keywords: carbon, climate change, markets, prescribed fire, *Quercus*, regeneration, restoration, silviculture, water, woodlands

PREFACE

Oak (*Quercus*) trees and forests have provided a myriad of wood resources and ecosystem services for millennia. Oaks are considered a keystone species in many regions of the world but are increasingly threatened by deforestation, nonnative invasive pests and pathogens, climate change, altered disturbance regimes, and gaps in critical knowledge for silviculture and management. Despite commonalities of these threats across many oak ecosystems around the globe, general application of solutions are often elusive and difficult to develop. Rural, tribal, and urban communities will continue to lose vital ecosystem services and values provided by oak trees and forests without further development and application of practical science-based silviculture and management at stand and landscape levels.

Substantial progress has been made in research and science delivery for oak ecology, silviculture, and management since the mid-20th century. Relatively narrowly focused international meetings have been hosted and sponsored in part by the International Union of Forest Research Organizations (IUFRO) research groups or working parties, particularly Unit 1.01.06, Ecology and Silviculture of Oaks (IUFRO 2024). In 1994, the International Symposium on Ecology and Physiology of Oakswas held in Nancy, France (Dreyer and Aussenac 1996). In 2000, the IUFRO International conference, *Oak 2000—Improvement of Wood Quality and Genetic Diversity of Oaks* (Vukelić and Anić 2000) was held in Zagreb, Croatia. Several regional symposia have been held in the Central Hardwood Region of eastern North America to synthesize the state of the knowledge and provide opportunities for exchanges among researchers and practitioners. A 1992 symposium, *Oak Regeneration: Serious Problems, Practical Recommendations* (Loftis and McGee 1993) was held in Knoxville, TN. In 2002, *Upland Oak Ecology Symposium: History, Current Conditions, and Sustainability* (Spetich 2004) was held in Fayetteville, AR; *Oak Symposium: Sustaining Oak Forests in the 21st Century Through Science-Based Management* (Clark and Schweitzer 2019) was held in Knoxville, TN in 2017. A series of western North American regional meetings have been held as part of the *California Oak Symposium* (UCANR 2024), from 1979 to 2022, focusing primarily on oak conservation in northern and southern California.

The overall goal of the 2024 *International Oak Symposium* is to cultivate and promote synergy among natural resource managers and researchers working towards practical applications to sustain or restore oak ecosystems around the world. The symposium addresses the most current issues and complexities related to science-based management of oak species and forests at global, regional, and local scales. The 4-day program engages a diverse audience of managers and scientists in a forum that fosters innovation in silviculture and

management for sustainability of oak forests. Our specific objectives are to provide platforms, products, and opportunities for:

1. Technology transfer and dialogue between researchers and managers
2. Scientific exchanges among researchers
3. Fostering collaborations between managers and researchers
4. Production of peer-reviewed research papers
5. Contributing to professional development of students and early-career scientists

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ACKNOWLEDGMENTS

The symposium committee is grateful for the long hours and tireless work offered by numerous individuals and organizations that collaborated together to plan, host, facilitate, and execute the meeting. The symposium simply would not have been possible without their support and dedication. Don Hodges, Director of the School of Natural Resources at The University of Tennessee (SNR-UT) provided the impetus, instrumental direction, support, personnel, and facilities throughout the planning and implementation of this meeting. Lisa Widener and Katie Donaldson from the SNR-UT were instrumental in handling budgets, accounting, and website development, always in a timely and efficient manner. Scott Schlarbaum from SNR-UT provided necessary logistical support and personnel for field tours and social functions in times of need. Kevin Hoyt and Martin Schubert (The University of Tennessee Institute of Agriculture) helped plan and support the field tour at the AgResearch Oak Ridge and Cumberland Forest stations. Lucas Haden with the Tennessee Wildlife Resources Agency helped plan and facilitate the field tour at the Catoosa Wildlife Management Area. Jesse Webster with the National Park Service helped plan and facilitate the Great Smoky Mountains field tour. Jay Clark with Maryville College helped facilitate the Great Smoky Mountains field tour and provided cultural entertainment. Heather Alexander (Auburn University) provided support and planned the fire panel.

Trisha Johnson, Britt Townsend, and Stuart Hale (The Nature Conservancy) planned and provided support for the carbon panel. John Johnson, Melody Mount, and Kayla Stuart from SNR-UT assisted in executing myriad tasks and functions when requested. Jenny Lackey provided crucial support from the University of Tennessee's Conference Center to register attendees from all over the world. USDA Forest Service, Southern Research Station's publications team (Laurel Haavik, Jacqueline Patterson, and Christian Schroll) provided timely and valuable assistance with editing, layout, and publication to ensure the proceedings were available at the time of the meeting. Rebecca Chambers from the Hilton Hotel was exceedingly patient and thorough as we navigated group room bookings and room rentals. Jeremy Hoover from the Scott Brown Media Group provided professional audio-visual services. Pat Curtin and Jarrod Sanchez with the USDA Forest Service provided assistance with various functions of conference planning. The committee is grateful to the over 100 presenters from 15 countries who agreed to deliver their presentations and contribute to the proceedings and to the attendees who supported this symposium by showing up and asking the important questions.

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CONTENTS

Plenary: Featured Presentations on Foundational and Emerging Topics

Informing Management Through Predictions

Genetic and Evolutionary Foundations

Form and Function Under Environmental Stress

Natural Regeneration and Recruitment

Growth and Stand Development

Economic and Ecological Services

Historic Ecosystems Guide Management

Practices for Oak Restoration

Pests, Pathogens, and Beneficial Microorganisms

Ecological Dynamics

Woodland and Forest Restoration

Healthy Forests

Poster Session

(USDA Forest Service photo by Emile Gardiner)

Plenary: Featured Presentations on Foundational and Emerging Topics

MESOPHICATION OF OAK LANDSCAPES: MECHANISMS AND MANAGEMENT

Heather D. Alexander, Josue Chevez Sahona, Brice Hanberry, Tamara Milton, Arthur Lamounier Moura, Monika Rawat, Courtney Siegert, and John Willis

Across the Central and Eastern United States, historically fire-adapted oak savannas and woodlands are shifting to closed-canopied forests with increased dominance of fire-sensitive and/or opportunistic tree species. These changes in forest structure and composition are promoting a positive feedback known as mesophication, whereby encroaching species (i.e., mesophytes) create cool, moist understory conditions with low flammability fuels. Our recent work highlighted how mesophytes contribute to declining flammability of oak landscapes through 1) crown and bark traits that alter precipitation distribution, increase relative humidity, and decrease light availability; 2) leaf litter traits that lower fuel loads and increase fuel moisture; and 3) generalist traits that allow regeneration to persist regardless of fire history. Our research also demonstrated that open-canopied oak landscapes with frequent, low-intensity surface fires promoted a bilayer structure with high plant biodiversity that contains lower stocks of highly vulnerable aboveground carbon pools in live trees, snags, and coarse woody debris. Restoring fire to historically fire-adapted oak landscapes through the application of repeated prescribed fire in combination with silvicultural practices that open the canopy, increase understory light, and promote flammable herbaceous and leaf litter fuels is critical for preserving biodiversity and preventing catastrophic wildfires.

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THE WORLD OF OAKS—DIVERSITY, CULTURAL HISTORY, AND CONSERVATION

Timothy M Boland

The number of species of oaks worldwide currently stands at 430. Recent advancements in genome sequencing have helped elucidate the evolutionary history of oaks, their diversification, and dispersal. Throughout the world, oaks hold great importance as a human food source and for several byproducts. Oaks have tremendous value to humanity, yet they remain undervalued and understudied. The last decade has witnessed a greater societal awareness of the role oaks play in supporting biodiversity within every habitat in which they are found. The ecological connectivity of the natural world is on display in the genus *Quercus* with its numerous codependent fauna. Despite our best efforts to value oak trees, they are threatened by various challenges, including exploitation, poor land management, habitat fragmentation, increasing incidence of pests and diseases, and the uncertainties posed by a rapidly warming planet. How will oaks respond? Through the efforts of multiple conservation organizations and nongovernmental organizations, the development of The Red List of U.S. Oaks (2017) and The Red List of Oaks (2020) provides the most updated information on the conservation status of oaks worldwide. In 2019, the Global Conservation Consortium for Oak, led by The Morton Arboretum in partnership with Botanic Gardens Conservation International, was established to create a network of collaborators to work on pragmatic solutions for oaks under imminent threat of extinction. The International Oak Society (IOS) is a key partner in this effort. In 2020, the IOS created the Oak Conservation and Research Fund. The fund has supported 11 projects, many involving rare oaks worldwide.

ACKNOWLEDGMENTS

I extend my appreciation to Amy Byrne, the Morton Arboretum, and Emily Ellingson, the Polly Hill Arboretum, for reviewing my presentation and abstract.

Timothy M. Boland, The Polly Hill Arboretum, West Tisbury, MA 02575, USA

THE PAST, PRESENT, AND FUTURE OF WHITE OAK IN NORTH AMERICA: OPPORTUNITIES TO GROW AND STABILIZE THE HARDWOOD MARKET

Dallin Brooks

PURPOSE AND SCOPE

No matter what you believe about the past, wood was the most important natural resource in early human economies. This presentation will go over the history of hardwoods in North America from Native Americans leading up to the Industrial Revolution. I will then discuss hardwoods and white oak today for industrial, consumer, and other uses.

METHODS AND APPROACH

To help the hardwood industry grow and stabilize, we need to research appearance applications for rustic grades, urban wood, thermal modification, and biophilic design. Designers and architects need to be better informed on these applications to improve wood utilization and the public's connectivity to nature. We need to research process improvements for hardwood log grades, quality control, yield recovery, wood utilization, drying, sap stains, automation, and pressure treating to name a few. We also need to examine and research the environmental tools and regulations in more depth. Product category rules, environmental product declarations, life cycle assessments, certifications, tracking, DNA identification, and European Union's regulation on deforestation-free products geolocation can all be used to showcase wood's unique capabilities as a renewable resource. The National Hardwood Lumber Association conducted a focus group with architects and designers to discuss wood, sustainability, and carbon sequestration.

FINDINGS AND IMPLICATIONS

The focus group discussions indicated that there were many misconceptions and lack of knowledge around preserved (treated) wood. As we look to the future, we need to help people recognize the importance of forest change, help them understand the need for super-sustainable wood. We also have a need to attract top talent. We need to demonstrate to the public and those professionals in building and design that the hardwood industry can be forever innovative and provide an endless future of wood use.

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CORK OAK AFFORESTATION USING INNOVATIVE TECHNIQUES TO MITIGATE CLIMATE CHANGE

Constança Camilo-Alves

PURPOSE AND SCOPE

Cork oak (*Quercus suber*) woodlands are distributed across the western Mediterranean. Renowned for their cork, their most iconic product is the stopper, essential for the wine industry. Cork is also extensively used in civil construction, aerospace, and sports industries. The renewable nature of cork allows harvesting every 9 to 10 years, with trees living for approximately two centuries and being debarked up to 17 times. However, cork oak woodlands face severe threats. Widespread cork oak mortality events have been occurring since the 1990s. Initially attributed to root disease caused by the oomycete *Phytophthora cinnamomi*, subsequent research suggests that multiple factors acting synergistically contribute to the decline (Camilo-Alves et al. 2013). These factors include drought events, soil constraints on root development, and improper management practices. Though the cork oak distribution area has remained relatively stable, tree loss has resulted in a steady reduction of canopy cover. Furthermore, an alarming decline in tree regeneration has been occurring, compromising the sustainability of these ecosystems. Faced with this situation, particularly the predicted cork shortage in the near future, the cork sector is collaborating with the scientific community to find solutions to promote tree regeneration, survival, vitality, and productivity.

METHODS AND APPROACH

Long-term experimental cork oak fertirrigation plots were tested under specific conditions. Research involved installing ponds to capture winter rains for irrigating new cork oak stands during summer droughts, in response to changing precipitation patterns. The developed protocol involved fertirrigation from planting to cork stripping, aimed to enhance plant survival and reduce the time until the first cork extraction. Subsequently, stands were converted to rainfed mode, or irrigation continued until the second or third cork extraction. The scientific research focused on the structural-functional responses of trees to water availability during periods of high air temperatures. The goal was to promote tree growth through efficient irrigation, using minimal water for a limited period.

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FINDINGS AND IMPLICATIONS

Results obtained in the experimental plots are very promising and highlight cork oaks' remarkable adaptability to varying environmental conditions (Camilo-Alves et al. 2020, 2022). For instance, irrigated cork oaks maintained high transpiration levels during summer droughts, even under extreme meteorological conditions, such as on very hot and dry days. This high transpiration translated into radial growth, indicating sustained photosynthesis and carbon sequestration. Cork stripping on these plots was brought forward to 12 years of age, instead of the 25 years required under rainfed conditions. Water and nutrient availability also influenced shoot development and tree architecture. In particular, root analyses indicated that trees were not solely relying on the irrigation wet bulbs and could be maintained under rainfed conditions. Successful fertirrigation removal on 15-year-old trees demonstrated their independence from the fertirrigation system: trees thrived just like any other cork oak growing under rainfed conditions. Although this approach is feasible only where water can be captured or is available, such as near irrigated agriculture, it represents a paradigm shift in cork oak silviculture. Establishing highly productive cork oak forests within 15 to 20 years from planting may encourage producers to opt for these forests over exotic tree species or agropastoral land use.

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FIRE AND THE OAK REGENERATION PROCESS

Daniel C. Dey

PURPOSE AND SCOPE

Oak species and fire have a long and generally positive relationship. For thousands of years, where there was a frequent, mixed-severity fire regime, oaks prospered. Oaks have a suite of adaptations to fire including thick bark on larger trees, high vegetative sprouting capacity in young growth and small-diameter timber, ability to develop numerous large advance reproduction in sufficient light, preferential carbon allocation to root growth important for rapid sprouting after fire, periodic acorn masting, highly flammable litter in some species, drought resistance and tolerance of xeric site conditions, and seed that is often dispersed and buried in soil by mammals and birds. Loss of oak in eastern forests has been attributed, in large part, to the removal of fire from ecosystems and other changes in disturbances and management practices. This presentation provides an overview of fire-oak interactions throughout the life cycle of oak as it impacts oak regeneration success. Managers and scientists now seek to understand and manage the role of fire in silvicultural prescriptions to restore and sustain oak forest ecosystems (i.e., forest, woodland, savanna).

METHODS AND APPROACH

Fire affects oak regeneration, including acorn production, seedling establishment, and advance reproduction growth. Recurring fire over time may indirectly influence acorn production by promoting crown growth in surviving mature oak trees. Fire conducted before acorns drop can help reduce deep litter layers that may inhibit oak seedling establishment, reduce acorn predator habitat and competing vegetation in the understory, deplete competitor seed in the soil seed bank, and release nutrients for oak sprout growth. Once acorns are on the ground, they are highly vulnerable to mortality by surface fires, as are new oak germinants and young seedlings, but larger and older oak stems can persist following topkill by fire through sprouting. Probability of topkill declines with increasing stem diameter. Repeated fire increases understory light by reducing overstory and midstory density, which promotes oak advance reproduction growth.

FINDINGS AND IMPLICATIONS

To sustain oak stocking in future forests, oak reproduction must be able to grow up into the overstory. Use of frequent fire may be good at increasing oak abundance and competitiveness as advance reproduction, especially when used with stand thinning or shelterwood harvesting, but its continued use truncates

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oak recruitment and locks oak in a long-term cycle of fire topkill and sprouting. Oak stems must grow to sufficient diameter with thicker bark to persist intact after fire and continue growing into the overstory, and this requires a sufficient fire-free period at the individual tree level.

There are no complete surrogates for fire in managing oak forests and other fire-dependent ecosystems. But fire alone is seldom the solution to restoring and sustaining these ecosystems, especially in the early stages of restoration, where novel vegetation conditions and threat of invasive species demand the combination of fire with other practices (mechanical and chemical). It is the combination of fire with other practices and the sequencing of treatments over time that are fundamental to prescription design and management success. Fire can benefit oak regeneration and stand development, but its role varies with life cycle and developmental stage of the oak forest, initial vegetation conditions, site conditions, threat of invasive species, other disturbances and management objectives.

CHALLENGES FOR MANAGEMENT OF RICH *QUERCUS* FORESTS IN EUROPE

Magnus Löf

PURPOSE AND SCOPE

Oak-dominated forests are naturally widespread in Eurasia, supporting high biodiversity and providing important ecosystem services (Gil-Pelegrín et al. 2017). In Europe, there are approximately 20 species of oaks and many of them are foundational species ranking among the most important tree species for biodiversity. Much of their value as habitat for many groups of organisms is attributed to their tolerance to disturbance and light demanding characteristics, long lifespan, and unique wood traits (Mölder et al. 2019). Therefore many oak habitats in Europe are planned to be set aside for conservation purposes. These forests also provide many ecosystem services including quality timber, forage, firewood, recreation, aesthetics, and watershed protection. Oak forests have been closely associated to humans throughout history, and one key for successful restoration and management of oak communities is to understand and utilize their potential for multiple uses. Additionally, oak forests, because of their high resilience to disturbance and environmental stress such as drought, offer a promising alternative for inclusion into management plans addressing increasingly common extreme weather events. Irrespective of their high capacity to provide many conservation values and ecosystem services, declines in oak dominance are occurring in Europe and this is often connected to changes in land use (Petersson et al. 2019). Here, some examples of challenges, implications and possible solutions for management and restoration of rich oak communities in Europe will be presented.

METHODS AND APPROACH

Central European temperate oak wood production is characterized by long rotations with the aim of producing high-quality timber (fig. 1a). Such forests often contain multiple companion tree species and are rich in biodiversity. Therefore they are targeted for conservation purposes and there is a need to develop multifunctional oak forest management. Another example targeted for conservation purposes are the many types of wood pastures with oak in Europe (fig. 1b). Historically, these have been sustained through a combination of land uses such as: free-range grazing livestock, fodder production, and wood production for special purposes (cork, fodder, and special timber). However, these land uses are in decline in favor of intensified agriculture or forestry and urbanization; therefore it is a great challenge to preserve such habitats. Finally, a typical form of oak-dominated habitat that is in decline is various forms of oak coppice (fig. 1c). These were also widespread in Europe during the last 1,000 years and met social and economic needs in preindustrial Europe, and are normally rich in biodiversity and associated with cultural values.

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Figure 1—(a) Production forest with *Quercus robur* in southern Sweden (photo courtesy of Jens Peter Skovsgaard); (b) production of cork from *Quercus suber* woodlands in Spain (photo courtesy of Spanish forestry photo library INIA-SGB 2004 ©); and (c) coppice with standards of *Quercus* spp. in central Italy (photo courtesy of Magnus Löf)

FINDINGS AND IMPLICATIONS

Oak forests and woodlands in Europe have often been developed and sustained through management systems that are characterized by multiple uses. Over large areas, and during the last 100 years, these systems have been in decline. Simultaneously, they are rich in biodiversity and therefore targeted today for conservation purposes. However, a nonmanagement approach together with other forms of land use (intensified agriculture and forestry and urbanization) will lead to the transformation of these biodiversity rich habitats to other forests types or land uses. Restoration and management strategies with the aim of sustaining and increasing oak dominances should therefore strive to develop methods that can combine different purposes of management. For central and northern temperate oaks, this can be various forms of integrative management practices for forestry and nature conservation. For oak woodlands in central and southern Europe, this can be various forms of combinations of production of both wood and animals. None of this is likely to be achieved without a system of political support measures which allow landowners to receive financial and knowledge support for their production of valuable ecosystem services.

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THE WHITE OAK INITIATIVE

Jason Meyer

The White Oak Initiative (WOI) is a diverse coalition of partners dedicated to ensuring the long-term sustainability of America's upland oak forests and the myriad benefits they provide. Since its establishment, the WOI has grown into a nationally recognized movement focused on advocating sustainable upland oak forest management and regeneration, with a focus on white oak regeneration. The WOI brings together stakeholders from various sectors, including private landowners, forestry professionals, conservationists, and industry leaders, to address the need for more active management of our upland oak forests. Through convening, connecting, and collaborating, the WOI acts as a catalyst for change, supporting on-the-ground partners who implement critical educational programs, management practices, and conservation efforts. One of the WOI's major successes has been its ability to unite a broad array of stakeholders around a common goal, resulting in increased awareness and action towards upland oak conservation. It has also provided a voice for all concerned about the future of our upland oak ecosystems, advocating for responsible policy that supports forest management, including the introduction of HF 5582, the White Oak Resilience Act and other policy efforts. Looking ahead, the WOI aims to deepen its impact by expanding partnerships, enhancing public awareness, and assisting partners with securing additional resources for research and conservation. By continuing to foster collaboration and supporting its partners, the WOI strives to ensure the vitality of America's upland oak forests for generations to come.

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LOW-DENSITY TREE PLANTING: SCOPE OF OAK CLUSTER PLANTING TO CREATE MIXED FORESTS

Somidh Saha

Creating mixed forests by converting monospecific stands or restoring degraded forests is seen as a climate change adaptation strategy and option for increasing the supply of ecosystem services. Cost-effective low-density tree planting combines enrichment planting of desired tree species with natural regeneration and is seen as an alternative to cost-intensive high-density row planting. Oak cluster planting is a type of low-density tree planting, and clusters comprise 20 to 30 seedlings in either nests (nest planting) with a very dense spacing of about 0.2 m between trees or groups (group planting) with 1 m between trees. In contrast to nest plantings, clusters in group plantations are encircled with varying individuals of a trainer tree species (e.g., lindens, hornbeams). Approximately 60 to 100 groups or 200 nests/ha were planted uniformly. I compared the silvicultural (e.g., growth, potential future crop trees, mortality) and ecological (e.g., tree species richness, stand basal area, competition) attributes between oak cluster and row plantings among 52 stands in Germany, Austria, and Switzerland in my Ph.D. dissertation. I found that the group planting of oaks can be a promising alternative to traditional row planting, which can guarantee a good amount of future crop trees of oaks and other species, high tree species diversity, and comparable stand basal area in the first two decades after planting. I recommend that group planting of different tree species should be experimented with in other temperate and tropical forest ecosystems where the goal is to create a mixed forest through low intervention.

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FIFTY YEARS OF OBSERVATIONS ON OAK (*QUERCUS*) TREE IMPROVEMENT AND ARTIFICIAL REGENERATION PROGRAMS IN EASTERN NORTH AMERICA

Scott E. Schlarbaum

PURPOSE AND SCOPE

The author reflects on his personal experience in oak tree improvement research and artificial regeneration in eastern North America, starting in 1974 and continuing to the present day. Exposure to various tree improvement programs, evolution in technology, growing and establishing bare-root seedlings, and establishment and management of oak seed orchards are discussed. Biological and programmatic challenges to oak tree improvement programs and successful artificial regeneration on different sites are identified.

METHODS AND APPROACH

Pedigreed studies of different oak species range from genetic diversity tests, such as provenance and open-pollinated progeny tests, to performance tests in bare-root seedling nurseries and field plantings. Genetic variation in growth, reproductive maturation and capacity, seedling and acorn characteristics, form, seedling quality, acorn production, flood tolerance, and other traits have been detected, and selections for these traits can be made. Different approaches to creating seed orchards have been used, depending on the desired outcome.

FINDINGS AND IMPLICATIONS

Oak improvement programs encounter a plethora of biological variability that can impede progress. Two significant problems are variability in reproductive maturation and reproductive capacity. Moreover, there appear to be different reproductive patterns among oak species. Nonpruned nursery-grown oak seedlings show family differences and within family, can exhibit a five-fold difference in height and overall quality, which significantly impacts initial survival in field plantings. Seedling variability has spawned different statistical approaches to experimental design and analyses of field studies. Oak seed orchards are expensive to create and can require decades of investment before enough acorns are produced to make collection worthwhile for nursery production. Adding to the expense, is the necessity of creating duplicate orchards at remote locations in case of destruction by disease, fire, or weather events. The most significant problem oak improvement programs face is continuity of effort

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over time. Genetic testing leading to the development of mature seed orchards often exceeds the career of their originator(s) and may be discontinued. Changes in laws governing Federal and State programs need to be enacted to ensure continuity of applied oak improvement programs over generations.

AMAZING AMERICAN *QUERCUS* COMMUNITIES UNDER THREAT

Callie Schweitzer

PURPOSE AND SCOPE

Quercus is the most species rich genera in the Northern Hemisphere, and 60 percent of its 435 species occur in the Americas (Canda, United States, Mexico, Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama, and Columbia) (fig. 1). This geographic and evolutionary omnipresence is attributed to lineages that allowed advantageous use of site resources and phenological fitness and plasticity, with modern maintenance and spread a result of the role of humans (Cavender-Bares 2019). For example, drought adaptations separate close *Quercus* relatives along an elevation gradient, and tradeoffs between growth rate and reproductive fecundity separate species along fire intensity gradients. White oaks and red oaks often coexist in the same stands, partly because they differ in their susceptibility to disease and tend to not spread the same diseases. Hybridization of *Quercus* also contributes to its adaptation across the Americas. *Quercus*-dominated forests, predicated on high genetic diversity, rapid migration rate, high rates of ecological divergence and physiological flexibility, and hybridization, are nevertheless under local and global threats. Some examples of those threats and conservation practices to increase sustainability will demonstrate our knowledge and determination to maintain this valuable genus throughout the Americas.

Figure 1—(a) *Quercus douglasii* is a California, USA, endemic oak species found on thin, dry sites (USDA Forest Service photo by Erik Knapp); (b) *Q. humboldtii* is found in montane cloud forests of Columbia, South America (USDA Forest Service photo by Dan Dey); and (c) *Quercus* species dominate the canopy of a mature upland hardwood forest in Kentucky, USA (USDA Forest Service photo by Callie Schweitzer)

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APPROACH

Oak wilt is a predominant threat to Canadian oaks, especially in urban areas. In western Canada, *Q. garryana* woodlands are threatened due to changes in Indigenous land management and fire regimes. In the Western United States, *Q. garryana* and *Q. chrysolepis* woodlands are also of high concern, with integrated ranch-woodland management needed for retention. In the Eastern United States, mesophication, the result of disruptions in the disturbance regime (lack of fire, decreases in harvesting, climate change) created conditions in which natural regeneration of all *Quercus* species is concerning, with restoration by using adaptive silviculture ongoing. The golden-cheeked warbler (*Setophaga chrysoparia*), a globally endangered bird, drives collaborative conservation practices in *Quercus* forests in Mesoamerica that include habitat connectivity, oak utilization, and mitigating land-use changes (Perez et al. 2007). In Columbia, treating montane cloud forests containing *Q. humboldtii* is focused on curbing grazing and fuelwood collection, while using silviculture to encourage establishment and growth of natural reproduction (Avella et al. 2016).

FINDINGS AND IMPLICATIONS

Quercus landscapes in the Americas are often mosaics of production systems (i.e., agriculture, livestock). They suffer from overexploitation of original forest cover for forest products and land-use changes, primarily agricultural expansion and urbanization. Restoration strategies focus on integration of maintaining, sustaining, and increasing oak dominance in these forests while meeting the demands of the local communities, including hydrological regulation, soil protection, and sustained sources of timber, fuelwood, and other nontimber forest products. Sustaining *Quercus* in Canada, the Eastern United States, and Columbia is possible through shared silviculture prescriptions that favor the establishment, recruitment, and release of natural regeneration through sequential introduction of disturbances that decrease stand density and increase understory light. Woodland systems integrated with ranching in the Western United States and Mesoamerica are promoting conservation strategies that detail native *Quercus* distributions, existing threats, and natural regeneration status, while supporting farming and ranching operations compatible with oak woodlands. Success of adaptive management for conserving American oaks is predicated on social and economic drivers, and addresses our changing environments, from fire regimes to wood utilization demands.

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WHY WHITE OAK?

Ken Smith

My discussion will open with an overview of the cooperage industry with a brief history of the origins of coopering and barrel production and the importance of transporting goods for commerce and trade. The conversation will move to present day coopering and the importance of white oak (*Quercus alba*) in barrel manufacturing from harvesting to production at a stave mill, the seasoning and drying process and the barrel raising process. Finally, the discussion will conclude with where we are as an industry, the importance of white oak in the forest industry, and what we can do as an industry to promote white oak.

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HOW CAN OAKS SURVIVE AND THRIVE IN FUTURE CLIMATES?

Victoria L. Sork

Oaks (*Quercus*) are an amazingly resilient genus of trees. They evolved approximately 60 million years ago in the Paleoarctic. As the planet cooled, they spread southward and diversified throughout the Northern Hemisphere into almost 500 species, and dominate ecosystems where they occur. One secret to their success is large effective population sizes that maintain genetic variation allowing them to adapt to new environments. A second secret is their ability to hybridize and exchange genes resulting in adaptive introgression. However, humans are now exposing oak species to unprecedented rates of climate warming. Provenance studies already indicate that many populations show signs of maladaptation to current temperatures. In this talk, I will explore ways that genomics can provide tools to help oaks persist in future climates. First, I will discuss how landscape genomics, which associate genetic gradients with climate gradients across a region or species range, can identify populations that are particularly vulnerable to climate warming. Second, I will review the concept and benefits of assisted gene flow, which is the active transport of genotypes into existing populations. Third, I will describe existing and potential genomic methods that can identify genotypes that would enhance tree response to warmer climates. Such methods could be used for the management of existing oak populations vulnerable to climate warming and the restoration of populations destroyed by prior deforestation or recent fires. Oaks have been a resilient genus throughout their evolutionary history. Active intervention may allow some species to survive and eventually thrive in future climates.

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NORTH COAST OAK WOODLAND RESTORATION: OREGON WHITE OAK AND CALIFORNIA BLACK OAK TREE AND STAND RESPONSE TO RELEASE FROM DOUGLAS-FIR ENCROACHMENT

Yana Valachovic, Jeff Stackhouse, Lenya Quinn-Davidson, Brendan Twieg, Wallis Robinson, and Chris Lee

PURPOSE AND SCOPE

California's North Coast oak woodlands, dominated by deciduous Oregon white oak (*Quercus garryana*) and California black oak (*Q. kelloggii*), have long been central to the ecology and culture of the region. Oak woodlands support high levels of biodiversity, provide unique habitats for wildlife, and are deeply rooted in the region's human history, because oaks have been sustained by Native Americans, ranchers, and other local groups throughout recent history. However, management, lack of management, and landscape changes over the last century have altered these ecosystems, and both black and white oak woodlands are in decline throughout their ranges in California as well as in the Pacific Northwest.

One of the primary concerns in North Coast oak woodlands is the absence of the disturbance regimes that historically shaped and maintained these ecosystems. Both black and white oak woodlands are fire-adapted, depending on frequent, low- to moderate-intensity fires to prevent the establishment of invading fire-sensitive vegetation and supply conditions suitable for regeneration. Over the last century, fire exclusion has resulted in direct and indirect impacts on oak woodlands, affecting their recruitment and persistence, stand structures and fire regimes, and overall ability to persist on the landscape.

METHODS AND APPROACH

This talk will coalesce a decade of study by regional scientists and managers on the ecology of these woodlands, the effectiveness of management interventions, including conifer removal and the use of prescribed fire for the control of reinvasion (Cocking et al. 2012, Engber et al. 2011, Schriver et al. 2018).

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FINDINGS AND IMPLICATIONS

This work has demonstrated many of the deleterious effects of encroachment on terrestrial ecosystems, including oak mortality, severe decreases in (and often complete loss of) herbaceous cover and species richness, and important changes to fuels and fire behavior. Additionally, recent intense droughts have magnified the connections between forest densification, water availability, and tree health and mortality across the State, prompting important questions about the impacts of encroachment (i.e., the silent straws) on the region's limited water supplies and the natural and human communities that they support.

Our team has documented the effectiveness of managing Douglas-fir (*Pseudotsuga menziesii*) encroachment into Oregon white and California black oak woodlands and the response of stand health variables, wildlife habitat values, and fuels, along with other variables.

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Informing Management Through Predictions

HABITAT SUITABILITY MODEL OPTIMIZATION FOR STAND INITIATION IN BOTTOMLAND HARDWOOD FORESTS, LOWER MISSISSIPPI ALLUVIAL VALLEY

Segun M. Adeyemo, Joshua J. Granger, Krishna P. Poudel, Yun Yang, and Brady Self

PURPOSE AND SCOPE

The purpose of this study was to develop a habitat suitability model for eight selected oak species in the Lower Mississippi Alluvial Valley (LMAV). The habitat suitability model used localized soil conditions, hydrology, and climatic conditions to identify suitable habitats for oak regeneration in the LMAV. The model aimed to improve afforestation success and ecosystem services in this unique ecosystem by matching species requirements to microsite conditions in the LMAV ecoregions and incorporating projected climate changes. The geographic scope of the study was the LMAV, which spans about 26.7 million acres across seven States in the Southern United States.

METHODS AND APPROACH

This study developed habitat suitability models for eight oak species in the LMAV by using species occurrence data from the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis program and environmental predictor variables. Tree-level coordinates were estimated from plot center coordinates using azimuth and distance. Predictor variables were selected based on factors contributing to regeneration challenges in the LMAV. An ensemble modeling approach combining machine learning and generalized linear models was used to predict suitable habitats using the 'sdm' package in R (Naimi and Araújo 2016). The models were evaluated using area under the ROC curve (AUC) and true skill statistics (TSS), from a 5-fold cross validation in 10 runs for each algorithm.

FINDINGS AND IMPLICATIONS

The niche distribution model, based on five indices, revealed that the niches of eight oak species highly overlap within the LMAV, confirming their generalist nature, as supported by Kirsch and Kaproth (2022). However, our study quantified the suitability of different ecoregions for these species, unveiling significant variability in each ecoregion's ability to support oak regeneration.

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For instance, the Northern Holocene Meander Belts ecoregion was found to be most suitable for willow oak (3.34 million acres), and the St. Francis Lowlands ecoregion was most suitable for swamp chestnut oak (*Quercus michauxii*) (0.99 million acres). Water oak (*Q. nigra*) was predicted to grow best in the Southern Holocene Meander Belts (1.16 million acres), southern backswamps (0.21 million acres), inland swamps (1.28 million acres), and deltaic coastal marshes and barrier islands (0.76 million acres) ecoregions. Cherrybark oak (*Q. pagoda*) showed the highest suitability in the Western Lowlands Pleistocene Valley Trains (2.86 million acres) (fig.1). Furthermore, the study identified the climatic variables responsible for the suitability of each oak species and their responses to climatic changes. As Self (2024) emphasizes, understanding hardwood ecology, including the five "S" factors (site, species, species-site relationships, succession, and stand development) and their interactions, is crucial for successful management and avoiding costly delays or failures in meeting specific objectives. Our study provides a baseline for the successful regeneration of oaks in the LMAV by quantifying and identifying suitable ecoregions, contributing to the understanding of hardwood ecology in this region.

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ACKNOWLEDGMENTS

This study is a contribution of the Forest and Wildlife Research Center and Mississippi State University, and was conducted with funding from the Mississippi State University Department of Forestry, as well as U.S. Department of Agriculture, National Institute of Food and Agriculture McIntire-Stennis project MISZ-70000.

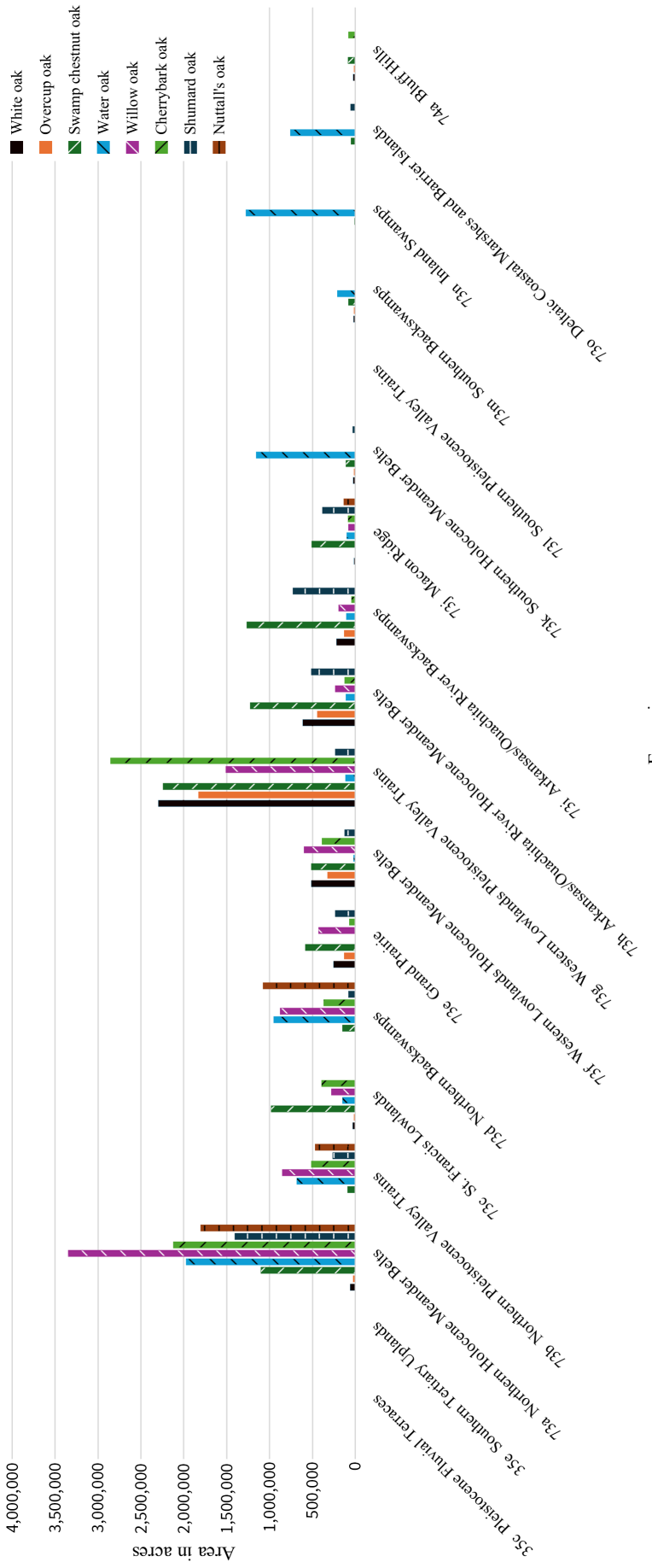

Figure 1—Oak species regeneration in each ecoregion of the Lower Mississippi Alluvial Valley as predicted by the niche distribution model.

