



Proceedings of the 21st Biennial Southern Silvicultural Research Conference

March 16-17, 2021

Virtual Conference

sil.vics \ 'sil-viks \ n pl but sing in constr [NL silva] : the study of the life history, characteristics, and ecology of forest trees esp. in stands
sil.vi.cul.tur.al \ ,sil-və-'kəlch-(ə)rəl \ adj : of or relating to silviculture — *sil.vi.cul.tur.al.ly* \ -ē \ adv
sil.vi.cul.ture \ 'sil-və-'kəl-cher \ n [F, fr. L silva, sylva forest + cultura culture] : a phase of forestry dealing with the development and care of forests — *sil.vi.cul.tur.ist* \ ,sil-və-'kəlch-(ə)rəst \ n
sil.vics \ 'sil-viks \ n pl but sing in constr [NL silva] : the study of the life history, characteristics, and ecology of forest trees esp. in stands
sil.vi.cul.tur.al \ ,sil-və-'kəlch-(ə)rəl \ adj : of or relating to silviculture — *sil.vi.cul.tur.al.ly* \ -ē \ adv
sil.vi.cul.ture \ 'sil-və-'kəl-cher \ n [F, fr. L silva, sylva forest + cultura culture] : a phase of forestry dealing with the development and care of forests — *sil.vi.cul.tur.ist* \ ,sil-və-'kəlch-(ə)rəst \ n
sil.vics \ 'sil-viks \ n pl but sing in constr [NL silva] : the study of the life history, characteristics, and ecology of forest trees esp. in stands
sil.vi.cul.tur.al \ ,sil-və-'kəlch-(ə)rəl \ adj : of or relating to silviculture — *sil.vi.cul.tur.al.ly* \ -ē \ adv
sil.vi.cul.ture \ 'sil-və-'kəl-cher \ n [F, fr. L silva, sylva forest + cultura culture] : a phase of forestry dealing with the development and care of forests — *sil.vi.cul.tur.ist* \ ,sil-və-'kəlch-(ə)rəst \ n

DISCLAIMER

The use of trade or firm names in these proceedings is for reader information and does not imply endorsement by the U.S. Department of Agriculture or Louisiana Tech University of any product or service.

PESTICIDE PRECAUTIONARY STATEMENT

Some of the papers and extended abstracts within these proceedings include research involving pesticides. They do not contain recommendations for their use, nor do they imply that the uses discussed here have been registered. All use of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife if they are not handled or applied properly. Use all herbicides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and their containers.

EDITORS' NOTE

Papers published in these proceedings were submitted by authors in electronic media. Some editing was done to improve the readability, accuracy, and consistency of contributed papers. Authors are responsible for content and accuracy of their individual papers and the quality of illustrative materials.

September 2022

<https://doi.org/10.2737/SRS-GTR-268>



Forest Service
Research & Development
Southern Research Station
General Technical Report SRS-268



Southern Research Station
200 W.T. Weaver Blvd.
Asheville, NC 28804
www.srs.fs.usda.gov

Proceedings of the 21st Biennial Southern Silvicultural Research Conference

**March 16-17, 2022
Virtual Conference**

**Edited by
John Willis
Andrew B. Self
Courtney M. Siegert**

**Hosted by
Mississippi State University
USDA Forest Service, Southern Research Station**

Preface

The 21st Biennial Southern Silvicultural Research Conference (BSSRC) was held on March 16-17, 2021, in a virtual format due to COVID -19. This was the first time the BSSRC has been held in a virtual format. The BSSRC is designed as a forum to exchange silvicultural information between researchers, land managers, forest industry, and graduate students. Historically, the BSSRC proceedings has served as a repository of the research presented at the conference and can be referenced by anyone interested in the stewardship of southeastern forests.

The two-day event was highlighted by a keynote address from Jim Guldin, Retired Scientist, Southern Research Station, USDA Forest Service, recognizing the previous success of silviculturists in the region and identifying existing challenges. During the conference, presenters offered 64 oral and 22 poster presentations. Of those presentations, 27 were presented by graduate students (18 oral and 9 posters). No field tours were offered due to the pandemic. Overall, 160 people attended the virtual conference.

Acknowledgments

The organizers would like to acknowledge additional sources of support in this year's virtual meeting. We are grateful to Mississippi State University for developing the conference website, helping with the registration process, and its diligence in handling the fiscal responsibilities of the meeting. We are grateful to Leslie Boby, Darryl Outlaw, and others at the Southern Regional Extension Forestry's Agriculture and Forestry Webinar Portal for serving as the platform host for this meeting. And finally, we are endlessly grateful to Aries Spruell (PhD Student, Department of Instructional Systems and Workforce Development, Mississippi State University) for her technical savvy and support.

Program Chairs and Local Arrangements:

Courtney Siegert, Mississippi State University

John Willis, USDA Forest Service, Southern Research Station

Steering Committee Members:

Brian Lockhart, Retired, USDA Forest Service, Southern Research Station

Brian Oswald, Stephan F. Austin State University

Gordon Holley, Louisiana Tech University

Conner Fristoe, Weyerhaeuser

Joshua Adams, Louisiana Tech University

Brady Self, Mississippi State University

Kyle Cunningham, University of Arkansas

Eric Taylor, Texas A&M Forest Service

Andrew Ezell, Professor Emeritus, Mississippi State University

Callie Schweitzer, USDA Forest Service, Southern Research Station

Don Bragg, USDA Forest Service, Southern Research Station

Jim Guldin, USDA Forest Service, Southern Research Station

David Wilkinson, Hancock Forest Management

Tom Dean, Louisiana State University
John Willis, USDA Forest Service, Southern Research Station
Courtney Siegert, Mississippi State University
Mike Blazier, University of Arkansas Monticello

Proceedings:

John Willis, USDA Forest Service, Southern Research Station
Brady Self, Mississippi State University
Courtney Siegert, Mississippi State University

**21st BSSRC Student Oral and Poster Presentation Contest Winners
(major professor in parentheses)**

Oral Presentations:

Darcey Collins—Mississippi State University (Dr. Joshua Granger)
Norman Cone—Louisiana Tech University (Dr. Joshua Adams)
Isreal Ojo—Florida A&M University (Dr. Alfredo Lorenzo and Dr. Lucy Ngatia)

Poster Presentations:

Elizabeth Baach—Mississippi State University (Dr. Austin Himes)
Amelia MacDonald—Western Carolina University (Dr. Beverly Collins)
Sally Shroyer—Stephen F. Austin University (Dr. Rebecca Kidd)

Contents

KEYNOTE

A Status Report on Silviculture in the South—Amazing Successes, and Challenges That Remain

James M. Guldin 2

PRESCRIBED FIRE

Radial Growth Response of Shortleaf Pine (*Pinus echinata*) and Post Oak (*Quercus stellata*) to Climatic Variability and Management in Southeastern Oklahoma

Rodney E. Will, Arjun Adhikari, Ronald Masters, Henry Adams, Omkar Joshi, and Chris Zou . . . 14

Flammability of Litter From 50 Southeastern Tree Species Along Mesophication Gradients

J. Morgan Varner, Jeffrey M. Kane, Jesse K. Kreye, and Timothy M. Shearman 16

Variation in Bark Allocation and Rugosity Across Seven Co-Occurring Southeastern U.S. Tree Species

Timothy M. Shearman and J. Morgan Varner 18

Temporal Effects of Hurricanes and Prescribed Fire on Fuel Loading and Pine Reproduction in the Southeastern United States

Lauren S. Pile Knapp, Shanyue Guan, Bo Song, and G. Geoff Wang 21

BOTTOMLAND AND RIPARIAN FORESTS

Occurrence and Growth Dynamics of Natural Regeneration in an East Texas Bottomland Hardwood Forest

Lydia J. Voth Rurup, Kathryn R. Kidd, Jeremy P. Stovall, Brian P. Oswald, and Steven B. Jack . . . 33

Evaluating Watershed-scale Effects of Longleaf Pine Restoration on Water Yield using a Paired Watershed and Modeling Approaches

Devendra M. Amatya, Herbert Ssegane, Mohamed D. Hamidi, and Carl C. Trettin 39

Impact of Forest Land Use Changes on Groundwater Resources in a Basin of Lower Mississippi River Alluvial Valley Over the Past 100 Years

Ying Ouyang 43

Options for Riparian Buffer Tree Planting in North Alabama

Callie Jo Schweitzer, Daniel C. Dey, and Naijiang Wang 44

The Effect of Drought on Loblolly Pine (<i>Pinus taeda</i>) Photosynthesis and Whether Thinning or Genetic Entry Can Improve Plantation Drought Resilience <i>Norman J. Cone IV, Joshua P. Adams, Michael A. Blazier, Mary Anne S. Sayer, and Michael C. Tyree.</i>	51
---	----

LOBLOLLY PINE MANAGEMENT

Three-Year Growth of Loblolly Pine Seedlings Following Herbaceous Weed Control Applications of Sulfometuron, Imazapyr, Hexazinone, and Indaziflam <i>Andrew W. Ezell, Andrew B. Self, John E. Ezell, and Jason Belcher</i>	56
--	----

Use of Glufosinate to Control Natural Pines—a Possible Replacement for Glyphosate <i>Andrew W. Ezell, Andrew B. Self, and John E. Ezell.</i>	59
--	----

Four-Year Results of a Chopper® Gen2™ and Forestry Garlon® XRT Rate and Timing Study for Loblolly Pine Site Preparation on the Lower Coastal Plain of Georgia <i>David C. Clabo and E. David Dickens.</i>	62
---	----

Fertilization and Post-Drought Recovery Growth Help Compensate for 9 Years of Precipitation Reduction in a Mid-Rotation <i>Pinus taeda</i> Plantation in the Western Gulf Region, USA <i>Noah T. Shephard, Omkar Joshi, Cassandra R. Meek, and Rodney E. Will</i>	69
---	----

Control of Natural Pines Using Site Preparation Mixes With Imazapyr, Glyphosate, Saflufenacil, BAS #1, and BAS #2 <i>A. Brady Self and Andrew W. Ezell</i>	72
--	----

Russell R. Reynolds, Pioneering Forest Service Silviculture Researcher <i>Don C. Bragg.</i>	75
---	----

First Year Height Performance of Planted Loblolly Pine Following Site Preparation and Herbaceous Release Treatments on a Lower Coastal Plain Site <i>Stephen E. Peairs.</i>	78
---	----

NATURAL DISTURBANCES AND CLIMATE CHANGE

Forest Landowner Resources for Hurricane and Soil Salinization Preparation and Recovery in the Southeastern United States <i>Nancy Gibson, Steven McNulty, Michael Gavazzi, Chris Miller, and Elijah Worley</i>	84
---	----

Effects of Tornado and Salvage Harvesting Disturbances on Vegetative Community Dynamics in Upland Mixed Pine—Hardwood Stands Within the Davy Crockett National Forest, Texas <i>Cassey L. Edwards, Amber N. Blair, Sally J. Shroyer, Alanna B. Crowley, Kathryn R. Kidd</i>	86
---	----

Current and Emerging Risks to Southeastern U.S. Forests <i>Kelsey Bakken, Steven McNulty, Michael Gavazzi, Eva Paradiso, and Elijah Worley</i>	92
Adapting Traditional Forest Management Practices to Address Changing Environmental Stresses <i>Elijah Worley, Steven McNulty, Michael Gavazzi, Kelsey Bakken, and Eva Paradiso</i>	95
Exploring Economics of Loblolly Pine Management in Drought Using Efficiency Analysis <i>Noah T. Shephard, Andres Susaeta, Omkar Joshi, and Rodney E. Will</i>	98
Evaluation of Landowner Accessible Control Methods for Japanese Stiltgrass (<i>Microstegium vimineum</i>) <i>Casey L. Beam, Courtney M. Siegert, Joshua J. Granger, and Raymond B. Iglay</i>	100
Connecting Strategic Planning with Forest Operations Using the Forest Adaptive Management Online User System (FAMOUS) <i>Kelsey Bakken, Eva Paradiso, Steven McNulty, Michael Gavazzi, and Elijah Worley</i>	107
Assessing the Flood Tolerance of Willows and Cottonwoods Planted in Riparian Cropland of the Lower Mississippi Alluvial Valley <i>Thu Ya Kyaw, Courtney M. Siegert, Heidi J. Renninger, and Randall J. Rousseau</i>	109

LONGLEAF PINE MANAGEMENT

Can Longleaf Pine Plantations be Modeled by Calibrating Mixed-Effects Models of Other Species? <i>Curtis L. VanderSchaaf</i>	115
Linkage Between Longleaf Pine Seedling Morphology and Grass Stage Emergence <i>Mary Anne S. Sayer and Shi-Jean Susana Sung</i>	123
Seasonal Biennial Burning Has Negligible Effects on Longleaf Pine Basal Area Growth <i>John L. Willis, Ajay Sharma, and John S. Kush</i>	126
Understanding Wind Risk to Forests: Towards Mechanistic Models of Wind Risk in the Southeastern Coastal Plain <i>Jeffery B. Cannon, Brandon T. Rutledge, R. Kevin McIntyre, Angela M. Holland, and Steven B. Jack</i>	128
The Percentage of Trees Bearing Cones as a Predictor of Annual Longleaf Pine Cone Production <i>Thomas W. Patterson</i>	132
Planted Longleaf Pine Stands in the Face of a Tropical Cyclone <i>Seth W. Bigelow, Andrew W. Whelan, Jeffery B. Cannon, Gregory Starr, Christina L. Staudhammer, Gavin R. Kenney, and Steven T. Brantley</i>	136

UPLAND HARDWOODS MANAGEMENT

Natural Pruning Varying With Sweetgum Variety and Density <i>Joshua P. Adams, Michael Blazier, and Curtis L. VanderSchaaf</i>	140
Thirty Years of Cooperative Oak Research and Technology Development in The Southern Region <i>Stacy L. Clark, Scott E. Schlarbaum, Barbara Crane, and Tom Tibbs</i>	143
Effects of Forest Management Practice (Prescribed Burning) on Mercury Transport: a Case Study in a Paired Experimental Watershed in the Lower Coastal Plain of South Carolina <i>Peijia Ku, Martin Tsui, Troy Farmer, Huan Chen, Devendra Amatya, Carl C. Trettin, and Alex Chow</i>	147
Fifth Year Development of Natural Regeneration Following Pre-Commercial Herbicide Release Treatments <i>Stephen E. Peairs and Wayne K. Clatterbuck</i>	150
Is There Hope for Hybrid Poplars in the Southern United States? <i>Randall J. Rousseau, Kiah M. Smith, Mark Murphy, and Taylor Bowling</i>	156
Water Use, Efficiency, and Stomatal Sensitivity in Eastern Cottonwood and Hybrid Poplar Varietals on Contrasting Sites in the Southeastern United States <i>Heidi J. Renninger, Leah F. Stewart, and Randall J. Rousseau</i>	166

SHORTLEAF PINE MANAGEMENT

Development and Competitive Status of Shortleaf Pine Seedling Sprouts After Prescribed Burning in a Mid-Atlantic Mixedwood Forest <i>Matthew G. Olson</i>	171
Are Local Seed Sources Still Recommended for Planting Shortleaf Pine in Southern New Jersey and Central Pennsylvania? <i>Grant Gallagher and Matthew G. Olson</i>	174
Height of Pitch and Shortleaf Pine is Increased by Intraspecific Competition 13 Years After Planting in the Southern Appalachians <i>W. Henry McNab</i>	181
Restoration Planting of Pitch and Shortleaf Pines After Clearcutting a Mixed Hardwood Stand on a Ridge Site in the Southern Appalachians: Lessons Learned After 13 Years <i>W. Henry McNab</i>	189

POSTER SESSIONS

Hedonic Analysis of Loblolly Pine Plantation First Thinning Costs <i>T. Eric McConnell</i>	197
--	-----

Probabilistic Estimates of Costs for Treating Southern Pine Beetle Infestations by Cut-and-Leave Suppression Measures During an Outbreak	
<i>Curtis L. VanderSchaaf, T. Eric McConnell, Michael K. Crosby, Jason J. Holderieath, James R. Meeker, Chris A. Steiner, Brian Strom, Crawford (Wood) Johnson</i>	202
Projecting Stand Development and Economics of Longleaf Pine Planted Outside its Known Historical Range	
<i>Curtis L. VanderSchaaf, Michael A. Blazier, Joshua P. Adams</i>	208
Breast Level Height Displacement: Do Standing Trees Sink Into the Soil	
<i>Curtis L. VanderSchaaf, Boris Zeide, and William B. Patterson</i>	217
Ability of Site Index to Differentiate Merchantable Yield in Southern Yellow Pine Plantations	
<i>Curtis L. VanderSchaaf</i>	222
Developing a Simple Longleaf Pine Plantation Growth and Yield Model for the Gulf Region	
<i>Curtis L. VanderSchaaf</i>	231
Growth Response of Mature Longleaf Pine to Drought and Thinning at The Harrison Experimental Forest in South Mississippi	
<i>John R. Butnor, Robert J. Eaton, and C. Dana Nelson</i>	241
A Photographic Record of The First Silvicultural Research by The Southern Forest Experiment Station	
<i>Don C. Bragg.</i>	249
Effects of Planting Stock on Growth and Survival in an Artificially Regenerated Shortleaf Pine Forest in the Southern Appalachian Mountains	
<i>Tara L. Keyser and Amelia L. MacDonald.</i>	256

Keynote



A STATUS REPORT ON SILVICULTURE IN THE SOUTH—AMAZING SUCCESSES, AND CHALLENGES THAT REMAIN

James M. Guldin

ABSTRACT

Over the past century, foresters in the Southern United States have achieved remarkable success in the practice of silviculture. Key elements of success include learning how to plant southern pines, which gave rise to genetic improvement and cultural practices that have placed short-rotation planted pine stands on a quarter of the South's timberlands. A second element was the application of conservative silvicultural practices, including uneven-aged methods in southern pines, to help recover cutover but partially stocked stands. Both these advances contributed to retaining industrial forestry capacity in the South through the middle of the 20th century, with the result today that the South has become the “woodbasket” of the Nation. Other key silvicultural advances were the success in applying seed-tree and shelterwood methods in pines, shelterwood methods in oaks, and restoration of prescribed fire which has helped recover open fire-adapted pine-dominated forests and woodlands across the South. Despite these successes, the South faces silvicultural challenges in the 21st century within the realm of economics, ecological issues, and social concerns. It's certainly an exciting time, and a challenging one, for foresters in the first decade of their careers.

INTRODUCTION

The period of aggressive harvesting of virgin forests in the Southern United States lasted for about 40 years, roughly from 1880 to 1920. Private investors bought timberland, built sawmills, and milled dimension lumber that served as the primary raw material for a rapidly growing Nation, especially for residential construction. In 1903, President Theodore Roosevelt embraced that view in his address to the new Society of American Foresters (SAF) when he highlighted that the purpose of the forest policy of the United States was the “making of prosperous homes” (Roosevelt 1905).

But when the virgin pine timber was all harvested, some mill owners followed the “cut out and get out” philosophy—they closed the mill, abandoned the cutover land and the towns built to support it, loaded the mill's machinery onto rail cars, and moved a thousand miles or more to harvest the remaining virgin timberlands in the Western United States. Other mill owners made a different gamble, placing a bet on the inherent productivity of southern pines and on the new profession of forestry. A century later, the success that foresters enjoy in southern silviculture has been directly related to the ways the profession responded to the varying conditions that remained following the harvest of those virgin stands.

FOREST CONDITIONS AT THE START OF THE 20th CENTURY

Foresters faced a host of difficult conditions through the 20th century, but four general types of conditions stand out.

The first was typified by conditions found on the lower Gulf Coastal Plain west of the Mississippi River. Millions of acres were completely cutover, with virtually no residual seed sources or standing volume (fig. 1). Wahlenberg (1960)



Figure 1—Cutover landscape in the early 1940s on the lower Gulf Coastal Plain on the Longleaf Tract, Palustris Experimental Forest, near Alexandria, LA (USDA Forest Service photo).

Author Information: James M. Guldin, Retired Research Forest Ecologist, U.S. Department of Agriculture, Forest Service, Southern Research Station, Springfield, MO 65804.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.



Figure 2—Planting the arboretum at the Crossett Experimental Forest, Ashley County, Arkansas, spring 1935. A caption on the back of the photo states “the timber stand in the background is typical of the unmanaged second-growth stands at Crossett EF” (USDA Forest Service photo).

estimated that there were 29 million acres of cutover forest land in need of regeneration.

A different challenge was found on millions of acres of cutover land that retained some degree of stocking after the virgin stands were cut. Harvests were basically a stump-limit harvest; trees were cut if they had a stump diameter of 15 inches, or roughly a diameter at breast height (d.b.h.) of 12 inches and were not defective (Reynolds 1959). After that harvest, depending on local conditions, an understocked stand of pines and hardwoods typically remained, consisting of trees that were smaller than 12 inches d.b.h., augmented by new pine seedlings and saplings that either predated the harvest or became established from seedfall of the mature defective pines that remained scattered across the stand (fig. 2).

In bottomland hardwood systems such as those found in the lower Mississippi Alluvial Valley, flood control and agriculture played significant roles in the loss of bottomland hardwood forests. More than half of the landscape was deforested by the early 1900s, and by the latter part of the 20th century, deforestation had removed 70 percent of the original bottomland hardwood forest cover (figs. 3A and 3B) (Gardiner 2014). Much of this was converted into agricultural land that still today provides crops that feed and clothe the Nation, but the loss of those bottomland hardwood forests is still being felt.

In the Appalachians, the profession dealt with the unimaginable loss of the American chestnut (*Castanea dentata*). American chestnut constituted 25-50 percent of the canopy trees in its native range; it was 25 percent of all timber cut in the Southern Appalachians, and it was the most widespread and abundant species in the Eastern United States since the last glaciation (Wang and others 2013). Hepting (1974) noted that most of the land formerly occupied by chestnut has been taken over by young growth of oaks,



Figure 3—Changes in bottomland hardwood forests illustrated by two current images: (A) aerial view of the White River National Wildlife Refuge near Stuttgart, AR, showing heavily forested bottomland hardwood forests found in the Mississippi Delta; (B) aerial view of the town of Stuttgart, AR surrounded by modern agricultural fields (USDA Forest Service photo by James M. Guldin).

maples, poplars, ashes, and other species that were associated with the chestnut. The challenges that foresters face with oak regeneration and the imbalance of mature hardwood age classes across the Eastern United States in the 21st century may well date back to the loss of chestnut.

SUCCESS STORIES FROM THE 20th CENTURY

Across the South, creative silvicultural approaches emerged in response to the challenges faced by resource managers a century ago. Their combined efforts allowed forest products companies to stay in the South. The modernization of industrial forestry enabled the growth of cities and towns across the South, and helped build the vibrant regional forest products economy that landowners and managers enjoy today.

Success Story 1—Learning How to Plant Trees

The harvests of virgin pine forests led directly to the first amazing success of southern silviculture. In the middle of the 20th century, foresters realized that they had to learn how to plant southern pines, and to raise them in huge quantities in nurseries. Since then, genetic improvement and cultural practices have combined to produce trees that grow to sawtimber size in 25 years or less, on nearly 25 percent of the forested land base in the South.

The only solution in completely cutover stands with no residual stocking was to develop research and technology for the widespread application of artificial regeneration of southern pines. The pinnacle of this excellent effort was the publication of Wakeley's monograph, "Planting the Southern Pines" (Wakeley 1954), which became the most frequently cited publication in the U.S. Department of Agriculture (USDA) Forest Service's Research and Development deputy area in the 20th century. Wakeley's work spoke to cone collection, seed extraction, seed sowing, nursery practice, and outplanting, all of which remain applicable today.

The real advantage of the idea of raising pine seedlings in nurseries was also to take advantage of genetic improvement (Dorman 1976). Extraordinary genetic gains in volume growth, stem straightness, stem form, and disease resistance have been obtained through several generations of breeding, especially in loblolly pine (*Pinus taeda*) (McKeand and others 2003) and slash pine (*P. elliottii*) as well. After two decades in the 21st century, third-cycle selections for loblolly pine are widely operational, and fourth- and fifth-cycle selections are in progress (McKeand 2019, McKeand and others 2015). Volume gains at age 6 from open-pollinated third generation selections average 48 percent greater than unimproved checks; of the top 100 families for volume gain, 48 of those families have volume increment that is, on average, 63 percent greater than unimproved checks (McKeand 2019). However, full-sib families developed by crossing the best parents produce trees that are faster growing, straighter, and more fusiform rust resistant than open-pollinated families (McKeand 2019). As a result, roughly 173 million full-sib seedlings were planted across the South in 2018 and 2019, which represents 21 percent of all loblolly planted seedlings. Southwide, that number is likely to increase annually in the foreseeable future (McKeand and others 2021). McKeand and others (2021) report that a gain of at least 1 percent annually will continue for decades, but they provide an important caveat—if resources to continue tree improvement efforts remain available.

Cultural practices have been equally important in realizing the potential of planted loblolly pine and slash pine stands (Fox and others 2007), especially from the operational perspective. Advances in nursery production and seedling transportation



Figure 4—First thinning in a planted loblolly pine stand at age 12, Ashley County, Arkansas, May 2014 (USDA Forest Service photo by James M. Guldin).

have led to seedling survival rates that typically exceed 90 percent. Site preparation, especially chemical site prep for control of both woody hardwoods and herbaceous weed control, has been instrumental in optimizing seedling growth, especially in the first year of outplanting (Allen and others 2005). Fertilization has also been important both in giving a boost to newly planted seedlings, and to maintain volume growth during mid-rotation using N and P fertilization. As a result, stands are managed through the first commercial thinning around age 12, followed by a clearcut harvest between the ages of 22 to 25 years (fig. 4). This intensive silvicultural practice produces yields in excess of 10 tons per acre annually (Fox and others 2007).

As an interesting historical silvicultural aside, the development of the concept of 25-year rotations for southern pines was based on data taken during the final clearcut harvest of the Sudden Sawlog Study which lasted from 1947 to 1992 on lands of the Crossett Lumber Company and, later, the Georgia-Pacific Corporation near the Crossett Experimental Forest in Ashley County, Arkansas (fig. 5) (Baldwin and others 1998, Burton 1982). During the final harvest of the Sudden Sawlog Study in the early 2000s, scientists from Weyerhaeuser, the USDA Forest Service Southern Research Station, and the USDA Forest Service

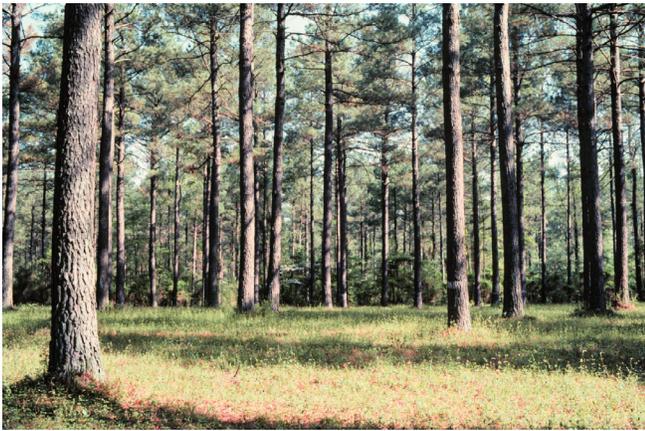


Figure 5—The Sudden Sawlog Study, on Georgia-Pacific Company timberlands in Ashley County, Arkansas, April 1983 (USDA Forest Service photo by James M. Guldin).

Forest Products Laboratory took detailed measurements and wood samples. Data from that final harvest showed that trees from the Sudden Sawlog Study had a high specific gravity, which meant that trees <30 years old could be sawn for dimension lumber.

In bottomland hardwoods, planting has also become an important management tool. In the second half of the 20th century, the most productive stands in the South were probably planted stands of cottonwood (*Populus deltoides*) on batture lands of the Mississippi River in north Mississippi, planted using improved cottonwood cuttings on pulpwood rotations of 10-11 years. These trees were managed to produce fiber for high-quality magazine paper, with mean annual increment varying with site conditions from 4 to 7 green tons per acre depending on soils (Carter and others 2015, McKnight 1970, McKnight and Biesterfeldt 1968, Stanturf and Portwood 1999). More recently—over the past few decades—abandoned agricultural lands in the Lower Mississippi Alluvial Valley have been planted under the U.S. Department of Agriculture Natural Resources Conservation Service Conservation Reserve and Wetlands Reserve programs, primarily in bottomland oaks (*Quercus* spp.) and sweet pecan (*Carya illinoensis*); to date, more than 500,000 acres have been planted (Gardiner 2014).

Finally, planting is a critical tool used to re-establish species on sites to which they are adapted, but from which they have been locally extirpated due to past management or land use practices. The best example of this is the restoration of longleaf pine (*P. palustris*) on National Forest System lands as well as other public and private lands across the South (fig. 6). Nearly one-third of longleaf pine-dominant forests currently found in the South are of planted origin, and younger than 40 years old (Oswalt and Guldin 2021)—which bodes well for ongoing efforts to recover that iconic ecosystem.



Figure 6—Rhett Johnson, co-founder of The Longleaf Alliance, stands in a longleaf plantation entering its fourth growing season on the Winn Ranger District of the Kisatchie National Forest, May 2009 (USDA Forest Service photo by James M. Guldin).

Success Story 2—Restoration of Understocked Stands

Not all cutover sites required planting after the harvest of the virgin southern pine forests. Many stands retained some measure of stocking that could be returned to productivity, if managed using judicious silvicultural treatments. During the Depression, foresters undertook the development of the art and science behind recovery of understocked stands, using conservative thinning practices and natural regeneration to regenerate southern pines and hardwoods. The archetypal example was found in south Arkansas and north Louisiana. The owners of the Crossett Lumber Company enlisted the support of Yale professor, H.H. Chapman, who was convinced that mixed stands of second-growth loblolly and shortleaf pine (*P. echinata*) could produce good dimension lumber and advised the company to mix the harvest of the last of their old growth with this developing second-growth timber (Chapman 1942, Reynolds 1980).

The silvicultural approaches used to manage cutover stands took two directions over time. At the Crossett Lumber Company and in a number of longleaf pine (*P. palustris*) ownerships, an uneven-aged management approach was very effective in restoring pine stands to full stocking (Guldin



Figure 7—Uneven-aged cutting cycle harvest marking in the Good Farm Forestry Forty, Crossett Experimental Forest, March 2011 (USDA Forest Service photo by James M. Guldin).

and Baker 1998; Reynolds 1959, 1969; Reynolds and others 1984). But stands managed using uneven-aged silviculture on private forest lands in the Southern United States are increasingly rare (fig. 7). In some ways, the method was a victim of its own success—5,000 board feet Doyle per acre is a highly liquid capital asset when forest lands change ownership. The high dollar value of the standing volume in continuous-cover stands factors into the purchase price during land sales, and the new landowners are often eager to harvest that valuable standing volume to help recover the costs of the land purchase. For example, in Arkansas, that reality led to the sale of the two largest family forest land holdings who practiced uneven-aged silviculture on a large scale—the Crossett Lumber Company, whose 2.1 million acres of forest lands were sold to Georgia-Pacific in 1962, and the Dierks Forests, whose 1.75 million acres were sold to Weyerhaeuser in 1969. The few southern yellow pine stands remaining in the United States that are managed using continuous-cover methods are increasingly on public forest lands and private timberlands where conservation is a dedicated goal of ownership, and where the future sale of forest lands is unlikely.

Success Story 3—Even-aged Silviculture Using Natural Regeneration in Pines and Oaks

As pine and hardwood stands come back to full stocking, awareness grew that even-aged seed tree and shelterwood approaches with natural regeneration could be effective, especially in conjunction with the application of prescribed fire. The seed tree method, as applied by Georgia-Pacific in south Arkansas, maintained relatively open stands at low residual basal area throughout the 45-year rotation (fig. 8). Prescribed fire helped reduce the need for herbicides, both mid-rotation and at site preparation. In the 1980s, the company had the first large-scale active prescribed

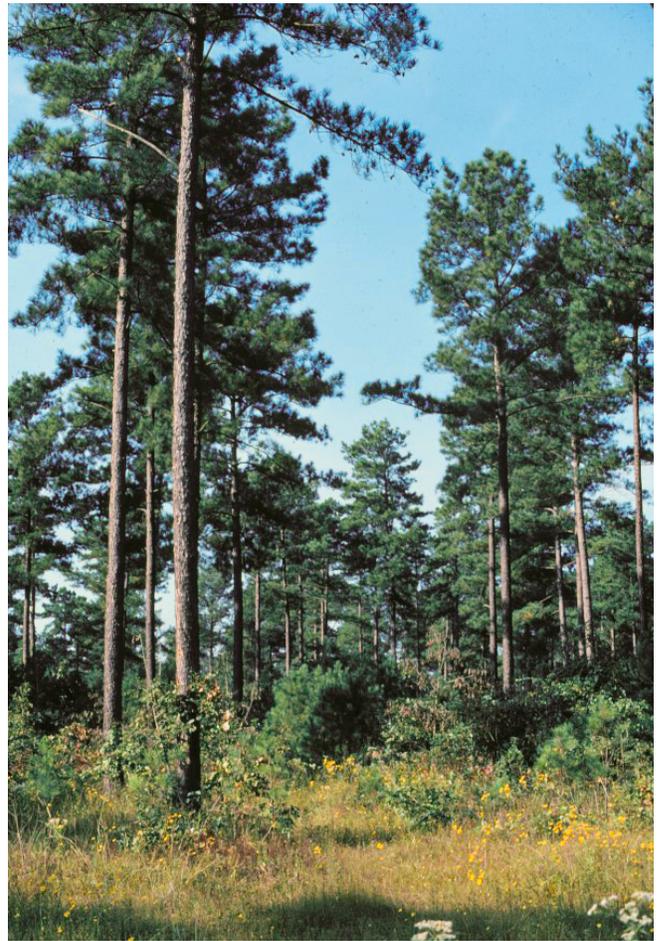


Figure 8—Loblolly-shortleaf pine stand late in the 45-year rotation on timberland managed by Georgia-Pacific Corporation in Drew County, Arkansas, 1983, showing the influence of thinning and prescribed burning (USDA Forest Service photo by James M. Guldin).

fire program in Arkansas. A detailed tabulation of typical company silvicultural practice was clearly presented in Zeide and Sharer (2000, 2001), and could easily be a cookbook approach for landowners interested in this approach to forestry today.

The shelterwood method also showed promise in upland oak. Ivan Sander and colleagues in the Missouri Ozarks led the way to identify the importance of oak advance growth present in stands in advance of a harvest using the shelterwood method (Sander 1979, Sander and others 1984, Schlesinger and others 1993). Scientists followed up by developing shelterwood systems in the Appalachians to capture the conditions needed there for oak advance growth (Brose 2010, Grayson and others 2012, Keyser and Loftis 2015, Loftis 1990). This includes work to explore the relationship of prescribed fire in upland oak stands, especially from the advance growth perspective (Arthur and others 2012; Brose 2011, 2014; Brose and others 1999, 2001). This approach in developing advance growth and overstory conditions to release it is expanding to include consideration

of increasingly diverse structures, such as small openings (Keyser and Loftis 2021, Spetich 2020).

But arguably the best description of the shelterwood method was outlined for longleaf pine on the Escambia Experimental Forest in southern Alabama. In 1956, Forest Service scientist Tom Croker had one of those “chance favors the prepared mind” moments when he reported on the establishment and release of accidentally-obtained advance growth of longleaf pine (Croker 1956). That work grew into an outstanding synthesis of research to support practical implementation in the field. Croker and Boyer (1975) described key elements of the shelterwood method to include management before regeneration, making the preparatory and seed cuts, monitoring the seed crop, preparing the seed bed, protecting reproduction, making the removal cuts, and making post-harvest treatments (fig. 9). It’s interesting to note that Croker and Boyer included a list of 10 longleaf pine demonstration areas that were established in 1966 as part of this new shelterwood effort in longleaf pine. The site on the Catahoula Ranger District of the Kisatchie National Forest is still active



Figure 9—One of the shelterwood study treatments in longleaf pine on the Escambia Experimental Forest near Brewton, AL, 1982 (USDA Forest Service photo by James M. Guldin).



Figure 10—The Croker Shelterwood demonstration in longleaf pine, on the Catahoula Ranger District of the Kisatchie National Forest in Grant Parish, LA, May 2017 (USDA Forest Service photo by James M. Guldin).

(fig. 10). It would be very interesting to learn whether the other sites still exist and what they might look like today.

Success Story 4—Reintroduction of Fire to Fire-Adapted Ecosystems

The final category of unabashed success in southern silviculture has been the awareness of the importance of prescribed burns in fire-adapted southern pine and pine-hardwood ecosystems, and increasingly to some degree in hardwood-dominated ecosystems as well. The major driver for this has been widespread concern about the loss of mature open forest and woodland habitat—especially, in southern pines, for the endangered red-cockaded woodpecker (*Leuconotopicus borealis*). Three of the four major southern pines have unusual adaptations to coexistence and dependence on fire. Shortleaf pine will resprout if young growth is top-killed by fire, an attribute noted as early as 1915 by Mattoon, who reported that virtually all of the shortleaf pine-dominated forests in Arkansas were of coppice origin (Mattoon 1915). This sprouting ability has been nicely characterized in the past decade by Rodney Will and his students at Oklahoma State University (Bradley and others 2016, Lilly and others 2012a, Lilly and others 2012b). Longleaf pine saplings are protected by physiognomy, with the arrangement of long needles in whorls and budscales that insulate the bud from the heat of a fire (Croker and Boyer 1975). Loblolly pine has a different tactic, especially in the western part of its range, where it produces bumper seed crops 4 years in 5 (Cain and Shelton 2001). Essentially, the loss of a new age cohort of loblolly pine due to fire is often followed by a bumper seed crop on the recently burned site.

The judicious use of thinning in conjunction with prescribed burning has been instrumental in bringing back pine-grassland habitat in loblolly pine-dominated systems such as



Figure 11—A shortleaf pine stand in the Shortleaf Pine-Bluestem Management Area on the Poteau Ranger District of the Ouachita National Forest in Scott County, Arkansas. The tree with aluminum band supports an active nest cavity for the endangered red-cockaded woodpecker, January 2018 (USDA Forest Service photo by James M. Guldin).

at the Moro Big Pine Management unit in south Arkansas (Bragg and others 2014) and Felsenthal National Wildlife Refuge on the Arkansas-Louisiana border, in longleaf pine-dominated stands especially on National Forest System lands in the Southern Region, and notably in shortleaf pine-dominated ecosystems on the Ouachita National Forest in western Arkansas (fig. 11). In all of these examples, a primary justification for the work has been to create habitat for the recovery of the red-cockaded woodpecker. There have been other benefits for all manner of species of flora and fauna adapted to these open pine forest and woodland conditions maintained by the use of prescribed fire (Guldin 2019a).

CHALLENGES FOR THE 21ST CENTURY

There is plenty of opportunity for foresters in the first decade of their career to solve problems faced by the profession, and some of these are difficult to the point of being intractable. They can be subjectively grouped into three general categories—economic, ecological, and social challenges.

Economic Challenges

The first challenge is that our success with planting the southern pines has led to an ever-growing surplus of standing pine volume. As a result, stumpage prices to landowners have been depressed, and experts doubt that these will be alleviated any time soon (Dezember and Mong'a 2021). During 2020, writers with the Wall Street Journal (WSJ) argued that home improvement projects during the pandemic have led to increased demand for lumber, but sawmills have a buyer's market for logs because of the high levels of supply. This followed a similar report in the WSJ in October 2018 that noted investments by family forest landowners in planted southern pine stands have not provided financial returns that were expected, because supply far outstrips demand (Dezember 2018).

Data available from the Forest Inventory and Analysis Evaluator online web portal show that across the 13 Southern States, growing stock volume in 2018 was at 356.4 billion cubic feet, an increase of 21 percent from 2005. Similarly, forest land area in 2018 was at 265.5 million acres, an increase of only 0.6 percent since 2005. The area of forests in plantations as of 2018 was 47.6 million acres, an increase of 2.3 million acres since 2005, and virtually all of this as of 2018 was on private lands, primarily real estate investment trust (REIT) and timber investment management organization (TIMO) lands. One might also suspect that it may be a difficult investment decision for a family forest landowner to replant after harvest, given the likelihood of depressed stumpage prices for another decade or two.

A second economic challenge for forest landowners tiers to changes in sawmill configuration and logging technology.

Sawmills are optimized to produce #2 common lumber from logs with d.b.h. 16-18 inches, which is the least expensive feedstock for the mill. Logging technology has also adapted to efficiently harvest 16-18 inches trees grown in uniform conditions found in planted stands. And with the dissolving of vertically-integrated forest products companies in the last decade of the 20th century, long-term supply agreements for logs are increasingly common between mills, loggers, and REIT-TIMO forest lands.

Logger demographics are consistent with this trend. Chain-saw felling of pine timber is virtually extirpated in the South; most businesses are fully mechanized, using feller-bunchers and grapple skidders. As a result, logging safety has increased substantially and the implementation of best management practices has also increased (Conrad and others 2018a). Additionally, logging business owners "aging in place" is a nationwide trend in the logging industry. In 2017, fewer than 25 percent of logging business owners were younger than 40 years old and approximately one-third were 60 years or older (Conrad and others 2018b). This raises the question of what a logging crew will look like in 2050, and what changes in a logging business model will occur as a result.

These economic trends have a number of implications for silviculturists to consider. Because of the changes in sawmill configuration and supply agreements with large private landowners, family forest landowners have increasingly difficult access to markets and loggers. For example, logger capacity is limited for family-owned forest land in Arkansas; REIT and TIMO and other institutional ownerships are using most of the logging capacity (Tian and Pelkki 2021). Limits on the size of logs that are merchantable as stumpage are also increasingly common; as sawlog size reaches d.b.h. >24 inches, logging equipment that is designed to harvest trees 16-18 inches can't easily harvest larger logs, and mills can't easily or efficiently process them. This raises questions about how foresters should manage stands where management objectives emphasize long rotations that will result in retaining trees >20 inches d.b.h., such as on National Forest System lands, on conservation easement properties, and on family forest lands managed for diverse ecological and economic goals.

Moreover, the need for consistency of size and easy access for logging equipment is complicating the market for small diameter feedstocks, or for salvage cutting after disturbances such as windstorms and insect infestations that kill, break, or uproot trees at a broad scale. For example, efforts to salvage loblolly pine mortality in Mississippi caused by the southern pine beetle in the past decade often resulted in no-bid sales; similarly, windstorm salvage in the Florida panhandle after Hurricane Michael in 2018 was difficult to obtain, and if a contractor was found, stumpage prices were less than \$1 per ton.

With respect to these economic issues, nothing about silviculture will be easy, especially for family forest landowners with limited access to forestry advice and forest products markets. If there is no market for the trees that a landowner is growing, loggers don't have equipment or incentive to harvest trees, and mills are reluctant to use diverse feedstocks, forestry advice to landowners will be very difficult. Advice that was common in the latter part of the 20th century, such as to encourage nonindustrial private landowners to grow high-quality southern pine sawlogs to large diameter, will certainly need to be reconsidered in light of changing markets in the 21st century.

Ecological Challenges

Foremost among the ecological challenges that foresters face are the stand-level silvicultural decisions to account for changing climatic conditions. In the latter part of the 20th century, Dave Smith at Yale University defined silviculture as an ecological art and science subject to economic and social constraints (Smith 1986). Even in the last few decades of the 20th century, foresters generally acted as if the broad parameters of temperature, precipitation, and seasonality were likely to be more or less constant on any given site.

Scientists know now that the ecological background will not be constant over the 21st century. The prevailing temperature, precipitation, and seasonality at any given location will change, but the exact magnitude of those changes is difficult to precisely quantify—though different models do consistently suggest that warmer and drier conditions will generally prevail (Wear and Greis 2013). Even backyard gardeners are aware of this, given the changes that USDA made in 2012 in updating the boundaries of the Plant Hardiness Zone map, when zone boundaries crept northward across the region from 50 to 100 miles. Foresters are still asking questions and installing studies to better understand silvicultural concepts of resistance, resilience, and adaptation that can be accomplished in the event that the prevailing temperature and precipitation at a given site changes (Nagel and others 2017). It seems unlikely that major regional efforts to assist in the broad migration of species northward is ecologically or silviculturally feasible; it's more likely that landowners who are actively managing their forest lands will be able to make decisions about species composition when stands are being regenerated or thinned (Guldin 2019b).

It is already apparent, though, that disturbance events associated with changing climatic conditions are likely to increase in frequency and severity. In the 20th century, foresters were adept at responding to disturbance, provided that salvage could occur. But as discussed previously, recovery from 21st-century disturbance events will be

more difficult if markets and logging capacity make salvage logging impractical.

An example of an effect that has its origins in changing climatic conditions is the apparent increase in hybridization in wind-pollinated pines, especially in shortleaf pine stands west of the Mississippi River. Shortleaf pine hybridization rates were 3 percent in the 1950s and increased to 46 percent in 2012 (Stewart and others 2012), with increasing hybridization when native shortleaf pine stands are in close proximity to loblolly pine planted stands (Stewart and others 2013). Dorman and Barber (1956) show that the timing of pollen ripening in loblolly pine at a given latitude is about 3 weeks earlier than that seen in shortleaf pine. With increasingly warm spring temperatures, this window of pollen ripening may be reduced to the point where shortleaf pine cones are receptive to pollination when loblolly pollen is still airborne. Shortleaf pine stands that may already contain hybrids may produce hybrid progeny that might outgrow native shortleaf, all things being equal. Hybrids do not resprout as effectively if top-killed by fire (Bradley and others 2016); prescribed burning of new age cohorts frequently can help eliminate hybrids and maintain pure shortleaf genotypes (Stewart and others 2015, 2017). But it takes a silviculturist with a certain measure of fortitude to burn a 2-year-old age cohort of planted or naturally-regenerated shortleaf pine that has been successfully established.

The management of hardwood-softwood mixtures or mixed woods was largely neglected by silvicultural research in the 20th century, perhaps with the exception of Doug Phillips, Dave van Lear, Tom Waldrop, and their students at Clemson University (Blizzard and others 2006, Brose 2011, Phillips and Abercrombie 1986, Randles and others 2002, Waldrop 1989). But Guldin (2019b) pointed out that silvicultural options are a hedge against changing climatic conditions, such as ensuring that stands have genetic diversity, species diversity, and structural diversity. The mixed woods initiative underway between the Northern Research Station and Southern Research Station to study efforts to manage mixed stands of hardwoods and pines illustrates opportunities and challenges (Kabrick and others 2017, 2020; Kern and others 2021; Schweitzer and others 2016). Mixed stands are probably the rule rather than the exceptions within the range of shortleaf pine east of the Mississippi River, and in the Appalachians, in conjunction with pitch and Table Mountain pines (Waldrop 1989).

In bottomland hardwood stands, mixtures of different hardwood species offer opportunities to take advantage of differences in developmental dynamics to provide both short-term and long-term silvicultural benefits. For example, the canopy stratification effects between oaks and sweetgum that are known to exist (Lockhart and others 2006) may provide opportunities for recommendations other than a planted

stand consisting of a single hardwood species for landowners under the Conservation Reserve or Wetlands Reserve programs (Gardiner 2014).

Social Challenges

The social challenges the profession faces in the 21st century were eloquently summarized by His Royal Highness, Charles, the Prince of Wales, in his opening address at the 2014 International Union of Forest Research Organizations World Congress in Utah.¹ The major challenge is the ever-burgeoning population in the United States, and in the world. Between 1940 and 2017, the U.S. population grew from 132 million to 326 million, a 2.5x increase; over that same timeframe, the world population grew from ~2.3 billion to 7.5 billion people. Projections of the United Nations suggest that the global population will reach 11 billion people by 2100.² Few of our problems with resource management, either in the United States or globally, will be easier to handle as the world population continues to grow at these rates.

Related to this, there are cultural differences at play in the United States that have a basis in whether one is from urban vs. rural settings. In 1950, roughly two-thirds of the U.S. population were found in urban areas, and one-third in rural areas. In 2010, Census data show that 80 percent of the U.S. population was urban, and 20 percent rural. Without efforts to educate people in urban settings about the value of resource management in rural areas, the social license to continue to practice resource management that includes harvesting of trees and activities such as prescribed fire may be at risk.

Finally, there are issues of concern with research capacity in the forestry sector. McGinley and others (2019) reported that the number of research scientists on the faculty at SAF-accredited institutions, within the Forest Service, and with forest industry, has decreased by approximately 12 percent since 2002. They also report that within the USDA Forest Service Research and Development deputy area, the number of research scientist positions has declined from 985 in 1985, to 540 in 2016; moreover, research foresters declined from 350 in 1985 to 104 in 2016 (McGinley and others 2019). In short, the profession has seen a sharp reduction in the number of research scientists, especially in fields related to production and management, over the past four decades, at a time when expanded research is critically needed to address the challenges in resource management that society is facing in the 21st century.

SUMMARY

Our late colleague, Kurt Gottschalk, offered advice to the Society of American Foresters in 2015 that urged leadership to “Play the Rookies” (Gottschalk 2015). In his essay, Gottschalk noted the importance of getting young professionals active in the leadership of the profession at an early stage of their career. This advice has value with respect to the challenges the profession faces in the 21st century. It will be the research scientists and land managers in the first decade of their career who will do the hard work needed to rise to the challenges the profession faces in the 21st century. But, as Kabrick and Pile (2019) report, the 21st century is an exciting time to be a silviculturist in the Southern United States. Those of us in the last decade of our career wish our younger colleagues all the best, and we’ll be around to offer feeble advice if asked, and probably sometimes if not asked, too.

REFERENCES

- Allen, H.L.; Fox, T.R.; Campbell, R.G. 2005. What is ahead for intensive pine plantation silviculture in the South? *Southern Journal of Applied Forestry*. 29(2): 62–69.
- Arthur, M.A.; Alexander, H.D.; Dey, D.C. [and others]. 2012. Refining the oak-fire hypothesis for management of oak-dominated forests of the Eastern United States. *Journal of Forestry*. 110(5): 257–266.
- Baldwin, V.C.; Leduc, D.J.; Ferguson, R.B. [and others]. 1998. The not-so-sudden results of the Sudden Saw Log Study—growth and yield through age 45. In: Waldrop, T.A. 1998. Proceedings of the Ninth Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station: 574–578.
- Blizzard, E.M.; van Lear, D.H.; Wang, G. [and others]. 2006. Performance of mixed pine-hardwood stands 16 years after fell-and-burn treatments. Gen. Tech. Rep. SRS-92. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 499–501.
- Bradley, J.C.; Will, R.E.; Stewart, J.F. [and others]. 2016. Post-fire resprouting of shortleaf pine is facilitated by a morphological trait but fire eliminated shortleaf x loblolly pine hybrid seedlings. *Forest Ecology and Management*. 379: 146–152.
- Bragg, D.C.; O’Neill, R.; Holimon, W. [and others]. 2014. Moro Big Pine: conservation and collaboration in the pine flatwoods of Arkansas. *Journal of Forestry*. 112(5): 446–456.
- Brose, P.H. 2010. Long-term effects of single prescribed fires on hardwood regeneration in oak shelterwood stands. *Forest Ecology and Management*. 260: 1516–1524.
- Brose, P.H. 2011. A comparison of the effects of different shelterwood harvest methods on the survival and growth of acorn-origin oak seedlings. *Canadian Journal of Forest Research*. 41: 2359–2374.
- Brose, P.H. 2014. Development of prescribed fire as a silvicultural tool for the upland oak forests of the Eastern United States. *Journal of Forestry*. 112(5): 525–533.
- Brose, P.; Schuler, T.; Van Lear, D.; Berst, J. 2001. Bringing fire back—the changing regimes of the Appalachian mixed-oak forest. *Journal of Forestry*. 99(11): 30–35.
- Brose, P.H.; van Lear, D.H.; Cooper, R. 1999. Using shelterwood harvests and prescribed fire to regenerate oak stands on productive upland sites. *Forest Ecology and Management*. 113 (1999): 125–141.

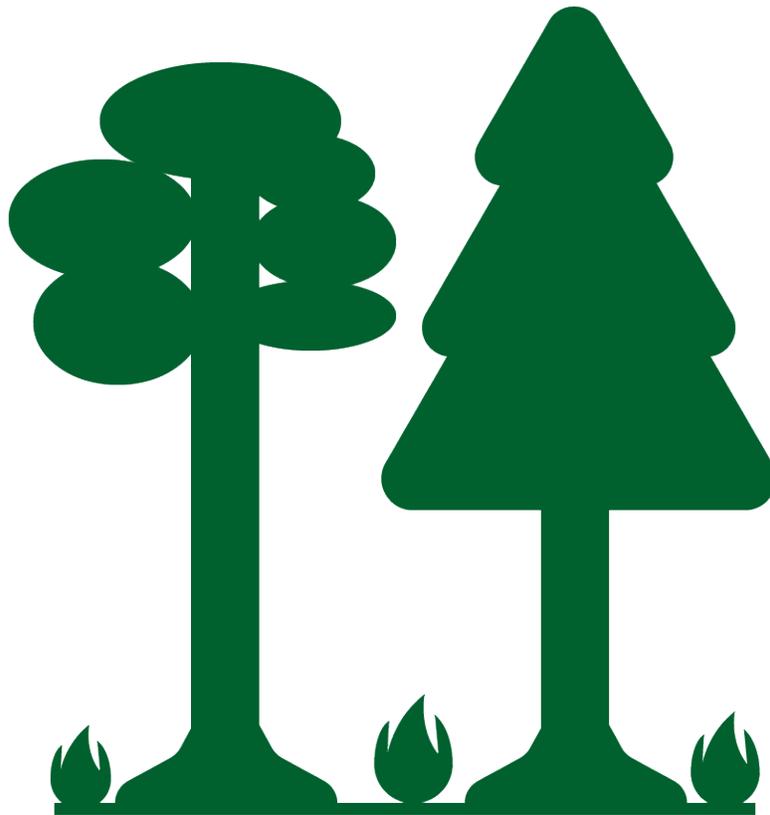
¹ Available at: <https://www.youtube.com/watch?v=VfvvffW6DFA>.

² <https://www.un.org/development/desa/en/news/population/world-population-prospects-2019.html>.