PREDICTING FUEL CONSUMPTION UNDER HIGH-FREQUENCY FIRE REGIMES IN OAK-PINE MIXEDWOOD FORESTS BY USING THE FIRST ORDER FIRE EFFECTS MODEL IN ALABAMA, USA

Julia DeFeo, Adam Coates, Callie Schweitzer, and John Craycroft

In the Southeastern Region, long-term fire suppression has been tied to mesophication and a landscape-scale decline in the prevalence of oak-dominated forests. To combat this, the restoration of historic, high-frequency, low-intensity prescribed fire regimes is regularly proposed as a management practice for xeric oak-pine systems. The First Order Fire Effects Model (FOFEM) is a fire effects prediction tool designed for use with cover types that span North America, but its accuracy in predicting fuel consumption for frequently burned forest systems in the Eastern United States has not been fully evaluated. We evaluated FOFEM consumption relative to destructive and nondestructive field consumption, over the course of six prescribed burns on a 3-year fire return interval, in pine-dominated mixedwoods on the William B. Bankhead National Forest, AL. FOFEM overestimated consumption of litter, duff, and fine woody fuels (1-hour and 10-hour), but repeated burning reduced the magnitude of this error, such that FOFEM predictions were equivalent to field values within 2.75 Mg ha^{-1} (or less) after three fires. Sampling methodology did not have a strong influence on modeled percentage of consumption, but nondestructive sampling underestimated destructive preburn biomass of litter, duff, and 1-hour fuels and overestimated that of 10-hour fuels. Based on our findings, we will present recommendations for managers interested in using FOFEM to model fuel consumption in Southern United States mixedwoods.

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SITE FACTORS, DISTURBANCES, AND THE DISTRIBUTION OF OAKS

John M. Kabrick and Lance A. Vickers

Oaks (*Quercus* spp.) are widely distributed, with more than 400 species worldwide, including 20 species in Europe, 100 species in North America, and 150 species in Central and South America. They are economically, ecologically, and culturally important throughout their range. Most oaks share traits causing them to be more abundant on relatively dry or frequently disturbed sites. These traits are most expressed by young oaks during regeneration and include moderate shade tolerance, slow juvenile shoot growth rate, large root system with abundant carbohydrate stores, and reliance on advance reproduction. These traits enable rapid recovery and resprouting after topkill from drought, fire, or browsing but also cause young oaks to grow slowly and succumb to competition on high-quality sites favoring shade tolerant or faster-growing competitors. Associations between site and oak regeneration strategies, stand development patterns, and oak abundance have long been recognized but recent advances in data availability through the U.S. Department of Agriculture, Forest Service, Forest Inventory Analysis (FIA) program and the Soil Survey Geographic Database allow relationships between site characteristics and oaks to be examined quantitatively. We examined the relationships between site factors, disturbance patterns, and abundance of oaks worldwide and discuss different approaches to modeling oak abundance, oak site suitability, and regeneration potential in the Eastern United States by using FIA and site data.

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SYNTHESIZING CHANGING OAK SPECIES DISTRIBUTIONS, MAST AVAILABILITY, AND EFFECTS ON WILDLIFE SPECIES UNDER FUTURE CLIMATE, SOCIAL, AND LAND-USE CHANGE

Laura M. Thompson, Joseph D. Clark, Stacy L. Clark, Jane Foster, and Scott E. Schlarbaum

The eastern hardwood forests of the United States play a crucial role in supporting wildlife through the production of mast crops, particularly acorns, which serve as vital energy sources for various species during fall and winter. However, mast failures and historical forest disturbances have raised concerns about the future abundance of mast-producing trees, especially oak species. Despite the recovery of forests since the late 19th century, oak regeneration rates have declined. Understory fire suppression has allowed fire-intolerant species to encroach, posing a risk of shifting forest types. Climate change further complicates the picture, with warming temperatures and drought affecting oak regeneration differently. Given that a significant portion of the eastern deciduous forest is privately owned, social challenges arise in decisionmaking by landowners. We address these complexities by leveraging a diverse knowledge base in forest and wildlife ecology. Compiling data on changing oak abundance, masting variability, and impacts to wildlife, we synthesized available science as part of an expert-elicited ecosystem model to depict interactions among hardwoods, masting events, wildlife abundance, and survival under future climate, social, and land-use scenarios. The outcomes can inform decisionmaking processes regarding forested regions and evolving wildlife abundance, providing a comprehensive understanding of the challenges and potential futures for these vital ecosystems.

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WHITE OAK POPULATION TRENDS—DISTILLING REGENERATION, RECRUITMENT, GROWTH, AND DRAIN CONCERNS ACROSS THE RANGE

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White oak (*Quercus alba*) is an important species globally as one of only two species in the world that regularly produce cooperage (barrels or casks) for wine and aged spirits production and the only one of significance native to the United States. The native range of white oak is vast, over 100 million acres (approximately 40.5 million ha) that spans the Eastern United States. Almost three-quarters of white oak-dominated forests are mature and, in those forests, white oaks tend to be prevalent as large trees, ranking third in standing sawtimber volume across the Eastern United States. However, white oaks are scarce as saplings and highly variable as advance reproduction. Difficulties regenerating oak forests are well-known, and concern over the scarcity of small-diameter white oaks has spurred great interest in the long-term sustainability of this valuable resource among stakeholders in the Eastern United States. In this presentation, we offer analysis of national forest inventory data and other studies that highlight patterns of white oak regeneration, canopy recruitment, growth, and drain at regional and rangewide scales. We discuss sustainability risks and limitations or opportunities for different regions within the range. Finally, we discuss implications and questions raised by those results for future research and management.

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Genetic and Evolutionary Foundations

SPRING BUD PHENOLOGY OF *QUERCUS ALBA* SEEDLINGS PLANTED IN A COMMON GARDEN IN SOUTHERN VERMONT, USA

John Butnor, Paula M. Murakami, and Laura DeWald

White oak (*Quercus alba*) occurs throughout Eastern U.S. forests where it is an important component of forest biodiversity. It is predicted that white oak habitat will expand north beyond its historic range in response to changing climate patterns. A common garden was established in East Dorset, VT on the Green Mountain National Forest (GMNF) in 2023 to better inform restoration and assisted migration strategies for white oak at the northern limit of its range. Twenty replicates of 44 half-sibling families sourced from latitudes 35° to 46° and grown at a nursery in Kentucky, were planted in this common garden. The families are broadly grouped geographically into an eastern transect (North Carolina to Vermont) and a midwestern transect (western Pennsylvania to Minnesota). On May 18, 2023, a regionwide freeze event caused significant foliar damage to trees throughout northern New England and New York. In the GMNF common garden, we observed that foliage of white oak seedlings sourced from colder environments was more likely to have flushed and be damaged compared to seedlings from warmer environments. To better understand differences in phenological response of individual families, we conducted weekly assessments of leaf-out in Spring 2024 and will relate our findings to source climate statistics. These results combined with winter injury assessments, growth, and physiologic performance will help refine seed transfer distance recommendations for the species.

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A GENETIC CONSERVATION PROGRAM FOR THE ENDANGERED MAPLELEAF OAK (*QUERCUS ACERIFOLIA*) IN THE SOUTHEASTERN UNITED STATES

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In 2020, we initiated a gene conservation program for mapleleaf oak (*Quercus acerifolia*), an endangered oak species on the International Union for Conservation of Nature Red List, endemic to the Ouachita National Forest (NF) in Arkansas. This program is based at the Stephens Lake Park Arboretum, part of the City of Columbia Parks and Recreation Department in Columbia, MO. Our approach to conserving this species is unique, and we firmly believe, applicable to additional Red Listed *Quercus* species growing on NFs across the Southeastern United States. The uniqueness of our approach is based on establishment of spatially distinct *ex situ* populations that accurately reflect the *in situ* subpopulation structure of the species. To accomplish this, we established grafts representing both wild trees and individuals held in botanic gardens and arboreta. In the latter case, we grafted individuals that were both source-identified in the wild and known to contribute to the overall genetic diversity of the species, based on genetic analyses. To date, we have assembled 52 clonal accessions. By 2026, all clones will be repropagated and established at the Mt. Ida Genetic Resources Management Area in the Ouachita NF in westcentral Arkansas. This new orchard will facilitate future restoration efforts for this species. Nine other Red Listed oak species are native to the Southeastern United States and found on 14 different NFs across 10 States. We will apply our experiences with *Q. acerifolia* to develop parallel programs for these species.

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PROMOTING WHITE OAK (*QUERCUS ALBA*) SUSTAINABILITY THROUGH A RANGEWIDE TREE IMPROVEMENT PROGRAM IN THE EASTERN UNITED STATES

Laura E. DeWald, Zachary Hackworth, Jeffrey Stringer, and John Lhotka

PURPOSE AND SCOPE

Genetic variation in white oak (*Quercus alba*) provides significant opportunities for tree improvement. The White Oak Genetics and Tree Improvement Program (WOGTIP) (DeWald and Williams 2024) is a collaborative (academia, industry, State, and Federal agencies) program to quantify white oak genetic variation, improve traits that will promote seedling survival and growth in natural forests, and improve traits that have economic and ecological value in this keystone species. WOGTIP supports the White Oak Initiative through creation of a sustainable supply of genetically improved, high-quality seedlings for reforestation.

METHODS AND APPROACH

Twenty-three white oak progeny tests have been established throughout white oak's geographic range with 85 percent of the genetic material within each test considered regionally adapted, 10 percent is from just outside the adapted region, and 5 percent of the material represents large latitudinal moves to examine responses to future climate conditions. In addition, an extensive 9-ha rangewide provenance test (500 seed sources) has been established in the center of white oak's geographic range. Material from these tests is available for research and for applied tree improvement. Superior parents of sources in the progeny tests will be grafted to form clonal seed orchards and the progeny tests will be rogued and converted to acorn production areas. Additionally, an independent seed orchard program will engage private and public landowners and organizations in the establishment of a network of certified white oak seed orchards.

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FINDINGS AND IMPLICATIONS

Early results show a significant (P <0.001) positive relationship between nursery height at the time of lifting and first year height growth in the field, and these trends may continue long term. Height growth varied significantly (P <0.001) within and between half-sibling families, and at geographic spatial scales. Some of the height growth variation was related to adaptive latitudinal photoperiod + temperature responses where seed sources moved south to north tended to grow significantly more than those moved north to south. However, some seed sources exhibited superior (or poor) height growth regardless of their origins or distance moved. Clark et al. (in press) found that outplanted white oak seedlings often do not grow in height until the second growing season or they grow well initially when planted but then die back. We found similar conservative growth strategies and there appears to be some genetic control over expression of this trait. Stems of some fast-growing half-sibling families died back, some half-sibling families did not grow in height, and others had significant height growth with no dieback regardless of their initial height at the time of planting. Finally, there is lack of phenological adaptation and cold damage showing up in seed sources moved north suggesting caution in climate change movement strategies.

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ACKNOWLEDGMENTS

Initial funding for WOGTIP was provided by the University of Kentucky Department of Forestry and Natural Resources, Kentucky Agriculture Experiment Station, Kentucky Division of Forestry, and the U.S. Department of Agriculture, Forest Service, Southern Research Station. In addition, we thank over 2,000 volunteers and over 75 organizations including the many acorn collectors, progeny test partners, and collaborators who have helped make WOGTIP a success including: the Forest Service, State forestry and natural resources agencies, city and county governments and organizations, US Army, public and private academic institutions, public and private botanical gardens and arboretums, State and county extension programs, Master Gardener and Master Naturalist programs, state tree nurseries, private woodland owners, nongovernmental organizations, bourbon distilleries including Maker's Mark, citizen scientists, and youth groups (4-H, Future Farmers of America).

THE EVOLUTION OF FREEZING TOLERANCE IN OAKS (*QUERCUS*)

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PURPOSE AND SCOPE

Freezing tolerance is a critical factor controlling the broad-scale distribution of organisms. The American oaks (*Quercus*) are an important representative lineage for studying the evolution of freezing tolerance given their biogeographic history, assembling at high latitudes in the Americas and expanding southward as they diversified (Cavender-Bares et al. 2018, Hipp et al. 2018). Freezing temperatures result in intra and extracellular ice crystal formation, which can cause physical damage and cellular dehydration, resulting in losses of xylem function. Within the nonliving cells of the xylem, freezing temperature is likely to cause cavitation resulting in losses of xylem function, depending on the size of the conduits as well as the freezing temperature and tension in the xylem. The capacity of plants to tolerate freezing varies widely and many species have evolved adaptations that allow them to survive episodic freezing (Zanne et al. 2014). How rapidly plants can adapt to changing climate and whether there are tradeoffs between freezing tolerance and growth remain poorly understood.

METHODS AND APPROACH

We grew 48 species of oaks from five sections of the genus under temperate and tropical growth conditions and measured their stem freezing tolerance and growth rate. We used the electrolyte leakage method to determine stem freezing sensitivity. The electrolyte leakage method measures changes in electrical conductivity to predict cell lysis in response to freezing. To assess whether current adaptation influenced freezing evolution in the oaks, we performed a comparative analysis modeling traits as evolving under an Ornstein-Uhlenbeck model of evolution in a maximum likelihood framework.

FINDINGS AND IMPLICATIONS

We found significant differences among species in their freezing tolerance and capacity to cold acclimate. We found that species from colder regions have higher freezing tolerance and slower growth rates than species from warmer climates. Nevertheless, a direct evolutionary tradeoff did not emerge because

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deciduousness rather than freezing tolerance appears to constrain growth rates. Deciduous species have consistently slower growth rates than evergreen species regardless of climatic niche but vary markedly in freezing tolerance in step with the broad climatic range they span. In contrast, evergreen species occur only in warm climates and have low freezing tolerance. Species from colder regions also have higher acclimation potential than species from warmer areas, indicating that cold-climate species have evolved higher capacity to acclimate to seasonal fluctuations in climate, and warm-climate species have constraints to surviving in colder climates. Freezing tolerance in the oaks is relatively close to its optimal evolutionary state ($r = 0.77$), yet the phylogenetic half-life is 8.9 million years. Consequently, despite a high level of adaptation to the climates in which species occur, evolution towards optimal freezing tolerance has a considerable lag time. Freezing tolerance thus appears to evolve independently from growth rate and investment in freezing tolerance does not impose a constraint on growth. However, leaf phenological habit plays a crucial role in both growth and freezing avoidance. All species, regardless of their climatic origin, have higher growth rates in the tropical treatment where season length is longer. Deciduous species pay a price of losing the opportunity to gain carbon after leaf drop, a price the evergreen species do not pay. Deciduous species are able to persist in both cold and warm latitudes, though evergreen species are relegated to mild climates. At the same time, stem freezing tolerance—and the loss of freezing tolerance—has evolved in coordination with climate and cold tolerant species are not found in warm regions. These findings suggest there may be tradeoffs associated with freezing tolerance, other than growth, that make freezing-resistant species less competitive in warm climates.

Figure 1—Oaks in winter on the banks of the Mississippi River, Minneapolis, MN. (Courtesy photo by Jeannine Cavender-Bares, Department of Ecology, Evolution and Behavior, University of Minnesota)

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POPULATION GENETIC SURVEY OF AN OLD WORLD OAK, *QUERCUS CERRIS*, AS A STARTING POINT FOR THE DEVELOPMENT OF ADAPTIVE OAK MANAGEMENT IN CENTRAL EUROPE

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PURPOSE AND SCOPE

Turkey oak (*Quercus cerris*) is a widespread species of cork oak, distributed from Central and southeastern Europe to Asia Minor. The species has long been known for its enormous phenotypic-genotypic variability and extreme adaptability. According to recent results of climate-based modelling of species' future distribution, Turkey oak could be a winner of climate change in Central Europe (Illés and Móricz 2022). For this reason, this species may be a key element in forestry climate adaptation in this region. However, it is necessary to collect detailed information on the species' ecological characteristics, drought adaptation characteristics, and genetic diversity and structure of wild populations throughout its range to develop effective adaptation strategies. In this study, we investigated the genetic diversity and population structure of 32 natural Turkey oak populations throughout the Carpathian Basin and the Balkan Peninsula.

METHODS AND APPROACH

To allow for a detailed survey of genetic diversity and population structure in the study region, we extensively sampled 32 natural populations throughout the Balkans and the Carpathian Basin. As a result, samples of 321 Turkey oak individuals were included in our analyses. Genotyping was carried out by using double digest restriction-site associated DNA sequencing. During single

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nucleotide polymorphism calling, we used the Turkey oak genome and the well-annotated genome of cork oak (*Q. suber*) to establish two high-resolution reference-mapped datasets. In our population genetic analyses, we implemented multiple clustering approaches such as fastSTRUCTURE, principal components analysis, and randomized axelerated maximum likelihood to infer population structure.

FINDINGS AND IMPLICATIONS

According to the different clustering approaches, we found strong genetic structures among the investigated Turkey oak populations. Throughout the Balkan Peninsula, populations were separated into three genetic groups (West-Balkan group, Central Balkan group, East-Balkan group), representing the legacy of former glacial refugia. Inside the Carpathian Basin, the West Balkan and Central Balkan groups are mixing, constituting an admixture zone in the central part of Hungary. In addition, we also found an outlier population which constitutes a separate genetic group in the northern part of Romania. This strongly separating group may be the result of a founder event. According to diversity indices, Turkey oak populations have a relatively high level of diversity in the study regions. Based on the more genetically diverse and structured Balkan populations, wild populations of this biogeographical region seem promising for further studies on the species' adaptation to climate change. In addition, the strong genetic structures of natural Turkey oak populations draw attention to the careful implementation of long-distance reproductive material transfers in the practice. Although long-distance movements can increase the local genetic diversity, thus improving adaptability, they can also irreversibly change the locally evolved genetic variation and, by causing introgression, may blur the differences between the naturally differentiated genetic groups.

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ACKNOWLEDGMENTS

This article was made in frame of the project TKP2021-NKTA-43 which has been implemented with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the TKP2021-NKTA funding scheme.

GENETIC INTROGRESSION AND HYBRIDIZATION AMONG WHITE OAK SPECIES: DEVELOPING APPROACHES TO MANAGEMENT THAT EMBRACE OAKS' COMPLEX GENETIC HISTORIES

Drew A. Larson, Margaret E. Staton, Andrew L. Hipp, Seth DeBolt, Dana Nelson, and Matthew W. Hahn

Oak species have long been thought to hybridize, and there is growing genomic evidence that this has led to genetic introgression among several groups of oak species. Here, we present results from our recent work characterizing the evolutionary histories of white oak species, including genomic evidence of introgression. We show evidence of past introgression among several species in the white oak clade, as well as relatively recent introgression with cooccurring species that differs across the range of *Quercus alba*. We discuss how the genetic interconnectivity of oaks might warrant special consideration in the way we approach their management and propose a path forward for research to better inform management approaches.

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Form and Function Under Environmental Stress

EFFECT OF REVEGETATION METHOD (DIRECT SEEDING VERSUS OUTPLANTING) ON HOLM OAK ROOT ARCHITECTURE

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The development of a proper root system is essential to increase the long-term success of reforestations and forest restoration. In the case of large-seeded species, like oaks, the cultivation of the plants in containers typically produces the deformation and even abortion of the tap root. By contrast, direct seeding is more likely to produce a normal, deeper tap root. In this study, we compared the root system of 104 holm oak (*Quercus ilex*) saplings grown in a common garden site. Half of the plants were cultivated in 300 ml containers for 1 year in a nursery, and the other half were established through direct seeding in the field. After 5 years, the plants were uprooted with a bulldozer until circa 50–60 cm depth, and the roots were scanned using a 3D laser scanner. The point clouds were then used to reconstruct the roots with quantitative structural models to calculate different metrics of root architecture. Metrics differed in their capacity to differentiate between the effect of revegetation method on root morphology. Nonetheless, seedling cultivation in the nursery consistently produced permanent deformities in the roots, with a lower proportion of the volume directed to the central root, which even disappeared as a unique axis in many cases. This could have implications for the resistance and resilience of the plants to environmental stressors such as drought or pests and supports that direct seeding should be a revegetation method to consider for oak forest restoration.

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LOCAL ACCLIMATION OF HOLM OAKS IS DRIVEN BY EARLY-LIFE PLASTIC TRAIT ADJUSTMENTS

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Functional traits shape plant performance. However, understanding within-species functional trait variability is challenging due to diverse responses to environmental heterogeneity. Moreover, acclimation to local conditions during early development is vital for securing tree growth. The holm oak (*Quercus ilex*) is an ideal candidate for studying intraspecific early performance, given its wide leaf economic spectrum. This study aimed to unravel the tradeoffs among aboveground biomass, water-use efficiency (leaf $\delta^{13}C$ and $\delta^{18}O$), and nutrients (leaf nitrogen-phosphorus-potassium [N-P-K] concentrations) in young holm oaks in Mediterranean semiarid conditions. By using a randomized block design in a common garden experiment, trait data from 240 holm oaks from diverse populations and mother trees were analyzed. Origin population and mother tree had low contributions to trait variation, whereas the block factor was more influential, reflecting trait variations at fine spatial scale. Aboveground biomass correlated positively with P concentrations but negatively with N:P ratio, indicating that P is key for holm oak growth on calcareous soils. $\delta^{13}C$ and $\delta^{18}O$ were positively correlated, and both showed positive links with P and K concentrations, reflecting that an anisohydric behavior and plastic tradeoffs shape resource-acquisition strategies at early-life stages. These findings call for a need to focus on abiotic and biotic limitations at individual plant scale to promote functional holm oak reforestations.

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EXPLORING THE EFFECTS OF FIRE RETURN INTERVALS ON RESOURCE-USE STRATEGIES OF PYROPHYTIC AND MESOPHYTIC SPECIES

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PURPOSE AND SCOPE

Fire exclusion in Southeastern U.S. forests has led to significant changes in species composition. This change is typically associated with mesophication, a phenomenon characterized by fire-sensitive, shade-tolerant species (mesophytes) replacing fire-tolerant, shade-intolerant species (pyrophytes). To reverse mesophication, managers reintroduce low-intensity fires in these systems, but they usually fail to change species demographics. We hypothesized that trait plasticity, specifically a transition to a more conservative strategy, may account for the persistence of mesophyte species in fire-disturbed areas (Ruswick et al. 2021). Thus, the goal of this study was to test the occurrence of functional plasticity of mesophytes under frequent fire disturbance and compare them with a pyrophytic competitor.

METHODS AND APPROACH

The study was conducted at Tall Timbers Research Station in Tallahassee, FL, and the Bankhead National Forest in northern Alabama. To test this, we investigated the effects of fire return intervals on above and belowground functional traits of three species: one pyrophyte, southern red oak (*Quercus falcata*), and two mesophytes, sweetgum (*Liquidambar styraciflua*) and red maple (*Acer rubrum*). At Tall Timbers, resprouts were sampled across unburned plots, 3-year, 2-year, and 1-year fire return interval plots, and at the Bankhead National Forest, they were sampled across unburned plots and 3-year fire return interval plots. We measured above and belowground traits, including specific leaf area (SLA), leaf dry matter content, root nonstructural carbohydrates (NSC), and height before and after prescribed burns. We analyzed our data using two-way analysis of variance to test the differences due to species, fire-return interval, and their interaction.

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FINDINGS AND IMPLICATIONS

Our preliminary findings on SLA support the trait plasticity hypothesis, showing a shift towards a more conservative resource-use strategy in both sweetgum and southern red oak in response to fire frequency (P <0.001). Despite this trait plasticity, sweetgum maintained a more acquisitive strategy than oaks across all fire return intervals (P <0.001). This suggests that sweetgum has the potential for a higher relative growth rate and resource acquisition while conserving resources under frequent fire disturbances (fig. 1a).

Our findings on NSC revealed an interaction between species and fire-return interval (P <0.001). We observed a significant increase in total root NSC percentages in sweetgum in fire-disturbed plots at Tall Timbers, with values significantly exceeding those of oaks (fig. 1b). Analysis of postburn resprout heights, which reflects the mobilization of NSC reserves, revealed consistent taller growth in sweetgum compared to southern red oak across all fire-return intervals except for the 2-year cycle (fig. 1c), indicating higher resprout vigor and a competitive advantage over oaks.

We propose that trait plasticity and sweetgum's generalist strategy might explain its persistence across the landscape, irrespective of fire frequency. Our findings highlight species' functional responses to fire, posing challenges for forest and fire management aimed at restoring fire-tolerant vegetation. Future analyses will explore red maple's response to varying fire frequencies.

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ACKNOWLEDGMENTS

We would like to thank all members of the Forest and Fire Ecology Lab at Auburn University, especially Dylan Ogle, Payton Brewer, Lucas Hart, Tamara Milton, Emily Acer, and Nathan Kurtz. We are also grateful to Tall Timbers Research Station and the Upland Hardwood Ecology and Management Research Work Unit for the logistical support. Funding for this project was provided by the U.S. Department of Agriculture, Forest Service (#FS-21-JV-11330170-095).

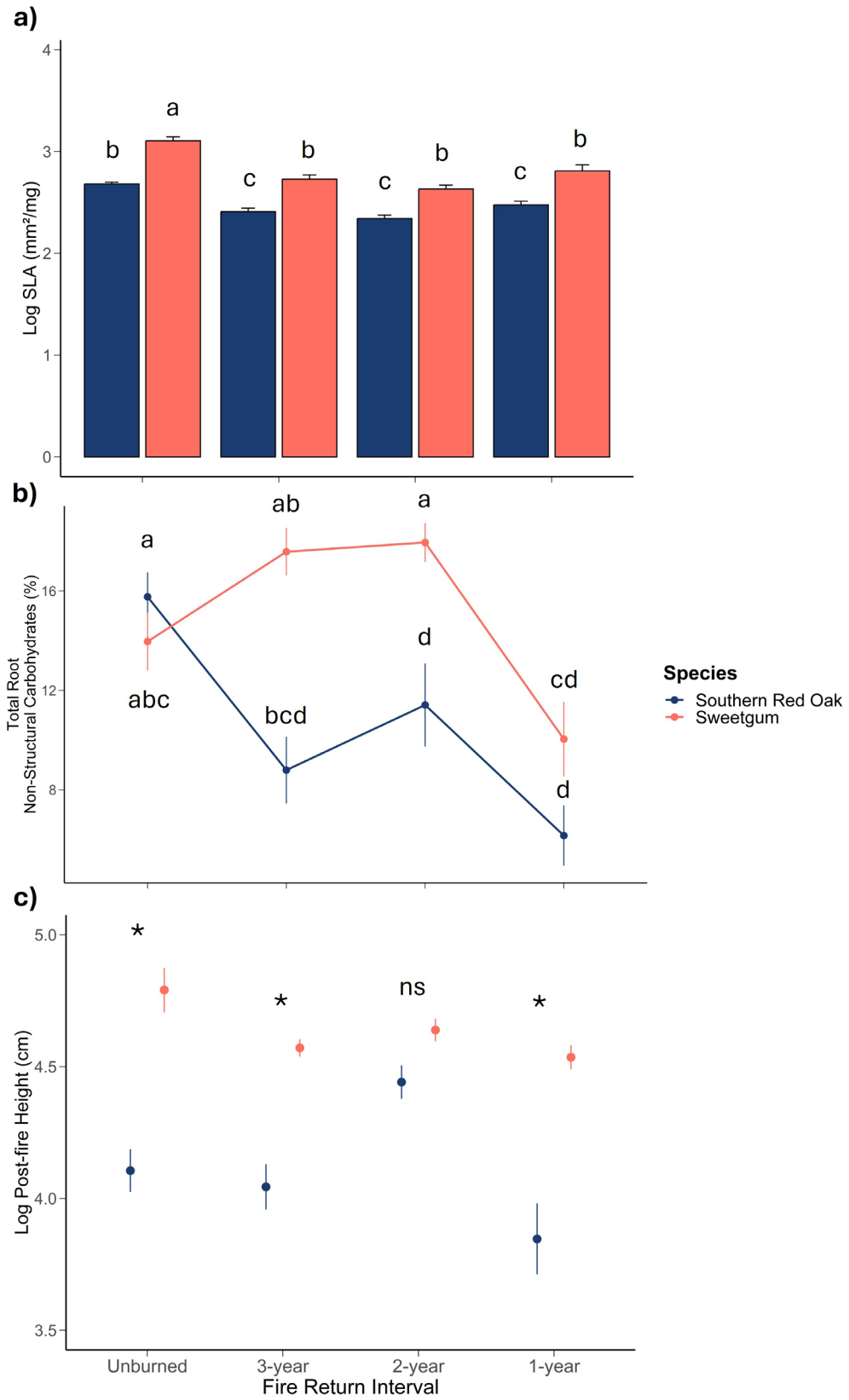

Figure 1—Above and belowground traits measured across fire return intervals in southern red oak (blue) and sweetgum (orange) resprouts. (a) Specific leaf area (SLA) (log-transformed); (b) total root nonstructural carbohydrates; (c) postfire height (log-transformed). Letters in (a) and (b) indicate statistical similarity or differences after Tukey's HSD corrections, where groups sharing the same letter are statistically similar, and groups with different letters are statistically different. In (c), * = significant differences in postfire height between species; ns = nonsignificant differences. Error bars represent one standard error from the mean.

POTENTIAL ROLE OF PLANT-SOIL FEEDBACK IN OAK REGENERATION DECLINE

Sarah McCarthy-Neumann, Katherine E.A. Wood, and Richard K. Kobe

Plant-soil feedbacks (PSFs) could exacerbate the decline of oaks (*Quercus* spp.) (associated with ectomycorrhizal fungi [EMF]) as mesophytic species such as red maple (*Acer rubrum*) (associated with arbuscular mycorrhizal fungi [AMF]) increase in abundance. To test this hypothesis, we carried out a greenhouse experiment where we grew seedlings of five temperate tree species under soils cultured by conspecific versus heterospecific adults at low and high light availability and assessed survival after 12 weeks. We found that negative PSF experienced by seedlings associating with AMF almost always occurred when they were compared with heterospecific adults associating with EMF. Conversely, positive PSF experienced by EMF seedlings occurred when compared to soils cultured by AMF adults. Although PSF occurred regardless of light level, the magnitude of the effect—negative for AMF and positive for EMF seedlings—was greatest at low light. Our results suggest that mesophytic species that are associated with AMF will have greater survival near oak adults (which are associated with EMF) due to the negative PSFs these species experience when establishing under conspecific crowns relative to establishing near oak adults. Likewise, oak establishment is reduced as the abundance of canopy adults of these AMF-associated mesophytic species increases, resulting in fewer areas for oaks to disperse associated with EMF, where oak seedings experienced enhanced survival.

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INTRASPECIFIC VARIATION IN GROWTH, PHOTOSYNTHETIC, AND FUNCTIONAL TRAITS IN *QUERCUS ROBUR* IN RELATION TO DROUGHT AND VAPOR PRESSURE DEFICIT

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PURPOSE AND SCOPE

Drought, driven by rising temperatures and decreasing soil moisture, has a profound influence on ecological shifts and species distribution. It is often assumed that tree seedlings from populations native to drier regions are more drought tolerant than those from wetter areas. However, intraspecific variation in drought tolerance has not been well characterized, despite its critical role in developing climate change mitigation and adaptation strategies and predicting the effects of drought on forests (Candido-Ribeiro et al. 2024). To better understand tree responses and intraspecific variability to drought and increased vapor pressure deficit (VPD), we conducted an experiment using four *Quercus robur* (QR) provenances from latitudes 44 to 54 °N.

METHODS AND APPROACH

One-year-old seedlings in a common garden experiment were subjected to three treatments: drought, water deficit (50 percent of control), and control (optimal irrigation) in a randomized complete block design. During the nearly 60-day drought treatment, we monitored short-term stress responses by measuring gas exchange parameters, including photosynthesis, stomatal conductance, and transpiration. These measurements were taken during both the drought phase and a subsequent 30-day regeneration period. Long-term effects on growth parameters, such as height, diameter, and biomass allometry, were assessed over 2 years. To analyze the data, we used general additive models to investigate stomatal sensitivity to VPD and linear mixed models to examine the responses of provenances to treatments over time.

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FINDINGS AND IMPLICATIONS

All provenances showed similar stomatal responses to decreasing soil moisture ($P \geq 0.54$), and the interaction between provenance, treatment, and time was not significant ($P \geq 0.85$) at the physiological level (gas exchange). Importantly, all seedlings quickly and completely recovered from the stress at the physiological level. The statistically significant differences in stomatal sensitivity were increasing VPD between provenances, with the most southern provenance being the least sensitive.

Growth responses revealed long-lasting consequences of reduced photosynthesis during drought stress, as the growth differences between contrasting treatments persisted for over a year after the stress period. The root-to-shoot ratio was highest in the water deficit treatment, but roots generally showed increased growth after rewatering in the drought treatment, demonstrating the great potential of oak to recover.

Our study has shown that decreasing soil moisture has a lasting effect on photosynthesis and consequently also on growth parameters. In forest ecosystems, this decrease can be reflected in lower biomass production. Furthermore, the study suggested limited local adaptation to soil drought, with adaptations observed mainly in response to a higher VPD in a clinal gradient. Although the southernmost provenance was less sensitive to increased VPD, it also exhibited maladaptation in phenology, compromising its growth. These findings highlight the potential limitations of utilizing assisted gene flow over long distances. Nevertheless, *Q. robur* exhibited a high recovery potential after stress on both physiological and allometric levels.

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ACKNOWLEDGMENTS

The authors thank their colleagues, Szymon Krajewski and Piotr Zajączkowski, for their assistance in preparing the experiment and collecting data. They also extend their gratitude to Piotr Gołos, Rafał Mitlejner, and Marek Sybilski for their administrative support and help in constructing the experiment's infrastructure. This research was funded by the General Directorate of the State Forests (Poland), grant no. 500468, and by Forest Research Institute subsidies, grant no. 900253, awarded to Marzena Niemczyk.

SHEDDING LIGHT ON OAK DOMINANCE IN SOUTHERN APPALACHIAN FORESTS UNDER MODERN NITROGEN CONDITIONS

Sarah Ottinger, Chelcy Miniat, Joel Scott, and Nina Wurzburger

Historically, oaks have dominated forests in the Eastern United States, but forest composition is shifting with disturbances such as intensive logging, fire exclusion, loss of key species such as the American chestnut (*Castanea dentata*), increases in frugivores, recent pluvials, and chronic nitrogen deposition. Forests increasingly contain red maple (*Acer rubrum*) and yellow-poplar (*Liriodendron tulipifera*), with the latter characterized by rapid growth under high-light conditions. Oaks provide significant ecosystem services, and managers have few tools to promote recovery of oak-dominated forests. Here, we examined how two abiotic factors, light and nitrogen, influence competition between three oak species (white, chestnut, and red [*Quercus alba*, *Q. montana*, and *Q. rubra*]), yellow-poplar and red maple. In a greenhouse, we grew seedlings for 12 weeks along gradients of light and nitrogen, both alone and sharing a pot with two competitors. All oaks were competitive in 10 percent light regardless of their fertilization, but as light increased, white oak and chestnut oak only maintained dominance until 40 percent light when not fertilized. This study shows that oaks are most competitive in dark shade. In moderate shade, white and chestnut oaks can outcompete red maple and yellow-poplar in nitrogen-poor conditions. However, in brighter light, red maple and yellow-poplar outcompete all oaks in both nitrogen scenarios. Our findings may help promote oak recovery with tools such as selective harvest and prescribed fire that create a mosaic of light gaps and shade under modern, high-nitrogen soil conditions.