- Burton, J.D. 1982. Sawtimber by prescription—the sudden sawlog story through age 33. Res. Pap. SO-179. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 11 p.
- Cain, M.D.; Shelton, M.G. 2001. Twenty years of natural loblolly and shortleaf pine seed production on the Crossett Experimental Forest in southeastern Arkansas. Southern Journal of Applied Forestry. 25(1): 40–45.
- Carter, M.C.; Kellison, R.C.; Wallinger, R.S. 2015. Forestry in the U.S. South: a history. Baton Rouge, LA: Louisiana State University Press. 386 p.
- Chapman, H.H. 1942. Management of loblolly pine in the pine-hardwood region of Arkansas and in Louisiana west of the Mississippi River. Bulletin No. 49. New Haven, CT: Yale University, School of Forestry. 150 p. plus illustrations.
- Conrad, J.L., IV; Greene, W.D.; Hiesl, P. 2018a. The evolution of logging businesses in Georgia 1987-2017 and South Carolina 2012-2017. Forest Science. 64(6): 671–681.
- Conrad, J.L., IV; Greene, W.D.; Hiesl, P. 2018b. A review of changes in U.S. logging businesses, 1980-present. Journal of Forestry. 116(3): 291–303.
- Croker, T.C. 1956. Can the shelterwood method be used to regenerate longleaf pine? Journal of Forestry. 54(4): 258–260.
- Croker, T.C.; Boyer, W.D. 1975. Regenerating longleaf pine naturally. Res. Pap. SO-75. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 21 p.
- Dezember, R. 2018. Thousands of southerners planted trees for retirement. It didn't work. The Wall Street Journal. 9 October 2018. New York.
- Dezember, R.; Mong'a, P. 2021. Lumber prices are soaring. Why are tree growers miserable? The Wall Street Journal. 24 February 2021. New York.
- Dorman, K.W. 1976. The genetics and breeding of southern pines. Agric. Handb. 471. Washington, DC: U.S. Department of Agriculture Forest Service. 407 p.
- Dorman, K.W.; Barber, J.C. 1956. Time of flowering and seed ripening in southern pines. Station Paper 72. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. 15 p.
- Fox, T.L.; Jokela, E.J.; Allen, H.L. 2007. The development of pine plantation silviculture in the Southern United States. Journal of Forestry. 105(7): 337–347.
- Gardiner, E.S. 2014. Outlook for Mississippi Alluvial Valley forests: a subregional report from the Southern Forest Futures Project. Gen. Tech. Rep. SRS-201. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 83 p.
- Grayson, S.F.; Buckley, D.S.; Henning, J.G. [and others]. 2012. Understory light regimes following silvicultural treatments in central hardwood forests in Kentucky, USA. Forest Ecology and Management. 279: 66–76.
- Gottschalk, K.W. 2015. Play the rookies. Forestry Source, March 2015. Washington, DC: Society of American Foresters. 1 p.
- Guldin, J.M. 2019a. Restoration of native fire-adapted southern pine-dominated forest ecosystems: diversifying the tools in the silvicultural toolbox. Forest Science. 65(4): 508–518.
- Guldin, J.M. 2019b. Silvicultural options in forests of the Southern United States under changing climatic conditions. New Forests. 50: 71–87.
- Guldin, J.M.; Baker, J.B. 1998. Uneven-aged silviculture, southern style. Journal of Forestry. 96 (7): 22–26.
- Hepting, G.A. 1974. Death of the American chestnut. Journal of Forest History. 18(3): 60–67.
- Kabrick, J.M.; Clark, K.L.; D'Amato, A.W. [and others]. 2017. Managing hardwood-softwood mixtures for future forests in Eastern North America: assessing suitability to projected climate change. Journal of Forestry. 115(3): 190–201.
- Kabrick, J.M.; Clark, K.L.; D'Amato, A.W. [and others]. 2020. Research and management partnerships for resolving regeneration and recruitment challenges in hardwood-softwood mixtures in Eastern North America. In: Pile, L.S.; Deal, R.L.; Dey, D.C. [and others], comps. The 2019 National Silviculture Workshop: a focus on forest management-research partnerships. Gen. Tech. Rep. NRS-P-193. Madison, WI: U.S. Department of Agriculture Forest Service, Northern Research Station: 129–140.
- Kabrick, J.M.; Pile, L.S. 2019. 21st century silviculture: the best-kept secret? Journal of Forestry. 117(4): 421–423.
- Kern, C.C.; Waskiewicz, J.D.; Frelich, L. [and others]. 2021. Understanding compositional stability in mixed wood forests of Eastern North America. Canadian Journal of Forest Research. 24: 897–909.
- Keyser, T.L.; Loftis, D.L. 2015. Stump sprouting of 19 upland hardwood species 1 year following initiation of a shelterwood with reserves silvicultural system in the southern Appalachian Mountains, USA. New Forests. 46(3): 449–464.
- Keyser, T.L., Loftis, D.L. 2021. [In press]. Long-term effects of alternative partial harvesting methods on the woody regeneration layer in high-elevation *Quercus rubra* forests of the southern Appalachian Mountains, USA. Forest Ecology and Management. 482: 118869.
- Lilly, C.J.; Will, R.E.; Tauer, C.G. 2012a. Physiological and morphological attributes of shortleaf x loblolly pine F1 hybrid seedlings: Is there an advantage to being a hybrid? Canadian Journal of Forest Research. 42: 238–246.
- Lilly, C.J.; Will, R.E.; Tauer, C.G. [and others]. 2012b. Factors affecting the sprouting of shortleaf pine rootstock following prescribed fire. Forest Ecology and Management. 265: 13–19.
- Lockhart, B.R.; Ezell, A.W.; Hodges, J.D.; Clatterbuck, W.C. 2006. Using natural stand development patterns in artificial mixtures: a case study with cherrybark oak and sweetgum in east-central Mississippi, USA. Forest Ecology and Management. 222: 202–210.
- Loftis, D.L. 1990. Predicting post-harvest performance of advance red oak reproduction in the southern Appalachians. Forest Science. 36(4): 908–916.
- Mattoon, W.R. 1915. Life history of shortleaf pine. Bulletin 244. Washington, DC: U.S. Department of Agriculture Forest Service. 46 p.
- McGinley, K.A.; Guldin, R.W.; Cabbage, F.W. 2019. Forest sector research and development capacity. Journal of Forestry. 14(2): 369–388.
- McKeand, S.E. 2019. The evolution of a seedling market for genetically improved loblolly pine in the Southern United States. Journal of Forestry. 117(3): 293–301.
- McKeand, S.E.; Mullin, T.; Byram, T.; White, T. 2003. Deployment of genetically improved loblolly and slash pines in the South. Journal of Forestry. 101(3): 32–37.
- McKeand, S.E.; Payn, K.G.; Heine, A.J.; Abt, R.C. 2021. Economic significance of continued improvement of loblolly pine genetics and its efficient deployment to landowners in the Southern United States. Journal of Forestry. 119(1): 62–72.
- McKeand, S.; Peter, G.; Byram, T. 2015. Trends in deployment of advanced loblolly pine germplasm. In: PINEMAP Year 4 Annual Report, March 2014–February 2015. Washington, DC: U.S. Department of Agriculture: 26–27. Chapter 11. https://www.pinemap.org/reports/annual-reports/PINEMAP_AnnualReport_press4v2.pdf. [Date accessed: 9 July 2021].
- McKnight, J.S. 1970. Planting cottonwood cuttings for timber production in the South. Research Paper SO-60. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 17 p.
- McKnight, J.S.; Biesterfeldt, R.C. 1968. Commercial cottonwood planting in the Southern United States. Journal of Forestry. 66 (9): 670–675.
- Nagel, L.M.; Palik, B.J.; Battaglia, M.A. [and others]. 2017. Adaptive silviculture for climate change: a national experiment in manager-scientist partnerships to apply an adaptation framework. Journal of Forestry. 115(3): 167–178.
- Oswalt, C.; Guldin, J.M. 2021. Status of longleaf pine in the South: an FIA update. 25 p. Unpublished report. On file with: Christopher Oswalt, Southern Research Station, Forest Inventory and Analysis, 4700 Old Kingston Pike, Knoxville, TN 37919.
- Phillips, D.R.; Abercrombie, J.A. 1986. Pine-hardwood mixtures—a new concept in regeneration. Southern Journal of Applied Forestry. 11(4): 192–197.
- Randles, R.B.; van Lear, D.H.; Waldrop, T.A.; Simon, D.M. 2002. Periodic burning in Table Mountain-pitch pine stands. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 114–118.
- Reynolds, R.R. 1959. Eighteen years of selective timber management on the Crossett Experimental Forest. Tech. Bull. No. 1206. Washington, DC: U.S. Department of Agriculture Forest Service. 68 p.

- Reynolds, R.R. 1969. Twenty-nine years of selective timber management on the Crossett Experimental Forest. Res. Pap. SO-40. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 19 p.
- Reynolds, R.R. 1980. The Crossett Story: the beginning of forestry in southern Arkansas and northern Louisiana. Gen. Tech. Rep. SO-32. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 40 p.
- Reynolds, R.R.; Baker, J.B.; Ku, T.T. 1984. Four decades of selection management on the Crossett Farm Forestry Forties. Bull. 872. Fayetteville, AR: University of Arkansas, Division of Agriculture, Agricultural Experiment Station. 43 p.
- Roosevelt, T. 1905. Forestry and foresters; delivered before the Society March 26, 1903. Proceedings of the Society of American Foresters. Vol. 1(1), May 1905: 3–9.
- Sander, I.L. 1979. Regenerating oaks with the shelterwood system. In: Holt, H.A.; Fischer, B.C., eds. Proceedings, regenerating oaks in upland hardwood forests, the 1979 John S. Wright Forestry Conference. Purdue University: 54–60.
- Sander, I.L.; Johnson, P.S.; Rogers, R. 1984. Evaluating oak advance reproduction in the Missouri Ozarks. Res. Pap. NC-251. St. Paul, MN: U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station. 16 p.
- Schlesinger, R.C.; Sander, I.L.; Davidson, K.R. 1993. Oak regeneration potential increased by shelterwood treatments. Northern Journal of Applied Forestry. 10(4): 149–153.
- Schweitzer, C.J.; Dey, D.C.; Wang, Y. 2016. Hardwood-pine mixedwoods stand dynamics following thinning and prescribed burning. Fire Ecology. 12(2): 85–104.
- Smith, D.M. 1986. The practice of silviculture, 8th edition. New York: John Wiley and Sons. 537 p.
- Spetich, M.A. 2020. Survival of *Quercus alba* (white oak) advance reproduction in small group and single tree openings. Forests. 11(8): 889.
- Stanturf, J.A.; Portwood, C.J. 1999. Economics of afforestation with eastern cottonwood (*Populus deltoides*) of agricultural land in the lower Mississippi Alluvial Valley. In: Haywood, J.D., ed. Proceedings of the 10th Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 66–72.
- Stewart, J.; Nelson, C.D.; Tauer, C.G. 2012. Bidirectional introgression between loblolly pine (*Pinus taeda* L.) and shortleaf pine (*P. echinata* Mill.) has increased since the 1950s. Tree Genetics and Genomics. 8: 725–735.
- Stewart, J.F.; Tauer, C.G.; Guldin, J.M.; Nelson, C.D. 2013. Hybridization in naturally regenerated shortleaf pine as affected by distance to nearby artificially-regenerated stands of loblolly pine. Southern Journal of Applied Forestry. 37(2): 102–107.
- Stewart, J.F.; Will, R.; Crane, B.S.; Nelson, C.D. 2017. Occurrence of shortleaf x loblolly pine hybrids in shortleaf pine orchards: Implications for ecosystem restoration. Forest Science. 63(2): 225–231.
- Stewart, J.F.; Will, R.E.; Robertson, K.M.; Nelson, C.D. 2015. Frequent fire protects shortleaf pine (*Pinus echinata*) from introgression by loblolly pine (*P. taeda*). Conservation Genetics. 16: 491–495.
- Tian, N.; Pelkki, M. 2021. Timber Outlook for Arkansas. Fayetteville, AR: University of Arkansas, Division of Agriculture, Arkansas Forest Resources Center. 18 p.
- Wahlenberg, W.G. 1960. Loblolly pine: its, use, ecology, regeneration, protection, growth and management. Durham, NC: Duke University, School of Forestry. 603 p.
- Wakeley, P.C. 1954. Planting the southern pines. Agric. Monograph 18. Washington, DC: U.S. Department of Agriculture Forest Service. 233 p.
- Waldrop, T.A., ed. 1989. Proceedings of pine-hardwood mixtures: A Symposium on Management and Ecology of the Type. Gen. Tech. Rep. SE-58. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. 271 p.
- Wang, G.G.; Knapp, B.O.; Clark, S.L.; Mudder, B.T. 2013. The silvics of *Castanea dentata* (Marsh.) Borkh., American chestnut, Fagaceae (Beech Family). Gen. Tech. Rep. SRS-GTR-173. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 18 p.
- Wear, D.N.; Greis, J.G., eds. 2013. The Southern Forest Futures Project: technical report. Gen. Tech. Rep. SRS-GTR-178. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 542 p.
- Zeide, B.; Sharer, D. 2000. Good forestry at a glance: a guide for managing even-aged loblolly pine stands. Arkansas Forest Resources Center Series 003. Fayetteville, AR: Division of Agriculture, Arkansas Agricultural Experiment Station. University of Arkansas. 19 p.
- Zeide, B.; Sharer, D. 2001. Sustainable and profitable management of even-aged loblolly pine stands. Journal of Sustainable Forestry. 14 (1): 93–106.

Prescribed Fire



RADIAL GROWTH RESPONSE OF SHORTLEAF PINE (*PINUS ECHINATA*) AND POST OAK (*QUERCUS STELLATA*) TO CLIMATIC VARIABILITY AND MANAGEMENT IN SOUTHEASTERN OKLAHOMA

Rodney E. Will, Arjun Adhikari, Ronald Masters, Henry Adams,
Omkar Joshi, and Chris Zou

EXTENDED ABSTRACT

We investigated the radial growth response of shortleaf pine (*Pinus echinata*) [~24 cm average diameter at breast height (d.b.h.)] and post oak (*Quercus stellata*) (~36 cm average d.b.h.) to climatic variation and management using tree cores collected in southeastern Oklahoma near the drier, western limit of their ranges. In 1984, experimental units were created by combinations of pine harvest, hardwood thinning, and fire return intervals of 1, 2, 3, 4 years, and none (late dormant-season prescribed fire). These treatments produced ecosystems ranging from closed-canopy forest (4-year fire return interval or no fire) to savanna (3-year or shorter fire return interval) (Adhikari and others 2021a, 2021b; Feltrin and others 2016). Weather for previous year, current year, and years since fire was used to determine the relationship between radial growth and climate variability (1987–2018) for different management regimes.

Shortleaf pine radial growth increased with growing season precipitation, decreased with average summer temperature maximum, and increased with previous year's average October minimum temperature (Adhikari and others 2021a). Radial growth of shortleaf pine decreased by ~25 percent the first year after prescribed fire for 2- and 3-year fire return intervals. Suppressed shortleaf pine were less responsive to climate variability than intermediate or co-dominant trees. Shortleaf pine growing in savannas appeared less sensitive to annual variation in precipitation. When combined across all treatments, 100 mm decrease in growing season precipitation decreased relative width index (RWI) 5 percent, 1 °C increase in average summer temperature maximum decreased RWI by 7 percent, and a 1 °C increase in the previous year's average October minimum temperature increased RWI by 6 percent.

For post oak, RWI of all treatments was positively correlated to minimum daily temperature the previous September and precipitation late spring/early summer the current-year, and negatively correlated to maximum daily temperatures and drought index late spring/early summer. While absolute diameter growth was greater in stands with lower basal area, RWI of savanna and forest stands responded similarly to variation in weather, and prescribed

Author Information: Rodney E. Will, Professor, Oklahoma State University, Stillwater, OK 74078; Arjun Adhikari, Post Doctorate, Oklahoma State University, Stillwater, OK 74078; Ronald Masters, Professor, University of Wisconsin-Stevens Point, Stevens Point, WI 54481; Henry Adams, Assistant Professor, Washington State University, Pullman, WA 99164; Omkar Joshi, Assistant Professor, Oklahoma State University, Stillwater, OK 74078; and Chris Zou, Professor, Oklahoma State University, Stillwater, OK 74078.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

fire did not influence RWI when measured in stands with 4-year fire return intervals. On average, 100 mm reduction in June precipitation decreased RWI by 8 percent, 1 °C increase in previous year September daily minimum temperature increased RWI by 3.5 percent, and 1 °C increase in June maximum daily temperature decreased RWI by 3.7 percent.

Results indicate that hotter, drier spring/summer conditions will reduce growth of shortleaf pine and post oak likely due to reduced soil moisture and increased vapor pressure deficits. However, a warmer autumn may increase growth possibly by extending the length of the previous growing season resulting in more stored carbohydrate for the subsequent year. Savanna systems had more intense fires due to fuel load dominated by dried herbaceous vegetation (average of 1941 and 1381, kW m⁻² for the 2- and 3-year fire return intervals). This likely reduced shortleaf pine growth due to the scorching of some of the previous year's foliage cohort. In contrast, neither shortleaf pine or post oak were affected by fire at a 4-year return interval because fires were lower intensity. The fuels in the 4-year treatment were dominated by leaf litter and averaged 802 kW m⁻². In addition, oak trees did not have leaves at the time of burning. Management to reduce stand density may have increased the resistance of shortleaf pine to drought, but it did not influence the response of post oak trees to drier conditions.

ACKNOWLEDGMENTS

We thank the Oklahoma Department of Wildlife Conservation, Jack Waymire and the numerous Oklahoma State University faculty, students, and staff, and the staff of the Kiamichi Forestry Research Station for assistance managing the study area and helping with field work. The study was sponsored by USDA–National Institute of Food and Agriculture (Grant # 2018-67014-27504). HDA was supported by the USDA National Institute of Food and Agriculture, McIntire-Stennis project WNP00009. Additional funding was provided by Oklahoma Agricultural Experiment Station, McIntire-Stennis project #OKL0 3151 and Oklahoma Forestry Services.

LITERATURE CITED

- Adhikari, A.; Adams, R.H.; Mainali, K. [and others]. 2021a. Effects of climate variability and management on shortleaf pine radial growth across a forest-savanna continuum in a 34-year experiment. *Forest Ecology and Management*. 491: 119–125.
- Adhikari, A.; Masters, R.; Zou, C.B. [and others]. 2021b. Management and climate variability effects on understory productivity of forest and savanna ecosystems in Oklahoma, USA. *Ecosphere*. 12(6): e03576.
- Feltrin, R.; Will, R.E.; Meek, C.R. [and others]. 2016. Relationship between photosynthetically active radiation and herbaceous layer productivity across a forest-grassland continuum. *Forest Ecology and Management*. 374: 51–60.

FLAMMABILITY OF LITTER FROM 50 SOUTHEASTERN TREE SPECIES ALONG MESOPHICATION GRADIENTS

J. Morgan Varner, Jeffrey M. Kane, Jesse K. Kreye, and Timothy M. Shearman

EXTENDED ABSTRACT

Fire exclusion and land-use have resulted in dramatic shifts in overstory tree species composition and structure across many southeastern ecosystems. These changes are implicated widely in feedbacks termed “mesophication” (Nowacki and Abrams 2008) where invading species cast litter that diminishes the ignition and spread of surface fires. Past research across the United States illustrates differential flammability among tree species, including research on a number of southeastern tree species (Fonda 2001, Kane and others 2008, Mola and others 2014). There is widespread evidence for mesophication in many southeastern savanna and woodlands (Hanberry and others 2020), but the evidence from a litter flammability standpoint is lacking in many cases (Alexander and others 2021). We performed laboratory experiments and compiled published data from studies using similar methodology to fill holes in the broader understanding of differential flammability and to identify species across mesophication gradients in the Southeastern United States.

We used published data from eight studies that followed the laboratory flammability methods of Fonda (2001) and collected recently fallen litter to supplement this list of species. Surface litter was collected after litterfall from sites across the region. We collected litter beneath individual trees and shipped air-dried samples to the laboratory for experiments. In the laboratory, we followed methods in Fonda (2001) to burn each oven-dried 15-gram sample. Once ignited, we measured the maximum flame height, the duration of flaming, duration of smoldering, and the percentage consumption of the original fuel.

We placed species into their representative ecosystems (Coastal Plain uplands, oak-hickory woodlands, Appalachian forests, and bottomland forests), with some species occurring across more than one ecosystem. We compared species within each ecosystem based on their flammability measures.

Southeastern tree species varied widely in their litter flammability. Several pines were highly flammable, including *Pinus palustris*, *Pinus serotina*, *Pinus echinata*, *Pinus taeda*, and *Pinus rigida*. A few oaks were also highly flammable, including *Quercus laevis*, *Quercus falcata*, and *Quercus alba*. *Castanea dentata* was remarkably flammable. The least flammable species included *Tsuga canadensis*, *Torreya taxifolia*, *Taxus floridana*, *Pinus clausa* var. *clausa*, *Quercus virginiana*, and *Quercus geminata*. The species typically implicated in southeastern mesophication (*Acer rubrum*, *Nyssa sylvatica*, *Liquidambar styraciflua*, and *Tilia americana*) also burned with reduced flammability.

Author Information: J. Morgan Varner, Director of Research and Senior Scientist, Tall Timbers Research Station, Tallahassee, FL 32312; Jeffrey M. Kane, Associate Professor, Humboldt State University, Arcata, CA 95521; Jesse K. Kreye, Research Assistant Professor, Pennsylvania State University, University Park, PA 16802; and Timothy M. Shearman, Post-Doctoral Scientist, Tall Timbers Research Station, Tallahassee, FL 32312.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

Within the four forest communities, species followed somewhat predictable gradients that mimicked mesophication gradients. In the Coastal Plain uplands, a majority of the upland pines and oaks burned with high flammability. Exceptions to this pattern included the sand pines, which tend to occur in infrequently burned “scrubs” and a suite of invading evergreen oaks. In oak-hickory woodlands, *Quercus alba*, *Carya tomentosa* and *Carya glabra* burned well, while the mesophytes burned poorly. We found higher than expected flammability for *Oxydendrum arboreum*, *Fagus grandifolia*, and *Liriodendron tulipifera*. The most flammable species in Appalachian forests were *Castanea dentata*, *Pinus echinata*, *Pinus rigida*, *Quercus alba*, and *Carya glabra*, with *Tsuga canadensis* the least flammable. The diverse bottomland forest tree species contained flammable species (*Quercus* and *Pinus* species) and a large number of poorly flammable species that typify this fire-sheltered community.

Our results provide evidence for flammability or mesophication gradients across the four communities we studied and provide flammability data for species previously lacking this information. From a management standpoint, where frequent burning is desirable, our data suggest species that may be targeted for removal to facilitate flammable fuels. These data also illustrate the relative flammability of many southeastern species typically associated with frequently burned ecosystems. Many southeastern pines and oaks, as well as *Castanea dentata* have remarkable flammability that likely sustained open woodlands and deterred invasion by off-site mesophytic species (Kane and others 2008, Kane and others 2019, Kreye and others 2013). Linking these traits to fire protective traits such as bark thickness, reproductive strategies, and fire tolerance will provide a more complete picture of how these species dominated historically and how they may fare in future restoration and management efforts (Kane and others 2019, Varner and others 2016).

LITERATURE CITED

- Alexander, H.D.; Siegert, C.; Brewer, J.S. [and others]. 2021. Mesophication and oak landscapes: evidence, knowledge gaps, and future research. *BioScience*. 71(5): 531–542.
- Fonda, R.W. 2001. Burning characteristics of needles from eight pine species. *Forest Science*. 47: 390–396.
- Hanberry, B.B.; Abrams, M.D.; Arthur, M.A.; Varner, J.M. 2020. Reviewing fire, climate, and multiple factors as drivers of historically open oak and pine forests and transition to closed forests. *Frontiers in Forests and Global Change*. 3(56): 1–12.
- Kane, J.M.; Varner, J.M.; Hiers, J.K. 2008. The burning characteristics in southeastern oaks: discriminating fire facilitators from fire impeters. *Forest Ecology and Management*. 256: 2039–2045.
- Kane, J.M.; Varner, J.M.; Sauders, M.R. 2019. Resurrecting the lost flames of American chestnut. *Ecosystems*. 5: 995–1006.
- Kreye, J.K.; Varner, J.M.; Hiers, J.K.; Mola, J. 2013. Toward a mechanism for eastern North American forest mesophication: the role of litter drying. *Ecological Applications*. 23: 1976–1986.
- Mola, J.M.; Varner, J.M.; Jules, E.S.; Spector, T. 2014. Altered community flammability in Florida’s Appalachian ravines and implications for the persistence of the endangered conifer *Torreya taxifolia*. *PLoS ONE*. 9(8): e103933.
- Nowacki, G.J.; Abrams, M.D. 2008. The demise of fire and “mesophication” of forests in the Eastern United States. *BioScience*. 58: 123–138.
- Varner, J.M.; Kane, J.M.; Kreye, J.K.; Veldman, J.W. 2016. Suites of fire-adapted traits in the Southeastern USA oaks: multiple strategies for persistence. *Fire Ecology*. 12: 48–64.

VARIATION IN BARK ALLOCATION AND RUGOSITY ACROSS SEVEN CO-OCCURRING SOUTHEASTERN U.S. TREE SPECIES

Timothy M. Shearman and J. Morgan Varner

EXTENDED ABSTRACT

Bark is a complex multifunctional structure of woody plants that varies widely among species. Tree species that occur in frequently burned ecosystems generally develop thicker bark than those found in less flammable environments (Pausas 2015). Outer bark on species that allocate resources to thick bark also tends to be rugose, with bark being thickest at the ridges and thinnest in the furrows. Diameter is often used as a predictor for bark thickness, but little attention has been given to other factors that might affect bark development and allocation.

Our study site was located within the Tallahatchie Experimental Forest, Mississippi. We sampled saplings of *Carya tomentosa* (n = 10), *Nyssa sylvatica* (n = 10), *Pinus echinata* (n = 11), *Pinus taeda*, *Prunus serotina* (n = 10), *Quercus marilandica* (n = 10), and *Quercus falcata* (n = 11), ranging from 1.0–9.4 cm ground-line diameter. Cross-sections along the stem every 10 cm from the base (0 cm) to 100 cm and every 20 cm from 100 cm to 200 cm were measured for cross-section area, outer and inner bark area, and wood area.

Bark rugosity (B_r) was calculated as the ratio of the actual cross-sectional area at each measured height, A_{mht} , to the area of the convex hull at that measured height, $A_{conv(mht)}$. We then take the compliment to scale the ratio so that increasing value corresponds to increasing rugosity (fig. 1):

$$B_r = 1 - \frac{A_{mht}}{A_{conv(mht)}}$$

Mixed effect models were fit using bark rugosity, outer and inner bark cross-sectional area as a response variable, and tree individual as a random effect. Fixed effects included species, wood diameter, outer- and inner-bark thickness, wood cross-sectional area, measure height of the cross-section, and height growth rate.

Mean basal diameters were not significantly different between species ($P = 0.83$). Sapling ages ranged from 2 to 24 years across all species but did not significantly differ between species ($P = 0.64$). Outer-bark thickness ranged from 0.01 to 0.77 cm with the thickest maximum outer bark occurring in *P. taeda* (0.77 cm) and the thinnest maximum outer bark occurring in *P. serotina* (0.17 cm). Basal outer-bark thickness was significantly different between species ($P < 0.001$). Multiple comparisons showed that *C. tomentosa* had significantly thinner bark than *P. echinata* ($P = 0.014$), *P. taeda* ($P < 0.001$), and *Q. marilandica* ($P = 0.003$). *Prunus serotina* had significantly thinner bark than *P. echinata* ($P = 0.011$), *P. taeda* ($P < 0.001$), *Q. falcata* ($P = 0.042$), and *Q. marilandica* ($P = 0.002$). Bark rugosity varied among species from 0.00 (very

Author Information: Timothy M. Shearman, Post-Doctoral Scientist, Tall Timbers Research Station, Tallahassee, FL 32312; and J. Morgan Varner, Director of Research and Senior Scientist, Tall Timbers Research Station, Tallahassee, FL 32312.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

smooth) 0.17 (very rugose) with significant differences between species ($P < 0.001$). *Quercus marilandica* was significantly more rugose than *C. tomentosa* ($P < 0.001$) and *P. serotina* ($P < 0.001$). *Quercus falcata* was also significantly more rugose than *P. serotina* ($P = 0.023$). Height growth varied from 23.7 to 167.5 cm yr⁻¹ with *P. serotina* having the fastest vertical growth and *P. echinata* having the slowest growth among species.

Wood cross-sectional area was a positive significant effect for all outer bark investment models. Height growth rate was a negative effect (i.e., faster height growth had lower bark allocation) for *C. tomentosa*, *N. sylvatica*, *P. taeda*, and *P. serotina*, but not for *P. echinata* or either oak. Measure height also had a negative effect for all species except for *C. tomentosa* and *N. sylvatica*. Fixed effects explained 83–96 percent of the variance of outer bark investment (table 1).

Wood cross-sectional area was a significant fixed effect for all inner-bark models. The measure height had a negative effect on *C. tomentosa*, *Q. falcata*, and *Q. marilandica*, but was not significant for the other species. Fixed effects explained a slightly higher amount of the variance in the inner-bark models than the outer-bark models, explaining 93–98 percent of the variance (table 1).

Outer-bark thickness was the only significant fixed effect in the bark rugosity models. The models suggest a higher slope for *Q. marilandica* (0.28), *N. sylvatica* (0.23), and *Q. falcata* (0.20), than the other species. *Quercus marilandica* had significantly higher slopes than *C. tomentosa*, *P. echinata*, *P. taeda*, and *P. serotina*, but not *N. sylvatica* or *Q. falcata*. *Nyssa sylvatica* and *Q. falcata* also had significantly higher slopes than *P. taeda*, but not with any other species. Species and outer-bark thickness as fixed effects in the full model explained 77 percent of the variance.

Our results suggest that height growth may be a compromise to bark allocation for some species. We found an effect of measure height on outer-bark thickness in the oaks and pines, which indicates that outer bark tapers more than wood in these species. This result is consistent with the findings of others that suggest that pyrophytic species develop thicker bark at the base of the bole as a fire protection strategy (Graves and others 2014, Hammond and others 2015, Kidd and Varner 2019, Shearman and others 2018). However, we also found the effect of measure height in *P. serotina*, which is not consistent with this hypothesis.

The survival benefit of rugose bark is unclear because of its correlation with outer-bark thickness in the species we studied. Barlow and others (2003) found that bark texture (measured categorically as “rough”, “medium”, or “smooth”) was an important determination of tree mortality with surviving trees in burnt forests having significantly rougher bark in the smaller (0.2–0.6 cm) bark thickness classes. Rugosity might therefore benefit smaller diameter trees while larger trees can withstand fire due to having thick bark alone. Therefore, future heat transfer models might benefit from including a rugosity term as proposed in our study. Aside from providing data for several important yet understudied species, our rugosity measures offer promise for incorporating into fluid dynamics fire behavior models.

LITERATURE CITED

- Barlow, J.; Lagan, B.O.; Peres, C.A. 2003. Morphological correlates of fire-induced tree mortality in a central Amazonian forest. *Journal of Tropical Ecology*. 19: 291–299.
- Graves, S.J.; Rifai, S.W.; Putz, F.E. 2014. Outer bark thickness decreases more with height on stems of fire-resistant than fire-sensitive Floridian oaks (*Quercus* spp.; Fagaceae). *American Journal of Botany*. 101: 2183–2188.
- Hammond, D.H.; Varner, J.M.; Kush, J.S.; Fan, Z. 2015. Contrasting sapling bark allocation of five Southeastern USA hardwood tree species in a fire prone ecosystem. *Ecosphere*. 6: 1–13.
- Kidd, K.R.; Varner, J.M. 2019. Differential relative bark thickness and aboveground growth discriminates fire resistance among hardwood sprouts in the southern Cascades, California. *Trees*. 33: 267–277.
- Pausas, J.G. 2015. Bark thickness and fire regime. *Functional Ecology*. 29: 315–327.
- Shearman, T.M.; Wang, G.G.; Ma, P.T.; Guan, S. 2018. Patterns of bark growth for juvenile trees of six common hardwood species in the Eastern United States and the implications to fire-tolerance. *Trees*. 32: 519–524.

Table 1—Outer (ob) and inner (ib) bark area models for saplings of seven native tree species

Species codes	Best model	Coefficients					
		Intercept	Log(wood)	Llog(HTGR)	MHT	r_m^2	r_c^2
CATO	Log(ob)~log(wood) + log(HTGR) + (1 Treenum)	-1.01	1.37	-0.60	—	0.93	0.94
NYSY	Log(ob)~log(wood) + log(HTGR) + (1 Treenum)	0.27	1.36	-0.80	—	0.93	0.95
PIEC	Log(ob)~log(wood) + MHT + (1 Treenum)	-1.36	1.23		-0.53	0.83	0.96
PITA	Log(ob)~log(wood) + log(HTGR) + MHT + (1 Treenum)	-0.25	1.17	-0.29	-0.46	0.96	0.96
PRSE	Log(ob)~log(wood) + log(HTGR) + MHT + (1 Treenum)	0.39	0.86	-0.71	-0.71	0.88	0.89
QUFA	Log(ob)~log(wood) + MHT + (1 Treenum)	-1.47	1.42	—	-0.98	0.87	0.9
QUMA	Log(ob)~log(wood) + MHT + (1 Treenum)	-1.02	1.39	—	-0.37	0.86	0.97
CATO	Log(ib)~log(wood) + MHT + (1 Treenum)	-0.88	1.02	—	-0.22	0.96	0.99
NYSY	Log(ib)~log(wood) + (1 Treenum)	-1.70	0.97	—	—	0.98	0.99
PIEC	Log(ib)~log(wood) + (1 Treenum)	-2.01	0.62	—	—	0.94	0.97
PITA	Log(ib)~log(wood) + (1 Treenum)	-2.33	0.76	—	—	0.93	0.97
PRSE	Log(ib)~log(wood) + (1 Treenum)	-1.97	0.97	—	—	0.97	0.98
QUFA	Log(ib)~log(wood) + MHT + (1 Treenum)	-0.90	0.95	—	-0.23	0.96	0.97
QUMA	Log(ib)~log(wood) + MHT + (1 Treenum)	-0.75	0.95	—	-0.15	0.97	0.99

— = Non-applicable.

CATO = *Carya tomentosa*; NYSY = *Nyssa sylvatica*; PIEC = *Pinus echinata*; PITA = *Pinus taeda*; PRSE = *Prunus serotina*; QUFA = *Quercus falcata*; QUMA = *Quercus marilandica*. All models include a unique tree number (Treenum) as a random effect term. Fixed effects include wood cross-sectional area (wood), average height growth (HTGR), and measure height (MHT). Pseudo- r^2 values measure the amount of variance explained by the fixed effects (r_m^2) and combined fixed and random effects (r_c^2). Models were fit using maximum likelihood. Comparisons between nested model structures were made using AICc. All fixed effects were significant at $P < 0.05$.

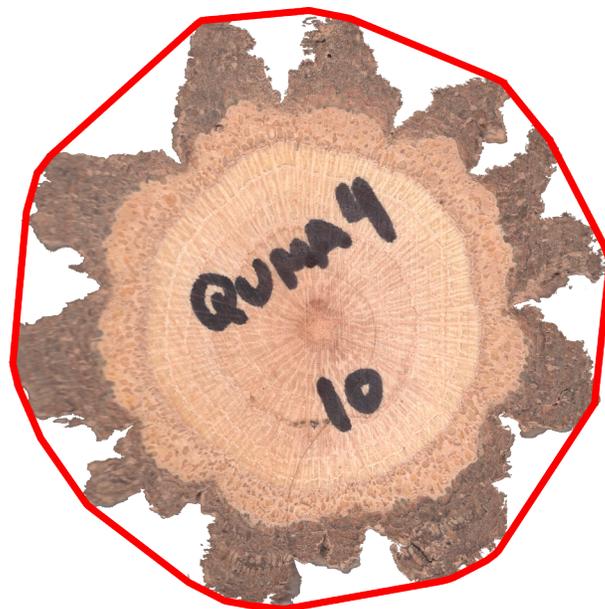


Figure 1—Bark rugosity of a cross-section, in this case a sample of *Q. marilandica* at 10 cm height can be measured as the compliment of the ratio of the cross-section area (area of the actual sample) to the area of its convex hull (red line).

TEMPORAL EFFECTS OF HURRICANES AND PRESCRIBED FIRE ON FUEL LOADING AND PINE REPRODUCTION IN THE SOUTHEASTERN UNITED STATES

Lauren S. Pile Knapp, Shanyue Guan, Bo Song, and G. Geoff Wang

ABSTRACT

The frequency and severity of extreme weather events, including hurricanes, are expected to increase in response to global change. Concurrently, southern U.S. forests will experience droughts that may facilitate a rise in wildfire. Wind damage can alter fuel dynamics and forest structure increasing susceptibility to wildfire, especially with drought. To mitigate fuel loads, managers commonly use salvage logging and prescribed fire. Time since disturbance may further reduce loading. To understand the effect of hurricanes on fuel loading, and the impact of time since disturbance and management action, we compared fuel loads and pine reproduction across four hurricanes spanning 24 years. Highly impacted stands were paired with less severely impacted control stands at each site. Fuel accumulations initially increased with hurricane disturbance but stabilized with time. With prescribed fire, coarse woody debris decreased more rapidly than without fire. Without prescribed fire, damaged stands had greater fuel loads than control stands, even after 24 years. Although overstory mortality can provide growing space for regeneration, effects from heavy woody fuel loads and frequent prescribed fire can override opportunities for establishment and recruitment.

INTRODUCTION

Hurricanes are an important component of the natural disturbance regime of coastal forested ecosystems in the Southeastern United States (Lugo and others 1983, Walker 1991). Coupled with other disturbance agents, such as prescribed burns, wildfire, and ice storms, hurricanes help shape the structure, composition, and function of the predominate vegetation within this region (Conner and Day, Jr. 1989; Lu and others 2020; Pile and others 2017). Typically, many hurricanes result in abundant precipitation without making severe impacts to coastal areas. Further, they are an important process to both short- and long-term increases in productivity for coastal estuaries. However, catastrophic hurricanes can bring powerful wind gusts, causing devastating impacts to forest trees across broad swaths of the landscape.

Forest recovery following hurricane damage is influenced by hurricane severity, ranging from defoliation and debranching to single tree or larger gap openings and removals that emulate uniform thinning or clearcuts (Everham and Brokaw 1996, Merrens and Peart 1992, Spurr 1956). Further, forest recovery following a hurricane can be altered by other compounding and interacting disturbance events, including fire, insect outbreaks, anthropogenic activities, and

subsequent wind events (Everham and Brokaw 1996). Because hurricanes create large fuel loads, with increased susceptibility to pest and disease for residual trees, wildfire is commonly predicted as the next substantive disturbance event (Gardner and others 1991, Glitzenstein and Harcombe 1988, Hook and others 1991, Putz and Sharitz 1991). Additionally, open stand conditions created by extreme wind can accelerate local airflow and expose down woody debris to solar radiation. This increased mid-flame windspeed and dried fuel make hurricane-impacted stands susceptible to fires with extreme behaviors. As a result, it has been hypothesized that the probability of a major wildfire increases significantly after a severe hurricane (Myers and van Lear 1998). Further, based on a 1,200-year proxy record of hurricanes and fires from the coastal region of the Gulf of Mexico, Liu and others (2008) reported that the likelihood and intensity of fire increased significantly following major hurricanes, resulting in high tree mortality and the impairment of recruitment and recovery. However, this hypothesis, also known as the hypothesis of hurricane–fire interaction, has not been supported by recent data (i.e., the lack of a major fire outbreak after a recent hurricane) likely because of active fire suppression and post-hurricane mitigation efforts, including salvage logging and prescribed burning.

Author Information: Lauren S. Pile Knapp, Research Ecologist, U.S. Department of Agriculture, Forest Service, Northern Research Station, Columbia, MO 65010; Shanyue Guan, Masters Student, Clemson University, Clemson, SC 29634; Bo Song, Associate Professor, Clemson University, Georgetown, SC 29440; and G. Geoff Wang, Professor, Clemson University, Clemson, SC 29634.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

In the Southeastern United States, periodic prescribed burns are one of the most used practices for managing the composition and structure of coastal pine forests and is an important mitigant in the reduction of fuel loading following extreme disturbance events. However, few studies have examined stand recovery following hurricanes and prescribed burning. In a study by Smith and others (1997), hurricanes and prescribed burning were unfavorable for loblolly pine (*Pinus taeda* L.) regeneration. A few studies have reported fuel characteristics in hurricane damaged stands (Cooke and others 2007, Wade 1993), but how post-hurricane fuel complexes and tree reproduction change with time and prescribed burning remains largely unknown.

The objective of this study was to examine the temporal effects of hurricanes on stand structure, fuel dynamics, and tree reproduction in southeastern coastal pine forests of the United States. To conduct this study, we examined forest stands that had suffered hurricane damage to neighboring, minimally damaged (“Control”) stands with similar management including prescribed burning. In situations where it allowed, we also compared Damaged and Control stands to salvage logging and damaged but without prescribed fire. Specifically, the study was designed to address the following questions: (1) What are the residual effects of hurricanes on forest stand structure? (2) How quickly do fuels recover to control levels following hurricanes? (3) How does increased fuel loading from hurricanes coupled with prescribed burning influence understory vegetation and tree reproduction? This

retrospective study was developed from a chronosequence of hurricanes over two decades from 1989 through 2008.

MATERIALS AND METHODS

Hurricane and Study Site Descriptions

We selected the most catastrophic hurricanes in recent history, including hurricanes Hugo, Opal, Katrina, and Ike and identified hurricane damaged pine stands on public lands within the impact zone with the aid of local land managers (fig. 1, table 1).

For Hurricane Hugo, we had two study locations, the Hobcaw Barony Wildlife Refuge (HBWR) and the Francis Marion National Forest (FMNF). HBWR (33°24'N, 79°15'W) is 6475 hectares of predominantly loblolly and longleaf pine (*P. palustris* Mill.) occupying the southern tip of the Waccamaw Peninsula in Georgetown County, South Carolina. Soils at HBWR are sandy, excessively to moderately drained on the western side, and moderately to poorly drained on the eastern side. The mean temperatures range from 8 °C in January to 23 °C in August with mean annual precipitation of approximately 1422 mm/year (NOAA National Centers for Environmental Information 2022). The FMNF, (33°9'N, 79°42'W) is 104 759 hectares of predominantly loblolly and longleaf pine located on the lower Coastal Plain of South Carolina, within Berkeley and Charleston counties. Soils in FMNF are sandy and moderately drained in pine stands with temperatures and precipitation

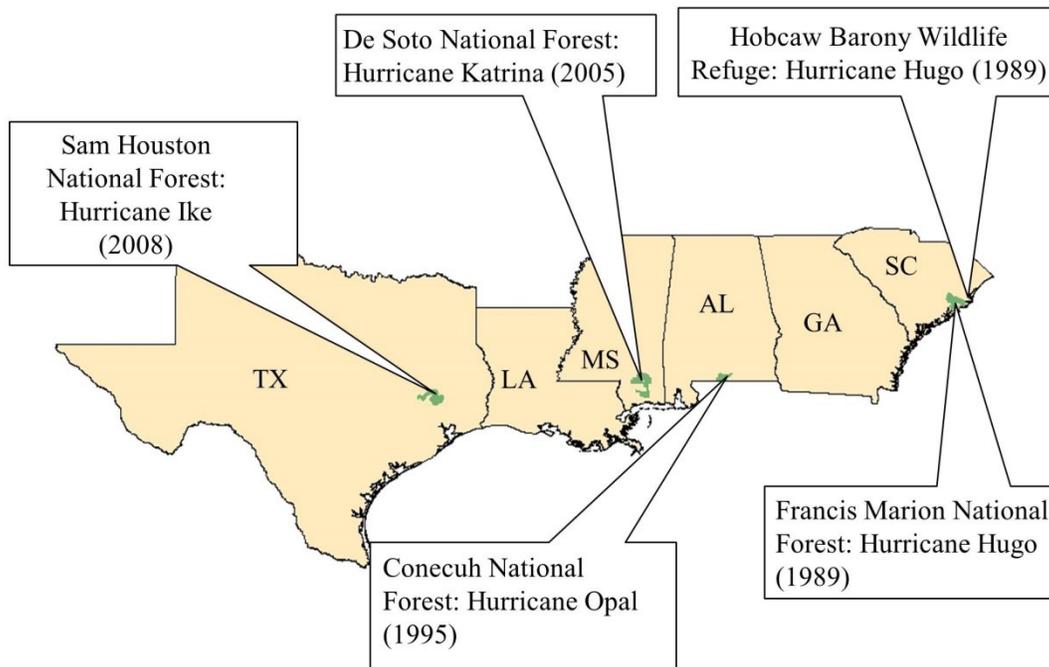


Figure 1—Location of study sites and associated hurricanes.

Table 1—Hurricane landfall date, location, Saffir/Simpson hurricane category and corresponding study site location and sampling design

	Hurricane category			
	Hugo	Opal	Katrina	Ike
Date	September 21, 1989	October 4, 1995	August 29, 2005	September 13, 2008
Landfall Location	Sullivan's Island, SC	Pensacola, FL Navarre Beach, FL	Buras-Triumph, LA	Galveston, TX
Category	4	3	3	4
Study site Location(s)	Francis Marion National Forest (FMNF) and Hobcaw Barony Wildlife Refuge (HBWR)	Conecuh National Forest (CNF)	Desoto National Forest (DNF)	Sam Houston National Forest (SHNF)
Sampled stands	12 Total Damaged Stands (8 Damaged and Unburned, 4 Damaged and Burned); 10 Control Stands	10 Damaged Stands; 10 Control Stands	10 Damaged Stands; 10 Damaged and Salvaged Stands; 10 Control Stands	10 Damaged Stands; 10 Control Stands

amounts similar to HBWR. For Hurricane Opal, our study location was the Conecuh National Forest (CNF) 31°7'N, 86°45'W. The CNF is the southern-most national forest in Alabama occupying 33 949 hectares of predominate longleaf and slash pine. Soil types are marked by deep sandy soils predominantly of the Troup and Fuquay series. The mean temperatures range from 10 °C in January to 28 °C in July with mean annual precipitation of approximately 1524 mm/year (National Climatic Data Center). Our study location for Hurricane Katrina was the De Soto National Forest (DSNF) 31°4'N, 88°59'W occupying 209 865 hectares of predominately longleaf and slash (*P. elliotii* Engelm.) pines spreads across six counties in Mississippi. Soil types are mainly sandy loams. The monthly mean temperature ranges from 9 °C in January to 27 °C in July with mean annual precipitation of approximately 1651 mm/year (National Climatic Data Center). Our study location for Hurricane Ike was the Sam Houston National Forest (SHNF) 30°32'N, 95°21'W occupying 65 979 hectares of predominate loblolly and shortleaf (*P. echinata* Mill.) pines across the counties of Montgomery, Walker, and San Jacinto in eastern Texas. Soil types are primarily characterized as loamy and sandy. The monthly mean temperature ranges from 12 °C in January to 28 °C in July with mean annual precipitation of approximately 1397 mm/year (National Climatic Data Center).

Experimental Design and Sampling

This retrospective study was conducted as a completely randomized design comparing upland pine stands damaged by hurricanes to similar, neighboring, less damaged stands across the chronosequence of hurricane events. For each hurricane, 10-12 severely damaged upland pine stands (“Damaged”) were identified based on existing records, aerial photos, and with the assistance of the local U.S. Department of Agriculture (USDA), Forest Service, Ranger District office (table 1). Damaged stands had observable overstory canopy mortality, primarily described as a majority of stems snapped or bent from wind damage. For comparison, 10 less

damaged pine stands, with similar stand and site conditions as those Damaged stands, were identified as (“Control”) stands. These stands formed a chronosequence consisting of four distinct times since hurricane disturbance classes, ranging from 6 years (Hurricane Ike in 2008, sampled in 2014) to 8 years (Hurricane Katrina in 2005, sampled in 2013) to 18 years (Hurricane Opal in 1995, sampled in 2013) to 24 years (Hurricane Hugo in 1989, sampled in 2013). With the exception of Hurricane Hugo, prescribed burns were applied within the management plan for each location, typically within 2- to 5-year return intervals. For Hurricane Hugo, due to lack of representation of Damaged stands that included prescribed fire, we were able to sample four hurricane damaged and burned stands, similar to the other hurricanes, but we were also able to sample eight “Damaged and Unburned” (D+ UnB) stands for within hurricane comparison. Further, to determine the role of salvage logging on fuel loading and tree reproduction, we sampled an additional 10 hurricane Damaged stands on the Desoto National Forest that were salvage logged (“Salvaged”).

In each identified stand, 1-3 plots were located at 30 m intervals along randomly established transects using ArcGIS. For the stands associated with Hurricane Hugo on the HBWR and FMNF, four of the Damaged stands had three plots, one had two plots, and three had one plot. Further, for the Control stands, six had one plot, and six had two plots. For stands sampled in the other hurricane areas, all stands had two plots each. To determine residual overstory stand structure and composition, the diameter at breast height (DBH) and species of all saplings (2.5 < DBH < 10.2 cm) were measured within 5.6 m radius from plot center and the DBH and species of all trees (DBH > 10.2 cm) were measured within 11.3 m radius of plot center.

To determine differences in woody fuel loading between Damaged and Control stands, a modified version (see Coates and others 2019, Hahn and others 2021) of Brown’s (1974) planar intercept method was used to measure fuel loading by

size class. At the plot center, three 15 m sampling transects were established from the plot center. The orientation of the center transect was established in a random direction, and the other two transects were placed at +120° and -120° from the initial transect. Measurements along two of the fuel transects began at the plot center, and the third transect worked backward from the end point at 15 m. Down woody fuels of 0.00–0.64 cm, 0.64–2.54 cm, 2.54–7.62 cm in diameter, and over 7.62 cm in diameter that intersected the sampling plane were tallied as 1-, 10-, 100-, and 1,000-hour fuel classes, respectively. For 1- and 10-hour fuels, intercepts were counted along the first 1.8 m of the transect. For 100-hour fuels, intercepts were counted along the first 3.6 m of the transect. The 1,000-hour fuel was recorded as either pine or hardwood and decay class (sound or decayed) and measured for diameter along the entire 15 m transect (Lutes and Keane 2006, Maser and others 1979). Counts of 1-, 10-, 100- and 1,000-hour fuels obtained from transect sampling in the field were converted to weights using equations given by Brown (1974). Depths of downed woody debris were measured to the nearest 0.3 cm at sections of 3.66 to 3.96 m, 7.62 to 7.92 m, and 12.19 to 12.50 m. Woody fuel depth was measured from the surface of mineral soil to the highest dead and down woody fuel particle (<1.83 m), which intersected the transect. Litter (Oi horizon) and duff (Oe + Oa horizon) depths were measured to the nearest 0.3 cm along the same transect intervals.

To assess differences in ground cover and tree reproduction between Damaged and Control stands, we recorded the coverage of ground flora (classified as forbs or graminoids) and woody plants (shrubs and vines) in 4 m² quadrats centered at 1.5, 4.6, 7.6, 10.7, and 13.7 m along each transect. Further, within each quadrat, we tallied small (<0.3 m tall) and large (>0.3 m tall but DBH <2.5 cm) tree reproduction by species.

For statistical analyses, we limited our comparison to within hurricane assessments of overstory structure, fuel loading, vegetation, and tree reproduction. For each hurricane, we compared stand level averages by condition type (Damaged, Salvaged, or Damaged and Unburned stands compared to Control stands) using general linear mixed models (GLIMMIX) with condition type as a fixed effect. The distribution of dependent variables was assessed prior to analysis and fit within the model. Analyses were conducted in SAS 9.4 with significance determined at an alpha of 0.05. Means are reported as the treatment means ± the standard deviation.

RESULTS AND DISCUSSION

The effects of increased fuel loads following hurricanes can have long lasting residual effects on fuel, and forest structure and management can influence outcomes. Our results

indicate that (1) prescribed burns are effective at reducing fine fuels, even after short time periods, with 1-hour fuels similar to Controls within 6 years and 10-hour fuels after 8 years; (2) salvage logging reduces fine and coarse fuels more effectively than prescribed burning alone and is the only treatment where 1,000-hour fuels were comparable to Controls; (3) without burning, fuel loads remained higher even 24 years following disturbance; and (4) higher fuel loadings and prescribed burning can alter the composition of the forest understory, promoting forbs and graminoids and reducing woody stems including tree reproduction.

Residual Stand Structure

As expected, relative to the Control, hurricanes significantly reduced overstory basal area (BA) m²/ha and density [trees per hectare (TPH)] in Damaged stands following 6 (BA: $F = 30.7$; $p < 0.001$; TPH: $F = 22.9$; $p < 0.001$), 8 (BA: $F = 17.8$; $p < 0.001$; TPH: $F = 9.7$; $p = 0.001$) and 18 (BA: $F = 14.2$; $p = 0.001$; TPH: $F = 8.9$; $p = 0.008$) years post-hurricane (fig. 2). However, 24 years following a hurricane, tree recruitment is likely reducing differences between Damaged and Control stands, and especially in the absence of prescribed burns in Damaged and Unburned stands for hardwood and pine regeneration. There were no differences in BA between stand conditions for Hurricane Hugo ($F = 1.9$; $p = 0.18$), although there were differences in stem densities ($F = 19.6$; $p < 0.001$). Damaged and Unburned (1466 ± 516 TPH) stands had more stems than either Damaged (576 ± 237 TPH) or Control (470 ± 246) stands, which were similar. The differences in stem densities between stand condition type were particularly apparent in the smaller size classes of the Damaged and Unburned stands (fig. 3)

Fuel Loading and Depth

Prescribed fire was effective at reducing fine woody fuels, but 1,000-hour fuels were more recalcitrant even following a quarter century. There were no differences between stand condition in litter or duff for Hurricane Ike (litter: $F = 0.0$; $p = 0.88$; duff: $F = 0.1$; $p = 0.79$) or Hurricane Katrina (litter: $F = 0.9$; $p = 0.39$; duff: $F = 2.0$; $p = 0.15$). However, litter accumulations were greater in Control (0.83 ± 0.25 tons/ha) stands than Damaged (0.49 ± 0.26 tons/ha) stands for Hurricane Opal ($F = 9.2$; $p = 0.007$). But there were no differences in duff accumulations ($F = 0.5$; $p = 0.48$). Differences in litter accumulation were also recorded for Hurricane Hugo ($F = 6.9$; $p = 0.005$). Litter accumulations were significantly higher in Damaged and Unburned (6.48 ± 2.36 tons/ha) stands than either Damaged (2.07 ± 0.88 tons/ha) or Control (3.81 ± 2.15 tons/ha) stands, which were similar. Differences were also recorded for duff accumulation ($F = 19.3$; $p < 0.001$). Stands impacted by Hurricane Hugo that were Damaged and Unburned ($D + UnB$, 5.51 ± 1.94 tons/ha) and those that were Damaged (4.93 ± 1.35 tons/ha)

had significantly greater duff accumulations than Controls (1.69 ± 1.03 tons/ha). The differences in litter and duff depths for Hurricane Hugo are likely attributed to the lack of fine fuel consumption by prescribed fire in the Damaged and Unburned stands.

For 1-hour fuels, significant differences were recorded 24 years following a hurricane but not at sites with a more recent hurricane disturbance history ($F = 12.3$, $p < 0.001$), however, this reflected differences in the use of prescribed burning following a hurricane (fig. 4). The Damaged and Unburned (D+ UnB) stands assessed from Hurricane Hugo had higher 1-hour fuel loads than either the Damaged or Control stands but Damaged and Control stands were similar in their 1-hour loads. Differences in 10-hour fuels were recorded 6- and 8-years following hurricane disturbance (Hurricane Ike: $F = 26.8$; $p < 0.001$ and Hurricane Katrina: $F = 5.2$; $p = 0.013$, respectively) (fig. 4). Six years following a hurricane, 10-hour fuels were nearly four times as high in Damaged (2.28 ± 0.91 tons/ha) stands than Control (0.60 ± 0.48 tons/ha) stands for

Hurricane Ike. Ten-hour fuels in Damaged stands (0.79 ± 0.67 tons/ha) remained higher 8 years following a hurricane, but Salvaged (0.28 ± 0.21 tons/ha) stands had similar loading as Control (0.24 ± 0.21 tons/ha) stands. Twenty-four years following a hurricane, Damaged and Unburned (4.12 ± 1.67 tons/ha) stands remained higher than the Control (1.13 ± 0.96 tons/ha). However, stands Damaged (2.56 ± 1.55 tons/ha) and treated with prescribed burning had 10-hour fuel loads similar to both Control and the Damaged and Unburned stands.

For 100-hour fuels, differences were recorded 6 years following hurricane disturbance, but not thereafter, except for the Damaged and Unburned stands from Hurricane Hugo (fig. 5). In Damaged (4.98 ± 3.95 tons/ha) stands, 100-hour fuels were nearly five times higher than Control (1.08 ± 0.85 tons/ha) stands in the 6 years following Hurricane Ike ($F = 9.3$; $p = 0.007$). After 24 years without prescribed burns, 100-hour fuels were significantly higher in the Damaged and Unburned (4.48 ± 2.46 tons/ha) stands than the Damaged

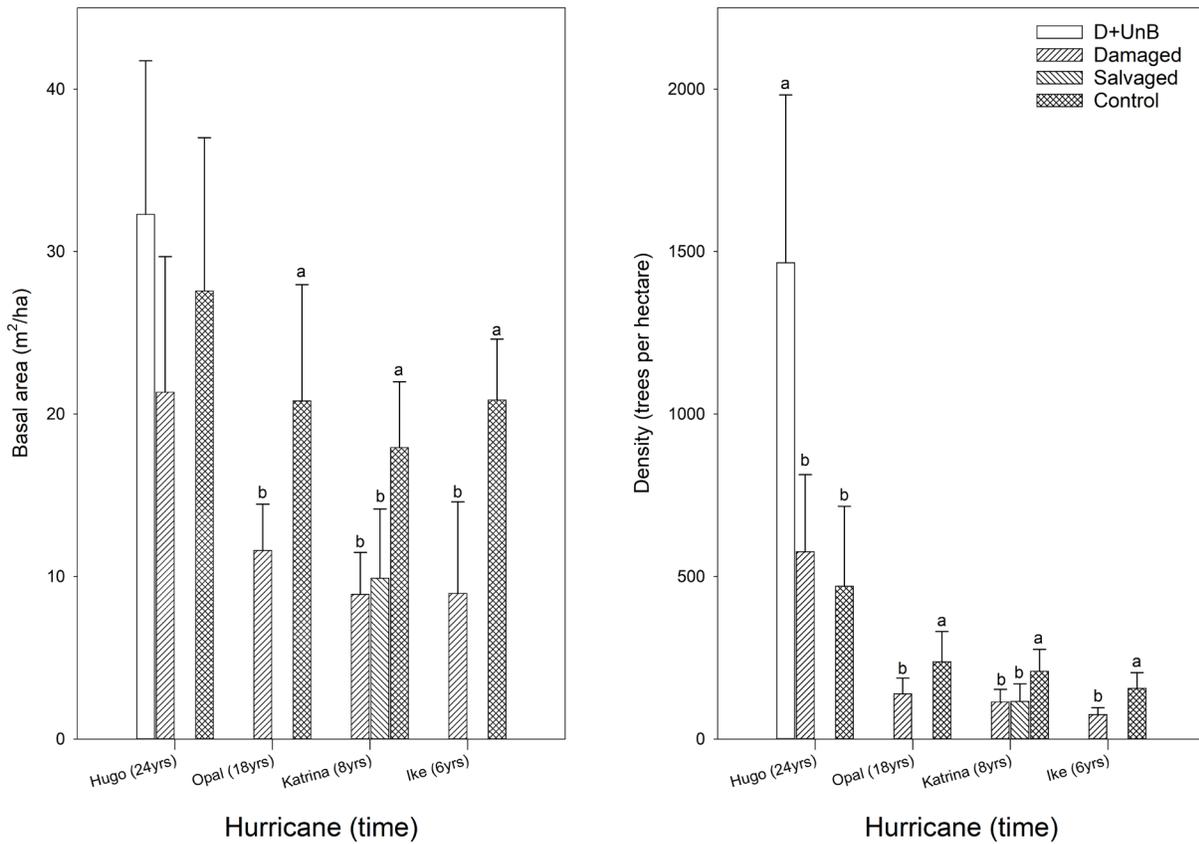
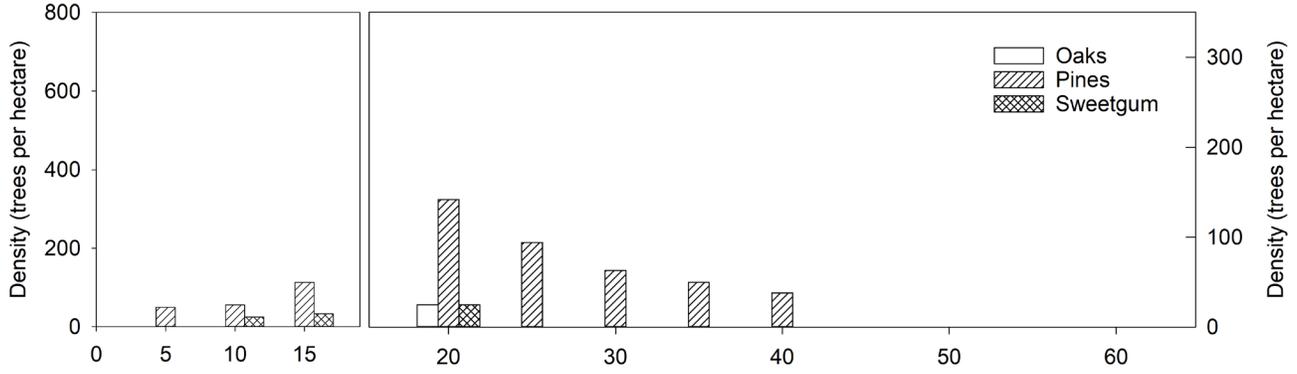
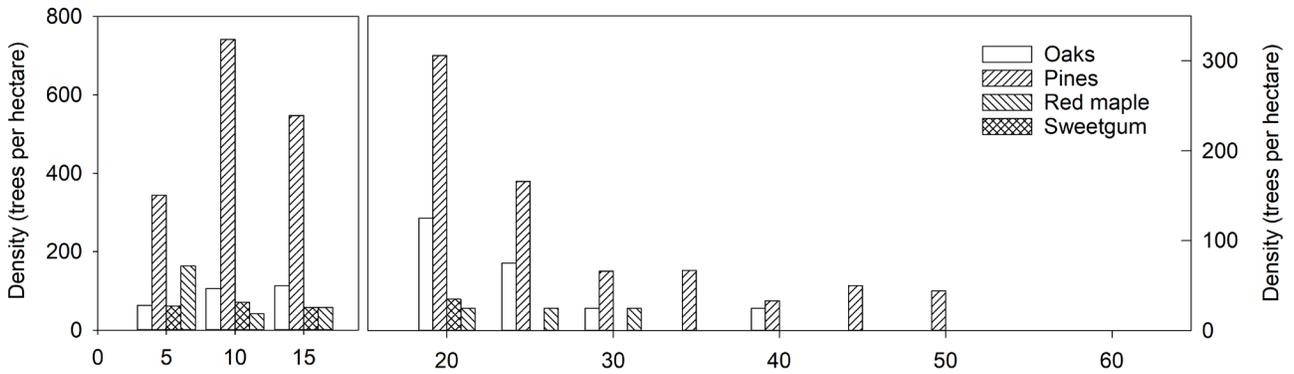


Figure 2—Basal area (m²/ha) and density by stand condition [Damaged and Unburned (D+UnB), Damaged, Salvaged, and Control] for each of the four hurricane events. Differences in letters indicates a significant difference between stand condition within hurricane.

Damaged



Damaged and Unburned



Control

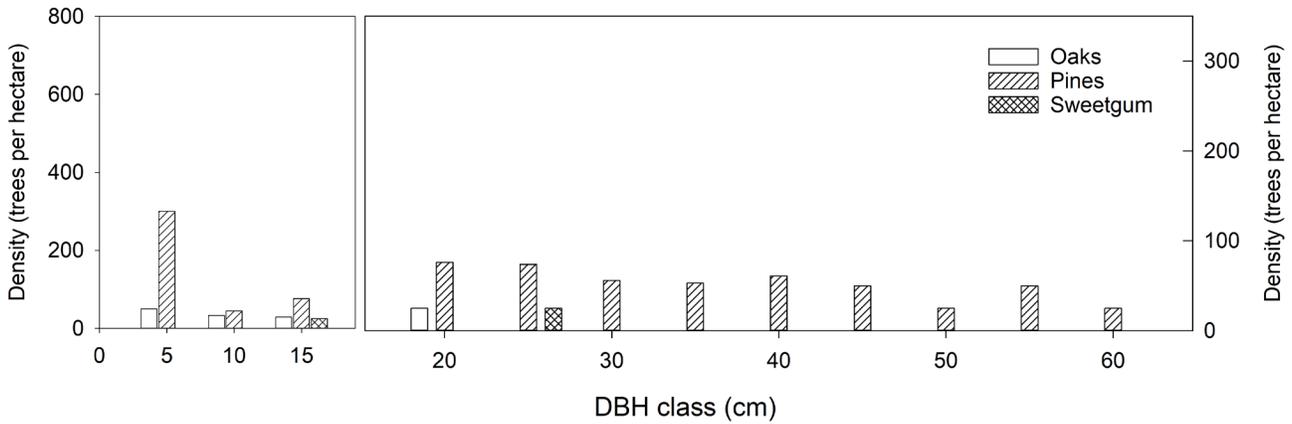


Figure 3—Diameter at breast height (DBH) distribution by species (oaks, pines, red maple, and sweetgum) of Damaged, Damaged and Unburned, and Control stands for Hurricane Hugo, 24 years post hurricane.

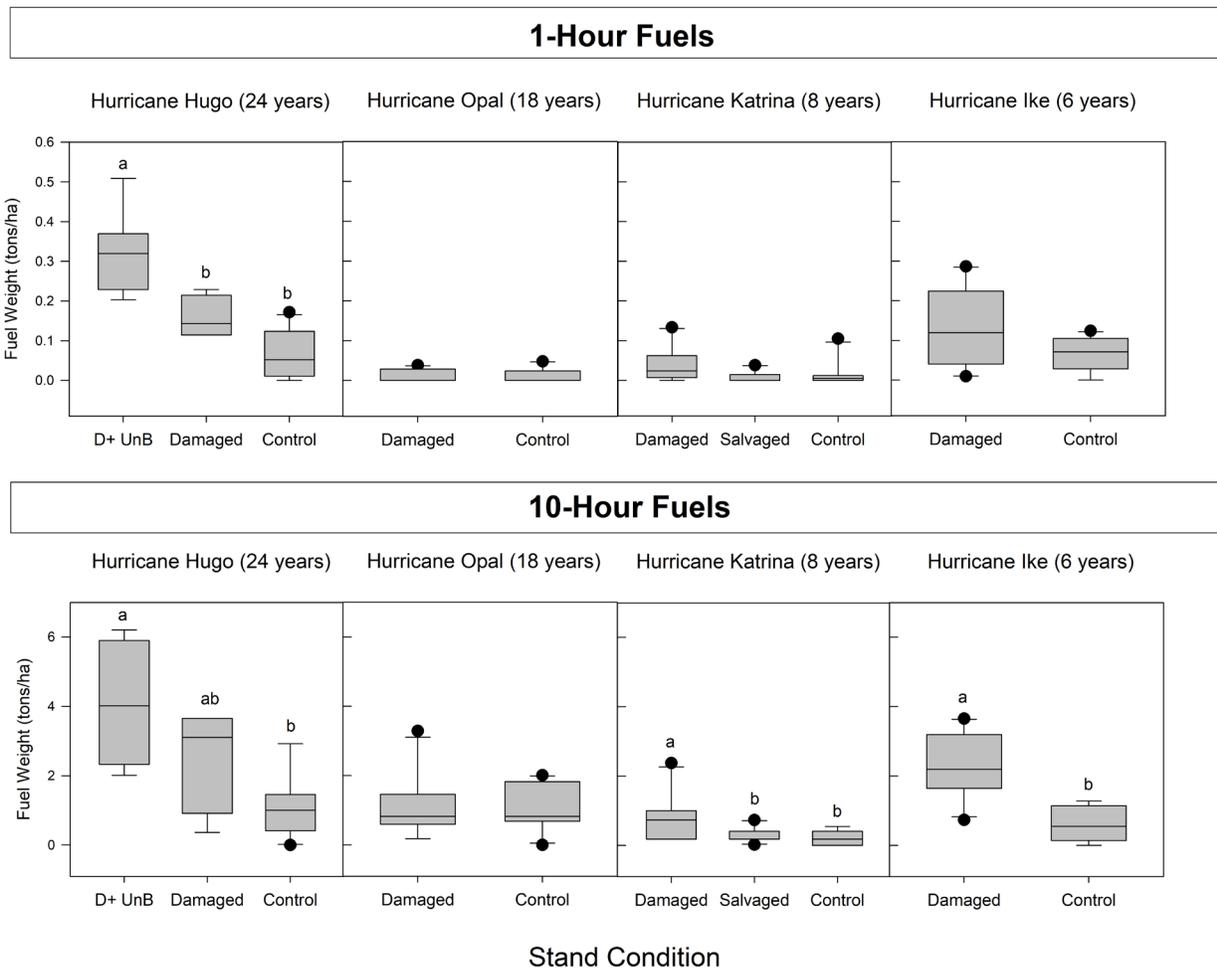


Figure 4—Fuel loading of 1- and 10-hour fuels by stand condition [Damaged, Salvaged, Damaged and Unburned (D+UnB) or Control] by hurricane representing a time-since-disturbance chronosequence. Means are compared within a hurricane. Different lowercase letters above a boxplot indicate significant disturbance effects between stand conditions. Boundaries of the box plot are represented by the 25th- and 75th-percentiles, the median line within the plot, whiskers represent the 10th- and 90th-percentiles, and points indicate outliers.

(1.81 ± 1.38 tons/ha) or Control (1.02 ± 1.49 tons/ha) stands. Differences in 1,000-hour fuels were still apparent from 6 to 24 years following a hurricane (fig. 5). Damaged (25.60 ± 14.74 tons/ha) stands from Hurricane Ike had more than four times the amount of 1,000-hour fuels than the Control (6.45 ± 6.75 tons/ha; $F = 13.9$; $p = 0.002$) stands. For Hurricane Katrina, Damaged (15.03 ± 8.46 tons/ha) stands had nearly twice the amount of 1,000-hour fuel loading as Salvaged (8.37 ± 6.25 tons/ha) stands, and five times the amount of Control (3.46 ± 2.71 tons/ha) stands ($F = 8.6$; $p = 0.001$) however, salvage logging did reduce 1,000-hour fuel loads within the range of the Control. One-thousand-hour fuel loads for Hurricane Opal, 18 years following a hurricane, were generally lower than hurricanes Katrina or Ike, but Damaged (5.50 ± 3.50 tons/ha) stands had significantly greater 1,000-hour fuels than Control (1.67 ± 2.91 tons/ha) stands ($F = 7.0$; $p = 0.016$). In our study, stands Damaged and Unburned (27.23 ± 18.09 tons/ha) had similar, but higher 1,000-hour fuels than

Damaged (12.35 ± 13.29 tons/ha) stands for Hurricane Hugo ($F = 11.2$; $p = 0.001$). Control (1.91 ± 2.50 tons/ha) stands had 1,000-hour fuel loads that approximated Damaged stands. The high variation and non-significance of our results are likely from our unbalanced sampling design for Hurricane Hugo, however, the large amount of residual 1,000-hour fuels in Damaged and Unburned stands is quite notable.

Understory Vegetation and Tree Reproduction

The differences in coverage of shrubs and vines, forbs, and graminoids between stand conditions were not consistent across hurricanes. For Hurricane Ike, shrubs and vines ($F = 5.7$; $p = 0.028$) were higher in Control stands but forbs ($F = 7.1$; $p = 0.016$) and graminoids ($F = 5.8$; $p = 0.027$) coverage was greater in the Damaged stands (fig. 6). For Hurricane Katrina, forb and graminoid coverage were greatest in Salvaged stands and comparable between Damaged and Control Stands (forbs: $F = 5.0$; $p = 0.014$; graminoids: $F = 6.4$; $p = 0.005$).

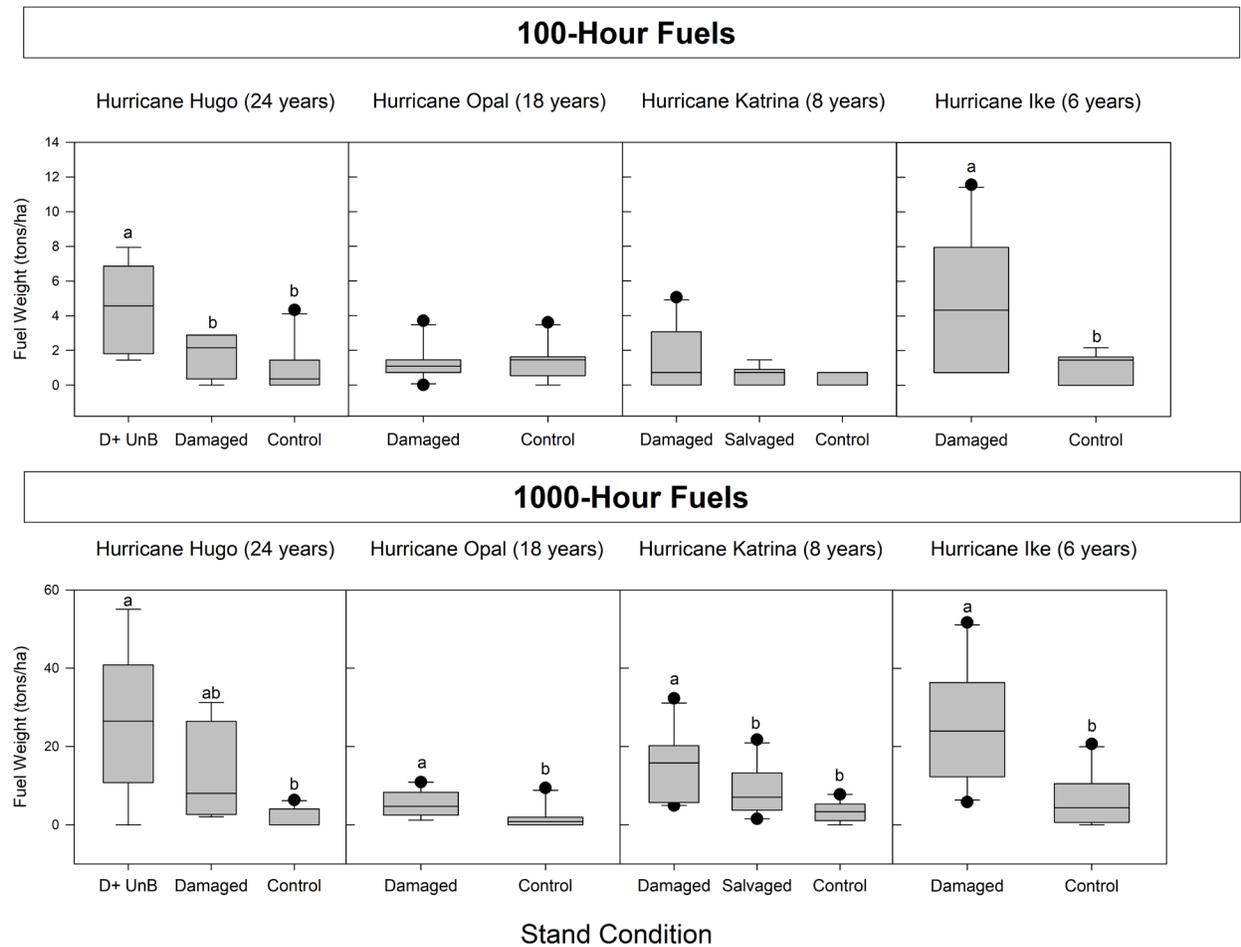


Figure 5—Fuel loading of 100- and 1,000-hour fuels by stand condition [Damaged, Salvaged, Damaged and Unburned (D+UnB) or Control] by hurricane representing a time-since-disturbance chronosequence. Means are compared within a hurricane. Different lowercase letters above a boxplot indicate significant disturbance effects between stand conditions. Boundaries of the box plot are represented by the 25th- and 75th-percentiles, the median line within the plot, whiskers represent the 10th- and 90th-percentiles, and points indicate outliers.

For Hurricane Opal, forb coverage was greater in Damaged stands than Control stands ($F = 6.8$; $p = 0.018$). The coverage of shrubs and vines differed for Hurricane Hugo, with coverage greatest in Damaged and Control stands and lowest in Damaged and Unburned stands ($F = 13.6$; $p < 0.001$).

After catastrophic wind damage, forest recovery follows one or more paths: regrowth, release, recruitment, or repression (Everham and Brokaw 1996). The path of recovery of a given site is greatly determined by both the severity of the disturbance and by the environmental dynamics of resources. Severe hurricane damage will create gaps in the canopy, which will provide light and space for new regeneration and other understory vegetation. These gaps favor shade intolerant species such as pines, and pioneer and sprouting hardwoods. Many studies have reported that gaps resulting from hurricanes have the appropriate gap size for the growth of longleaf pine and loblolly pine seedlings (Brockway and Outcalt 1998, McGuire and others 2001). Mitigations, such

as salvage logging, may change the ecosystem processes and population of species (Lindenmayer and Noss 2006). Further, periodic fire in hurricane damaged stands may impair regeneration processes. In our study, the density of total and pine reproduction was greatest in stands that were Damaged and Unburned for Hurricane Hugo (total: $F = 13.9$; $p < 0.001$; pine: $F = 21.8$; $p < 0.001$). However, pine reproduction was greatest in Salvaged stands for Hurricane Katrina ($F = 3.8$; $p = 0.034$) when compared to Damaged and Control stands (fig. 7). This is in contrast to Greene and others (2006) who reported that salvage logging reduced reproduction density due to limited seed source availability.

Although limited by our sample size and unbalanced experimental design for Hurricane Hugo, we were able to compare management with prescribed fire to that without 24 years following hurricane disturbance. Pine and total reproduction were greatest in Damaged and Unburned stands for Hurricane Hugo when compared to Damaged and

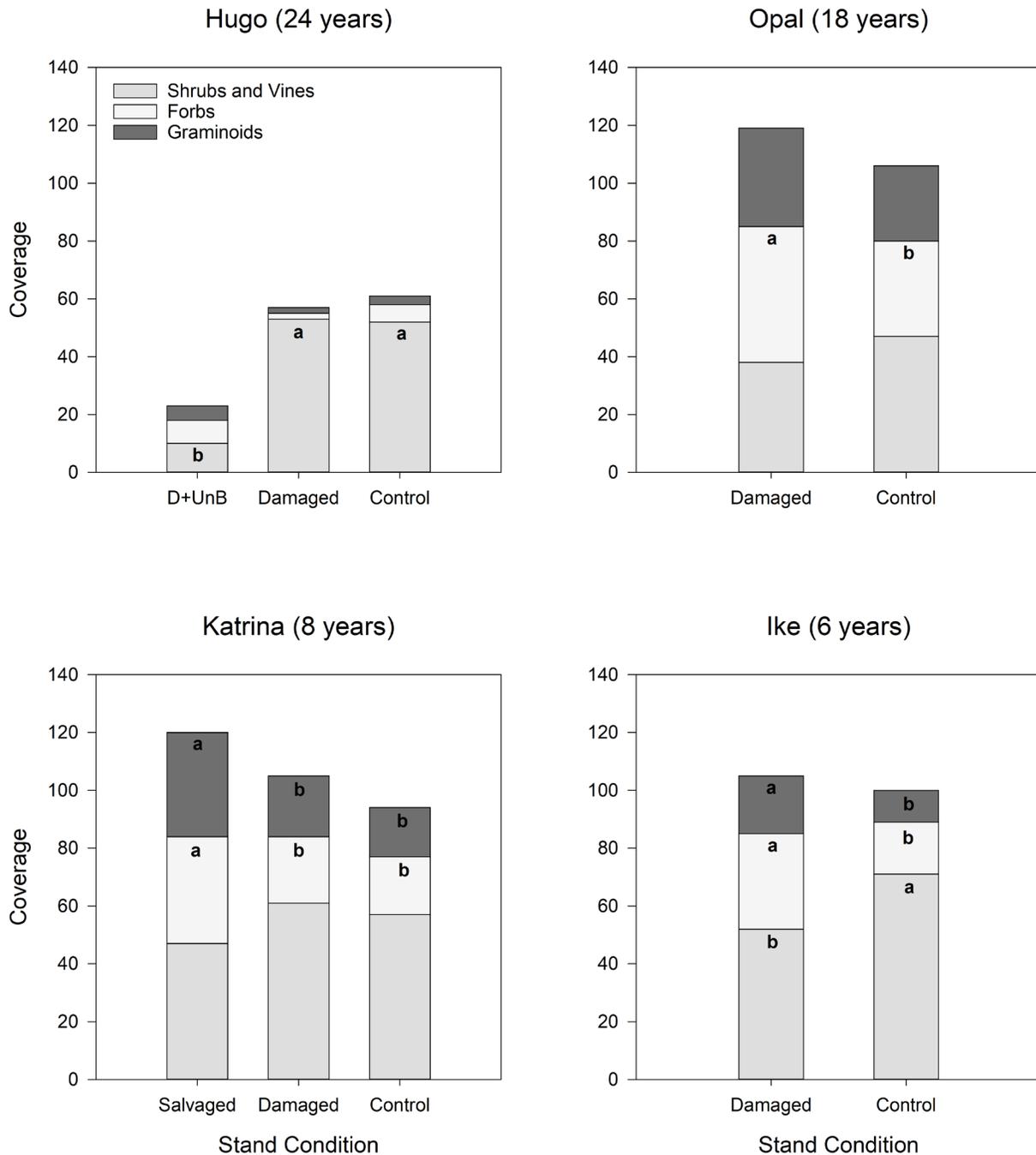


Figure 6—Coverage of shrubs and vines, forbs, and graminoids by hurricane and stand condition. Lower case letters indicate a significant difference between understory vegetation type within a hurricane based on an alpha of 0.05.

Control stands. The Damaged and Unburned stands also had lower coverage of shrubs and vines when compared to the other stand condition types where prescribed burns is a management practice. Over 50 percent of the reproduction in the Damaged and Unburned stands was pine, with loblolly pine the primary pine species. Its sensitivity to fire and ability to dominate a site following disturbance likely contributes to the increase in reproduction densities in the Damaged and Unburned stands. This contrasts with Hurricane Katrina, where salvage logging with prescribed fire reduced fuel

loading, increased forb and graminoid coverage, and resulted in more pine reproduction, specifically longleaf pine.

CONCLUSIONS

Frequent prescribed fire can reduce fine and coarse woody fuels in hurricane damaged stands. However, although beneficial for mitigating catastrophic events like drought-induced wildfire, frequent burning in hurricane impacted stands with high fuel loads can alter understory plant

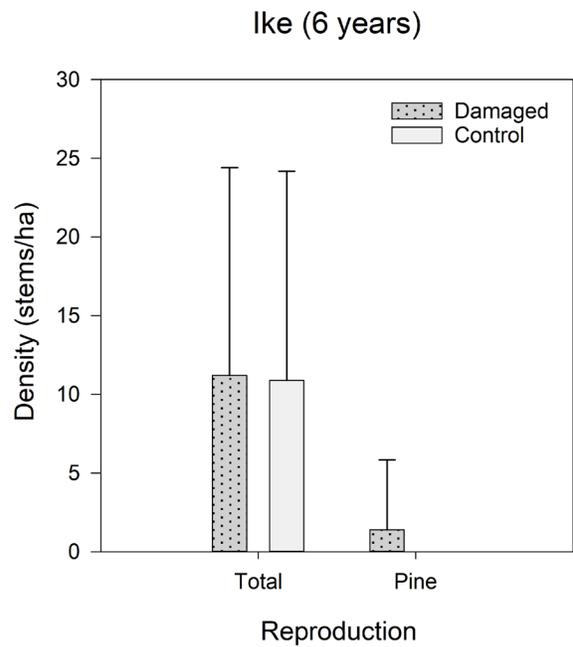
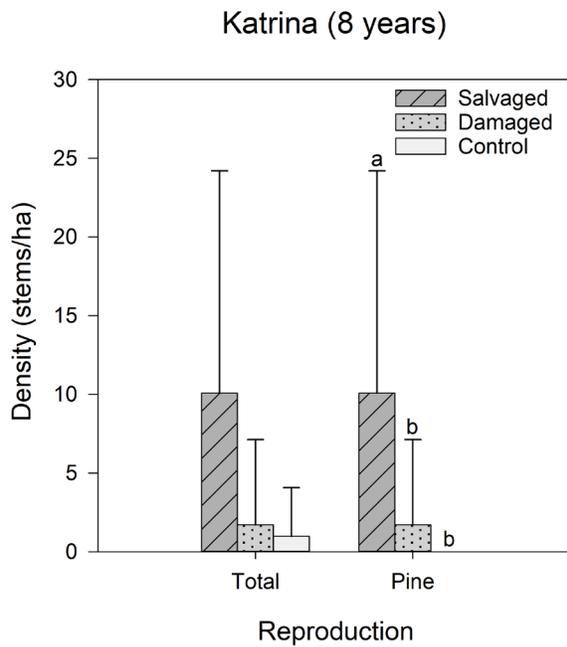
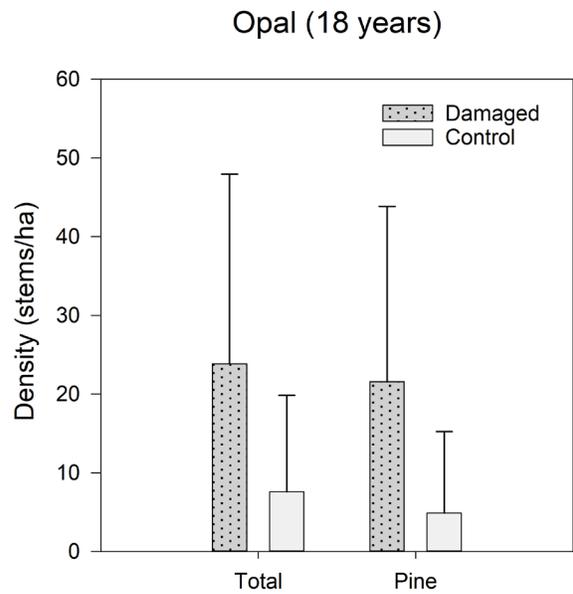
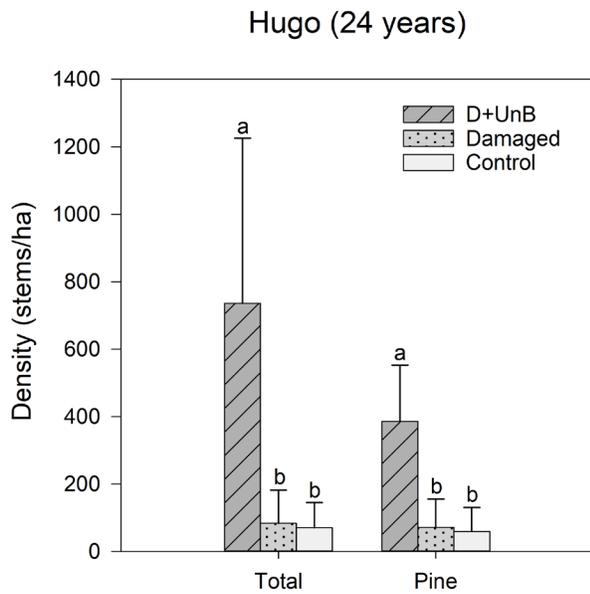


Figure 7—Total and pine reproduction densities by hurricane. Lower case letters indicate a significant difference between stand condition for either total or pine reproduction based on an alpha of 0.05.

communities and limit the establishment and recruitment of tree reproduction for some species. Nevertheless, if woodland structures with open canopies and increased coverage of grass and forb-dominated ground flora are desired, management including prescribed fire and salvage logging may accelerate meeting restoration objectives following hurricane damage.

ACKNOWLEDGMENTS

This project was funded in part by the USDA Forest Service Forest Health Monitoring program serviced through the South Carolina Forestry Commission to Clemson University (PI: G. Geoff Wang). We would like to thank our cooperators on the project, including George Chastain, executive director of Hobcaw Barony and the USDA Forest Service National Forest staff specifically, Mark Danaher, Tim Mersmann, Keith Coursey, Tate Thriffley, and Bob Allen. Further, we would like

to thank our field support, Artimus Wimberley and Patrick Ma. We would also like to thank our reviewers, Dr. Adam Coates and Dr. Matt Olson for their great insights and helpful comments and the proceedings editor, Dr. John Willis.

LITERATURE CITED

- Brender, E.V.; Loftus, N.S. 1969. Growth of advance loblolly reproduction after removal of overwood. *Journal of Forestry*. 67: 830–831.
- Brockway, D.G.; Outcalt, K.W. 1998. Gap-phase regeneration in longleaf pine wiregrass ecosystems. *Forest Ecology and Management*. 106: 125–139. [https://doi.org/10.1016/S0378-1127\(97\)00308-3](https://doi.org/10.1016/S0378-1127(97)00308-3).
- Brown, J.K. 1974. Handbook for inventorying downed woody material. Gen. Tech. Rep. INT-16. Ogden, UT: U.S. Department of Agriculture Forest Service, Intermountain Forest and Range Experiment Station. 24 p.
- Clapp, R.T. 1938. The effects of the hurricane upon New England forests. *Journal of Forestry*. 36: 1177–1181.
- Coates, T.A.; Waldrop, T.A.; Mohr, H.H.; Hutchinson, T. 2019. The Appalachian Mountain fuel photo series: A resource for fire managers and practitioners. Gen. Tech. Rep. GTR-SRS-241. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 180 p.
- Conner, W.H.; Day, Jr, J.W. 1989. Response of coastal wetland forests to human and natural changes in the environment with emphasis on hydrology. In: Hook, D.D.; Lea, R., eds. Proceedings of the symposium: forested wetlands of the Southern United States; 1988 July 12–15; Orlando, FL. Gen. Tech. Rep. SE-50. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station: 34–43.
- Cooke, W.H., III; Grala, K.; Evans, D.; Collins, C. 2007. Assessment of pre- and post-Katrina fuel conditions as a component of fire potential modeling for southern Mississippi. *Journal of Forestry*. 105: 389–397.
- Everham, E.M.; Brokaw, N.V.L. 1996. Forest damage and recovery from catastrophic wind. *The Botanical Review*. 62: 113–185. <https://doi.org/10.1007/BF02857920>.
- Gardner, L.R.; Michener, W.K.; Blood, E.R. [and others]. 1991. Ecological impact of Hurricane Hugo—Salinization of a coastal forest. *Journal of Coastal Research*: 301–317.
- Glitzenstein, J.S.; Harcombe, P.A. 1988. Effects of the December 1983 tornado on forest vegetation of the big thicket, southeast Texas, U.S.A. *Forest Ecology and Management*. 25: 269–290. [https://doi.org/10.1016/0378-1127\(88\)90092-8](https://doi.org/10.1016/0378-1127(88)90092-8).
- Greene, D.F.; Gauthier, S.; Noël, J. [and others]. 2006. A field experiment to determine the effect of post-fire salvage on seedbeds and tree regeneration. *Frontiers in Ecology and the Environment*. 4: 69–74. [https://doi.org/10.1890/1540-9295\(2006\)004\[0069:AFETDT\]2.0.CO;2](https://doi.org/10.1890/1540-9295(2006)004[0069:AFETDT]2.0.CO;2).
- Hahn, G.E.; Coates, T.A.; Aust, W.M. [and others]. 2021. Long-term impacts of silvicultural treatments on wildland fuels and modeled fire behavior in the Ridge and Valley Province, Virginia (USA). *Forest Ecology and Management*. 496: 119–475. <https://doi.org/10.1016/j.foreco.2021.119475>.
- Hook, D.D.; Buford, M.A.; Williams, T.M. 1991. Impact of Hurricane Hugo on the South Carolina Coastal Plain forest. *Journal of Coastal Research*. 8: 291–300.
- Lindenmayer, D.B.; Noss, R.F. 2006. Salvage logging, ecosystem processes, and biodiversity conservation. *Conservation Biology*. 20: 949–958. <https://doi.org/10.1111/j.1523-1739.2006.00497.x>.
- Liu, K.-b.; Lu, H.; Shen, C. 2008. A 1,200-year proxy record of hurricanes and fires from the Gulf of Mexico coast: Testing the hypothesis of hurricane–fire interactions. *Quaternary Research*. 69: 29–41. <https://doi.org/10.1016/j.yqres.2007.10.011>.
- Lu, D.; Pile, L.S.; Yu, D. [and others]. 2020. Differential responses of tree species to a severe ice storm and their implications to forest composition in the southeast United States. *Forest Ecology and Management*. 468: 118–177. <https://doi.org/10.1016/j.foreco.2020.118177>.
- Lugo, A.E.; Applefield, M.; Pool, D.J. [and others]. 1983. The impact of Hurricane David on the forests of Dominica. *Canadian Journal of Forest Research*. 13: 201–211.
- Lutes, D.; Keane, R. 2006. Fuel load (FL) sampling method. In: Lutes, D.C.; Keane, R.E.; Caratti, J.F., eds. FIREMON: fire effects monitoring and inventory system. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station: 116–140.
- Maser, C.; Anderson, R.G.; Cromack, K. [and others]. 1979. Dead and down woody material. In: Thomas, J., ed. *Wildlife habitats in managed forests, the Blue Mountains of Oregon and Washington*. Agric. Handb. 53. Washington, DC: U.S. Department of Agriculture Forest Service, Washington Office: 78–95.
- McGuire, J.P.; Mitchell, R.J.; Moser, E.B. [and others]. 2001. Gaps in a gappy forest: plant resources, longleaf pine regeneration, and understory response to tree removal in longleaf pine savannas. *Canadian Journal of Forest Research*. 31: 765–778. <https://doi.org/10.1139/x01-003>.
- Merrens, E.J.; Peart, D.R. 1992. Effects of hurricane damage on individual growth and stand structure in a hardwood forest in New Hampshire, USA. *Journal of Ecology*. 80: 787–795. <https://doi.org/10.2307/2260866>.
- Myers, R.K.; van Lear, D.H. 1998. Hurricane–fire interactions in coastal forests of the south: a review and hypothesis. *Forest Ecology and Management*. 103: 265–276. [https://doi.org/10.1016/S0378-1127\(97\)00223-5](https://doi.org/10.1016/S0378-1127(97)00223-5).
- National Oceanic Atmospheric Administrations (NOAA), National Centers for Environmental information. 2022. Climate at a Glance: Global Mapping. <https://www.ncdc.noaa.gov/cag/>. [Date accessed: March 3, 2022].
- Pile, L.S.; Wang, G.G.; Knapp, B.O. [and others]. 2017. Comparing morphology and physiology of Southeastern U.S. pinus seedlings: implications for adaptation to surface fire regimes. *Annals of Forest Science*. 74: 68. <https://doi.org/10.1007/s13595-017-0666-6>.
- Putz, F.E.; Sharitz, R.R. 1991. Hurricane damage to old-growth forest in Congaree Swamp National Monument, South Carolina, U.S.A. *Canadian Journal of Forest Research*. 21: 1765–1770. <https://doi.org/10.1139/x91-244>.
- Smith, G.F.; Nicholas, N.S.; Zedaker, S.M. 1997. Succession dynamics in a maritime forest following Hurricane Hugo and fuel reduction burns. *Forest Ecology and Management*. 95: 275–283. [https://doi.org/10.1016/S0378-1127\(97\)00014-5](https://doi.org/10.1016/S0378-1127(97)00014-5).
- Spurr, S.H. 1956. Natural restocking of forests following the 1938 hurricane in central New England. *Ecology*. 37: 443–451. <https://doi.org/10.2307/1930166>.
- Wade, D. D. 1993. Photo series for estimating post-hurricane residues and fire behavior in southern pine. U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. 19 p.
- Walker, L.R. 1991. Tree damage and recovery From Hurricane Hugo in Luquillo Experimental Forest, Puerto Rico. *Biotropica*. 23: 379–385. <https://doi.org/10.2307/2388255>.

Bottomland and Riparian Forests



OCCURRENCE AND GROWTH DYNAMICS OF NATURAL REGENERATION IN AN EAST TEXAS BOTTOMLAND HARDWOOD FOREST

Lydia J. Voth Rurup, Kathryn R. Kidd, Jeremy P. Stovall, Brian P. Oswald, and Steven B. Jack

ABSTRACT

Bottomland hardwood forests provide critical ecosystem services such as water quality improvement, nutrient cycling, flood and erosion control, carbon sequestration, and support of biodiversity. In recent decades, these systems have been reduced due to land conversion or negatively impacted by river regulation, which alters hydrology and flooding patterns and allows the invasion of species such as Chinese tallow (*Triadica sebifera* L.). As a result, these forests have experienced declines in productivity and regeneration potentials of desired species. This study quantified density, height, and diameter of natural regeneration of native and non-native species among two areas previously treated for Chinese tallow and an untreated area along the Neches River in east Texas. Chinese tallow, green ash, (*Fraxinus pennsylvanica* Marsh.), and the white oak (*Quercus alba*) group varied in density among treatments for the seedling size classes. Tallow sapling height was lower in the twice-treated area, while tallow seedling basal diameter was greater in the same area. Other species groups did not differ in density or size among treatment areas in any strata. Future management to increase light availability to the forest floor and repeated control of undesired species will be necessary to ensure that desired native species will be positioned to be recruited as canopy gaps are created.

INTRODUCTION

Riparian forests are key ecosystems worldwide. Floodplain forests, frequently bottomland hardwood forests, occur along meandering streams and rivers and are dependent on seasonal flooding for their characteristic formation and processes (Kroschel and others 2016, Romano 2010). These forests provide an array of important ecosystem services, such as water quality improvement, nutrient cycling, chemical conversion, flood and erosion control, carbon sequestration, biodiversity, and aesthetic and recreational value (Dybala and others 2019, Kellison and Young 1997, Kozlowski 2002, Lowrance and others 1984, Schindler and others 2014). Unfortunately, these diverse and essential values of floodplain forests have not always been realized and, thus, protected.

A significant portion of floodplain forests in the United States has been lost due to land conversion and urban development. Due to their productive soils, many bottomland hardwood forests have been converted to agriculture (Dybala and others 2019, Kellison and Young 1997). The construction of river-regulating structures such as dams, levees, and reservoirs has altered the natural river hydrology that these forests developed under and have become adapted to

(Kozlowski 2002, Nilsson and Berggren 2000). Decades of high-grading have also decreased the quality and value of trees in many hardwood forests in the Eastern United States (Kellison and Young 1997). These issues combined have led to a lack of adequate desired, native natural regeneration in many bottomland hardwood forests. Additionally, the presence of invasive species can have negative implications for native regeneration. Floodplains are susceptible to plant invasions due to their connectivity, facilitating widespread seed dispersal, frequent disturbances, and high availability of water (Predick and Turner 2008, Repka and others 2015). Once established, invasive plants can outcompete native plant communities. Chinese tallow (*Triadica sebifera* L.) is a prevalent non-native invader in east Texas, the region in which this study was conducted. As a woody invader, Chinese tallow threatens to impact multiple forest strata, from the ground layer to the overstory canopy (Boyce 2015, Greene and Blossey 2012).

In light of these concerns, research is needed to evaluate the impacts of both prior treatments to control invasive species and associated environmental conditions on natural regeneration dynamics in floodplain forests. As Chinese tallow becomes more prevalent, specific research on these

Author Information: Lydia J. Voth Rurup, Graduate Research Assistant, Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, TX 75962; Kathryn R. Kidd, Associate Professor, Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, TX 75962; Jeremy P. Stovall, Professor, Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, TX 75962; Brian P. Oswald, Professor, Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, TX 75962; and Steven B. Jack, Executive Director, Boggy Slough Conservation Area, T.L.L. Temple Foundation, Lufkin, TX 75901.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

topics is important in the ecosystems that this species has invaded in order for managers to identify effective strategies to promote native regeneration. This research examined natural regeneration dynamics in a bottomland hardwood forest adjacent to a river. The objectives of this study were to (1) evaluate species composition, density, height, and diameter of native and non-native seedlings and saplings, and (2) determine impacts of past treatments used to reduce the abundance of Chinese tallow.

METHODS

Study Area

This study was conducted within the Pineywoods Ecoregion of east Texas, which has a subtropical humid climate and receives 40 to 60 inches of precipitation annually (Diggs and others 2006). The study site, Boggy Slough Conservation Area (BSCA), is located in Trinity and Houston Counties, Texas, approximately 7 miles northeast of Apple Springs, TX. The eastern border of BSCA is formed by the Neches River, with areas adjacent to the river characterized by seasonally flooded bottomland hardwood forests. The overstory cover is comprised of mesic to flood-tolerant species, including several oaks (*Quercus* spp.), sweetgum (*Liquidambar styraciflua* L.), and green ash (*Fraxinus pennsylvanica* Marsh.). American hornbeam (*Carpinus caroliniana* Walt.) and water-elm (*Planera aquatica* J.F.Gmel.) are common species in the midstory. Chinese tallow is present at variable densities throughout the bottomlands at the study site. Herbicide (primarily triclopyr) treatments have been applied to different areas of BSCA annually since 2014. These treatments are a combination of broadcast spraying with a 2.5 percent Garlon[®] XRT solution in areas with small, dense tallow stems and hack-and-squirt application of a 30 percent Garlon[®] XRT solution in areas with more variable density and poor tractor access.

Field Methods

Sampling was conducted across three treatment areas directly adjacent to the Neches River: (1) an untreated control (Ctrl), and areas treated for Chinese tallow in (2) 2019 (1-Trt), and (3) both 2015 and 2018 (2-Trt). In each treatment area, 12 plots were established along four transects located perpendicular to the river. Along each transect, plots were systematically spaced 164, 492, and 984 feet (50, 150, and 300 m) from the river to account for variation in microtopography and sedimentation patterns.

Plots were inventoried in August 2020. Overstory trees [diameter at breast height (DBH) \geq 4 inches] were tallied via point-sampling at plot center using a 10 basal area factor prism. The species and DBH of tallied trees were recorded. Regeneration was inventoried in a 1/100th-acre

circular plot. Saplings were classified by a DBH of 0.6 to 3.9 inches and measured throughout the entire plot. Seedlings (DBH \leq 0.6 inches) were classified as ephemeral (height $<$ 6 inches) or non-ephemeral (height \geq 6 inches). Both seedling size classes were assessed in the northeast and southwest quadrants of the 1/100th-acre regeneration plot. The species were recorded for living stems of all regeneration classes; height and basal diameter were measured for non-ephemeral seedlings and saplings.

Data Analysis

Data were analyzed using JMP[®] Pro 14.0.0 (SAS Institute Inc., Cary, NC). Density (stems per acre) of each regeneration-size class, seedling-basal diameter, and sapling height were compared by species group among the three treatment areas. Normal data were analyzed with a one-way ANOVA by treatment and Tukey's honestly significant difference (HSD) post-hoc test. Non-normal data (Chinese tallow density and size for all groups) were analyzed with a nonparametric Kruskal-Wallis test by treatment with a Wilcoxon post-hoc test. All tests were conducted at a significance level of $\alpha = 0.10$.

The oak species recorded at the site were divided into two groups. The white oak group consisted of overcup oak (*Quercus lyrata* Walt.), swamp chestnut oak (*Quercus michauxii* Nutt.), and bottomland post oak (*Quercus similis* Ashe.). Only overcup oak was observed for the white oak group for the regeneration classes. The red oak group consisted of willow oak (*Quercus phellos* L.), water oak (*Quercus nigra* L.), and cherrybark oak (*Quercus pagoda* Raf.). Green ash and sweetgum were prominent non-oak native species. Other commonly observed native species, grouped into an "other" category, were water hickory (*Carya aquatica* (Mich. f.) Nutt.), blackgum (*Nyssa sylvatica* Marsh.), American hornbeam, common persimmon (*Diospyros virginiana* L.), American elm (*Ulmus americana* L.), and water-elm. For the ephemeral and non-ephemeral seedling classes, American elm and water-elm were separately classified as the "elm family" (Ulmaceae) due to greater abundance.

RESULTS AND DISCUSSION

Overstory basal area ranged from approximately 70 to 100 square feet per acre among the three areas. Density of each overstory species group was fairly consistent across the treatments (fig. 1). The density of Chinese tallow overstory was low ($<$ 15 square feet per acre) in all areas. Sapling density did not significantly differ among treatments for any species group (fig. 2). However, the "other group" had a noticeably high sapling density in the control; this was primarily due to very high densities of water-elm, hornbeam, and persimmon. Among all treatments, there was a relatively low proportion of oak saplings (i.e., overcup oak) compared to the overstory, suggesting future recruitment issues for

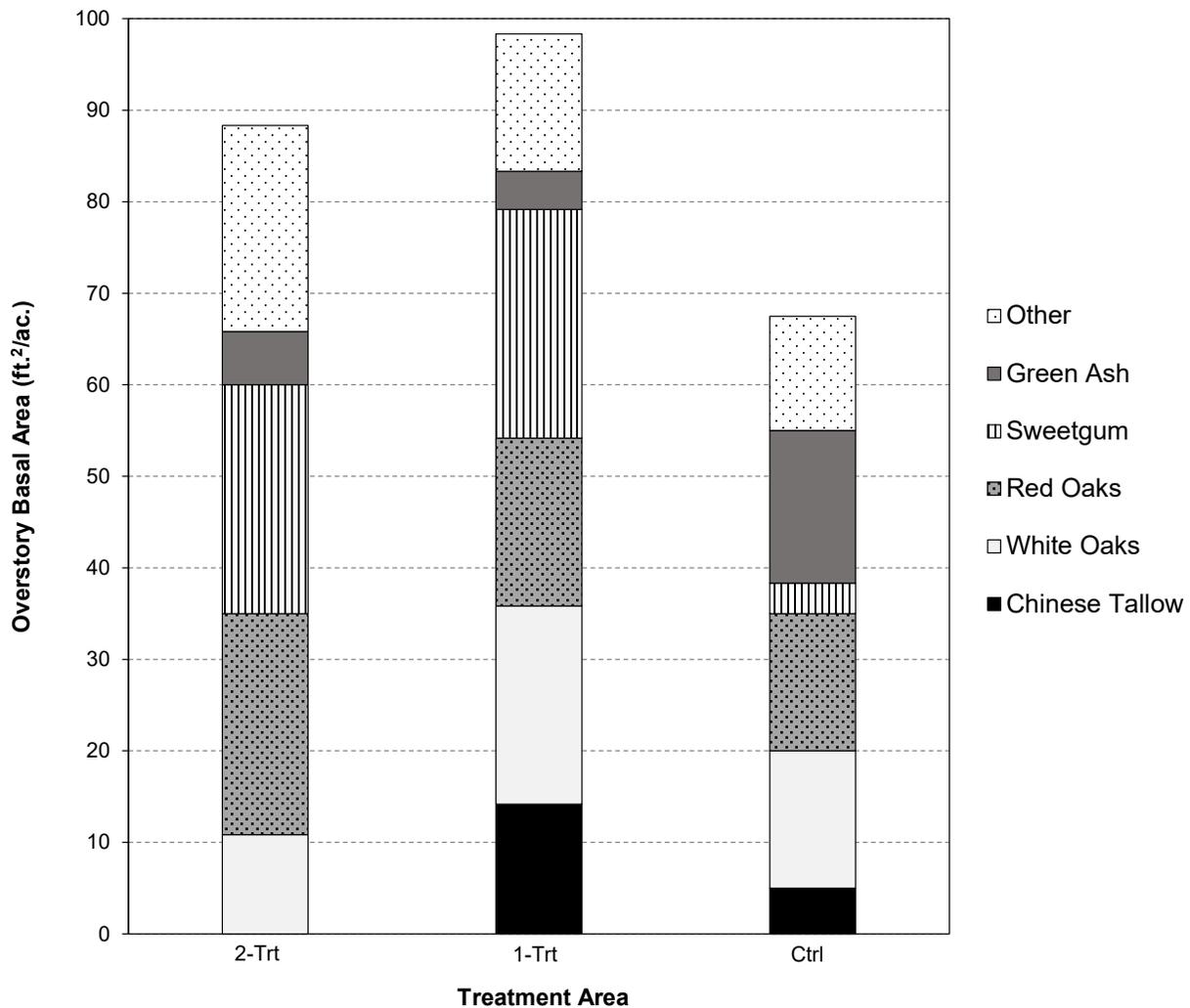


Figure 1—Mean basal area (square feet per acre) for overstory trees for native and non-native species groups among two areas treated for Chinese tallow and an untreated control area at Boggy Slough Conservation Area.

oaks. This finding echoes the results of Oliver and others (2005), who found that red oak regeneration was not sufficient to replace the overstory in the Mississippi Delta. The high density of very shade-tolerant species in the “other” group also indicates a lack of desired species positioned to be recruited into the overstory.

Non-ephemeral seedling densities were significantly different among treatments for three species groups. Chinese tallow density was greater in the 2-Trt area compared to the control ($p=0.04$). The density of white oaks was greater in the control area ($p<0.01$) than two treatment areas, while green ash density was greater in the 2-Trt area ($p=0.06$) than 1-Trt or Ctrl. In the ephemeral seedling class, Chinese tallow density was significantly lower in the 2-Trt area ($p=0.03$) than 1-Trt or Ctrl, and the density of white oaks was greater in the control ($p<0.01$) than in the treatment areas (fig. 3).

Though tallow seedling density differed among the areas, the higher density of the non-ephemeral class in the 2-Trt

area indicates that tallow regeneration is still prevalent in the post-herbicide areas. There may also be a tradeoff occurring, where the treatments create an environment that favors tallow at the expense of the white oak group, evidenced by the higher densities of white oak seedlings in the untreated area. Anfang and others (2020) found that the removal of invasive European buckthorn (*Rhamnus cathartica* L.) via mowing facilitated the growth and survival of its regeneration by increasing light availability. The growth rate of Chinese tallow has also been shown to increase with increased light levels (Siemann and Rogers 2003). Due to their carbon allocation patterns, oak seedlings are initially more slow growing than many of their competitors (Hodges and Gardiner 1993). Thus, if conditions become favorable for prolific Chinese tallow regeneration, it is likely that the white oak group will be outcompeted by this fast growing invasive species. Additionally, herbicide applications against exotic plants can negatively impact non-target native species (Peterson and others 2020, Rinella and others 2009). It is also

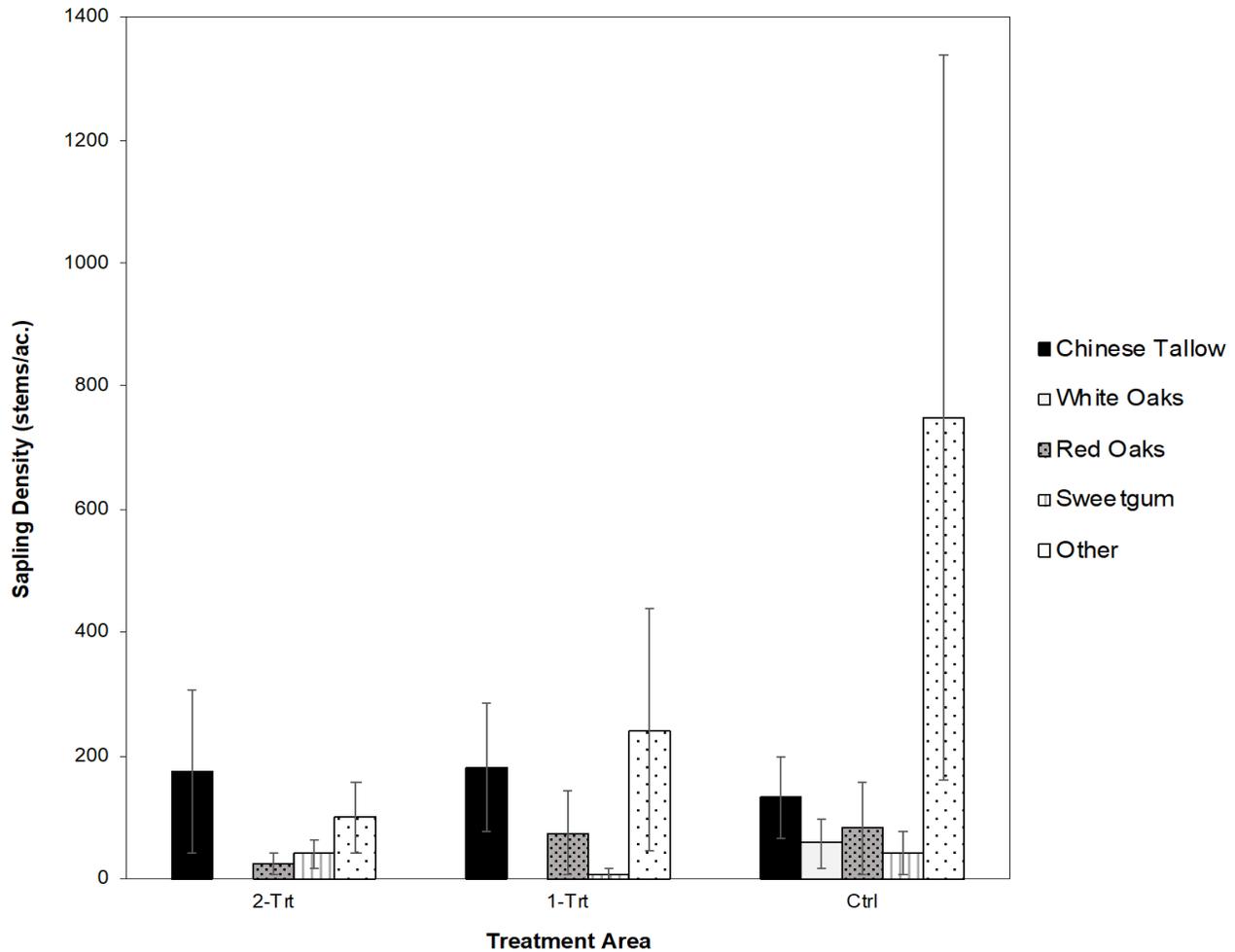


Figure 2—Mean density (stems per acre) for saplings for native and non-native species groups among two areas treated for Chinese tallow and an untreated control area at Boggy Slough Conservation Area. Error bars represent standard error.

possible, then, that some of the regeneration in the white oak group was unintentionally damaged and/or killed through the broadcast spraying of Chinese tallow, contributing to its greater density in the control area.

Chinese tallow was the only species group to significantly vary in size among the three treatment areas, which is likely a result of incorporated treatments that directly targeted tallow (i.e., hack-n-squirt). Tallow saplings were taller in the control (19.1 feet) compared to the 2-Trt (8.0 feet) area ($p=0.09$). Conversely, non-ephemeral tallow seedling basal diameter was greater in in the 2-Trt (0.29 inches) area versus the control (0.10 inches) area ($p=0.04$). The two treatments may have successfully eliminated most of the older, larger tallow saplings. However, this elimination of intraspecific competition may also have created an environment with more light and growing space for the younger or newly-established tallow stems to grow. Thus, it appears that even areas that were treated twice still have tallow that may be capable of outcompeting other species.

CONCLUSIONS

The protection of riparian forests is critical, and invasive species like Chinese tallow continue to be a prominent threat. This study did not evaluate the efficacy of herbicide treatments, due to a lack of pre-treatment data, but assessed regeneration dynamics in the post-treatment environment. Tallow and the white oak groups showed some differences in density and/or size among the treatment areas. These effects were variable and did not always favor the native, desired species. Based on these results, it seems that management beyond herbicide treatments of tallow will be necessary to facilitate recruitment of the native species that have historically made up the overstory of these forests.