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EXPLORING LEAF LITTER FLAMMABILITY IN EASTERN U.S. OAK AND PINE FORESTS: IMPLICATIONS FOR FIRE ECOLOGY

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PURPOSE AND SCOPE

The purpose of this study was to investigate the relationship among leaf litter traits associated with flammability across a gradient from pyrophytic (fire-adapted) to mesophytic (moisture-loving) species. This research was conducted in forests of the Southeastern United States, having a regional and climatic gradient, and includes both burned and unburned areas. By examining leaf litter traits and their variability, this study aimed to understand the factors influencing leaf litter flammability, determine an overall effect of burning on litter traits across all species and locations, and determine how the effect of burning differed among species and locations.

METHODS AND APPROACH

Leaf litter of 12 different species (pyrophytic to mesophytic) was collected from 12 locations in the Southeastern United States with burned and unburned sites at each location. Leaf litter from eight sites was collected between January and February 2022 and the remaining three sites from January to March 2023. At each site, we selected a stand that had been burned regularly in the past 10 years and one that had no regular prescribed fire implementation for at least 10 years. We measured leaf litter traits related to fuel bed characteristics and forest flammability, which included leaf curl, leaf thickness, leaf perimeter, leaf one-sided surface area, specific leaf area (SLA), leaf volume, surface area to volume ratio (SA:V), and leaf dissection index (LDI). Data were analyzed using analysis of variance and principal component analysis.

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FINDINGS AND IMPLICATIONS

LDI and SLA varied among species in response to burning and the interaction between species and burning. A significant effect of species (P >0.001) and location (P >0.001) was observed on flammability traits in both burned and unburned sites. This analysis compared the effects of burning on LDI and leaf conservatism (mass/square root of area) among and within hardwood species. Overall, there was no significant effect of burning on dissectedness or conservatism because different species responded differently to burning. The general patterns for hardwood species in response to burning showed that tulip poplar (*Liriodendron tulipifera*) increased in dissectedness, whereas black oak (*Quercus velutina*) decreased in dissectedness. However, post oak (*Q. stellata*) and sweetgum (*Liquidambar styraciflua*) showed no significant change in dissectedness with burning. Other species exhibited intermediate responses. Post oak showed the greatest increase in conservatism (higher mass/area ratios) in response to burning, and sweetgum showed the greatest decrease in conservatism with burning. Additionally, there was significant variation among sites: black oak generally decreased in LDI in response to burning but increased in LDI at Strawberry Plains. Post oak typically increased in mass/area at most sites but decreased at Penny Bend. Overall, this study enhances understanding of the relationships between leaf litter traits and flammability. The relationship between plant traits and flammability at the species level is important for a broader understanding of the vegetation-fire dynamic at both local and landscape scales.

SENSITIVITY OF NATIVE (*QUERCUS ROBUR*) AND EXOTIC (*QUERCUS RUBRA*) OAK TREES TO PERIODIC DROUGHT EVENTS IN A WARMING CITY OF SOUTHWEST GERMANY

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Extreme drought events in urban areas can predispose single-standing city trees to drought-induced mortality and early senescence. We compared trees' radial growth, tolerance to periodic drought, and internal trunk damage of native and exotic oak species growing in contrasting habitats of parks and streets. We randomly selected 40 *Quercus robur* trees and 40 *Q. rubra* trees from across the city, evenly distributed between parks and streets. We measured the internal trunk damage by impulse tomography using an ARBOTOM® (Rinntech-Metriwerk GmbH & Co. KG of Heidelberg, Germany) and performed a tree health and dendrometric survey. The radial growth was higher in park trees than in street trees in both species. The correlations between stem growth and drought were more substantial in *Q. robur* than in *Q. rubra*, and *Q. robur* was more sensitive to winter and spring drought than *Q. rubra*. The resilience, recovery, and resistance often showed alternating trends between species and years of drought. The recovery time after the drought has almost doubled since 2003 compared to droughts between 1959 and 1991 in both species. *Quercus rubra* needed more time to recover than *Q. robur*. The impulse tomography result showed that trees with higher drought-induced growth decline also had more significant internal damage. *Quercus robur* had more wood damage inside the trunk than *Q. rubra*. We can conclude that with increased drought intensity and frequency in cities, both *Q. rubra* and *Q. robur* trees take more time to recover from droughts, which leads to internal damage to the trunk due to secondary pathogen infections that warrant further investigations.

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ECOHYDROLOGICAL RESPONSES OF *QUERCUS RUBRA* AND *Q. VELUTINA* TO 7 YEARS OF EXPERIMENTAL DROUGHT

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PURPOSE AND SCOPE

Red oaks (northern red oak, *Quercus rubra* and black oak, *Q. velutina*) are an abundant and valuable timber resource in much of New England, and are physiologically and ecologically distinct from other tree species with which they co-occur. Oaks are generally thought to be deeply rooted and well suited to dry sites, so it is often assumed that they will outperform conifers and more mesic hardwoods as the climate warms and the interannual variability of precipitation leads to more intense drought despite increases in mean precipitation. However, despite their ability to avoid moderate drought stress via their rooting structure, it has been suggested that their risky hydraulic architecture may make them as vulnerable as other species (Novick et al. 2022) to severe droughts.

METHODS AND APPROACH

We experimentally simulated growing-season drought in two oak-pine forest stands at Thompson Farm in Durham, NH for seven growing seasons (2016 to 2022). Approximately 50 percent of throughfall was diverted from two 30-m by 30-m plots between mid-May and late September each year, with intensified diversion (estimated at 90 percent) during the final treatment year in 2022 (fig. 1). Each treated plot was paired with a nearby control plot of similar species composition, and pretreatment data collection began in 2015. Soils were Inceptisols, developed on thin glacial till, and Entisols, on deeper glacial outwash. Water use was monitored using sapflow sensors employing the heat ratio method, and diameter growth was monitored using band dendrometers and increment cores. Root depth distributions were analyzed in quantitative soil pits and power cores in 2019. Leaf water potential, stomatal conductance, and photosynthesis were monitored in a subset of years.

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Figure 1— Part of a throughfall diversion structure covering one of two 30-m by 30-m plots at Thompson Farm in Durham, NH. Half of growing season throughfall was diverted for 6 years, and in the final year, as shown here, coverage was increased to the maximum degree feasible. (Photo courtesy of Matt Vadeboncoeur)

FINDINGS AND IMPLICATIONS

All monitored codominant oaks and pines in treatment and control plots survived the experiment. Oaks downregulated water use more slowly than pines as soils dried, and their intrinsic water-use efficiency was less responsive than pines to both the throughfall reduction treatment and naturally dry summers (Asbjornsen et al. 2021). Preliminary interpretation of xylem water stable oxygen isotope ratios suggests that oaks access water from deeper soil horizons than do pines or maples, which is consistent with observed root depth distributions (Vadeboncoeur et al. 2023) and observations of predawn leaf water potential. However, cumulative reductions in oak basal area increment (27 percent) were surprisingly greater than reductions in co-occurring pine basal area increment (19 percent). Because oaks generally completed each year's radial growth by early August, and soils were usually driest in both the drought and control plots during August and September, the growth effect of a particularly dry summer was typically seen in the following year's growth. No significant differences between northern red and black oak were observed in any of measured treatment effects.

Monitoring of recovery of growth and water-use efficiency after the completion of experimental drought treatments is ongoing. Together, these data will improve our understanding of how these species may respond to a warmer climate with a more variable precipitation regime.

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ACKNOWLEDGMENTS

The authors are grateful to the UNH Woodlands Office for field site access and logistical support. We thank Cameron McIntire, Katie Jennings, David Moore, Adam Coble, Tanner Frost, Victor Garcia, Korik Vargas, Emily Anders, Andy Ouimette, and many other students and technicians who assisted with the maintenance of experimental infrastructure and data collection between 2015 and 2024. This study was funded by the New Hampshire Agricultural Experiment Station (accessions 1003450, 1013351, 1022415) and the Iola Hubbard Climate Endowment at the University of New Hampshire.

EFFECTS OF DORMANT SEASON FLOODING ON PIN OAK (*QUERCUS PALUSTRIS*) ROOT GROWTH

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PURPOSE AND SCOPE

Many bottomland forests in the Lower Mississippi Alluvial Valley have experienced changes to their historic hydrologic regimes (Heitmeyer et al. 2006). Some forests, managed as greentree reservoirs (GTRs), are artificially flooded during the late fall/early winter to create seasonal habitat for migratory waterfowl. Oak species (*Quercus* spp.) provide important habitat structure and a food source via acorn production in GTRs. Observations of oak mortality and poor regeneration success create concerns for sustaining the oak component, habitat quality, and forest health. Relatively little is known about how artificial flooding for waterfowl habitat may contribute to the decline of oaks in these forests. This flooding often occurs earlier in the year, when soil temperatures may still be relatively warm compared to that of historic hydrologic conditions. We conducted this study to determine how flooding during the apparent dormant season affects above and belowground growth of pin oak (*Q. palustris*) seedlings overwintered at different soil temperatures.

METHODS AND APPROACH

This study was conducted in a greenhouse at the Center for Bottomland Hardwoods Research in Stoneville, MS. Pin oak acorns were sown into 1-L nursery pots filled with potting mix, and the resulting seedlings were grown in a greenhouse. Seedlings of similar size and morphology were randomly selected and placed into insulated water baths arranged in a 3 by 2 factorial, randomized complete block design. Soil temperature treatment levels were 5, 10, and 15 °C, and flooding treatment levels were 60-day soil flooding from January 6 to March 7 and no soil flooding. A random sample of seedlings were destructively sampled every 30 days and measured for tap root, lateral root, stem, and leaf masses. We used linear mixed effects models to test the effects of soil flooding, soil temperature, time, and their interactions on seedling biomass growth. Statistical differences were determined using an alpha of 0.05.

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FINDINGS AND IMPLICATIONS

Soil temperature and soil flooding had no significant effects on stem or leaf masses ($P \geq 0.108$). Tap root mass was affected by the interactions of soil flooding and soil temperature ($P = 0.040$) and soil flooding and time ($P = 0.013$). Seedlings that did not receive soil flooding had the greatest root mass at the highest soil temperature, and those that did receive soil flooding showed a similar tap root mass for all temperature levels. Additionally, seedlings raised in 15 °C soil and subjected to flooding developed a lesser tap root mass than those that did not experience soil flooding. Seedlings subjected to soil flooding, regardless of temperature, showed reduced tap root mass during and immediately after flooding, however, tap root mass did not differ between these treatment levels by the end of the study (fig. 1).

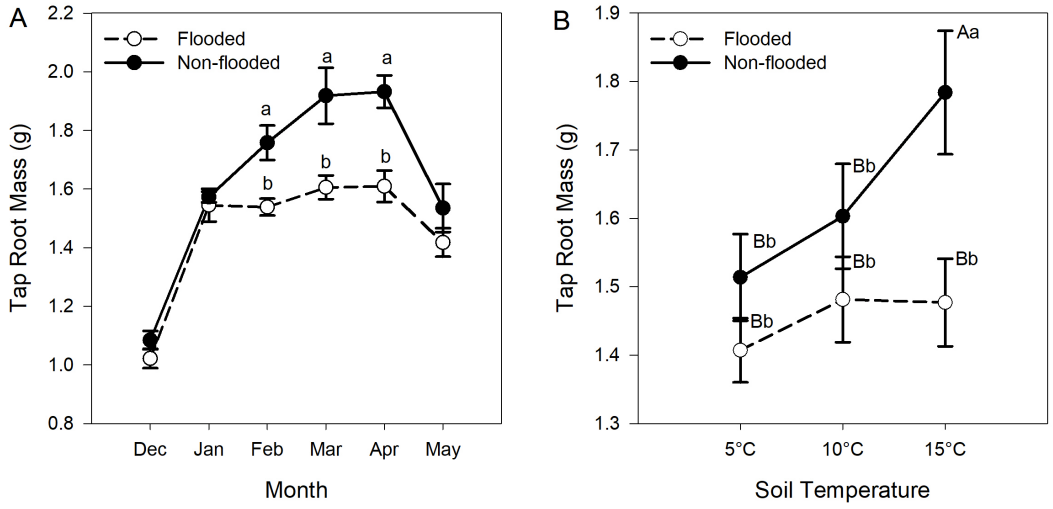

Figure 1—Mean tap root mass by flooding treatment through (A) time and (B) soil temperature. Lowercase letters indicate significant differences between (A) flooding levels and (B) soil temperature levels within a flooding level; (B) uppercase letters indicate significant differences between flooding levels within a soil temperature level. Error bars show one standard error from the mean.

Pin oak seedlings subjected to soil flooding in the late fall/early winter showed reduced root growth, with the greatest reduction occurring at the highest soil temperature. Delaying the application of floodwater in GTRs until soil temperatures cool to 10 °C or less may limit the effects of flooding induced stress on pin oak seedlings. Following drainage, seedlings in all temperature treatments recovered from flooding stress. The ability of pin oak to recover from 60 days of apparent dormant season soil flooding is indicative of their resilience to this stress, however, more severe effects are expected with increased flooding depth or duration (Hall and Smith 1955).

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ACKNOWLEDGMENTS

Funding for this work was provided by Missouri Department of Conservation through cooperative agreement 434 under the master memorandum of understanding MCC-01-01-00; the Pittman-Robertson Wildlife Restoration Program (Grant #AR-W-F 14AF002920) of the U.S. Fish and Wildlife Service, through an agreement with the Arkansas Game and Fish Commission; U.S. Department of Agriculture, National Institute of Food and Agriculture, McIntire-Stennis Federal Capacity Funds; and the U.S. Department of Agriculture, Forest Service, Southern Research Station.

Natural Regeneration and Recruitment

SILVICULTURAL TRIALS FOR CLIMATE-ADAPTIVE CAPACITY IN OAK-DOMINATED SYSTEMS

Amanda Bunce, Thomas Worthley, Robert Fahey, and Christopher Riely

A series of silvicultural trials were initiated in southern New England, affiliated with the Adaptive Silviculture for Climate Change Network, a continent-spanning forest research and demonstration project focused on enhancing adaptive capacity in forest ecosystems to climate-related changes. Experimental sites were oak-hickory systems in a highly fragmented exurban landscape, where uses of the forest are diverse and multiple layers of management objectives apply. Treatment plans were codeveloped by local experts in response to significant loss of mature oaks following a severe drought-pest combination event in 2016 through 2018. Treatments were designed to foster oak regeneration and recruitment because these drought-tolerant species have potential to thrive on our trial sites in future climate scenarios under recommended stewardship practices. Oak regeneration is challenged by factors both climate-related and otherwise. We will monitor oak regeneration success going forward to validate techniques meant to support it, such as "slash carpets" as protection from deer browse, or gap creation to encourage graduation from seedling to sapling. Diversity is the key to resilience in the face of an uncertain future, and so our plans foster heterogeneity of species, while aiming to keep oak dominant, and increase structural diversity. In these early stages of the trial, we will discuss our visons for these ecosystems and the early effects of management in terms of diversity indices and the distribution of oak in relation to other species, and how we can use these factors to steer future action.

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EFFECTS OF MIDSTORY REMOVAL TIMING ON NATURAL OAK REGENERATION IN ARKANSAS, USA

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PURPOSE AND SCOPE

Oak (*Quercus*) reproduction failure in the Eastern United States is largely attributed to competition from faster growing seedlings that shade out oak seedlings. Thus, there is a need to determine and evaluate effective management strategies that facilitate oak seedling success. Shelterwood regeneration methods promote natural oak regeneration by maintaining an overstory, i.e., shelter, of mature conspecifics while creating a relatively open canopy through an establishment cut of select mature trees. The efficacy of this process can be enhanced through removal of midstory (MR) competitors. However, there are few tests to determine the optimal timing of MR implementation. We tested the hypothesis that 1) MR has an effect on oak regeneration (OR), 2) MR differs in efficacy on north- and south-facing slopes, and 3) MR timing impacts OR.

METHODS AND APPROACH

In 2017, initial abundance of OR was measured from 18 plots on 5 treatment blocks that included both north- and south-facing forests (n = 9 plots on each slope) in Arkansas. Treatments were MR in relation to establishment cut: 1) 2 years before, 2) 1 year before, 3) year of, 4) 1 year after, and 5) control (no MR). Three years after the establishment cut (4 years after initial measurements), OR was measured. Data were analyzed using generalized linear mixed models to test for effects of MR timing, slope direction, and their interaction.

FINDINGS AND IMPLICATIONS

Three years after establishment cuts, black oak (*Q. velutina*) seedlings, including advance regeneration, were most abundant (≥2-fold) on north-facing slopes with MR 1 year before establishment cut compared to all other treatments ($P = 0.005$). This was the only treatment where black oak seedlings increased in abundance. Southern red oaks (*Q. falcata*) were generally more abundant on south-facing slopes, but this was dependent on treatment ($P = 0.03$). Specifically, 3 years after establishment cuts, north-facing slopes with an MR 1 year before the establishment cut was the only treatment where southern red oak seedlings increased in abundance ($P < 0.001$). White oaks (*Q. alba*) were most abundant on plots overall, but did not significantly differ by treatment timing or slope direction ($P \geq 0.132$) although they had marginal increases on south-facing slopes

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with MR the year of the establishment cut (P = 0.072) and on north-facing slopes with MR 1 year prior to the establishment cut (P = 0.089). Northern red oak (*Q. rubra*) seedlings were the least abundant and showed no effect of treatment timing or slope direction.

These results suggest MR can be an effective silviculture tool to help promote OR, and MR was generally most effective when implemented 1 year prior to the establishment cut on north-facing slopes. However, effects differed among oak species and slope direction.

LIVING ON THE EDGE: DEVELOPMENT OF AN OAK SEEDLING BANK IN RESPONSE TO SILVICULTURALLY CREATED OPENINGS IN A PRODUCTIVE MIXED HARDWOOD FOREST IN THE SOUTHERN APPALACHIAN MOUNTAINS

Tara L. Keyser and Jodi Forrester

In oak forests of the Eastern United States, successful oak regeneration and recruitment is predicated on the presence of large oak seedlings and saplings capable of successfully competing with shade tolerant and intolerant species after disturbance. In contemporary oak forests, lack of disturbance has promoted the recruitment of shade-tolerant species (e.g., red maple [*Acer rubrum*], American beech [*Fagus grandifolia*]) and limited the recruitment of oak seedlings, which, though often abundant, remain small and noncompetitive. Intense and punctuated disturbances (e.g., even-aged regeneration harvests), while releasing and promoting the growth of existing oak seedlings, also stimulate the establishment and recruitment of shade-intolerant competitors (e.g., yellow-poplar [*Liriodendron tulipifera*], sweet birch [*Betula lenta*]). Although competitors thrive in canopy openings, observations suggest oak seedlings display greater growth than competitors along the gap edge, creating an environment where canopy gaps indirectly promote the growth and development of the oak seedling bank in edge environments. In 2014, we initiated a study to examine the efficacy of using a Bavarian femelschlag (expanding gap) system to regenerate oak in a productive temperate oak forest in western North Carolina. Six stands were selected and approximately 25 percent of each stand's area was regenerated in gaps (70 gaps, 18 randomly selected for intensive vegetation measurements). Five years postharvest, we tested the effects of gap size (range: 0.15–1.3 ha), proximity to gap edge, light, and numerous environmental variables on the height and abundance of oak seedlings (stems <1.5 cm in diameter at breast height [d.b.h.]) and major competitors. Results will form the basis for using an expanding gap femelschlag for regenerating oak and conserving diversity in temperate oak forests.

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EFFECTS OF SELECTIVE CUTTING ON STRUCTURAL ATTRIBUTES AND OAK RECRUITMENT IN STANDS OF MIXED FORESTS IN SOUTHERN SWEDEN

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Oak-dominated and mixed oak forests worldwide support high levels of biodiversity and provide many ecosystem services. Despite their importance as foundational species for many ecosystems, oak dominance is declining worldwide. One of the main explanations for the decline in oak forests is failure in oak regeneration and its inability to grow and reach into the overstory. So far, research has focused on influences of browsing and fire on the early stages of natural regeneration. Examples of successful recruitment of oak into the overstory in mixed, uneven-aged forests are largely missing. This study investigated the effect of selective cutting on stand structure and oak recruitment, and, which specific stand structural attributes favour oak recruitment into the overstory. We focused on recruiting oak trees in the lower and middle canopy (diameter at breast height [d.b.h.] 5.0 to 9.9 cm and 10.0 to 19.9 cm, respectively) that were outside the browsing height. Our results showed that stand density negatively influenced oak recruitment of the smaller size class. An increase in canopy openness had a positive effect on the density of the larger diameter size class. Further, a higher canopy openness with a lower shade-casting index suggested a potential positive relationship of light transmission and oak recruitment. The study results show that different size classes of oak recruitment benefit from either a decrease in stand density or an increase in canopy openness. These variables

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together with the light transmission of the overstory should be considered when ensuring the continuity of mixed, uneven-aged forests with a high proportion of oak in closer-to-nature forest management systems.

QUERCUS REPRODUCTION RESPONSE TO A MULTIPHASED SHELTERWOOD ON THE DANIEL BOONE NATIONAL FOREST, KENTUCKY, USA

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PURPOSE AND SCOPE

Broadleaved forests of the east-central United States are dominated by the *Quercus-Carya* forest type and can include 8 species of *Quercus* and 6 of *Carya*, as well as over 30 other canopy-dominant species. These forests are characteristically older and closed canopied, with requisite management to maintain *Quercus* in the reproduction cohort. Mesophication, the shift to shady understories and the establishment of species that thrive under these conditions, is a serious threat to recruiting *Quercus* seedlings into competitive positions. Managers of the U.S. Department of Agriculture, Forest Service, Daniel Boone National Forest partnered with Forest Service researchers to study intensive management aimed at creating conditions to recruit *Quercus* and deter *Acer rubrum*, the primary mesophytic competitor (Schweitzer et al. 2020).

METHODS

Stands selected for this study are part of a larger study examining treatments to increase forest resiliency and resistance to spongy moth (*Lymantria dispar*) defoliation (Schweitzer et al. 2014). Our goal was to use even-aged silviculture in a shelterwood regeneration prescription to increase light to advance oak reproduction to stimulate height growth and competitive advantage once released. Six shelterwood and six control stands, all dominated by *Quercus-Carya*, were used. Two herbicide treatments were implemented over 10 years. The first treatment removed 445 midstory stems/ha (SPH) of 8 different tree species that averaged 7.6 cm in diameter at breast height (d.b.h.) (fig. 1). The second treatment targeted *A. rubrum* stems in the 1.3–30.2 cm d.b.h. size class. Following the second herbicide treatment, a commercial harvest that retained 5.3 m^2/ha of basal area was done in the shelterwood treatment.

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Figure 1—Oak shelterwood treatment in 2016 after midstory herbicide treatment in 2009; dominant *Quercus* in overstory and Acer rubrum in the reproduction layer of the understory (USDA Forest Service photo by Callie Schweitzer).

FINDINGS AND IMPLICATIONS

Reproduction changes were compared over time and to control stands. From 2005 to 2022 the largest *Quercus* seedling size class increased for both treated and control stands, from 49 to 445 SPH for the control and from 198 to 353 SPH for the treated stands. In 2009 and 2016 total *A. rubrum* seedling densities were not different between control and treated stands. However, in 2022 control stands

had a greater density of total *A. rubrum* stems (50,137 SPH) than treated stands (27,058 SPH). Mesophication coupled with changes in disturbance regimes has complicated historical expected responses of *Quercus* to management (Schweitzer et al. 2024). Additional treatments may be warranted to maintain *Quercus*.

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ACKNOWLEDGMENTS

The authors thank the staff of the Daniel Boone National Forest, especially the Cold Hill District, for their continued support of this project. Field work assistance was provided by Ryan Sisk, Matthew Zirbil, and Preston Durham with the U.S. Department of Agriculture, Forest Service, Southern Research Station.

EARLY RESULTS FROM OAK REGENERATION AND RECRUITMENT TRIALS IN CONNECTICUT

Thomas Worthley

Field trials focused on the long-term goal of perpetuating mixed oak and oak-hickory types in Connecticut have been established in several locations. Low light levels and deer browse are two issues that cause established oak regeneration to languish and prevent its recruitment to sapling stage. Test treatments are designed to address three general objectives: 1) reduce subcanopy shade and increase ambient light in areas with established oak regeneration; 2) discourage deer browse of established oak regeneration; and 3) promote a management activity that can be accomplished by individual landowners on their own property with minimum training. This presentation will describe and illustrate the silvicultural approaches being examined and share early results.

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Growth and Stand Development

UPLAND OAK SIZE-DENSITY RELATIONSHIPS: A MODERN EXAMINATION OF GINGRICH (1967) STOCKING

John M. Lhotka and Lance A. Vickers

In oak-dominated forests of the Eastern United States, foundational understanding of size-density relationships was formed by the seminal work of Gingrich in 1967. However, relationships defined by Gingrich have received limited quantitative evaluation in the context of broader historical data contemporary to Gingrich's original work or under present-day oak stand conditions where extensive research has documented fundamental regionwide shifts in forest structure and composition over the past 50 years. Our first research objective compiled available historical data documenting oak size-density relationships and assessed how appropriately the Gingrich stocking chart represented those historical patterns. To support this objective, we conducted an extensive survey of published literature and research archives from the U.S. Department of Agriculture, Forest Service, Central States Forest Experimental Station (currently Northern Research Station). Twenty-three historical sources were assembled including data from the majority of studies originally utilized by Gingrich in 1967. Our second objective compared historical data and Gingrich stocking charts with current oak size-density trends from the Forest Service, Forest Inventory and Analysis database. With this second objective, analysis evaluated whether our historical understanding of oak size-density relationships and established density management tools (i.e., Gingrich stocking chart) are appropriate to represent today's changing forest conditions.

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QUERCUS RUBRA PURE AND MIXED PLANTATIONS PERFORMANCE GROWING IN A NONNATIVE HABITAT

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PURPOSE AND SCOPE

Red oak (*Quercus rubra*) is an ecologically and economically important forest tree native to North America, with a presumably high climate tolerance (Nicolescu et al. 2020). Its valuable multipurpose timber also used in cabinetmaking (Massafra 2002), shows promising productive potential in Chile due to its growth, trunk form, and health status. Mixed plantations including companion species have been shown to enhance timber quality and productivity of several species (Pretzsch and Schütze 2016). Performance of *Q. rubra* under different associations is mostly unknown. The goal of this study was to assess growth, health, and timber quality of red oak trees growing in monoculture and several mixtures including trees or shrubs as companion species.

METHODS AND APPROACH

Growth measurements were taken periodically in pure and mixed plantations established in 2001 in Los Lagos, southern Chile, for a 22-year period after planting. The tested mixtures were a main species mixture (Mix1: *Castanea sativa*, *Quercus rubra, Quercus robur*, and *Prunus avium*); three mixtures including main forest species plus one arboreal companion (Mix2: Mix1 + *Alnus glutinosa*; Mix3: Mix1 + *Gevuina avellana*; Mix4: Mix1 + *Embothrium coccineum*); one including main forest species plus the shrub (Mix5: Mix1 + *Fabiana imbricata*); and three mixtures including one of the arboreal companion species and the shrub (Mix6: Mix2 + *Fabiana imbricata*; Mix7: Mix3 + *Fabiana imbricata*; Mix8: Mix4 + *Fabiana imbricata*). Timber quality and health status variables were assessed at age 22. Growth variables were analyzed using linear mixed models to assess plantation effect over time. Quality timber variables were analyzed with a χ^2 test. Kaplan-Meier survival analysis and a log rank test ($\alpha = 0.05$) were used to compare red oak tree survival among treatments.

FINDINGS AND IMPLICATIONS

Results showed that *Q. rubra* trees grew well in all plantation types, with average sizes of 14.5 m in height and 22.3 cm in diameter at breast height (d.b.h.) at age

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22. Treatment effect was statistically significant for d.b.h. only at age 22, and for height starting from age 11. Across years, treatment effect on d.b.h. and height were significant (P <0.0001 and P = 0.0087, respectively); however, none of the treatments showed a marked benefit for red oak tree growth. Treatment by age interactions were significant only for d.b.h. (P = 0.0011).

At age 22, red oak trees in the monoculture showed the best performance in d.b.h., being 16.2 percent higher than average values of all mixtures. For height, Mix3 and Mix6 showed the best performance, superior to the monoculture (7.5 percent higher), and to the other tested mixtures (12.2 percent higher).

Regarding timber quality variables, no differences were found among plantation types (P >0.05). However, four mixtures had 100 percent vigorous trees (Mix2, Mix3, Mix4, Mix5); one mixture had 100 percent of monopodial trees (Mix7); and two mixtures showed a superior percentage of straight trees (Mix3, Mix7). No pests or diseases were recorded on any red oak tree.

Results of the log rank test applied to the survival curves estimated for red oak trees revealed no statistical differences among plantation types (χ^2 = 10.622, P = 0.2241). However, at age 22, survival of red oaks in the pure plantation was the lowest (72.2 percent), and the average value under associations was 92.7 percent. Four associations had 100 percent survival (Mix1, Mix2, Mix3, and Mix8).

The biplot of the two principal components by plantation type, growth, and timber quality variables, explained 70.1 percent of the variability (fig. 1); it shows that Mix3, including the four main species and the arboreal companion *Gevuina avellana*, was the plantation type with the highest growth and better stem form. Results suggest that the impact of associating red oak trees on growth and timber quality was not totally evidenced at age 22.

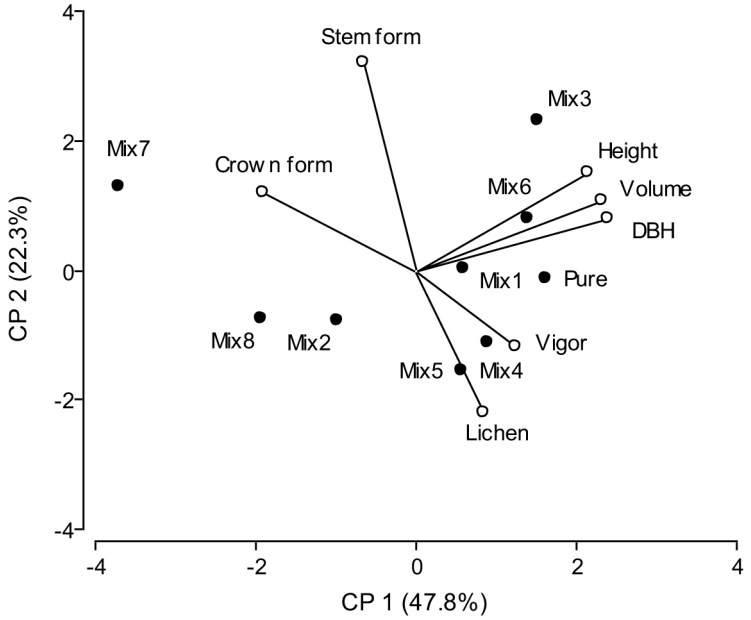

Figure 1— Biplot of the principal component analysis by plantation type, growth and quality timber variables.

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ACKNOWLEDGMENTS

The authors thank the program "Development and contributions for the use of high value forest and fruit-forest species for Chile" (INFOR-Chilean Ministry of Agriculture), and ANID BASAL FB210015 (CENAMAD) for funding the study.

CHERRYBARK OAK (*QUERCUS PAGODA*) CROWN PROFILES AFTER 10 YEARS OF GROWTH IN MIXED SPECIES STANDS OF THREE SPACINGS IN THE CUMBERLAND MOUNTAINS OF MORGAN COUNTY, TENNESSEE

Martin Schubert, Wayne Clatterbuck, and John Zobel

Forest canopy structure and morphology can have a dramatic impact on individual tree ontogeny. In single cohort, mixed species stands, neighboring crown morphology may exhibit a competitive or a complimentary role in the development of desirable species such as oak and their ability to occupy growing space as the stand matures. In 2009, 6.5 acres on the University of Tennessee's Cumberland Forest was identified for hardwood afforestation and subdivided into 27 one-quarter acre blocks. Nine blocks each were planted in yellow-poplar (*Liriodendron tulipifera*), sweetgum (*Liquidambar styraciflua*), or black cherry (*Prunus serotina*). Each block was also planted at one of three spacings: 6 feet by 6 feet, 8 feet by 8 feet, and 10 feet by 10 feet. Cherrybark oak (*Quercus pagoda*) was intermixed in these plantings so that an oak was planted in every other row as every other tree in that row. In this arrangement, each oak seedling was surrounded by six seedlings of a competitor species. The species-specific crown architecture of these competitors at these spacings created distinguishably unique neighborhoods within 3 years from establishment and began acting on the survival and growth responses in the oak through 10 years of stand development. In particular, the interactions of specific stand mixtures modified oak crown allometry and canopy occupancy when measured after 10 years of growth. Since the ability to model crown profiles is essential to physiological-based process models of trees and stands, cherrybark oak crown dimensions were modeled and presented as differential crown profile diagrams.

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FOREST MANAGEMENT OF SESSILE AND PEDUNCULATE OAK IN GERMANY—FROM COPPICE FORESTS TO CLIMATE-SMART FORESTS FOR DIVERSE ECOSYSTEM SERVICES

Peter Spathelf, Jens Schröder, and Hiltrud Bontrup

PURPOSE AND SCOPE

This contribution is divided into two parts. First, a brief overview of the development of oak management in Germany is given. Second, the empirical results of different thinning strategies in a young sessile oak stand are presented.

The German native oak species sessile oak (*Quercus petraea*) and pedunculate oak (*Quercus robur*) developed from a preferred species in coppice systems for the livelihoods of the people in past centuries to a widely appreciated high-value timber species in suitable German regions such as the Spessart mountains (Schröder 2016). The production of high-value timber is conducted in a two-stage approach mostly in even-aged pure stands established after artificial regeneration (Spiecker 1995). Decisive in the regeneration phase is light management, i.e., the size and shape of canopy openings to give oak a competitive advantage in growth over the late successional European beech. In the face of a recent decline of oak and the challenges of climate change, the management of oak is revised, so that mixed stands in irregular stand structures are preferably pursued (continuous cover forestry) to provide diverse ecosystem services. Moreover, oak plays a central role in rehabilitating the large, damaged forest areas formerly covered by conifer species after the subsequent hot droughts from 2018 to 2020. Here, innovative approaches, such as cluster planting, come into play.

METHODS AND APPROACH

The aim of the empirical study (see Bontrup 2023) was to compare early intensive thinnings to traditional low-input strategies. Therefore, larger and more vital crowns of future crop trees were developed, allowing for an earlier harvest and the promotion of a larger share of desired admixed tree species.

In a stand that is now 29 years old, 4 trial plots with 50 future crop trees of sessile oak were established. These have been treated in three different variants

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since 2014: a) in accordance with the silvicultural guidelines of the federal state of Brandenburg with only a few removals of competing trees, b) with a strong selection thinning, and c) with a moderate high thinning, in which severe competitors of the future crop trees and other poorly shaped trees in the stand were removed. The fourth plot has not been treated and served as a reference plot.

In the plots, the following individual tree and stand parameters were measured: tree number, tree species, diameter at breast height (d.b.h.), tree vitality, stem straightness, number of water sprouts per future crop tree, basal area, and standing volume of the stand.

FINDINGS AND IMPLICATIONS

The evaluation of the results shows that there are hardly any significant differences in the overall stand. What is positive is the growth performance of the plot, which underwent a strong selection thinning. The diversity of tree species, which also naturally established and rejuvenated, improved especially in this plot. As far as quality and vitality are concerned, selection thinning hardly seems to have any disadvantages; nevertheless, the results were slightly lower than those of the plots with higher density.

Thus, early thinning is a suited measure to enhance growth performance and vitality of oak trees, with expected advantages for tree resilience under a changing climate.

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ACKNOWLEDGMENTS

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EVALUATING 15 YEARS OF EXPERIMENTAL MANAGEMENT TREATMENTS IN SOUTHERN APPALACHIAN FORESTS OF NORTH CAROLINA

Melanie K. Taylor, Donald L. Hagan, T. Adam Coates, Julia A. DeFeo, Mac A. Callaham Jr., Helen H. Mohr, Thomas A. Waldrop, and Nina Wurzburger

Forests of Southern Appalachia have experienced the widespread loss of oaks, which are increasingly replaced by other species. To understand if management actions could halt or reverse this change (among other problems), a group of researchers and land managers installed a site replication of the Fire and Fire Surrogate Study at the Green River Game Lands (GRGL) in western North Carolina in 2001. The GRGL study implemented three experimental treatments replicated across three spatial blocks: mechanical felling of small stems, particularly the ericaceous understory (mech), prescribed fire (fire), a combination (mech + fire), and untreated controls (control). We evaluated forest attributes after 15 years of continually applied treatments. We found that basal area increased in control and mech, was unchanged in fire, and decreased in mech + fire. Decreases in basal area in mech + fire were driven by overstory tree mortality, which was correlated with loss of duff depth. Saplings were most abundant in mech + fire and were dominated by maples and oaks. Comparing the two, oak saplings were more abundant in plots where basal area decreased, though maple saplings were unaffected by changes to basal area. Taken together, these results indicate that mech + fire may be the best strategy of those tested to facilitate oak dominance in the sapling layer, but creating those conditions likely requires the mortality of overstory trees, including oaks.