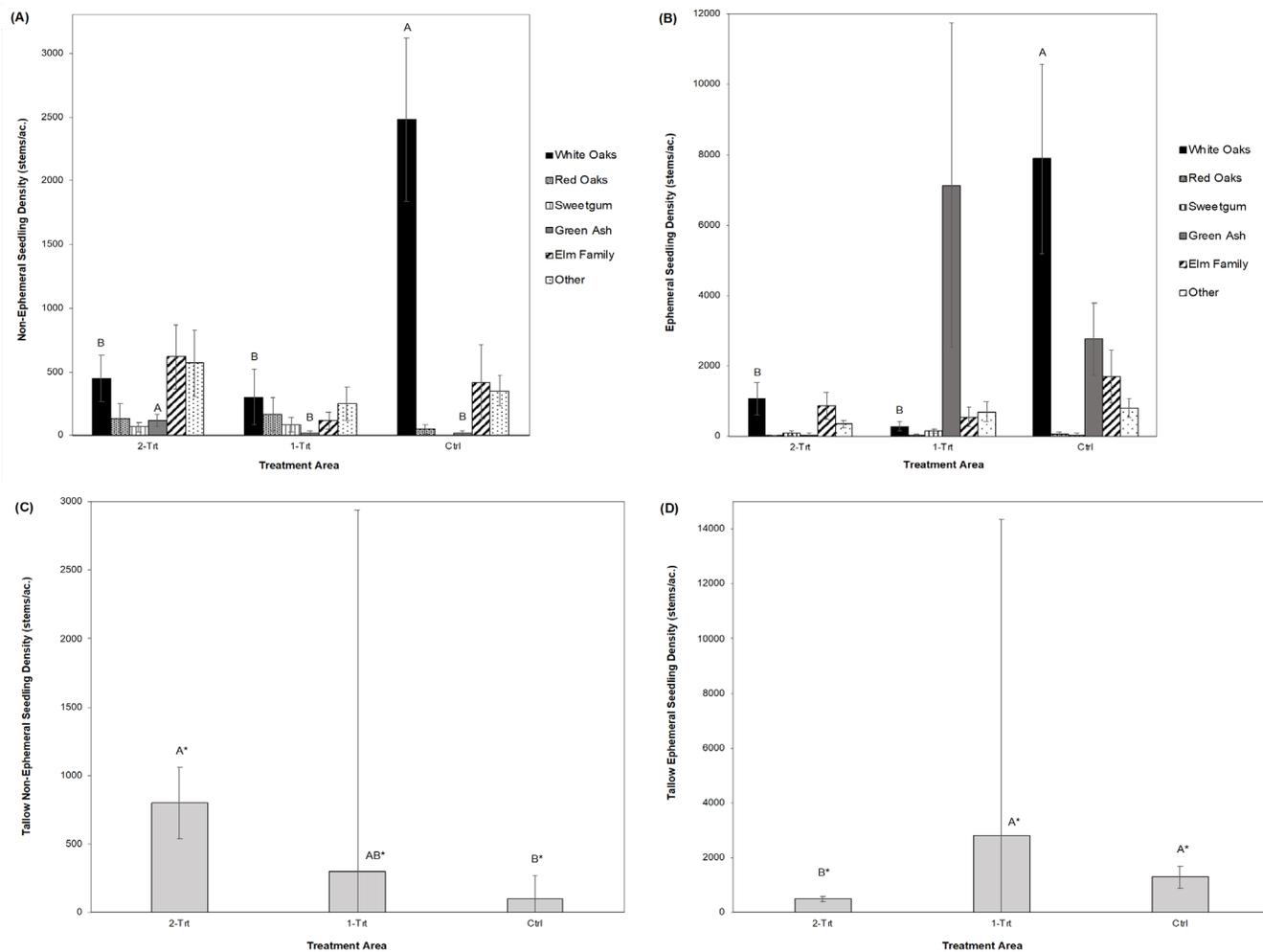


Figure 3—Mean density (stems per acre) for (A) non-ephemeral and (B) ephemeral seedlings for native species groups and median density (stems per acre) for (C) non-ephemeral and (D) ephemeral Chinese tallow seedlings among two areas treated for Chinese tallow and an untreated control area at Boggy Slough Conservation Area. Different letters above each species group indicate that means (native groups) or medians (tallow) are significantly different from other areas at $\alpha = 0.10$ based on ANOVA and post-hoc Tukey's HSD analyses or Kruskal-Wallis and post-hoc Wilcoxon analyses (marked with an asterisk). Species groups without letters did not show significant differences among treatment areas. Error bars represent standard error.

ACKNOWLEDGMENTS

This work was supported by the USDA National Institute of Food and Agriculture McIntire-Stennis Cooperative Forestry Research Program project [Accession No: 1012158]. The management initiatives at BSCA are funded by the T.L.L. Temple Foundation. Additional support for this research was provided by the Arthur Temple College of Forestry and Agriculture at Stephen F. Austin State University, Nacogdoches, TX. Field assistance was provided by Sally Shroyer and Tyler Jones.

LITERATURE CITED

- Anfang, C.; Schuster, M.J.; Wragg, P.D.; Reich, P.B. 2020. Increased light availability due to forestry mowing of invasive European buckthorn promotes its regeneration. *Restoration Ecology*. 28(2): 475–482.
- Boyce, R.L. 2015. Recovery of native plant communities in southwest Ohio after *Lonicera maackii* removal. *The Journal of the Torrey Botanical Society*. 142(3): 193–204.
- Diggs, G.M.; Lipscomb, B.L.; Reed, M.D.; O’Kennon, R.J. 2006. Illustrated flora of east Texas, Volume 1. Botanical Research Institute of Texas & Austin College. 26: 1–1594.
- Dybala, K.; Matzek, V.; Gardali, T.; Seavy, N.E. 2019. Carbon sequestration in riparian forests: A global synthesis and meta-analysis. *Global Change Biology*. 25: 57–67.
- Greene, B.T.; Blossey, B. 2012. Lost in the Weeds: *Ligustrum sinense* reduces native plant growth and survival. *Biological Invasions*. 14: 139–150.
- Hodges, J.; Gardiner, E. 1993. Ecology and physiology of oak regeneration. In: Loftis, D.; McGee, C.E., eds. 1993. Oak regeneration: serious problems, practical recommendations. Symposium Proceedings; 1992 September 8–10; Knoxville, Tennessee. Presented by the Center for Oak Studies. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. 319 p.
- Kellison, R.C.; Young, M.J. 1997. The bottomland hardwood forest of the Southern United States. *Forest Ecology and Management*. 90: 101–115.
- Kozlowski, T.T. 2002. Physiological-ecological impacts of flooding on riparian forest ecosystems. *Wetlands*. 22: 550–561.
- Kroschel, W.A.; King, S.L.; Keim, R.F. 2016. Tree regeneration by seed in bottomland hardwood forests. *Southeastern Naturalist*. 15(9): 42–60.
- Lowrance, R.; Todd, R.; Fail, J. [and others]. 1984. Riparian forests and nutrient filters in agricultural watersheds. *BioScience*. 34(6): 374–377.
- Nilsson, C.; Berggren, K. 2000. Alterations of riparian ecosystems caused by river regulation. *BioScience*. 50(9): 783–792.
- Oliver, C.; Burkhardt, E.; Skojac, D. 2005. The increasing scarcity of red oaks in Mississippi river floodplain forests: influence of the residual overstory. *Forest Ecology and Management*. 210: 393–414.
- Peterson, P.G.; Merrett, M.F.; Fowler, S.V. [and others]. 2020. Comparing biocontrol and herbicide for managing an invasive non-native plant species: efficacy, non-target effects and secondary invasion. *Journal of Applied Ecology*. 57: 1876–1884.
- Predick, K.I.; Turner, M.G. 2008. Landscape configuration and flood frequency influence invasive shrubs in floodplain forests of the Wisconsin River (USA). *Journal of Ecology*. 96: 91–102.
- Repka, R.; Sebesta, J.; Madera, P.; Vahalik, P. 2015. Comparison of the floodplain forest floristic composition of two riparian corridors: species richness, alien species, and the effect of water regime changes. *Biologia*. 70(2): 208–217.
- Rinella, M.J.; Maxwell, B.D.; Fay, P.K. [and others]. 2009. Control effort exacerbates invasive-species problem. *Ecological Applications*. 19(1): 155–162.
- Romano, S.P. 2010. Our current understanding of the upper Mississippi river system floodplain forest. *Hydrobiologia*. 640: 115–124.
- Schindler, S.; Sebesvari, Z.; Damm, C. [and others]. 2014. Multifunctionality of floodplain landscapes: relating management options to ecosystem services. *Landscape Ecology*. 29: 229–244.
- Siemann, E.; Rogers, W.E. 2003. Changes in light and nitrogen availability under pioneer trees may indirectly facilitate tree invasions of grasslands. *Journal of Ecology*. 91: 923–931.

EVALUATING WATERSHED-SCALE EFFECTS OF LONGLEAF PINE RESTORATION ON WATER YIELD USING A PAIRED WATERSHED AND MODELING APPROACHES

Devendra M. Amatya, Herbert Ssegane, Mohamed D. Hamidi, and Carl C. Trettin

EXTENDED ABSTRACT

Restoration of longleaf pine (LLP) (*Pinus palustris* Mill.) ecosystems is a public land management objective throughout the Southeastern United States, including the Francis Marion National Forest in South Carolina. While there have been numerous plot or stand-scale studies regarding LLP ecology, silviculture, and other ecosystem services (Samuelson and others 2012), there are uncertainties regarding the watershed-scale effects of re-establishing LLP forests due to the spatial heterogeneity of soil conditions, micro-topography, slope, and understory vegetation. In contrast to loblolly pine (*Pinus taeda* L.) (LP) stands managed for timber production, LLP stands managed for open canopy conditions with frequent prescribed fire have a much lower stocking, a longer period of open canopy, a sparse midstory, and an understory generally dominated by grasses and sedges, potentially influencing soil moisture and transpiration (Brantley and others 2018). As a result of these differences in stand structure and composition, it may be expected that the LLP stands will exhibit lower leaf area index (LAI), therefore, reduced interception loss and evapotranspiration (ET), and more infiltration of precipitation recharging groundwater and thus increasing water yield than LP stands managed for timber production. Thus, a careful examination of spatial characteristics of the watershed, including stand vegetation LAI, root depth, and albedo is fundamental for an accurate interpretation of the water yield (WY), as part of the LLP restoration experiment (Trettin and others 2019), which is using a paired watershed approach, where one control and one treatment are monitored concurrently during calibration (pre-treatment) and post-treatment periods (Amatya and others 2021, Jayakaran and others 2014, Loftis and others 2001, Ssegane and others 2013), backed also by a modeling approach (Amatya and others 2022) to assess effects of silvicultural practices on hydrology and WY.

The key objective of this study is to develop a calibration relationship between monthly WY of paired headwater watersheds [155-ha WS77 (treatment) and 160-ha WS80 (control)] that is statistically significant ($\alpha = 0.05$) with a predictive capability, in anticipation of a later study to assess the hydrologic response [WY and soil moisture (SM)] to restoring the LLP using the relationship backed by a watershed hydrologic modeling on Forest

Author Information: Devendra M. Amatya, Research Hydrologist, U.S. Department of Agriculture, Forest Service, Southern Research Station, Cordesville, SC 29434; Herbert S. Ssegane, Research Scientist, Oshkosh Corporation, Oshkosh, WI 54902; Mahamed D. Hamidi, PhD student, Durham University, Durham, U.K. DH1 3LE; and Carl C. Trettin, Team Leader/Supv. Research Soil Scientist, U.S. Department of Agriculture, Forest Service, Southern Research Station, Cordesville, SC 29434.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

Service, U.S. Department of Agriculture, Santee Experimental Forest (SEF) in coastal South Carolina. (fig. 1A). The watersheds impacted by Hurricane Hugo in 1989 (Hook and others 1991) and regenerated since then was reported to start a full recovery from 2004 (Jayakaran and others 2014). The regenerated vegetation on WS77 and WS80 is dominated by LP and mixed hardwood-pine stands on WS80, respectively. Soils on the watersheds are poorly- to moderately-well drained sandy clay loam overlaying clay in the uplands and relatively wetter soils in the riparian zones (fig. 1B). The climate is warm-humid temperate, with average daily temperature of 17.8 °C and annual rainfall of about 1370 mm (Dai and others 2013). Daily rainfall, streamflow (runoff), and water table (WT), as a proxy of SM, measured on both the watersheds only from 2011 until 2019, as a pre-treatment period covering extreme wet and dry periods, were used for the analysis of paired annual difference in WY and monthly WY relationship, which was also compared with an earlier reported study (2004-2011 post-hurricane recovery periods) (Jayakaran and others 2014). Data has also been recently used for calibration of MIKE SHE hydrologic model (Amatya and others 2022). Both the historic and current hydrology and meteorology data for the WS77 and WS80 study sites are reported by Amatya and Trettin (2019) and Amatya and Trettin (2021), respectively.

Results showed annual runoff responses (flow and runoff coefficient [flow/rainfall]) with WS77 > WS80 in 2011-2019 with average annual WS80 ET > WS77 ET, as expected (table 1). Note the average annual ET of the WS80 (control) was very close to the PET, indicating no SM limitation. Similarly, the mean monthly runoff difference (WS80-WS77) of -6.80 mm was not significantly different ($p = 0.54$) from -3.89 mm for the 2004-2011 period, possibly indicating ongoing post-Hugo recovery (Amatya and others 2021). Monthly streamflow calibration relationship (WS77 = 1.15*WS80 + 3.70; $R^2 = 0.87$; $p < 0.0001$), excluding the extreme October 2015 event, for the 2011-2019 was highly significant and not different from the WS77 = 1.14*WS80 + 1.70 ($R^2 = 0.87$) for the 2004-2011 period. The model predicted monthly runoff which agreed well ($R^2 = 0.96$; Nash-Sutcliffe efficiency = 0.95 for all data and $R^2 = 0.89$; NSE = 0.82 after deleting two extreme events of October 2015 and 2016) with observed data (Amatya and others 2022). However, the daily WT predictions at a single well were not as satisfactory, especially in dry summer months with high ET demands. So, the model is also being tested with data from additional wells to test the possible heterogeneity-related discrepancies in soil hydraulic properties used from the adjacent control site (Dai and others 2010) (fig. 1A).

This study is important because it is the first to re-evaluate the paired watershed flow calibrations after a major natural disturbance. While the basic question regarding WY will be answered through the runoff measurements, the value of this study will be realized through analyses of the factors regulating the hydrologic responses, especially the SM of dominant soil types as well as the WT on them (Trettin and others 2019). Accordingly, SM sensors near WT wells are also being deployed on all treatments being implemented following the silvicultural treatments for LLP restoration (fig. 1B), which include regeneration cut (56 ha) retaining an overstory canopy and foraging trees for red cockaded woodpecker (*Picoides borealis*), thinning (65 ha), and group selection (24 ha)—a hybrid approach suited to areas without LLP (fig. 1B). A 3m x 3m planting in early 2023 soon after a second prescribed burning is proposed (Trettin and others 2019). While 2020-2023 data will be used to examine post-treatment WY response and test the MIKE SHE model calibrated with pre-treatment data (Amatya and others 2021), the model will also be applied to simulate the hydrologic effects of restored LLP stands (reduced basal area/LAI) using future climatic projections for this region. However, lack of LAI, root depth, and albedo data for the LLP stands may likely influence the model predictions.

ACKNOWLEDGMENTS

The authors would like to acknowledge Julie Arnold and Andy Harrison from SEF for their assistance with field data collection/analysis and the Forest Service Data Archive Team for hosting our data at their web portals.

Table 1—Measured annual rainfall, flow, runoff coefficient for the WS77 and WS80 watersheds

Year	WS80 Rainfall	WS80 Flow	WS80 ROC	WS80 ET	WS77 Rainfall	WS77 Flow	WS77 ROC	WS77 ET	WS80-Forest P-M PET
	<i>mm</i>	<i>mm</i>			<i>mm</i>	<i>mm</i>			<i>mm</i>
2011	934	31	0.03	903	977	58	0.06	920	1351
2012	1174	28	0.02	1146	1148	56	0.05	1092	1239
2013	1433	219	0.15	1214	1502	334	0.22	1168	1017
2014	1375	199	0.14	1176	1340	293	0.22	1047	1123
2015	2171	967	0.45	1204	2146	950	0.44	1196	1098
2016	1743	556	0.32	1187	1709	579	0.34	1131	1197
2017	1443	217	0.15	1226	1555	392	0.25	1163	1177
2018	1633	361	0.22	1272	1661	474	0.29	1187	1146
2019	1381	201	0.15	1180	1429	334	0.23	1095	1200
Average	1476	309	0.19	1168	1496	385	0.23	1111	1172
Standard deviation	351	294	0	105	339	272	0	87	94
COV	0.24	0.95	0.71	0.09	0.23	0.71	0.53	0.08	0.08

ROC = rainfall/flow; ET = rainfall–flow; COV = Coefficient of variance.
 Penman-Monteith based PET for forest on WS80 is included (Amatya and Harrison 2016).

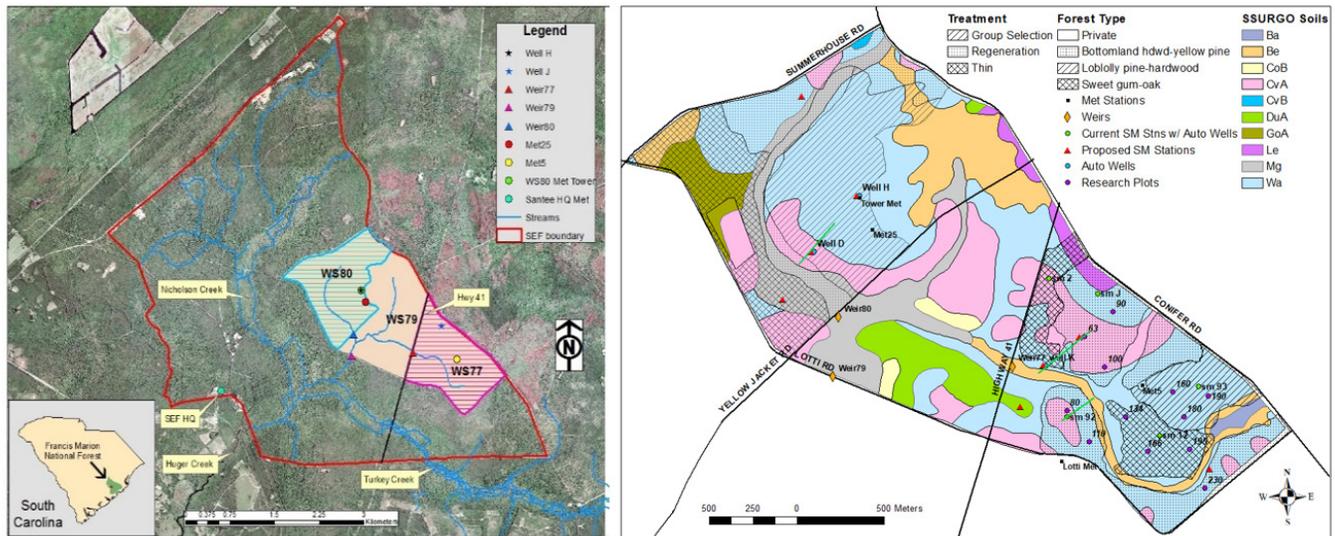


Figure 1—(A) Site map of Santee Experimental Forest with paired watersheds (WS77-treatment and WS80-control) in South Carolina, and (B) SSURGO Soil and forest vegetation types on WS77 and WS80 with locations of weirs (gauging stations), automatic (Auto) wells, and weather (Met) stations.

REFERENCES

- Amatya, D.M.; Hamidi, D.M.; Trettin, C.C.; Dai, Z. 2022. Simulating hydrology of current stands and post-longleaf pine restoration on a coastal watershed, South Carolina. In: Latimer, J.S.; Trettin, C.C.; Bosch, D.D.; Lane, C.R., eds. Proceedings of the Seventh Interagency Conference on Research in the Watersheds. November 16-19, 2020. Hosted virtually by the USDA-ARS and the University of Georgia, Tifton, GA. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. [In Press].
- Amatya, D.M.; Harrison, C.A. 2016. Grass and forest potential evapotranspiration comparison using five methods in the Atlantic Coastal Plain. *Journal of Hydrologic Engineering*. 21(5): 1–13.
- Amatya, D.M.; Ssegane, H.; Trettin, C.; Hamidi, D. 2021. Pre-treatment hydrology of a paired coastal watersheds at Santee Experimental Forest for evaluating watershed-scale effects of longleaf pine restoration on water yield. *Water*. 13(21): 3121. <https://doi.org/10.3390/w13213121>.
- Amatya, D.M.; Trettin, C.C. 2019. Santee Experimental Forest, Watershed 77: streamflow, water chemistry, water table, and weather data. Fort Collins, CO: Forest Service Research Data Archive. <https://doi.org/10.2737/RDS-2019-0033>.
- Amatya, D.M.; Trettin, C.C. 2021. Santee Experimental Forest, Watershed 80: streamflow, water chemistry, water table, and weather data. Fort Collins, CO: Forest Service Research Data Archive. <https://doi.org/10.2737/RDS-2021-0043>.
- Brantley, S.T.; Vose, J.M.; Wear, D.N.; Band, L. 2018. Potential of longleaf pine restoration to mitigate water scarcity and sustain carbon sequestration: planning for an uncertain future. In: Kirkman, L.K.; Jack, S.B., eds. *Ecological restoration and management of longleaf pine forests*. CRC Press-Taylor and Francis: 291–310.
- Dai, Z.; Li, C.; Trettin, C.C. [and others]. 2010. Bi-criteria evaluation of the MIKE SHE model for a forested watershed on the South Carolina coastal plain. *Hydrology and Earth System Science*. 14: 1033–1046. <https://doi.org/10.5194/hess-14-1033-2010>.
- Dai, Z.; Trettin, C.C.; Amatya, D.M. 2013. Effects of climate variability on forest hydrology and carbon sequestration on the Santee Experimental Forest in coastal South Carolina. Gen. Tech. Rep. SRS-172. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 32 p.
- Hook, D.D.; Buford, M.A.; Williams, T.M. 1991. Impact of Hurricane Hugo on the South Carolina Coastal Plain. *Journal of Coastal Research*: 291–300.
- Jayakaran, A.D.; Williams, T.M.; Ssegane, H. [and others]. 2014. Hurricane impacts on a pair of coastal forested watersheds: implications of selective hurricane damage to forest structure and streamflow dynamics. *Hydrology Earth System Science*. 18: 1151–1164. <https://doi.org/10.5194/hess-18-1151-2014>.
- Loftis, J.C.; MacDonald, L.H.; Streett, S. [and others]. 2001. Detecting cumulative watershed effects: the statistical power of pairing. *Journal of Hydrology*. 251: 49–64.
- Samuelson, L.J.; Stokes, T.A.; Johnsen, K.H. 2012. Ecophysiological comparison of 50-year-old longleaf pine, slash pine and loblolly pine. *Forest Ecology and Management*. 274: 108–115.
- Ssegane, H.; Amatya, D.M.; Chescheir, G.M. [and others]. 2013. Consistency of hydrologic relationships of a paired watershed approach. *American Journal of Climate Change*. 2(2): 147–164. <https://doi.org/10.4236/ajcc.2013.22015>.
- Trettin, C.C.; Amatya, D.M.; Gaskins, A.H. [and others]. 2019. Watershed response to longleaf pine restoration—application of paired watersheds on the Santee Experimental Forest. In: Latimer, J.S.; Trettin, C.C.; Bosch, D.D.; Lane, C.R., eds. *Proceedings of the sixth Interagency Conference on Research in Watershed*. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 194–201.

IMPACT OF FOREST LAND USE CHANGES ON GROUNDWATER RESOURCES IN A BASIN OF LOWER MISSISSIPPI RIVER ALLUVIAL VALLEY OVER THE PAST 100 YEARS

Ying Ouyang

EXTENDED ABSTRACT

Groundwater overdraft, resulting from anthropogenic activities, is an issue of critical concern. Many regions of the world are now facing challenges related to the decline and/or shortage of groundwater resources. This issue is also occurring in the Lower Mississippi River Alluvial Valley (LMRAV), which is a key region for crop and forest production in the midsouth United States. To enhance crop production, the land area for crop irrigation in the LMRAV has increased 92 percent since 1998 and resulted in a significant depletion of groundwater resources. It is reported that the average loss of groundwater in the Mississippi Delta was approximately 493,000,000 cubic meters per year from 1987 to 2014.

Although forest lands have been recognized for conserving the water resource, improving water quality and mitigating flooding, the impacts of silvicultural treatments on groundwater resources in the LMRAV are poorly understood. Using the historical data of forest reduction, recorded precipitation, and groundwater recharge along with the U.S. Geological Survey's Mississippi Embayment Regional Aquifer Study groundwater model, we assessed the impacts of forest land use changes over the past 114 years (1900 to 2014) on groundwater resources in the Yazoo River basin (YRB), which is within the LMRAV and is the largest river basin in Mississippi. The specific objectives of this study were to: (1) simulate the temporal and spatial distributions of groundwater level due to the past deforestation, and (2) ascertain the long-term contribution of forest lands to groundwater resource.

Simulation results show that the groundwater level at a point in the Big Sunflower River watershed of the YRB declined 13.5 m from 1900 to 2014 and occurred because of groundwater pumping for crop irrigation. Conversion of the crop land into forest land in the Upper Yazoo River watershed (UYRW) increased the average groundwater head by 1.01 m after 20 years from 1987 to 2007. Afforestation could conserve 157,887 cubic meters per year of groundwater in the UYRW because no groundwater pumping occurs after afforestation. Knowledge gained from this historical study provides useful information to the local and regional foresters and water resource managers in planning groundwater supply strategies.

Author Information: Ying Ouyang, U.S. Department of Agriculture, Forest Service, Southern Research Station, Mississippi State, MS 39762.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

OPTIONS FOR RIPARIAN BUFFER TREE PLANTING IN NORTH ALABAMA

Callie Jo Schweitzer, Daniel C. Dey, and Naijiang Wang

ABSTRACT

We worked with private, State, and Federal agencies to examine one approach of habitat restoration of degraded riparian zones along active agriculture fields in northern Alabama. We wanted to determine which species of high-value timber trees would grow exceptionally well using artificial regeneration (planting) and semi-intensive silviculture (tending activities for competition control). We also examined sediment transport from each block of species to ascertain which blocks provided the highest level of protection to minimize non-point source pollution. We planted eight species, including black walnut (*Juglans nigra*), yellow-poplar (*Liriodendron tulipifera*), green ash (*Fraxinus pennsylvanica*), sweetgum (*Liquidambar styraciflua*), Shumard oak (*Quercus shumardii*), Nuttall oak (*Q. nuttallii*), cherrybark oak (*Q. pagoda*), and loblolly pine (*Pinus taeda*) at two locations. A sediment barrier was used to capture sediment movement off each tree species planting block. After 10 growing seasons, survival across all blocks averaged 78 percent. Loblolly pine was the tallest (34.1 feet) and had the greatest diameter (7.4 inches), followed by green ash. Black walnut had the lowest survival and growth. Over a 5-year period, sediment deposited was related to precipitation, with more sediment in December compared to June for all areas.

INTRODUCTION

Planting trees for profit is common in the South. Planting hardwood trees for profit has a more complicated history, with large-scale restoration and afforestation efforts common in areas such as the Mississippi Alluvial Delta region (Allen 1997, Stanturf and others 1998) and smaller efforts concentrated on private land holdings. Federal and State cost share and assistance programs, including the Environmental Quality Incentives program, Wildlife Habitat Incentives program, and the Wetland Reserve program all support tree planting programs to increase timber production returns and provide environmental benefits (Kennedy 1990). Restoring, enhancing, and maintaining forested riparian zones continues to be of interest to landowners and managers, as these often small but influential areas provide myriad ecosystem functions, including providing a buffer zone that filters sediments and nutrients and potential income from tree harvests (Richardson and others 2007).

We developed case studies and demonstration sites to examine tree planting in areas adjacent to a river that was abutted by cultivation for crops. Although originally designed with three sites, one site experienced tampering that negated its inclusion. These two case studies were designed to assess survival and growth of commonly planted species for riparian areas and to examine natural restoration under no planting scenarios. We also tested the use of sediment

barriers to quantify the amounts and change of sediment movement from planted and control areas.

METHODS

Demonstration Sites

Two sites located along the Flint River in northeastern Alabama, Madison County, were used (fig. 1). The northern site, Hazel, was located on the Alabama A&M University's Winfred Thomas Agricultural Research Station and the southern site, Gurley, was located on private landowner property. Both sites have been in various row cropping uses for over 50 years. The Hazel site had two mapped soil series, Abernathy silt loam and Baxter clay loam (Soil Survey Madison County Alabama 1958). Abernathy silt loam is young, local alluvium soil that is the most extensively mapped soil type in Madison County, Alabama. It occurs in narrow strips or bands along drainages and is high in fertility and moisture availability. Baxter clay loam has low fertility and moderate internal drainage. At the Gurley site, most of the soil was Lindside clay loam, alluvium derived from limestone with some sandstone and shale, making it moderate in fertility with productivity limited by slow internal drainage. Lindside is the most extensive soils of first bottoms and occurs along many streams in Madison County, Alabama. The other Gurley soil type was Tyler sandy loam, which is poorly drained with low fertility that is

Author Information: Callie Jo Schweitzer, Research Forester, U.S. Department of Agriculture, Forest Service, Southern Research Station, Huntsville, AL 35801; Daniel C. Dey, Project Leader and Research Forester, U.S. Department of Agriculture, Forest Service, Northern Research Station, Columbia, MO 65211; and Naijiang Wang, Associate Professor of Forestry, Northwest Agriculture and Forestry University, Yangling, Shaanxi 712100, PR China.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.



Figure 1—Map of riparian planting sites in Madison County, Alabama. Green stars indicate location of sites, referred to as Hazel (north) and Gurley (south).

mainly under native deciduous forest cover. At each site, the plantings were located between row cropped fields and the Flint River.

Tree Species, Planting Methods, and Measurements

We delineated 10 planting areas that were approximately 0.1 acres each. All planting areas were disked prior to winter 2003 planting, except for one, undisked control. We also had a disked control that was not planted. Eight tree species were tested. These species were chosen based on recommendations from the Alabama Forestry Commission and local forestry consultants and were purchased from ArbonGen (<https://www.arborgen.com/hardwood-seedlings-for-revenue-generation>). Tree species planted included black walnut (*Juglans nigra* L.), yellow-poplar (*Liriodendron tulipifera* L.), green ash (*Fraxinus pennsylvanica* Marsh.), sweetgum (*Liquidambar styraciflua* L.), Shumard oak (*Quercus shumardii* Buckl.), Nuttall oak (*Q. nuttallii* Palmer), cherrybark oak (*Q. pagoda* Raf.), and loblolly pine (*Pinus taeda* L.). All seedlings were 1-0 bareroot. Seedlings were planted with shovels by a crew of three people in February 2003. Fifty-four seedlings were planted in each area at a 9 x 9-foot spacing. Planted areas were weeded mechanically using a brushcutter with either a line or saw blade in 2003, 2004, and 2005.

Each seedling was assessed for survival and health status (any noticeable damage was recorded) following each growing season from 2003 to 2012. We used calipers to measure basal diameter to the nearest 0.01 inch immediately after planting, and then following each growing season. If trees reached 6 feet in height, we then measured diameter at breast height (d.b.h., measured at 4.5 feet above ground level) using a diameter tape, to the nearest 0.1 inch. Seedling heights were measured with a height pole to the nearest 0.1 foot.

Sedimentation Estimation

We used a ditch witch to create a 12-inch furrow around each of the 10 areas. We installed aluminum flashing in these furrows and connected the flashing to a sheet-metal gutter that was the only outlet for any sediment flow from each area (Carter 2013). Attached to each gutter using metal clips was a felted fabric bag, approximately 18 x 22 inches in which deposited sediment was captured. Bags were weighed prior to field installation, collected monthly, oven dried at 221 °F for 48 hours, and then reweighed to obtain an estimate of deposited sediment. An Onset RG3 HOB0 data logging rain gauge was installed on a specially built wooden platform at each site (Onset Corporation, Cape Code, MA) and data was downloaded bi-monthly. Deposited sediment was collected from 2004 through 2009.

Statistics

Sites were analyzed separately and considered fixed. We used analysis of variance to determine differences among survival, diameter growth and height growth, as well as deposited sediment amounts, all random variables. If significant differences were found, Duncan's Multiple Range Test was performed post hoc to measure specific difference among means. All analyses were performed in SAS PROC MIXED in SAS 9.4 (SAS Institute 2013).

RESULTS

Tree Survival and Growth

Survival after 10 years was higher at the Gurley site at 91.7 percent compared to the Hazel site at 64.4 percent. At the Gurley site, survival ranged from 100 percent for green ash to 75.9 percent for black walnut (fig. 2). Green ash also had the highest survival at the Hazel site at 92.6 percent and yellow-poplar had the lowest survival at 14.8 percent (fig. 2). After one growing season, there were no differences in survival by species at each site. By 2012 at the Gurley site, green ash had significantly greater survival compared to Shumard oak, loblolly pine, and black walnut ($F_{6,33}$, $P < 0.0001$). At the Hazel site, three groups of survival emerged ($F_{21,37}$, $P < 0.0001$) with green ash, loblolly pine, Nuttall oak, and Shumard oak greater than black walnut, sweetgum, and cherrybark oak, and all were greater than that of yellow-poplar.

At the time of planting, seedlings at the Gurley site had root-collar diameters that ranged from 0.42 inches for green ash to 0.18 inches for cherrybark oak. Nuttall oak and yellow-poplar root-collar diameters were 0.31 and 0.29 inches, respectively, with the remaining seedlings at 0.20 inches. After 10 growing seasons, some seedlings were large enough to record d.b.h. and some were not. For the seedlings with a root-collar diameter, green ash seedlings were the largest at 2.10 inches, followed by Shumard oak (2.04 inches), cherrybark oak (1.70 inches), and black walnut (1.69 inches). There were significant differences in the d.b.h. of trees at the Gurley site ($F_{70,81}$, $P < 0.0001$), and they were separated into four distinct groups. The largest diameter trees were loblolly pine (7.9 inches) followed by sweetgum (4.3 inches). The third group contained yellow-poplar (3.5 inches), Nuttall oak (3.5 inches), green ash (3.2 inches), and cherrybark oak (3.2 inches). The smallest diameter was for Shumard oak at 2.2 inches d.b.h.

Hazel site seedlings also had a range of root-collar diameters at planting, from 0.38 inches for green ash to 0.18 inches for Shumard oak. Root collars were not significantly different for the five trees with measurements for root collar at year 10 (i.e., not large enough to have d.b.h.) ($F_{1,30}$, $P = 0.2784$). Three species—loblolly pine, green ash, and yellow-poplar—had trees large enough to have only d.b.h. measurements. At year 10, d.b.h. was significantly different among species ($F_{6,99}$,

$P < 0.0001$), with loblolly pine (6.8 inches) greater than all others except cherrybark oak (5.14 inches). Cherrybark oak d.b.h. did not differ from the remaining species, green ash (3.3 inches), black walnut (2.8 inches), Nuttall oak (2.6 inches), Shumard oak (2.4 inches), and yellow-poplar (2.2 inches).

Seedling height varied greatly among species. For both sites, green ash seedlings were the tallest at the time of planting at 2.4 feet tall, and loblolly pine seedlings were the shortest, at 1.0 foot tall. The remaining seedlings averaged 1.4 feet tall at planting, except black walnut, which was 2 feet tall. After 10 years loblolly pine was significantly taller than all other species at both sites, 33.7 feet tall at the Hazel site ($F_{161,31}$, $P < 0.0001$) and 34.5 feet tall at the Gurley site ($F_{160,65}$,

$P < 0.0001$). At the Hazel site, green ash and sweetgum ranked second in height (23.8 feet and 22.5 feet), and Nuttall oak was the shortest (9.3 feet). At the Gurley site, sweetgum (28.6 feet) and yellow-poplar (27.9 feet) ranked second in height, and black walnut was the shortest (8.1 feet). Although we did not make comparisons among sites, there were some interesting trends (fig. 3). Nuttall oak, cherrybark oak, Shumard oak, and yellow-poplar had greater height on the Gurley site, and black walnut and green ash were taller on the Hazel site compared to the Gurley site.

In the control sites that were disked but were not planted and did not receive any weed control, we tallied 15 species on the Hazel site and 17 on the Gurley site. Eight of these

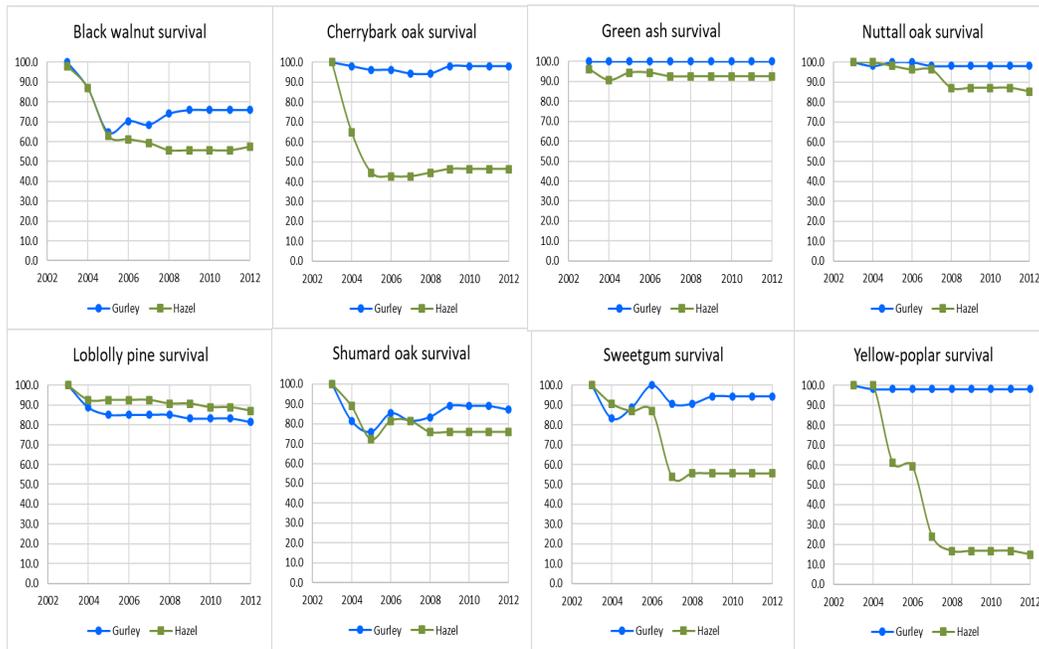


Figure 2—Tree survival over 10 years for eight species planted in two riparian areas in Madison County, Alabama.

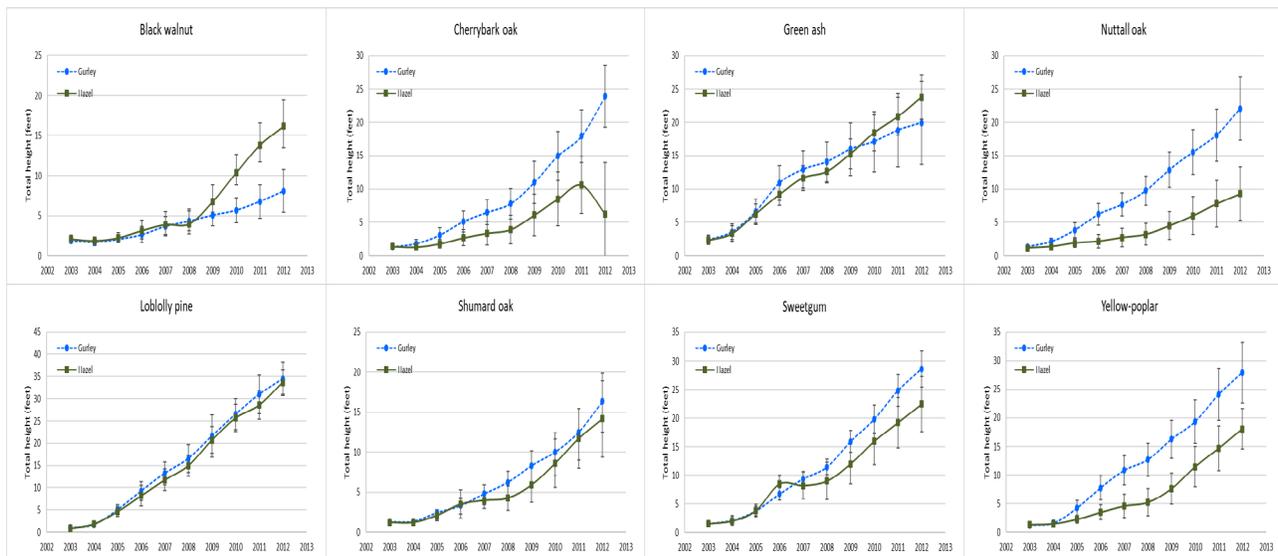


Figure 3—Total tree height over 10 years for eight species planted in two riparian areas in Madison County, Alabama.

species were found on both sites, including black cherry (*Prunus serotina* Ehrh.), boxelder (*Acer negundo* L.), Eastern redcedar (*Juniperus virginiana* L.), privet (*Ligustrum vulgare* L.), red maple (*A. rubrum* L.), sweetgum, water oak (*Q. nigra* L.), and winged elm (*Ulmus alata* Michx.). In 2012 on both sites, the majority of the volunteer trees were greater than 4 feet tall but less than 1.5 inches d.b.h. Volunteer woody species in this predominant size class had densities of 850 stems per acre (SPA) out of a total 1,358 SPA on the Hazel site and 1,775 SPA out of a total of 2,233 SPA at the Gurley site. By species for stems greater than 4 feet tall but less than 1.5 inches d.b.h., privet (242 SPA), winged elm (175 SPA), and sweetgum (142 SPA) had the highest densities at the Hazel site, and red maple (1,175 SPA) and green ash (117 SPA) had the highest densities at the Gurley site. Trees that were greater than 1.5 inches d.b.h. included Eastern redcedar (83 SPA) and winged elm (50 SPA) at the Hazel site, and red maple (83 SPA) and sycamore (*Platanus occidentalis* L.) (83 SPA) at the Gurley site. Species unique to the Hazel site included hophornbeam (*Ostrya virginiana* K. Koch.), black oak (*Q. velutina* Lamarck), *ilex* spp., pignut hickory (*Carya glabra* Sweet), scarlet oak (*Q. coccinea* Muench.), willow oak (*Q. phellos* L.), and yellow-poplar. Species unique to the Gurley site included flowering dogwood (*Cornus florida* L.), green ash, honeylocust (*Gleditsia triacanthos* L.), persimmon (*Diospyros virginiana* L.), plum (*Prunus americana* Marsh.), slippery elm (*U. rubra* Muhl.), sycamore, and winged sumac (*Rhus copallina* L.).

Precipitation and Sediment Movement

We measured precipitation on each site from 2003 until 2009. For the Gurley site, total annual precipitation amounts, ranked from highest to lowest were 2009 (67.2 inches), 2004 (64.3 inches), 2003 (61.3 inches), 2008 (48.6 inches), 2005 (45.6 inches), 2006 (37.5 inches), and 2007 (22.3 inches). Over these 7 years, December was the wettest month (averaged 6.3 inches), and June was the driest (3.0 inches). We had rain every month of the year during the 7 years that data were collected except March 2007. At the Hazel site, total precipitation amounts were (highest to lowest): 2004 (61.2 inches), 2009 (59.4 inches), 2003 (53.8 inches), 2008 (51.1 inches), 2005 (35.8 inches), 2006 (31.8 inches), and 2007 (28.2 inches). Rain was recorded every month over the 7-year period, and the wettest month was December (averaged 5.9 inches), and the driest month was June (2.8 inches).

The amount of deposited sediment from each area was heavily influenced by precipitation. June consistently had the lowest accumulated sediment and December had the highest. The amount of sediment collected over the 4 years of the study remained consistently related to precipitation. For example, at the Hazel site the most sediment was collected in the wettest year of 2004 (average of 53.77 grams across all areas) and the least was collected in the driest year of

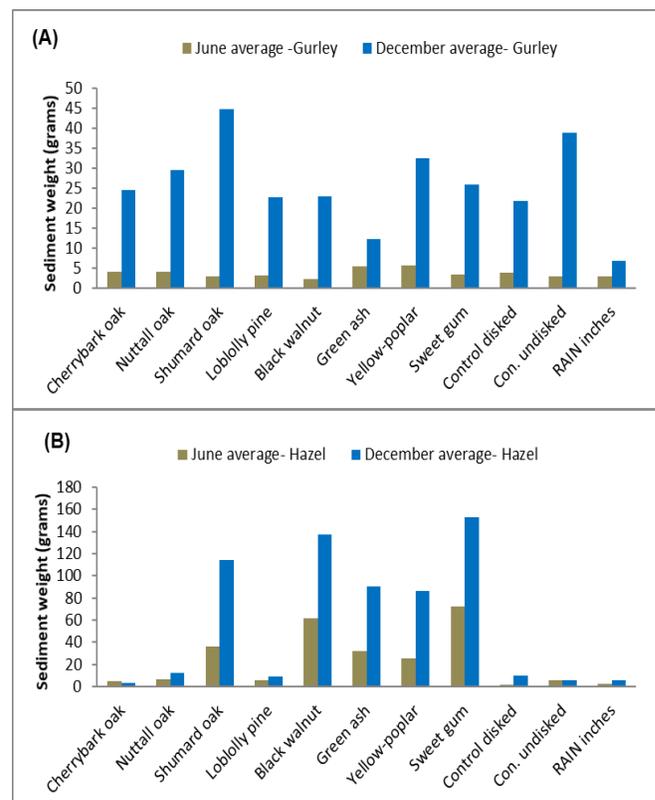


Figure 4—Average deposited sediment weights collected from two sites planted with eight different species and two unplanted control areas, one disked at the time of planted and one left undisturbed (A) Gurley site; (B) Hazel site. Data presented for 2 months that represent the average highest precipitation (December) and lowest (June) from 2004 to 2009.

2007 (5.29 grams). Damage to the sampling areas ended our collection after 6 years. For both June and December, the sediment deposited on the bags from all planted areas was higher at the Hazel site (30.68 grams in June and 75.59 grams in December) compared to the Gurley site (3.88 grams in June and 26.87 grams in December). At the Gurley site, more sediment was collected from Shumard oak, black walnut, green ash, yellow-poplar, and sweetgum planted areas (fig. 4A) in both June and December. There were no discernable trends in the sediment deposited by area (planted or controls) at the Hazel site (fig. 4B).

DISCUSSION

Demonstration areas allow landowners and practitioners to observe management practices. Planting marginal agricultural lands with hardwood species continues to be of interest to landowners, and this case study was designed to examine species success on specific sites, as well as attempting to quantify potential ecosystem benefits related to control of sediment movement. We solicited input from foresters in species selection, obtained seedlings from a local commercial nursery, and used common planting and tending methods. Predicting which species would provide maximum profit at some future date is unreliable, but all species

planted have commercial value that fluctuates with changes in markets and consumer demand. Exports of important eastern hardwoods includes oaks, ashes, and walnut, supporting the inclusion for this assessment (Luppold and Bumgardner 2021). An extensive history of planting loblolly pine in the South supports its inclusion (Zang 1998).

We had high survival rates for most species on the Gurley site, from a low of 76 percent of black walnut to a high of 98–100 percent for green ash, Nuttall oak, cherrybark oak, and yellow-poplar. We also had high growth on this site, with an increase of almost 20 feet of height growth for Shumard oak, green ash, and Nuttall oak, and over 21 feet of growth for cherrybark oak, yellow-poplar, sweetgum, and loblolly pine. On the Hazel site, both green ash and Nuttall oak had high survival, but only green ash displayed good growth, increasing by almost 22 feet in height. Nuttall oak seedlings grew much more slowly at the Hazel site, increasing by 8 feet in 10 years. The selection of these bottomland species was aligned with natural species-site relationships. Green ash is common on both major and minor bottoms, and is successional replaced by sweetgum, Nuttall oak, cherrybark oak, and Shumard oak, depending on elevation and successional stage. Yellow-poplar can be found on better drained bottoms (Hodges 1997). These single-species plantings were an initial step in creating restoration demonstration sites for landowners to observe. Following these preliminary results, a next phase would be to examine mixed species plantings with those species deemed most desirable (Lockhart and others 2008).

Black walnut only increased by 3.8 feet, and that coupled with low survival are indicative of unfavorable suitability to this site. A desire to plant black walnut may be predicated on the idea that, black walnut trees, when planted to maximize tree growth, can grow as much as 3 to 4 feet per year in good soil, reaching a mature height of over 100 feet and 30 to 40 inches in diameter, with 16-inch diameter saw logs ready to harvest in 30 years. However, the area of greatest commercial importance for the species is limited to the central part of its range, particularly the States of Missouri, Iowa, Illinois, Indiana, Michigan, Ohio, West Virginia, Kentucky, and Tennessee (Landt and Phares 1973). Black walnut is sensitive to soil conditions and develops best on deep, well-drained, nearly neutral soils that are generally moist and fertile (Brinkman 1965). Walnut has best growth in its natural range along streams. Other benefits of including black walnut include both promoting biodiversity and producing mast for wildlife, and its inclusion in mixed plantings for alternative benefits may be considered. The Hazel site also had low black walnut survival and growth.

Yellow-poplar survival was low on the Hazel site, with only eight seedlings surviving. They grew 17 feet in 10 years, compared to 98 percent survival at the Gurley site with 27 feet of height growth. Both sweetgum and cherrybark oak had low survival at the Gurley site and surviving sweetgum seedlings grew 20 feet and cherrybark oak seedlings only grew about 12 feet in 10 years.

Green ash, Nuttall oak, and loblolly pine experienced high survival and growth on both sites. Planting green ash is questionable given that the emerald ash borer (EAB) (*Agrilus planipennis*) has killed millions of ash trees in the Eastern United States. The remaining regeneration cohort is often not in competitive recruitment positions, hence green ash fate remains uncertain (Siegert and others 2021). However, establishing green ash in riparian plantings may be one way to safeguard this species, especially in areas of none to low EAB invasion, and these trees may also serve a future seed source.

We tried to quantify potential sediment deposition as a surrogate for erosion mitigation impacts under different species plantings. Because our design did not measure actual runoff (water), we were left to examine some general trends. Unfortunately, damage to our sampling system truncated our study. We found that there were differences among sites and species, but all were related to the amount of precipitation. We were unable to explain the small amount of collected sediment from the Hazel control site, which was not found on the Gurley site. Both sites had high levels of volunteer species and were quickly colonized by woody species.

Removing the main disturbance (soil cultivation for agriculture) allowed these sites to colonize with many native species, and one non-native invasive. While invasive privet plants can develop into dense thickets, competition with other fast-growing volunteer trees may diminish this response. Desirable timber species, such as the oaks, were part of the volunteer cohort, but not in sufficient numbers to result in a fully stocked stand and thus potential to provide future timber revenue would be low. These demonstration sites allowed us to examine restoration techniques that are commonly used by landowners. Planting desirable tree seedlings in these riparian areas will result in stocked stands as survival is generally high, especially for loblolly pine, green ash, and Nuttall oak. Future management that addresses tree density, tree form, and other issues, such as non-native invasive species will be needed.

ACKNOWLEDGMENTS

The authors would like to recognize Kozma Naka (faculty) and Tom Green (retired faculty) and Lewis Bingham (retired technician) at Alabama A&M University for their involvement in this study. Funding was provided by the Alabama Department of Environmental Management and the U.S. Department of Agriculture, Forest Service, Southern Research Station. Special appreciation to Southern Research Station technicians Ryan Sisk, Matt Zirbel, Jamie Hernandez, Nathan Brown, Trey Petty, Jonathan Lampley, and Jennifer Rice.

LITERATURE CITED

- Allen, J.A. 1997. Reforestation of bottomland hardwoods and the issue of woody species diversity. *Restoration Ecology*. 5: 125–134.
- Brinkman, K.A. 1965. Black walnut (*Juglans nigra L.*). *Agric. Handb.* 271. In: Fowells, H.A., comp. *Silvics of forest trees of the United States*. Washington, DC: U.S. Department of Agriculture, Forest Service: 391–399.
- Carter, E. 2013. Erosion response of a harvested Piedmont loblolly pine plantation in Alabama: preliminary results. *Gen. Tech. Rep. SRS-GTR-175*. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 385–393.
- Hodges, J.D. 1997. Development and ecology of bottomland hardwood sites. *Forest Ecology and Management*. 90: 117–125.
- Kennedy, H.E., Jr. 1990. Hardwood reforestation in the South: landowners can benefit from Conservation Reserve Program incentives. *Res. Note SO-364*. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 6 p.
- Landt, E.F.; Phares, R.E. 1973. Black Walnut (*Juglans nigra L.*) an American wood. FS-270. Washington, DC: U.S. Department of Agriculture, Forest Service. 7 p.
- Lockhart, B.; Gardiner, E.; Leininger, T.; Stanturf, J. 2008. A stand-development approach to oak afforestation in the Lower Mississippi Alluvial Valley. *Southern Journal of Applied Forestry*. 32(3): 120–129.
- Luppold, W.; Bumgardner, M. 2021. Regional analysis of U.S. lumber exports for important hardwood species from 1990 to 2020. *Forest Products Journal*. 71(3): 216–223.
- Richardson, D.M.; Holmes, P.M.; Esler, K.J. [and others]. 2007. Riparian vegetation: degradation, alien plant invasions, and restoration prospects. *Diversity and Distributions*. 13: 126–139.
- SAS Institute. 2013. SAS/ACCESS® 9.4 Interface to ADABAS. https://documentation.sas.com/doc/en/pgmsascdc/9.4_3.5/acadbastitlepage.htm. [Date accessed: March 7, 2022].
- Siegert, N.W.; Engelken, P.J.; McCullough, D.G. 2021. Changes in demography and carrying capacity of green ash and black ash ten years after emerald ash borer invasion of two ash-dominated forests. *Forest Ecology and Management*. 494: 1–11.
- Soil Survey Madison County Alabama. 1958. Series 1947, No. 3. U.S. Department of Agriculture, Soil Conservation Service. 104 p.
- Stanturf, J.A.; Schweitzer, C.J.; Gardiner, E.S. 1998. Afforestation of marginal agricultural land in the Lower Mississippi River Alluvial Valley, U.S.A. *Silva Fennica*. 32: 281–297.
- Zang, D. 1998. Estimating land value for growing timber on agricultural land. ANR-1132. Alabama Cooperative Extension System. 6 p.

THE EFFECT OF DROUGHT ON LOBLOLLY PINE (*PINUS TAEDA*) PHOTOSYNTHESIS AND WHETHER THINNING OR GENETIC ENTRY CAN IMPROVE PLANTATION DROUGHT RESILIENCE

**Norman J. Cone IV, Joshua P. Adams, Michael A. Blazier,
Mary Anne S. Sayer, and Michael C. Tyree**

EXTENDED ABSTRACT

Loblolly pine (*Pinus taeda*) is an essential economic timber species that brings in billions of dollars to the economy of Southeastern States; however, climate projections predict a warmer and more droughty climate over the next century (Ahmadalipour and others 2017, McNulty and others 2019, Oswalt and others 2019). Plantation managers must adopt new practices to maintain timber production despite these future adverse conditions. Two main methods are proposed to ameliorate drought stress in timber plantations: Reducing plantation density through thinning and planting drought-resistant genotypes. During the 2011 extreme drought in Texas, Klockow and others (2020) observed that loblolly plantations exhibited superior survival rates to natural stands and attributed those survival rates to the lower tree density.

For decades foresters have analyzed growth differences among loblolly pine genotypes and seed sources. Seed sources from the Atlantic Coastal Plain (ACP) exhibit superior growth rates and form, but loblolly pine seedlings from the Western Gulf Region (WGR) are thought to be more drought-resistant (Schmidting 2001). While ACP seed sources are preferred by landowners due to their superior productivity, future drought conditions may incentivize the planting of WGR seed sources. This study set out to understand whether thinning could ameliorate loblolly pine tree drought stress and if there was genotypic variation in drought resistance.

A loblolly pine plantation was established in Homer, LA in 2005 at the LSU AgCenter Hill Farm Research Station. Three genotypes of loblolly pine were planted: (LA) an open-pollinated Louisiana family commonly recommended for landowners in North Central Louisiana, (756) an open-pollinated North Carolina family from the Atlantic Coastal Plain, and (93) a clonally propagated variety based on the rooted cuttings of a robust 756 individual. Additional site details and genotypic information can be found in Blazier and others (2018). Half of the trees were thinned in 2018 to create thinned (561 trees ha⁻¹) and non-thinned (1122 trees ha⁻¹) treatments. Beginning in 2019, half of the plots were

Norman J. Cone IV, Former Graduate Research Assistant, Louisiana Tech University, Ruston, LA 71270; Joshua P. Adams, Head of Forestry and Associate Professor, Louisiana Tech University, Ruston, LA 71270; Michael A. Blazier, Dean, College of Forestry, Agriculture, and Natural Resources, University of Arkansas at Monticello, Monticello, AR 71656; Mary Anne S. Sayer, Plant Physiologist, U.S. Department of Agriculture, Forest Service, Southern Research Station, Pineville, LA 71360. Michael C. Tyree, Associate Professor of Plant Ecology, Department of Biology, Indiana University of Pennsylvania, Indiana, PA 15705-1001.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

trenched 1 m deep, and plastic was lined in the trenches to restrict lateral flow of water in soil. Precipitation exclusion shelters were built around each drought plot to cause complete water exclusion, which was fully initiated on June 5, 2020. All possible combinations of genotype, thinning, and drought treatments were replicated three times for a total of 36 experimental units.