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ADAPTIVE STRATEGIES OF WHITE OAK (*QUERCUS ALBA*) IN RESPONSE TO CLIMATE CHANGE: INSIGHTS FROM A 40-YEAR STUDY OF GROWTH AND PHENOLOGY

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This comprehensive 40-year study investigated the adaptive capacity of white oak (*Quercus alba*) in a southern Indiana common garden setting. We documented notable variations in growth, survival, and phenological responses among different white oak provenances, emphasizing the crucial role of white oak genetic adaptation to climate in forest management strategies. Our findings suggest that white oak provenance significantly influences characteristics of growth and phenology. In particular, these findings underscore the potential of southern provenances for central hardwood reforestation and the poor competitive ability of northern seed sources in warmer and longer growing seasons. Southern provenances experienced very little mortality while exhibiting superior growth and form. Conversely, northern seed sources widely experienced competition-induced mortality, even after thinning at age 12, with most trees dying or languishing in the understory by age 40. This study also showcases the common garden's high yield and site index, despite overstocking and the presence of low-performing provenances. The remarkable productivity of the plantation underlines the efficacy of plantation forestry for quality timber yield. The comprehensive data from this long-term study provides a robust framework for predicting white oak responses to environmental changes, informing adaptive management practices in forestry.

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Economic and Ecological Services

QUANTIFYING POTENTIAL COSTS AND BENEFITS OF ALTERNATIVE OAK MANAGEMENT REGIMES IN THE CENTRAL HARDWOOD REGION OF THE UNITED STATES

Gaurav Dhungel, Justin Baker, and Jesse Henderson

Both the regionwide studies as well as isolated case studies of historically oak-dominated stands in the Central Hardwood Region (CHR) indicate abundant stocking of large-sized trees and dearth of small-sized trees with proliferation of fire sensitive species such as maples and beech in sapling and pole stages. Exacerbating the status quo of oak forests in the region are pervasive harvesting practices such as high-grading, with active forest management largely absent in the hardwood growing region. In this study, we posited that a mix of forest management practices geared towards making oaks more competitive: crop tree release, clearcutting, or shelterwoods, would have 2-fold impacts in the long run, to 1) meet the ever-growing demand of high-quality timber while maintaining a sustainable oak resource base; and 2) enhance (or not) the carbon capture potential of these hardwoods. To this end, our study linked growth and yield curves under a suite of management scenarios from the U.S. Department of Agriculture, Forest Service, Forest Vegetation Simulator with a detailed intertemporal optimization model of the U.S. forest sector to assess implications of alternative management strategies to mitigate mesophication impacts in the CHR. Further, results were used to quantify market thresholds or policy inputs needed to incentivize management techniques that improve the long-term sustainability of hardwood systems in the region, while recognizing potential near-term tradeoffs from different management techniques.

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ECONOMIC IMPACTS OF PROJECTED WHITE OAK (*QUERCUS ALBA*) TIMBER SUPPLY IN KENTUCKY: A COMPUTABLE GENERAL EQUILIBRIUM MODEL ANALYSIS

Gaurav Dhungel and Thomas Ochuodho

Demand for high-quality white oak saw logs in Kentucky has been increasing for decades. Concurrently, Kentucky is witnessing ecological shifts in the historically white oak dominated forests mirroring the structural changes in oak forests in the Eastern United States. This demand-supply dissonance presents growing concern among stakeholders on sustainability of white oak (*Quercus alba*) and its associated economic implications. In this context, the objective of this study was to assess potential economic impacts of projected white oak timber supply following overall increased supply of white oak saw logs but reduced supply of high-quality white oak saw logs in Kentucky. Results generated from a dynamic computable general equilibrium model indicate a cumulative present value GDP reduction of $3.66 billion, a decline in consumer welfare of $0.71 billion, and other sectoral contractions over 40 years (2018 through 2058). These results can be used to advocate for more proactive forest management practices to stabilize a sustained supply of high-quality white oak timber in Kentucky and beyond.

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CARBON STORAGE OF RESTORED OAK SAVANNAS TREATED WITH VARYING FIRE FREQUENCY AND SEASONALITY COMPARED TO A CLOSED-CANOPY FOREST AND AN OLD FIELD IN TENNESSEE, USA

Tamara Milton, Craig Harper, Nathan Wilhite, and Heather D. Alexander

PURPOSE AND SCOPE

Oak savannas comprise a bilayer structure of low-density, pyrophytic overstory oaks and a diverse herbaceous understory maintained by frequent, low-intensity surface fire. However, oak savannas represent <1 percent of their original range because of fire exclusion over the last century and consequent transition to closed-canopy forests (Barrioz et al. 2013). Generally, savannas store less overstory carbon (C) than closed-canopy forests because of fewer trees, but savannas and other fire-dependent open forests may store more resilient C in understory vegetation, fine roots, and mineral soil (Bennett et al. 2017). The specifics of fire implementation required to effectively restore and maintain oak savannas, such as frequency and seasonality, also may influence C storage.

METHODS AND APPROACH

We conducted a study at the Bridgestone/Firestone Centennial Wilderness Wildlife Management Area in central Tennessee, to investigate the effects of fire frequency and seasonality on C sequestration in restored oak savannas. Stands sampled represented 1-, 2-, and 3-year fire return intervals, with both early and late growing-season fire in separate burn units. In addition, we sampled an adjacent closed-canopy forest and old field for comparison. We estimated C pools within three 15-m fixed-radius plots per stand by estimating biomass of live trees, snags, downed fine and coarse woody debris, understory vegetation, leaf litter, and organic soils by using current or modified U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis protocols, in combination with published or laboratory-determined bulk density and C content values for litter, organic soils, and understory vegetation. We additionally harvested soil monoliths for coarse root estimates and cored soils to 30-cm depth for fine root and mineral soil C estimates.

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FINDINGS AND IMPLICATIONS

Based on preliminary analyses, aboveground C pools were greatest in the closed-canopy forest, intermediate in restored savannas, and lowest in the old field, apart from understory vegetation, which was significantly lower in the closed-canopy forest than everywhere else. Fire frequency and seasonality treatments within the restored savanna had no impact on aboveground C pools. Fire seasonality but not frequency appears to influence fine root C, with early growing-season burn units exhibiting higher fine root C than late-season units. No differences in percentage of C in mineral soil were detected, however trends and tradeoffs in C pool quantity and location may change as the study continues. Our project contributes to a holistic understanding of the benefits of oak savannas, which include herbaceous species diversity and resilient C storage as aboveground C pools become increasingly vulnerable.

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The authors thank members of the Auburn Forest and Fire Ecology Lab for field and lab assistance. This research was supported in part by the U.S. Department of Agriculture, Forest Service FS-22-JV-11330180-064, and the U.S. Department of Agriculture, Forest Service with funding from the Inflation Reduction Act of 2022 (FS-23-JV-11221632-156).

COMPARATIVE ANALYSIS OF ORGANIC SOIL HORIZON CHARACTERISTICS AND CARBON SEQUESTRATION POTENTIAL IN OAK AND PINE FORESTS OF THE SOUTHEASTERN UNITED STATES

Basanta Shrestha, Heather D. Alexander, Yaniv Olshansky, and Jeffery B. Cannon

Forest ecosystems are the largest terrestrial carbon (C) sink for the United States, and the Southeastern United States. Forest ecosystems are a crucial part of the C sink. The capacity of forest ecosystems to act as terrestrial C sinks is significantly influenced by the characteristics of the organic soil horizon, which encompasses both leaf litter and duff. This study presents a comparative analysis of organic soil horizon characteristics between two prominent forest types in the Southern United States: oak and pine forests. We hypothesized that different forest types with different fire disturbance histories lead to variations in C sequestration potential and storage mechanisms. We examined soil organic horizon characteristics such as depth, bulk density, and C content across Southeastern U.S. oak (*Quercus* spp.) and pine (*Pinus* spp.) stands. Using standardized methodology, we sampled soil organic layer (SOL) from various oak and pine forests, considering the impacts of forest composition, structure, and fire disturbance history on soil carbon pools. Our preliminary analysis revealed differences in SOL properties, attributable to litter quality, decomposition rates, and C storage capacity. The findings suggest that oak forests, with distinct SOL characteristics, may uniquely contribute to C storage, differing from pine forests. This study enhances understanding of forest-specific C dynamics, providing a foundation for more accurate soil C estimation models in diverse ecosystems. The implications are critical for management and conservation strategies to maximize C sequestration, thereby enhancing Southeastern U.S. forests' role in climate change mitigation.

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CHANGES IN GROUNDLAYER COMMUNITIES WITH VARIATION IN TREES, SAPLING LAYERS, AND FIRES DURING 34 YEARS OF OAK SAVANNA RESTORATION IN OHIO, USA

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PURPOSE AND SCOPE

Like many open habitats, sustainability of oak savannas in midwestern North America depends on periodic disturbances such as fires to curtail encroachment by tall woody plants. An uncertainty in restoring and sustaining oak savannas is how frequently fires must occur to maintain the groundlayer of herbaceous plant diversity savannas are known for and what levels of tree canopy and sapling layer encroachment trigger shifts in groundlayers. In an oak savanna undergoing restoration in northwestern Ohio, we examined how groundlayers changed with temporal variation in tree (≥10 cm in diameter) and sapling (<10 cm in diameter) layers and prescribed fires. We also discuss the ongoing challenges and alternative management strategies of maintaining oak savannas.

METHODS AND APPROACH

The study site is a restored oak savanna (40 ha) on sandy soil at Oak Openings Preserve Metropark (1737 ha), OH. Six permanent vegetation plots (0.05 ha) were remeasured up to 17 times from 1988 to 2021. During this period, prescribed fires were implemented in spring or fall on a variable schedule, and a tornado in 2010 hit the site, greatly reducing oak tree canopy cover. For each vegetation sampling event, we visually categorized percentage of aerial cover of 42 vascular, savanna plant species, and measured basal area of all trees ≥1 cm in diameter. We used regression trees to model savanna plant cover and richness, and indicator species analysis to associate species cover with tree and fire estimators (Dufrêne and Legendre 1997).

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FINDINGS AND IMPLICATIONS

Groundlayer cover was maximized when tree basal area was <13 m^2/ha (35 percent of tree canopy cover), there were fewer than 100 trees/ha, and fire had occurred since the previous growing season (fig. 1). Illustrating attrition in groundlayers above these thresholds, two-thirds of savanna groundlayer cover disappeared when tree density exceeded 100 trees/ha and when over 2 years passed without fires. Through savanna species persisting at low cover, species richness endured longer between fires (>4 years), doubled during periods with at least one fire in 3 years, and increased by a third when saplings were sparse (<80 stems/ha). Savanna groundlayers during the 34-year study fluctuated with intermittent increases and decreases associated with dynamics in trees, saplings, and time since fire.

For oak savanna restoration, oaks are both a critical component of the habitat as well as one of the biggest threats, in the form of rapidly encroaching saplings. Although frequent prescribed fires are a critical management method for restoring or maintaining oak savannas, additional complementary disturbances on the sapling layer such as mastication or grazing may also be necessary.

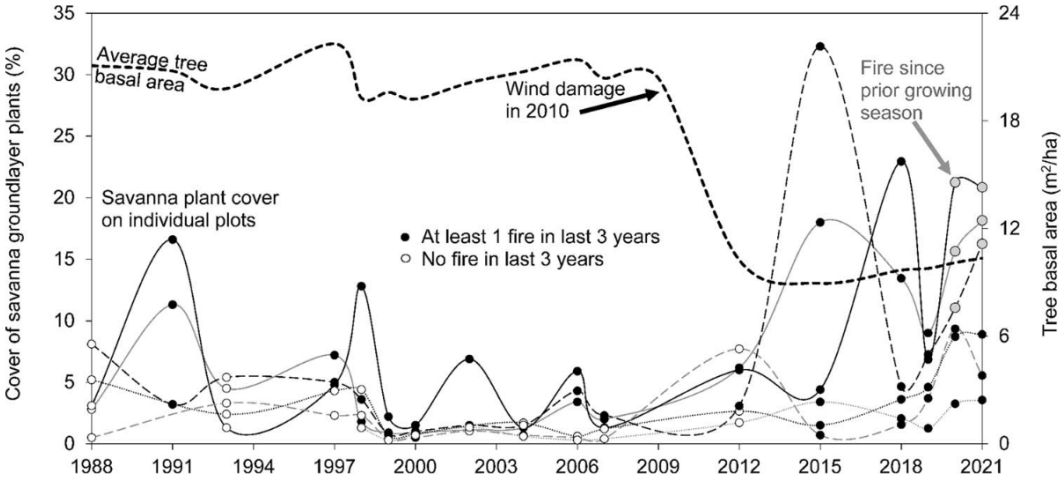

Figure 1—Prescribed fire history, change in basal area of trees, and cover of savanna plants during 34 years of oak savanna restoration, northwestern Ohio. Circles represent sample years on six plots. For the last 2 years of the study, fire history is subdivided into whether a plot received fire since the prior growing season (gray = yes; black = no, but still burned at least once in the last 3 years).

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ACKNOWLEDGMENTS

We thank Metroparks Toledo staff for helping implement prescribed fires and fieldwork during the study, John Jaeger for organizing sampling from the mid-1990s to mid-2000s, Tim Walters for help with fieldwork and plant identification, and Metroparks Toledo for funding the study from 2018 to 2021 through a contract with Natural Resource Conservation LLC.

Historic Ecosystems Guide Management

OAK DEMOGRAPHICS AND DISTRIBUTIONS ON THE PAINT ROCK FOREST DYNAMICS PLOT IN NORTHERN ALABAMA, USA

Helen A. Czech, Dawn Lemke, Patience E. Knight, and Daniela Granato De Souza

PURPOSE AND SCOPE

Understanding the factors that influence growth, distribution, and regeneration of oaks (*Quercus*) in uneven-aged forests is important for addressing ongoing concerns about viable oak regeneration and for explaining oak demographics seen in mixed mesophotic forests in North America (Cavender-Bares 2016, McEwan et al. 2011). To explore oak demographics, we used census data from nine species of oak identified in the 20-ha Paint Rock Forest Dynamics Plot. The plot is in northern Alabama and within the Cumberland Plateau physiographic region. Forests within the region are mature, and prior disturbances to the site, circa 1900 included repeated high-grade logging, forest roads creation, and small-scale clearings for agriculture. We present results from the first census, including size-class and species distribution analyses for all *Quercus* species in the plot. These data should help clarify the demographic status and distribution patterns for oaks under natural regeneration, and guide future research directions.

METHODS AND APPROACH

Between 2019 and 2022, all woody stems (excluding lianas) at least 1 cm in diameter at breast height (d.b.h., at 1.37 m height) were tagged with a unique number, mapped, and identified to species within the 20-ha plot. Aboveground biomass was estimated using updated biomass equations for North American tree species. Biomass was calculated as Mg/ha using R Studio Statistical Software (R Core Team 2023). Percentage of biomass by species and percentage of stems by species were calculated, along with the total biomass of each species at a resolution of 20 m by 20 m (fig. 1). Diameter distributions were graphed. To examine biomass relative to topography and moisture, landform position index and a topographic wetness index were used to assess relationships.

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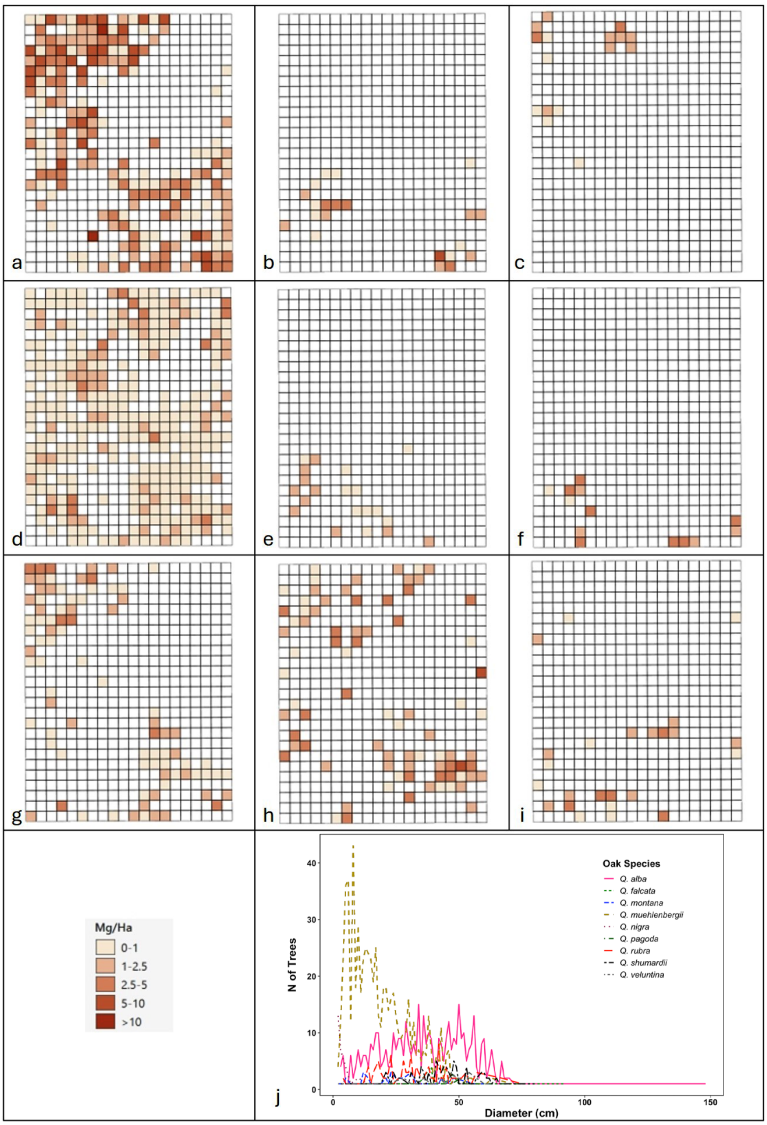

Figure 1—Mapped biomass estimates within the research plot for (a) *Quercus alba*: 446 stems and average 25.8 Mg/ha biomass; (b) *Q. falcata*: 29 stems and average 2.8 Mg/ha biomass; (c) *Q. montana*: 40 stems and average 1.1 Mg/ha biomass; (d) *Q. muehlenbergii*: 674 stems and average 10 Mg/ha biomass; (e) *Q. nigra*: 40 stems and average 0.9 Mg/ha biomass; (f) *Q. pagoda*: 19 stems and average 1.6 Mg/ha biomass; (g) *Q. rubra*: 121 stems and average 4.9 Mg/ha biomass; (h) *Q. shumardii*: 102 stems and average 7.4 Mg/ha biomass; (i) *Q. veluntina*: 30 stems and average 1.8 Mg/ha biomass; and (j) diameter distribution graph for all oak species.

FINDINGS AND IMPLICATIONS

Nine species of *Quercus* (three Section *Quercus*: *Q. alba*, *Q. montana*, *Q. muehlenbergii*, and six Section *Lobatae*: *Q. nigra*, *Q. pagoda*, *Q. rubra*, *Q. shumardii*, and *Q. veluntina*) were identified, making oaks and the family Fagaceae the most represented group in the plot. Though not the most abundant group with only 1,501 (5 percent) of all tagged stems, oaks contributed the most to total biomass at 56.0 Mg/ha or 27 percent of the total plot biomass of 210.9 Mg/ha. *Quercus muehlenbergii* was the most numerous oak species, accounting for 674 (45 percent) of oak stems and 10 percent of total plot biomass. *Quercus alba* was the second most numerous oak species accounting for 446 (30 percent) of oak stems and 25.8 Mg/ha, which was the greatest biomass for any species on the plot. The

least numerous oak species was *Q. pagoda* with only 19 (1 percent) tagged stems. Most *Q. muehlenbergii* had a d.b.h. of <50 cm, though most *Q. alba* had a d.b.h. of >50 cm. The largest d.b.h. on the plot, 148 cm, belonged to a *Q. alba*. In addition to having the greatest number of individuals, *Q. muehlenbergii* was the most widely distributed oak. *Quercus alba* was absent from the lowest elevations and higher biomass was positively correlated with slopes with higher wetness values. When *Q. muehlenbergii* was excluded, most (80 percent) oak stems were >40 cm d.b.h., suggesting that there may be overall low oak recruitment. Future research will look at the effects of soil pH, seed dispersal, and seedling and mortality patterns.

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ACKNOWLEDGMENTS

The Paint Rock Forest Dynamics Plot was established with the help of Alabama A&M University interns, undergraduate students, and a botanist (Loretta Lynne Weninegar). All crew members are acknowledged at https://forestgeo.si.edu/sites/north-america/paint-rock/paint-rock-field-crew. We thank the managers and staff of The Nature Conservancy for access to the Sharp Bingham Mountain Preserve, on which the plot is found, along with the Paint Rock Forest Research Center for access to the field house. This research was supported in part by the intramural research program of the U.S. Department of Agriculture, National Institute of Food and Agriculture, Evans-Allen #1024525, and Capacity Building Grant # 006531. It was also supported in part by the U.S. National Science Foundation RII (Research Infrastructure Improvement) Track 2 FEC: Leveraging Intelligent Informatics and Smart Data for Improved Understanding of Northern Forest Ecosystem Resiliency (INSPIRES) #1920908, and by The Lyndhurst Foundation.

REACCESSING HISTORICAL OAK COMPOSITION OF KENTUCKY

Brice B. Hanberry

Outcomes of European colonization encompass surface fire exclusion followed by forestation of open ecosystems and tree densification within forests, with concomitant replacement of fire-tolerant oak and pine species by fire-sensitive tree species. In Kentucky, a comparison of tree composition between an historical assessment (1907 to 1909) and modern surveys (2010 to 2014) revealed the same progression. Historically dominant, fire-tolerant oaks decreased from 52 percent of all trees to 21 percent of all trees, maples increased from 5 to 19 percent of all trees, eastern redcedar (*Juniperus virginiana*) increased from 1 to 6 percent of all trees, and yellow-poplar (*Liriodendron tulipifera*) increased from 3.5 to 9.0 percent of all trees. Following time since Euro-American settlement, and associated severity of land-use change, greater divergence in tree composition occurred in the Loess Hills and Central Interior regions than in the Appalachian region of Kentucky.

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AGROFORESTRY HISTORICAL LANDSCAPES IN EVRYTANIA: OLD GROWTH OAKS AS HERITAGE IDENTITY AND A DRIVER FOR SUSTAINABLE TOURISM

Vasiliki Lappa, Andreas Papadopoulos, Eleni Kelesi, and Anastasia Pantera

Evrytania is a mountainous region in the center of Greece with a long livestock farming tradition. The pastoral communities in the mountains of southern Pindos practiced communal management of the mountain pastures until the last decades of the 20th century. This traditional management has shaped the mountain agricultural and agroforestry mosaic landscape around the communities. Large parts of the forests adjacent to the mountain settlements are characterized as social forests as well as sacred forests and have a special protective character that is highly respected even at present. The structural features of this high nature and cultural value landscape were documented in dissertation research focusing on the dominant elements of those historical landscapes, the monumental century-old oak trees that coexist with stone-built rural monuments of traditional architecture such as churches. The interdisciplinary team at the university is working towards evaluation and mapping of mature oaks, both evergreen and deciduous, recognizing their ecological and cultural values. An environmental education program was designed and implemented for students, giving them the opportunity to learn about the biodiversity of species and habitats that support these giant trees and to connect them to local history through experiential exploratory cooperative learning activities.

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VALONIA OAK (*QUERCUS ITHABURENSIS* SUBS. *MACROLEPIS*) IN GREECE: FROM MYTHOLOGY TO RESEARCH BREAKTHROUGHS FOR A SUSTAINABLE FUTURE

Anastasia Pantera, Andreas Papadopoulos, Vassiliki Lappa, Georgios Mpakogiorgos, and Alexia Stokes

PURPOSE AND SCOPE

Valonia (*Quercus ithaburensis* subs. *macrolepis*) is a high natural, economical, social, and culturally valued oak species that forms traditional agroforestry systems, mainly silvopastoral, in Greece (Pantera et al. 2018). Livestock has been grazing in the area since the time of Homer, the Roman and Byzantine periods, and continues to this day. The species since antiquity provided wood and acorns, tannins for tannery, and dye production extracted from the acorn cups, and was famous for religious reasons. Through time, these systems' value switched to other uses with more economic value but nowadays it is confined to firewood production and for grazing livestock. Natural regeneration in these systems is affected (besides grazing which is a major factor in limiting valonia oak natural regeneration) by a number of factors with climate change being an important one (Papadopoulos et al. 2017). The impact of climate change on valonia oak silvopastoral systems has not being thoroughly studied apart from one report on climate change that incorporates this species. Based on climate change scenarios, it is estimated that valonia oak is the third species that may face significant decrease to its populations area, scaling up to a loss of 56 percent (Bank of Greece 2011). Based on the same scenarios, in Greece and in the study area in particular, the expected temperature increase, and precipitation decrease, represents a crucial factor affecting the establishment of saplings and young seedlings or even the survival of young and older valonia oak trees. The major goal of the present work was to investigate grazing effects on valonia oak root growth parameters and wildlife species abundance.

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METHODS AND APPROACH

Permanent experimental plots have been established inside the forest since 2014 to evaluate several parameters including soil. The experimental area is located in the Xeromero valonia oak silvopastoral system in western Greece composed of open to relatively open stands with 25 to 50 trees/ha. Twelve rectangular plots covering an area of 40 m^2 were established and fenced against grazing from livestock and wild animals. In 2023, 12 rhizotrons were established to monitor root growth under different management (grazing). The rhizotrons were constructed by opening small pits of 70 cm by 50 cm by 50 cm size and consisted of four small glasses secured over the pit wall and one big glass (50 cm by 50 cm) against another pit wall. Two months after establishment, root growth was evident in the glasses. Additionally, wildlife cameras were established to monitor biodiversity based on tree density.

FINDINGS AND IMPLICATIONS

Roots were found in all rhizotrons. So far, the management applied does not seem to affect root growth, but more data is expected this year. Currently several vertebrates have been recorded with wild boars being the most abundant (fig. 1). It appears that the highest number of species is recorded in the highest density plots, which are the ones further away from human construction (houses).

There have been increased discussions lately on the preservation of such forests, not only for their valuable ecosystem services provision but also over the right of nature to be protected. Research, such as the study conducted under the framework of the eco2adapt project is valuable because it provides proof of the necessity to protect this forest as a biodiversity hotspot. It also provides measurable data and input to support policy regulations that favor nature preservation and restoration.

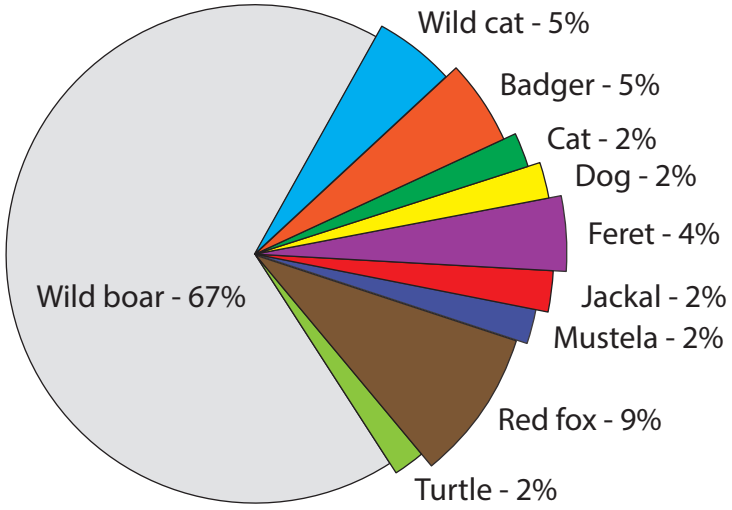

Figure 1—Percentage of total wildlife captured by camera monitoring after one year of camera establishment in the Xeromero valonia oak silvopastoral system in western Greece.

Presently there are more projects related to this oak forest that will provide tools and data for its management such as the AF4EU project that aims to create business models and strengthen extension services. Additionally, in fall 2024 two

more HORIZON EUROPE projects will be launched with dedicated activities in this oak forest: the DRYAD and SUSSOIL projects. The DRYAD project will investigate the hydrological aspects and parameters that affect the forest, whereas the SUSOIL project will investigate the soil and carbon balance.

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ACKNOWLEDGMENTS

This work was funded from the European Union under the eco2adapt project (grant agreement N 101059498).

FLAMMABILITY OF 34 NORTH AMERICAN OAKS

J. Morgan Varner, Timothy M. Shearman, and Jeffrey M. Kane

Oaks and other members of the Fagaceae are widely noted for their relationships with wildland fire. These vegetation-fire feedbacks result in adaptive traits related to local fire regimes over evolutionary time. A primary adaptation in trees is the flammability of their senesced litter, which is a primary fuel sustaining surface fires in woodlands and forests globally. We coalesced previously disparate flammability data on 34 North American oaks and allies using identical laboratory methods. We used multivariate analyses to evaluate dimensions of flammability for the different oak species and discriminate similar clusters. Our analyses revealed that North American oaks span wide gradients in flammability, with some species approximating the most flammable species on the continent (*Castanea dentata*, *Quercus laevis*, *Q. kelloggii*, and *Q. garryana*, among others), several were intermediates, and some had poor flammability (evergreen oaks *Q. virginiana*, *Q. geminata*, *Q. durata*, and *Q. vaccinifolia*, among others). Additionally, we show some preliminary results of combining flammability data with bark data for a subset of these species. Additional research on other North American oaks as well as including other fire-adapted traits will offer greater clarity for how oaks have evolved with contrasting fire regimes and how these species may fare in future regimes.

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HISTORIC AND CURRENT FORESTS AND FIRE CULTURE IN THE SOUTHERN APPALACHIANS

J. Adam Warwick and Brice D. Hanberry

Forest assessments during the first decade of the 1900s can supply missing information of quantified tree composition, particularly in mountainous locations that were the last locations to be cleared of original forests. An extent of about 2 million ha in the Blue Ridge Mountains of the southern Appalachian Mountains, primarily North Carolina, was assessed by two spatially overlapping studies during the first decade of the 1900s. According to the assessments, fire-tolerant oaks (*Quercus* spp.) and American chestnut (*Castanea dentata*) historically were the dominant species with 61 to 63 percent of all trees for both study extents. In modern tree surveys, red maple (*Acer rubrum*) became the most abundant species, with 15 percent of all trees, increasing from an historical combined maple percentage of 2.5 percent. Eastern white pine (*Pinus strobus*; 7 percent of all trees) and Virginia pine (*P. virginiana*; 4 percent of all trees) increased to 14 percent of all trees from 4 percent historically. Therefore, in addition to loss of American chestnut to disease, oaks declined to 27 percent of all trees. The historical assessments documented an active fire culture, with evidence of light fires throughout 80 percent of the study area, which was converted into fire exclusion through an antifire campaign and land use. Despite small fire compartments in mountainous terrain, and a later transition date, this region conforms to the same progression of change since Euro-American settlement as most other upland regions in the Eastern United States.

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CAUSES OF A SEEDLING RECRUITMENT ADVANTAGE FOR AN ENCROACHING OAK OVER A HISTORICALLY DOMINANT OAK IN A FIRE-RESTORED OPEN OAK WOODLAND

Griffin L. Williams and J. Stephen Brewer

The lack of natural oak regeneration within forests is one of the most pressing conservation issues facing oak-dominated ecosystems in eastern North America. Although the restoration of suitable fire regimes appears to favor oaks over fire-sensitive mesophytes in many cases, differences in the effects of fire restoration on different species of oak have not received nearly as much attention. In particular, greater sapling recruitment of historically lowland *Quercus alba* compared to that of the historically upland and dominant *Q. stellata* in response to fire restoration may be related to differences in seedling establishment. We investigated species differences in seedling emergence, survival, and vigor over two growing seasons (fall 2020 to fall 2022) in a restored oak woodland in northern Mississippi. Seedling survival and vigor were greater in *Q. alba* than in *Q. stellata*. Both species had significantly lower performance in patches dominated by the invasive *Microstegium vimineum* than in those dominated by native species. Neighboring vegetation and litter removal significantly increased seedling survival in both species, but its effect was no greater in patches dominated by *M. vimineum* than in those dominated by native species, a result consistent with the existence of legacy effects of *M. vimineum*. Altogether, our findings suggest that higher seedling establishment in *Q. alba* than in *Q. stellata* may contribute to the lower regeneration rates of the historically dominant *Q. stellata* compared to encroaching *Q. alba* in fire-maintained woodlands. Negative effects of an invasive grass, *M. vimineum*, may further complicate restoration efforts.

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Practices for Oak Restoration

REVERTING HOMOGENOUS FOREST LANDSCAPES INTO MIXED OAK FORESTS IN SOUTHWESTERN EUROPE

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PURPOSE AND SCOPE

Transformation of homogenous pinewood landscapes into mixed oak forests through silvicultural interventions can contribute to increased resilience and adaptation to changing social and environmental conditions. The goal of this study was to implement an adaptation of the irregular shelterwood system in a Mediterranean-type climate in southwestern Europe. The success of the method was evaluated through the control of pine natural regeneration and the performance of artificial regeneration of oaks in gaps.

METHODS AND APPROACH

Las Llanas experimental site is located in Cabañeros National Park (39.40ºN, -4.45ºW). Transformation treatments consisted of creating small gaps (8 m in diameter) and medium gaps (16 m in diameter) followed by plantation of holm oak (*Quercus ilex*), cork oak (*Q. suber*), and quejigo oak (*Q. faginea*) in all possible combinations and three replicates. Another three gaps per treatment remained unplanted to follow natural regeneration, which also occurred in three 16 m by 16 m control plots. Nine plots with nine individuals per species were also underplanted in the control area. Pine and oak seedling density 4 years after harvest were modelled using a Poisson generalized linear mixed model. Predictors included treatment, abiotic and biotic features (global site factor, position in the gap, moss, stones, and herbaceous cover), and gap as a random effect was included in the intercept. Plantation survival after 2 years was analyzed with a general linear model approach by species and treatment.

FINDINGS AND APPLICATIONS

After 4 years, treatment and position in the gap were found to be significant predictors of pine abundance, whereas moss cover and treatment were significant predictors for oak. For both genus, medium-sized gaps had a positive impact. Pine regeneration was lower in the northern part of the gap. Harvest residues had a globally negative impact on pine regeneration, but a positive

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impact in the southern part of the gap. Oak regeneration was favoured by the presence of moss cover (table 1).

Table 1—Significant predictors of pine and oak seedlings density (plants/m^2) in the gap experiment 4 years after harvest

Variable	Pine regeneration		Oak regeneration	
	Estimate	*Standard error*	*Estimate*	*Standard error*
Intercept	NS	NS	-1.8686	0.6300
Medium gaps	0.53365	0.17083	2.0448	0.7729
Harvest residues	-0.69544	0.33158	NS	NS
North position	-0.45753	0.23261	NS	NS
Harvest residues x South position	1.39623	0.47982	NS	NS
Moss cover	NS	NS	6.8913	3.2537

NS = nonsignificant.

Mortality of all planted oak species was higher in control plots than in gaps. Holm oak had a significantly higher survival rate 2 years after planting in medium-sized gaps, whereas cork oak and quejigo oak treatments did not differ.

In the Northern Hemisphere, regeneration is higher in the northern part of gaps due to higher solar radiation (Raymond et al. 2011), however under semiarid conditions, like in the Mediterranean, high soil temperature and low moisture are expected in the northern part of the gap (Bagnato et al. 2021) and regeneration could benefit from protection of edge trees in the southern part of the gap. This protection increases if harvest residues are left in place. Moss cover is a possible indicator of more humid spots within the gap where successful oak regeneration occurs. However, low regeneration indicates that planting oaks in gap openings seems to be a feasible option to transform pine reforestations into mixed oak forests, though underplanting is not recommended due to high oak mortality.

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ACKNOWLEDGMENTS

The experimental site was established and measured thanks to COMFOR-SUDOE SOE4/PI/E1012 Interreg-Sudoe and IMFLEX – Integrated Forest Management along complexity gradients grant PID2021-126275OB-C21 funded by MCIN/AEI/10.13039/501100011033 and by "ERDF A way of making Europe".

REFINING THE ARTIFICIAL REGENERATION PRESCRIPTION FOR WHITE OAK (*QUERCUS ALBA*) BY USING PEDIGREE AND ADVANCED NURSERY PRACTICES

Stacy L. Clark, Scott E. Schlarbaum, and Callie J. Schweitzer

PURPOSE AND SCOPE

Artificial regeneration (i.e., planting) of white oak (*Quercus alba*) will become more important because forest succession, climate change, urban development pressures, and nonnative species are ever-increasing threats to this important resource. Early survival and growth of planted white oak seedlings are critical for predicting long-term responses, but these dynamics are not well understood. The goal of this study was to refine artificial regeneration techniques used to restore or enhance the white oak component in eastern hardwood forests. Our specific objective was to quantify factors affecting white oak seedling survival and planting shock in the first growing season. We specifically examined effects of stock type (1-0 versus 2-0), seedling size parameters, and genetic family on survival and dieback.

METHODS AND APPROACH

Acorn collections were made in 2020 and 2021 in Moore County, TN from seven white oak orchard trees and were then sown at the Tennessee State nursery. Collections from over a dozen trees in northern Alabama were made in 2021, bulked and sown at the Georgia State nursery. Seedlings were lifted and visually graded (Clark et al. 2000) in February 2023 as 1-0 (2021 collection) or 2-0 (2020 collection) bareroot seedlings. Height, root-collar diameter (RCD), and total weight of each seedling were measured. Trees were planted on a 3-m by 3-m spacing on the Bankhead (BH) (34.3 °N, 87.4 °W), Cherokee (CH) (36.5 °N, 82.0 °W), and Daniel Boone (DB) (37.0 °N, 82.3 °W) National Forests. The effects of genetic family and stock type on first-year survival and incidence of dieback were analyzed using general linear mixed models, and differences in treatment least-squares means (LSM) were determined. Logistic regression tested how seedling size parameters affected dieback.

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FINDINGS AND IMPLICATIONS

Survival (raw mean = 95 percent) was affected by family, but not by stock type, with one family having lower survival (LSM = 81 percent) than all others (LSMs >92 percent). Dieback (raw mean = 44 percent) was affected by family and stock type, and family dieback LSMs ranged from 25 to 36 percent. The 1-0 seedlings (raw mean = 40 percent) generally had less dieback than 2-0 trees (raw mean = 48 percent), but stock type differences were only significant for one family. Total weight and RCD interacted to explain variability in dieback though height was less predictive. Dieback increased for seedlings weighing more than 300–400 g, particularly for trees with smaller RCDs (fig. 1).

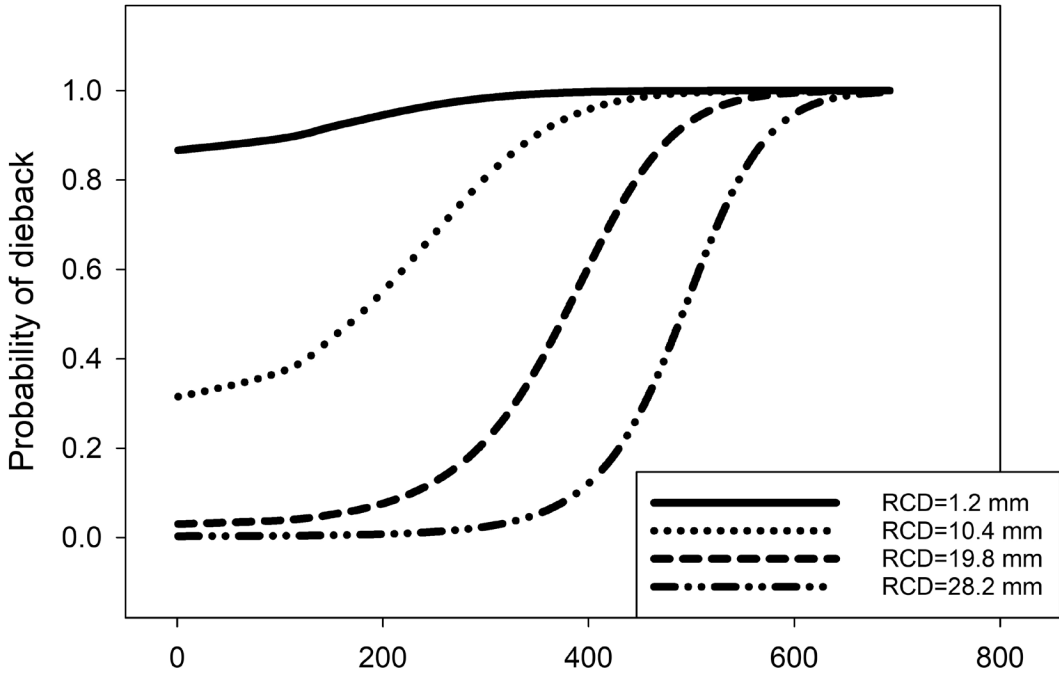

Figure 1—The probability of first-year dieback based on total seedling nursery weight and four root-collar diameter (RCD) classes for 1-0 and 2-0 white oak seedlings grown in a commercial tree nursery in Tennessee, USA.

Despite the increased planting shock in larger (i.e., heavier) and older (2-0) seedlings, previous studies have demonstrated that larger seedlings will maintain their growth advantages over time (Clark et al. 2015). Challenges with planting heavier seedlings with putatively larger root systems are temporary and could be partially mitigated by planting seedlings with larger RCD. Ideally, large 1-0 stock would be used instead of 2-0 to reduce nursery operation costs. Families could be selected to favor development of large-calipered 1-0 seedlings that have reduced dieback. Until tree improvement is more advanced, we suggest using genetically diverse seed sources and large calipered seedlings from 1-0 or 2-0 stock types.

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IMPACT OF FIRES ON SOILS IN OAK AND PINE STANDS

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Galicia in the European Union has the highest forest growth rate but also the highest incidence of forest fires in the last three decades. Around 55 percent (1.65 million ha) of Galicia has burned in the last four decades. Oaks (*Quercus* spp.) have the capacity to incorporate leaves into the soil every year, increasing the soil fertility and resilience of the land after the forest burns. The objective of this study was to analyze the impact of a forest fire on soil fertility. The experiment consisted of sampling in two areas: forest land burned in 2020 and nearby unburned areas. Soil fertility was analyzed for soil water pH, total cations, cation exchange capacity, and nutrient availability. In general, fire reduced soil quality, but the reduction was much lower in the case of *Q. robur* burned stands than *Pinus pinaster* burned stands. Topsoil (i.e., organic soil) pH was always above and below five in *Q. rubra* and *P. radiata* stands, respectively, but was not significantly different in these two forest types after fire. Mineral soil (i.e., subsoil) was also better in *Q. rubra* stands before fire than in the rest of the treatments before (*P. pinaster*) and after (*Q. robur* and *P. pinaster*) fire. However, topsoil potassium chloride pH was much higher in *Q. robur* than in *Pinus* stands in both pre and postburned soils. Cation exchange capacity was mainly composed of aluminum for *P. pinaster* stands, whereas in *Q. robur* stands it was dominated by calcium and magnesium. Soils were degraded in stand types after fire but the impact was higher in *Pinus*-derived soils. The improvement of soils in *Q. robur* stands resulted in better soil and vegetation recovery 1 year following fire.

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DEVELOPMENT OF UNDERPLANTED BOTTOMLAND OAK SPECIES UNDER CHEMICALLY TREATED JUVENILE STANDS WITHIN SOUTH CAROLINA FLOODPLAINS

Stephen Peairs and Nilesh Timilsina

Oak regeneration often fails to occupy dominant positions after crown closure in clearcut stands. Faster growing species such as American sycamore (*Platanus occidentalis*), green ash (*Fraxinus pennsylvanica*), and sweetgum (*Liquidambar styraciflua*) are prone to outcompete oak on more productive bottomland sites. Oak enrichment planting with overstory reduction may be a means to alter species composition in such stands. This study evaluated partial deadening of overstory stems with juvenile (<20 years of age) bottomland hardwood stands in the Savannah River floodplain, Wateree River floodplain, and a minor floodplain of Love Creek. Chemical cut stem and ring girdling with herbicide treatments were applied in the summer 2020. Trycera® (Helena Agri-Enterprises, LLC, Collierville, TN) herbicide (triclopyr acid formulation) was applied at a 50 percent solution with water. The residual stand basal area per acre was reduced to approximately 25 square feet. A nonnative, invasive spot spray of Chinese privet (*Ligustrum sinense*) and Nepalese browntop (*Microstegium vimenium*) was applied on one of the sites. Cherrybark oak (*Quercus pagoda*), nuttall oak (*Q. nuttallii*), laurel oak (*Q. laurifolia*), and willow oak (*Q. phellos*) were underplanted in late winter/early spring of 2021. Five-foot tree tubes were placed atop approximately half of the planted seedlings. No chemical herbaceous release treatments were applied to any of the areas. Planted oak seedling height measurements were taken in the spring of 2023 on the Savannah River and Love Creek sites. Seedling measurements were not taken on the Wateree River.

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COMPETITION CONTROL AND INCREASING CANOPY OPENNESS BENEFIT ARTIFICIAL WHITE OAK (*QUERCUS ALBA*) REGENERATION IN AN EXPANDING SHELTERWOOD IN INDIANA, USA

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PURPOSE AND SCOPE

White oak (*Quercus alba*) artificial regeneration can theoretically be used in tandem with shelterwood regeneration systems to bolster flagging or nonexistent natural oak regeneration, particularly on sites where the use of prescribed surface fires may be logistically or legally difficult. Few have explicitly examined the efficacy of combing these two management strategies. Likewise, competition control has been shown to benefit growth of white oak understory regeneration (Dreisilker et al. 2014), but has not been examined in combination with underplanting and shelterwood harvesting in central hardwood forests. We tested the impacts of competition control on artificial white oak regeneration planted along a canopy closure gradient in an expanding shelterwood (i.e., femelschlag) in southern Indiana. Our objective was to inform successful white oak regeneration practices in the Central Hardwood Region.

METHODS AND APPROACH

This study was installed on the Naval Surface Warfare Center in Crane, IN. Four plots were installed on two sites that received an expanding group shelterwood treatment (Greenler and Saunders 2019) in winter 2018/2019; the plots extended from the center of a 0.5-ha group, through an area of midstory removal, and into unharvested forested matrix. This design created an overstory canopy and light gradient, which was quantified using a camera with a fisheye lens. Each plot was further split and randomly assigned to 0, 2, or 4 years of understory competition control, by both chemical and mechanical means. In each split-plot, 1-0 and 2-0 bareroot white oak stock were planted at a spacing of 1.8 m by 1.8 m. Height and groundline diameter were measured seasonally, and incremental growth as a percentage of these metrics at the time of planting was analyzed using mixed effects models.

$$\text{Incremental growh} = \frac{(\text{Year 2 Size} - \text{Size initial})}{\text{Size initial}} \times 100 \quad [1]$$

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FINDINGS AND IMPLICATIONS

The analysis presented here summarizes growth after two complete growth seasons; hence 2- and 4-year weed control treatments were collapsed into a single treatment (i.e., weed control versus no weed control). Incremental height growth (HT) and groundline diameter growth (GLD) were significantly influenced by competition control (P_{HT} = 0.013, P_{GLD} <0.001) and canopy closure (P_{HT} <0.001, P_{GLD} <0.001). HT was greatest in untreated split-plots, and GLD was greatest in split-plots with competition control. Canopy closure impacted HT and GLD similarly, with both metrics at their greatest in areas of greater canopy openness (table 1).

Table 1—Average (± 1 standard error) incremental groundline diameter growth (GLD) and height growth (HT) as affected by overstory canopy closure

Canopy closure (%)	GLD (%)	HT (%)
0–25	66.7 ± 6.0	40.0 ± 5.1
25–50	61.8 ± 6.0	32.8 ± 5.7
50–75	43.2 ± 5.2	20.4 ± 5.1
75–100	33.3 ± 2.7	21.1 ± 2.6

Given that GLD is commonly utilized as a proxy for belowground growth, competition control likely improved the resilience of white oak to disturbances such as drought and surface fire. Underplanted white oak also grew most vigorously in group openings regardless of understory competition control. This contradicts Greenler and Saunders (2019) who indicated that natural white oak regeneration thrived in edge conditions, but was not unexpected given the higher resource levels in the opening. These resources, however, are fleeting as faster-growing competitors eventually make the environment light-limited for white oak (Lhotka and Stringer 2013). We suggest that midstory control and competition control should both be used to expand the zone where white oak can successfully compete in gap-based harvests.

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ACKNOWLEDGMENTS

We would like to thank Trent Osmon, Rob McGriff, and Rhett Steele for installation of the expanding group shelterwood harvests at NSWC-Crane. We thank David Mann for installation of the underplanted plots. Funding for this research was provided by the U.S. Department of the Navy through the Great

Lakes-Northern Forest Cooperative Ecosystem Studies Unit, the McIntire-Stennis Cooperative Forestry Research Program (project number IND00008276MS) and the Hardwood Tree Improvement and Regeneration Center.

Finally, we wish to acknowledge the traditional homelands of the Indigenous People that Purdue University is built upon. We honor and appreciate the Bodéwadmik (Potawatomi), Lenape (Delaware), Myaamia (Miami), and Shawnee People who are the original Indigenous caretakers. We recognize that all Indigenous caretakers had a fundamental impact on our eastern forest ecosystems that still reverberate through the forest's structure, function, and diversity today.

BEST PRACTICES FOR REGENERATION OF CALIFORNIA BLUE OAK (*QUERCUS DOUGLASII*)

Andrea L. Warner, Dustin K. Flavell, and Nikolas S. Schweitzer

PURPOSE AND SCOPE

In the 1900s, rangeland managers often cleared, removed, and burned trees from heavily wooded pastures to increase forage production for cattle grazing. Forestry and rangeland managers are now interested in restoring native rangeland. However, successful regeneration strategies for California blue oak (*Quercus douglasii*) are not well documented in scientific literature. The objective of this demonstration was to test and identify effective management strategies, including seedling source, shelter type, and vegetation control, for seedling growth and survival of California blue oak. This study was implemented to observe the most effective regeneration practices through annual monitoring and to develop a best practices module over time to share with community and industry stakeholders.

METHODS

Approximately 6,000 individual planting sites on 17.8 ha of previously cleared rangeland were prepared for this demonstration. Planting sites were spaced in rows 5.5 m apart and equipped with a gravity fed irrigation system to supply 2 L of water per hour once per month during the dry season. Acorns were harvested on site and stored until planting. Additionally, seedlings were procured from a local nursery to be planted during phase one. All seedlings and acorns were initially sheltered with a 46 cm plastic cone once planted. When seedlings exceeded the cone height, cones were removed, and the seedlings were placed into one of several shelters. Vegetation between and among tree rows was managed through herbicide application and mowing. Individual sites were monitored once per year, to assess survival of seedlings, shelter type, and seeding heights.

FINDINGS AND IMPLICATIONS

After 4 years of planting, maintenance, and data collection, approximately 64 percent of all seedlings survived. Although intensive, several management strategies tested appear to aid in the survival and success of blue oak seedlings. One of the primary setbacks to natural blue oak regeneration is predation by

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browsers, and small rodents (McCreary 1990). Implementing several varieties of shelter to young seedlings, including various Tubex (Tubex, South Wales, UK) and 4-foot-tall wire cages, provided protection for seedlings compared to cone shelters. Seedlings sheltered with a Tubex exhibited rapid vertical growth, and seedlings in a cone or cage appeared larger in diameter. The average height of a seedling sheltered in a Tubex was 1.5 m compared to 0.9 m when sheltered with a cage. In addition to shelter, vegetation management played a critical role in survival of the seedlings by decreasing habitat for small rodents around planting sites. However, 41 percent of overall seedling deaths (786 seedlings in 2023) were still attributed to gophers and voles. This demonstration has implications for landowners who are interested in restoring oaks on native rangeland and provides a starting point for management strategies in both small- and large-scale regeneration. The Sierra Foothill Research and Extension Center plans to execute additional oak regeneration projects at this site and utilize it as a hands-on space for workshops and demonstrations in the future.

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Pests, Pathogens, and Beneficial Microorganisms

SOIL FUNGAL RESPONSE INTERACTIONS WITH SEEDLING STOCK AGE ACROSS WHITE OAK (*QUERCUS ALBA*) OUTPLANTINGS IN KENTUCKY, TENNESSEE, AND ALABAMA, USA

Shawn P. Brown, Amira Noui, Richard Baird, Scott E. Schlarbaum, Callie Schweitzer, and Stacy L. Clark

PURPOSE AND SCOPE

Integration of soil fungal communities into white oak artificial regeneration studies can provide insight into growth success (Brown et al. 2022). Yet, little work has been conducted to understand the interrelationships between soil fungi, white oak outplanting success, and how this might be influenced by planting location and the age of seedling stock. The goal of this study was to investigate how white oak planting practices influence soil fungal dynamics. We implemented white oak outplanting experiments across three national forest sites (Daniel Boone National Forest [DBNF], KY; Cherokee National Forest [CNF], TN, and Bankhead National Forest [BNF], AL) in the Southeastern United States. These experiments included multiple white oak genetic families (half-siblings) that consisted of different seedling ages (1-0 and 2-0) but were planted concurrently.

METHODS AND APPROACH

As part of a lager study (planted February 2023), six trees from each genotype and seedling age were selected from three blocks in CNF and BNF and six blocks in DBNF and root associated soils (5-cm depth) were collected twice during the first growing season (April and July 2023). Soil genomic DNA was extracted and metabarcoding of the fungal ITS2 region of the rDNA operon was conducted and sequenced using Illumina MiSeq. Sequences were processed the program mothur (Schloss et al. 2009). We estimated relative operational taxonomic unit (OTU) richness and Shannon's diversity (2,000 sequences per sample for 1,000 iterations). We tested if richness and diversity were impacted by outplanting locations and seedling stock age by using a two-way analysis of variance (ANOVA) separately for each of the sampling events (April and July). We used

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permutational multivariate ANOVA (PerMANOVA) to test if fungal community structure (Jaccard similarity index) differed between location, stock age, and their interaction.

FINDINGS AND IMPLICATIONS

We found that fungal OTU richness and diversity was significantly different in our model for April sampling ($F_{5,187}$ = 5.65, P <0.001 and $F_{5,187}$ = 3.77, P = 0.003, respectively; table 1) with location being the only significant factor (stock age and stock age x location being nonsignificant). Bankhead National Forest samples had on average 20.3 and 33.5 percent more OTUs than DBNF and CNF, respectively. For July sampling, approximately 6 months after planting, fungal OTU richness and diversity responded to our model ($F_{5,264}$ = 2.38, P = 0.041 and $F_{5,264}$ = 5.81, P <0.001, respectively). Seedling stock age was the only significant factor for richness with 1-0 seedling having on average 18.5 percent more OTUs than 2-0 seedlings. Diversity, stock age, location, and stock age x location interaction all differed in our model. Further, our PerMANOVA test indicated that fungal community structure differed across locations ($F_{2,268}$ = 12.617, P <0.001), and by seedling stock age ($F_{1,268}$ = 12.617, P = 0.011), but not by the location x stock age interaction ($F_{2,268}$ = 1.093, P = 0.161).

Table 1—Mean ± standard error values for fungal operational taxonomic unit richness and Shannon's diversity (H') estimates of white oak-associated soil fungi

Model factor		Sampling	Richness	Diversity (H')
Location	**Bankhead National Forest, AL**	April	137.91 ± 4.46A	3.19 ± 0.05A
	Cherokee National Forest, TN	April	102.81 ± 6.12B	2.85 ± 0.07B
	Daniel Boone National Forest, KY	April	114.26 ± 3.88B	3.01 ± 0.04B
Seedling stock type	**1-0**	April	122.34 ± 3.91	3.08 ± 0.05
	2-0	April	118.47 ± 4.11	3.01 ± 0.05
Location	**Bankhead National Forest, AL**	July	135.94 ± 5.11	3.27 ± 0.06A
	Cherokee National Forest, TN	July	133.81 ± 6.12	3.02 ± 0.07B
	Daniel Boone National Forest, KY	July	135.94 ± 7.27	2.99 ± 0.08B
Seedling stock type	**1-0**	July	143.76 ± 6.06A	3.27 ± 0.07A
	2-0	July	126.49 ± 6.50B	3.07 ± 0.08B

Data are from 2023 outplantings.
Different letters represent significant differences for main factors according to Tukey HSD post hoc results; interaction terms not shown.

These findings suggest that white oak outplanting management strategies directly influence plant-associated soil fungal dynamics. This and previous work which showed little soil fungal differences in white oak soils (Brown et al. 2023) suggests that much more work is needed to understand drivers of oak-associated soil fungal dynamics. However, coupled plant management strategies and fungal community analyses can be an additional tool for white oak reforestation success.

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The authors thank the U.S. Department of Agriculture, Forest Service for funding (Award number 23-CS-11330170-060 to SPB). The authors thank Sedona Brown and Alexis Gallegos for their assistance in sampling and Tina Wadhwa and Jaia Craig for their assistance with molecular work.

OAK PROCESSIONARY MOTH (*THAUMETOPOEA PROCESSIONEA*)—HAZARD ASSESSMENT AND DECISION SUPPORT FOR MANAGEMENT

Paula Halbig, Anne-Sophie Stelzer, Peter Baier, Josef Pennerstorfer, Horst Delb, and Axel Schopf

PURPOSE AND SCOPE

Outbreaks of oak processionary moth (OPM, *Thaumetopoea processionea*) threaten the vitality of oak (*Quercus* spp.) trees through defoliation and endanger human and animal health due to the release of urticating hairs (setae) by larvae. Since about 1990, the occurrence of OPM has increased in forests and urban areas of central Europe. OPM was accidentally introduced into the United Kingdom in 2005 and is currently spreading in the southeast of England. Climate change and shifts in land use may trigger higher abundances and range expansions of OPM in the future (Godefroid et al. 2020). Levels of tree defoliation due to OPM infestation generally increase during late spring and early summer, as do health hazards because numbers of setae per larva increase from the 3rd to 6th instar (L3–L6). This requires development of an effective integrated pest management program for OPM to avoid oak decline and setae accumulation. For hazard assessment and decision support, an online early warning system "PHENTHAUproc—phenology modelling of *Thaumetopoea processionea*" was created in the early 2020s. In addition, the setae contamination potential emanating from OPM larvae and OPM-infested trees, as well as the *in-situ* spatiotemporal pollution by airborne OPM setae, were quantified.

METHODS AND APPROACH

PHENTHAUproc was created by combining existing temperature-based phenology models for OPM larval hatching and leaf unfolding of two host trees, *Quercus robur* and *Q. petraea*, with new models for OPM development and oak bud swelling. To predict the development of OPM stages from larval hatching

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to eclosion, a linear mixed effects model was generated based on data from OPM reared in the laboratory under constant temperatures (14 to 28 °C) during a 5-year period. Moreover, a model for *Q. robur* bud swelling was created for the first time, based on field observations. The existing and new models were validated by means of field data from different sites and years in southwest and northeast Germany.

In further studies, besides the development of PHENTHAUproc, the number of setae per OPM larva was determined by use of scanning electron microscope (SEM) photos, and the setae contamination potential of whole infested trees was extrapolated. In addition, passive samplers and volumetric samplers were used to assess the airborne distribution of OPM setae in the field.

FINDINGS AND IMPLICATIONS

PHENTHAUproc provides phenological forecasts at local and regional levels (i.e., for weather station locations and grid maps), as well as recommendations for OPM control, such as the use of biological insecticides or mechanical measures. An exemplary prototype of the early warning system was created for Germany (fig. 1, Halbig et al. 2024). Furthermore, the free R software package "PHENTHAUproc" was developed including all algorithms (Bachfischer 2024). The models can be used anywhere in Central Europe for OPM hazard assessment as soon as air temperature data and information on potential adaptations of OPM to local climate and changes in host tree phenology are available. Starting in 2025, the early warning system will be provided as a free web application with daily updates for all of Germany in 1-km by 1-km resolution by the German Meteorological Service (DWD). Besides integrating the weather forecast for 7 days, the phenological predictions are supplemented by *in situ* observations of oak bud swelling and leaf unfolding to determine optimal timing of control measures and responses.

The additional studies on setae contamination potential revealed that several billion setae per infested tree is common during OPM outbreaks. Airborne setae distribution ranged up to hundreds of meters from the source tree. These findings and tools help ensure the integrated management of OPM for forest health as well as human and animal health in Central Europe.

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ACKNOWLEDGMENTS

This work was supported by the Federal Ministry of Food and Agriculture (BMEL) and the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV), Germany (grant ID numbers: 22WC409001, 371262203). We thank the FVA research assistants Shirin Masino,

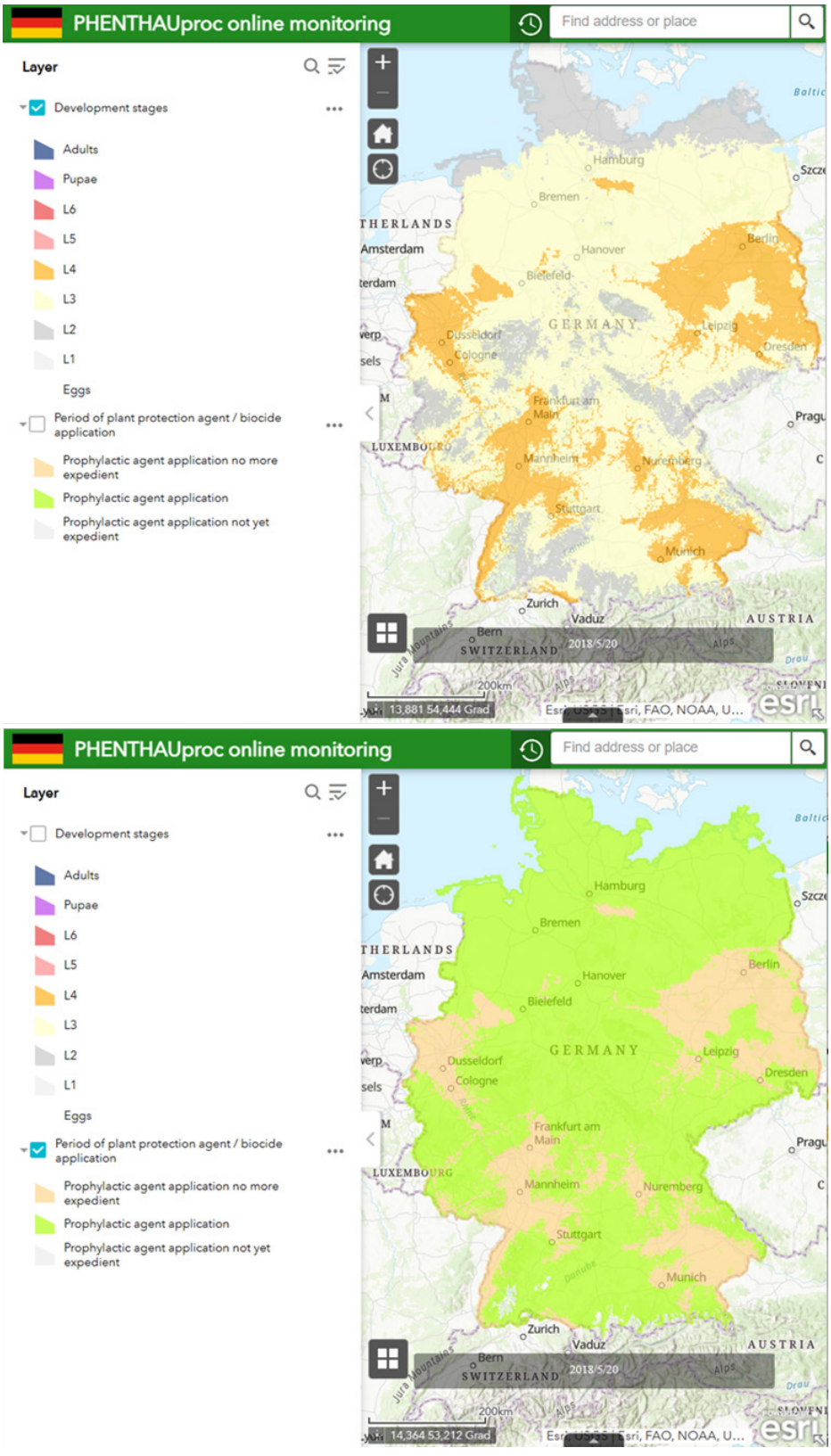

Figure 1—Screenshots of the web map service of the PHENTHAUproc prototype; (top) phenological development of oak processionary moth (*Thaumetopoea processionea*, OPM) on May 20, 2018 (layer "development stages" was selected) and (bottom) recommendation of preventive OPM control by means of plant protection agents or biocides on May 20, 2018 (layer "period of plant protection agent/biocide application" was selected). Available on BOKU University website for risk analyses: https://ifff-server.boku.ac.at/wordpress/index.php/phenthauproc-online-monitoring-2/project_info/. [Date accessed: 11 June 2024].

Daniel Zapf, and the technician Ricardo Rivero for supporting the laboratory and field studies. We further thank Peter Jork, Michael Noack, Matthias Kirsch, and Tanja Klasen from the local forestry commission offices Neustadt/Dosse and Brieselang, as well as our contractors Thomas Jäger and Peer Wischenkow from the company IFD-Industrie- & Forstdienste for providing OPM egg batches and phenological data from Brandenburg, Germany. They as well as Dörte Görtz, Thomas Weinkopf (formerly BOKU University), and Markus Hans Grabenhofer (formerly Medical University of Vienna, Austria) assisted in measuring the airborne OPM setae pollution in the field. Moreover, we thank Ottmar Fischer (Chair of Forest Entomology and Forest Protection, University of Freiburg, Germany) for taking the SEM-photos. Hubert Schmuck (National Forests Office, Sarrebourg, France) was instrumental in collecting OPM egg batches from Lorraine. For reviewing this manuscript, we thank Christopher J. Fettig (U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station) and Gernot Hoch (Austrian Research Centre for Forests).

FORWARDING DIAGNOSTICS AND MONITORING FOR THE OAK WILT PATHOGEN THROUGH DEVELOPMENT OF A LAMP ASSAY

Colton Meinecke, Andrew Loyd, Rhys Eshleman, Demian Gomez, and Caterina Villari

Oak wilt, caused by the fungal pathogen *Bretziella fagacearum*, is a destructive vascular disease of several oak species in the United States. Throughout the past decade, increased incidence and intensity of oak wilt outbreaks has been observed across the United States. Regular surveillance and detection of the oak wilt pathogen is essential in preventing and controlling outbreaks; however, there is currently a lack of rapid diagnostic methods for oak wilt. Symptoms of oak wilt are often hard to distinguish from other causes, and current conventional molecular methods of detection are unreliable and reliant on pathogen isolation. We propose an approach to oak wilt diagnostics using LAMP (loop-mediated isothermal amplification), which would resolve several of the current obstacles in oak wilt detection. LAMP can be performed in the field, does not require expensive laboratory equipment, and is faster than conventional polymerase chain reaction (PCR). Our assay can detect *B. fagacearum* in as fast as 11 minutes from multiple types of field samples with a sensitivity of as low as 1 pg of DNA. Additionally, the assay is highly specific, overcoming some of the cross-reaction issues associated with the nested PCR protocol. Finally, because it does not react with uninfected oak DNA, the assay can be used directly on the host plant tissues, without the need for prior pathogen isolation. We hope this assay will serve as a rapid, accurate, and accessible diagnostic tool to assist in managing and preventing oak wilt.

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MOLECULAR DETECTION OF OAK WILT PATHOGEN BY PAIRING TAQMAN PROBES WITH AN INEXPENSIVE BLUE-FLASHLIGHT

Meher A. Ony, Grace Pietsch, Monique L. Sakalidis, William E. Klingeman, Meg Staton, and Denita Hadziabdic

Oak wilt (OW) is a vascular wilt disease caused by the fungal pathogen *Bretziella fagacearum* (Bf) and vectored by sap beetles (Coleoptera: Nitidulidae). It is lethal to many species of oaks, with high susceptibility in red oaks (*Quercus* section *Lobatae*) and intermediate susceptibility in live oaks (*Quercus* section *Virentes*). Infected trees die within weeks or months due to vascular girdling, likely by overproduction of tyloses and fungal exudates and mycelium following infection. Current screening methods lack sensitivity to detect Bf from mixed host tissue and vector samples, leading to false negative reports particularly when the OW titer is low. We have developed a cost-effective and highly sensitive OW detection method easily visualized and interpreted by end-users with limited training. A custom microsatellite-based TaqMan probe enables quantitative polymerase chain reaction (qPCR) as well as conventional PCR amplification with an inexpensive blue flashlight that illuminates positive PCR amplifications, avoiding a costly qPCR program. Primer and probe pair sensitivity using pure Bf DNA was 0.008 ng/uL and 0.04 ng/uL using qPCR and conventional PCR, respectively. The sensitivity of this new tool also was validated by detection of Bf DNA from asymptomatic oak trees at early stages of infection and by screening insect vectors collected from oak wilt-positive locations. These tools will provide direct benefits for local, State, and Federal officials to engage in early detection and monitoring.

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ERYTHMELUS KLOPOMOR—PROMISING CANDIDATE FOR CLASSICAL BIOLOGICAL CONTROL AGAINST THE INVASIVE OAK LACE BUG

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PURPOSE AND SCOPE

The North American oak lace bug (OLB, *Corythucha arcuata*) is a potentially very dangerous invasive pest of European oaks. It was first detected in Europe in 2000 and in Hungary in 2013, and currently occurs in 26 countries. Most Eurasian deciduous oaks are suitable host plants, therefore about 30 million ha of oak-dominated forests in Europe can facilitate its rapid spread. Its negative effects can be very diverse: decreasing photosynthetic activity, deteriorating health, decreasing acorn yield, negative effect on other oak herbivorous insects, and more (Kern et al. 2021, Paulin et al. 2020). One of the main reasons for its rapid expansion and mass proliferation is that native European predators and insect pathogens are unable to control it (Csóka et al. 2009). The only control option is a classical biological control program, the essence of which is to find and introduce a specialist regulatory species that is effective in the pest's native range.

METHODS AND APPROACH

In the first half of July 2023, we collected oak leaves with OLB egg bunches from 13 different locations in five States of the United States. Leaves collected were first observed, and only further processed if a large percentage of unhatched eggs was found. The leaf parts with the egg bunches were cut, producing approximately 2-cm by 2-cm pieces. These were then put into transparent 25-ml containers, with a piece of paper tissue, held at room temperature and checked every day for emergence. Parasitoids emerged on the same day were collected and put into 2-ml Eppendorf tubes with 90 percent ethanol, for identification later. Checking continued until late August; data collected were the location and time of sampling, and number of parasitoids and their time of emergence. Individual eggs of bunches with parasitoids were also counted, to produce a parasitism rate for these samples.

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FINDINGS AND IMPLICATIONS

In the field our initial observation was that collecting OLB eggs proved more challenging than we first assumed. In 13 locations we were only able to collect a total of 400 egg masses as samples. They were close to natural habitats, in which we found only a handful of OLB-infested leaves. Our largest samples were collected in or near urban areas. Results showed that almost a quarter of the samples were parasitized.

Based on the information so far, the egg parasitoid, *Erythmelus klopomor* (Hymenoptera: Mymaridae), is the most suitable candidate for a biological control program against OLB. This is based on the following aspects: it is a specialist parasitoid of lace bugs, reproduces parthenogenetically, and is multivoltine with a short life cycle. It can also be found in different climatic conditions and can be collected en masse in its native area of distribution.

Our results also indicate that the presence of a resident parasitoid is the most likely factor of low OLB numbers in its native range. Further studies of this parasitoid are planned, to understand its ecology better. For example, experiments on overwintering habits, parasitism rates throughout the vegetative season, and host specificity are all studies that will form the cornerstones of this species' suitability as a biological control agent.

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ACKNOWLEDGMENTS

We would like to thank the following colleagues for helping us out in the field: Warren and Chris Abrahamson, Matt Buffington, Eric Day, Kim Hoelmer, Sandy Liebhold, Gino Luzader, Carol Mapes, Laura Miller, and Michael Joseph Skvarla. Our research was funded from project 'K 142858', implemented with the support of the Ministry of Innovation and Technology of Hungary from the National Research, Development and Innovation Fund, financed under the 'K22-OTKA' funding scheme.