Photosynthetic measurements were recorded during each season to understand seasonal variation in photosynthesis and drought resistance. A LiCor 6400 XT (LiCor Inc., Lincoln, NE, USA) was utilized to measure photosynthesis. Foliage was destructively measured by removing branches from the trees. Two flushes from each branch were measured when present. Curve fitting software was utilized to convert field data into P_{gmax} and R_d for analysis (Lobo and others 2013).

Repeated measures analysis of variance (ANOVA) was conducted in SAS (SAS Institute, Inc., Cary, NC) using PROC GLIMMIX which incorporates fixed and random effects to compare P_{gmax} and R_d between treatments. Genotype, thinning, and drought and their interactions were included in the model as fixed effects, while date and its interactions with fixed effects were random effects. An alpha level of 0.10 was utilized to account for the inherent variation in photosynthesis among needles in a large tree canopy (Tang and others 1999). Each flush generation (F18, F19, F20) was analyzed separately. Flush 2018 did not have date or drought incorporated into the statistical model because it was only measured on one date prior to water exclusion.

Following initiation of drought simulation on June 5, 2020, treatment differences in volumetric soil water content (VWC) did not manifest until August 3, 2020 (fig. 1). A large increase in VWC occurred in non-drought plots following Hurricane Laura on August 27, 2020. Despite the site experiencing a massive amount of precipitation from the hurricane, water exclusion shelters were able to prevent soil water recharge in drought plots.

Strong date effects were observed in this study (table 1). Leaf photosynthesis and dark respiration were greatest during the summer and lowest during the dormant season. Photosynthetic analysis observed significant differences in P_{gmax} and R_d among the genotypes. In the F18 flush, LA and 756 genotypes had significantly greater P_{gmax} than the clonal 93 genotype ($P=0.09$). Genotypic differences were maintained during the F19 flush, with LA having significantly greater P_{gmax} than clonal 93 ($P=0.09$). No genotypic differences in P_{gmax} were observed in the F20 flush ($P>0.1$).

Significant genotypic differences in R_d were also observed among the genotypes. In F18, 756 and LA exhibited significantly greater R_d than 93 ($P=0.09$). In F20, 93 exhibited significantly greater R_d than LA, while 756 was not significantly different than either genotype. No significant differences were observed in the F19 flush.

No significant drought or thinning effects were observed during the study, but there was a marginally nonsignificant trend for non-drought plots to exhibit greater P_{gmax} than drought plots during the F20 flush ($P=0.12$).

This study demonstrated clear genotypic differences in P_{gmax} and R_d among eastern and western loblolly pine genotypes. While significant photosynthetic differences in drought treatments were not observed, the marginally non-significant trend indicates that photosynthetic differences may develop as differences in soil moisture increase. While the 2011 southeastern drought caused extreme drought conditions for 11 months, plantation loblolly pine only experienced 10 percent increased mortality (Klockow and others 2020). That trend suggests that loblolly pines are considerably drought-resistant and that more time is needed in this experiment for drought effects to manifest.

Table 1—Statistical analysis (ANOVA F-Tests) test of fixed effects of maximum gross photosynthesis (P_{gmax}) and dark respiration (R_d) in F20, F19, and F18 foliage

Fixed Effects	P_{gmax}		R_d	
	df	<i>P</i>	df	<i>P</i>
F20				
Genotype	2	0.3014	2	0.0146
Drought	1	0.1184	1	0.1763
Thin	1	0.9383	1	0.8781
Date	3	<0.0001	3	<0.0001
Genotype x Drought	2	0.7417	2	0.9120
Genotype x Thin	2	0.7945	2	0.2842
Thin x Drought	1	0.8202	1	0.3452
Genotype x Drought x Date	6	0.3397	6	0.7476
F19				
Genotype	2	0.0862	2	0.7080
Drought	1	0.5808	1	0.9225
Thin	1	0.6963	1	0.1718
Date	5	<0.0001	5	<0.0001
Genotype x Drought	10	0.3580	10	0.3339
Genotype x Thin	2	0.4830	2	0.4434
Thin x Drought	1	0.7697	1	0.1775
Genotype x Drought x Date	6	0.7711	6	0.7418
F18				
Genotype	2	0.0926	2	0.0516
Drought	—	—	—	—
Thin	1	0.8934	1	0.1637
Date	—	—	—	—
Genotype x Drought	—	—	—	—
Genotype x Thin	2	0.9294	2	0.5827
Thin x Drought	—	—	—	—
Genotype x Drought x Date	—	—	—	—

Em dash (—) indicates that drought and date effects were not analyzed in F18.

Degrees of freedom (df) and probability of a greater F (*P*) are provided for each variable and flush. F20 and F19 foliage were measured over multiple dates and analyzed with a repeated measures ANOVA. F18 developed prior to drought initiation, and values only represent a single measurement period. Significant *P* values ($\alpha \leq 0.10$) are bolded while marginally nonsignificant values are italicized.

Volumetric Soil Water Content (0 - 30 cm)

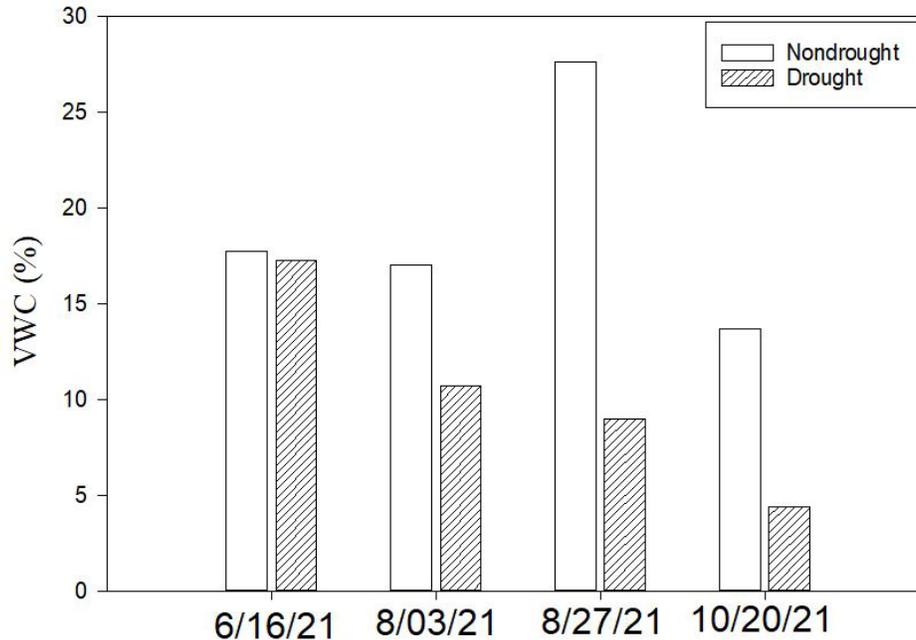
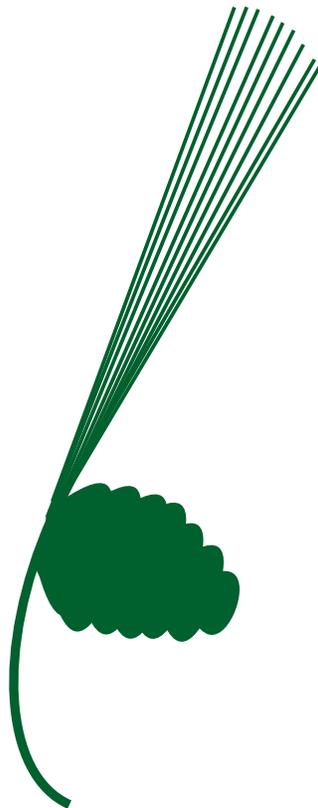


Figure 1—Volumetric Soil Water Content (VWC) (0 - 30 cm) of drought and nondrought plots following drought initiation on June 5, 2020.

LITERATURE CITED

- Ahmadalipour, A.; Moradkhani H.; Svoboda, M. 2017. Centennial drought outlook over the CONUS Using NASA-NEX downscaled climate ensemble. *International Journal of Climatology*. 37(5): 2,477-2,491.
- Blazier, M.A.; Tyree, M.C.; S. Sayer, M.A. [and others]. 2018. Gas exchange and productivity in temperate and droughty years of four eastern, elite loblolly pine genotypes grown in the Western Gulf Region. *International Journal of Agronomy*. Article ID 3942602: 1-10.
- Klockow, P.A.; Edgar, C.B.; Moore, G.W.; Vogel, J. G. 2020. Southern pines are resistant to mortality from an exceptional drought in east Texas. *Frontiers in Forests and Global Change*. 3(March): 1-12.
- Lobo, F. de A.; Barros M. P.; Dalmagro, H. J. [and others]. 2013. Fitting net photosynthetic light-response curves with Microsoft Excel—a Critical look at the models. *Photosynthetica*. 51(3): 445-456.
- McNulty, S.; Baca, A.; Bowker, M. [and others]. 2019. Managing the effects of drought in the Southeast United States. In: Vose, James M.; Peterson, David L.; Luce, Charles H.; Patel-Weynand, Toral. *Effects of drought on forests and rangelands in the United States: translating science into management responses*. Gen. Tech. Rep. WO-98. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office: 191-220. Chapter 9.
- Oswalt, S.; Smith, W.; Miles, P. [and others]. 2019. *Forest resources of the United States, 2017: a technical document supporting the Forest Service 2020 RPA Assessment*. Gen. Tech. Rep. WO-97. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 223 p.
- Schmidtling, R.C. 2001. *Southern pine seed sources*. Gen. Tech. Rep. SRS-44. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 25 p.
- Tang, Z.; Chambers, J. L.; Guddanti, S; and Barnett, J. P. 1999. Thinning, Fertilization, and Crown Position Interact to Control Physiological Responses of Loblolly Pine. *Tree Physiology* 19(2): 87-94.

Loblolly Pine Management



THREE-YEAR GROWTH OF LOBLOLLY PINE SEEDLINGS FOLLOWING HERBACEOUS WEED CONTROL APPLICATIONS OF SULFOMETURON, IMAZAPYR, HEXAZINONE, AND INDAZIFLAM

Andrew W. Ezell, Andrew B. Self, John E. Ezell, and Jason Belcher

ABSTRACT

A total of 10 treatments (including an untreated check) were used to evaluate herbaceous weed control, survival, and 3-year growth in a newly established loblolly pine plantation. All treatments were replicated three times in a randomized complete block design. The treatments of (1) Oust XP + Velpar L or (2) Oust XP + Velpar L + Esplanade SC (5 ounces) provided the best overall results in herbaceous weed control, survival, height growth, and groundline diameter growth. Indaziflam demonstrated potential for future use in such applications over loblolly pine seedlings.

INTRODUCTION

For more than 30 years, herbaceous weed control (HWC) has been a standard practice in the establishment of pine plantations in the South. Through the years, a variety of herbicides have been used in these applications. Currently, a combination of sulfometuron methyl and imazapyr is the most widely utilized application for loblolly pine seedlings. Indaziflam has demonstrated efficacy in tank mixtures for such applications and there is some evidence that indaziflam can provide residual weed control into the next year after application. Such residual control could provide additional growth in recently planted loblolly pine seedlings.

OBJECTIVES

The primary objective of this study was to compare survival and growth of loblolly pine seedlings over a 3-year period following HWC applications. Of particular interest was to determine if treatments using Esplanade SC® (indaziflam) produced better growth than those without the material.

METHODS

Study Site

The study was installed on Weyerhaeuser land in Choctaw County, Mississippi. The site was harvested in 2016, received

a combination plow treatment in the summer of 2017, chemical site prep in September 2017, and was planted in January 2018. Shortly after planting, extreme cold temperatures damaged many seedlings. For that reason, the original seedlings were removed from the research area and new Weyerhaeuser loblolly pine seedlings were planted on February 28, 2018.

Plot Layout

All plots consisted of an area 5 feet x 100 feet with the planted pine seedlings along the midline of the plot. Of the 15 to 16 total seedlings which occurred in each plot, 10 were marked with pin flags as sample trees prior to treatment application.

Experimental Design

A randomized complete block design was utilized in the study due to the slight elevational difference that occurred across the site. Blocks were arranged across this gradient. Three replications of each treatment were installed.

Treatments

A complete list of treatments is presented in table 1. Please note that the Arsenal® used in the study is a 2-pound active ingredient (AI) imazapyr product while the Arsenal AC® in Treatment 10 is a 4-pound AI imazapyr product.

Author Information: Andrew W. Ezell, Switzer Distinguished Professor Emeritus and Department Head Emeritus, Mississippi State University, Mississippi State, MS 39762; Andrew B. Self, Associate Extension Professor, Mississippi State University, Mississippi State, MS 39762; John E. Ezell, Clinical Professor, Mississippi State University, Mississippi State, MS 39762; and Jason Belcher, Stewardship and Development Manager—Eastern United States, Bayer CropSciences, Auburn, AL 36830.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

Table 1—List of treatments in 2018 Bayer HWC study (product amounts are per-acre rates)

1. Untreated check
2. Oust XP (2 ounces) + Arsenal (8 ounces)
3. Oust XP (2 ounces) + Velpar L (32 ounces)
4. Oust XP (2 ounces) + Arsenal (8 ounces) + Esplanade SC (3 ounces)
5. Oust XP (2 ounces) + Velpar L (32 ounces) + Esplanade SC (3 ounces)
6. Oust XP (2 ounces) + Arsenal (8 ounces) + Esplanade SC (5 ounces)
7. Oust XP (2 ounces) + Velpar L (32 ounces) + Esplanade SC (5 ounces)
8. Oust XP (2 ounces) + Arsenal (8 ounces) + Esplanade SC (7 ounces)
9. Oust XP (2 ounces) + Velpar L (32 ounces) + Esplanade SC (7 ounces)
10. Oust XP (2 ounces) + Arsenal AC (4 ounces)

Application

All treatments were applied on March 9, 2018, using a CO₂-powered backpack sprayer with a hand-held wand and TK 2.5 Floodjet nozzle. Total spray volume was 20 gallons per acre. Treatments were applied in a 5-foot swath over the top of the planted seedlings with the seedlings serving as the midpoint of the spray swath.

Evaluation

Herbaceous weed control and crop tolerance of the planted seedlings were evaluated by ocular estimates in June, July, and September 2018. HWC was recorded by vegetation classes and any signs of phytotoxicity were recorded by type (e.g., necrosis, epinasty, rosetting). Survival was recorded in June and September 2018; October 2019; and October 2020. Seedling height and groundline diameter (GLD) were recorded in March 2018; October 2018; October 2019; and October 2020.

RESULTS

Competition Control

All herbicide treatments except Treatment 2 had 70 percent or more bare ground in June 2018 (table 2). No apparent rate response was evident from the addition of Esplanade SC® at either the June or September evaluations. Treatments continued to provide an average of 16.7-48.3 percent bare ground in September 2018 (table 3). Treatments with Velpar L®, both with Esplanade® (Treatment 7) and without (Treatment 3) provided the most bare ground in the September evaluations. It should be noted that retention of 20+ percent bare ground in September is considered to be very good or excellent results in the South.

Table 2—Average coverage by treatment and vegetation class, June 2018 (average all replications)

Treatment	Grass	Forbs	Bare
	-----percent-----		
Untreated	40.0	50.0	20.3
O + A	8.7	53.3	38.3
O + V	2.7	15.0	82.3
O + A + E(3)	1.0	10.0	90.0
O + V + E(3)	5.3	25.0	70.0
O + A + E(5)	0.3	25.0	75.0
O + V + E(5)	2.0	8.3	90.0
O + A + E(7)	1.0	13.3	86.7
O + V + E(7)	6.7	10.0	78.3
O + AC	4.0	16.7	80.0

A = Arsenal; O = Oust XP; V = Velpar; E = Esplanade.

Table 3—Average coverage by treatment and vegetation class—September 2018 (average all replications)

Treatment	Grass	Forbs	Bare
	-----percent-----		
Untreated	56.7	60.0	0.0
O + A	33.3	41.7	25.0
O + V	33.3	26.7	40.0
O + A + E(3)	26.7	40.0	32.3
O + V + E(3)	56.7	26.7	16.7
O + A + E(5)	40.0	36.7	23.3
O + V + E(5)	10.0	41.7	48.3
O + A + E(7)	31.7	43.3	25.0
O + V + E(7)	40.0	31.7	28.3
O + AC	63.3	16.7	20.0

A = Arsenal; O = Oust XP; V = Velpar; E = Esplanade.

Crop Tolerance

No symptoms of injury were observed in any treatment plots. Loblolly pine tolerance to indaziflam had been evaluated previously, but not in all the mixtures in this study.

Survival

Survival among the treatments ranged from an average of 80.0 percent to 100 percent (table 4). Overall survival in the study was 93.0 percent after three growing seasons which would be considered excellent for a loblolly pine plantation. Overall survival after the first growing season was 93.7 percent, again demonstrating that the vast majority of mortality usually occurs in the first growing season.

Table 4—Average survival, height, and groundline diameter (GLD) by treatment after three growing seasons (average all replications)

Treatment	Survival	Height	GLD
	<i>-percent-</i>	<i>-feet-</i>	<i>-mm-</i>
Untreated	93.3a ^a	6.86d	38.7e
0 + A	100.0a	8.63ab	54.0a
0 + V	96.7a	9.07a	54.9a
0 + A + E(3)	80.0b	7.53c	44.7d
0 + V + E(3)	100.0a	8.30b	53.6ab
0 + A + E(5)	93.3a	8.03b	49.9c
0 + V + E(5)	90.0a	9.40a	54.5a
0 + A + E(7)	86.7ab	8.53ab	50.7c
0 + V + E(7)	100.0a	8.93a	52.9b
0 + AC	90.0a	8.00b	48.5c

A = Arsenal; 0 = Oust XP; V = Velpar; E = Esplanade.

^aValues in a column followed by the same letter do not differ at alpha = 0.05.

Height

There was notable variation in total tree height among the blocks. As might be expected, the lower elevation area had taller trees which is attributed to soil moisture availability during the growing season. After three growing seasons, 9 of 10 treatments had the highest averages in the lowest elevation block. While the difference in elevation was not great, it seemingly was sufficient to result in a growth difference. While HWC did not result in a statistical difference when herbicide treatments were compared to untreated plots for survival, it did result in a significant difference in average total height after 3 years (table 4). The same treatments that produced the most bare ground during the first growing season (Oust XP® + Velpar L® and Oust XP® + Velpar L® + Esplanade SC® -5 ounces per acre) also resulted in the greatest average heights. Generally, increasing the rate of Esplanade SC® from 3 to 5 ounces per acre resulted in increased height, but additional increases to 7 ounces per acre did not always produce greater heights.

Groundline Diameter

While average GLD was greater in the lowest elevation block in 8 of the 10 treatments, GLD was more consistent among blocks than heights. Again, herbicide treatments all resulted in significantly greater growth as compared to the untreated plots (table 4). The same treatments that resulted in the greatest average heights (treatments 3 and 7) also resulted in the greatest average GLD. It is consistent that these two treatments which provided the best HWC results also had the greatest average height and GLD.

SUMMARY

Survival in this study was excellent. The results of this study reflect that the study site is very well suited for the growth of loblolly pine. Grass control from the treatments was very good except for *Andropogon* later in the growing season and none of the treatments were expected to control that genus. Forb control was also very good except for fireweed or American burnweed (*Erechites*). The addition of indaziflam generally provided additional competition control. Rate response from the addition of indaziflam was not strong, but 5 ounces per acre appears to provide the best results of the rates tested. The addition of indaziflam to Oust XP® + Velpar L® consistently provided better results than the same additions to Oust XP® + Arsenal®. After three growing seasons, the best growth in this study resulted from two treatments—Oust XP® + Velpar L® (Treatment 3) and Oust XP® + Velpar® + Esplanade SC®-5 ounces (Treatment 7).

USE OF GLUFOSINATE TO CONTROL NATURAL PINES—A POSSIBLE REPLACEMENT FOR GLYPHOSATE

Andrew W. Ezell, Andrew B. Self, and John E. Ezell

ABSTRACT

Recent concerns over the use of glyphosate have prompted land managers to seek a replacement for that herbicide. Two treatments containing glufosinate (Finale VU) were compared to one treatment without glufosinate and an untreated check. The primary focus was the control of naturally occurring loblolly pine. All treatments were replicated three times in a completely randomized design. After 8 months, all herbicide treatments demonstrated excellent control of loblolly pine. Based on this pilot study, glufosinate appears to have good potential for control of loblolly pines.

INTRODUCTION

Site preparation continues to be the largest forestry vegetation management effort in the South. While most species encountered in these situations can be effectively managed at this time, control of natural pines continues to be a challenge. Recent concerns over the use of glyphosate have further complicated the situation. As a result, some forest managers are seeking a replacement for glyphosate in site preparation applications. In addition to effective chemicals, land managers have sought ways to expand the application window for chemical site preparation. Thus, any information on the efficacy of glufosinate and mid-summer application would be a useful addition to the current body of knowledge.

OBJECTIVES

The objectives of this study are as follows:

1. To evaluate the efficacy of Finale VU® (glufosinate) in the control of natural loblolly pines (*Pinus taeda*) and hardwoods
2. To evaluate the July timing of site preparation applications for control of natural pines and hardwoods

METHODS

Study Site

The study was installed on a Tennessee Valley Authority right-of-way in Oktibbeha County, Mississippi. The site was

selected due to the presence of naturally occurring loblolly pines which were 1 to 10 feet tall. A variety of hardwood species were also found across the site.

Treatments

A list of treatments is found in table 1. The overall thrust of the study was to determine if glyphosate could be effectively replaced by glufosinate.

Experimental Design

The study utilized a completely randomized design. Three replications of each treatment were installed and evaluated.

Application

All treatments were applied on July 15, 2019. A CO₂-powered backpack sprayer with pole extension and KLC-9 nozzle were used to simulate an aerial application. Total spray volume was 10 gallons per acre (10 GPA).

Table 1—List of treatments in 2019 glufosinate study

- | |
|--|
| 1. Untreated check |
| 1. Arsenal AC (20 ounces per acre) + Accord XRTII (4 quarts per acre) + Detail (2 ounces per acre) + MSO (1 percent v/v) |
| 2. Arsenal AC (20 ounces per acre) + Accord XRTII (2.5 quarts per acre) + Finale VU (1.5 quarts per acre) + Detail (2 ounces per acre) + MSO (1 percent v/v) |
| 3. Arsenal AC (20 ounces per acre) + Accord XRTII (3 quarts per acre) + Finale VU (1 quart per acre) + Detail (2 ounces per acre) + MSO (1 percent v/v) |

Author Information: Andrew W. Ezell, Switzer Distinguished Professor Emeritus and Department Head Emeritus, Mississippi State University, Mississippi State, MS 39762; Andrew B. Self, Associate Extension Professor, Mississippi State University, Mississippi State, MS 39762; and John E. Ezell, Clinical Professor, Mississippi State University, Mississippi State, MS 39762.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

Evaluation

Treatment plots were rectangular areas which measured 30 feet x 50 feet. Rebar was placed at the plot center on each end of the plot and nylon string was connected to the rebar to establish the plot midline. All woody stems in a sample area 10 feet x 50 feet centered in the treatment plot were recorded by species and height class prior to application. Brownout was recorded at 30 days after treatment (DAT) and percent control was recorded at 90 DAT. Pine control was recorded at 8 months after treatment (MAT).

RESULTS

All herbicide treatments provided good to excellent brownout at 30 DAT (table 2). Herbaceous plants typically exhibit brownout response to herbicide treatments faster than woody species, and hardwoods are slower to respond than pines in most applications. There was very little difference between

the brownout of vegetation groups in Treatments 2 and 4. Less brownout was observed on hardwoods in Treatment 3, and this was attributed to the increased number of green ash (*Fraxinus pennsylvanica*) stems which occurred in these plots.

Overall control in the herbicide plots could be considered excellent at 90 DAT, but hardwood response in Treatment 3 continued to lag behind the control observed in Treatments 2 and 4 (table 3). Of greater interest was the control of pines which ranged from 96.0 to 99.3 percent among the herbicide treatments.

The evaluation of control at 8 MAT was restricted to only pines as this timing (March) may have been prior to some hardwoods breaking dormancy. Pine control at 8 MAT was excellent in all herbicide treatments (table 4). Control at this timing was based on both “stems” (number living at 8 MAT vs. number recorded prior to application) and “heights” (the cumulative heights of all living pines vs. the

Table 2—Average brownout at 30 DAT by treatment and vegetation group (average all replications)

Treatment	Vegetation group			
	Grass	Forbs	Pine	Hardwoods
	-----percent-----			
Untreated	5.0	1.0	0.0	0.0
A + Ac (4) + D + M	90.0	95.0	93.3	66.7
A + Ac (2.5) + F (1.5) + D + M	80.0	93.3	90.0	46.7
A + Ac (3) + F (1) + D + M	93.3	96.0	95.0	56.7

DAT=days after treatment.

Table 3—Average control at 90 DAT by treatment and vegetation group (average all replications)

Treatment	Vegetation group			
	Grass	Forbs	Pine	Hardwoods
	-----percent-----			
Untreated	4.3	5.0	0.0	5.3
A + Ac (4) + D + M	100.0	98.0	99.3	100.0
A + Ac (2.5) + F (1.5) + D + M	99.0	98.0	96.0	63.3
A + Ac (3) + F (1) + D + M	100.0	97.3	97.7	91.7

DAT=days after treatment.

Table 4—Average reduction in pine stems and cumulative heights at 8 MAT by treatment (average all replications)

Treatment	Stems	Heights
	-percent-	-percent-
Untreated	0.0	+6.3 ^a
A + Ac (4) + D + M	100.0	100.0
A + Ac (2.5) + F (1.5) + D + M	97.8	99.6
A + Ac (3) + F (1) + D + M	100.0	100.0

^aPlus sign indicates an increase in total heights.

cumulative heights of pines recorded prior to application). While Treatment 3 had slightly less (1-2.2 percent) control than Treatments 2 and 4, all treatments were considered to be successful.

SUMMARY

Can Finale VU® (glufosinate) replace glyphosate? Results from this pilot study indicate that this material has very good/excellent potential for the control of natural pine. The July applications provided excellent results. Mid-summer applications in previous work have typically demonstrated lower control but it would be difficult to improve the pine control in this study. It was also notable that excellent pine control was obtained with 10 GPA. Most pine control work is complete with 15 GPA in operational settings. All herbicide treatments in this study included Detail® (saflufenacil). This material is known to increase the control of pines using glyphosate. Future work with glufosinate may evaluate applications without the addition of saflufenacil. Additional testing will be required to fully evaluate the use of glufosinate in site preparation.

FOUR-YEAR RESULTS OF A CHOPPER® GEN2™ AND FORESTRY GARLON® XRT RATE AND TIMING STUDY FOR LOBLOLLY PINE SITE PREPARATION ON THE LOWER COASTAL PLAIN OF GEORGIA

David C. Clabo and E. David Dickens

ABSTRACT

Chopper® GEN2™ and Forestry Garlon® XRT are frequently applied as a tank mix for chemical site preparation in the Coastal Plain region of the Southeastern United States. The purpose of this study was to assess age 4 loblolly pine (*Pinus taeda*) survival and growth following four site preparation application rates of these herbicides (alone and in tank mixes), discern potential growth and survival differences among three application timings, and compare loblolly pine growth and survival with chemical site preparation alone to chemical site preparation plus first-year herbaceous weed control (HWC). Loblolly pine survival was not improved by any chemical site preparation treatments compared to the control, while height, diameter, and volume index were all significantly greater with chemical site preparation than the control. The early application timing (July) resulted in less growth than September or October applications. First year HWC improved loblolly pine volume index by as much as two times over no HWC.

INTRODUCTION

Chemical site preparation is recognized as one of the most important and cost-effective steps in successful pine plantation establishment throughout the South. Certain herbicides may be used alone during application, but more often compatible herbicides are tank-mixed to broaden the spectrum of control of competing vegetation on a given site. Effective site preparation that combines chemical, mechanical and/or prescribed fire can minimize woody plant influence on planted pines for 4 or more years (Tiarks and Haywood 1986). Imazapyr is frequently used for forestry site preparation in the South because of its low toxicity and the broad spectrum of plants controlled (Dickens and others 2020). It can also be used in tank mixtures with other forestry herbicides to control specific species or vegetation types, which imazapyr does not control well alone (Lauer and Quicke 2006). In the Flatwoods region of the Lower Coastal Plain, imazapyr and ester triclopyr are often tank-mixed as the triclopyr offers improved control of species with thick and/or waxy leaf cuticles. These waxy leaf species may include: gallberry (*Ilex* spp.), saw palmetto (*Serenoa repens*), bayberry (*Myrica* spp.), blueberries (*Vaccinium* spp.), and sweetbay (*Magnolia virginiana*) (Lauer and Quicke 2006, Lowery and Gjerstad 1991, Shiver and others 1991). Chemical site preparation applications using these chemicals can be

completed any time after full leaf development during the growing season but are more commonly applied during late summer into fall before leaf color change.

Chopper® GEN2™ is an aqueous solution of a 2-pound acid equivalent (ae) imazapyr product that can be mixed with water or applied as an emulsion with a seed oil for improved uptake. Forestry Garlon® XRT is a relatively new 6.3-pound ae equivalent ester triclopyr product that can be applied at lower rates than previous 4-pound ae ester triclopyr products (Dow AgroSciences 2008). Forestry site preparation application rates for Chopper® GEN2™ range from 32 to 64 ounces per acre for loblolly pine site preparation (BASF Corporation 2021), while for Forestry Garlon® XRT, pine site preparation rates range from 80 to 128 ounces per acre when applied alone and 40 to 80 ounces per acre when applied in tank mixes. Studies have investigated rate and timing of Chopper® GEN2™ site preparation applications (Ezell and others 2013, Grogan and others 2015, Lauer and Quicke 2013), but no published studies have reported on side-by-side comparisons of Chopper® GEN2™ applied alone, Forestry Garlon® XRT applied alone, and various labeled tank mixtures and application timings of these two herbicides and long-term loblolly pine growth on Lower Coastal Plain sites. Additionally, the impacts of first-year, post-plant herbaceous weed control (HWC) combined with Chopper® GEN2™ and Forestry Garlon® XRT chemical site preparation

Author Information: David C. Clabo, Assistant Professor of Silviculture Outreach, University of Georgia, Tifton, GA 31793; and E. David Dickens, Professor of Forest Productivity, University of Georgia, Statesboro, GA 30458.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

on loblolly pine survival and growth has not been thoroughly investigated with tank mixtures of these herbicides.

OBJECTIVES

The objectives of this study were (1) to assess loblolly pine survival and growth response to Chopper® GEN2™ and Forestry Garlon® XRT chemical site preparation with each herbicide applied alone and in two tank mixes, (2) to investigate if loblolly pine survival and growth differences occur with three distinct application timings, and (3) to determine if first growing season post-plant HWC in addition to chemical site preparation improves loblolly pine survival and growth over chemical site preparation alone.

STUDY SITE

The study was installed at a site near Egypt, GA (32.482525°N -81.504423°W) under industrial ownership. This region of Georgia is known as the Sea Island Flatwoods ecoregion (Griffith and others 2001). This ecoregion is characterized by mostly poorly drained, flat plains with minor areas of better drained soils. Soils at the site were primarily from the Pelham series with a minor component of Orsino soils. Pelham soils are loamy, siliceous, subactive, thermic Arenic Paleaquults, while Orsino soils are hyperthermic, uncoated Spodic Quartzipsamments (Sowell 2015). Previously, the site was a mature loblolly pine stand. Woody vegetation onsite prior to study installation consisted primarily of grapevine (*Vitis* spp.), sweetgum (*Liquidambar styraciflua*), rusty staggerbush (*Lyonia ferruginea*), and red maple (*Acer rubrum*). Abundant grass, broadleaf weeds, and brambles including blackberry (*Rubus* spp.) were present onsite prior to study establishment.

METHODS

Study installation began during early July 2014 with mechanical site preparation on the 21.4-acre site. The site was sheared during early July and bedded during early September at a 90-degree angle to windrows still present from the previous stand. Three replications of five chemical site preparation treatments (including an untreated control) and three application timings were assigned to 39 experimental units. Experimental units were 150 x 120 feet (10 planting rows per experimental unit). Each experimental unit was divided into two sub-plots (five planting rows per sub-plot) and assigned first-year HWC or no HWC. Chemical site preparation treatments included: (1) 24 ounces per acre Chopper® GEN2™ plus 96 ounces per acre Forestry Garlon® XRT (C24G96), (2) 32 ounces per acre Chopper® GEN2™ plus 48 ounces per acre Forestry Garlon® XRT (C32G48), (3) 48 ounces per acre Chopper® GEN2™ (C48), (4) 96 ounces per acre Forestry Garlon® XRT (G96), and (5) an untreated

control (control). All treatments received 1.25 percent v/v methylated seed oil in 20 gallons of water per acre. A utility task vehicle (UTV) was used to apply the late July site preparation treatments. A boomless sprayer attached to the back of the UTV with two Boominator® 1250 nozzles was used under constant speed and pressure settings to apply the chemical site preparation treatments. Due to the bedding treatment, the UTV could not be used for the September and October application timings. A solo backpack sprayer with a pressure gauge and a 48-inch boom with three TeeJet® 8003 flat fan nozzles was used to apply the September and October application timings. Constant pressure and boom height were maintained to apply 20 gallons of solution per acre. The three application timings during 2014 were July 31, September 18-21, and October 29-30. Select, bare-root (1-0) loblolly pine seedlings were machine planted February 4-7, 2015 at 6 x 12 feet spacing. The HWC application was applied April 29, 2015 as a 4 feet wide band with the planted seedling as the center of the band. Oustar® (63.2 percent active ingredient hexazinone and 11.8 percent sulfometuron methyl) was applied using a Solo backpack sprayer with a pressure regulator at a rate of 10 ounces per acre in 10 gallons of water per acre. This treatment was applied to one-half of a sub-plot in all experimental units (including the no chemical site preparation control treatment). The entire research area received two aerial fertilizer applications (industry protocol) between establishment and an age-4 assessment.

At age 4, within the no HWC internal measurement plots, an average of 43 trees per sub-plot were aluminum tree tagged and nailed, while an average of 45 trees were tagged in the HWC internal measurement plots. Fourth year assessments were conducted during February 2019. Survival was assessed, and measurements included diameter at breast height (DBH) and total height. Volume index per tree (vi) was derived from DBH (inches) and tree heights (feet) (Spurr 1952).

$$vi = DBH^2 \times height$$

Data were analyzed using analysis of variance (ANOVA) as a randomized complete block experimental design with replication and sampling, and a split-plot treatment design. Response variables included survival, DBH, total height, and volume index. Fixed model factors included treatment, application timing, and HWC status (yes or no). Block was the random term in the model. Blocking was used to account for soil drainage differences across the site. Fisher's protected least significant difference test was used for all pairwise comparisons of least-squares means to detect survival and growth differences among treatments. An alpha level of $p=0.05$ was used for all analyses. The binomial distribution was used for the survival analysis. All analyses were conducted in SAS 9.4 using the Proc Mixed procedure (SAS Institute 2012).

RESULTS

Loblolly pine survival results indicated no significant differences ($p=0.081$) among chemical site preparation treatments after 4 years. Survival ranged from 84.4 percent in the control treatment to 95.2 percent in the C48 treatment. Application timing did not significantly affect loblolly pine survival ($p=0.438$). Survival rates ranged from an average of 90.3 percent with the July application timing to 93.1 percent with the September application. The HWC application did significantly affect survival ($p=0.035$), and survival was greater in the no-HWC treatment (93.0 ± 1.9 percent) versus the HWC treatment (91.1 ± 2.1 percent). The chemical site preparation treatment by application timing interaction was not statistically significant ($p=0.599$).

Diameter growth was significantly different ($p=0.012$) among the five chemical site preparation treatments. All four treatments that included chemical site preparation had significantly greater average diameters than the control, but they were not statistically different than each other (table 1). Average diameter was least in the control treatment (2.0 inches) and greatest in the G96 and C24G96 treatments (2.6 inches each). Application timing also was significantly different ($p=0.019$) among treatments (table 2). July application resulted in significantly smaller average loblolly pine diameter at age 4 (2.2 inches) compared to September and October (2.5 inches each) applications. Trees that received the HWC treatment had significantly greater diameters ($p=0.039$, 2.8 ± 0.1 inches) after 4 years compared to the no-HWC treatment (2.2 ± 0.1 inches). The chemical site preparation treatment by application timing interaction

was significant for DBH ($p=0.039$). The control treatment had the smallest average diameter (2.0 inches) while the C24G96 treatment when applied during October had the greatest average diameter (2.8 inches) (fig. 1).

Table 1—Average DBH growth by chemical site preparation treatment at age 4 for the Lower Coastal Plain loblolly pine chemical site preparation rate and application timing study near Egypt, GA

Treatment	Estimate	Standard Error	Letter grouping
	<i>inches</i>		
C24G96	2.6	0.08	a
C32G48	2.4	0.08	a
C48	2.5	0.08	a
G96	2.6	0.07	a
Control	2.0	0.09	b

Note: Treatments with the same letter are not significantly different at the $p=0.05$ level.

Table 2—Average DBH growth by application timing at age 4 for the Lower Coastal Plain loblolly pine chemical site preparation rate and application timing study near Egypt, GA

Month	Estimate	Standard error	Letter grouping
	<i>inches</i>		
July	2.2	0.07	b
September	2.5	0.08	a
October	2.5	0.08	a

Note: Months with the same letter are not significantly different at the $p=0.05$ level.

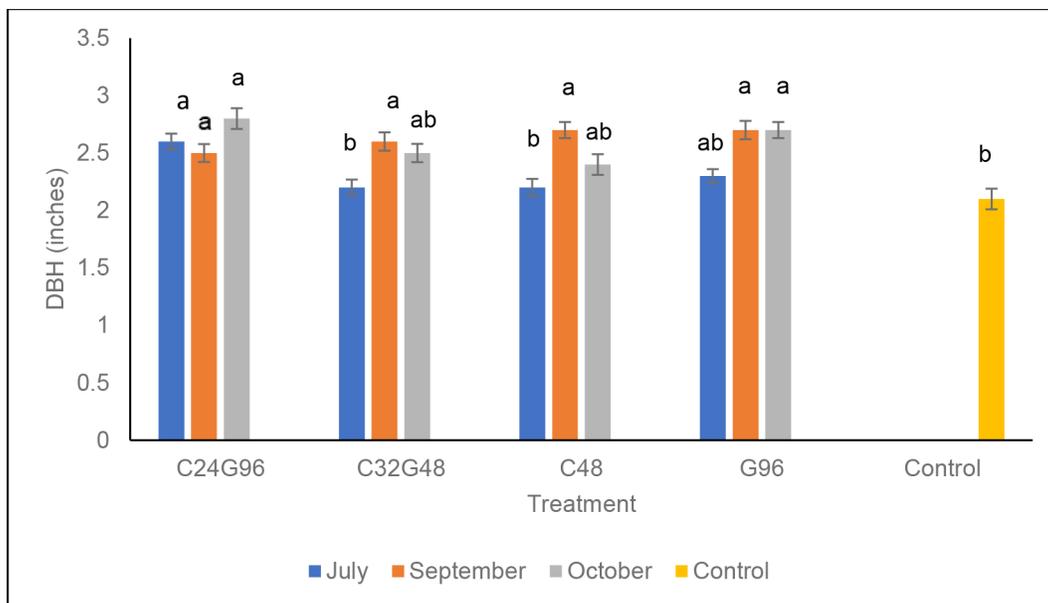


Figure 1—Diameter at breast height means, standard errors, and letter groupings for the statistically significant treatment by month interaction term ($p=0.039$) at age 4 for the Lower Coastal Plain loblolly pine chemical site preparation rate and application timing study near Egypt, GA. Individual treatment and month combinations that do not share a letter are significantly different at the $p=0.05$ level.

Loblolly pine total height was significantly different among the chemical site preparation treatments ($p=0.036$). Average height was greatest in the C24G96 treatment (13.8 feet) and least in the control (11.3 feet) (table 3). Application timing effects on height growth were significant ($p=0.042$). July applications resulted in significantly shorter average height (12.1 feet) than the September application (13.4 feet) (table 4). The addition of HWC resulted ($p<0.001$) in a nearly 3 feet height growth improvement (14.3 feet) over no HWC (11.4 feet). The treatment by application interaction term was significant for loblolly pine height ($p<0.001$). The control treatment had the shortest average heights (11.3 feet), whereas the C24G96 October application had the tallest average height (14.2 feet) (fig. 2).

Table 3—Average total height by chemical site preparation treatment at age 4 for the Lower Coastal Plain loblolly pine chemical site preparation rate and application timing study near Egypt, GA

Treatment	Estimate	Standard error	Letter grouping
	<i>feet</i>		
C24G96	13.8	0.3	a
C32G48	12.7	0.3	ab
C48	13.0	0.3	a
G96	13.5	0.2	a
Control	11.3	0.3	b

Note: Treatments with the same letter are not significantly different at the $p=0.05$ level.

Table 4—Average total height by application timing at age 4 for the Lower Coastal Plain loblolly pine chemical site preparation rate and application timing study near Egypt, GA

Month	Estimate	Standard error	Letter grouping
	<i>feet</i>		
July	12.1	0.2	b
September	13.4	0.3	a
October	13.0	0.3	ab

Note: Months with the same letter are not significantly different at the $p=0.05$ level.

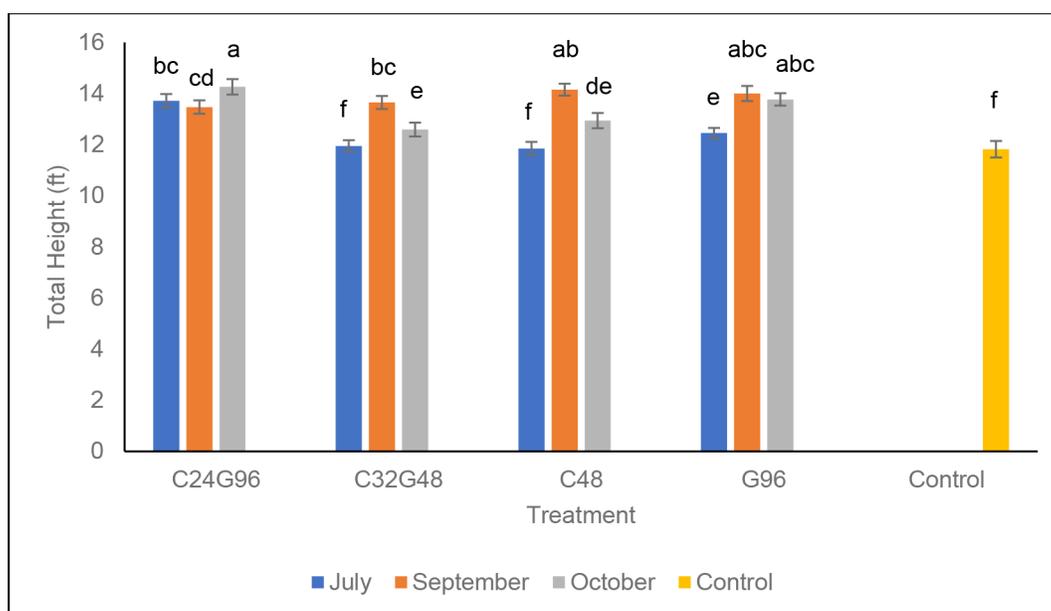


Figure 2—Total height means, standard errors, and letter groupings for the statistically significant treatment by month interaction term ($p<0.001$) at age 4 for the Lower Coastal Plain loblolly pine chemical site preparation rate and application timing study near Egypt, GA. Individual treatment and month combinations that do not share a letter are significantly different at the $p=0.05$ level.

Volume index per tree had similar trends as diameter. Volume index was significantly different ($p=0.014$) among the five chemical site preparation treatments. All four treatments that included chemical site preparation had significantly greater average volume index than the control, but they were not statistically different amongst themselves (table 5). The July application timing had significantly ($p=0.003$) smaller average loblolly pine volume index than September or October applications (table 6). Average volume index for the HWC treatment (133.5) was more than twice as great for the no-HWC treatment (64.0) ($p<0.001$). The treatment by month interaction term was statistically significant ($p=0.014$). The July C48 treatment had the smallest average volume index, and values tended to be low for all chemical site preparation treatments applied during July. Again, the C24G96 treatment applied during October was the early leader in average volume index per tree (fig. 3).

Table 5—Average volume index per tree by chemical site preparation treatment at age 4 for the Lower Coastal Plain loblolly pine chemical site preparation rate and application timing study near Egypt, GA

Treatment	Estimate	Standard error	Letter grouping
C24G96	122.4	7.5	a
C32G48	98.9	6.2	a
C48	99.5	6.5	a
G96	113.9	6.1	a
Control	58.8	5.8	b

Note: Treatments with the same letter are not significantly different at the $p=0.05$ level.

Table 6—Average volume index per tree by application timing at age 4 for the Lower Coastal Plain loblolly pine chemical site preparation rate and application timing study near Egypt, GA

Month	Estimate	Standard error	Letter grouping
July	76.0	5.3	a
September	111.6	7.2	b
October	108.6	7.3	b

Note: Months with the same letter are not significantly different at the $p=0.05$ level.

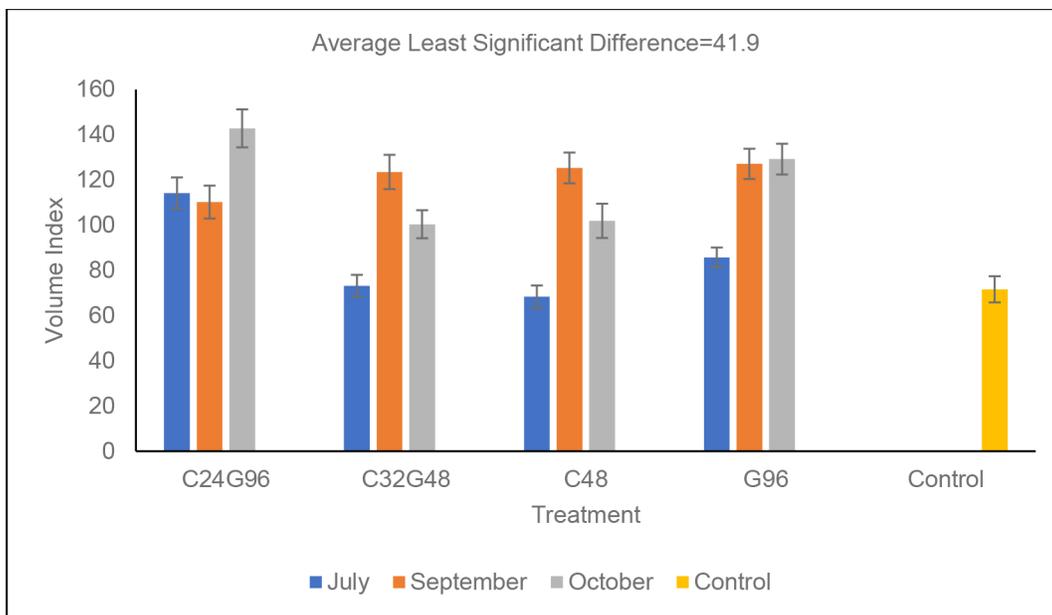


Figure 3—Volume index per tree means, standard errors, and letter groupings for the statistically significant treatment by month interaction term ($p=0.014$) at age 4 for the Lower Coastal Plain loblolly pine chemical site preparation rate and application timing study near Egypt, GA. Individual treatment and month combinations that differ by more than a value of 41.9 are significantly different at the $p=0.05$ level.

DISCUSSION AND CONCLUSIONS

Loblolly pine survival rates were excellent through 4 years. Chemical site preparation improved survival rates by 7 to nearly 11 percent over the control, but these differences were not statistically significant among treatments. Other studies have reported similar survival trends for young loblolly pine plantations. Minogue and Quicke (1999) tested three rates of 2-pound ae imazapyr, two rates of 2-pound ae imazapyr and glyphosate, two rates of 2-pound ae imazapyr and triclopyr and one rate of 4-pound ae imazapyr at sites throughout the Piedmont and Coastal Plain regions. Two-years post application, they noted no loblolly pine survival differences among treatments, but survival rates were less than this study (survival ranged from 63 to 70 percent). Application timing did not impact survival rates in this study, unlike another Chopper® GEN2™ timing study (Grogan and others 2015) that tested early July, mid-August, and late September application timings with one application rate (32 ounces per acre) on planted loblolly pine performance. At two of the three sites in that study, the average mid-August survival rate was less than July or September applications at age 5. Other studies have suggested that hardwood and shrub competition, which are the focus of control with chemical site preparation, may take longer to impact pine stand survival and growth than herbaceous weeds as herbaceous weeds typically affect pine plantations from establishment to potentially age 5 or 6 (Minogue and others 1991, Zutter and others 1995). This study has likely not reached an age where site preparation survival differences may become more apparent. The significant difference in HWC versus no HWC on survival could be explained by low weed pressure and above average first year precipitation (University of Georgia Weather Network 2021).

Diameter, height and volume index per tree trends were similar across the five site preparation treatments. In general, growth was greater with the four chemical site preparation treatments than the control. By age 4, no chemical site preparation treatments had differentiated in diameter growth from one another, but height growth associated with the C32G48 treatment was statistically similar to the control. Similar growth results were reported for 2-year-old, planted loblolly pine stands at three sites in the Piedmont and Coastal Plain regions. Eight treatments containing a 4-pound ae imazapyr alone or in tank mixes showed no significant differences in loblolly pine growth (Harrington and others 1998). Application timing did significantly affect diameter, height and volume index. The July application resulted in significantly less growth than September or October application timings. This result may originate from the timing of shearing (early July) and the stage of vegetation development when the late July chemical

site preparation application was completed. Lauer and Quicke (2006) suggested that shearing and other forms of mechanical site preparation that sever competing vegetation stems and roots and lack of development of resprouts for several weeks following mechanical site preparation may limit herbicide uptake when herbicide applications are made soon after these types of mechanical treatments. The bedding treatment in early September may have also prevented optimal imazapyr uptake by competing vegetation through the soil because bedding was completed within 40 days after the July chemical site preparation treatment. Lauer and Quicke (2006) stated that 2-year pine volume index is not impacted by competing vegetation if bedding is completed about 3 or more weeks prior to chemical site preparation. This may explain why growth associated with the September application timing was not impacted. The treatment by timing interaction term was significant for all three growth variables. The October timing of the C24G96 treatment resulted in the best growth across all treatment and timing combinations. It is likely given sufficient precipitation during this period, that competing vegetation was more developed by late October following the two mechanical herbicide treatments in early July and early September. Improved plant uptake of the herbicides (especially triclopyr which has limited soil activity) would have been more likely with greater plant development (Lauer and Quicke 2006).

The impacts of HWC on growth were significant and volume index growth improved by more than two-fold over no HWC. Improvements in loblolly pine volume index with Chopper® Gen2™ site preparation and post-plant HWC application versus Chopper® Gen2™ without HWC were similar (greater than two-fold volume index improvement) in a study by Lauer and Quicke (2013). Survival and growth improvements with HWC tend to increase with greater weed pressure and dryer first spring conditions.

Overall, planted loblolly pine responded well to the Chopper® Gen2™ and Forestry Garlon® XRT chemical site preparation treatments and application timings utilized in this Lower Coastal Plain study. Growth was significantly improved over an untreated control with all four treatments tested. Chemical site preparation completed between two mechanical site preparation treatments separated by 2 months may not be optimal for herbicide control of competing vegetation and future pine growth. First-year HWC should be used to improve pine growth as volume gains can be large (two-fold) after 4 years.

ACKNOWLEDGMENTS

The authors would like to thank Rayonier and Corteva Agriscience for their support of this project. Special thanks also go to Travis Rogers, Sam Ingram, Cassandra Waldrop, and Ben Cantrell for their contributions to the project.

LITERATURE CITED

- BASF Corporation. 2021. Chopper® Gen2™ Herbicide. <http://www.cdms.net/ldat/ld86L005.pdf>. [Date accessed: March 25, 2022].
- Dickens, E.D.; Minogue, P.; Clabo, D.C.; Moorhead, D.J. 2020. A guide to using imazapyr for chemical site preparation in southern pine plantation establishment. WSFR-20-95B. Athens, GA: University of Georgia, Warnell School of Forestry and Natural Resources. 8 p.
- Dow AgroSciences. 2008. Forestry Garlon® XRT. <http://www.cdms.net/ldat/ld7NS003.pdf>. [Date accessed: March 24, 2022].
- Ezell, A.W.; Yeiser, J.L.; Lauer, D.K.; Quicke, H.E. 2013. Effect of application timing on efficacy of site preparation treatments using Chopper® Gen2™. In: Guldin, J.M., ed. Proceedings of the 15th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-GTR-175. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 219–221.
- Griffith G.E.; Omernik J.M.; Comstock J.A.; Lawrence, F.T. 2001. Ecoregions of Georgia. Corvallis, OR: U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory. 48 p. (map scale 1:1,1,500,000).
- Grogan, J.; Ezell, A.; Yeiser, J.; Lauer, D. 2015. First- and fifth-year results of a Chopper Gen2 Site Preparation Timing Trial. In: Holley, A.G.; Connor, K.F.; Haywood, J.D., eds. Proceedings of the 17th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-203. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 263–264.
- Harrington, T.B.; Minogue, P.J.; Lauer, D.K.; Ezell, A.W. 1998. Two-year development of southern pine seedlings and associated vegetation following spray-and-burn site preparation with imazapyr alone or in mixture with other herbicides. *New Forests*. 15: 89–106.
- Lauer, D.K.; Quicke, H.E. 2006. Timing of Chopper® herbicide site preparation on bedded sites. *Southern Journal of Applied Forestry*. 30(2): 92–101.
- Lauer, D.K.; Quicke, H.E. 2013. Pine growth following chemical site preparation and post-plant herbaceous weed control compared to chemical site preparation only. In: Guldin, J.M., ed. Proceedings of the 15th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-GTR-175. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 227–229.
- Lowery, R.F.; Gjerstad, D.H. 1991. Chemical and mechanical site preparation. In: Duryea M.L.; Daugherty P.M., eds. *Forest regeneration manual*. Boston, MA: Kluwer Academic Publishing: 251–261.
- Minogue, P.J.; Cantrell R.L.; Griswold H.C. 1991. Vegetation management after plantation establishment. In: Duryea M.L.; Daugherty P.M., eds. *Forest regeneration manual*. Boston, MA: Kluwer Academic Publishing: 335–358.
- Minogue, P.J.; Quicke, H.E. 1999. Early-season forest site preparation with imazapyr and combinations of imazapyr and glyphosate or triclopyr in oil emulsion carrier: second year response for planted pine and associated woody and herbaceous vegetation. In: Haywood, J.D., ed. Proceedings of the 10th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 307–311.
- SAS Institute. 2012. SAS/STAT user's guide. Version 9.4. Cary, NC: SAS Institute. 824 p.
- Shiver, B.D.; Knowe, S.A.; Edwards, M.B.; Kline, W.N. 1991. Comparison of herbicide treatments for controlling common Coastal Plain Flatwoods species. *Southern Journal of Applied Forestry*. 15(4): 187–193.
- Sowell, C. 2015. Natural resources conservation service soil mapper. Statesboro, GA: Statesboro Service Center. <https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>. [Date accessed: April 2015].
- Spurr, S.H. 1952. *Forest inventory*. New York: The Ronald Press Company. 476 p.
- Tiarks, A.E.; Haywood, J.D. 1986. Pinus taeda L. response to fertilization, herbaceous plant control, and woody competition control. *Forest Ecology and Management*. 14: 103–112.
- University of Georgia Weather Network. 2021. Bulloch County Board of Education Maintenance and Transportation Annex. Historical Data for 2015. <http://www.georgiaweather.net/?variable=HI&site=STATES>. [Date accessed: March 24, 2022].
- Zutter, B.R.; Miller, J.H.; Zedaker, S.M. [and others]. 1995. Response of loblolly pine plantations to woody and herbaceous control—eighth-year results of the region-wide study—COMPROJECT. In: Edwards, M.B., ed. Proceedings of the eighth biennial southern silvicultural research project. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 75–80.

FERTILIZATION AND POST-DROUGHT RECOVERY GROWTH HELP COMPENSATE FOR 9 YEARS OF PRECIPITATION REDUCTION IN A MID-ROTATION *PINUS TAEDA* PLANTATION IN THE WESTERN GULF REGION, USA

Noah T. Shephard, Omkar Joshi, Cassandra R. Meek, and Rodney E. Will

EXTENDED ABSTRACT

Climate change induced drought will likely decrease forest growth (Vose and others 2018). Reduced soil moisture typically decreases aboveground stem production in loblolly pine (*Pinus taeda*) plantations (Shephard and others 2021a). Drought effects on loblolly pine production is of concern due to its commercial importance in the Southern United States. Anticipated drought effects are likely to occur first on loblolly pine's drier, western commercial edge in Texas and Oklahoma. Silvicultural practices like fertilization (Maggard and others 2017) and thinning (D'Amato and others 2013) could counterbalance decreased stem production from drought. In prior studies, interactions of throughfall reduction and fertilization (Maggard and others 2017) and fertilization and thinning (Sayer and others 2004) were examined in loblolly pine. The three-way interaction of throughfall reduction and fertilization and thinning has yet to be studied in North American forestry.

To understand if intensive silviculture could remediate reduced soil moisture, we studied a mid-rotation loblolly pine stand in southeastern Oklahoma from 2012 (age 5) to 2020 (age 13). A 2 x 2 factorial of 30 percent throughfall reduction and fertilization was initiated in the spring of 2012 and replicated four times (16 plots). We hypothesized that (1) throughfall reduction would reduce volume production, (2) mid-rotation fertilization would compensate for throughfall reduction, in that ambient plots would have similar volume production as would fertilization and throughfall reduced plots, and (3) the negative effects of throughfall reduction would be less for thinned plots.

Throughfall was captured by excluder troughs that covered approximately 30 percent of each plot and diverted throughfall off-plot. Fertilizer was hand applied at 224 kg N ha⁻¹, 28 kg P ha⁻¹, and 56 kg K ha⁻¹, plus micronutrients (Will and others 2015). A split-plot treatment of thinning was applied to each plot in the spring of 2017 (age 10, 32 plots) via girdling and an injection of herbicide above the girdle. At this time, fertilizer treatments were reapplied. Diameter at breast height (DBH) and height were measured at the end of each growing season from 2012 to 2020 (age 5 to age 13).

Author Information: Noah T. Shephard, Graduate Student, Oklahoma State University, Stillwater, OK 74078; Omkar Joshi, Assistant Professor, Oklahoma State University, Stillwater, OK 74078; Cassandra R. Meek, Research Associate, Oklahoma State University, Idabel, OK 74745; and Rodney E. Will, Professor, Oklahoma State University, Stillwater, OK 74074.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

From 2011 to 2013, the site experienced drought conditions and precipitation was below the normal 1300 mm: 1207 mm in 2011, 1023 mm in 2012, and 1260 mm in 2013. Precipitation was close to average in 2014, above average from 2015 to 2016 and 2019 to 2020, and mild drought occurred in 2017. The net effect after 9 years of treatment (age 13) was that fertilization increased DBH by 4 percent ($p=0.004$) and thinning increased DBH by 7 percent ($p<0.0001$). By age 13 only throughfall reduction significantly (-4 percent, $p=0.01$) decreased height. Related to height, throughfall reduction decreased site index at base age 25 from 20.9 m (ambient throughfall) to 20.4 m (throughfall reduction). The DBH and height trends were reflected in total gross volume current annual increment (CAI). Throughfall reduction decreased total CAI by 7 percent ($p=0.03$), fertilization increased total CAI by 8 percent ($p=0.02$) and thinning decreased total CAI by 17 percent ($p<0.0001$). Treatments were generally dependent on annual conditions. Throughfall reduction usually had stronger negative effects on CAI in dry years and following dry years (2013, 2014, 2018), and fertilization had stronger positive CAI effects immediately following fertilization (2012, 2017). Thinning did not significantly interact with throughfall reduction or fertilization for height, diameter, or CAI. Somewhat surprisingly, throughfall reduced plots showed greater relative basal area growth once wetter conditions returned following periods of meteorological drought than non-throughfall reduced plots (Shephard and others 2021a). This increased the basal area increment in the drought plots and likely indicates “recovery growth”.

Similar to other studies (Maggard and others 2016, 2017), our two hypotheses that drought would decrease CAI and mid-rotation fertilization would counteract reduced soil moisture were supported. Our study emphasizes the importance of treatment timing on stand production. After 9 years of soil moisture reduction, throughfall reduction decreased the height-diameter relationships. Throughfall reduction showed a modest 7-percent decrease in volume and 0.5 m reduction in site index. Water stress has changed other DBH-height relationships of tree species as well (Fortin and others 2018). This production decline could increase rotation age and decrease landowner profits (Shephard and others 2021b).

Fertilization results mimicked previous studies (Maggard and others 2017) and showed greater increases in diameter than height (Allen and others 2005). Positive fertilization effects on CAI were realized shortly after application and only affected DBH. Throughfall and fertilization treatments were additive in terms of CAI (i.e., no interactions) and opposed one another: fertilization $+7$ percent, throughfall reduction -8 percent.

Our third hypothesis that thinning would mitigate throughfall reduction was not supported. However, increased relative basal area increment occurred in throughfall reduced plots post-meteorological drought, termed recovery growth, and may indicate resilience to drought conditions, perhaps due to increased carbohydrate storage during dry conditions (Hallgren and others 1991) that is then used for growth during wetter periods.

Our study showed possible production outcomes under a moisture-limited climate. Throughfall reduction marginally reduced, -7 percent, volume production. Mid-rotation fertilization compensated for dry conditions. Throughfall reduced plots showed recovery growth when wet conditions returned. Results from our study provide support for continued site-intensive silviculture in a future that is likely to be drier.

ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Agriculture McIntire Stennis projects (OKLO3042, OKL0 2929), the Oklahoma Agricultural Experiment Station, and the Department of Natural Resource Ecology and Management at Oklahoma State University. Special thanks to the gracious support of Mr. Ed Hurliman for the use of his property to support the Broken Bow, OK PINEMAP Tier III site. Funding for installation and

measurement of the study site (2012-2017) was provided by the Pine Integrated Network: Education, Mitigation, and Adaptation Project (PINEMAP), a Coordinated Agriculture Project funded by the U.S. Department of Agriculture National Institute of Food and Agriculture, award number 2011-68002-30185. Thanks to Casey Meek and the researchers at the Kiamichi Forest Research Station for the installation and measurement of the study site.

REFERENCES

- Allen, C.B.; Will, R.E.; Jacobson, M.A. 2005. Production efficiency and radiation use efficiency of four tree species receiving irrigation and fertilization. *Forest Science*. 51(6): 556–569.
- D’Amato, A.W.; Bradford, J.B.; Fraver, S.; Palik, B.J. 2013. Effects of thinning on drought vulnerability and climate response in north temperate forest ecosystems. *Ecological Applications*. 23(8): 1735–1742.
- Fortin, M.; Van Couwenberghe, R.; Perez, V.; Piedallu, C. 2018. Evidence of climate effects on the height-diameter relationships of tree species. *Annals of Forest Science*. 76(1): 1–20.
- Hallgren, S.W.; Tauer, C.G.; Lock, J.E. 1991. Fine root carbohydrate dynamics of loblolly pine seedlings grown under contrasting levels of soil moisture. *Forest Science*. 37(3): 766–780.
- Maggard, A.O.; Will, R.E.; Wilson, D.S. [and others]. 2017. Fertilization can compensate for decreased water availability by increasing the efficiency of stem volume production per unit of leaf area for loblolly pine (*Pinus taeda*) stands. *Canadian Journal of Forestry*. 47(4): 445–457.
- Maggard, A.O.; Will, R.E.; Wilson, D.S. [and others]. 2016. Fertilization reduced stomatal conductance but not photosynthesis of *Pinus taeda* which compensated for lower water availability in regards to growth. *Forest Ecology and Management*. 381: 37–47.
- Sayer, M.S.; Goelz, J.; Chambers, J.L. [and others]. 2004. Long-term trends in loblolly pine productivity and stand characteristics in response to thinning and fertilization in the West Gulf region. *Forest Ecology and Management*. 192(1): 71–96.
- Shephard, N.T.; Joshi, O.; Meek, C.R.; Will, R.E. 2021a. Long-term growth effects of simulated-drought, mid-rotation fertilization, and thinning on a loblolly pine plantation in southeastern Oklahoma, USA. *Forest Ecology and Management*. 494: 119–323.
- Shephard, N.T.; Joshi, O.; Susaeta, A.; Will, R.E. 2021b. A stand level application of efficiency analysis to understand efficacy of fertilization and thinning with drought in a loblolly pine plantation. *Forest Ecology and Management*. 482: 1–10.
- Vose, J.M.; Peterson, D.L.; Domke, G.M. [and others]. 2018. Forests. In: Reidmiller, D.R.; Avery, C.W.; Easterling, D.R., eds. *Impacts, risks, and adaptation in the United States: fourth national climate assessment, Volume II*. Washington, DC: U.S. Global Change Research Program: 232–267.
- Will, R.; Fox, T.; Akers, M. [and others]. 2015. A range-wide experiment to investigate nutrient and soil moisture interactions in loblolly pine plantations. *Forests*. 6(12): 1–15.

CONTROL OF NATURAL PINES USING SITE PREPARATION MIXES WITH IMAZAPYR, GLYPHOSATE, SAFLUFENACIL, BAS #1, AND BAS #2

A. Brady Self and Andrew. W. Ezell

ABSTRACT

Control of natural pine continues to be problematic in forestry site preparation efforts. Thirteen treatments were used in a study testing efficacy of two numbered BASF products (BAS #1 and BAS #2) for natural pine control in combinations with imazapyr and glyphosate. This study was established on a cutover forestry site in northeast Mississippi on August 31, 2018. Natural pine and hardwood stems were recorded prior to treatment applications and again at 14 days after treatment (DAT), 56DAT, 90DAT, and 1 year (YR). Results clearly indicate that addition of glyphosate is necessary for adequate control of natural pines and BAS #1 or BAS #2 serve to enhance glyphosate efficacy. In addition, neither product provided satisfactory levels of natural pine control in stand-alone treatments.

INTRODUCTION

Chemical site preparation is the largest end use of herbicides in forest management efforts. It is also one of the greatest expenses in plantation establishment. Consequently, cost efficacy is always a concern, and any new herbicide chemistry creates interest. The commonly applied mixture of imazapyr and glyphosate provides good woody and herbaceous control in chemical site preparation tank mixes, but natural pine control continues to be problematic when using these applications.

Interest in increasing efficacy of standard site preparation treatments has resulted in research using several compounds designed to increase efficacy of these treatments on natural pine germinants. Herbicides containing carfentrazone, aminocyclopyrachlor, saflufenacil, (Ezell and Yeiser 2010, Ezell and others 2012a, Ezell and others 2012b) and others have provided various results regarding pine control. However, the need for a cost-effective efficacy enhancing additive remains with product development and continued testing.

While saflufenacil (Detail®) has been recognized for enhancing “burn down” effects in agriculture and forestry for years, BASF continues to develop new herbicides to serve as glyphosate enhancers in vegetation management. Subsequently, two new proprietary compounds (henceforth called BAS #1 and BAS #2) have shown promise in this role. The objective of this study was to evaluate the efficacy of site preparation tank mixtures containing these two compounds in natural pine control efforts.

MATERIALS AND METHODS

Study Site

The study was installed on Mississippi State University property near Starkville, MS. Adequate numbers of pine germinants could not be found in a cutover setting in time for protocol installation, so a powerline right-of-way was utilized. The site had not been mown or chemically treated for 2 years prior to study installation. Soil series is Mathiston silt loam with an average pH of 5.3. Loblolly pine (*Pinus taeda*) was the dominant woody species onsite with densities ranging between 3,200 and 14,000 (averaging 6,500) seedlings per acre. These stems ranged between 6 inches and 4 feet tall but averaged 1 foot in height overall. Oaks (*Quercus* spp.), sweetgum (*Liquidambar styraciflua*), red maple (*Acer rubrum*), and green ash (*Fraxinus pennsylvanica*) comprised a minor vegetative component.

Treatments

A complete list of treatments is found in table 1. Plots were rectangular areas measuring 25 by 50 feet, marked at each end by vinyl pin flags with string stretched along the plot midline between pin flags. Treatments were applied using a CO₂-powered backpack sprayer with pole extension and a KLC-9 spray tip to simulate aerial spraying. Total spray volume was 15 gallons per acre and all treatments were applied August 31, 2018.

Author Information: A. Brady Self, Associate Extension Professor, Mississippi State University, Grenada, MS 38901; and Andrew W. Ezell, Professor Emeritus, Mississippi State University, Mississippi State, MS 39762.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

Table 1—List of treatments applied in 2018 BASF natural pine control study

Treatment number	Herbicide and rate per acre
1	Control
2	Chopper Gen2 ^a (48 ounces) + Velocity ^b (2 ounces) + Elite Pinnacle ^c (19 ounces)
3	Chopper Gen2 (48 ounces) + BAS #1 (2.74 ounces) + Velocity (2 ounces) + Elite Pinnacle (19 ounces)
4	Chopper Gen2 (48 ounces) + Detail ^d (2 ounces) + Velocity (2 ounces) + Elite Pinnacle (19 ounces)
5	Chopper Gen2 (48 ounces) + BAS #2 (2.74 ounces) + Velocity (2 ounces) + Elite Pinnacle (19 ounces)
6	Chopper Gen2 (48 ounces) + BAS #2 (5.48 ounces) + Velocity (2 ounces) + Elite Pinnacle (19 ounces)
7	Chopper Gen2 (48 ounces) + Accord Concentrate ^e (4 quarts) + Velocity (2 ounces) + Elite Pinnacle (19 ounces)
8	Chopper Gen2 (48 ounces) + BAS #1 (2.74 ounces) + Accord Concentrate (4 quarts) + Velocity (2 ounces) + Elite Pinnacle (19 ounces)
9	Chopper Gen2 (48 ounces) + Detail (2 ounces) + Accord Concentrate (4 quarts) + Velocity (2 ounces) + Elite Pinnacle (19 ounces)
10	Chopper Gen2 (48 ounces) + BAS #2 (2.74 ounces) + Accord Concentrate (4 quarts) + Velocity (2 ounces) + Elite Pinnacle (19 ounces)
11	Chopper Gen2 (48 ounces) + BAS #2 (5.48 ounces) + Accord Concentrate (4 quarts) + Velocity (2 ounces) + Elite Pinnacle (19 ounces)
12	Chopper Gen2 (48 ounces) + Detail (2 ounces) + BAS #1 (1.37 ounces) + Accord Concentrate (4 quarts) + Velocity (2 ounces) + Elite Pinnacle (19 ounces)
13	Accord Concentrate (4 quarts) + Velocity (2 ounces) + Elite Pinnacle (19 ounces)

^a Imazapyr.

^b Bispyribac sodium.

^c Surfactant.

^d Saflufenacil.

^e Glyphosate (5.4 pounds active ingredient per gallon or 4 pounds acid equivalent).

Evaluations

Vegetation assessments were completed on a sample area 10 by 50 feet centered in the treatment plot. Prior to treatment, pine seedlings were recorded by 1-foot height class. Pine control was evaluated at 14 DAT, 56DAT, 90DAT, and finally, at 1 year.

Experimental Design and Data Analysis

Treatments were replicated three times in a randomized complete block design. Cumulative heights were calculated by multiplying the number of stems by respective height classes. Percent brownout averages were calculated and are presented herein. Percent values were arcsine transformed, but for ease of interpretation, actual values are presented. Means separation was performed using Duncan's New Multiple Range Test at $\alpha = 0.05$.

RESULTS

Average brownout estimates are presented in table 2. As expected, 14 DAT brownout was appreciably less than brownout at 56 DAT. While statistical testing was not performed on brownout averages at 14 DAT, treatment differences were already separating from those lacking glyphosates as part of the application. By 56 DAT, treatments containing glyphosate (Treatments 7-13) all exhibited similar brownout rates ranging between 89.7 and 100 percent. This trend continued through both 90 DAT and 1 year after treatment (YAT) evaluations with a clear separation of treatment efficacy exhibited between plots with and without glyphosate as a part of their respective tank mixes.

Table 2—Percent brownout averages of pine seedlings in 2018 BASF natural pine control

Treatment	Percent brownout averages			
	14 DAT ^a	56 DAT	90 DAT	1 YAT ^b
1	0.0	0.0a ^c	0.7a	0.0a
2	3.7	3.7a	8.7a	0.0a
3	4.3	4.3a	2.3a	0.0a
4	6.7	7.3a	13.3ab	11.1b
5	6.7	8.3a	6.7a	0.0a
6	25.0	25.0b	21.7b	0.0a
7	86.7	98.3c	100.0c	100.0c
8	71.7	100.0c	100.0c	100.0c
9	81.7	100.0c	100.0c	100.0c
10	93.3	100.0c	100.0c	99.6c
11	76.7	99.7c	100.0c	99.7c
12	90.0	99.3c	100.0c	100.0c
13	10.0	89.7c	86.7c	99.6c

^a Days after treatment.

^b Year after treatment.

^c Values within a column followed by the same letter do not differ at $\alpha = 0.05$.

Imazapyr is not expected to provide loblolly pine control, and throughout the duration of this study treatments not containing glyphosate (Treatments 1-6) all exhibited levels of control for pine seedlings that would be considered unsatisfactory in commercial operations. Only treatments containing glyphosate (Treatments 7-13, all approaching 100.0 percent at 1 YAT) provided control that would be acceptable.

Earlier work utilizing Detail[®] (saflufenacil) has shown that addition of this glyphosate enhancer can prove beneficial (Self and Ezell 2019). The addition of additives (Detail[®], BAS #1, and BAS #2) did serve to increase early efficacy in some treatments not containing glyphosate (especially Treatment 6 with the higher rate of BAS #2) in this study. However, by the time 1 YAT evaluations were performed, brownout

percentages had dropped to 0 percent in all treatments except Treatment 4 (11.1 percent brownout).

Typically, high levels of pine control using glyphosate treatment alone is not expected and the degree of brownout observed in Treatment 13 (99.6 percent at 1 YAT) was somewhat unexpected. An explanation for this high level of control can be found when considering the nature of vegetation present on this site. This right-of-way has been well maintained over the last two decades and hardwood stems were limited. The shielding effect of hardwood stems, common on cutover sites, was not present and resulted in a higher-than-normal level of pine seedling exposure to applications.

SUMMARY

Chemical site preparation will continue to be utilized in a large percentage of pine plantation establishment efforts across the South. As we continue to develop genetically advanced planting stock, control of natural pine will continue to increase in importance. Currently prescribed site preparation mixtures vary in pine control efficacy and a desire to increase control will continue to drive additional research in the area. Both numbered compounds and Detail' increased glyphosate effectiveness; however, a need for two additives is not warranted by the results of this study. Finally, using currently tested products and product mixtures, if glyphosate is not used, pine control will not be satisfactory in site-preparation efforts.

LITERATURE CITED

- Ezell, A.W.; Turner, R.; Yeiser, J.L. 2012a. Use of aminocyclopyrachlor for forestry site preparation in the Southeastern U.S. In: Butnor, J.R., ed. Proceedings of the 16th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-156. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 120–121.
- Ezell, A.W.; Yeiser, J.; Minogue, P. 2012b. Efficacy of treatments using MAT-28 for pine site preparation. In: Butnor, J.R., ed. Proceedings of the 16th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-156. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 117–119.
- Ezell, A.W.; Yeiser, J. 2010. Use of carfentrazone for control of natural pine in forestry site preparation areas. In: Stanturf, J.A., ed. Proceedings of the 14th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-121. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 125–127.
- Self, A.B.; Ezell, A.W. 2019. Control of natural pines with a mix of imazapyr, glyphosate, and saflufenacil. In: proceedings of the 72nd annual meeting of the Southern Weed Science Society. Oklahoma City, OK: Southern Weed Science Society: 72: 197.

RUSSELL R. REYNOLDS, PIONEERING FOREST SERVICE SILVICULTURE RESEARCHER

Don C. Bragg



Figure 1—Russell Reynolds, 1962 (USDA Forest Service photo by Dan Todd).

EXTENDED ABSTRACT

Russell Roy Reynolds (fig. 1) was a researcher, experimental forest manager, and project leader with the Forest Service, U.S. Department of Agriculture, Southern Forest Experiment Station (SOFES) between 1930 and 1969. Reynolds was born on December 21, 1906 near Howard City, MI, and would later receive bachelor's and master's degrees in forestry from the University of Michigan (in 1929 and 1930, respectively). Shortly after completing graduate school, Reynolds accepted a junior forester position with the SOFES and reported to New Orleans, LA, in July of 1930.

As a researcher with the SOFES, Reynolds worked on forest operations and economics studies with various companies, including the Ozark-Badger and Crossett lumber

Author Information: Don C. Bragg, Project Leader and Research Forester, U.S. Department of Agriculture, Forest Service, Southern Research Station, Monticello, AR 71656.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

companies. It was his work with the Crossett Lumber Company (CLC) in 1932 and 1933 that led to Reynolds' big career opportunity. The CLC, impressed with Reynolds, offered the Forest Service 1,680 acres of second-growth timber in Ashley County, Arkansas, for an experimental forest. By late 1933, Reynolds and A.E. Wackerman had located a suitable parcel of land, and Reynolds began developing the facility and crafting a research program (Reynolds 1980). With few permanent staff, dependent on relief workers, and limited by budgets reduced by the Great Depression, Reynolds oversaw the construction of an impressive facility and installed studies on uneven-aged silviculture (UEAS) on the newly christened Crossett Experimental Forest (CEF).

From some of his earliest work on the efficacy of using trucks for logging to the improvement of silviculture in southern pines, Reynolds focused on practical and low-cost solutions for foresters and landowners. His signature research was on the adaptation of UEAS for loblolly (*Pinus taeda*) and shortleaf (*P. echinata*) pine-dominated stands of natural origin. Most renowned of these were the Good and Poor Farm Forestry Forties on the CEF. These roughly 40-acre parcels were established in 1937 to help foresters and landowners see the value of good forestry practices; since then, these compartments have kept their stand structure and still produce high quality wood. To achieve this, Reynolds adapted Swiss forester Henri Biolley's approach to UEAS for the shade-intolerant loblolly and shortleaf pines, following an approach he coined "volume guided diameter limit" cutting (Reynolds 1980).

Reynolds' talents included making this UEAS system known far and wide, which helped earn him Progressive Farmer's 1959 Man of the Year Award. With a pragmatic, hands-on, landowner-focused approach to his teaching and extension efforts, Reynolds developed a well-earned reputation as an educator and advocate for the practice of forestry. In addition, Reynolds also published many reader-friendly articles, gave lectures, and provided other consultations. During his tenure, the CEF hosted thousands of forestry students, professional foresters, landowners, researchers, and policymakers, and Reynolds provided many of those workshops and tours. For instance, the Good and Poor Farm Forestry Forties demonstration areas became world-renowned silvicultural tour stops, thanks in part to the meticulous recordkeeping of Reynolds. His documentation of his work in these compartments still provide valuable information used today, such as a recent article in the *Swiss Forestry Journal* (Guldin and others 2017).

A big personality, over the years Reynolds sometimes clashed with other prominent researchers, such as Yale Professor H.H. Chapman and SOFES scientist Philip Wakeley. However, he retained their respect, as can be seen in the following quote by Wakeley (Wakeley and Barnett 2016, p. 97):

Despite what I consider its long run with only half its cylinders firing—and the poorer half at that!—there is no denying the immense impetus that the Crossett Experimental Forest, under Russ Reynolds' direction, has given to both the [SOFES] and to technical forestry throughout the South.

While Reynolds did not favor even-aged silviculture, plantations, or prescribed fire, he supported the work of others that did and even facilitated those research efforts on the CEF. For example, the CEF was one of the first locations in the SOFES to conduct forest genetics and tree improvement, a productive effort that continued until several years after Reynolds' retirement (Bragg and others 2016, Wakeley and Barnett 2016).

Outside of his duties with the SOFES, Reynolds was active in the local community, worked with the Society of American Foresters (SAF), supported the establishment of a forestry degree program at Arkansas A&M College, and then served years as an advisor to Arkansas A&M. After retiring, Reynolds teamed up with some like-minded colleagues to continue advocating for UEAS (Reynolds 1974). Reynolds had been steered by the

Station to retirement as the agency shifted away from UEAS as a management tool in southern pines. After Reynolds' 1969 retirement, the SOFES closed the CEF in 1974. Years of pressure from Georgia-Pacific and Reynolds (amongst others) led to the reopening of the CEF in 1979. Shortly thereafter, Reynolds published his account of the early days of the development of UEAS in southern Arkansas in his "Crossett Story" (Reynolds 1980).

By his death on August 1, 1986, Reynolds had contributed approximately 175 publications and hundreds of presentations. In addition to numerous local and regional recognitions, his more than 50 years of SAF membership earned him a Golden Member Award and Fellow status in the Society. In 1995, Reynolds was posthumously elected to the inaugural class of the Arkansas Foresters Hall of Fame and in August 2021 he was also inducted into the Arkansas Agriculture Hall of Fame. In summary, Russ Reynolds was a true pioneer in silviculture, a practical economist, a tireless promoter of UEAS, an advocate for good forestry of all types, a skilled extension specialist, a highly capable administrator, and a Forest Service legacy!

LITERATURE CITED

- Bragg, D.C.; Riddle, J.; Adams, J.; Guldin, J.M. 2016. The Crossett Experimental Forest's contributions to the southern pine improvement programs. In: Adams, J., ed. Proceedings of the 33rd southern forest tree improvement conference; 8–11 June 2015, Hot Springs, AR. Ruston, LA: Southern Forest Tree Improvement Committee: 40–50. <http://www.sftic.org>. [Date accessed: April 29, 2022].
- Guldin, J.M.; Bragg, D.C.; Zingg, A. 2017. Plentern mit Kiefern—Ergebnisse aus den USA [Plentering in pines—outcomes from the USA]. *Schweizerische Zeitschrift für Forstwesen*. *Swiss Forestry Journal*. 168(2): 75–83.
- Reynolds, R.R. 1974. Selective timber management—its role. *Forest Farmer*. 33(5): 6–7, 12.
- Reynolds, R.R. 1980. The Crossett story: the beginnings of forestry in southern Arkansas and northern Louisiana. Gen. Tech. Rep. SO-32. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 40 p.
- Wakeley, P.C.; Barnett, J.P. 2016. Early research in the South: a personal history. Gen. Tech. Rep. SRS-137. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 159 p.

FIRST YEAR HEIGHT PERFORMANCE OF PLANTED LOBLOLLY PINE FOLLOWING SITE PREPARATION AND HERBACEOUS RELEASE TREATMENTS ON A LOWER COASTAL PLAIN SITE

Stephen E. Peairs

ABSTRACT

Chemical applications for site preparation and herbaceous release are critical for establishing stands of loblolly pine in the Southeastern United States. Sandy soils commonly found in lower Coastal Plain sites require lower herbicide application rates compared to other soil types but experience reduced length of competition control. This study examines conducting both treatments (fall site preparation and spring herbaceous release) as opposed to individual applications of site preparation or herbaceous release only on lower Coastal Plain sites. A complete block design was utilized to evaluate five treatments: Two individual site preparation treatments utilizing either (1) glyphosate + triclopyr, (2) imazapyr + triclopyr + glyphosate + metsulfuron methyl, (3) herbaceous release treatments using a midrange (but high for sandy soil) label application rates of hexazinone + sulfometuron methyl, (4) a combination of the second site preparation treatment above plus a lower application rate of herbaceous release mixture, and (5) control. A clearcut harvest occurred in 2018; site preparation treatments were applied in early fall of 2019; loblolly pine seedlings were planted in February 2020; and the herbaceous release treatments were applied during May 2020. Vegetation on these sites was well established after a full growing season following clearcutting. All herbicide treatments enhanced seedling ground line diameter compared to control. First year height growth was similar for control and one-time applications, however combined site preparation plus herbaceous release caused stunted growth which was statistically significant. Implementation of release treatments after chemical site preparation treatments should be delayed until after completion of the first growing season.

INTRODUCTION

Land managers must routinely decide when to apply herbicides to sites intended for loblolly pine (*Pinus taeda*) production. In some instances, the application window may be less than ideal with possible restrictions on timing and weather, applicator readiness, or herbicide availability. Individuals may question the necessity of using soil active herbicides versus those that do not bind with soil colloids and whether better growth and yield can be achieved through conducting both site preparation and seedling release treatments on sandy sites. Research has suggested that loblolly pine establishment and growth can be enhanced by controlling competing hardwood trees (Borders and Bailey 2001, Glover and Zutter 1993, Miller and others 1991). Chemical applications can produce greater gains compared to mechanical site preparation (Shiver and Martin 2002). Use of chemical site preparation without mechanical treatments can also alleviate some of the financial burden to landowners. The land manager must decide which herbicide(s) are optimal for the control of vegetation communities on the site and optimal seasonal application dates. Various soil active

herbicides have been researched for both site preparation and herbaceous release applications. Hexazinone herbicides have provided positive loblolly pine diameter and height growth when applied as a site preparation treatment (Wittwer and others 1986). Post-planting herbicide release combined with a chemical site preparation treatment can increase pine growth at a level greater than site preparation alone (Zhao and others 2008). An increase in application rate of hexazinone pellets (1.12, 1.68, and 2.24 kg active ingredient ha⁻¹ treatment rates per acre) applied in March resulted in greater hardwood control along with improved pine seedling diameter and height growth (Zutter and others 1988). Increased rates of hexazinone controlled a greater range of competing hardwood species in pine plantation over 3 years of age (Zutter and Zedaker 1987). Herbaceous release using solutions of hexazinone with sulfometuron methyl can improve pine growth and extend vegetation control into the growing season (Yeiser and Ezell 2004). Herbaceous and woody control improve pine diameter at breast height, basal area, and individual tree volume growth when applied singularly, but the greatest gains result from combined applications (Zutter and Miller 1998). Summer

Stephen E. Peairs, Assistant Professor, Department of Forestry and Environmental Conservation, Clemson University, Clemson, SC 29634.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

applications of 2 pounds active ingredient imazapyr appeared optimal for controlling hardwoods in a young pine plantation. Hexazinone applied at 2 pounds active ingredient with metsulfuron methyl had better results when compared to summer applications of imazapyr at lower application rates (Quicke and others 1996a). Applications of hexazinone (pre-plant) with sulfometuron methyl (release) had similar growth response compared to post-plant applications of imazapyr with metsulfuron methyl (Blazier and Clason 2006). Post-applications of hexazinone (4 pounds after ingredient) were statistically similar to imazapyr + metsulfuron. Gardiner and Yeiser (1991) found a mixture of hexazinone with sulfometuron applied as herbaceous release promoted pine seedling development at a higher level than mixtures containing imazapyr and sulfometuron methyl. The reliability of the aforementioned herbicides in vegetation management within pine stands has been consistent for over two decades. Thus, these herbicides are typically the preferred choice by land managers.

OBJECTIVES

This study investigated chemical site preparation and herbaceous weed control applications to establish loblolly pine plantations. Analyses aimed to determine if differences in pine seedling diameter and height growth exist between (1) two individual site preparation treatments only, (2) chemical herbaceous release only (applied at the middle of the standard release rate, higher than typically used on sandy soils) using hexazinone and sulfometuron methyl, and (3) chemical site preparation with a chemical herbaceous release applied during the first growing season after planting. The increased application rate for the release only treatment was used to determine if sufficient control of both woody (need for more active ingredient–hexazinone) and herbaceous stems could be accomplished with a one-time spring treatment.

STUDY SITE

The research installation is located on Interfor Corporation property outside of the town of Andrews, SC in Georgetown County. Two soil types (Echaw and Lynn Haven sands) exist within the 7.5-acre study site. Echaw sand is well-drained with a site index value of 85 feet; base age 50 for loblolly pine. Lynn Haven sand is poorly-drained with a loblolly pine site index value of 80 feet; base age 50 (USDA NRCS Soil Survey Staff 2021). The previous stand was clearcut and removed all standing trees with the exception of live oak (*Quercus virginiana*). Live oak remained due to an ordinance in Georgetown County that restricts felling of the species. The timber harvest occurred during the winter of 2019. There was no mechanical site preparation applied

on the site. Research installation occurred at the end of the initial growing season after the disturbance. Competing herbaceous and woody vegetation on the site included asters (*Pityopsis* spp.), dogfennel (*Eupatorium capillifolium*), eastern baccharis (*Baccharis halimifolia*), fireweed (*Erechtites hieracifolia*), gallberry (*Ilex glabra*), large gallberry (*Ilex coriacea*), greenbriars (*Smilax* sp.), panic grasses (*Panicum* sp.), partridge pea (*Chamaecrista fasciculata*), sumacs (*Rhus* spp.), swamp titi (*Cyrilla racemiflora*), muscadine grape (*Vitis rotundifolia*), water oak (*Quercus nigra*), red maple (*Acer rubrum*), sweetbay magnolia (*Magnolia virginiana*), and bracken fern (*Pteridium* sp.). Site preparation treatments were applied in September/October of 2019. Loblolly pine was planted by hand crews in February 2020. Herbaceous release was applied in May 2020.

METHODS

The study area and treatment unit boundaries were established in August/September of 2019 by use of a handheld compass and 100-foot reel tape. The installation was a complete block containing 15 individual, ½-acre treatment units. Treatment unit dimensions were approximately 175 feet × 125 feet. Five individual treatments were conducted including two distinct site preparation applications: (1) site prep #1 (SP1), (2) site prep #2 (SP2), (3) a seedling release only (REL) applied near the middle range of the recommended label release rate (higher rate than normally used for sandy soils), (4) a site preparation using SP2 mixtures plus seedling release at slightly less than the standard label application rate for sandy soils (RSP), and (5) control. Site preparation treatments included DLZ® surfactant (incorporated into solution at ½-percent) which is a blend of methylated seed oil, paraffinic oil, and non-ionic surfactant. Release treatment applications excluded DLZ® from the mixture solutions. Spray treatments were applied at 20 gallons of solution per acre in late September of 2019 using 4-gallon backpack sprayers on site preparation units. All unit's housing release applications only received 8 gallons per acre of solution applied with backpack sprayers. SP2 treatment units were sprayed using a Model T® CO2 pressurized backpack sprayer by Bellspray, Inc. Follow-up treatments within site preparation spray units, to control "missed" vegetation targeted any remaining live vegetation. Follow-up sprays were conducted approximately 1 month (late October 2019) after the initial treatments. These sprays were incorporated into the rates depicted in table 1. Untreated vegetation was easily discernable (healthy appearance) from treated vegetation. The SP1 treatment utilized a solution of 41 percent glyphosate product (Winnfield® product) + triclopyr acid (Trycera®) + surfactant (DLZ® by Helena Chemical®). The SP2 treatments consisted of imazapyr (Polaris®) + triclopyr acid + 41 percent glyphosate + metsulfuron methyl (MSM60®) + surfactant.

Herbaceous release only treatments incorporated hexazinone + sulfometuron methyl applied at double the rate used for the RSP treatment. Treatment application rates are presented in table 1.

Table 1—Treatment herbicide application rates

Treatment	Herbicide	Application rate per acre (oz. product)
Site Prep #1 (SP1)	41% glyphosate	72
	Trycera®	72
Site Prep #2 (SP2)	Polaris®	36
	Trycera®	48
	MSM60®	3
Release only - double rate (REL)	Velossa®	34
	Oust XP®	2.66
Site Prep #2 + Release (RSP)	Polaris®	36
	Trycera®	48
	MSM60®	3
	Velossa®	17
	Oust XP®	1.33

REL treatment rate is twice the amount used in the RSP treatment. The REL rate is near the midrange of the amount advised on the product label. This rate is high for sandy soils, however.

Two of the 15 treatment units were submerged prior to seedling measurement and experienced total seedling mortality. These units (SP2 and Control) were likely inundated for a lengthy duration due to the extensive mortality rate. These treatment units were dropped from the analysis. Second generation loblolly pine seedlings were planted using 7 feet × 10 feet spacing in the research installation in February 2020.

The experimental design was a complete block design (CRD) with sampling to analyze ground line diameter and total height measurements taken on the pine seedlings in November 2020. Fifty samples per treatment unit with a total of 550 seedlings (150 seedlings for RSP, SP1, and REL). The SP2 and Control treatments only had 100 samples each available for analysis due to unit inundation by water (two

inundated treatment units excluded from analysis). All seedlings were numbered with aluminum tags and flagged with florescent flagging for future measurement collection. Ground line diameter was taken near the ground surface with digital calipers. Total height was taken with a retractable tape measure. Individual analyses were performed to determine if differences existed between treatments for seedling diameter and seedling height growth. Treatments were considered a fixed variable in the model. Random variables included the replicates and seedlings. Statistical analyses were conducted using analysis of variance PROC Glimmix; SAS version 9.4 (SAS Institute 2018) at a 95-percent alpha level. The Kenward-Roger test was also used for approximation of degrees of freedom.

Percent ground cover was quantified using ocular estimation for each treatment unit. Plant coverage was calculated to the nearest 5 percent. Vegetative resistance to herbicide or coverage by live plants was not statistically analyzed in this project.

RESULTS

The degree of plant control was maximized with the combined RSP treatment over all other treatments. The RSP units had less than 5 percent live vegetation cover (close to bare ground conditions) on each unit. SP1 and SP2 treatments also decreased live plant abundance to less than 15 percent ground coverage. The REL treatment had the greatest coverage by resistant plants (primarily woody stems, in particular large gallberry). These treatment units had an ocular estimation of approximately 60 percent live vegetation coverage during seedling measurement in November. Most of the vegetation controlled was herbaceous only. Thus, the REL treatment was ineffective at controlling most of the woody stems at the increased application rate. Increased growth gains experienced in the first year will likely diminish with the advancement in competitive status by uncontrolled woody plants.

A difference in pine diameter growth was detected between treatments and the untreated check ($P = 0.0404$). The

Table 2—Loblolly pine diameter and height results taken after initial first full growing season

Treatment	n	Ground diameter Mean	Ground diameter Standard deviation	Total height (inches) Mean	Total height (inches) Standard deviation
RSP	150	0.523 a	0.0325	18.0 b	1.66
SP1	150	0.516 a	0.0325	26.3 a	1.66
SP2	100	0.557 a	0.0399	25.0 a	2.03
REL	150	0.552 a	0.0325	26.0 a	1.66
Control	100	0.363 b	0.0399	23.6 ab	2.03

n = number of seedlings samples for each treatment; RSP = Site Prep #2 plus seedling release; REL = seedling release only. The release only was at double the rate used for the RSP release.

control treatment had a significantly lower mean (0.363 inches) compared to all herbicide treatments. Herbicide treatments ranged from a low mean diameter of 0.516 inches for SP1 to a high of 0.557 for SP2 (table 2). Thus, herbicide treatments yielded comparable results after one complete growing season.

A difference was also found to exist for height growth between the one-time applications (SP1, SP2, REL) compared with the combination RSP treatment ($P = 0.0442$). Average seedling height in the RSP treatment mean was 18.0 inches (table 2). The control treatment mean (23.6 inches) was not significantly different from the RSP treatment in regard to seedling height. The SP1 treatment yielded the greatest average height (26.3 inches). However, no significance difference was detected among the untreated control and one-time herbicide application treatments.

DISCUSSION

Pine mortality with the two units dropped from the analysis due to water inundation that could have been avoided with mechanical site preparation. Bedding may have provided improved aerated soil conditions more preferred by loblolly pine. Land managers should address such concerns that may be encountered within lower elevation areas in the Coastal Plain.

Some vertical stunting was evident with the more intensive site preparation plus release treatment. One potential explanation may entail that the use of four herbicides with residual soil activity (imazapyr, hexazinone, sulfometuron methyl, and metsulfuron methyl) applied with approximately 7 months between applications, could have obviated vertical height growth. First year stunting of loblolly pine following herbicide applications has been noted in previous research involving some of these herbicides (Gardiner and Yeiser 1991, Quicke and others 1996b). Usage avoidance of these four soil active herbicides within a short timespan should be acknowledged. A period of approximately 4 months transpired between site preparation treatments and tree planting which should have been adequate time for herbicide degradation and thus minimized detrimental effects to planted seedlings. These herbicides have both pre- and post-emergent properties which can impact root growth. Barnes and others (1989) found that greenhouse grown loblolly pine root growth was decreased within 28 days following sulfometuron methyl applications. Findings from Gardiner and Yeiser (1991) suggest that a combination of imazapyr + hexazinone + sulfometuron methyl was more antagonistic to seedling development as the combination caused the most visual seedling injury, reduced root biomass, and inhibited height growth compared to individual or two-way mixes of soil active herbicides. However, seedlings in these studies

rebounded and experienced enhanced growth at the end of the first growing season or in subsequent growing seasons. Given the sandy soils present, soil active herbicides could be more available for pine seedling uptake as it may not be as readily absorbed by soil particles.

Seedling height stunting related to these tank mixes should be alleviated by delaying herbaceous release until the onset of the second growing season. McCaskill and others (2019) suggest that imazapyr applications conducted two growing seasons after longleaf pine establishment coupled with a previous site preparation treatment yielded optimal growth on flatwood sites as opposed to herbaceous release applied in the initial growing season. Lauer and Glover (1995) found combining shrub control with herbaceous weed control did not promote pine growth over either treatment applied alone. The extended timing may enable applicators to use three or more soil persistent herbicides on a particular site without potential losses in growth. An applicator may also opt to avoid the use of all soil residual herbicides if a herbaceous release treatment is scheduled for the immediate growing season following chemical site preparation. Early competition to pine seedlings in the first 3 years is most commonly affected by herbaceous vegetation. Woody vegetation becomes the greater competitor thereafter. Use of non-soil active herbicides, such as the active ingredients used in SP1, may provide more beneficial results in lieu of imazapyr and metsulfuron methyl.

The herbaceous REL treatment had minimal efficacy on controlling the majority of hardwood species on site. The REL units contained more plant competition for loblolly pine compared to all other herbicide treatments but did provide a scattered bare ground condition due to the deadening of herbaceous plants including bracken fern. This treatment did provide better first-year groundline diameter and height growth over the control. No significant separation was found between release and site preparation treatments leaving uncertainty that release applications may be substituted for site preparation treatments. Future measurements are expected to show that release only treatment areas will have inferior growth compared to site preparation treatment areas.

A more distinct separation between treatments and control will likely become apparent at the conclusion of the second growing season. The deleterious stunting by the combined site preparation with herbaceous release may decrease as the visibly greater control of competing vegetation may extend into the second growing season as weed emergence may be dependent on off-site windblown seed invasion. This prolonged suppression of weed species may promote growth gains more so than single application treatments.

SUMMARY

All site preparation mixtures, herbaceous release, and the combination site preparation plus release treatment significantly improved first-year loblolly pine groundline diameter growth. One-time applications for site preparation only or release only significantly increased pine height growth. The combined site preparation plus release treatment resulted in height stunting. The use of four soil-active herbicides (sulfometuron methyl, metsulfuron methyl, imazapyr, and hexazinone) within approximately 7 months was the most probable cause for this deleterious result. The release only treatment applied at a higher rate for sandy soil provided marginal control of woody plants. The continued presence of competitor plants is expected to yield inferior growth compared to the other chemical treatments in subsequent years. Land managers may opt to avoid using four soil active herbicides altogether or utilize release applications at least one complete growing season following site preparation. A REL treatment applied at a high application rate for sandy soils may only provide early growth promotion but yield inferior long-term results compared to chemical site preparation.

LITERATURE CITED

- Barnes, A.D.; Zedaker, S.M.; Feret, P.P.; Seiler, J.R. 1989. The effects of sulfometuron on the root growth of loblolly pine. *New Forests*. 3: 289–295.
- Blazier, M.A.; Clason, T.R. 2006. Eleven-year loblolly pine growth in response to site preparation and seedling type in north Louisiana. In: Conner, K.F., ed. Proceedings of the 13th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-92. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 167–170.
- Borders, B.E.; Bailey, R.L. 2001. Loblolly pine—pushing the limits of growth. *Southern Journal of Applied Forestry*. 25(2): 69–74.
- Gardiner, E.S.; Yeiser, J.L. 1991. First-year survival and growth of loblolly pine seedlings released from perennial weeds in old fields of northeastern Arkansas. U.S. Department of Agriculture Forest Service. *Tree Planters Notes*. 44(1): 25–32.
- Glover, G.R.; Zutter, B.R. 1993. Loblolly pine and mixed hardwood stand dynamics for 27 years following chemical, mechanical, and manual site preparation. *Canadian Journal of Forest Research*. 23(10): 2126–2132.
- Lauer, D.K.; Glover, G.R. 1995. Pine and competing vegetation response to herbaceous weed control and levels of shrub control in the Flatwoods. In: Edwards, B., ed. Proceedings of the eighth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 111–118.
- McCaskill, G.L.; Shibu, J.; Ogram, A.V. 2019. Low-dose herbicide effects on tree establishment and nitrogen biogeochemistry within pine savannas. *Soil Science Society of America Journal*. 83(s1): S153–S160.
- Miller, J.H.; Zutter, B.R.; Zedaker, S.M. [and others]. 1991. A regional study on the influence of woody and herbaceous competition on early loblolly pine growth. *Southern Journal of Applied Forestry*. 15(4): 169–179.
- Quicke, H.E.; Glover, G.R.; Lauer, D.K. 1996a. Herbicide release of 3-year-old loblolly pine from competing hardwoods in Arkansas. *Southern Journal of Applied Forestry*. 20(3): 121–126.
- Quicke, H.E.; Glover, G.R.; Lauer, D.K. 1996b. Growth responses following herbicide release of loblolly pine from competing hardwoods in the Virginia Piedmont. *Southern Journal of Applied Forestry*. 20(4): 177–181.
- SAS Institute. 2018. SAS/STAT 15.1 user's guide, The GLIMMIX Procedure. Version 9.4. Cary, NC: SAS Institute. 370 p.
- Shiver, B.D.; Martin, S.W. 2002. Twelve-year results of a loblolly pine site preparation study in the Piedmont and Upper Coastal Plain of South Carolina, Georgia, and Alabama. *Southern Journal of Applied Forestry*. 26(1): 32–36.
- United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), Soil Survey Staff. 2021. Web Soil Survey. <https://websoilsurvey.sc.egov.usda.gov/>. [Date accessed: August 18, 2022].
- Wittwer, R.F.; Dougherty, P.M.; Cosby, D. 1986. Effects of ripping and herbicide site preparation treatments on loblolly pine seedling growth and survival. *Southern Journal of Applied Forestry*. 10(4): 253–257.
- Yeiser, J.L.; Ezell, A.W. 2004. Oustar herbicide for efficient herbaceous weed control and enhanced loblolly pine seedling performance in the southeastern US. *Forest Ecology and Management*. 192: 207–215.
- Zhao, D.; Kane M.; Borders, B.; Harrison, M. 2008. Pine growth response to different site-preparation methods with or without post-plant herbaceous weed control on North Florida's Lower Coastal Plain. *Forest Ecology and Management*. 255: 2512–2523.
- Zutter, B.R.; Gjerstad, D.H.; Webb, A.L.; Glover, G.R. 1988. Response of a young loblolly pine (*Pinus taeda*) plantation to herbicide release treatments using hexazinone. *Forest Ecology and Management*. 25(2): 91–104.
- Zutter, B.R.; Miller, J.H. 1998. Eleventh-year response of loblolly pine and competing vegetation to woody and herbaceous plant control on a Georgia Flatwoods Site. *Southern Journal of Applied Forestry*. 22(2): 88–95.
- Zutter, B.R.; Zedacker, S.M. 1987. Short-term effects of hexazinone applications on woody species diversity in young loblolly pine (*Pinus taeda*) plantations. *Forest Ecology and Management*. 24(3): 183–189.

Natural Disturbances and Climate Change



FOREST LANDOWNER RESOURCES FOR HURRICANE AND SOIL SALINIZATION PREPARATION AND RECOVERY IN THE SOUTHEASTERN UNITED STATES

Nancy Gibson, Steven McNulty, Michael Gavazzi, Chris Miller, and Elijah Worley

EXTENDED ABSTRACT

Hurricanes cause billions of dollars in damage each year, and the risk from hurricanes is projected to increase. Hurricane Michael (2018) and Laura (2020) are prominent, recent examples of storms that reached far inland while maintaining a category 4 and category 3 status. Hurricanes negatively impact forests through wind damage, storm surge flooding, causing reduced tree growth, mortality, and carbon loss. Storm surge can cause soil salinization when saltwater inundates coastal stands and infiltrates the soil. Sea-level rise associated with climate change also contributes to soil salinization in coastal areas through saltwater intrusion and rising ground-water levels. Forest yield decreases as soil salinity increases. Soil salinity is often measured as electrical conductivity (EC), and EC levels of $8 < 16 \text{ dS m}^{-1}$ render forest stands economically inviable. Foresters need management information to address these threats. Unfortunately, this information is hard to find or inconsistent across localities. Therefore, the U.S. Department of Agriculture Southeast Climate Hub developed hurricane and salinization guides to help producers prepare for, recover from, and adapt to these threats.

The Pine Forest Landowner Hurricane Preparedness and Recovery guide provides State-specific recommendations to build resilience and speed recovery from hurricanes. The guide covers planning phases such as the initial site location and operation building, annual maintenance and recordkeeping, and preparation for when a hurricane is imminent. The guide also includes steps for bringing the site back into production after a hurricane. The guide has four main sections: (1) the *Building a Resilient Operation* section outlines actions that producers can put in place to increase their resilience to hurricanes, (2) the *Long-Term Operation Maintenance* section lists specific pre-hurricane actions and periodic checks annually (before hurricane season) and monthly (during hurricane season), (3) the *Short-Term Preparedness* section lists specific actions to be done in the week before a hurricane arrives, and (4) the *Post-Hurricane Recovery* section outlines activities that producers can take to minimize losses following a hurricane. This section begins with safety-oriented actions immediately following a hurricane and continues with ongoing actions (e.g., post-hurricane inventory, recovery assistance programs) that can be taken in the following week and month.

Author Information: Nancy Gibson, Environmental Technician, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709; Steven McNulty, Director, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709; Michael Gavazzi, Coordinator, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709; Chris Miller, Manager/Plant Specialist, U.S. Department of Agriculture, National Resources Conservation Service, Cape May Court House, NJ 08210; and Elijah Worley, Environmental Technician, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

In the Southeastern United States, soil salinization can be associated with hurricane-caused storm surge in the short term and with sea-level rise in the long term. Both hurricane and sea-level rise impacts are more significant concerns due to climate change. Salinization reduces the productivity of working lands and can prevent crops from growing. The salinization guide describes the impacts of soil saltwater intrusion and includes adaptation measures to maintain productivity in working lands. The first two chapters of the salinization guide describe the background information and assessment and minimization of salinity risk. These chapters include details concerning salinization processes, testing soil for salinity levels, and other descriptive information. The salinization guide frames soil salinization as stages, ranging from low (Stage Zero) to high (Stage Five) salinity impacts. Stage Zero is non-impacted land, and Stage Five is the point where sea-level rise has converted the land to chronic surface water. Each stage in this guide is assigned a range of EC values (e.g., Stage Zero: $0 < 2 \text{ dS m}^{-1}$), and they increase as the stages progress (Stage Five: $\text{EC} = >25 \text{ dS m}^{-1}$). The productivity of working lands decreases as soil salinity increases. The guide includes a description of each stage and productivity limitations to expect, along with mitigation and adaptation measures appropriate for the given stage.

Baseline site characteristics, such as productivity, are established at Stage Zero. Forest productivity is not impacted by salinity at this stage. However, the soil may be at risk of salinization due to proximity to a saltwater source. Stage One soils have low salinity, and forest stands are likely to recover from a single salinity event. Some seedling growth may be unaffected at these low levels of salinity. Mitigation efforts are only possible in Stage One, and conservation practices standards can be used for adaptation. Saltwater intrusion is expected to impact a growing extent in the Southeast. Eventually, salinization events will become a re-occurring issue.

Stage Two involves moderate salinity levels ($4 < 8 \text{ dS m}^{-1}$) as salinization events occur at a faster rate than soil recovery. Forests may begin to show signs of salinity stress but can still be economically profitable. Site recovery depends on local hydrology and elevation. However, sea-level rise will continue to bring saltwater inland, leading to chronic salinization. Stage Three is characterized by chronic salinity and makes commercial forestry no longer a viable option. In Stage Three, trees exhibit a severe decrease in overall vigor, increased insect problems, sparse crown, inferior growth, increased mortality, short needle length in pines, small foliage in hardwoods, and increased overall appearance of poor health. Forestry operations in these areas are unlikely to be successful.

Chronic salinity can be identified in forests by encroaching salt-tolerant species, such as wax myrtle (*Morella cerifera*). The land can be left to transition naturally into saltmarsh, converted to a conservation easement, or cultivated with alternative salt-tolerant crops. Alternative crops such as salt meadow cordgrass (*Spartina patens*), seashore mallow (*Kosteletzkya virginica*), switchgrass (*Panicum virgatum*), coastal panicgrass (*Panicum amarulum*), prairie cordgrass (*Spartina pectinata*), eastern gamagrass (*Tripsacum dactyloides*) can be planted in entire fields. Forests can survive at Stage Four, though their productivity will be very low. Tree mortality will lead to salt-tolerant vegetation such as cattail (*Typha* sp.), common reed (*Phragmites australis*), and sawgrass (*Cladium* sp.) that move into the open spaces left by the dead trees. Freshwater tree seedlings are unlikely to grow in a more saline environment. The saltmarsh described in Stage Five has environmental benefits such as carbon sequestration, shoreline stabilization, biodiversity, improvement of water quality through filtration of contaminants and sediments, reduction of flooding impacts, waterfowl, wildlife habitat, inland protection, hunting leases, and recreational value.

This presentation will provide an overview of both the hurricane and salinization guides. Additionally, the presentation will discuss where additional information on these topics can be found online.

EFFECTS OF TORNADO AND SALVAGE HARVESTING DISTURBANCES ON VEGETATIVE COMMUNITY DYNAMICS IN UPLAND MIXED PINE—HARDWOOD STANDS WITHIN THE DAVY CROCKETT NATIONAL FOREST, TEXAS

Cassey L. Edwards, Amber N. Blair, Sally J. Shroyer, Alanna B. Crowley, Kathryn R. Kidd

ABSTRACT

Natural disturbances have the potential to alter forest successional and developmental patterns. We examined vegetative community structure and composition 18 months following an EF-3 tornado (April 2019) and salvage operations (completed July 2019 to June 2020) within the Johnson Creek and Burrantown timber sale areas of the Davy Crockett National Forest in east Texas. A total of 25 plots were located across undisturbed, tornado damaged without salvage, and tornado damaged with salvage areas. Tornado severity was measured based on the tornado path, with high-severity damage being within the touch down event and medium-severity damage was adjacent to the event. Multivariate analysis indicated distinct differences within the vegetative communities across the disturbance groups. Unharvested tornado-disturbed areas had the greatest diversity of seedlings while tornado disturbed with salvage areas had the greatest diversity of herbaceous vegetation with the greatest occurrence of invasive species. The medium- and high-severity levels tended to have an overall higher diversity with a lower overstory basal area compared to the control. A more diverse and complex forest structure and community composition can be obtained by adjusting salvage operations and retaining patches of unharvested areas.

INTRODUCTION

Wind disturbance has been recognized as a major driver of forest dynamics (Holzmueller and others 2012; Nelson and others 2008, 2010; Peterson 2000; Peterson and others 1997; Rossi and others 2017). These uncontrollable natural disturbances can alter species composition, canopy structure and gap size, and overstory distribution (Holzmueller and others 2012, Peterson and others 1997). Forest successional patterns following tornado disturbances can also differ from that of other natural and anthropogenic disturbances due to the sporadic nature of catastrophic wind events (Holzmueller and others 2012, Nelson and others 2010, Peterson 2000, Peterson and others 1997). On many forests following a natural disturbance, foresters tend to implement salvage operations as a means to lessen economic losses caused by these unexpected disturbances. Salvage logging is a forestry practice in which standing and fallen trees are removed following natural stand altering disturbances. Multiple disturbances in quick succession may have impacts beyond

the scope of single, discrete disturbance events (Kleinman and others 2017).

Most wind disturbances have a positive relationship with forest dynamics by enhancing habitat heterogeneity, resource availability, and variation in microtopography (Kleinman and others 2017, Nelson and others 2008, Peterson and others 1997, Rossi and others 2017). The results of natural disturbances, such as woody debris or tip-up mounds, often promote species diversity (Santoro and D'Amato 2019). Salvage harvesting is often viewed negatively for reducing these beneficial effects. The compound disturbance of wind severity and salvage harvesting may result in a plant community adapted to high-disturbance levels with prolific reproductive capabilities out competing plants with more sensitive requirements (Curtze and others 2018, Kleinman and others 2017, Santoro and D'Amato 2019). As the severity and frequency of natural and anthropogenic disturbances intensifies with global change and increasing human demand, it has become increasingly pertinent to obtain a greater understanding of vegetative recruitment and forest

Author Information: Cassey L. Edwards, Graduate Student, Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, TX 75962; Amber N. Blair, Forestry Technician, U.S. Department of Agriculture, Forest Service, Davy Crockett National Forest, Kennard, TX 75847; Sally J. Shroyer, Undergraduate Research Technician, Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, TX 75962; Alanna B. Crowley, Undergraduate Research Technician, Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, TX 75962; and Kathryn R. Kidd, Associate Professor, Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, TX 75962.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

successional patterns following interacting disturbances (Kleinman and others 2017).