PUTTING A NEW SPIN ON AN OLD DISEASE: USING MOLECULAR TOOLS TO IDENTIFY BEETLES CARRYING SPORES FROM THE OAK WILT FUNGUS IN GILLESPIE COUNTY, TEXAS, USA

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PURPOSE AND SCOPE

Oak wilt fungus, *Bretziella fagacearum* (Bf), affects oak populations in the Midwestern and Northeastern United States. Red oaks (*Quercus* subgenus *Erythrobalanus*) are most impacted by oak wilt, with mature trees declining and dying within one season. Bf also occurs in central Texas, infesting and killing live oaks (*Q. virginiana*), spreading through root grafts. Red oak species, such as Spanish oak (*Q. texana)* and blackjack oak (*Q. marilandica*), may form mycelial mats that attract nitidulid beetles (Coleoptera: Nitidulidae) that serve as vectors to aboveground spread across longer distances. Previous studies have identified nitidulid beetles associated with oak wilt infested areas (Appel et al. 1986), including *Cryptarcha concinna* and *Colopterus maculatus*. In prior work, beetles were assayed for Bf spores by crushing and growing fungi on culture (Appel et al. 1990). This method required time and space to grow identifiable cultures. Recent advances in pathogen testing by using molecular detection and improved protocols for quantitative polymerase chain reaction (qPCR) have decreased time requirements and increased diagnostic sensitivity. Our lab has developed Bf-specific simple sequence repeat (SSR) markers, which, when combined with a TaqMan probe, can be used with qPCR to screen beetles quickly for presence of fungal DNA.

METHODS AND APPROACH

Wind-orienting fermentation and lure-baited traps were deployed in an oak wilt-infested, wooded landscape in Gillespie County, TX from March 2022 to April 2024. Beetles were removed at 2-week intervals from traps, then frozen and shipped to The University of Tennessee, Knoxville. Thawed specimens were visually identified to species based on morphology. By date and trap, species

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were refrozen in vials until DNA was extracted. Individual beetles were placed in lysis buffer and sonicated to dislodge fungal structures from the beetle body surface. Extracted DNA was assayed using novel Bf-specific SSR markers with a TaqMan probe developed in our lab using qPCR. Because of small amounts of recovered pathogen DNA and high fungal species specificity enabled by the SSR marker, beetles were considered positive for the fungus if at least one of three replications amplified.

FINDINGS AND IMPLICATIONS

Screening beetles in advance of finding mycelial mats in a forest or urban landscape can give managers and integrated pest management scouts advance warning that Bf inoculum is present. Our study site had been heavily impacted by oak wilt, so we expected to find evidence of fungal spores associated with bodies of sap beetle species. Eleven different sap beetle species and one bark beetle were captured in baited wind traps. Across seasons, the most abundant beetles were *Carpophilus mutilatus* followed by *Colopterus maculatus, Cryptarcha concinna*, and *Carpophilus sayi* and a few *Colopterus truncatus*. Beetles were captured from March through May, and then from October through November. Similarly, Appel et al. (1986) found peak flight times of sap beetles in Texas occurring from February through June with little or no beetles captured from November through January.

From the more than 300 body wash samples from sap beetles that we have assayed over 2 years, six species tested positive for Bf DNA presence (table 1). Most beetles were captured from March through May 2022, which corresponds with expected timing of mycelial mat formation in Texas (Appel et al. 1987). So far, no beetle species have tested positive in 2023 or 2024, even during expected peak mat formation. These negative results could indicate that new mats did not form on oaks in the area during the past 2 years. Consequently, in years when peak flight times of sap beetle species correspond with mycelial mat formation, sap beetles are most likely to associate with Bf inoculum that may be transmitted to new oak trees.

Table 1—Sap beetle species (Colopterus: Nitidulidae) that were tested for *Bretziella fagacearum* DNA

Sap beetle species	Positive qPCR results			Total beetles	Collection dates from positive results
	3 of 3	2 of 3	1 of 3		
Carpophilus corticinus	0	1	0	7	Apr. 5, 2022
Carpophilus mutilatus	2	6	16	207	Apr. 5, 2022; Apr. 21, 2022; May 5, 2022; July 27, 2022; Nov. 2, 2022
Carpophilus sayi	2	2	2	22	Apr. 5, 2022; Apr. 21, 2022
Colopterus maculatus	0	1	0	36	Apr. 5, 2022
Colopterus truncatus	3	1	1	17	Apr. 5, 2022
Cryptarcha concinna	2	0	1	26	Apr. 5, 2022
Other species[1]	0	0	0	11	
Total	9	11	20	326	

Samples were tested in triplicate and considered positive if the base threshold was reached.

[1] includes specimens of *Carpophilus hemipterus*, *Colopterus unicolor, Cryptarcha strigulata*, *Lobiopa undulata*, and *Phenolia grossa*, as well as a *Xylobiops basalaris* bark beetle (Coleoptera: Bostrichidae).

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ACKNOWLEDGMENTS

This work was partially supported with funding and resources from U.S. Department of Agriculture, National Institute of Food and Agriculture CPPM Project TEN2020-07421, NIFA Hatch Project #7002511 (TEN00600) *IPM and Sustainable Strategies for Arthropod Pests and Plant Diseases in Nurseries, Managed Landscapes and Urban Forests*, and UTIA AgResearch. We appreciate in-field support provided by Kalyn Petsch and McKayla McIntosh (in Texas), and field and lab support from Gaige Lariscy, Anji Reyes, and Axel Gonzalez Murillo (in Tennessee).

Ecological Dynamics

ESTABLISHMENT OF OAKS AFTER WILDFIRE DEPENDS ON FIRE INTENSITY

Jennifer Franklin and Matthew Aldrovandi

There is abundant evidence that fire is important in the maintenance of oak species in hardwood forests of the Eastern United States, and prescribed fire is commonly used as a tool to promote oak regeneration. Many of the oak species that occur in the region have traits that are characteristic of fire-adapted species, such as thick bark and the ability to produce sprouts from the root collar. Although the effects of fire on oak establishment have been studied for decades, research findings are often contradictory, likely due the wide range of variables involved. We measured oak establishment in the Great Smoky Mountains National Park in 2018, approximately 20 months after a wildfire, and again in 2022. Ten plots covered a range of fire severity from very low to very high, and these were compared to eight unburned controls in nearby areas. The majority of oaks present were northern red oak (*Quercus rubra*), chestnut oak (*Q. prinus*), and black oak (*Q. velutina*). Establishment in the areas burned at a low or moderate severity was primarily from seed, though oaks established from both seed and sprouts in severely burned areas. In 2022, oak density and recruitment into the 1-m height class was greater in all burned areas than in unburned control plots. Thus at lower fire severities oaks are likely to suffer minimal injury and act as seed sources in the following years, and their ability to produce fast growing sprouts upon the death of the main stem is beneficial in establishment after severe fires.

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MASTING DYNAMICS OF BOTTOMLAND OAKS IN THE MISSISSIPPI ALLUVIAL VALLEY, USA

Emile S. Gardiner

PURPOSE AND SCOPE

The biological process of masting is foundational to the ecology and silviculture of oaks (*Quercus* spp.) and oak-dominated forests. Limited knowledge on the masting dynamics of the bottomland oaks impedes informed decisionmaking for rehabilitation of degraded oak stands and sustainable management of healthy, oak-dominated stands in floodplains across the Southern United States. A 5-year study on acorn production by two key species, Nuttall oak (*Q. texana*) and willow oak (*Q. phellos*), was conducted in the Mississippi Alluvial Valley to assess masting dynamics of mature, bottomland oaks at four different locations.

METHODS AND APPROACH

In 2012, mature bottomland oak stands with strong Nuttall and willow oak canopy components were selected for study in the Delta National Forest in Sharkey County, MS, Dahomey National Wildlife Refuge in Bolivar County, MS; Cut-Off Creek Wildlife Management Area in Drew County, AR; and Sheffield Nelson Dagmar Wildlife Management Area in Monroe County, AR. At each location, 35 trees per species were chosen as sample trees and assigned seed traps relative to total ground area covered by the canopy. All acorns were collected from seed traps over the course of each collection year and processed into categories of maturation and viability. After 5 years of observation (2013 to 2018), repeated measures analysis of variance was used to test for fixed effects and interaction on variables of acorn count and condition to assess interannual acorn production and acorn fate among locations and for individual trees.

FINDINGS AND IMPLICATIONS

Mean annual total acorn production in both species was affected by year at all locations ($P \leq 0.012$), but synchronous acorn production among locations and species within locations was not consistently observed. In other words, the level of acorn production observed each year for either Nuttall oak or willow oak was specific to the location.

Immature acorns shed in various stages of underdevelopment comprised the greatest proportion of mean annual total acorn production. For all sites, Nuttall oak shed a greater percentage of immature acorns than willow oak ($P \leq 0.00154$). Percentages of shed immature acorns averaged across year for each location ranged between 61 ±2 percent (mean ±standard error) and 85 ±2 percent for Nuttall oak, and 47 ±6 percent and 80 ±3 percent for willow oak.

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In each collection year, 7 to 10 of the 35 sample trees for each species produced ≥50 percent of the mature acorns at a location. Fewer than half of these trees typically showed an annual acorn production sufficient to remain in this subset for all 5 collection years.

Results illustrate the temporal and geographic complexities of bottomland oak masting at species, tree, and stand levels. These observations highlight the unpredictable nature of oak masting and imply that managers aiming to promote natural regeneration of bottomland oak stands will need to monitor mast development in target stands and incorporate flexibility into scheduling stand entry activities that are used to encourage germination and seedling establishment.

ACKNOWLEDGMENTS

This work was conceived and initiated by Tracy Hawkins. Shelley Griffin, Rory Thornton, and Justin Williams worked tirelessly to establish and maintain the sampling grid and process acorn collections.

PRESCRIBED FIRE IMPROVES RED OAK (*QUERCUS RUBRA*) REGENERATION IN NORTHERN NEW HAMPSHIRE

Khanh Ton, Matt Vadeboncoeur, Nat Cleavitt, Abigail Powell, and Heidi Asbjornsen

PURPOSE AND SCOPE

Quercus rubra currently faces many regeneration problems in the Northeastern United States, with further uncertainties as climate change expands its potential range northward (Iverson et al. 2019). It has been hypothesized that prescribed fire might be the answer (Abrams 1992). Fire has been integral to upland oak systems in the Eastern United States for millennia. Over time, *Q. rubra* became more adapted to a periodic fire regime than other hardwoods and, as a result, can take advantage of the postfire environment. However, fire suppression became mainstream policy in the 1920s and promoted forest mesophication (Nowacki and Abrams 2008). As the eastern landscape becomes wetter and shadier, mesic microenvironmental conditions improve and favor the regeneration of shade-tolerant species. This positive feedback loop further shrinks suitable habitats for *Q. rubra* over time. Therefore, bringing back fire in a controlled manner to reverse the feedback loop may help restore upland oak ecosystems (Abrams 1992).

METHODS AND APPROACH

In summer 2023, 43 transects were established in 6 pairs of burned and control study stands across the White Mountains, including a total of 393 plots. Along each transect 1-m^2 plots were spaced 10 m apart from their centers. Woody species <2 cm in diameter at breast height (d.b.h.) were identified, and their stems counted. Oak seedlings were tagged, aged, measured for height and diameter at root collar, and checked for herbivory and pathogen damage. Within the 5-m radius of each quadrat, trees >2 cm d.b.h. were identified and measured, and oak seedlings were counted. Seedlings continue to be monitored, along with soil analysis and leaf area index measurements. We also established a mesocosm experiment, in which acorns were planted in soil collected from the wildfire stand and its paired control, to separate the mechanisms facilitated by the fire-altered soil.

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FINDINGS AND IMPLICATIONS

In burned stands, red oak (*Q. rubra*) mainly competes with early successional seedlings such as raspberries (*Rubus* spp.), pin cherry (*Prunus pensylvanica*), birches (*Betula* spp.), and stump sprouts of beech (*Fagus grandifolia*) and red maple (*Acer rubrum*). In control stands, species reflect tree composition particular to the sites including ash (*Fraxinus* spp.), sugar maple (*Acer saccharum*), and hophornbeam (Ostrya virginiana). Oak seedling density increased threefold in burned stands (30 ±2 per ha) relative to control stands (9 ±2 per ha) (P <0.0001). Diameter at root collar was greater for seedlings in burned stands (4.51 ±0.46 mm) versus control stands (3.35 ±0.54 mm) (P = 0.01) (fig. 1). Oak germination rates rose substantially during at least the 3 years following the burns. In the mesocosm experiment, fastest seedling growth was observed in unsterilized soil from the burned stand.

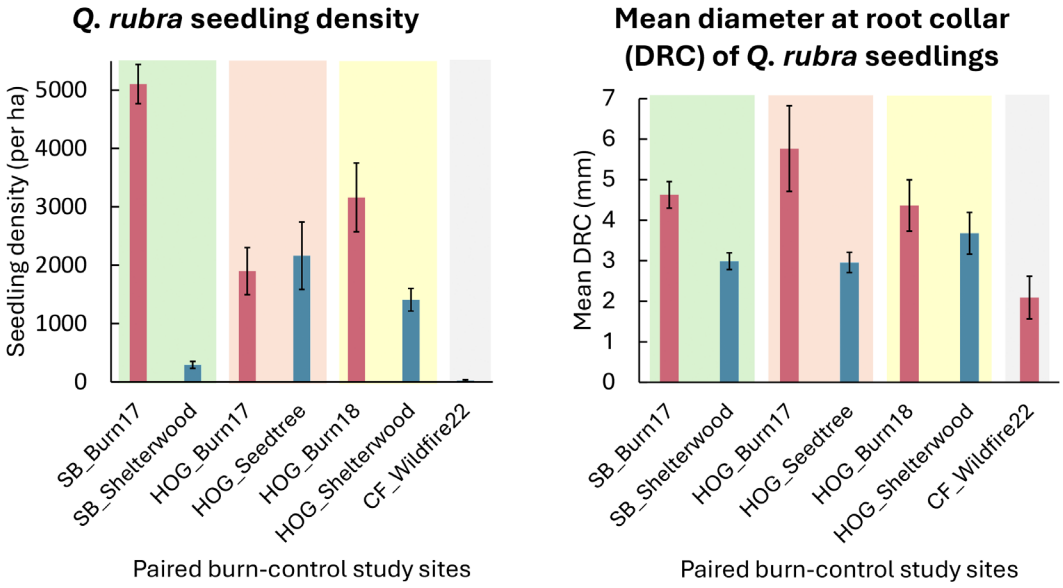

Figure 1—Oak seedling density and mean diameter at root collar (DRC) in Stevens Brook (SB), Hogsback (HOG), and Crawford Notch (CF). Error bars represent +1 standard error from the mean.

Our preliminary results show promise that fire plays a unique role in advancing oak regeneration. Seedlings were more abundant and greater in size in burned stands, where heavy recruitment was observed in the first 3 years since the burns. Potted seedlings similarly matched this trend with higher growth rates, suggesting fire alteration of soil properties, whether physical, chemical, or biological, may help promote oak establishment and recruitment in the northern hardwoods of New Hampshire.

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ACKNOWLEDGMENTS

The authors thank the Northeastern States Research Cooperative for funding this project, John Neely and Erin Lane from the U.S. Department of Agriculture, Forest Service for their knowledge and expertise, and summer 2023 and 2024 technicians for helping with data collection.

Woodland and Forest Restoration

LAND RESTORATION AFTER A BIG FIRE EVENT: OAKS VERSUS PINES

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Galicia in the European Union (EU) has the highest incidence of fire in the region, and approximately 1.65 million ha of Galicia (55 percent) burned in the last four decades. Recovery of burned areas is one of the aims of the Galician Government to restore degraded land. Galicia is heavily influenced by the Gulf Stream, and temperatures are higher than found at similar latitudes (e.g., New York) in the Northern Hemisphere. Two EU projects, namely LIFE-VAIA (Value Afforestation of damaged woods with innovative agroforestry [LIFE20 CCA/IT/001630]) and LIFE-SILFORE (LIFE21-CCA-ES-LIFE SILFORE/101074445), were conducted to examine how restoration should be conducted by forest owners. The LIFE-VAIA project analyzed the evolution of 11 forest species, including 4 oaks adapted to Mediterranean (*Quercus ilex*, *Q. suber*), Atlantic (*Q. robur*), or transitional (*Q. pyrenaica*) areas in the Monte de los Remedios in Quiroga. The other forest species tested were broadleaves (*Castanea sativa*, *Sorubus aria*, *Betula alba*, *Acer pseudoplatanus*, and *Prunus avium*) and one conifer (*Pinus pinaster*). Mediterranean performed worse than Atlantic or transitional oaks, probably due to the low amount of calcium in the soil and the soil pH. The LIFE-SILFORE project addressed the conservation and management of resilient agroforestry systems through silvopasture to examine how *Q. robur* and *P. pinaster* can establish after a forest fire. The main experiment in Galicia combined a set of treatments linked with the addition of fertilizers (different doses of rabbit [fermented or not] and horse manure), organic amendments (pruned oak residues and straw) and legume sowing (*Trifolium repens* and *Lotus corniculatus*). Results showed that the survival and growth of oak was improved when the rabbit fermented manure was applied, oak residues were applied, and legume was sown.

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EVALUATION OF COMMON SILVICULTURAL PRACTICES ON THE SURVIVAL AND GROWTH OF WILLOW OAK (*QUERCUS PHELLOS*) ON OLD FIELD AGRICULTURAL SITES

Jason Steele, W. Michael Aust, and John Seiler

Due to their timber and wildlife value, oak species are desired for bottomland hardwood restoration and are a desirable species for afforestation of old field agricultural areas. However, establishment efforts for oak species on old field restoration sites have varied in success. Survival and growth of planted oaks are typically critical indices used to evaluate success of ecological restoration efforts. In order to evaluate techniques that could potentially enhance oak survival and growth, this study was implemented to evaluate five mechanical site preparation techniques (mound, bed, rip, disk, pit), four types of planting stock (gallon, tubeling, bare root, direct seed), and three planting aids (mat, tube, none) on survival and growth of willow oak (*Quercus phellos*) planted on an old field riparian area in the Piedmont of Virginia. Mounding mechanical site preparation techniques had over 25 percent greater survival, 75 percent greater tree height, and over 20 percent greater groundline diameter compared to disking, ripping, and bedding. Bare root and gallon planting stock survival rates exceeded 80 percent, and gallon or bare root planting stock and growth indices outpaced direct seed and tubeling stock by 75 percent. These treatments may increase the economic incentives for ecological restoration and make restoration efforts in marginal old field areas more attractive to landowners.

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Healthy Forests

URBAN SILVICULTURE STRATEGIES FOR OAK FORESTS: DIRECT PLANTING IN EXISTING AND IMMINENT CANOPY GAPS IN OAK-BEECH FORESTS

J. Bower, M.R. Piana, A. Reinmann, R. Hallett, L. DeWald, and T.L.E. Trammell

Forests in cities are a common and abundant resource that are socially and ecologically important, especially in the Northeastern United States, the most densely populated region of the country. Oak forests are the most common forest type across this region and a priority for municipal forest managers. The management challenges of these forests are similar to rural analogs, although the stressors are often co-occurring and exacerbated due to the urban social-ecological context. A particular challenge in managing oak in cities are constraints with implementing traditional oak silviculture (i.e., felling trees, shelterwoods) due to local ordinances that limit tree removal, as well as public perception. In 2020, we convened the Urban Silviculture Network to develop, study, and implement alternative management strategies for sustaining our urban oak forests. Here, we present a newly implemented study that leverages naturally existing and imminent canopy gaps in forests. With the introduction of beech leaf disease to the region, we identified an opportunity to test direct planting strategies and accelerate stand reinitiation in advance of canopy openings. The decline of mature forest from pests and pathogens is a threat to forests but may also be an opportunity for shade-intolerant species, like oak. Collectively, this research combines multiple threads of inquiry, including oak progeny study, the utility of direct planting in varied light and gap conditions, and the interaction between management strategies, including planting strategy and deer exclusion. Though conducted in cities, these approaches may scale up across the urban-rural continuum of eastern deciduous forest.

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CENTRAL EUROPEAN OAKS (*QUERCUS ROBUR* AND *Q. PETREA*) FROM A FOREST HEALTH PERSPECTIVE USING THE EXAMPLE OF SOUTHWESTERN GERMANY

Horst Delb and Jörg Grüner

PURPOSE AND SCOPE

In Central Europe, pedunculate and sessile oaks (*Quercus robur* and *Q. petraea*) are the most important oak species in forestry. They were widely promoted in the Middle Ages as coppice or sprout-seedling forests. This was mainly because of their value in pig husbandry (via acorn production) and for the production of tannin bark, firewood, or construction lumber. As a result, pedunculate and sessile oaks were widely cultivated in places outside their native ranges. Today, however, these species are highly prized for their lumber, barrel wood, and very valuable veneers.

Pedunculate and sessile oaks are widely distributed throughout the oceanic, continental, and sub-Mediterranean regions of Europe. Due to their wide climatic adaptation, they are considered to be of great importance in the context of climate change. However, it is important to be aware of the health risks to which pedunculate and sessile oaks are susceptible, which are known from several recent epidemics in Central Europe.

METHODS AND APPROACH

Oak health and mortality of oaks were inferred from crown condition surveys and by accounting for oaks from sanitation measures or salvage following disturbance. Subsequent cause and effect analyses considered data from forest pest and disease surveys, which consists of geospatial reports on pest and disease occurrence, as well as regular forest pest monitoring. Geospatial reports and timber records were collected by local foresters, and the other data were collected by the Forest Research Institute of Baden-Wuerttemberg. Climate data from the German Meteorological Service were also taken into account.

FINDINGS AND IMPLICATIONS

The last period of oak decline with significant widespread dieback occurred in the 1990s through the early 2000s. Therefore, the various potential insect pest

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and disease factors are well known. The physiology of oaks as ring-porous species plays a significant role in their susceptibility (e.g., Thomas et al. 2002).

Extreme weather conditions and in particular foliage-damaging biotic factors, especially defoliating insects and subsequent oak powdery mildew fungi (*Erysiphe alphitoides*), were important inciting factors. Notable defoliating insects include spongy moth (*Lymantria dispar*), winter moth (*Operophtera brumata*), and oak processionary moth (*Thaumetopoea processionea*). Bark-breeding beetles and various fungi, especially the oak buprestid beetle (*Agrilus biguttatus*) and honey fungus (*Armillaria* spp.), often colonized oaks weakened by other factors. The most prominent losses of oaks in southwestern Germany occurred after spongy moth defoliation, which, depending on site and weather conditions, facilitated mass outbreaks of the oak buprestid beetle as the main contributing factor (fig. 1).

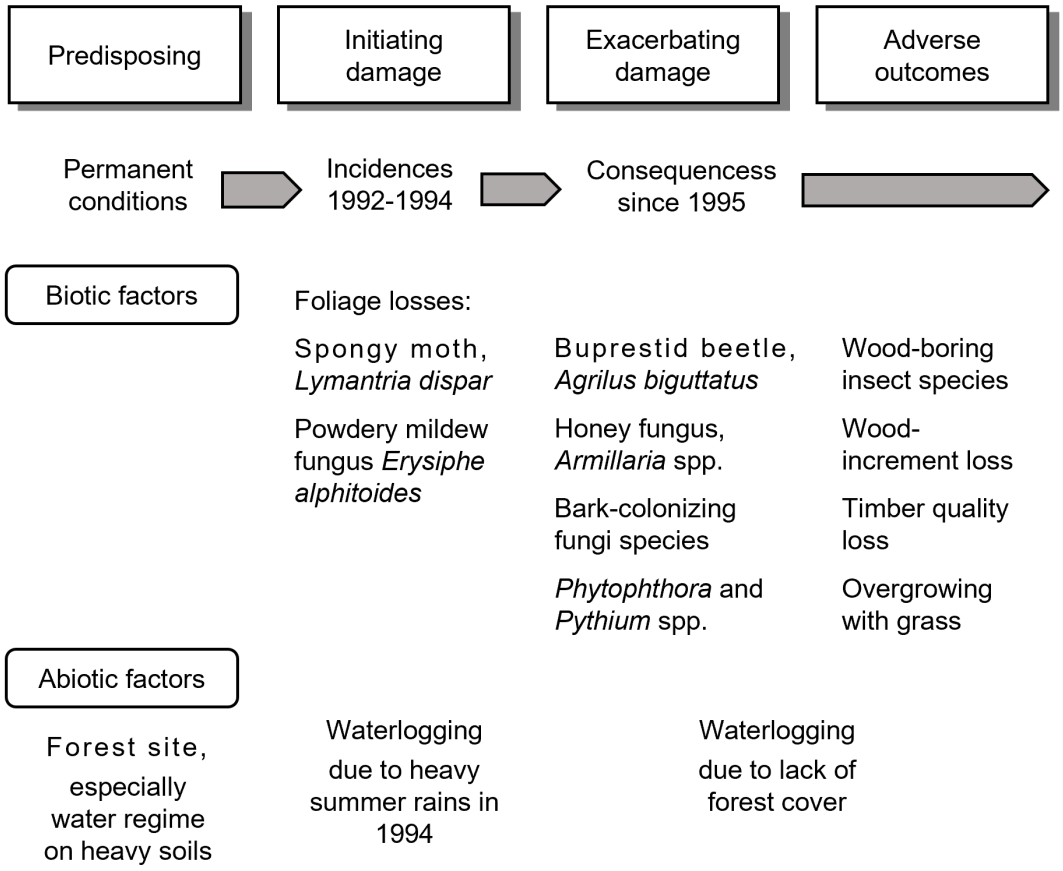

Figure 1—Damaging factors of oak dieback due to spongy moth calamity in the Bienwald Forest, Upper Rhine Valley, Germany (from Delb and Block 1999).

Control of defoliating insects, such as spongy or winter moth, may reduce levels of oak defoliation. However, the current prolonged drought represents a new challenge because it has also become a major inciting factor. Sanitation harvests are now used to contain the spread of the oak buprestid beetle, a crucial contributing factor.

It is important to learn more about the physiology and susceptibility of oaks to different stressors and disturbances, especially those likely to be exacerbated by climate change (e.g., drought and warming). The same is true for pest biology. For example, recent research on oak processionary moth suggests a possible

increased temporal mismatch between egg hatching and bud burst of host plants due to climate change, which could lead to its decline as a consequence of warming. However, this has not yet been confirmed in southwestern Germany (Wagenhoff et al. 2014).

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ACKNOWLEDGMENTS

We thank Christopher J. Fettig (U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station) and Rainer Hurling (Department of Forest Protection, Northwest German Forest Research Institute) for their reviews.

TREE DAMAGE AND MORTALITY FOLLOWING WILDFIRE AND PRESCRIBED FIRE IN LONG UNBURNED MIXED OAK-PINE FORESTS

Kathleen Gabler, Heather D. Alexander, Geoff Sorrell, and Steve Trull

Intentionally excluding fire from fire-dependent mixed oak-pine forests in the Southeastern United States has dramatically changed forest composition and structure. In long-unburned stands, duff (Oe and Oa soil horizons) accumulation is greater than in frequently burned stands. When ignited, duff can smolder for long periods, contributing to tree mortality through cambial injury, fine root death, and susceptibility to other stresses. We present wildfire and prescribed fire data from two sites in northeast Alabama investigating fire effects along a mesophyte to pyrophyte gradient using measurements of duff accumulation, consumption patterns, and tree mortality. At each site, we established permanent transects at three slope positions, included trees >10 cm diameter at breast height (d.b.h.), and installed duff pins for repeated measurements. Prior to prescribed fire, duff accumulations were greatest at the base of *Pinus palustris*, and immediately adjacent to other pine species. Upland *Quercus* species, and all hardwood dominated stands showed little accumulation of duff. Postfire consumption in the prescribed fire sites is currently being sampled. Post wildfire, the remaining duff was patchy, with greatest consumption and measures of fire severity (extent of charring on the stem and crown damage) around *Pinus palustris* bases. Upland *Quercus* and other fire tolerant hardwoods exhibit limited postfire injury compared to pine species. However, when *Quercus* individuals are near *Pinus* individuals, they can potentially experience increased rates of injury. Reintroduction of fire continues to require special consideration to mitigate mortality for not only pines, but any species exposed to large accumulations of duff.

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A TALE OF TWO OUTBREAKS: ARE OAK POPULATIONS BECOMING MORE VULNERABLE TO INSECT OUTBREAKS AND CLIMATE STRESS IN CENTRAL MASSACHUSETTS, USA?

Audrey Barker Plotkin, Brian Keeven, and Jaclyn Hatala Matthes

PURPOSE AND SCOPE

Oaks (*Quercus*) have dominated biomass growth for more than half a century in southern New England (Eisen and Barker Plotkin 2015). However, spongy moth (*Lymantria dispar*) outbreaks and climate stress threaten oak dominance. Additionally, maturing oak forests may become more vulnerable to disturbance as they age, and the impact of losing a few large trees results in larger biomass losses (a metric of oak decline) than a disturbance in a younger stand comprising many small trees. We compared mortality rates following the two most recent major spongy moth outbreaks in central Massachusetts: an outbreak that peaked in 1980–1981, and a recent outbreak from 2016 through 2018. We hypothesized that the more recent outbreak caused larger losses of biomass because it affected an older forest composed of fewer, larger trees.

There is also increasing evidence that oaks are impacted by hydrological stress from climate change. Although oaks tend to be more deeply rooted than co-occurring species, their stomata tend to be less sensitive to periods of low soil moisture and dry atmospheric conditions, which might help to explain why oaks experience larger growth reductions and higher rates of mortality during intense drought than neighboring species (Novick et al. 2022). Climate stress, together with spongy moth impacts and changes with forest age, might create compound stress that influence the growth and mortality of oaks.

METHODS AND APPROACH

We analyzed data from a permanent plot network in the Quabbin Reservoir Watershed Forest in which individual trees in 283 plots were measured once per decade from 1970 through 2020. Averaged across all censuses, the oaks together comprised 27 percent of the total live trees. More than half of the oaks were northern red oak (*Q. rubra*). We used the *Forest Health Atlas* (Kosiba et al. 2018) to document the timing and spatial pattern of spongy moth defoliation during the two outbreaks. We estimated mortality risk for individual trees among the five census intervals using a generalized linear mixed modeling regression approach, with census interval, tree size (diameter), species group (oak, all others), and oak abundance as predictor variables.

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We put the data from the permanent plots into context with 25-year trajectories of climate data and dendrometer band measurements from 130 oak trees at the nearby Harvard Forest Long-Term Ecological Research Site. Dendrometer bands were installed in 1998 on trees in 34 plots, and new recruits that exceeded the 10 cm minimum diameter threshold were added to the survey each year. All dendrometer bands were measured at least four times annually to track interannual tree growth.

FINDINGS AND IMPLICATIONS

We found that spongy moth outbreaks were a major cause of oak mortality. The percentage of oaks that died during outbreak intervals (1980–1990; 2010–2020) was more than triple that of nonoutbreak intervals (fig. 1). In general, smaller trees (<30 cm diameter at breast height) were more likely to die, but the largest diameter trees (>60 cm) also had an elevated risk of mortality. Mortality risk was significantly higher during the 2010s outbreak than during the 1980s outbreak.

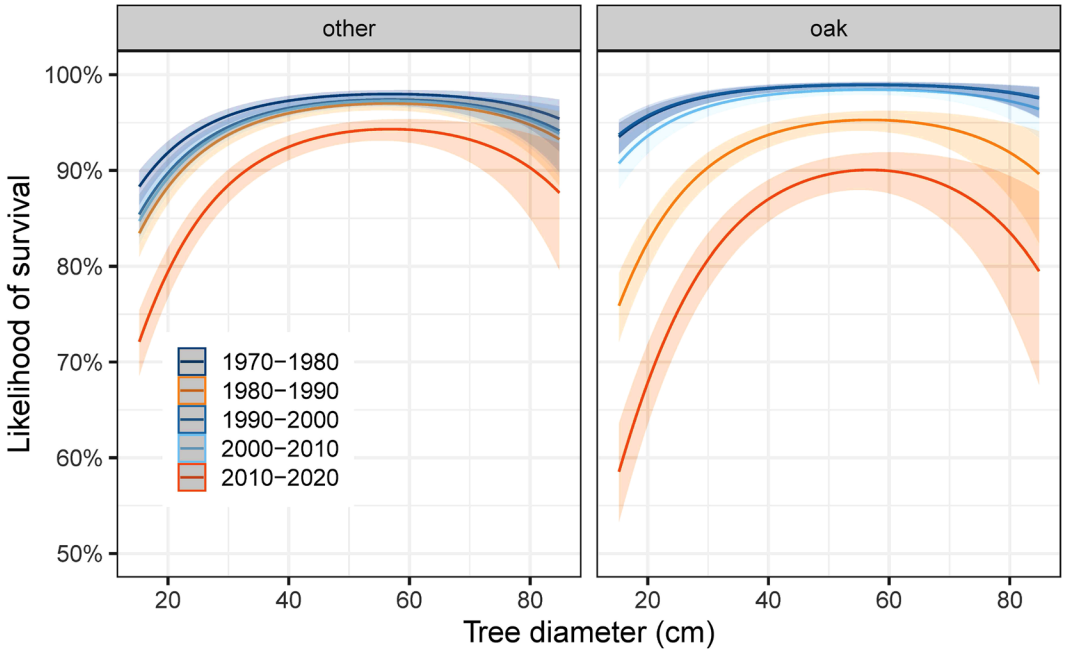

Figure 1—Modeled tree mortality risk for (right) oaks and (left) all other species. Mortality risk varied by census interval, species group, and tree size (diameter at the beginning of the interval). The lines show the predicted survival probability (shading shows 95-percent confidence intervals) for trees at the end of each census interval. Outbreak intervals are shown in orange tones; nonoutbreak intervals are shown in blue tones.

As expected, we found greater loss of oak biomass during the 2010s outbreak than during the 1980s outbreak, partially because the average tree that died between 2010 and 2020 was larger and contained much more biomass than the average tree that died between 1980 and 1990. However, the changing size structure of the maturing forest does not adequately explain why the individual-tree mortality risk was higher in the 2010s than in the 1980s. Other stressors likely contributed, highlighting the increased risk of oak mortality in an era of accelerating global change. Oak growth rates from dendrometer band measurements sustained a decadal decline after a series of droughts in 2010, 2016, and 2020.

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ACKNOWLEDGMENTS

The authors thank Fred Hunt, Bruce Spencer, Thom Snowman, and many other foresters for their collective 60 years of maintenance of the Quabbin CFI program. We are grateful to Bill Munger, Evan Goldman, Naomi Hegwood, Katherine McKain, and Tim Whitby for sustaining the dendrometer measurements at Harvard Forest. This work received support from the Massachusetts Department of Conservation and Recreation and the Harvard Forest Long-Term Ecological Research Program (NSF DEB 1832210).

Poster Session

A PHASED, CHROMOSOME-SCALE GENOME ASSEMBLY FOR SOUTHERN LIVE OAK, *QUERCUS VIRGINIANA*

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PURPOSE AND SCOPE

Like many members of *Quercus* subgenus *Quercus*, the southern live oak (*Quercus virginiana*) often remains genetically distinct despite living in sympatry and experiencing repeated interspecific hybridization (Cavender-Bares and Pahlich 2009). A comprehensive characterization of the oak syngameon requires the

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synthesis of population genetic and genomic approaches. High-quality reference genomes are essential to the goal of understanding this phenomenon, allowing us to more precisely describe the landscape of recombination and genetic variation in target species. As part of the American Campus Tree Genome Project, the goal was to develop a fully phased, chromosome-scale genome assembly for *Q. virginiana* to aid in efforts to improve and understand oak genetics.

METHODS AND APPROACH

Tissue samples for DNA and RNA were collected from a young clone of Auburn University's "Toomer's Oak" (*Q. virginiana*). The genome size, ploidy, and heterozygosity were estimated with Illumina short reads. First, the mitochondrial and chloroplast genomes were constructed from long reads with *oatk*. Then, the nuclear genome was assembled with *hifiasm* utilizing PacBio Hifi reads and scaffolded utilizing Dovetail Omni-C short-reads with *YAHS*. RNA was extracted from young and senescing leaves as well as roots, and subsequently used to annotate the genome with *Braker3*. Repetitive elements were characterized with *EDTA*, and comparative genomic analyses with other *Quercus* and Fagales members were conducted using the *GENESPACE* package.

FINDINGS AND IMPLICATIONS

The resulting diploid (2n = 24) assembly was highly contiguous and complete. The final haplotype assemblies included HAP1 with 777.1 Mb in 175 total contigs (contig N50 = 48.1 Mb, L50 = 7) and HAP2 with 769.9 Mb in 132 contigs (contig N50 = 53 Mb, L50 = 7). The k-mer completeness of the combined assemblies was 97.5 percent (QV 42.9). Repeats represent approximately 60 percent of the sequence in both haplotypes. Approximately 30,500 gene models were annotated in both haplotypes, consistent with previous annotations of species in this genus.

Initial comparative analyses suggest an extraordinary level of synteny between this species and other members of subgenus *Quercus*. Extensive chromosomal rearrangements are common among plants and these rearrangements can impact hybridization between related species. This unusual degree of conserved gene order may provide insights into the biology of the syngameon as more oak genomes are released. Additionally, alongside other references, the *Q. virginiana* genome will contribute to further research into all aspects of oak biology, such as longevity, biotic and abiotic environmental adaptations, disease resistance, and more.