In April 2019, an EF-3 tornado damaged a large swath of a mixed upland forest within the Davy Crockett National Forest in east Texas. Some of the disturbed areas were subject to salvage logging of downed trees from July 2019 to June 2020. These activities resulted in a wide array of canopy and ground disturbances. The primary objectives of this study were to assess the vegetative response and determine if responses in species diversity differed among undisturbed, tornado disturbed, and tornado + salvage areas within the Johnson Creek and Burrantown timber sale areas of the Davy Crockett National Forest in east Texas.

MATERIALS AND METHODS

Study Area

This study was conducted on the Davy Crockett Ranger District in the national forests and grasslands in Houston and Trinity Counties, located about 120 miles north of Houston, in east Texas. At an elevation of 360 feet, the Davy Crockett Ranger District has an average summer high temperature ranging in the low-90s, winter high temperatures in the mid-60s, receives 48 inches of rain annually, and experiences, on average, 205 sunny days each year (U.S. Department of Agriculture 2020). The overstory consists predominantly of loblolly pine (*Pinus taeda* L.) and shortleaf pine (*Pinus echinata* Mill.). The midstory is characterized by white oak (*Quercus alba* L.) southern red oak (*Quercus falcata* Michx.), water oak (*Quercus nigra* L.), post oak (*Quercus stellata* Wangenh.), sweetgum (*Liquidambar styraciflua* L.), and winged elm (*Ulmus alata* Michx.). Soils consisted of Kirin and Cuthbert fine sandy loam along the Johnson Creek, medium-severity impacted area, as well as the Lilbert and Darco loamy fine sands along the Burrantown, high-severity area. The Johnson Creek location consists predominantly of loblolly and shortleaf pine with a mix of white oak, southern red oak, water oak, post oak, and sweetgum. A similar mix was observed in the Burrantown locations with the inclusion of hickory species (*Carya spp.*) and winged elm with the exclusion of southern red oak. This area is primarily managed for timber production with an emphasis on wildlife management.

On April 13, 2019, the Davy Crockett National Forest was hit by three tornadoes. The tornado paths were in a northeasterly direction and ranged in severity from EF-1 (up to 110 miles per hour winds) to EF-3 (135-160 miles per hour winds). It was estimated that more than 3,000 acres of the forest were impacted. All tornado-affected areas occurred on the northern half of the Davy Crockett National Forest. Salvage operations were conducted from July 2019 to June 2020. The requirement for salvage included non-hardwood trees that were broken, recently dead, leaning at more than a 45-degree

angle with extensive bole damage, and susceptible to insect-induced mortality. Snags were left for wildlife habitat.

Data Collection

Sample plots were randomly identified by overlaying a 650-foot (200 m) grid within the Burrantown and Johnson Creek EF-3 affected areas. A total of five plots was located in each treatment of tornado damage and tornado + salvage harvest. Five plots were also identified adjacent to these areas to represent non-affected areas for a total of 25 plots. Treatment areas included control (non-affected areas), high-severity tornado damage and tornado + salvage areas, and medium-severity tornado damage and tornado + salvage areas. Tornado-damaged areas were located within the path of the tornado but did not undergo salvage logging operations. The tornado damage + salvage were tornado damage areas located within the path of the tornado and underwent salvage logging operations within 1 year of the tornado event. Tornado severity was measured based on the tornado path, with high-severity damage within the touch down event and medium-severity damage adjacent to the event. The control plots were not impacted by the tornado event or salvage operations.

Plots were located at a minimum of 650 feet from roads and outside of streamside management zones. Plots were located 650 feet apart. Each plot consisted of a circular 1/10th-acre overstory plot, a 1/100th-acre nested regeneration plot, and five 3.28- by 3.28-foot understory quadrats. In the 1/10th-acre overstory plot, all standing live trees and snags were tallied to species and diameter at breast height, 4.5 feet aboveground level. The total height was measured for all trees >5 inches. In the regeneration layer, seedlings (<12 inches in height) were tallied by species. Understory vegetation (including both woody and herbaceous growth forms) occurrence was quantified within a 1-m by 1-m quadrat. The species and percent coverage were recorded for each of the five nested quadrates (plot center, north, east, south, and west). The ground cover was estimated using Daubenmire cover classes (Daubenmire 1959) for subplot vegetation, bare ground, and downed woody debris. Data were not recorded before the tornado event, so all the collected data represents post-disturbance conditions.

Data Analysis

The basal area was calculated for overstory by species. The density was calculated by species for the seedling strata. The importance value for each stratum and for each treatment level were calculated following the protocols of Curtis and McIntosh (1950). The species diversity was calculated using the Shannon-Wiener Diversity index (Dejong 1975) using Past 4.06b (Hammer and others 2001) for each stratum at each treatment level. The Shannon-Wiener Diversity index was chosen because it was the most sensitive for the presence of rare or uncommon species (Beals and others 2000, Morris

and others 2014) and took into account the total number of species sampled while adjusting for relative frequency and relative cover. The Hutcheson t-test was conducted to determine significances between the diversity indices calculated, significance was based on p-values < 0.1. The N-way analysis of variance (ANOVA) of expected mean squares was used to examine species abundance of each stratum for each site. The abundance data were transformed using log base-10 and significance was based on p-values < 0.1. The analysis of similarity (ANOSIM) comparisons using the Bray-Curtis dissimilarities was used to test for differences in community composition for each of the treatment levels previously listed using RStudio and the vegan package (version 1.7.8) (Oksanen and others 2020).

The indicator species analysis (ISA) is typically used to determine ecological indicators of community types (De Cáceres and others 2010). For this study, the ISA was used to determine if disturbance levels could be skewed as an indicator for vegetative species present (Bakker 2008), using RStudio and indicpecies package (version 1.7.8) (De Cáceres and others 2012). The ISA was run using species abundance data for each vegetative species, in each stratum, for each treatment level. Host specificity and intercardinal specificity were determined based on p-values < 0.1.

RESULTS AND DISCUSSION

Overstory

The dominant species consisted of *P. taeda*, *P. echinata*, *L. styraciflua*, and *Q. alba* across all treatment levels (table 1). The basal area decreased for all species as disturbance intensity increased (ANOVA, $P=0.073$) (fig. 1). Tukey's pairwise comparison between treatments showed significant differences between tornado damage + salvage and tornado damage ($p<0.001$) regardless of the tornado intensity at each site with the addition of the salvage harvest having a smaller overstory basal area per acre than that of the control and the tornado-impacted locations. The Hutcheson t-test indicated a difference in Shannon's diversity (table 2) between disturbance, tornado damage ($P=0.083$), and tornado damage + salvage ($P=0.066$).

The overstory vegetation within each treatment type showed a dissimilarity between treatment areas (ANOSIM statistic $R: 0.2072$; $P=0.010$). Significant dissimilarity occurred between high-severity tornado damage + salvage and medium-severity tornado damage + salvage, this included snags ($p=0.032$), *L. styraciflua* ($p=0.029$), and *F. pennsylvanica* ($p=0.045$).

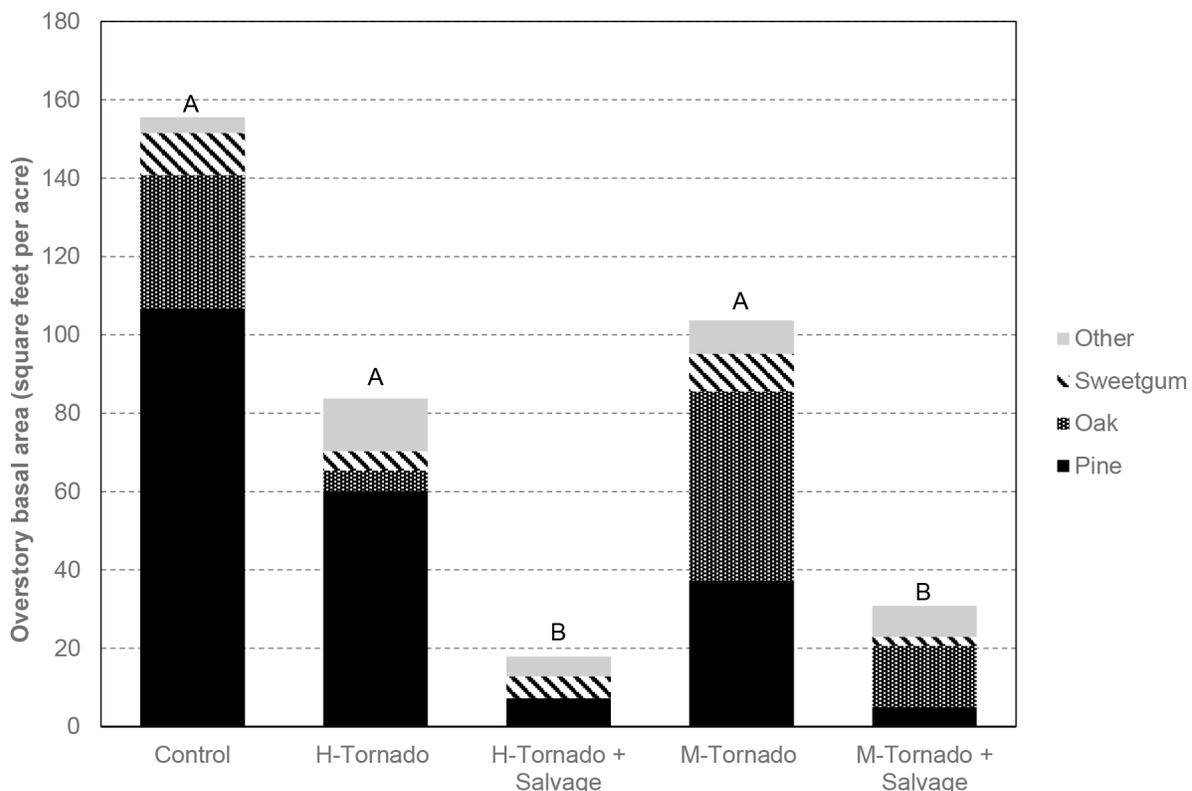


Figure 1—Total basal area per acre of the overstory live standing trees and snags (mixture of spp.) for each treatment area (ANOVA, $P=0.073$). Values represented by the same letter are not significantly different at $\alpha=0.1$ level. Tukey's pairwise comparison between treatments showed significant differences between tornado damage + salvage and tornado damage ($p<0.001$).

Table 1—Importance values (IV), with a total IV >20, of the overstory live standing trees and snags for each treatment

Species	Control	H-tornado + salvage	H-tornado	M-tornado + salvage	M-tornado
<i>Liquidambar styraciflua</i>	8	32	12	6	13
<i>Pinus echinata</i>	8	–	15	6	23
<i>Pinus taeda</i>	38	19	35	7	4
<i>Quercus alba</i>	13	–	3	17	12
Snag (mixture of spp.)	6	19	4	16	6

– = no values; species were not observed in that area.

Table 2—Species richness and diversity using the Shannon-Wiener diversity index for herbaceous cover, overstory, and seedling cover for each treatment

		Control	H-tornado + salvage	H-tornado	M-tornado + salvage	M-tornado
Overstory	Richness	12	5	11	10	11
	Diversity	1.6	1.7	1.8	2.2	2.1
Seedling	Richness	13	14	16	14	17
	Diversity	1.9	1.7	2.3	2.4	2.4
Herbaceous	Richness	21	34	33	35	37
	Diversity	2.2	3.1	2.9	3.1	2.9

Seedlings

The seedling density (stems per acre) increased within the medium-severity areas despite treatment type, excluding the high-severity tornado damage + salvage ($p=0.054$) (fig. 2). Tukey’s pairwise comparison between treatments showed significant differences between tornado intensity ($p<0.001$) and tornado damage + salvage and tornado damage ($p<0.001$). Shannon’s diversity of seedlings increased with disturbance excluding the high-severity tornado damage + salvage when compared to the control groups, with the medium-severity plots having a higher diversity than that of the high-severity plots (table 2). The Hutcheson t-test showed a difference in Shannon’s diversity between severity of disturbance for the compound disturbance but no difference in just the severity of tornado damage; tornado damage ($P=0.471$) and tornado damage + salvage ($P=0.0001$). Seedling density, richness, and diversity (excluding shrub species) were the greatest within the tornado-affected areas although not significantly different between the tornado and tornado + salvage areas. Similar results were documented in other research (Kleinman and others 2017).

Seedlings within each disturbance type showed a dissimilarity between treatment locations (ANOSIM statistic $R: 0.433$; $P<0.0001$). Significant dissimilarity occurred between high-severity tornado damage + salvage and medium-severity tornado damage + salvage that included *Q. falcata* ($p=0.013$), *Q. nigra* ($p=0.009$), *U. alata* ($p=0.006$),

S. nigra ($p=0.010$), *Q. stellata* ($p=0.092$), and *F. americana* ($p=0.011$). Significant dissimilarity occurred between three medium-severity impacted areas, *P. taeda* ($p=0.009$), *L. styraciflua* ($p=0.012$), and *O. virginiana* ($p=0.001$). Significant dissimilarity occurred between three high-severity impacted areas that included *S. albidum* ($p=0.001$), *I. opaca* ($p=0.004$), and *F. caroliniana* ($p=0.001$).

Herbaceous

Species richness and diversity increased with disturbance compared to the control groups (table 1). The Hutcheson t-test had no difference in Shannon’s diversity between severity of disturbance of tornado damage; tornado damage ($P=0.201$) and tornado damage + salvage ($P=0.620$). However, the Hutcheson t-test had differences between the compound disturbance diversity; high severity ($P=0.004$) and medium severity ($P=0.031$).

Herbaceous vegetation within each treatment type showed a dissimilarity between treatment locations (ANOSIM statistic $R: 0.4219$; $P<0.0001$). Significant dissimilarity occurred between two medium-severity impacted areas, leaf litter ($p=0.007$) and *L. japonicum* ($p=0.004$).

On the short-term response, salvage logging appeared to have a negative impact on species richness and diversity compared to that of just the tornado-impacted location for the overstory. The compound disturbance did provide a greater species richness and diversity of seedlings and

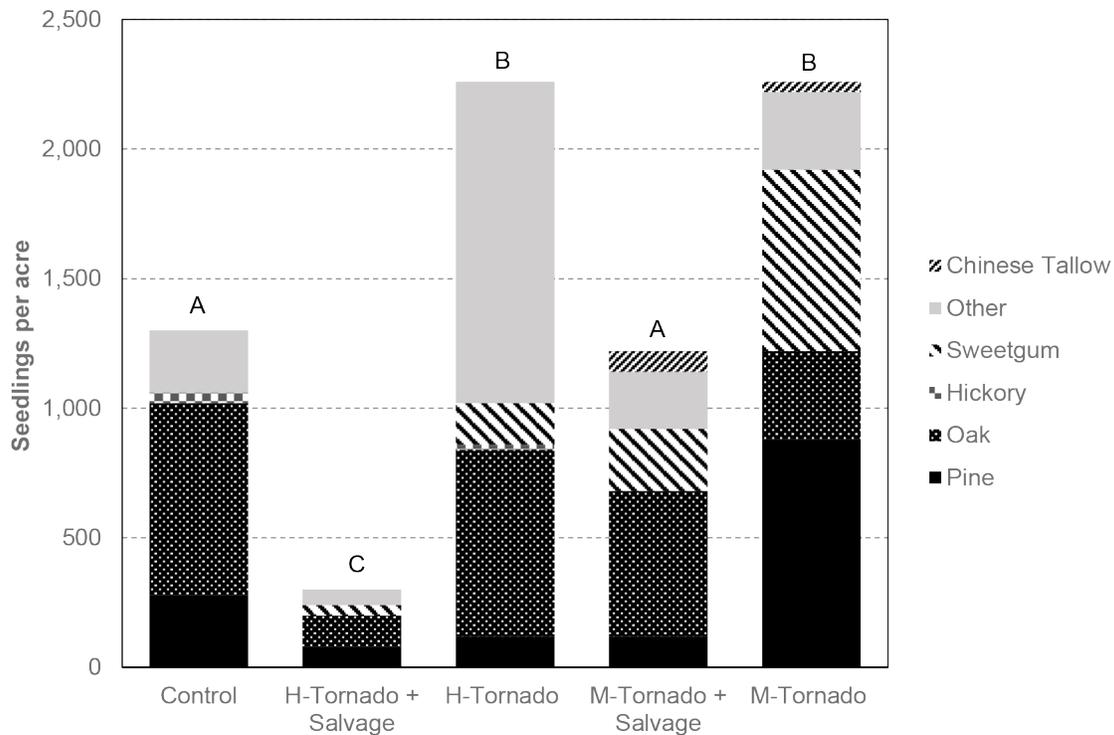


Figure 2—Number of seedlings per acre for each treatment. Other category includes maple, ash, elm, and sassafras species (ANOVA, $P=0.054$). Values represented by the same letter are not significantly different at $\alpha=0.1$ level. Tukey's pairwise comparison between treatments showed significant differences between tornado intensity ($p<0.001$) and tornado damage + salvage and tornado damage ($p<0.001$).

herbaceous vegetation compared to that of the control areas. Other studies investigating salvage logging and vegetation responses have observed similar results (Kleinman and others 2017, Lindenmayer and Noss 2006, Nelson and others 2010, Palik and Kastendick 2009, Santoro and D'Amato 2019).

Two species had an indicator value of significance across all disturbance levels and strata. For the high-severity tornado damage + salvage areas within the herbaceous layer, *Lygodium japonicum* had a significance of ($p=0.016$). The medium-severity tornado damage areas and tornado damage + salvage areas had a significant ISA result for *Triadica sebifera* ($p=0.007$).

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Overall, our study identified the primary short-term response post-tornado and salvage logging within the understory facilitated regeneration. These results may be in response to favorable growing conditions such as greater solar radiation available along the soil surface. These favorable conditions also facilitate regeneration for disturbance-adapted species. The significance of *L. japonicum* and *T. sebifera* on compound-disturbed areas based on indicator species analysis suggest that compound disturbance (salvage logging following a natural disturbance) may ultimately alter

community structure and composition as compared to the noncompound-disturbed areas. These impacts can shift species and functional composition of the regeneration layer, resulting in a different future forest community. Because the observed trends were only recorded for short-term recovery, we are unable to determine if salvage logging together with a natural disturbance will permanently result in successional trajectories varying from that of undisturbed or natural disturbed areas. While there are many benefits of salvage operations following a disturbance (Lindenmayer and Noss 2006), our results together with results from others show that it has an immediate, and possibly lasting, impact on the surrounding forest community (Curtze and others 2018; Kleinman and others 2017; Nelson and others 2008, 2010; Palik and Kastendick 2009; Santoro and D'Amato 2019). Structural legacies are essential in facilitating the recovery of species diversity; therefore, management should focus on retaining some of these structures during salvage operations (Franklin and others 2002, 2007; Kleinman and others 2017; Santoro and D'Amato 2019). The creation of a patchy mosaic of salvage and non-salvage areas will contribute to community and structural diversity, helping to emulate historical disturbance patterns and encourage structural and spatial diversity of the recovering forest.

ACKNOWLEDGMENTS

This study was funded by the McIntire-Stennis Cooperative Forestry Research Program. Additional support was provided by Stephen F. Austin State University located in Nacogdoches, TX and the U.S. Department of Agriculture Forest Service, Davy Crockett National Forest located in Kennard, TX. Additional field assistance was provided by Christoph W. Tomford of the Davy Crockett National Forest.

LITERATURE CITED

- Bakker, J.D. 2008. Increasing the utility of Indicator Species Analysis. *Journal of Applied Ecology*. 45: 1829–1835.
- Beals, M.; Gross, L.; Harrell, S. 2000. Diversity Indices: Shannon's H and E. Knoxville, TN: The Institute for Environmental Modeling (TIEM), University of Tennessee. <https://lgross.utk.edu/www-tiem/index.html>. [Date accessed: April 8, 2022].
- Curtis, J.; McIntosh, R. 1950. The interrelations of certain analytic and synthetic phytosociological characters. *Ecological Society of America*. 31(3): 434–455.
- Curtze, A.C.; Carlo, T.A.; Wenzel, J.W. 2018. The effects of a tornado disturbance and a salvaged timber extraction on the seed-rain and recruitment community of an eastern temperate deciduous forest. *Northeast Naturalist*. 25: 646–655.
- Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. *Northwest Science*. 33: 43–64.
- De Cáceres, M.; Legendre, P.; Wiser, S.K.; Brotons, L. 2012. Using species combinations in indicator analyses. *Methods in Ecology and Evolution* 3(6): 973–982.
- De Cáceres, M.; Legendre, P.; Moretti, M. 2010. Improving indicator species analysis by combining groups of sites. *Oikos*. 119: 1674–1684.
- Dejong, T.M. 1975. A comparison of three diversity indices based on their components of richness and evenness. *Oikos*. 26(2): 222–227.
- Franklin, J.F.; Lindenmayer, D.B.; Thornburgh, D.A. [and others]. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecology and Management*. 155: 399–423.
- Franklin, J.F.; Mitchell, R.J.; Palik, B.J. 2007. Natural disturbance and stand development principles for ecological forestry. Gen. Tech. Rep. NRS-19. Newtown Square, PA: U.S. Department of Agriculture Forest Service, North Research Station. 44 p.
- Hammer, Ø.; Harper, D.A.; Ryan, P.D. 2001. PAST: paleontological statistics software package for education and data analysis. https://palaeo-electronica.org/2001_1/past/issue1_01.htm. [Date accessed: March 30, 2022].
- Holzmueller, E.J.; Gibson, D.J.; Suchecki, P.F. 2012. Accelerated succession following an intense windstorm in an oak-dominated forest. *Forest Ecology and Management*. 279: 141–146.
- Kleinman, J.S.; Ford, S.A.; Hart, J.L. 2017. Catastrophic wind and salvage harvesting effects on woodland plants. *Forest Ecology and Management*. 403: 112–125.
- Lindenmayer, D.B.; Noss, R.F. 2006. Salvage logging, ecosystem processes, and biodiversity conservation. *Conservation Biology*. 20: 949–958.
- Morris, E.K.; Caruso, T.; Buscot, F. [and others]. 2014. Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories. *Ecology Evolution*. 4: 3514–3524.
- Nelson, J.L.; Groninger, J.W.; Battaglia, L.L.; Ruffner, C.M. 2008. Bottomland hardwood forest recovery following tornado disturbance and salvage logging. *Forest Ecology and Management*. 256: 388–395.
- Nelson, J.L.; Groninger, J.W.; Battaglia, L.L.; Ruffner, C.M. 2010. Regeneration response to tornado and salvage harvesting in a bottomland forest. Proceedings of the 14th biennial southern silviculture research conference. Gen. Tech. Rep. SRS-121 Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 307–311.
- Oksanen, A.J.; Blanchet, F.G.; Friendly, M. [and others]. 2020. Vegan: Community Ecology Package. R package Version 2.5-7. <https://cran.r-project.org/web/packages/vegan/index.html>. [Date accessed: March 30, 2022].
- Palik, B.; Kastendick, D. 2009. Woody plant regeneration after blowdown, salvage logging, and prescribed fire in a northern Minnesota forest. *Forest Ecology and Management*. 258: 1323–1330.
- Peterson, C.J. 2000. Damage and recovery of tree species after two different tornadoes in the same old growth forest: a comparison of infrequent wind disturbances. *Forest Ecology and Management*. 135: 237–252.
- Peterson, C.J.; Rebertus, A.J.; Journal, S. [and others]. 1997. Tornado damage and initial recovery in three adjacent, lowland temperate forests in Missouri. *Journal of Vegetation Science*. 8(4): 559–564.
- Rossi, E.; Granzow-de la Cerda, I.; Oliver, C.D.; Kulakowski, D. 2017. Wind effects and regeneration in broadleaf and pine stands after hurricane Felix (2007) in Northern Nicaragua. *Forest Ecology and Management*. 400: 199–207.
- Santoro, J.A.; D'Amato, A.W. 2019. Structural, compositional, and functional responses to tornado and salvage logging disturbance in southern New England hemlock-hardwood forests. *Forest Ecology and Management*. 444: 138–150.
- U.S. Department of Agriculture Forest Service. 2020. Davy Crockett National Forest. https://www.fs.usda.gov/detail/texas/about-forest/districts/?cid=fswebdev3_008441. [Date accessed: March 30, 2022].

CURRENT AND EMERGING RISKS TO SOUTHEASTERN U.S. FORESTS

**Kelsey Bakken, Steven McNulty, Michael Gavazzi,
Eva Paradiso, and Elijah Worley**

EXTENDED ABSTRACT

The Southeastern United States contains a variety of ecosystems that are categorized into 22 level-three ecoregions. Ecoregions are divisions of land area grouped by similar features, including geology, vegetation, soils, land use, and wildlife (Omernik 1987). Forest vegetation across ecoregions includes the following major forest types: oak-hickory, oak-pine, loblolly-shortleaf pine, longleaf-slash pine, and other mixed hardwood and conifer forests. Each forest type is subject to unique stresses, including hurricanes and catastrophic wind, sea-level rise, drought, insects and pathogens, invasive species, and wildfire. These threats are expected to increase in severity and frequency under a changing climate. Here we summarize current impacts and projected changes in forest threats in the Southeastern United States.

Each year, hurricanes cause billions of dollars of damage. Intense winds from hurricanes, tornadoes, and storms are known to impact forest land by causing damage like defoliation, stem bending, breakage, and uprooting (Barlow and others 2021, Vogt and others 2020). Although coastal ecoregions have a much higher risk of hurricane damage, non-coastal (inland) ecoregions are also vulnerable to hurricane damage. Hurricane intensity and frequency have increased since 1960 (Bruyère and others 2012, Holland and Bruyère 2014) and are expected to continue increasing into the future (Knutson and others 2010, 2020; Sugi and others 2017). There is also evidence that hurricanes are moving slower (Kossin 2018), and this reduced speed may result in higher local rainfall totals and subsequent flooding relative to past hurricanes.

Drought is a unique forest threat that directly and indirectly impacts trees. Many areas of the Southeast have moderate to extreme cumulative drought severity indices based on 1987-2013 data (Clark and others 2016). Precipitation variability, frequency, and severity of summer droughts are projected to increase in the future (McNulty and others 2019, Zhao and Dai 2015). Generally, temperatures are expected to increase and summer precipitation is expected to decrease (Kunkel and others 2013). Drought can directly induce tree mortality, or indirectly reduce tree vigor with subsequent increases in susceptibility to other threats like wildfire, insects, and pathogens. Vose and others (2016) reported that 30 days of drought dried all fuel-class sizes, increasing wildfire risk in southern forests. Productivity is also slowed by drought and trees can experience reduced growth rates for years following drought (Berdanier and Clark 2016).

Many native and non-native insects, including but not limited to southern pine beetle (SPB), hemlock woolly adelgid (HWA), emerald ash borer (EAB), gypsy moth, and spotted

Author Information: Kelsey Bakken, Environmental Technician, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709; Steven McNulty, Director, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709; Michael Gavazzi, Coordinator, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709; Eva Paradiso, Environmental Technician, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709; and Elijah Worley, Environmental Technician, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

lanternfly, threaten southeastern forests. Bark beetles (i.e., SPB) and sapsuckers (i.e., HWA and spotted lantern fly) reduce vascular function and wood borers (i.e., EAB) additionally degrade wood. Other insects consume leaves (i.e., gypsy moth) which reduces the tree's vigor as it must expend energy to re-leaf. This loss of tree vigor can lead directly to mortality, especially when insect populations are high, and trees are subject to repeated defoliation. Insects can also serve as vectors for pathogens, and this complex of factors increases tree stress and may lead to mortality. The native SPB is a particularly impactful insect and was reported to cause economic damage of \$43 million per year between 1973 and 2004 (Pye and others 2011). The range of many species is predicted to move northward (Olatinwo and others 2014) due to increasing winter temperatures, leading to reduced winter insect mortality. Some States north of the natural SPB range in the Northeastern United States have already experienced pine mortality and subsequent impacts from northward SPB infestations (Dodds and others 2018, Heuss and others 2019) and this range expansion is projected to continue (Lesk and others 2017). Insect pests are generally expected to continue to have even greater economic impacts as well as significant impacts on forest composition and structure in the future (Dukes and others 2009).

In 2020, over 33 percent of all wildland fires in the United States occurred in the Southeast region (National Interagency Coordination Center 2020). Many forest types in the South benefit from fire. For example, longleaf pine (*Pinus palustris*) forests rely on fire to maintain community composition and structure. However, some forest types are more susceptible to damage from wildfire due to long-term fire exclusion (Carpenter and others 2020). Wildfires are forecast to increase in the future due to projected increased temperature and drought conditions which may lead to longer fire seasons (Liu and others 2013). The risk of large wildfires (>12,355 acres) is forecast to increase in the Southeastern United States, especially in the Coastal Plain and Appalachian Mountain ecoregions (Barbero and others 2015). Fire may also be promoted or suppressed by certain invasive species, for instance C4 grasses like cogongrass (*Imperata cylindrica*) may increase fire intensity (Fusco and others 2019).

Sea-level rise and soil salinization are threats to coastal ecoregions. Globally, sea-level has risen approximately 3 inches since 1990, and some areas of the Southeast are particularly vulnerable (Carter and others 2018). The encroachment of saline water into coastal soils leads to the conversion of coastal forests to more saline wetland habitats where current forest types are no longer viable.

These threats are some of the significant disturbances to southeastern forests. As these threats change, so too should forest management practices that reduce risk. Strategies for adaptation and mitigation must be incorporated into forest management plans to increase resistance and resiliency to threats as the climate changes. The U.S. Department of Agriculture Southeast Climate Hub works to develop guides (Barlow and others 2021, Gibson and others 2021) and adaptive management tools to ensure the productivity and health of forests in the Southeast.

REFERENCES

- Barbero, R.; Abatzoglou, J.T.; Larkin, N.K. [and others]. 2015. Climate change presents increased potential for very large fires in the contiguous United States. *International Journal of Wildland Fire*. 24(7): 892–899.
- Barlow, B.; Andreu, M.; Asaro, C. [and others]. 2021. Pine forest landowners guide. Gen. Tech. Rep. SRS-260n. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 36 p. <https://doi.org/10.2737/SRS-GTR-260n>. (McNulty, Steven; Gavazzi, Michael, eds. Hurricane preparation and recovery in the Southeastern United States).
- Berdanier, A.B.; Clark, J.S. 2016. Multiyear drought-induced morbidity preceding tree death in southeastern U.S. forests. *Ecological Applications*. 26(1): 17–23.
- Bruyère, C.L.; Holland, G.J.; Towler, E. 2012. Investigating the use of a genesis potential index for tropical cyclones in the North Atlantic basin. *Journal of Climate*. 25(24): 8611–8626.
- Carpenter, D.O.; Taylor, M.K.; Callahan, M.A. [and others]. 2020. Benefit or liability? The ectomycorrhizal association may undermine tree adaptations to fire after long-term fire exclusion. *Ecosystems*: 1–16.

- Carter, L.; Terando, A.; Dow, K. [and others]. 2018. Southeast. In: Reidmiller, D.R.; Avery, C.W.; Easterling, D.R. [and others], eds. Impacts, risks, and adaptation in the United States: Fourth National Climate Assessment. Volume II. Washington, DC: U.S. Global Change Research Program: 743–808.
- Clark, J.S.; Iverson, L.; Woodall, C.W. [and others]. 2016. The impacts of increasing drought on forest dynamics, structure, and biodiversity in the United States. *Global Change Biology*. 22(7): 2329–2352.
- Dodds, K.J.; Aoki, C.F.; Arango-Velez, A. [and others]. 2018. Expansion of southern pine beetle into northeastern forests: management and impact of a primary bark beetle in a new region. *Journal of Forestry*. 116(2): 178–191.
- Dukes, J.S.; Pontius, J.; Orwig, D. [and others]. 2009. Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: what can we predict? *Canadian Journal of Forest Research*. 39(2): 231–248.
- Fusco, E.J.; Finn, J.T.; Balch, J.K. [and others]. 2019. Invasive grasses increase fire occurrence and frequency across U.S. ecoregions. *Proceedings of the National Academy of Sciences*. 116(47): 23,594–23,599.
- Gibson, N.; McNulty, S.; Miller, C. [and others]. 2021. Identification, mitigation, and adaptation to salinization on working lands in the U.S. Southeast. Gen. Tech. Rep. SRS-259. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 69 p. <https://doi.org/10.2737/SRS-GTR-259>.
- Heuss, M.; D'Amato, A.W.; Dodds, K.J. 2019. Northward expansion of southern pine beetle generates significant alterations to forest structure and composition of globally rare *Pinus rigida* forests. *Forest Ecology and Management*. 434: 119–130.
- Holland, G.; Bruyère, C. L. 2014. Recent intense hurricane response to global climate change. *Climate Dynamics*. 42(3-4): 617–627.
- Knutson, T.R.; McBride, J.L.; Chan, J. [and others]. 2010. Tropical cyclones and climate change. *Nature Geoscience*. 3(3): 157–163.
- Knutson, T.; Camargo, S.J.; Chan, J.C. [and others]. 2020. Tropical cyclones and climate change assessment: Part II: Projected response to anthropogenic warming. *Bulletin of the American Meteorological Society*. 101(3): E303–E322.
- Kossin, J.P. 2018. A global slowdown of tropical-cyclone translation speed. *Nature*. 558(7708): 104–107.
- Kunkel, K.E.; Stevens, L.E.; Stevens, S.E. [and others]. 2013. Regional climate trends and scenarios for the U.S. National Climate Assessment: Part 2. Climate of the Southeast U.S. National Oceanic and Atmospheric Administration Tech. Rep. 142-2. Washington DC: National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service. 103 p.
- Lesk, C.; Coffel, E.; D'Amato, A.W. [and others]. 2017. Threats to North American forests from southern pine beetle with warming winters. *Nature Climate Change*. 7(10): 713–717.
- Liu, Y.; Goodrick, S.L.; Stanturf, J.A. 2013. Future U.S. wildfire potential trends projected using a dynamically downscaled climate change scenario. *Forest Ecology and Management*. 294: 120–135.
- McNulty, S.; Baca, A.; Bowker, M. [and others]. 2019. Managing effects of drought in the Southeast United States. In: Vose, J.M.; Peterson, D.L.; Luce, C.H. [and others], eds. Effects of drought on forests and rangelands in the United States: translating science into management responses. Gen. Tech. Rep. WO-98. Washington, DC: U.S. Department of Agriculture Forest Service, Washington Office: 191–220. Chapter 9.
- National Interagency Coordination Center. 2020. Wildland Fire Summary and Statistics Annual Report. Boise, Idaho: National Interagency Fire Center. 54 p. https://www.predictiveservices.nifc.gov/intelligence/2020-statsum/annual_report_2020.pdf. [Date accessed: April 4, 2022].
- Olatinwo, R.; Guo, Q.; Fei, S. [and others]. 2014. Climate-induced changes in vulnerability to biological threats in the Southern United States. In: Vose, J.M.; Klepzig, K.D., eds. Climate change adaptation and mitigation management options: a guide for natural resource managers in southern forest ecosystems. Boca Raton, FL: Chemical Rubber Company Press: 127–172.
- Omerik, J.M. 1987. Ecoregions of the conterminous United States. *Annals of the Association of American Geographers*. 77(1): 118–125. Map (scale 1:7,500,000).
- Pye, J.M.; Holmes, T.P.; Prestemon, J.P.; Wear, D.N. 2011. Economic impacts of the southern pine beetle. In: Coulson, R.N.; Klepzig, K.D., eds. Southern Pine Beetle II. Gen. Tech. Rep. SRS-140. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 213–222.
- Sugi, M.; Murakami, H.; Yoshida, K. 2017. Projection of future changes in the frequency of intense tropical cyclones. *Climate Dynamics*. 49(1): 619–632.
- Vogt, J.T.; Gandhi, K.J.; Bragg, D.C. [and others]. 2020. Interactions between weather-related disturbance and forest insects and diseases in the Southern United States. Gen. Tech. Rep. SRS-255. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 255: 1–37.
- Vose, J.; Clark, J.S.; Luce, C.; Patel-Weynand, T. 2016. Effects of drought on forests and rangelands in the United States: a comprehensive science synthesis. Gen. Tech. Rep. WO-93b. Washington, DC: U.S. Department of Agriculture Forest Service, Washington Office. 93: 1–289.
- Zhao, T.; Dai, A. 2015. The magnitude and causes of global drought changes in the twenty-first century under a low-moderate emissions scenario. *Journal of Climate*. 28: 4490–4512.

ADAPTING TRADITIONAL FOREST MANAGEMENT PRACTICES TO ADDRESS CHANGING ENVIRONMENTAL STRESSES

Elijah Worley, Steven McNulty, Michael Gavazzi,
Kelsey Bakken, and Eva Paradiso

EXTENDED ABSTRACT

Climate patterns are changing across the Southeastern United States, influencing the frequency and intensity of natural disturbance events such as hurricanes, wildfires, and drought. Many of the devastating impacts from these disturbance events are being exacerbated by climate change, leading to widespread damage and losses, especially within the various forest ecosystems of the region. Examples of large-scale forest disturbance events are being experienced across many of the Southeastern States. In late 2018, Hurricane Michael destroyed approximately \$2 billion in timber across Florida and Georgia (Bates and McClure 2018, Florida Forest Service 2018). Studies have also predicted increasing drought frequency and subsequent wildfire occurrence across the Southeast, leading to declining forest productivity and increased fire-suppression costs (McNulty and others 2013, Mitchell and others 2014). Forests are increasingly susceptible to more severe and frequent disturbances, and managers are challenged to maintain stand health. Therefore, adaptive forest management is needed to increase forest resiliency to changing environmental conditions. Information must be readily available to help forest managers better understand these stressors and how to adapt their forest management approaches.

In 2010 the Forest Service, U.S. Department of Agriculture, created the Template for Assessing Climate Change Impacts and Management Options (TACCIMO). This web-based tool was developed to connect peer-reviewed climate change science with strategic-level forest planning and management. Users can input management objectives to gain access to summarized findings from scientific climate change publications that directly influence forest management. In addition to this search function, TACCIMO users may also filter climate change literature and publication selections by geographic location. While useful as a strategic information tool, TACCIMO is limited to forecasting expected outcomes. The Forest Operations Resource Tool (FORT) was created to connect those outcomes with operational (specific and stand-level) guidance to supplement TACCIMO.

FORT is a mobile application management tool that allows forest land managers to select adaptation practices to reduce or mitigate stand-level disturbances and threats. This tool provides management recommendations at differing levels of specificity from historical and widely used literature sources such as the Forestry Handbook, Service Forester's

Author Information: Elijah Worley, Environmental Technician, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709; Steven McNulty, Director, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709; Michael Gavazzi, Coordinator, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709; Kelsey Bakken, Environmental Technician, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709; and Eva Paradiso, Environmental Technician, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

Handbook, and various State forest management guides. FORT brings traditional practices from historical literature into an accessible, digital format. A field forester may access this information in the field when creating, implementing, or revising their management plans. FORT provides recommendations that encompass the entire timeline of a silvicultural regime, including site preparation and planting, intermediate treatments, and stand-initiation treatments. The management practices available from the tool are appropriate for the different forest types and species of the Southeastern United States. FORT provides a geospatial reference for these management practices by grouping applicable silvicultural prescriptions by ecoregion. Ecoregions are distinct assemblages of species, natural communities, and environmental conditions. The ecoregion scale ranges from the broadest (level 1) to the most specific (level 4) designations within the United States. (Commission for Environmental Cooperation 1997, Omernik 1987, Omernik and Griffith 2014). The geospatial reference aspect of FORT will allow a user to select management tactics appropriate for each ecoregion.

The integration of appropriate forest management practices from the source material into the database is FORT's primary function. This information is then divided into specific categories that help organize the management recommendations. These categories include general and sub-management goals, action and sub-actions, associated threats, species and forest type, ecoregion and location, and a standardized specificity rating. The management and sub-management goal categories correspond to the measurable outcomes accomplished by the management action. Goals in these categories may be sustaining ecological functioning within the forest stand or maximizing economic return through managing multiple timber products. The action and sub-action categories are descriptors of specific management recommendations. The associated threats category refers to specific disturbances (i.e., flooding, erosion, windthrow, etc.) the management action aims to mitigate. Species and forest type and ecoregion and location are categories designed to catalog geospatial and species-specific information. The specificity rating given to each management action ranges from level 1 to level 4. The specificity rating corresponds with the specificity of the management practice recommendation. For example, a recommendation of general thinning to improve tree vigor during a drought period would be in level 1, whereas a specific recommendation of basal area left following a cut for a specific forest type or species would be labeled as level 4. All categories can be accessed through the tool's search function, allowing users to generate a management plan specific to their forest stands.

As FORT is developed, more historical literature sources will be incorporated, giving users digital access to a variety of traditional management practices that foresters have implemented for generations. Access to this information is imperative for foresters facing increased natural disturbance frequencies and intensities. However, some management practices may be outdated. New implementation of traditional management tactics must be coupled with current climate science and projections to help forest managers adapt to a changing climate.

REFERENCES

- Bates, C.; McClure, M. 2018. Timber Impact Assessment: Hurricane Michael, October 10-11, 2018. Dry Branch, GA: Georgia Forestry Commission. 12 p. <https://gatrees.org/wp-content/uploads/2020/01/Hurricane-MichaelTimber-Impact-Assessment-Georgia-October-10-11-2018-2.pdf>. [Date accessed: April 6, 2022].
- Commission for Environmental Cooperation. 1997. Ecological regions of North America: toward a common perspective. Revised 2006. Montreal, Quebec, Canada: Commission for Environmental Cooperation. 71 p. + map. 1: 12,500,000; colored.
- Florida Forest Service. 2018. Initial value estimate of altered, damaged, or destroyed timber in Florida. Hurricane Michael initial timber damage estimation report. https://www.fdacs.gov/content/download/82204/file/hurricanemichaelinitialtimberdamageestimate_lite.pdf. [Date accessed: July 13, 2021].
- McNulty, S.; Caldwell, P.; Doyle, T.W. [and others]. 2013. Forests and climate change in the Southeast USA. In: Ingram, K.; Dow, K.; Carter, L.; Anderson, J., eds. Climate of the Southeast United States: variability, change, impacts, and vulnerability. Washington, DC: Island Press: 165–189.
- Mitchell, R.J.; Liu, Y.; O'Brien, J.J. [and others]. 2014. Future climate and fire interactions in the southeastern region of the United States. *Forest Ecology and Management*. 327: 316–326. <http://dx.doi.org/10.1016/j.foreco.2013.12.003>.
- Omernik, J.M. 1987. Ecoregions of the conterminous United States. *Annals of the Association of American Geographers*. 77(1): 118-125. 1: 7,500,000.
- Omernik, J.M.; Griffith, G.E. 2014. Ecoregions of the conterminous United States: evolution of a hierarchical spatial framework. *Environmental Management*. 54(6): 1249–1266.

EXPLORING ECONOMICS OF LOBLOLLY PINE MANAGEMENT IN DROUGHT USING EFFICIENCY ANALYSIS

Noah T. Shephard, Andres Susaeta, Omkar Joshi, and Rodney E. Will

EXTENDED ABSTRACT

Loblolly pine (*Pinus taeda*) is the most commercially important softwood in the Southern United States. Given its faster growth and the associated timber product price premiums, active forest management tools such as fertilization and thinning have long been used to increase loblolly pine growth in the Southern States. In Oklahoma, however, the precipitation gradient in the State has confined its growth in the southeastern counties where the trees grow under more xeric conditions than in most of the Southeast. With decreased stomatal conductance, photosynthetic rates, and transpiration caused by periodic droughts, the growth response of loblolly pine to active management may be different in Oklahoma. Therefore, this study was aimed to understand the economics of active management (e.g., thinning and fertilization) on loblolly pine growth, with and without drought in Oklahoma.

We used an efficiency analysis, known as data envelopment analysis (DEA), to understand the financial effectiveness of thinning and fertilization in loblolly pine plantations in Broken Bow, OK. Of note, the efficiency analysis gauges effectiveness by capturing inputs and outputs of any production system. In simple terms, a regime is considered most efficient if it utilizes minimum input to maximize output.

The requisite data for DEA was obtained from the Tier III site of Pine Integrated Network: Education, Mitigation, and Adaptation Project (PINEMAP). The growth in tree height and diameter were used as an input in the Forest Vegetation Simulator to project timber product volumes within pulpwood, chip-n-saw, and sawlog categories. The timber price information was obtained from the annual timber price reports published by the Texas A&M Forest Service. A slack-based data efficiency analysis was used to obtain effectiveness in terms of product and profit, which are called technical and economic efficiencies, respectively. Finally, information from both technical and economic efficiencies were used to obtain overall efficiencies.

The study results suggested that while thinning increased efficiency, +28 percent, across the board, fertilization as a stand-alone application was not financially attractive. The combination of thinning and fertilization, however, was the most efficient management regime. The study further suggested that efficiencies, -24 percent, associated with both thinning and fertilization will be negatively impacted by drought. Study results provide important information that can help landowners to navigate the best course of management actions to optimize return on their timberland investment under potential drought conditions.

Author Information: Noah T. Shephard, Graduate Student, Oklahoma State University, Stillwater, OK 74078; Andres Susaeta, Assistant Research Scientist, University of Florida, Gainesville, FL, 32611; Omkar Joshi, Assistant Professor, Oklahoma State University, Stillwater, OK 74078; and Rodney E. Will, Professor, Oklahoma State University, Stillwater, OK 74078.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Agriculture (USDA) McIntire Stennis projects (OKLO3042, OKL0 2929), the Oklahoma Agricultural Experiment Station, and the Department of Natural Resource Ecology and Management at Oklahoma State University. Special thanks to the gracious support of Mr. Ed Hurliman for the use of his property to support the Broken Bow, OK PINEMAP Tier III site. Funding for installation and measurement of the study site (2012-2017) was provided by PINEMAP, a coordinated agriculture project funded by the USDA National Institute of Food and Agriculture, Award no. 2011-68002-30185. Thanks to Casey Meek and the researchers at the Kiamichi Forest Research Station for installation and measurement of the study site.

EVALUATION OF LANDOWNER ACCESSIBLE CONTROL METHODS FOR JAPANESE STILTGRASS (*MICROSTEGIUM VIMINEUM*)

Casey L. Beam, Courtney M. Siegert, Joshua J. Granger, and Raymond B. Iglay

ABSTRACT

Japanese stiltgrass (*Microstegium vimineum*) is an invasive, annual C₄ grass that has spread extensively throughout riparian areas and upland forests in the United States. *Microstegium vimineum* can establish a dense monoculture in the understory of forest stands and inhibit the regeneration of native herbaceous and woody plant species. Controlling the occurrence and spread of this species is of great concern to both land managers and private landowners, but there are few direct comparisons of the effectiveness or application timing of different treatments for controlling *M. vimineum*. To fill this knowledge gap, a randomized complete block design was established in the Piedmont region of North Carolina to compare four potential control treatments (glyphosate, mechanical removal, manual removal, and vinegar) and three application timings (spring, summer, and fall). Prior to treatment and 6 weeks post-treatment, plots were measured for *M. vimineum* percent coverage and species richness, using a method of ocular estimation and Shannon's index, respectively. Results showed that 6 weeks post application, glyphosate was highly effective in removing *M. vimineum* regardless of timing (95-100 percent reduction) and vinegar was highly effective in the summer and fall applications (90-100 percent reduction). Species richness was higher in all treatment plots as opposed to control plots. These results provide preliminary evidence of the effectiveness of several common treatments on controlling *M. vimineum* that are accessible to landowners and have implications for plant diversity.

INTRODUCTION

Globalization has increased the spread of invasive species and is of particular concern in the Southeastern United States. One invasive plant species is Japanese stiltgrass (*Microstegium vimineum* [Trin.] A. Camus), an annual, C₄ grass physiologically suited for dry, open, sunlit conditions (Flory 2010, Hall and others 2014, Judge and others 2005). Native to Southeast Asia, *M. vimineum* was unintentionally introduced to the United States in Tennessee during the early 1900s (Barkworth and others 2003, Fryer 2011, Hall and others 2014, Judge and others 2005) when it was used as packaging material for Chinese porcelain (Culpepper and others 2018). Currently, *M. vimineum* is found in 27 states and Puerto Rico; however, it is most noted as a serious problem in the Eastern United States (EPPO 2016, North and Torzilli 2017). Unlike many C₄ grasses, this species has high habitat plasticity and can be found in a variety of low light, mesic conditions with moderate soil moisture and in soils with varying nutrient levels across upland and riparian areas (Hall and others 2014, Judge and others 2005).

Microstegium vimineum can produce up to 1,000 viable seeds during the growing season, and seeds can remain viable for 2 to 5 years in the soil seedbank (Gibson and others 2002,

Redwood and others 2018). Seeds are easily disseminated by a variety of vectors (e.g., vehicles, clothing, animal fur) (Manee and others 2015), including natural and anthropogenic disturbances (Hall and others 2014, Ward and Mervosh 2012). One example of seed dispersal through natural disturbance is flooding, because seeds are light-weight, buoyant, and therefore easily dispersed by water (Flory 2010, Nees 2016). Anthropogenic methods of transport include the transport of soil containing *M. vimineum* seeds (Christen and Matlack 2009, Rauschert and others 2010), timber harvesting using equipment that has worked in prior invaded areas and not been cleaned (Nees 2016), and attachment to human clothing and animal fur (EPPO 2016).

Microstegium vimineum has a competitive advantage among some native vegetation due to its ability to grow in a variety of soil and light conditions (Cutway 2017). *Microstegium vimineum* can occur in dry, sunlit locations such as open areas, blowdowns, hillsides, and manicured lawns, in addition to invading more heavily shaded areas like closed canopy forests (Flory 2010). Even at light levels as low as 18 percent, *M. vimineum* experiences little reduction in growth and often outcompetes and displaces other understory vegetation (Judge and others 2005, Ward and Mervosh 2012).

Author Information: Casey L. Beam, Graduate Student, Mississippi State University, Mississippi State, MS 39762; Courtney M. Siegert, Associate Professor, Mississippi State University, Mississippi State, MS 39762; Joshua J. Granger, Assistant Professor, Mississippi State University, Mississippi State, MS 39762; and Raymond B. Iglay, Assistant Professor, Mississippi State University, Mississippi State, MS 39762.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

Because *M. vimineum* is widely dispersed and can establish in mesic conditions, this species is often found along roadsides and riparian areas (Cole and Weltzin 2004, Hall and others 2014, Manee and others 2015, North and Torzilli 2017).

Once established, *M. vimineum* forms dense monocultures that slowly decompose at the end of the growing season, creating a mat of dense plant material inhibiting the regeneration of native species (Hall and others 2014, Ward and Mervosh 2012). Even after a disturbance, *M. vimineum*'s direct competition for resources and hypothesized allelopathy lead to decreased regeneration of native herbaceous plants and trees (EPPO 2016, North and Torzilli 2017, Pisula and Mieners 2010, Ward and Mervosh 2012). Pisula and Mieners (2010) found *M. vimineum* has an ability to inhibit germination through allelopathy of coexisting species within an ecosystem.

The ability of *M. vimineum* to outcompete native plant species and alter conditions conducive to native vegetation is concerning (Culpepper and others 2018, North and Torzilli 2017). Reductions in native plant diversity reduce habitat quality for wildlife and pollinators (Ward and Mervosh 2012). Frey and Schmit (2015) found that white-tailed deer (*Odocoileus virginianus*) avoid eating *M. vimineum*, as do other foragers. In addition, forests infested with *M. vimineum* can reduce aesthetic appeal and lead to decreased utilization of public parks and nature preserves (Ward and Mervosh 2012).

Methods of *M. vimineum* control include prescribed fire, application of pre- and/or post-emergent herbicides, hand pulling, and mowing. Prescribed burning can increase in *M. vimineum* growth post-fire (Wagner and Fraterrigo 2015, Ward and Mervosh 2012). Pre-emergent herbicides have been shown to have variable effects on *M. vimineum* emergence and reproduction. For example, Judge and others (2015) found that pre-emergent herbicides reduced *M. vimineum* biomass by 87 percent for at least 8 weeks. Post-emergent herbicides, including those registered for aquatic use, can be highly effective control methods. Studies show up to a 97 percent loss of *M. vimineum* biomass 8 weeks after application (Flory 2010) and a 75 to 100 percent loss, 6 weeks after application (Hall and others 2014). Ward and Mervosh (2012) showed that some post-emergent herbicides were equally effective at reducing *M. vimineum* biomass when applied at low doses as when applied at higher doses; however, using a low dosage of herbicide may require additional applications within the same season. Applications of post-emergent herbicides must be repeated annually, or *M. vimineum* will return to levels equivalent to untreated stands (Frey and Schmitt 2015, Hall and others 2014, Judge and others 2005, Ward and Mervosh 2012). The effectiveness of hand-pulling largely depends on the size of the treatment area (EPPO 2016, Ward and Mervosh 2012) and the care taken to completely remove all stems (Flory 2010). For

smaller sites where hand pulling would be feasible, hand pulling is considered the best and most cost-effective method of control when completed at the end of the growing season before seed release (EPPO 2016). Mowing and trimming was found to lead to an 82-percent loss of *M. vimineum* biomass during treatment years when performed during July or August (Ward and Mervosh 2012). However, a similar study by Flory and Lewis (2009) found that September or October mowing and trimming treatments were more effective. The difference in timing between the two studies could be due to the different phenological timing of the study locations. Ward and Mervosh (2012) completed their study in Connecticut, whereas Flory and Lewis (2009) completed their study in Indiana, which is more southern and would have an extended growing season relative to Connecticut. Mowing and trimming must be repeated in subsequent years, or it is hypothesized that *M. vimineum* biomass will return to levels of biomass present prior to the treatment application (Ward and Mervosh 2012). Thus, the seasonal timing of treatment applications is emerging as an important consideration of *M. vimineum* control.

With the threat that *M. vimineum* poses as an invasive species in forests evident, effective treatments for reducing *M. vimineum* cover need further evaluation among more diverse landscapes. Information is also needed regarding native vegetation responses to treatment applications including treatment types, rates, and timing. Prior studies regarding *M. vimineum* removal have investigated several control methods but lacked side-by-side comparisons to assess treatment effectiveness. Therefore, the objectives of this study are to: (1) compare effectiveness of four control methods for reducing *M. vimineum* cover among spring, summer, and fall application periods that are readily available and cost-effective to landowners in the Southeastern United States, and (2) evaluate species richness response to treatments and *M. vimineum* removal by comparing Shannon's Index of baseline and post-treatment vegetation communities.

MATERIALS AND METHODS

Study Site

The study occurred in Denver, NC (35° 31' 31.19" N, -81° 01' 28.20" W), in the western Piedmont, at ~ 235 m above sea level with minimal changes in topography (0-2 percent slope; Lincoln County GIS, Lincolnton, NC). Summer temperatures average 27.5 °C, and winter temperatures average 8.6 °C (U.S. Department of Commerce, NOAA 2021). Average annual precipitation is 119.6 cm (U.S. Department of Commerce, NOAA 2021). The soil type present throughout the study site is Chewlaca loam (Lincoln County GIS, Lincolnton, NC). Chewlaca loam soils are somewhat poorly drained with moderate permeability (U.S.

Department of Agriculture, NRCS 2021). The study site is located within a bottomland hardwood forest that is ~ 100 contiguous ha. The forest is comprised predominantly of yellow-poplar (*Liriodendron tuipifera* L.), American beech (*Fagus grandifolia* Ehrh.), red maple (*Acer rubrum* L.), and sweetgum (*Liquidambar styraciflua* L.). The midstory is largely absent, but where present, mostly comprised of *F. grandifolia*. The understory is predominantly *M. vimineum* and sparse Christmas fern (*Polystichum acrostichoides* Michx.). The site was chosen primarily because of the high-density coverage of *M. vimineum*.

Experimental Design

Within the study site, three study areas (~ 30-m²) were designated as treatment blocks. Within each study area, four treatments (see below) were implemented as well as a control ($n = 5$ treatment plots per block) among individual treatment plots of 2 x 2 m (4-m²) with a 1-m buffer in between. Basal area of overstory trees in each treatment block was determined within a 11.3-m fixed radius plot, and average canopy height of dominant and codominant trees measured using a clinometer (Ashton and Kelty 2018). Percent *M. vimineum* in each plot was estimated using an ocular estimation of cover in 10 percent interval categories (e.g., 0,10, 20, 30, ..., 100 percent) (Ward and Mervosh 2012). All understory vegetation within the 4-m² treatment plot was identified. Understory species richness was determined from the number of unique species in each plot. Understory species diversity was determined from the Shannon-Wiener Diversity Index. For species richness and diversity, *M. vimineum* was not included in calculations. Study areas had similar *M. vimineum* understory coverage density, based on ocular observation.