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ACKNOWLEDGMENTS

The authors thank the organizers and contributors to Tiger Giving Day, and the NSF IOS-PGRP CAREER #2239530 to AH, which provided funding for this project.

THE GENETIC AND ENVIRONMENTAL DRIVERS OF RED OAK (*QUERCUS RUBRA*) PHENOLOGY

Meghan Blumstein, Theresa Caso-McHugh, Isabelle Chuine, and David Des Marais

Bud phenology (budburst specifically) of temperate eastern North American trees has advanced 5 to 10 days over the past 50 years. This early onset of spring creates a feedback with the climate system, making our ability to predict phenological timing a key component of predicting climate change. This project leveraged a widespread system of phenological cameras (phenocams) in a novel way to quantify the genetic and environmental drivers of leafout variation in the dominant species red oak (*Quercus rubra*) and integrate this into a process-based model. First, we parameterized a phenological model by using branch cuttings and growth chamber experiments to find reaction norms across dormancy, warming, and photoperiod treatment of diverse populations. Next we validated our predictions using a network of phenocams, by genetically sequencing red oak individuals growing in phenocam "viewsheds". Our work thus far has highlighted the key environmental drivers of leafout phenology in *Q. rubra* populations from across the range, uncovered key genes associated with phenological timing, and is pioneering new methodology for taking both genes and environment into account for our predictions.

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HUMAN URINE DOES NOT PROTECT ACORNS AGAINST PREDATION BY THE WOOD MOUSE (*APODEMUS SYLVATICUS*)

Jorge Castro

Direct seeding is a revegetation method that can offer great advantages for forest restoration, but suffers the drawback of seed loss due to granivorous rodents. Thus, to make direct seeding a useful and scalable forest restoration method we need to find ways to protect seeds against rodents. Scents produced by carnivorous or omnivorous animals that elicit a fear response on rodents are a promising group of substances that can be used to protect seeds and that have demonstrated effectiveness in a number of cases. Here, I tested if human urine had a protective effect on holm oak (*Quercus ilex*) acorns against predation by mice. Human urine would be much easier and cheaper to obtain than the urine of other animals, providing the possibility, if effective, to scale the application of a repellent substance. I set up a field experiment in an area with high wood mouse (*Apodemus sylvaticus*) abundance and used eight urine donors. Neither urine nor donor had any effect on predation. Acorn removal was very fast and high, reaching 97.2 percent after 7 days. Video recording with camera traps showed that the wood mouse was the main predator, but the Eurasian jay (*Garrulus glandarius*) also removed acorns. I conclude that human urine is not useful as a repellent against mice and suggest efforts focus on finding other substances to repel seed predators.

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CARBON STORAGE POTENTIAL OF RESTORED OAK SAVANNAS IN NORTHWESTERN TENNESSEE

J. Josue Chevez-Sahona, Heather D. Alexander, and Dwayne Estes

Oak savannas are important ecosystems that provide a range of ecosystem services, including supporting complex food webs and high biodiversity, contributing to landscape resilience and health, and serving as effective carbon (C) sinks, making them vital for conservation and climate change mitigation. In Tennessee, there are several ongoing efforts to restore currently closed-canopy forests to oak savannas, but questions remain about the capacity of the restored savannas to provide C storage services similar to those in remnant savannas. Thus, the main questions addressed in this research are: a) what are the current C storage levels in remnant oak savannas before restoration? and b) how do C storage levels change with time since oak savanna restoration? To address these questions, we are stablishing plots in several oak savanna sites across northwestern Tennessee and measuring C stored in live and dead trees, understory vegetation, leaf litter, organic soils, and the top 30 cm of mineral soils by using a combination of allometric equations and harvesting techniques. We hope this research will enhance our understanding of the ecological role of oak savannas in C cycling and highlight the importance of restoration efforts by documenting C storage levels in restored and remnant oak savannas, ultimately informing effective conservation and management strategies.

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TARGETED HERBIVORY: PLANT COMMUNITY RESPONSE AND CULTURAL RELEVANCY IN A WILLAMETTE VALLEY OAK SAVANNA

Abby Andrus Colehour, Lindsay McClary, Anna Ramthun, Elizabeth Swanson, and Eric Jones

Land managers today face novel management challenges in Willamette Valley oak savanna plant communities, given decades of shrub encroachment and nonnative species introductions, increasing wildfire risk, and the desire to protect cultural values. Restoring historic ecocultural fire regimes is a priority but cannot be solely relied upon. Mowing is an option but is limited by seasonal restrictions and offers mixed success in sustaining plant communities of interest. Long-term herbicide use is not desirable to protect cultural uses. In response to these issues, a partnership among the Confederated Tribes of Grand Ronde, the Long Tom Watershed Council, and Oregon State University set out to explore targeted grazing by goats and sheep as a potential supplemental management tool to address shrub encroachment. The study site is on Tribal-owned land near Sheridan, OR with relatively high native grass and forb diversity, periodic invasive grasses, and a high density of native and nonnative shrub growth. This observational study set out to measure and compare changes to plant community structure and composition before and 1 year after either mowing, targeted grazing, burning, or no action. In this poster presentation, we outline the partnership's objectives, study design, and first year results. Land managers may consider these outcomes alongside cultural and logistical factors when determining best options for restoring and sustaining oak savannas.

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MANAGEMENT, MARKETS, AND MESOPHICATION: AN EMPIRICAL EXPLORATION OF OAK FORESTS IN THE SOUTHEAST

Gaurav Dhungel

The contemporary ecological change occurring in historically oak dominated forests in the Eastern United States illustrates the temporal externality of ecological change driven by policy and management choices. Fire suppression policies beginning circa 1930, in tandem with selective harvest of high-value oak trees have had the unintended consequence of mesophication, i.e., proliferation of maples and beeches over oaks. This paper adapts U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis data to perform empirical analysis to 1) examine stand conditions and disturbances driving mesophication, including harvest method and fire; and 2) assess on-site characteristics (biophysical and amenities) and market signals (price) driving the choice of harvest methods in oak forests of the Southeastern United States. The empirical model showed that partial harvesting practice has a significantly strong and positive association with mesophication whereas the presence of fire has a significantly strong and negative association. Further, the random utility-based harvest choice model reveals that amenities and timber outputs have a complementary effect on partial harvests. Additionally, I quantified the average marginal willingness-to-accept partial harvesting, i.e., the marginal costs of avoided mesophication in the case study region, as $7.42 per million board feet. Hence, estimates from this study could be used to design incentive-based programs to support oak preservation, restoration, and sustainable long-term management.

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FORECASTING CHANGES IN OAK FORESTS FOLLOWING SPONGY MOTH (*LYMANTRIA DISPAR*) INVASION WITH A LANDSCAPE SIMULATION MODEL

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PURPOSE AND SCOPE

Invasive spongy moth (*Lymantria dispar*) was introduced to the Northeastern United States in 1869, and then spread and caused novel defoliation outbreaks in oak-dominated forests. Once the moth establishes, population fluctuations cause periodic defoliation events that reduce growth and increase mortality among host tree species. Spongy moth larvae are generalists with a broad diet, but *Quercus* species are among their favorite hosts and suffer heavy defoliation, leading to predictions that oak abundance should decline following invasion. Yet oak species also have adaptations that allow them to withstand defoliation, including traits related to ring-porous wood anatomy and nonstructural carbohydrate storage.

METHODS AND APPROACH

We developed a model to simulate realistic defoliation outbreaks within the landscape forest succession and disturbance model, LANDIS-II. We used the model to forecast potential changes in species composition and carbon storage that occur following spongy moth outbreaks across a latitudinal range of oak-dominated sites monitored through the National Ecological Observatory Network (NEON). We initialized the model with NEON data (NEON 2023, Weinstein et al. 2024) and tested how sensitive measures of forest change were to the initial abundance of oak species, as well as to the extent, duration, and frequency of spongy moth outbreaks, and other disturbances (harvests, wind, insects, disease).

FINDINGS AND IMPLICATIONS

We found that shifts in forest composition to favor nonhost species took decades or centuries, depending on the disturbance scenario and site and that more severe outbreaks and compounding disturbances could facilitate oak persistence

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due to spillover on less-preferred hosts and increases in light availability for new cohort establishment. Spatial predictions of individual canopy tree species from NEON data (Weinstein et al. 2024) provided a novel input for initialization of the LANDIS-II model and could streamline workflows to create test landscapes for model development using data from intensively monitored ecological sites.

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LONG-TERM IMPACTS OF NURSE PLANTS ON SAPLING PERFORMANCE IN CALIFORNIA OAK SAVANNAS

Chrysanthe Frangos, Marta Peláez Beato, and Rodolfo Dirzo

PURPOSE AND SCOPE

To mitigate challenges facing California oaks and foster regeneration, leveraging natural ecological processes such as nurse plants presents a promising avenue. Nurse plants, such as the coyote brush (*Baccharis pilularis*), play a crucial role in facilitating the establishment and growth of oak saplings. They provide a protective microenvironment that shields young oaks from harsh abiotic conditions and herbivory pressure, thereby enhancing their survival and growth rates. This facilitative interaction not only buffers oak seedlings from stress but also expands their ecological niche, potentially enabling their persistence in changing environments.

Though the benefits of nurse plants for oak seedlings have been documented, their long-term effects on saplings remain less understood. Understanding how nurse plants influence the growth, distribution, and survival of oak saplings is critical for developing effective conservation strategies. Such insights can inform land management practices aimed at promoting the resilience and regeneration of California oaks amidst ongoing environmental challenges.

The primary objectives of this study were to:

1. Evaluate the impact of nurse plants on the height growth of oak saplings over time.
2. Compare the facilitative effects on deciduous and evergreen oak species.
3. Analyze how fluctuations in herbivore density influence the spatial distribution of beneficiary oaks under nurse plants.

METHODS AND APPROACH

The study was conducted at two sites in northern California's Silicon Valley: Jasper Ridge Biological Preserve 'Ootchamin 'Ooyakma, characterized by high herbivore stress (HHS) due to abundant deer populations, and the Stanford Dish Area, with lower herbivore stress (LHS). The study focused on three oak species—evergreen coast live oak (*Quercus agrifolia*), deciduous blue oak (*Q. douglasii*), and valley oak (*Q. lobata*) —facilitated by the native shrub *Baccharis pilularis*. In 2015, we identified 216 coyote brush individuals and assessed the oak saplings

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growing under and around these shrubs. Measurements included sapling height, herbivory damage, and distance from the edge of the nurse plant. The same plants were re-evaluated in 2023 to track changes over time.

FINDINGS AND IMPLICATIONS

Saplings under nurse plants exhibited significantly greater height growth than those in open areas, both in raw length and percentage of change. Evergreen oaks were on average taller than deciduous oaks in both 2015 and 2023. Evergreen saplings also benefited more from nurse plants compared to deciduous species, with no deciduous saplings from 2015 surviving under nurse plants until 2023. Deciduous species required larger nurse plants for effective facilitation, with the threshold size for facilitation increasing from 6.7 m in 2015 to 7.7 m in 2023, though the size remained constant for evergreen oaks at 4.3 m. Saplings under nurse plants in the HHS site were located further from the edge of the shrub compared to those in the LHS site, indicating a protective effect against herbivores. This trend was more pronounced in 2015, suggesting that changes in herbivory pressure can alter the spatial distribution of beneficiary oaks.

Nurse plants significantly enhance the height growth of oak saplings, particularly in high herbivory environments. However, their facilitative effects are more pronounced for evergreen species than for deciduous oaks. The size of the nurse plant and the density of herbivores are critical factors influencing oak sapling survival and growth. These findings underscore the importance of considering species-specific and environmental factors in oak woodland management and restoration efforts. Further research should focus on tailored management strategies for deciduous oaks, given their greater need for facilitation and the higher threshold of nurse plant size required for their regeneration.

ACKNOWLEDGMENTS

The authors thank the staff at the Jasper Ridge Biological Preserve ‘Ootchamin ‘Ooyakma and the Stanford Dish for their advice and assistance. Without funding from the Stanford University Vice Provost for Undergraduate Education, this project would not have been possible.

IMPACTS OF DIFFERENTIAL BROWSING OF SHORTLEAF PINE AND MULTIPLE HARDWOOD SPECIES IN RESTORATION PLANTINGS

Joshua J. Granger, David S. Buckley, Cole Browning, Krishna Poudel, and Courtney Siegert

The westernmost part of the Appalachian physiographic province, the Cumberland Plateau, is home to a diverse array of plant and animal species and is considered the largest forested plateau in the world. Unfortunately, the historic ecosystems and habitats of the Cumberland Plateau are under immense pressure due to anthropogenic changes in land use, invasive species, and shifts in climate. Historically, the forests of the Cumberland Plateau included loblolly-shortleaf pine (*Pinus taeda-P. echinata*), oak-hickory, and oak-shortleaf pine, but changes in disturbance regimes (i.e., wildfire suppression) have resulted in open savanna-like oak-pine forests shifting to more closed forests. Additionally, the widespread preference for growing loblolly pine in plantation monocultures has significantly increased its range in the region. The conversion of loblolly pine plantations into oak or oak-pine dominated forest types may be achievable through underplanting. However, native white-tailed deer (*Odocoileus virginianus*) populations can significantly hinder planting success with seedlings being subjected to repeated browsing. We established 1-0 bare root shortleaf pine and 2-0 bare root white oak (*Quercus alba*), post oak (*Q. stellata*), southern red oak (*Q. falcata*), northern red oak (*Q. rubra*), shingle oak (*Q. imbricaria*), red maple (*Acer rubrum*), and sweetgum (*Liquidambar styraciflua*) to evaluate deer preferences and impacts on underplanting in existing loblolly pine stands. All seedlings were planted in spring 2021 and inventoried annually for survival, growth, and presence of deer damage. By fall of 2023, all species indicated some level damage from deer. However, sweetgum appeared the least damaged with species such as white oak and northern red oak having the greatest level of damage.

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AGE DISTRIBUTIONS AND ESTABLISHMENT TRAITS OF WHITE OAK (*QUERCUS ALBA*) ADVANCE REPRODUCTION UNDER UNEVEN-AGED MANAGEMENT IN THE OZARK HIGHLANDS OF MISSOURI, USA

Ryan Gross, Abby Huffman, Michael Stambaugh, Benjamin Knapp, Brad Graham, and John Kabrick

PURPOSE AND SCOPE

In the Eastern United States, recent reductions in oak regeneration across oak-dominated forests have led to overstory oak mortality rates exceeding the recruitment of new and likely future oak seedlings (Knapp et al. 2021). Although accumulating oak advance regeneration (OAR) and promoting recruitment to the canopy can be achieved using even-aged management strategies, implementing uneven-aged management (UAM) has been of growing interest due to the benefits of promoting old-growth forests, maintaining forest age and structural diversity, maximizing carbon storage, and preventing bottlenecks in forest product supplies. Combining quantitative wood anatomy (QWA) and dendrochronological methods, OAR age distributions and aboveground stem origins (seed versus seedling resprout) were explored across a range of UAM sites within the Ozark Highlands of Missouri.

METHODS AND APPROACH

OAR seedlings (<1.37 m in height) were collected from UAM stands at the Missouri Ozark Forest Ecosystem Project. OAR were excavated from stands similar in species composition and topography, but that varied in their UAM frequency. Sample preparation involved microsectioning, staining, and digitizing thin, xylem tissue cross-sections (von Arx et al. 2016). Due to the resprouting ability of oak species, cross-sections from above and below ground (stem and root) were prepared to obtain separate stem and root ages for each seedling (Dee et al. 2022). Sections were individually ring counted, and their ring widths were crossdated to

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ensure the accuracy of age determinations. Crossdating also provided the year of the most recent resprouting event.

FINDINGS AND IMPLICATIONS

Aboveground stem ages for all seedlings ranged from 1 to 31 years and ages for belowground roots ranged from 2 to 49 years, aside from one outlier that was approximately 91 years old. Age differences between the stem and root of the same seedling ranged from 0 to 46 years. Seedlings with no stem-root age difference indicate no top-killing event since germination. Seedlings with an age differential of ≥2 years (≥1 year for crossdated seedlings) experienced at least one top-killing event. From this, 62 percent of OAR were resprouts.

For the effective UAM of white oak, attention should focus on establishing sufficiently large OAR populations and promoting sustained, competitive growth during the regeneration and recruitment phases. The results from this study could be used to assess the efficacy of forest management practices and harvesting strategies in promoting OAR accumulation and their continued growth towards the canopy.

This study provides new data and perspective on OAR populations and early growth by combining QWA and dendrochronological methods. These novel methods could be further developed and expanded to address oak regeneration questions and assess the management intended to sustain the vast array of ecological and economic benefits that oak species provide.

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ACKNOWLEDGMENTS

The authors thank the Missouri Department of Conservation for funding and Brad Graham for logistical support. We thank Holger Gärtner and Alan Crivellaro for sharing expertise in QWA. We thank Ian Vaughan (U.S. Department of Agriculture, Forest Service) for his contribution to study design, field sampling, and laboratory work.

FUNGAL DISEASES IN CENTRAL EUROPEAN OAKS

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Time series from forest protection reports for oaks in Germany show increased damage caused by fungal pathogens. However, the regional significance of pathogens varies. In southwest Germany, root damage caused by the weeping conk (*Pseudoinonotus dryadeus*) is of regional importance due to falling trees. This fungus causes massive root rot from below, which appears camouflaged in the soil and not visible to the forest owner. This can lead to spontaneous tree falls, sometimes with fatal consequences for the forest owner and timber. The honey fungus (*Armillaria mellea*) leads in the same way to symptoms of decay that begins at the root layer and grows throughout the cambium into the wooden structural tissue. An infestation with powdery mildew fungi (*Erysiphe* spp.) in the course of oak dieback can lead to additional stress for the affected trees; in the case of heavy infections, further recourse to reserves is required for new leaf growth. Atypically, bark pathogens also occur in connection with infestation by beetles or from woodpecker ringing. Reports from Great Britain mention chronic oak decline (COD; serious, long-term decline in tree health) and acute oak decline (AOD; much faster, and usually fatal, decline in tree health) as new complex disorders of oaks in which several damaging agents interact. In addition, oaks and beeches are particularly susceptible to infections of *Phytophthora ramorum*, which can cause severe damage to forests. Intensive efforts are being made to control and combat the spread of this disease in Europe. There are currently also diagnostic efforts and attention to bacterial evidence from weeping cankers in bark of oaks caused by bacterial pathogens such as *Gibbsiella quercinecans*, *Brenneria goodwinii*, and *Bretziella fagacearum*. Therefore, it is particularly important to determine not only the abiotic stressors for oak but also the etiology of different pathogens to monitor changes.

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SILVICULTURAL METHODS FOR *QUERCUS CRISPULA* REGENERATED IN SCARIFIED SITES: EFFECTS OF INTRA AND INTERSPECIFIC COMPETITION ON 17TH YEAR OF GROWTH AND STEM QUALITY

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PURPOSE AND SCOPE

Soil scarification has been suggested to be effective in the regeneration of Japanese oak (*Quercus crispula*) (Asada et al. 2017). This treatment involves using machinery to remove dwarf bamboo (*Sasa senanensis*), which is an inhibitor of tree regeneration. If there are seed trees (shelterwood), oak can grow densely by natural regeneration, and even if there are no seed trees, some regeneration is possible by artificial seeding. In the former, intraspecific competition among oak is dominant because other tree species have limited growth under the canopy. In the latter, interspecific competition with naturally regenerated birch (*Betula*) species becomes stronger. When growing oak for timber production, nursery practices that consider growth and tree shape are necessary. However, the growth of oak in scarified areas is not well understood. Competition with the neighbors has a tradeoff effect of reducing growth but also improving tree shape. We expected that these competitive effects would differ between under and out-of-canopy. Therefore, we scarified stands with and without seed trees, and seeded acorns for the latter. We aimed to clarify the effects of intra and interspecific competition, and to investigate appropriate silvicultural practices for Japanese oak.

METHODS AND APPROACH

This study was conducted in the Uryu Experimental Forest, Field Science Center for Northern Biosphere, Hokkaido University, Japan. In 2006, we scarified both an area with seed trees (canopy stand) and an area without them (open stand), and artificially seeded acorns in the latter. Circular plots (10 m^2 x 9 plots) were set in both stands. In 2023, the 17th year after scarification, the height and diameter of the trees in the plots were measured and their tree shapes were evaluated. In addition, sample trees of Japanese oak and Erman's birch (*B. ermanii*), a major competitor, were extracted from the plots for tree-stem analysis to examine biomass and past growth processes. The sky openness of the plots was also measured in 2023.

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FINDINGS AND IMPLICATIONS

In the 17th year, the mean (±1 standard deviation) height and diameter at breast height of oak were 2.8 m (±1.0) and 14.4 mm (±9.0), respectively, in the open stand and 2.5 m (±0.9) and 11.7 mm (±7.5) in the canopy stand, respectively. Oak trees in the open stand tended to be larger, but their height growth had been suppressed since about the 10th year (fig. 1). No such trend was observed in the canopy stand. The mean basal area sum (BA) of the open stand was 184.9 cm^2/m^2 (±112.8), including 56.8 cm^2/m^2 (±31.5) for oak and 128.1 cm^2/m^2 (±102.8) for birch, which overtopped the oak. The canopy stand (BA = 39.3 cm^2/m^2 [±32.2]) was dominated by oak (BA = 29.2 cm^2/m^2 [±23.3]) and placed birch (BA = 10.9 cm^2/m^2 [±8.2]) mainly in the understory. The BA of oak was positively related to the sky openness in each of the two stands. The trees in the open stand had a higher forking height, and lower number and volume of branches.

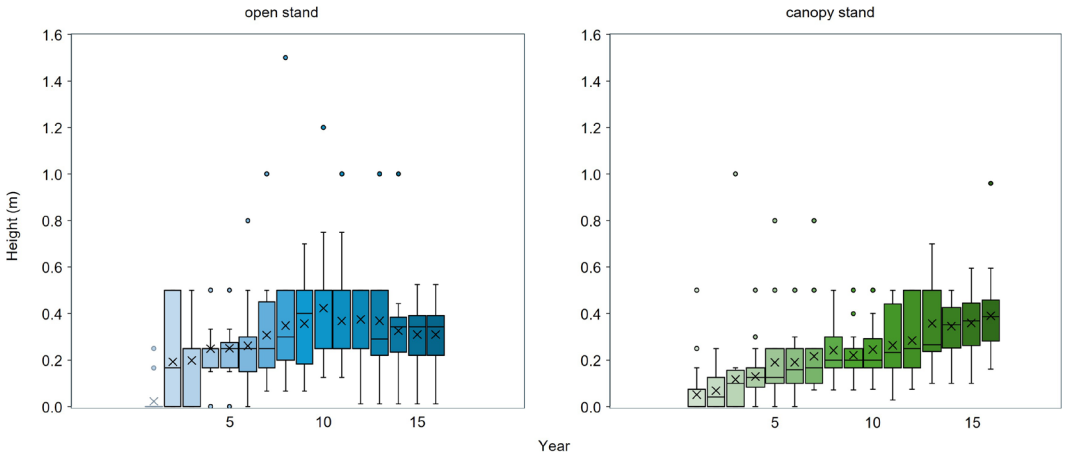

Figure 1—Annual height growth of Japanese oak over 17 years in (left) open and (right) canopy stands. The horizontal line in each box represents the median, the lower and upper ends of the box are the first and third quartiles, respectively. The two ends of the bars indicate the maximum and minimum values within 1.5 times the length of the box, and the circles indicate outliers.

These results seemed to be related to the fact that intra and interspecific competition are dominant under and outside the canopy, respectively. The strong suppressive effect of the latter suggests that the open stand requires immediate thinning of the dominant birch. The smaller tree size in the canopy stand is thought to be due to the presence of seed trees (shelterwood). Considering the lack of growth reduction in recent years and the maintenance of tree shape in this stand, removal of these seed trees is a high priority at this time, rather than thinning the conspecific neighbors.

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ACKNOWLEDGMENTS

We would like to thank members of the Nayoro office and the Uryu Experimental Forest, Hokkaido University for their cooperation in our research and fieldworks.

LOBLOLLY PINE TO WHITE OAK STAND CONVERSION ON BALLS MOUNTAIN IN THE BANKHEAD NATIONAL FOREST, ALABAMA

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PURPOSE AND SCOPE

Converting native hardwood stands to monoculture pine stands is well-established in the South due to the abundance of research on pine silvics and regeneration. Restoring a native hardwood or mixedwood stand on a previously converted pine stand is much more challenging, but is required to meet the Bankhead Ranger District's native ecosystem restoration goals. We discuss the intricate and multifaceted process of white oak (*Quercus alba*) restoration within a previously established loblolly pine (*Pinus taeda*) stand on the Bankhead National Forest, AL. The conversion from monoculture pine timber stands to a diverse and resilient hardwood woodland involves a nuanced set of steps and considerations, especially within a national forest. This includes project planning (National Environmental Policy Act [NEPA] analysis), site selection, timber sale management including timber receipt planning, stock procurement from seed to seedling, stand harvest, site preparation, planting, and survival and stocking monitoring.

METHODS AND APPROACH

Every step included substantial cooperative efforts among internal and external partners including the U.S. Department of Agriculture, Forest Service, Southern Research Station; University of Tennessee; and a local nonprofit. An interdisciplinary team consisting of district personnel from silviculture, timber, biology, fire, archeology, soil, and water from the Bankhead National Forest worked together to create this NEPA project. NEPA is required for all project undertakings on national forests. The NEPA process included situation assessment of the problem, which was the need for desired hardwoods; establishing the purpose and need for this project; developing a proposal; scoping, which is informing the public and allowing the public to voice opinions and concerns; developing alternatives; analyzing the effects of what is being proposed and the alternatives; and finally, writing a document to explain all of those items. To prepare for this endeavor, we considered suitable site locations to attempt this restoration. This was a critical first step because assessment of the site would bring understanding of the current ecological conditions and historic land-use

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practices. Following site selection and assessment, procurement of the stock was the next challenge in the process, because white oak acorns needed to be collected and shipped to a nursery where the seedlings could be grown for 1 year.

At the time of this project planning, the Forest Service, but most specifically the Bankhead National Forest, did not have a mechanism for efficiently acquiring acorns. This need presented a new opportunity for collaboration among the public, Forest Service research, and the National Forest. Research would provide the education for citizen scientists, and the citizens would provide the labor for the Forest Service by collecting acorns and assisting with seedling planting. This step required approximately 2 years' worth of effort and planning. Site preparation and competition control provided many more challenges, due to coordination of timber harvesting, chemical site preparation and prescribed burning. A glyphosate mix was used for site preparation during summer of 2022. Planting white oak seedlings is very different from planting pine seedlings. Equipment, timing of planting, and spacing were specific to oak planting.

FINDINGS AND IMPLICATIONS

Through the coordinated efforts of scientists from the Southern Research Station, Bankhead National Forest personnel, University of Tennessee students, The Nature Conservancy interns, and volunteer citizen scientists from the Wild Alabama monitoring group, the team was successful in planting white oaks in the stand. First year survival stocking yielded an 88.9 percent survival rate. The Bankhead and Southern Research Station continues to monitor the stand. Volunteer loblolly pine is competing for growing space within the stand. If allowed to continue without treatment the pines will outcompete the planted oak. A crop tree release by using brush saws is planned for October 2024.

WATER AND CARBOHYDRATE DYNAMICS IN MATURE FOREST-GROWN AND OPEN-GROWN *QUERCUS GARRYANA*, BEFORE AND AFTER RELEASING OAKS FROM CONIFER COMPETITION

Ava R. Howard and David Woodruff

Historic land-use changes have reduced Garry oak (*Quercus garryana*) savanna and woodland habitat along the west coast of North America, and much of the remaining habitat is threatened by conifer encroachment. Our research examines the stress imposed on native oaks from, and the response to the removal of, neighboring conifers. Ten mature oak trees were selected across an open-canopy savanna and a closed-canopy conifer-dominated forest in the Willamette Valley of Oregon. Forest-grown oaks experienced high competition (Hegyi = 3.04), were taller (25.16 ±0.89 m), and had less girth (diameter at breast height [d.b.h.] 47.2 ±2.40 cm), compared to open-grown oaks (Hegyi 0.39; height 14.44 ±1.20 m; d.b.h. 61.33 ±5.25 cm). Predawn and midday xylem water potential and nonstructural carbohydrates (NSC) in upper branch and bole sapwood were assessed for each study tree monthly from June to October in 2017 (prior to conifer removal), and in 2023 (post conifer removal in the forest). Forest-grown oaks were less water stressed than open-grown oaks on most sampling dates both before and after removing overtopping conifers. Seasonal changes in NSC varied substantially in 2017 between forest-grown and open-grown oaks, and with a general pattern of lower NSC and later seasonal peaks for closed-grown trees. These results demonstrate stress on native oaks from encroaching firs is likely primarily due to shading and not competition for water and that altered physiological stress patterns persist over many years even after removal of conifers.

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EVALUATION OF ECOSYSTEM RESPONSE TO SILVICULTURAL TREATMENTS IN UPLAND HARDWOOD FORESTS IN NORTHERN MISSISSIPPI, USA

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PURPOSE AND SCOPE

Upland hardwood forests (UHF) of Mississippi are important habitat for wildlife and have significant ecological, economic, and cultural values. These forests are dominated by oak-hickory and mixed pine-hardwood forest types, with other species common to both open woodland and closed-canopy forest conditions. The regeneration of hardwood species, especially oaks, is necessary to maintain species diversity and the proper functioning of these forests. Historically, open forests were more dominant ecosystems but are now rare due to historical forest management and changes in disturbance regimes (Hanberry et al. 2020). Oak-dominated UHFs serve as food sources for small rodents, wild turkeys (*Meleagris gallopavo*), white-tailed deer (*Odocoileus virginianus*), ruffed grouse (*Bonasa umbellus*), and woodcock (*Scolopax* spp.). However, successfully regenerating oak in UHF in the region can be challenging. The overall objective of this study was to assess how various silvicultural treatments impact residual tree growth, seedling recruitment and diversity, and aboveground carbon storage in upland hardwood forests. The aim was that treatments promoting oak regeneration will enhance biodiversity and provide diverse ecosystem benefits.

METHODS AND APPROACH

The study was conducted at Spirit Hills Farm, a mixed upland hardwood forest in Tate County, MS. The forest was naturally regenerated with a diverse mix of hardwood and softwood species. We used a randomized block design with three silvicultural treatments: T1: hack and squirt + overstory removal to residual basal area of approximately 11 m^2/ha; T2: hack and squirt + overstory removal to residual basal area of approximately 7 m^2/ha (fig. 1); and T3: no treatment (control). Hack and squirt were used to remove all nonoak species <20 cm in diameter at breast height. We divided the study area into 12 variable-sized

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treatment units ranging from 5 to 10 ha with 4 replicates per treatment and 98 nested fixed-area plots to monitor ecosystem responses. Plots of 0.05 ha, 0.01 ha, and 0.0013 ha were established to measure trees of large (≥25 cm), medium (≥5 cm and <25 cm), and small diameters (<5 cm), respectively. The 0.0013-ha plots were located 4 m from the center of the 0.05-ha plot at a 180° angle. In these plots, tree species were inventoried, and total vegetation cover, biodiversity indices of woody species, and aboveground carbon were measured and quantified.

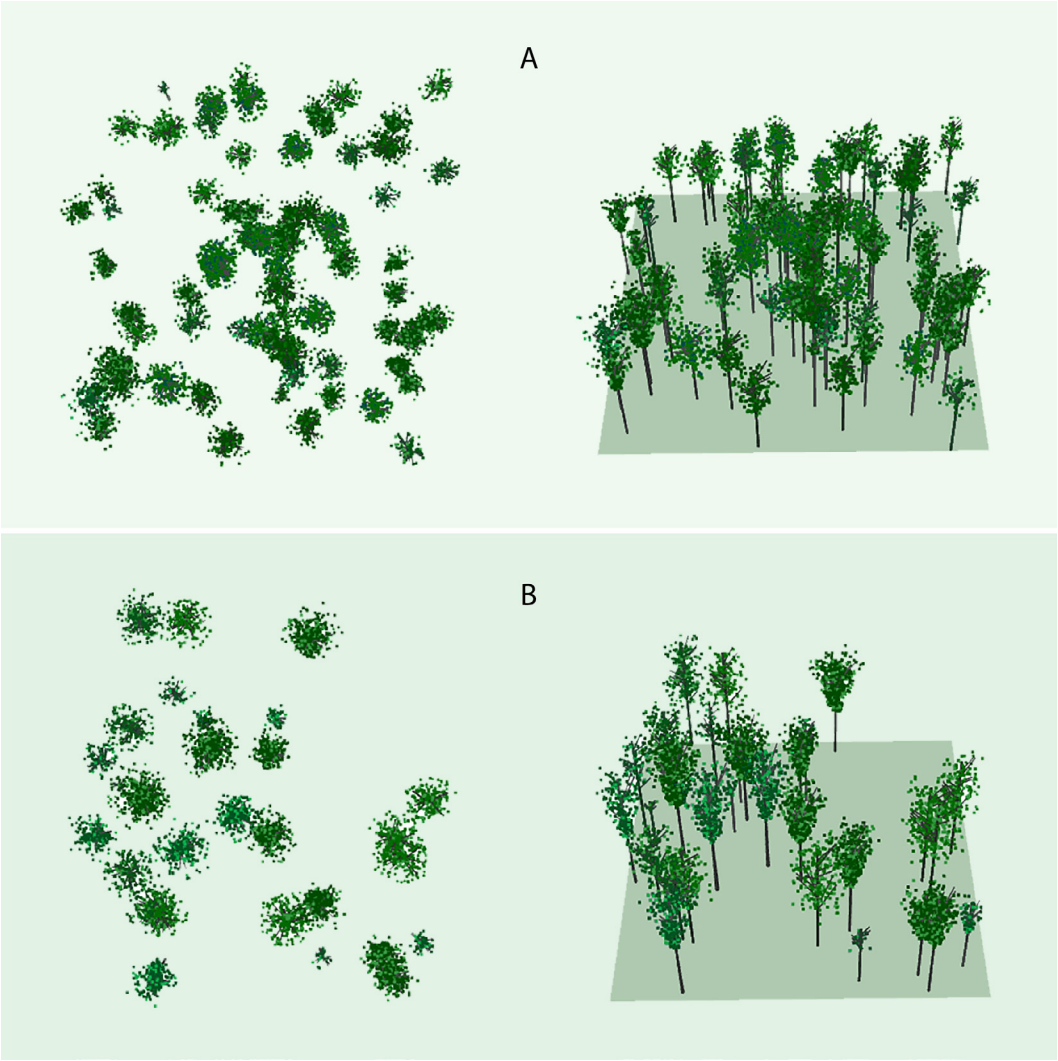

Figure 1—Overhead and perspective views of the overstory removal to the basal area of (A) approximately 11 m^2/ha and (B) approximately 7 m^2/ha.

FINDINGS AND IMPLICATIONS

The results of our study will inform the effectiveness of each treatment in promoting oak regeneration and enhance our understanding of how ecosystems respond to these treatments. Our study will contribute to forest management strategies that balance timber production with ecological restoration, thereby aiding the sustainable management of UHFs in the region. By addressing the challenge of oak regeneration, our study's outcomes could guide restoration and silviculture efforts in UHFs. The study will serve as a valuable demonstration site

for upland oak silviculture, facilitating outreach and educational efforts at both regional and national levels. The significance of oak species in upland hardwood forests, both for their commercial value and ecological benefits, underscores the importance of this research.

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We thank the Dean's Office, College of Forestry, and the Forest and Wildlife Research Center at Mississippi State University as well as the National Institute for Food and Agriculture, U.S. Department of Agriculture, McIntire Stennis project under accession 1019117, for funding the project. Special thanks to the kind support of Sheryl Bowen for the use of her property—the Spirit Hill Farm, and Hearne Foster (property manager) for his assistance on the project.

HOW USEFUL ARE ACORN RESOURCES? QUANTIFYING THE PLANT-AVAILABLE CARBON IN ACORNS WITH ACHLOROPHYLLOUS OAKS

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PURPOSE AND SCOPE

Acorn size is an important phenotypic trait commonly associated with the overall success of young seedlings (Devetaković et al. 2019). However, seedlings quickly become carbon self-sufficient, and thus less dependent on acorn reserves (e.g., Frost and Rydin 1997). Determining the actual plant-available resources provided by the seed is difficult. Here we utilize a one-of-a-kind natural mutation that has created a population of achlorophyllous (without chlorophyll) pedunculate oak (*Quercus robur*) to quantify the plant-available carbon in the acorns. Further, we estimate oak seedling carbon allocation, uptake, and use in a population of achlorophyllous and a co-occurring population of chlorophyllous (i.e., normal green) oaks during their first year of growth.

METHODS AND APPROACH

The achlorophyllous oak population was discovered in spring 2022 in an 80-year-old *Q. robur* forest in southern Sweden. Growth and survival were measured in both oak populations from germination, spring 2022, until all achlorophyllous seedlings had died. Throughout this period, we tracked individual seedling's carbon uptake and use, as well as shifts in leaf morphology and shoot dieback. To quantify biomass investment, we subsampled parts of the two populations several times during the study period. Finally, we applied a mechanistic growth model to estimate carbon allocation, uptake, and use in the two populations to understand the plant available carbon of the acorn in the first year.

FINDINGS AND IMPLICATIONS

The acorn resource sustained the achlorophyllous oaks for nearly a year. However, the mortality rate within the achlorophyllous oak population was significantly greater compared to the chlorophyllous oaks, wherein 76 percent of all seedlings survived the first year. The photosynthetic capacity developed with leaf maturation in the chlorophyllous oak population, with a maximum photosynthetic capacity averaging around 3–7 mmol m^{-2} s^{-1}, in mid-July. In the achlorophyllous oaks, we were unable at any time to detect any carbon uptake and only a very weak fluorescence signal from chlorophyll. Area-based daytime

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respiration was similar for both achlorophyllous and chlorophyllous seedlings, despite significantly thinner leaves in the achlorophyllous oaks. The number of leaves, leaf area, and seedling height were similar between the white (achlorophyllous) and green oaks, indicating similar seedling carbon investment independent of chlorophyll content and photosynthetic capacity.

Our findings suggest that the acorn provides the young seedling with sufficient resources for growth and maintenance respiration in the first year, independent of photosynthesis.

Figure 1—An achlorophyllous pedunculate oak seedling, in an oak-dominated stand in southern Sweden.

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ACKNOWLEDGMENTS

Funding was provided by The Bridge collaboration 2.0 and Erik Stenströms stiftelsen.

THE ECOLOGY AND SILVICULTURE OF OAKS

Paul S. Johnson, Stephen R. Shifley, Robert Rogers, Daniel C. Dey, and John M. Kabrick

This book is intended for forest and wildlife managers, ecologists, silviculturists, environmentalists, and students of those fields. It has been used as a text in graduate courses in hardwood ecology and silviculture. The third edition better serves all those audiences by providing greater consistency among chapters in depth and complexity, by including a broader range of topics, and by greater interweaving of content among chapters. *The Ecology and Silviculture of Oaks* is a source of information and ideas on how to think about oak forests as responsive ecosystems. Compared to earlier editions, the third edition includes new chapters on the important role of fire in sustaining oak forests and on managing oak forests in a changing climate that discuss potential habitat shifts and management practices that can help forests adapt to or mitigate climate change. The third edition also includes a new chapter that examines silvicultural methods for woodlands and savannas and provides guidance for restoring and sustaining savanna and woodland habitats. Other new sections address landscape-scale considerations in oak forest management and considerations when managing wildlife. A fourth edition is underway that includes an updated and expanded investigation of oak ecosystems and how they respond to natural and anthropogenic forces. It includes more graphics and illustrations than prior editions, with new color figures throughout that better convey complex relationships.

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DIFFERENCES IN COMPOSITION OF SOIL ORGANIC MATTER BETWEEN OAK AND PINE FORESTS

Erik Jones, Nina Wurzburger, Caitlin Hicks Pries, and Richard Lankau

Oaks are a dominant genus of ectomycorrhizal trees in the Southeastern United States. Ectomycorrhizal trees and their fungal associates drive biogeochemical cycles and can affect the stocks and composition of soil organic matter (SOM). However, it is unclear to what extent observed trends are generalizable across different lineages of ectomycorrhizal trees, such as oaks and pines, which associate with partially distinct fungal communities. Furthermore, both oaks and pines are typically fire-adapted in this region, but it is unknown how the effects of tree and fungal identity on SOM depend on the fire regime. In order to better understand drivers of SOM composition, soils were sampled from 19 pairs of adjacent oak-dominated and pine-dominated forest plots in the Piedmont and Blue Ridge, 10 of which were recently managed with prescribed fire. Soil samples were separated into particulate organic matter and mineral-associated organic matter (MAOM) fractions, and the carbon (C) and nitrogen (N) content of each fraction was measured. A higher proportion of soil C was mineral-associated in oak plots compared to pine plots, reflecting larger stocks of MAOM. However, oak and pine plots did not differ with regard to mineral-associated soil N. Soil C:N was significantly lower in unburned, but not in burned, oak plots compared to their pine-dominated counterparts. Metabarcoding of soil fungi will clarify whether the observed differences are tied to variance in fungal community composition and nutrient acquisition strategies between pine and oak forests.

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OAK-ASSISTED REGENERATION THROUGH SEEDING OR PLANTING: A COLLABORATIVE, CONTINENTAL-SCALE EXPERIMENT

Alexandro B. Leverkus

PURPOSE AND SCOPE

Assisted regeneration of oak involves the choice between direct seeding of acorns and the planting of nursery-grown seedlings. The effect of the revegetation method may hinge on how it modulates traits that are associated with the capacity of plants to cope with environmental stressors such as drought. Directly seeded acorns tend to develop extensive tap roots, facilitating access to deep resources, though planted seedlings often exhibit abnormal root systems dominated by lateral roots.

A recent systematic map that collated the existing scientific studies that compare the outcomes of seeding and planting (Lázaro-González et al. 2023) underscored that various constraints from local studies hinder concluding about the broader implications of revegetation method and the mechanisms explaining differences across studies. To address such limitations, coordinated collaborative experiments have emerged as a promising approach. By employing a standardized experimental protocol across multiple sites, these collaborative efforts aim to provide empirical evidence at regional, continental, or even global scales (Maestre and Eisenhauer 2019).

METHODS AND APPROACH

To assess the impact of seeding versus planting on oak seedling development and whether variation in environmental conditions or among species account for observed differences, I initiated a collaborative, continental-scale experiment in autumn-winter 2021. It spans 48 sites across 16 European countries, and comprises 12 oak species. Around 90 participants established plots with seeded and planted oaks, adhering to a protocol that prescribed the methods for seed collection, direct seeding, nursery cultivation, planting, herbivore protection, and the ongoing maintenance and measurement of seedlings (Leverkus et al. 2021). A second experimental cohort began in 2022. At present, participants are submitting demographic data through an online database. Further, participants submitted a subset of their acorn batches and a soil sample from the field site to the University of Granada. This allowed for germination tests, weighing acorn wet and dry mass, and analyzing key soil properties.

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FINDINGS AND IMPLICATIONS

As of March 2024, the participants submitted data on the emergence and initial growth of directly seeded individuals, the size of directly seeded and planted individuals at the time of planting, and the survival, resprouting, and growth of all individuals. Analyses will reveal whether there is a generalized benefit from either direct seeding or planting for oak seedling development, and/or whether climate, soil, or species explain differences in observed outcomes across studies.

The experimental design represents a notable improvement over prior studies, with the potential to offer insights into patterns across a large geographical scale using standardized procedures while trying to mitigate specific sources of bias associated with local studies. The international participant network involved in this experiment not only generates valuable knowledge but also fosters stronger connections within the scientific community.

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THE EFFECT OF SELECTIVE THINNING ON GROUND COVER, EPIPHYTIC MOSS AND LICHEN SPECIES, AND MICROHABITAT DIVERSITY IN *QUERCUS ROBUR*-DOMINATED STANDS

Agnese Anta Liepiņa, Jānis Donis, Diāna Jansone, Andis Adamovičs, Ilze Barone, Dace Dālberga, Āris Jansons

In the Baltics, selective release of oak trees is a specific forestry method aimed to improve light conditions and preserve the necessary environment for rare and protected species in the forests. In 2003, selective thinning was applied in nine forest stands, dominated by *Quercus robur*. In each stand selective removal of trees was carried out around four oak trees and, accordingly, four additional oak trees were chosen as the control, around which no management was implemented. In order to evaluate and compare whether differences in floristic diversity could be observed between the managed and control parts of the stand 20 years after the management, repeated measurements were carried out in the stands in 2022 and 2023. To characterise the biotic community associated with oak trees, vascular, epiphytic, and epixylic moss and lichen species, as well as the microhabitat presence and frequency was analysed. The Shannon-Wiener index was used to evaluate the species' diversity, the principal drivers of vegetation and epiphytic species on the studied oak trees were assessed by detrended correspondence analysis. The selective thinning has provided a positive long-term effect on the evaluated indicators of biodiversity, making it an applicable method for forest stands, the purpose of which is to maintain biodiversity in combination with moderate economic activity. A slightly increased number of species and a higher diversity index were found in managed parts of sites; a statistically significant difference was found only in the case of diversity of vegetation species.

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SELECTIVE THINNING INDUCED CHANGES IN RADIAL GROWTH OF *QUERCUS ROBUR* IN MIXED STANDS

Agnese Anta Liepiņa, Roberts Matisons, Guntis Brūmelis, Āris Jansons

In the Baltic sea region, *Quercus robur* is associated with high habitat and structural diversity of forests. Therefore, there are efforts to improve the survival of oaks using selective thinning. The enhanced light conditions can be favorable for oak trees and species associated with them, however, the changes in microclimate caused by thinning could have a contrasting effect on oak lifespan. In this study, the radial growth response of *Quercus robur* to environmental changes caused by selective removal of adjacent trees was analysed. Increment cores were sampled in 13 forest stands, where selective thinning was made around oak trees, and dendrochronological methods were used in data analysis. To determine whether thinning changed the trends in oak growth sensitivity, the chronological cluster analysis was used. Cumulative radial increment of oaks was reconstructed. Preliminary results show that selective thinning had no impact on *Quercus robur* growth sensitivity to meteorological conditions. The local stand conditions had a contrasting effect on the radial increment of the oak trees after thinning. Selective thinning in mixed stands improved radial growth for approximately half of studied oak trees, and the rest had negative or no changes in radial growth. Continued research is needed to determine the interaction of stand composition and thinning intensity on the further growth of oak trees.

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A COMPREHENSIVE REVIEW OF OAK DECLINE DRIVERS IN THE MEDITERRANEAN REGIONS OF THE NORTHERN HEMISPHERE

Marco Marques, Miguel N. Bugalho, Vanda Acácio, and Filipe X. Catry

PURPOSE AND SCOPE

Forest ecosystems of the *Quercus* genus, which is one of the most widespread genera in the Mediterranean-type climate (MTC) regions of the Northern Hemisphere, have been affected by a worrying decline. However, a systematic review synthesizing the causal factors of this phenomenon in these regions, contributing to a better understanding of the problem, has not been conducted. The aims of this study were to: (1) map peer-reviewed research on oak decline in MTC regions; (2) systematize factors identified as responsible for oak decline across these regions and analyze their distribution; (3) identify interactions between different causal factors; and (4) identify knowledge gaps and future research needs.

METHODS AND APPROACH

Oak decline was defined as a broad concept encompassing decline, mortality, dieback, degradation, and deforestation. Following this definition, we conducted a review, using systematic search guidelines in environmental management (CEE 2022), through peer-reviewed literature related to oak decline in MTC regions. Searches performed in Web of Science and Scopus yielded a total of 3,923 articles, from which 241 articles were selected for their relevance after screening.

FINDINGS AND IMPLICATIONS

Research on the causal factors of oak decline began in the 1980s. Within the two MTC regions, the Mediterranean Basin has seen the most research activity. In California, research is concentrated in the coastal areas, particularly near San Francisco County.

The research predominantly focuses on evergreen oak species and follows the distribution areas of species with significant economic and ecological importance.

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Pathogens and climatic agents were identified as the two key factors of oak decline in both regions. Human activities, especially in agroforestry systems, also play a significant role as a decline factor, though pests are important and closely related to pathogens. Regional differences in the distribution of pathogens and pests were observed, highlighting the need to consider biotic factors that can invade other regions with potentially unforeseen consequences. Moreover, results show that factors interact in multiple combinations potentially exacerbating oak decline. Climate factors emerge as the most interactive with all other factors, underscoring their significance in the context of climate change.

Three knowledge gaps were identified: (1) research is disproportionately focused on a few *Quercus* species; (2) there is asymmetric research between the north and southern/east Mediterranean Basin; and (3) studies tend to concentrate on individual decline causal factors, often neglecting the exploration of interactions between different factors.

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DEADWOOD MANAGEMENT AND FOREST HEALTH, PRINCE WILLIAM FOREST NATIONAL PARK, VIRGINIA, USA

Daria Maslyukova, Adam Coates, and Mark Ford

Deadwood, noted as the sum of down-and-dead woody material and standing-and-dead stems, is an integral component of forest health. Deadwood may serve as an important contributor to wildfire hazard estimation in many forest systems, particularly as future climate models predict increased precipitation and drought intensities. Deadwood is critical to carbon storage and nitrogen cycling as these processes may vary according to deadwood size. Additionally, deadwood structural variability has been found to positively affect species richness in bees, salamanders, and birds. However, in the Mid-Atlantic Piedmont of the Eastern United States, there are no accessible tools to estimate deadwood of long unmanaged, secondary growth forests to help inform management goals and priorities. Management entities, such as the National Park Service, seek to understand deadwood dynamics in the Eastern United States more comprehensively to better inform visitors and guide management actions. Using modified Brown's transects, deadwood was inventoried at 270 plots at Prince William Forest Park near Stafford, VA in the greater Washington, DC metropolitan area in summer 2023. In this presentation, we discuss our preliminary results, including how deadwood varied as a result of aspect, elevation, physiographic province, and forest cover type.

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COLORIMETRIC LOOP-MEDIATED ISOTHERMAL AMPLIFICATION (LAMP) ASSAY FOR THE DETECTION OF *BRETZIELLA FAGACEARUM* (CAUSAL AGENT OF OAK WILT DISEASE) IN TREE SAMPLES

Anil K. Meher, Lauren Aufdembrink, Akli Zarouri, and Abdennour Abbas

PURPOSE AND SCOPE

The purpose of this study was to develop a rapid and efficient diagnostic kit for detecting oak wilt, a devastating disease caused by the fungus *Bretziella fagacearum* (Juzwik et al. 2008). This research aimed to create a colorimetric loop-mediated isothermal amplification (LAMP) (Li et al. 2017) kit that can provide quick visual confirmation of the pathogen within 30 minutes, coupled with a simplified DNA extraction protocol. The scope includes testing the kit's specificity and sensitivity with real oak tree samples and ensuring its effectiveness for large-scale testing during the oak wilt season. The study also focuses on the practical application of the kit in field and lab settings by freeze-drying the reaction mixture and primers for easier transport and minimal error.

METHODS AND APPROACH

The study employed the LAMP technique, known for its rapid and efficient DNA amplification capabilities under isothermal conditions. The LAMP method involves the use of a set of six specially designed primers that recognize six distinct regions of the target DNA, ensuring high specificity and sensitivity. For the detection of *Bretziella fagacearum*, specific primers targeting the pathogen's unique DNA sequences were designed and tested.

A colorimetric LAMP assay was developed, where a color change from pink to yellow indicates the presence of the pathogen. The LAMP reaction mixture and primers were freeze-dried on reaction tubes to facilitate easy transport and on-site testing. A simplistic DNA extraction protocol was also developed, allowing DNA to be extracted from wood samples within 20 minutes using minimal equipment.

The assay was tested on 39 oak tree samples, showing a specificity of over 90 percent and a sensitivity of 100 percent. The entire detection process, including

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DNA extraction and amplification, can be completed in under 45 minutes, making it highly suitable for field applications during the oak wilt season.

FINDINGS AND IMPLICATIONS

The developed colorimetric LAMP kit demonstrated a high sensitivity of 100 percent and a specificity of 90 percent when tested on 39 oak tree samples, indicating its robustness in detecting *Bretziella fagacearum*. The rapid detection capability, with visual confirmation within 25 minutes and a total testing time of under 45 minutes, makes this method highly efficient for large-scale screening during the oak wilt season. The simplified DNA extraction protocol, requiring only 20 minutes, further enhances the practicality of this testing approach in field conditions.

The freeze-dried LAMP reaction mixture and primers allow for easy transport and minimal setup, reducing potential errors during on-site testing. This portable and user-friendly diagnostic tool has significant implications for managing and controlling the spread of oak wilt. By enabling early detection and timely removal of infected trees, this method can help prevent the widespread damage caused by the disease and protect healthy oak populations. The success of this LAMP-based detection platform paves the way for its application in other plant disease diagnostics, offering a valuable tool for both researchers and forestry professionals.

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ACKNOWLEDGMENTS

The authors would like to express their gratitude to Launch Minnesota for their generous support and assistance in facilitating this study. Their resources were crucial in the successful implementation of our research and development methodologies. Without their support, this work would not have been possible.

GROWTH CHARACTERISTICS OF STANDING OAK INDIVIDUALS SUITABLE FOR BARREL WOOD IN A SECONDARY OAK FOREST IN JAPAN

Akira Nakaya, Hisashi Ohsaki, Satoru Murakami, Yasuyuki Ohno, and Toshiya Yoshida

PURPOSE AND SCOPE

When Japanese oak (*Quercus crispula*) is used as barrel wood, the wood must have a small grain angle and a high tyloses filling ratio to prevent liquid leakage (Alamo-Sanza and Nevares 2019). However, there are very few oak trees with these wood properties, raising concern about resource decline. So, it is necessary to grow them through silvicultural management. This study was carried out to determine whether these wood properties could be controlled. We clarify the basic characteristics of grain angle and tyloses filling ratio, and their relationship with growth properties and site conditions of each standing oak tree.

METHODS AND APPROACH

This study was conducted in a natural mixed forest in northern Japan. More than 200 standing oak individuals were identified with tags, and diameter at breast height, stem curvature, bark crack angle, and local stand density were recorded. Wood samples were collected from a height of 3 m while maintaining the individual identification and were used to measure grain angle (GA) (using the splitting method: Nakada et al. 2024) and tyloses filling ratio (TR) together with the number of annual rings and diameter growth rate.

FINDINGS AND IMPLICATIONS

The average GA was 6.3 percent (standard deviation = 3.7, range = 1.7–19.5 percent). Assuming an upper limit of 5.3 percent GA usable as barrel wood (3 cm thickness and 100 cm long board), about half of all the trees were competent. There was no directionality in the grain direction (fig. 1). There was also a weak correlation between the mean GA and the bark crack angle (r = 0.20, P <0.05), but these directions did not coincide in some trees (23 of 71 trees). Although bark crack angle can be an indicator of fiber inclination, our results suggest that there may be trees with greater bark crack angle that are suitable for barrels,

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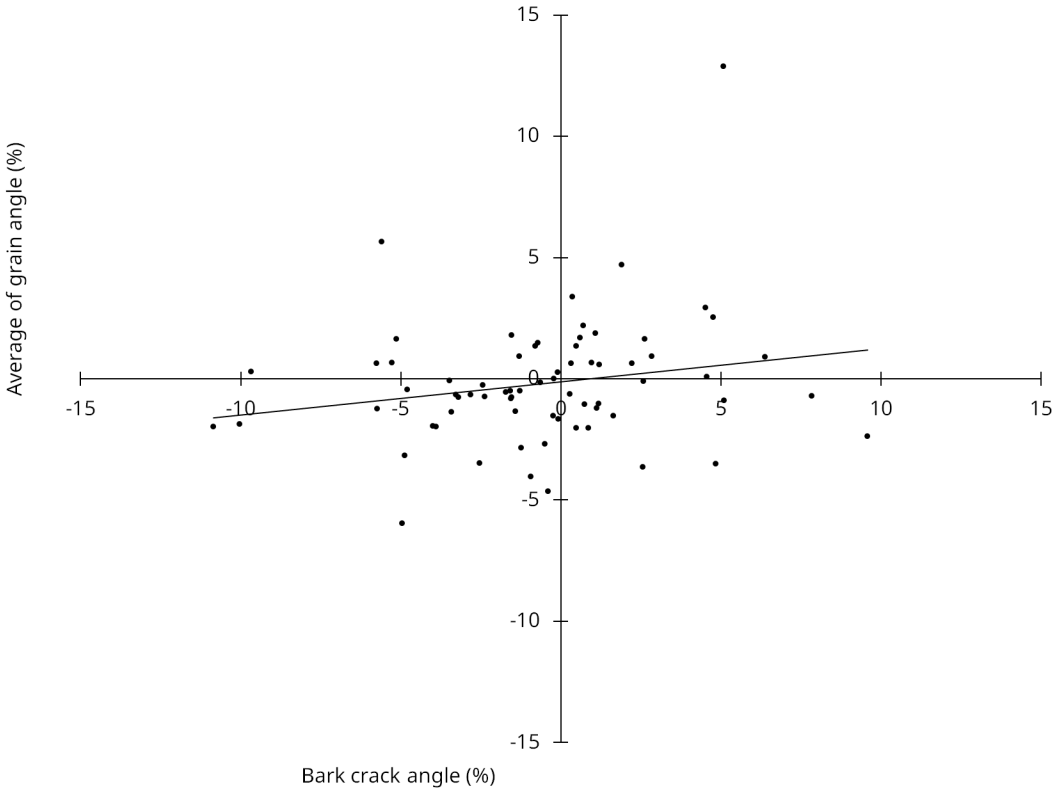

Figure 1—Relationship between average grain angle and bark crack angle. The solid line is a linear regression line.

even though they were previously considered unsuitable for barrels. On the other hand, the average TR was 28.1 percent, with considerable variation among individual trees (standard deviation = 27.3, range = 0.0–91.1). TR decreased towards the pith on the cross section, consistent with a previous report, which showed that tyloses in Japanese oak collapse over time (Sano et al. 1995).

The structural equation modeling suggested that GA and TR have positive and negative correlations with diameter growth rate, respectively. We further analyzed detailed relationships and discuss the possibility of controlling these characteristics through silvicultural practices.

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ACKNOWLEDGMENTS

The authors sincerely thank the Hokkaido Forest Products Research Institute, Hokkaido Forestry Research Institute, and members of the Uryu experimental forest for their assistance in implementing the treatments for this study. We thank also M. Kobayashi, K. Takagi, and members of the Nayoro laboratory at Hokkaido University.

SEED GERMINATION OF 12 EUROPEAN *QUERCUS* SPECIES

Marino Pedro Reyes-Martín, María Sampere-Medina, Alba Lázaro-González, Laura Levy, Jorge Castro, and Alexandro B. Leverkus

Germination potential underlies the capacity for natural regeneration and the success of assisted regeneration, yet data obtained in the field preclude separating intrinsic seed lot potential from environmental constraints. As part of a collaborative European-scale experiment on oak (*Quercus*) regeneration, we tested the germination potential of 93 acorn batches, which belonged to 12 oak species and were collected in 16 countries. Batches of 150 acorns were posted to the University of Granada. From each batch, 50 acorns were soaked in water for 48 hours and wet weighed at the batch level. These acorns were dried at 60 ºC for 72 hours and weighed at the individual acorn level. The remaining 100 acorns were subjected to a germination test. According to the protocol proposed by the International Seed Testing Association, acorns were placed in silica sand at a constant temperature of 20 °C, watered regularly to keep the sand moist, and monitored weekly for 8 weeks. Each acorn batch was separated into two trays, which were placed in different germination chambers. The species-level germination percentages ranged between 16 percent (*Q. trojana*, n = 2 trays) and 77 percent (*Q. frainetto*, n = 4 trays), with an overall germination of 58 percent of all acorns. Besides species-level differences, high variability in germination resulted from acorn batches and, to a lesser extent, from trays. This study contributes data of a trait that is key to our understanding of the ecology of oak regeneration and useful in basic and applied ecology.

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RESPROUTING OF TWO SEEDED AND PLANTED MEDITERRANEAN OAKS AND EFFECTS OF CLIMATE WARMING IN SOUTHERN SPAIN

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PURPOSE AND SCOPE

For large-seeded species such as oaks, selecting among seeding and planting as revegetation methods can influence survival and performance throughout the plant's life. The differences operate particularly through the development of the tap root and the consequent capacity of the plant to access deep water sources (Zadworny et al. 2014). Temperature increase through climate change could thus alter the balance between these two methods. The aim of this research was to study the early performance and resprouting capacity of two oak species with different drought sensitivity, holm oak (*Quercus ilex*) and Portuguese oak (*Q. faginea*), under two revegetation treatments (seeding and planting) and two climatic conditions (current temperature and an approximate 2 ºC increase in air temperature within open-top chambers [OTCs]).

METHODS AND APPROACH

In late 2020, we established a field experiment near Granada (Spain) by seeding acorns in the field and, in parallel, producing nursery seedlings from the same acorn batches. In early 2022, 522 nursery seedlings were transplanted to the field site (640 m²), where they grew with the 562 seedlings that emerged after direct seeding. In total, there were 160 plots, half of which had OTCs. Within the plots, there were 6 or 7 positions where the two species were randomly sown or planted. In late 2023, we harvested the live and dead aboveground biomass of 294 living and 456 dead seedlings and measured their weight and water content. At the beginning of 2024, weekly monitoring of the regrowth began. Seedlings were considered to have regrown if photosynthetic tissue was observed. Data were analyzed using linear mixed models to test fixed effects of revegetation method, species, and temperature increment, and treatment interactions.

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FINDINGS AND IMPLICATIONS

The only factor significantly affecting water content was species ($\chi^2 = 14.3$, $P < 0.001$). Portuguese oak (73.80 ±3.70 percent) had higher water content than holm oak (60.10 ±1.67 percent). Species also performed differently to OTCs: holm oak dry shoot mass was higher without OTC (12.4 ±1.65 g) than with OTC (6.16 ±1.09 g), whereas Portuguese oak showed no difference (7.28 ±1.27 g), resulting in an OTC × species interaction ($\chi^2 = 4.6$, $P < 0.05$). Resprouting was high in all treatments and species (table 1), but the increase in temperature reduced resprouting rate except for Portuguese oak from seeding.

Table 1—Percentage of individuals that resprouted from January through June 2024 according to revegetation method, air temperature in open-top chambers (OTC), and species

Revegetation method	OTC	Species	n	Regrowth % (n)
Planting	No	Holm oak	37	91.89 (34)
Planting	No	Portuguese oak	40	95.00 (38)
Planting	Yes	Holm oak	4	75.00 (3)
Planting	Yes	Portuguese oak	4	75.00 (3)
Seeding	No	Holm oak	68	94.12 (64)
Seeding	No	Portuguese oak	58	87.93 (51)
Seeding	Yes	Holm oak	49	89.80 (44)
Seeding	Yes	Portuguese oak	43	93.02 (40)

n = number of individuals initially present before being cut in December 2023.

Water content was only affected by species due to their different strategies: holm oak is evergreen and Portuguese oak is marcescent. This strategy is also linked to species growth; thus, holm oak grows less with increased temperature, whereas Portuguese oak is unaffected. Therefore, species that avoided the warmer season were expected to be less affected by temperature increases compared to those that tolerate it in terms of growth. For resprouting capacity, there do not appear to be significant differences between treatments. However, the number of individuals from planting with OTC is very small due to low survival after 2 years. Overall, it seems that an increase in temperature of 1.5 to 2 °C slightly decreases resprouting success. Therefore, we could expect that as temperatures continue to rise, the resilience of these species will decrease (Gea-Izquierdo et al. 2013).

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ACKNOWLEDGMENTS

This research was funded by grant TRANS-ECO (TED2021-130976B-100) from Ministry of Science and Innovation/NextGeneration, grant RESISTRES (C-EXP-267-UGR23) from University of Granada/Junta de Andalucía/FEDER, grants RESTAURABIEN (RTI2018-096187-J-100) from the Spanish Ministry of Science, Innovation and Universities/FEDER.

RESTORING A RARE OAK FOREST TYPE WITH ARTIFICIAL REGENERATION

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A forest restoration project was initiated in 2018 in urban northern Virginia with the intent to use artificial regeneration of oak species on a 21-acre site with little to no natural regeneration. The goal of the project was to restore a globally rare, oak-dominated forest type with a high diversity of herbaceous plants. The project objective was to establish future canopy trees and enhance herbaceous plant diversity. Methods included a shelterwood cut; best practices in nonnative invasive plant control; woody competition control; control of white-tailed deer (*Odocoileus virginianus*) herbivory by using electric fencing; use of enhanced bare root planting stock; development of contractor and nursery relationships; and intensive project management. Three separate planting events took place by using standard or enhanced bare root planting stock. Planting goals were to achieve 800 tree seedlings per acre. The first two plantings occurred in 2020, used standard planting stock and experienced a survival rate of 34 percent after 1 year. The second planting occurred in December 2021, used enhanced planting stock and experienced a survival rate of 65 percent after 1 year. Volunteer seedling presence was facilitated by use of the electric deer fence. In 2022 after 1 year, the site averaged 646 desirable trees per acre, of which 420 were plantings and 226 were volunteers. Data were collected in year two (fall of 2023) and results are forthcoming.

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THE RELATIONSHIP BETWEEN SOIL PROPERTIES AND OAK REGENERATION IN EASTERN KENTUCKY

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Oaks (*Quercus* spp.) are a keystone tree species in Kentucky, both ecologically and economically. However, that dominant status is at risk due to persistent and well-documented regeneration struggles in the absence of active management targeted at perpetuating oak into the next generation of forests. Oak regeneration problems typically vary in degree with soil and site characteristics, and the risk to oak regeneration is especially high on productive sites where oak is often overtaken by fast-growing competitor species. This project aims to examine the utility of soil physical and chemical properties in modeling the abundance of oak regeneration in eastern Kentucky, using both fine-scale and broad-scale data. Fine-scale models will be developed using soil and vegetation data collected within the study area, an approximately 200-acre watershed located in Improvement Hollow in Robinson Forest, Breathitt County, KY. Broad-scale models will be developed using soil and vegetation data from national databases such as the U.S. Department of Agriculture, Forest Service, Forest Inventory Analysis and the Soil Survey Geographic (SSURGO) databases. This poster highlights the prominent soil and forest characteristics of the study site and preliminary results of their relationships. As a result of this research, our understanding of the relationships between soil properties and oak regeneration will improve and, in turn, so will the precision in which we can identify areas that may benefit from silvicultural intervention.

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DYNAMICS OF *QUERCUS CRISPULA* (JAPANESE OAK) POPULATIONS IN NATURAL MIXED FORESTS UNDER A SELECTION CUTTING REGIME IN NORTHERN JAPAN

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PURPOSE AND SCOPE

In Japan, the demand for broadleaf trees, especially oak, has increased significantly due to the limited supply of logs from overseas and the increasing preference for domestic timber. Japanese oak (*Quercus crispula*) exists as a dominant species in natural mixed forests, but its sustainable management has not been established. In this study, I describe the long-term dynamics of Japanese oak under a selection system over a 40-year period. In the target experimental stand (37 ha in area), single-tree selection with a 10-year rotation has been continued since the 1970s based on an intensive tree survey. A previous study (Yoshida et al. 2006), covering the first 20 years, showed that Japanese oak was gradually increasing. Furthermore, additional investigations of natural regeneration (Miya et al. 2009, Noguchi and Yoshida 2007) have shown that Japanese oak saplings are predominantly found under a closed canopy, where dwarf bamboo, a major inhibitor, was less abundant on the forest floor. The aim of this study was to determine whether this trend continued over a 40-year period. I investigated factors related to long-term dynamics and clarify the conditions that will lead to the sustainable production of Japanese oak in the long term.

METHODS AND APPROACH

A long-term, wide-scale experiment was conducted in a natural mixed forest in Hokkaido, northern Japan. The dominant tree species were *Abies sachalinensis*, *Acer mono*, *Quercus crispula*, *Tilia japonica*, and *Betula ermanii*, and the forest floor was densely covered with dwarf bamboo. The predominant natural disturbance was windfall. The targeted experiment stand was 37 ha. From the 1970s, all living trees (diameter at breast height [d.b.h.] >12.5 cm) with individual identification have been measured, and selection cutting with a cutting rate of 10 to 20 percent by volume has been conducted every 10 years. Changes in volume over 40 years and demographic parameters (diameter-class promotion, recruitment, and survival rate) were calculated. In addition, for a 6.7-ha area where spatial data of individual tree location was available, I used a generalized linear model to analyze factors related to these parameters.

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FINDINGS AND IMPLICATIONS

The volume recovery of Japanese oak under selection cuttings was remarkable compared to the other tree species. It also showed a slight increase even in the period when a windfall disturbance occurred. The recruitment rate of Japanese oak was high, second only to birch species. The number of small-diameter trees increased significantly over time, and as a result, the frequency distribution, which had a mode around 20 cm, changed to a reverse J-shape (fig. 1). The growth rate of Japanese oak decreased with local crowding and increased with the intensity of selection cutting in the surrounding area. On the other hand, new recruitment around mother oak trees increased with the initial local crowding (possibly due to negative effect on dwarf bamboo), and increased with the intensity of selection cutting.

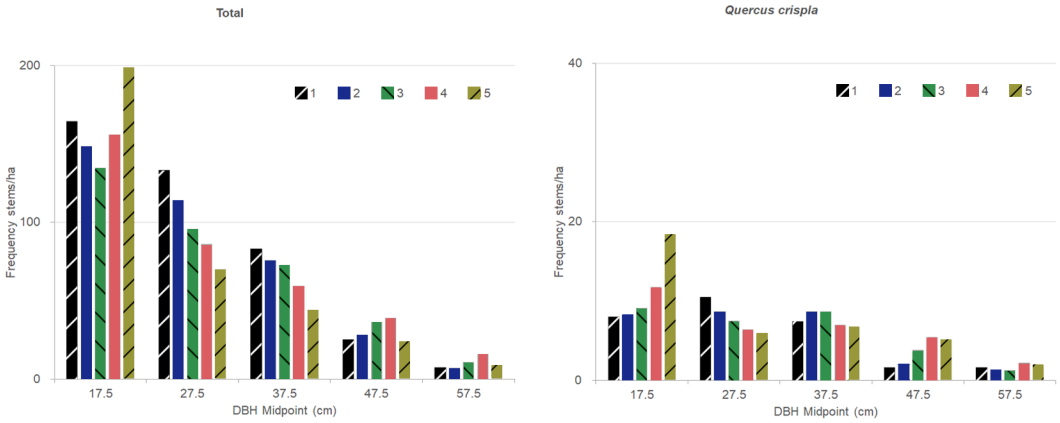

Figure 1—Diameter-class distribution of the 37-ha experimental stand over 40 years. All species combined (left); *Quercus crispula* (right). Surveys were conducted at 10-year intervals, at the beginning of rotations (numbers in legend).

Thus, in this forest, Japanese oak responded favorably to the stand changes. The increase in growth rate, especially in the latter period, may also be influenced by climate change. As for the high recruitment rate, it is possible that management operations significantly contributed to newly established individuals. Japanese oak could be a major target species, along with early successional species such as birch, for the selection system in this type of mixed stand. In order to make the system more sustainable, it is essential to carry out regeneration assistance in conjunction with single-tree cutting, and to periodically open the canopy to enhance growth of remaining trees.

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ACKNOWLEDGMENTS

I would like to thank members of the Nakagawa Experimental Forest, Hokkaido University for their cooperation in this research and fieldwork.

Martens, C.; Clark, S.; Schweitzer, C., eds. 2024. The International Oak Symposium: Science-Based Management for Dynamic Oak Forests. Gen. Tech. Rep. SRS-278. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 194 p. https://doi.org/10.2737/SRS-GTR-278.

The 2024 *International Oak Symposium* is an inaugural meeting in Knoxville, TN, USA and represents the first international symposium addressing broad ecological and forestry issues of the genus *Quercus* (oak) ever held in the United States. The symposium provides opportunities and platforms to exchange information and build collaborations around the best available science and technology on oak ecology and management for a global audience. The meeting provides innovative and progressive formats, such as panel discussions, field tours, receptions, surveys, and question and answer sessions to deliver and exchange information and foster collaborations between researchers and practitioners. Attendees chose one of three field tours that will showcase: 1) multidisciplinary research by the U.S. Department of Agriculture, Forest Service and The University of Tennessee Institute of Agriculture; 2) Indigenous and western ecological knowledge and cultural history of the Great Smoky Mountains National Park; or 3) prescribed fire and silviculture at the Catoosa Wildlife Management Area. The symposium features 13 invited plenary session speakers from North America and Europe and approximately 100 offered oral presentations and posters from four continents. Presentations address an array of topics: climate change impacts and climate-smart forestry; woodland restoration; genetics, genomics, and tree improvement; prescribed fire efficacy; emerging economic markets including carbon; forest health; and silvicultural applications for natural and artificial regeneration. Two common themes identified at the symposium are: 1) the difficulty and barriers that impede the delivery and application of the best available science to land managers, and 2) the need for active management while facing uncertainty. Presenters represent various organizations from nongovernmental organizations, Federal agencies, State agencies, research centers, universities, and industry.

Keywords: carbon, climate change, markets, prescribed fire, *Quercus*, regeneration, restoration, silviculture, water, woodlands

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