Treatment Applications

To assess the effectiveness of different *M. vimineum* control methods, four treatments were identified that were easily accessible to landowners: (1) herbicide application (glyphosate), (2) mechanical removal (mechanical trimmer), (3) manual removal (hand pulling), and (4) herbicide alternative (vinegar). Each removal treatment was then compared to a no treatment (control). The herbicide application consisted of a 2 percent solution of glyphosate, a broad-spectrum active ingredient, readily available to consumers using the pre-mixed solution Roundup® Ready-to-Use and its built-in spraying wand [2 percent glyphosate (isopropylamine salt), 2 percent pelargonic acid and related fatty acids, 96 percent other ingredients] Monsanto Company, Marysville, OH. The herbicide alternative application consisted of common white vinegar (acetic acid content of 5 percent) applied using a spray bottle. Both spray solutions were applied in all seasons during dry conditions with no precipitation during the 24- to 48-hour post-application

window. The mechanical removal application removed aboveground *M. vimineum* stems but left roots intact using a STIHL Pro Series FS70 R string trimmer. The manual removal application removed whole stems and root systems of *M. vimineum* biomass via hand-pulling. Any cut *M. vimineum* biomass remaining after manual treatment was removed from the plot and discarded outside of the study area.

Post-Treatment Data Collection and Analysis

All treatments were applied in early March 2020, early July 2020, and late September 2020, coinciding with phenological stages of *M. vimineum* development in the Piedmont of North Carolina. These stages were immediately after germination, after full stem expansion and moderate growth into the middle of growing season, and prior to seed-set for *M. vimineum*. Six weeks post-treatment, percent coverage of *M. vimineum*, understory vegetation species richness, and understory species diversity were measured for each treatment using the same methods for pre-treatment assessments. Post-treatment measurements were compared to pre-treatment measurements to determine treatment impacts (e.g., treatment type and timing) on *M. vimineum* coverage.

RESULTS

Removal of *M. vimineum* was most effective in the herbicide treatment with glyphosate (98 ± 0 percent average removal), followed by the herbicide alternative treatment with vinegar (79 ± 21 percent removal), and mechanical removal treatment (48 ± 15 percent removal) (fig. 1). Hand pulling was the least effective treatment for the removal of *M. vimineum* at 28 ± 14 percent (fig. 1). Glyphosate had consistent results for removal across seasons. Control of *M. vimineum* via vinegar and mechanical removal were more effective in the summer and fall treatment applications than spring (fig. 1). Hand pulling was slightly more effective at *M. vimineum* removal in the summer compared to spring or fall treatment applications, but never resulted in more than 50 percent removal in any seasonal application (fig. 1).

Average species diversity, as measured by the Shannon-Wiener Index, was low across all plots during the pre-treatment period due *M. vimineum* dominance (table 1). Six weeks following treatment applications, species diversity increased across all treatments and seasons. Following spring treatments, increases in plant diversity were modest, while greater increases in diversity were observed following summer and fall treatments. Manual removal had resulted in the largest overall plant diversity in spring (0.99), herbicide alternative treatments with vinegar resulted in the largest overall plant diversity in summer (1.32), and mechanical removal resulted in the largest overall plant diversity in the fall (1.03). The highest species richness in any treatment plot was observed after the summer application (1.32) with

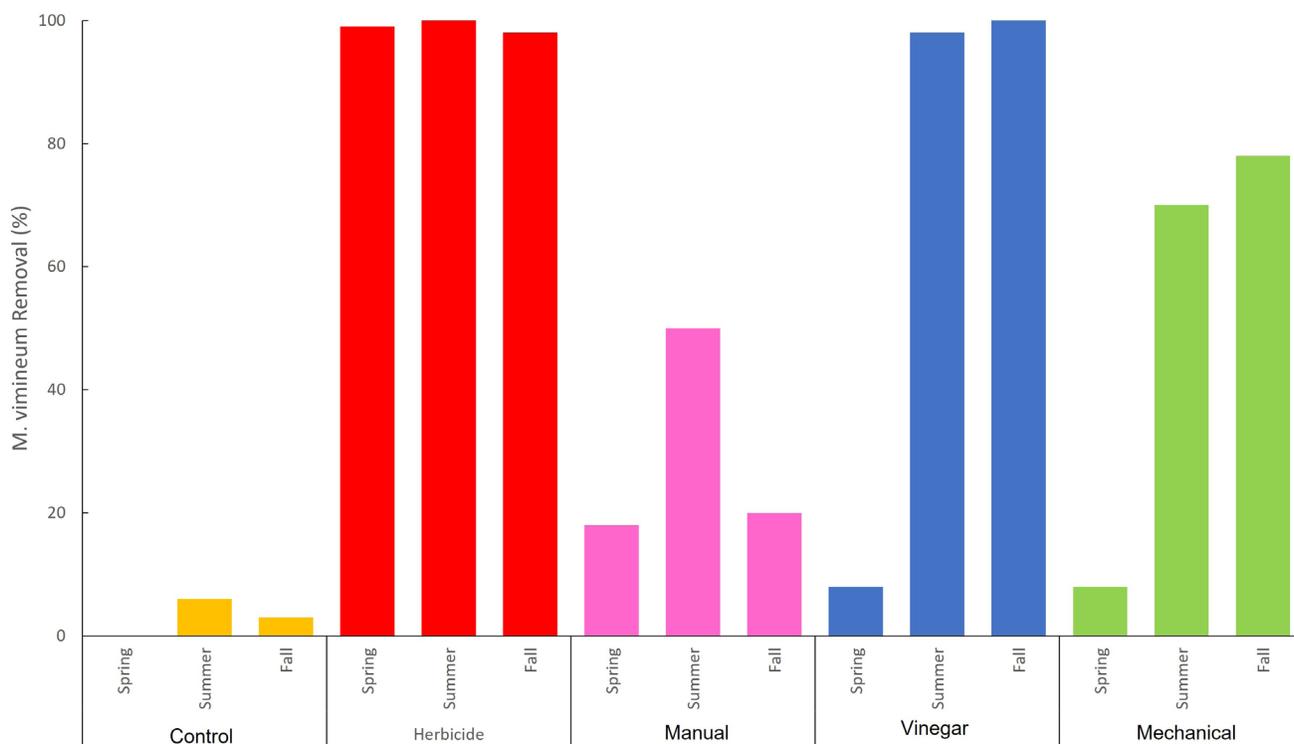


Figure 1—Percent *Microstegium vimineum* removed for each treatment type and time of application.

five species present among 23 individual stems. Glyphosate, despite being one of the more effective treatments for biomass removal, had adverse effects on species richness and had the lowest species richness and diversity over all the plots and application times (table 1).

The greatest variety of species returning 6 weeks post-treatment occurred in plots treated with vinegar in the summer with five different species emerging post-treatment, followed by the summer mechanical removal plot which had four different species emerge (table 1). The control plot and manual removal plots had similar numbers, but different species emerged post-treatment in each plot (two to three different species); however, the herbicide plots had the lowest number of species emerge post-treatment (one to two different species per plot) (table 1).

DISCUSSION

Herbicide application with glyphosate was the most effective treatment at reducing *M. vimineum* biomass. Post-emergent applications of fluazifop-P-butyl, acetic acid, pelargonic acid, imazapic, fenoxaprop-p-ethyl, glufosinate, glyphosate, clethodim, quinclorac, sethoxydim, and Monosodium Methanearsonate have all been considered effective treatments (Flory 2010, Frey and Schmitt 2015, Hall and others 2014, Judge and others 2005, Ward and Mervosh 2012). Flory (2010) found that the application of a post-emergent herbicide was more effective than hand pulling in

treating an area for *M. vimineum*. Despite being the most effective treatment at removing *M. vimineum*, herbicide had a negative correlation with species richness and diversity.

Glyphosate is a broad-spectrum, non-selective herbicide often killing plants within 2 weeks (Franz and others 1997). Six weeks after treatment, few species could have recovered or established due to the wide-ranging impact of glyphosate. In their review of glyphosate impacts on natural communities, Sullivan and Sullivan (2003) found vascular plant species richness was unaffected or increased in most (83 percent) studies after treatment. Miller and Miller (2004), along with others in a special issue of *The Wildlife Society Bulletin*, emphasized the short-term negative impacts (3-5 years) and selective impacts of forest herbicide applications on plant biodiversity, including broad spectrum glyphosate. However, Miller and Miller (2004) also showcased the unique advantages of selective herbicides for targeting unwanted plant pests. Future studies should explore selective herbicide impacts on *M. vimineum* and associated species richness and diversity. Such approaches could also help identify co-existing heterospecifics that may be released by treatments and tolerant of *M. vimineum* allelopathy (Pisula and Mierners 2010) such as other exotic species. Monitoring species richness and diversity recovery over longer periods (>6 weeks post-treatment) could also identify optimal control methods for concomitant *M. vimineum* control and native plant species conservation.

Table 1—Species richness as measured of unique individuals with number of stems in parentheses, and Species diversity as measured by the Shannon Wiener Index (SWI) in study plots prior to and 6 weeks post-treatment applications across all three seasons^a

Treatment	Pre-treatment		Post-treatment	
	Species richness	SWI	Species present	SWI
Spring				
Herbicide	<i>Parthenocissus quinquefolia</i> (2)	0.00	<i>Polystichum archo-stichoides</i> (1) <i>Vitis rotundifolia</i> (2)	0.64
Mechanical removal	<i>Allium canadense</i> (2) <i>Ligustrum sinense</i> (1)	0.64	<i>Allium canadense</i> (4) <i>Polystichum archostichoides</i> (3)	0.68
Manual removal	<i>Ligustrum sinense</i> (1) <i>Polystichum achrostichoides</i> (1)	0.69	<i>Lespedeza sp.</i> (5) <i>Ligustrum sinense</i> (2) <i>Polystichum archostichoides</i> (2)	0.99
Vinegar	<i>Acer rubrum</i> (1) <i>Ligustrum sinense</i> (2)	0.64	<i>Acer rubrum</i> (3) <i>Allium canadense</i> (1) <i>Ligustrum sinense</i> (10)	0.76
Control	No other species present ^b	0.00	<i>Allium canadense</i> (1) <i>Polystichum achrostichoides</i> (2)	0.64
Summer				
Herbicide	<i>Ligustrum sinense</i> (2)	0.00	<i>Ligustrum sinense</i> (1) <i>Polystichum achrostichoides</i> (3)	0.56
Mechanical removal	<i>Ligustrum sinense</i> (3)	0.00	<i>Allium canadense</i> (1) <i>Ligustrum sinense</i> (5) <i>Polystichum archostichoides</i> (3) <i>Vitis rotundifolia</i> (1)	1.17
Manual removal	<i>Ligustrum sinense</i> (2)	0.00	<i>Lespedeza sp.</i> (5) <i>Ligustrum sinense</i> (2) <i>Vitis rotundifolia</i> (1)	0.90
Vinegar	<i>Ligustrum sinense</i> (3)	0.00	<i>Allium canadense</i> (4) <i>Lespedeza sp.</i> (2) <i>Ligustrum sinense</i> (15) <i>Polystichum achrostichoides</i> (4) <i>Rubus fruticosus</i> (3)	1.32
Control	<i>Ligustrum sinense</i> (2)	0.00	<i>Ligustrum sinense</i> (3) <i>Panicum virgatum</i> (1) <i>Lespedeza</i> (1)	0.95
Autumn				
Herbicide	<i>Parthenocissus quin-quefolia</i> (3)	0.00	<i>Allium canadense</i> (5)	0.00
Mechanical removal	<i>Allium canadense</i> (2) <i>Ligustrum sinense</i> (2)	0.69	<i>Allium canadense</i> (10) <i>Ligustrum sinense</i> (9) <i>Vitis rotundifolia</i> (4)	1.03
Manual removal	<i>Ligustrum sinense</i> (1) <i>Polystichum archo-stichoides</i> (2)	0.64	<i>Ligustrum sinense</i> (3) <i>Polystichum archostichoides</i> (4)	0.68
Vinegar	N/A	0.00	<i>Carya tomentosa</i> (1) <i>Ligustrum sinense</i> (4) <i>Polystichum archostichoides</i> (3)	0.97
Control	<i>Ligustrum sinense</i> (1)	0.00	<i>Carya tomentosa</i> (1) <i>Ligustrum sinense</i> (5)	0.45

^aFor species richness and diversity, *Microstegium vimineum* was not included in calculations.

^bOnly *Microstegium vimineum* present.

After herbicide application, vinegar (an herbicide alternative) and mechanical removal were the next most effective controls of *M. vimineum*. These two treatments also had the greatest species richness and diversity measures, even greater than the untreated control plot. The removal of *M. vimineum* by vinegar and mechanical removal likely stimulated the seedbank and provided access resources to other native species. The ability of vinegar and mechanical removal to reduce *M. vimineum* cover and promote species richness and diversity would make them attractive options for private landowners with management goals that favor a more diverse herbaceous understory compared to herbicide application. These two treatments had the greatest success in the summer and fall applications. That is likely because *M. vimineum* was unable to recover from having expended resources earlier in the growing season. Understanding the seasonal dynamics of *M. vimineum* control options is critical to ensure treatments are effective both ecologically and economically to the landowner. Additionally, understanding how repeated annual applications of these treatments affects *M. vimineum* is an important next step in developing guidance for landowners to control *M. vimineum*.

Hand pulling was the least effective treatment application for *M. vimineum* removal. Hand pulling was the most labor intensive of all the treatment applications and required every stem and root system to be extracted from the soil to be effective (Flory 2010). Given the physical labor required to achieve <50 percent *M. vimineum* removal rate through hand pulling, this treatment application is less likely to be adopted by landowners and land managers when other less intensive and more successful treatment options exist.

CONCLUSIONS

Preliminary results suggest that chemical applications of commercial and alternative herbicides (e.g., glyphosate and vinegar) were most successful at reducing *M. vimineum* coverage and alternative herbicides likewise resulted in higher species diversity in treatment plots. Due to the success of glyphosate and vinegar in the first portion of the project, these two treatments will be replicated across three new studies sites using the same methods for the second portion of this study.

LITERATURE CITED

- Ashton, M.S.; Kely, M.K. 2018. *The Practice of Silviculture: Applied Forest Ecology*. John Wiley and Sons. 776 p.
- Barkworth, M.E.; Capels, K.M.; Long, S.; Piep, M.B. 2003. *Flora of North America North of Mexico*. Volume 25: Magnoliophyta: Commelinidae (in part): Poaceae, part 2. New York: Oxford University Press. 814 p.
- Christen, D.; Matlack, G.R. 2009. The habitat and conduit functions of roads in the spread of three invasive plant species. *Biological Invasions*. 11: 453–465.
- Cole, P.G.; Weltzin, J.F. 2004. Environmental correlates of the distribution and abundance of *Microstegium vimineum*, in east Tennessee. *Southeastern Naturalist*. 3: 545–562.
- Culpepper, L.Z.; Wang, H.H.; Koralewski, T.E.; Grant, W.E. 2018. Understory upheaval: factors influencing Japanese stiltgrass invasion in forestlands of Tennessee. *Botanical Studies*. 59: 1–8.
- Cutway, H.B. 2017. Effects of long-term manual invasive plant removal on forest understory composition. *Natural Areas*. 37: 530–539.
- European and Mediterranean Plant Protection Organization (EPPO). 2016. *Microstegium vimineum* (Trin.) A. Camus. EPPO Bulletin 46. European and Mediterranean Plant Protection Organization: 14–19.
- Flory, L.S. 2010. Management of *Microstegium vimineum* invasions and recovery of resident plant communities. *Restoration Ecology*. 18: 103–112.
- Flory, S.L.; Lewis, J. 2009. Nonchemical methods for managing Japanese stiltgrass (*Microstegium vimineum*). *Invasive Plant Science and Management*. 2: 301–308.
- Franz, J.E.; Mao, M.K.; Sikorski, J.A. 1997. *Glyphosate: a unique global herbicide*. American Chemical Society Monograph 189. Washington, DC: American Chemical Society. 653 p.
- Frey, M.; Schmitt, J.P. 2015. Suppressing Japanese Stiltgrass (*Microstegium vimineum*) with the grass-specific herbicide sethoxydim. *Natural Areas*. 35: 585–589.
- Fryer, L. 2011 *Microstegium vimineum*. In: *Fire Effects Information System*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. <https://www.fs.fed.us/database/feis/plants/graminoid/micvim/all.html>. [Date accessed: June 1, 2022].
- Gibson, D.J.; Spyreas, G.; Benedict, J. 2002. Life history of *Microstegium vimineum* (Poaceae), an invasive grass in southern Illinois. *The Journal of the Torrey Botanical Society*. 129: 207–219.
- Hall, K.R.; Spooner, J.; Richardson, R.J. [and others]. 2014. Post emergence control of *Microstegium vimineum* on riparian restoration sites with aquatic-use registered herbicides. *Journal of the American Water Resources Association*. 50: 533–543.
- Judge, C.A.; Neal, J.C.; Derr, J.F. 2005. Preemergence and postemergence control of Japanese stiltgrass (*Microstegium vimineum*). *Weed Technology*. 19: 183–189.
- Manee, C.; Rankin, W.L.D.; Kauffman, G.; Adkinson, G. 2015. Association between roads and the distribution of *Microstegium vimineum* in Appalachian Forests of North Carolina. *Southeastern Naturalist*. 14: 602–611.
- Miller, K.V.; Miller, J.H. 2004. Forestry herbicide influences on biodiversity and wildlife habitat in southern forests. *Wildlife Society Bulletin*. 32: 1049–1060.

- Nees, P. 2016. *Microstegium vimineum* (Trin.) A. Camus. OEPP/EPPO Bulletin 46. European and Mediterranean Plant Protection Organization. 46: 14–19.
- North, B.A.; Torzilli, A.P. 2017. Characterization of the root and soil mycobiome associated with invasive *Microstegium vimineum* in the presence and absence of a native plant community. *Botany*. 95: 513–520.
- Pisula, N.L.; Meiners, S.J. 2010. Relative allelopathic potential of invasive plant species in a young disturbed woodland. *Journal of the Torrey Botanical Society*. 137: 81–87.
- Rauschert, E.S.J.; Mortenson, D.A.; Bjornstad, O.N. [and others]. 2010. Slow spread of the aggressive invader, *Microstegium vimineum* (Japanese stiltgrass). *Biological Invasions*. 12: 563–579.
- Redwood, M.E.; Matlack, G.R.; Huebner, C.D. 2018. Seed longevity and dormancy state suggest management strategies for garlic mustard (*Alliaria petiolata*) and Japanese stiltgrass (*Microstegium vimineum*) in deciduous forest sites. *Weed Science*. 66: 190–198.
- Sullivan, T.P.; Sullivan, D.S. 2003. Vegetation management and ecosystem disturbances: impact of glyphosate herbicide on plant and animal diversity in terrestrial systems. *Environmental Review*. 11: 37–59.
- U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS). 2021. Web Soil Survey. <https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>. [Date accessed: May 3, 2022].
- U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA). 2021. National Weather Service, Greenville-Spartanburg Station. <https://www.weather.gov/gsp/>. [Date accessed: May 3, 2022].
- Wagner, S.A.; Fraterrigo, J.M. 2015. Positive feedbacks between fire and non-native grass invasion in temperate deciduous forests. *Forest Ecology and Management*. 354: 170–176.
- Ward, J.S.; Mervosh, T.L. 2012. Nonchemical and herbicide treatments for management of Japanese stiltgrass (*Microstegium vimineum*). *Invasive Plant Science and Management*. 5: 9–19.

CONNECTING STRATEGIC PLANNING WITH FOREST OPERATIONS USING THE FOREST ADAPTIVE MANAGEMENT ONLINE USER SYSTEM (FAMOUS)

**Kelsey Bakken, Eva Paradiso, Steven McNulty,
Michael Gavazzi, and Elijah Worley**

EXTENDED ABSTRACT

Forests in the Southeastern United States have always been impacted by various disturbances, including wildfires, storms, insects, and diseases. Through increasing temperatures and drought, climate change amplifies these threats and adversely affects forest productivity and resilience. There are many forest management and planning resources, but traditional strategic planning and management practices often do not address the evolving threats of climate change and variability. Therefore, the Forest Service, U.S. Department of Agriculture (USDA), Southeast Climate Hub is currently developing a three-component tool that will improve forest management as environmental challenges to forests continue to evolve.

The Template for Assessing Climate Change Impacts and Management Options (TACCIMO), the first component, is a tool that was developed by the Forest Service as an online database of climate change impacts and adaptation options for forests across the United States. TACCIMO has been used by the National Forest System for over a decade to assist with long-term (i.e., strategic) forest planning and is continuously being updated with the most recent scientific findings on forest threats and adaptation. Forest managers use TACCIMO's dropdown menus to select location, forest type, and management goal of interest. TACCIMO then searches the database and generates a report of potential impacts to those forests and strategies to increase forest resiliency. These recommendations are broad (e.g., reduced stand density will reduce insect outbreaks associated with drought) and developed for use in forest planning, but not operational management.

The Forest Operation Resource Tool (FORT), the second component, is an electronic version of the silviculture prescriptions and management recommendations from the handbook of the Society of American Foresters and the handbook of the Forest Service (among others). Like TACCIMO, FORT will also use a dropdown menu to allow the forest manager to select their location, forest type, age, stand condition, and management goal. FORT will then search through the database to provide tactical (i.e., operational) level management prescriptions.

Author Information: Kelsey Bakken, Environmental Technician, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709; Eva Paradiso, Environmental Technician, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709; Steven McNulty, Director, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709; Michael Gavazzi, Coordinator, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709; and Elijah Worley, Environmental Technician, U.S. Department of Agriculture, Southeast Regional Climate Hub, Research Triangle Park, NC 27709.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

The Forest Adaptive Management Online User System (FAMOUS), the third component, is a tool being developed to combine the broad adaptive forest management recommendations from TACCIMO and the operational scale of FORT. The design of FAMOUS is intended to be an interactive tool that forest managers can use to find management techniques that adapt to a changing climate. Forest managers may use adaptative techniques from FAMOUS to manage stands in the face of a specific threat. For example, potential southern pine beetle damage within a particular pine stand may be of particular concern. Users can select options for their management goal, forest type, threat, and ecoregion in the interface of FAMOUS. Based on the selections made, a climate-smart adaptive management plan will be produced that includes specific, operational management options from FORT (e.g., thinning to a specific stand density) that are adapted using strategic information from TACCIMO.

Future iterations of FAMOUS will include geospatial components and information from forest inventory and monitoring (e.g., stand stocking data from the National Forest System). FAMOUS is designed to be used interactively, to help find the best, science-backed adaptive practices to address changing forest threats. FAMOUS will initially be developed for the Southeastern United States, and if successful, the tool will expand across the United States.

ASSESSING THE FLOOD TOLERANCE OF WILLOWS AND COTTONWOODS PLANTED IN RIPARIAN CROPLAND OF THE LOWER MISSISSIPPI ALLUVIAL VALLEY

Thu Ya Kyaw, Courtney M. Siegert, Heidi J. Renninger,
and Randall J. Rousseau

EXTENDED ABSTRACT

The Lower Mississippi Alluvial Valley (LMAV) is a vital agricultural watershed of the United States. In addition to productive farmland, the LMAV has about 3 million ha of marginal lands (Amacher and others 1997), which are usually underutilized due to seasonal flooding during the spring and summer. These riparian floodplain areas are not optimal for agricultural food production, however, they may be suitable for growing short rotation woody crops (SRWCs) for bioenergy production. Since backwater flooding is common in the marginal lands of the LMAV, the selected SRWCs need to be tolerant of flooding. Although eastern cottonwood (*Populus deltoides* W. Bartram ex Marshall) and black willow (*Salix nigra* Marshall) are well-known riparian species (Amlin and Rood 2001), their flood tolerance threshold has not yet been reported through field trials. This study leveraged the high and extended flooding that occurred in the LMAV in 2019 to examine the flood tolerance of eastern cottonwood and black willow, planted as SRWCs for bioenergy on a riparian floodplain of the Yazoo River. To determine the flood tolerance thresholds of both species, this study developed models to predict survival or mortality probability of trees by considering hydrologic and environmental parameters as predictors. From the prediction models, this study estimated how timing, seasonality, and depth of flooding threatened the survival of both species.

In June 2018, a bioenergy plantation was established at the interface between cropland and an oxbow of the Yazoo River, located in Sidon, MS in the Mississippi Delta of the LMAV. Unrooted cuttings of 300 eastern cottonwood and 300 black willows were planted in a 1.8 m by 2.7 m (6 feet × 9 feet) spacing. Before flooding that started in November 2018, the establishment survival was 60 percent and 96 percent for eastern cottonwood and black willow, respectively. Flood depth and duration were monitored every half hour by installing HOBO U20L-01 loggers in 10 groundwater wells throughout the plantation site. An additional HOBO logger was mounted about 1.6 m above the ground surface to record air temperature and more importantly, atmospheric pressure to standardize the well sensors. To obtain flood depths for each individual tree during the study period, spatial interpolation was performed by considering flood depths recorded at groundwater wells and a digital elevation model created from LiDAR point cloud data (Photo Science 2010) as input parameters. Individual tree survival was modeled using binary logistic regression

Thu Ya Kyaw, Ph.D. Candidate, Mississippi State University, Starkville, MS 39762; Courtney M. Siegert, Associate Professor, Mississippi State University, Starkville, MS 39762; Heidi J. Renninger, Associate Professor, Mississippi State University, Starkville, MS 39762; Randall J. Rousseau, Extension and Research Professor, Mississippi State University, Starkville, MS 39762.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

with the “glm” function in R (R Core Team 2021). Five predictor variables were used: (1) average monthly flood depths, (2) growing season accumulated flood depth; (3) total accumulated flood depth; (4) flood duration; and (5) accumulated air temperature during flooding. Variable selection was conducted using the “bestglm” package (McLeod and others 2020) to select five candidate models using BIC (Bayesian Information Criteria) as the selection criteria. Then, those models were re-ranked based on test data accuracy by using *k*-fold cross-validation (Moreno-Torres and others 2012). During cross-validation, data were split into training (70 percent) and testing (30 percent), and their accuracy was calculated. Finally, flood tolerance threshold values were defined for each predictor included in the models.

Post-flooding survival was 17 percent for eastern cottonwood and 41 percent for black willow. The most common predictors included in the best fit models were flood duration (included in four models) and February flood depth (included in four models) for eastern cottonwood, and March (included in four models) and April (included in all five models) flood depths for black willow (table 1). As per threshold values, black willow could tolerate higher flood depth (up to 2.73 m in March and 2.28 m in April) than eastern cottonwoods (up to 2.63 m in March and 2.20 m in April) (table 1). The best fit models did not suggest that flood duration was a predicting factor of mortality in black willow. Compared to black willow, the survival of eastern cottonwood was affected by more factors, such as flood depth, flood duration and air temperature during flooding. Generally, dissolved oxygen is inversely correlated with water temperature (Joyce and others 1985, Null and others 2017, Post and others 2018), and water temperature can be increased with warming air temperature (Kaushal and others 2010). Thus, deficiency of dissolved oxygen due to the increase in water temperature can exert a compounding stress especially when the oxygen level is limiting in the flooded rhizosphere.

The overall accuracy of the best fit model for eastern cottonwood (88 percent) was slightly higher than that of the black willow (86 percent) (table 1). In predicting individual tree mortality, the eastern cottonwood model had fewer false positive predictions (i.e., the model predicted survival, but it was a mortality) than the black willow model. On the other hand, the model of black willow was better at predicting tree survival than that of eastern cottonwood because the former had fewer false negative predictions (i.e., the model predicted mortality, but it was a survival) than the latter.

Black willow was found more tolerant than eastern cottonwood. Only elevated flood depth posed a threat to survival. The results of this study suggest that flood depth during the pre-growing season (January, February, March) and growing season months are critical for predicting the survival of both species. Initial flooding months, such as November and December, did not greatly impact the survival of either species. In this study, black willow was taller than eastern cottonwood on average. Having a height advantage may have given black willow the ability to adapt to oxygen deficiency in the soil by increasing the formation of spongy aerenchyma tissues to undertake greater oxygen transport from aerial plant parts to the roots (Pezeshki and others 1998). In summary, this study identified threshold values, and beyond which, mortality was more likely than survival. This study further confirmed that willow was more flood-tolerant than cottonwood. Information about specific flood depth, flood duration, and air temperature can be useful for modeling optimal sites for establishing eastern cottonwood and black willow in frequently flooded, marginal lands of the LMAV.

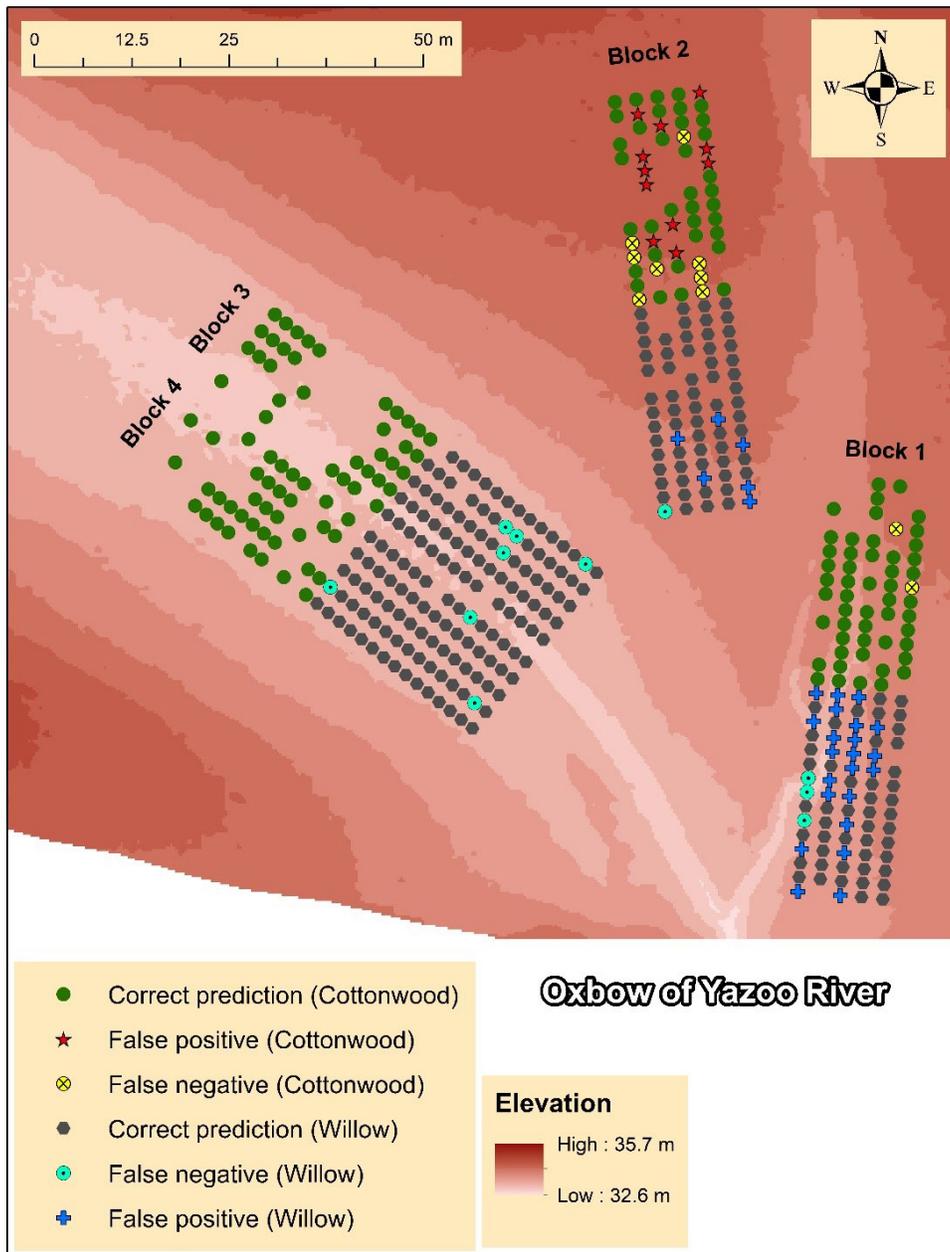


Figure 1— Map depicting the accuracy of the model with the highest test data accuracy (i.e., Model 1) for eastern cottonwood and black willow. Empty areas within the plantation plots represented mortality during the establishment period prior to flooding. False positives meant that the model predicted survival, but the individual died. False negatives meant that the model predicted a mortality, but the tree survived.

Table 1—Top five best fit models for predicting the survival or mortality probability of eastern cottonwoods (top) and black willows (bottom) based on test data accuracy

EASTERN COTTONWOOD											
No.	Variables included in the model	k-fold test data accuracy (%)	All data accuracy (%)	BIC	Flood depths (m)					Flood duration (weeks)	Accumulated air temperature during flooding (°C)
					Jan	Feb	March	April	May		
1	Feb and April flood depths, and flood duration	83	88	107.4		2.10		2.20			25.47
2	Jan and May flood depths, and flood duration	83	88	108.2	1.80				2.06		25.21
3	Feb and May flood depths, and flood duration	81	88	106.9		2.10			2.07		25.76
4	Feb and March flood depths, and flood duration	81	88	108.6		2.10	2.65				24.80
5	Feb and March flood depths, and accumulated air temperature during flooding	81	88	109.3		2.10	2.65				453.57

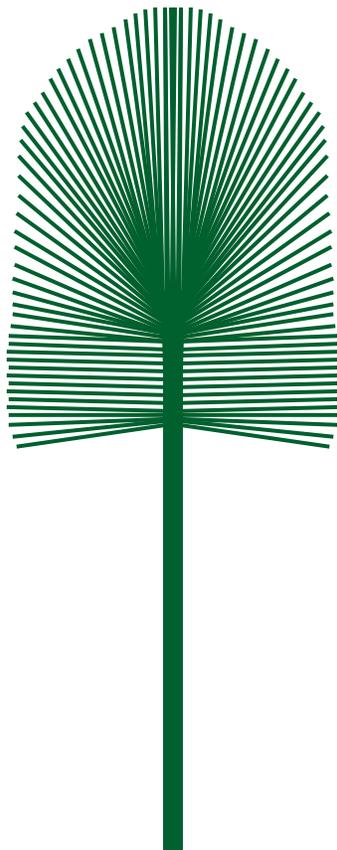
BLACK WILLOW											
No.	Variables included in the model	k-fold test data accuracy (%)	All data accuracy (%)	BIC	Flood depths (m)						Total accumulated
					Jan	Feb	March	April	May	June	
1	March, April, and June flood depths	90	86	215.5			2.73	2.28		0.52	
2	Feb, March, and April flood depths	90	86	217.5		2.19	2.73	2.28			
3	Jan, March, and April flood depths	88	86	216.6	1.96		2.73	2.28			
4	Jan, April, May, and June flood depths	88	88	219.6	1.96			2.28	2.15	0.51	
5	Jan, March, April, and total accumulated flood depths	87	86	218.9	1.96		2.73	2.28			14.73

Columns containing flood depths (m) in each month, flood duration (weeks), and accumulated air temperature during flooding (°C) represented threshold values that trees could tolerate.

LITERATURE CITED

- Amacher, G.S.; Sullivan, J.; Shabman, L.A.; Zepp, L.J. 1997. Restoration of the Lower Mississippi Delta bottomland hardwood forest: Economic and policy considerations. Research Bulletin 185. Blacksburg, VA: Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University. 85 p.
- Amlin, N.A.; Rood, S.B. 2001. Inundation tolerances of riparian willows and cottonwoods. *Journal of the American Water Resources Association*. 37(6): 1709–1720.
- Joyce, K.; Todd, R.L.; Asmussen, L.E.; Leonard, R.A. 1985. Dissolved oxygen, total organic carbon and temperature relationships in Southeastern U.S. Coastal Plain watersheds. *Agricultural Water Management*. 9(4): 313–324.
- Kaushal, S.S.; Likens, G.E.; Jaworski, N.A. [and others]. 2010. Rising stream and river temperatures in the United States. *Frontiers in Ecology and the Environment*. 8(9): 461–466.
- McLeod, A.I.; Xu, C.; McLeod, M.A.I. 2020. Best subset glm using information criteria or cross-validation. <https://cran.r-project.org/web/packages/bestglm/bestglm.pdf>. [Date accessed: March 30, 2021].
- Moreno-Torres, J.G.; Sáez, J.A.; Herrera, F. 2012. Study on the impact of partition-induced dataset shift on k-fold cross-validation. *IEEE Transactions on Neural Networks and Learning Systems*. 23(8): 1304–1312.
- Null, S.E.; Mouzon, N.R.; Elmore, L.R. 2017. Dissolved oxygen, stream temperature, and fish habitat response to environmental water purchases. *Journal of Environmental Management*. 197: 559–570.
- Pezeshki, S.R.; Anderson, P.H.; Shields, F.D. 1998. Effects of soil moisture regimes on growth and survival of black willow (*Salix nigra*) posts (cuttings). *Wetlands*. 18(3): 460–470.
- Photo Science, I. 2010. Mississippi river delta project contract: W912EE-07-D-0005. Mississippi Automated Resource Information System (MARIS). https://www.maris.state.ms.us/ftp3LIDAR/DeltaPhaseI_LIDAR_byCounty/Leflore/. [Date accessed: February 14, 2021].
- Post, C.J.; Cope, M.P.; Gerard, P.D. [and others]. 2018. Monitoring spatial and temporal variation of dissolved oxygen and water temperature in the Savannah River using a sensor network. *Environmental Monitoring and Assessment*. 190(5): 1–14.
- R Core Team. 2021. R: A language and environment for statistical computing. Version 4.0.4. Vienna, Austria: R Foundation for Statistical Computing. <https://www.R-project.org>. [Date accessed: February 11, 2021].

Longleaf Pine Management



CAN LONGLEAF PINE PLANTATIONS BE MODELED BY CALIBRATING MIXED-EFFECTS MODELS OF OTHER SPECIES?

Curtis L. VanderSchaaf

ABSTRACT

A growth-and-yield model system applicable for the relatively greater growth rates of more recently planted longleaf pine (*Pinus palustris* Mill.) is needed. The present analysis uses mixed-effects models of other pines fit using measurements across a more complete range of stand development stages to predict the future development of contemporary longleaf pine plantations. This approach could be useful when there are insufficient measurement ages across a rotation for newer silvicultural treatments. Testing data were obtained of container-planted longleaf pine in central Louisiana. Mixed-effects models both published and newly fit were used for testing purposes. Calibration ages of 6, 7, 8, 9, and 11 were helpful in “molding” trajectories of other species to the characteristics of these longleaf plots at age 20. However, to obtain accurate predictions at ages beyond 20 may require calibration measurements of longleaf pine at older, but still mid-rotation ages. It appears that there are likely “optimum” ages to conduct an inventory such that models of other species can be calibrated to produce accurate predictions at ages 25, 30, 35, etc.

INTRODUCTION

A complete growth-and-yield model system for the relatively greater growth rates of more recently planted longleaf pine (*Pinus palustris* Mill.) silvicultural systems is needed, particularly on cutover sites. These newer silvicultural systems often plant containerized seedlings, conduct herbaceous weed control treatments, and are established using relatively intensive site preparation, etc. This mixed-effects modeling approach asks if absolute age can be modified such that it is a relative measure rather than an absolute measure, and if so, perhaps the biological growth patterns can be applied across a range of species.

Thus, when entering data into traditional growth-and-yield models (for example, a stand table), the simulator can be considered to be “calibrated” to site-specific conditions. However, mixed-effects models could be advantageous because calibration can include more than one temporal observation that may allow for a better calibration and ultimately prediction of the future basal area trajectory.

VanderSchaaf and others (2020) showed a variety of mixed-effects basal area species models following calibration produced reasonable estimates of stand development for other species. The thought process was perhaps mixed-effects models could be calibrated using younger data from a stand of interest to produce reasonable estimates at older,

more common rotation ages. Could you in a sense “stretch”, “pull”, etc., through calibration of a mixed-effects model, a growth trajectory of a model developed using data with measurements across stand development stages of another species to produce reasonable projections for a trajectory of the species of interest? As shown in figure 1, can we take observed data from a longleaf pine stand and use it, through the calibration process, to “mold” a loblolly pine model (or any species or combination of species) such that we obtain a more appropriate trajectory through time for our (e.g., longleaf) stand of interest? Alternatively, we can think of it as can we “borrow” information from a loblolly pine model to better regulate how young data “mold” the stand of interest’s trajectory through time.

Basal area is thought to be advantageous as the variable of calibration, as opposed to volume, to ultimately produce volume of the species of interest because basal area measurements are not dependent on other relationships such as individual tree volume equations. The objective of this analysis is to use mixed-effects models of other species to predict the future development of more recently established longleaf pine plantations. It also examines if using more than one measurement to calibrate the models increases predictive ability.

Author Information: Curtis L. VanderSchaaf, Assistant Professor, Mississippi State University, Raymond, MS 39154.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

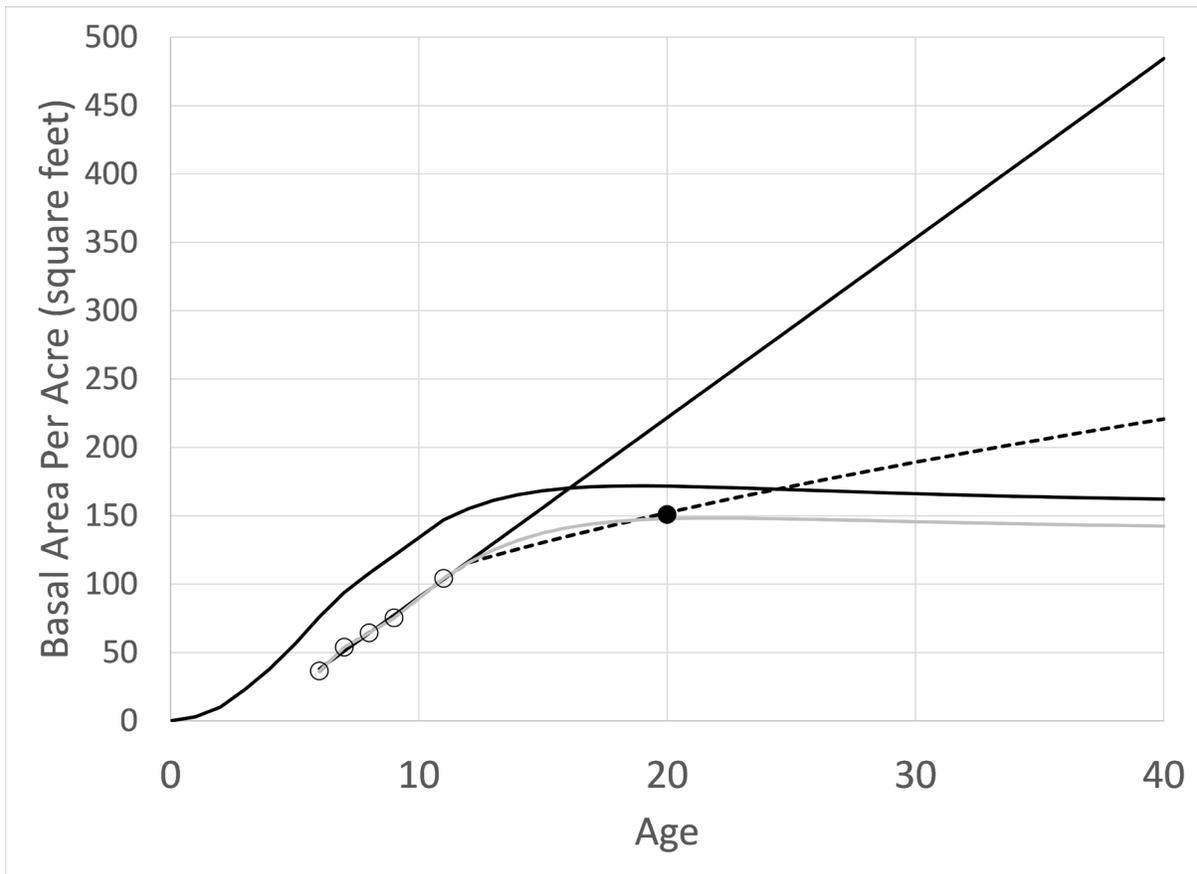


Figure 1—Black curve is a loblolly pine basal area trajectory (in this example from VPI). The white circles are observed basal areas (used in calibration) and the black circle is an observed basal area from block 4 used to test this modeling approach. The black line is a linear regression line fit using observations from ages 6 to 11. The dashed line, following calibration, are future projections by age obtained by always using observed data at age 11 as the previous basal area. The gray curve, following calibration, depicts basal area at age 12 using observed data from age 11, predicted basal area at age 13 using predicted basal area at age 12, and then subsequent annual predictions of basal area using the previous predicted annual basal area.

METHODS

Two linear mixed-effects equations presented in VanderSchaaf and others (2020) were used in this analysis. One fit using loblolly pine (*Pinus taeda* L.) from east Texas:

$$\ln BA_j = (2.6179 + u_{0i}) + (-0.1782) \ln(\text{Age}_{j-1} / \text{Age}_j) + (0.4583 + u_{2j}) \ln BA_{j-1} \quad (1)$$

where

\ln is natural logarithm; BA is basal area (square feet per acre); the variances of u_{0i} and u_{2j} are 0.1505, and 0.006589, respectively, there is also a covariance of -0.02998, and the constant random error variance is 0.02071; i indexes a specific stand, and j indexes the current and previous measurements. The dataset used to fit these equations is further referred to as ETX.

And the same equation form fit using a combined dataset of loblolly pine from east Texas and central Mississippi, ponderosa pine (*Pinus ponderosa* Lawson and C. Lawson) from the inland Northwest, and red pine (*Pinus resinosa* Aiton) from Ontario:

$$\ln BA_j = (2.1755 + u_{0i}) + (-0.4686) \ln(\text{Age}_{j-1} / \text{Age}_j) + (0.5508 + u_{2j}) \ln BA_{j-1} \quad (2)$$

where

\ln is natural logarithm; BA is basal area (square feet per acre); the variances of u_{0i} and u_{2j} are 0.2563, and 0.01236, respectively, there is also a covariance of -0.05446, and the constant random error variance is 0.01518; i indexes a specific stand, and j indexes the current and previous measurements. The dataset used to fit these equations is further referred to as ALL.

Data Used in Both Model Testing and Model Development

Study Site Description

The study site is on two soil complexes on the Kisatchie National Forest (KNF) within the humid, temperate, Coastal Plain and flatwoods province of the West Gulf Region of the Southeastern United States. The site is on uplands suitable for restoring longleaf pine forests. Site preparation consisted of a hot burn prior to planting.

Treatment Establishment

Research plots were established in a randomized complete block design of four blocks with three treatments (three pine species) each installed in the fall of 1997. Each of the 12 research plots measured 96 by 96 feet and contained 16 rows of 16 seedlings arranged in 6- by 6-feet spacing. Blocking was by soil complex (two blocks on each complex) and topographic location within each complex. The three southern pines studied, loblolly, longleaf, and slash pine (*Pinus elliotii* Engelm. var. *elliotii*), were randomly assigned to different plots within each block.

Seeds for all three species were supplied by the Stuart Seed Orchard, KNF, Louisiana, and were open-pollinated native Louisiana parent trees. Seedlings were grown in containers

by Forest Service, U.S. Department of Agriculture personnel in Pineville, LA. Seedlings, 1-0 container stock, were planted in March 1998.

Hexazinone was banded over the rows of planted pine seedlings in April 1998 on all 12 plots. A tricopyr tank-mix was applied as a directed foliar spray to hardwood trees and shrubs in April 1998 and June 1999.

More information can be found in Haywood and others (2015). Table 1 provides summary statistics by species and age. This dataset will further be referred to as LSSL, excluding age-20 data of longleaf pine. The age-20 data of longleaf pine is used for model testing purposes. The longleaf pine data from ages 6 to 11 exclusively will further be referred to as LL.

Table 1—Summary statistics of data used in both model testing and fitting (longleaf pine) and model fitting (slash and loblolly pine), (*n* = 4 per species)

Slash pine		Quadratic mean diameter				Basal area per acre				Total height			
		<i>inches</i>				<i>square feet per acre</i>				<i>feet</i>			
Age	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	
6	4.0	0.46	3.6	4.4	84	16.46	70	103	26.7	1.85	24.9	28.5	
7	4.4	0.37	4.1	4.8	103	14.00	91	120	28.7	1.99	27.0	30.8	
8	4.7	0.41	4.4	5.2	117	15.73	104	136	31.3	2.11	29.4	33.2	
9	5.0	0.41	4.6	5.4	129	15.73	116	149	36.6	2.46	34.0	38.8	
11	5.4	0.41	5.1	6.0	150	12.87	141	168	42.3	2.90	39.4	45.4	
20	6.6	0.56	6.0	7.3	199	11.49	191	216	57.5	4.99	53.2	63.1	
Longleaf pine		Quadratic mean diameter				Basal area per acre				Total height			
		<i>inches</i>				<i>square feet per acre</i>				<i>feet</i>			
Age	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	
6	3.1	0.26	2.8	3.4	42	6.41	36	51	18.5	0.56	17.9	19.1	
7	3.7	0.25	3.4	4.0	59	7.65	53	69	21.8	0.43	21.4	22.3	
8	4.1	0.29	3.7	4.4	71	8.99	64	83	25.0	0.65	24.2	25.7	
9	4.4	0.31	4.0	4.8	84	9.12	75	95	30.1	0.98	29.1	31.2	
11	5.1	0.32	4.7	5.5	112	11.55	101	126	36.3	1.22	34.8	37.5	
20	6.7	0.42	6.3	7.3	169	16.92	151	191	58.3	2.89	55.3	62.2	
Loblolly pine		Quadratic mean diameter				Basal area per acre				Total height			
		<i>inches</i>				<i>square feet per acre</i>				<i>feet</i>			
Age	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	
6	3.9	0.43	3.4	4.3	76	13.59	60	92	25.7	1.70	23.3	27.2	
7	4.3	0.36	3.9	4.7	94	12.43	80	110	27.4	1.80	25.0	29.2	
8	4.7	0.43	4.2	5.2	108	14.10	92	126	30.1	2.22	27.2	32.0	
9	4.9	0.45	4.5	5.5	121	14.76	104	140	35.5	2.42	32.3	37.6	
11	5.5	0.47	5.0	6.1	147	13.71	131	164	40.7	2.92	37.1	43.4	
20	6.7	0.74	6.0	7.5	190	22.64	161	211	56.8	7.05	49.2	63.2	

SD=standard deviation; Min=minimum; Max=maximum.

Validation Analyses

Prediction errors, following transformation back to the original units, were compared between equations (equations 1 and 2) using the validation process proposed by Arabatzis and Burkhart (1992). The difference between the predicted and observed basal area per acre ($e_i = PBA_i - BA_p$, respectively, for each individual plot $[i]$) was calculated for all equations. The mean residual (\bar{e}) and the sample variance (v) of residuals were computed and considered to be estimates of bias and precision, respectively. An estimate of mean square error (MSE) was obtained combining the bias and precision measures using the following formula:

$$MSE = \bar{e}^2 + v \quad (3)$$

To account for logarithmic transformation bias, the procedure recommended by Baskerville (1972) was used. All validation statistics presented in this paper are based on untransformed errors.

Additional Models

After preliminary analyses, it was thought to test mixed-effects models using other, more complete, and available datasets in terms of measurements across a range of

stand development stages on the same site. Hence, data from a long-term loblolly pine planting density study (VanderSchaaf and Burkhart 2012) was used to fit the same model form (equation 1) described above using the model fitting approach and criteria utilized by VanderSchaaf and others (2020). Quadratic mean diameter and trees per acre were measured annually between ages 5 and 21 on one of the Coastal Plain sites and to age 22 on the other site. On the Piedmont sites, measurement ages end at 18 at one location and 21 at the other. At the latter Piedmont site, one replication had measurements to 22 years of age. This dataset will be further referred to as VPI. Parameter estimates of equation 1 for this additional model are shown in table 2.

Additionally, datasets of two datasets were created and used to fit equation 1. The VPI dataset was combined with ETX, further referred to as ETXVPI, and the loblolly pine, ponderosa pine, and red pine dataset (ALL), further referred to as ALLVPI. Furthermore, LL was combined with these datasets. It was combined with the VPI dataset (further referred to as LLVPI), the ETX dataset (further referred to as LLETX) and the ALL dataset (further referred to as LLALL). The reason for combining the younger LL data with these

Table 2—Parameter estimates and standard errors (in parentheses) of equation (1) by model-fitting dataset for mixed-effects models

Dataset	b_0	b_1	b_2	Var	b_0 Var	b_2 Var	Covar (b_0, b_2)	neg 2LL	AIC	n
LLALL	2.14191 (0.11228)	-0.44908 (0.08794)	0.55833 (0.02241)	0.01589 (0.00087)	0.57486 (0.10517)	0.02670 (0.00494)	-0.12230 (0.02276)	-688.3	-674.3	202
ALLVPI	1.49807 (0.04514)	-0.44110 (0.05018)	0.69682 (0.00908)	0.00500 (0.00013)	0.40034 (0.03839)	0.01874 (0.00179)	-0.08587 (0.00825)	-7650.9	-7636.9	390
LLALLVPI	1.53334 (0.04927)	-0.42332 (0.05041)	0.68983 (0.00998)	0.00519 (0.00013)	0.53497 (0.04941)	0.02470 (0.00230)	-0.11421 (0.01060)	-7463.3	-7449.3	394
LLETX	2.77348 (0.12458)	-0.05602 (0.13020)	0.43115 (0.02267)	0.02210 (0.00171)	0.36516 (0.06847)	0.01559 (0.00341)	-0.07399 (0.01507)	-191.1	-177.1	97
ETXVPI	1.63685 (0.04740)	-0.24032 (0.05335)	0.67124 (0.00949)	0.00442 (0.00012)	0.37698 (0.03502)	0.01780 (0.00168)	-0.08142 (0.00763)	-7189.8	-7175.8	285
LLETXVPI	1.68533 (0.05157)	-0.22630 (0.05401)	0.66132 (0.01038)	0.00467 (0.00013)	0.49457 (0.04501)	0.02307 (0.00216)	-0.10633 (0.00981)	-6981.4	-6967.4	289
LLVPI	1.14065 (0.05763)	-0.74988 (0.09654)	0.77134 (0.01016)	0.00258 (0.00007)	0.29338 (0.01253)	0.00997 (0.00030)	-0.05405 (0.00198)	-8184.2	-8170.2	194
VPI, b_0	1.20082 (0.02767)	-0.42958 (0.06862)	0.76229 (0.00461)	0.00261 (0.00007)	0.00121 (0.00015)	-	-	-8611.3	-8601.3	191
VPI, b_2	1.15535 (0.02639)	-0.53679 (0.06697)	0.76970 (0.00443)	0.00276 (0.00008)	-	0.00004 (0.00001)	-	-8496.7	-8486.7	191

b_0 Var and b_2 Var are estimates of the random effects variance components when applicable, Covar (b_0, b_2) is the covariance estimates between b_0 and b_2 when applicable, neg 2LL is -2 negative log-likelihood, and AIC is Akaike Information Criterion. For the VPI dataset models, since convergence criterion was not obtained when including both b_0 and b_2 as random effects, there is no covariance between the random effects of b_0 and b_2 ; - = lack of parameter estimates; LL = longleaf pine age 11 and younger in Central Louisiana; VPI = loblolly pine in the Atlantic Coastal Plain and Piedmont; ETX = loblolly pine in east Texas; ALL = ETX plus loblolly pine in Mississippi, ponderosa pine in the inland Northwest, and red pine in Ontario.

For both model fitting criterion, more negative numbers are superior. n is the number of clusters (or plots) used in model fitting.

Table 3—Parameter estimates and standard errors (in parentheses) of equation (1) by model-fitting dataset for fixed-effects models

Dataset	b_0	b_1	b_2	Var	neg 2LL	AIC	n
LSLL	0.91222 (0.07966)	-0.43080 (0.04290)	0.82224 (0.01854)	0.00185 (0.00035)	-193.5	-185.5	56
LL	0.74564 (0.10592)	-2.15966 (0.24302)	0.79986 (0.02670)	0.00084 (0.00030)	-67.8	-59.8	16

neg 2LL is -2 negative log-likelihood; AIC is Akaike Information Criterion; LL = longleaf pine age 11 and younger in Central Louisiana; LSLL = all loblolly and slash pine ages, longleaf pine age 11 and younger in Central Louisiana.

For both model fitting criterion, more negative numbers are superior. *n* is the number of individual basal area observations (not plots) used in model fitting.

other datasets is to determine if by combining observed younger data with more biologically-complete datasets using a mixed-effects modeling approach, can we then achieve better predictions beyond the observed younger data of the species of interest (longleaf in this case)? When modeling newer silvicultural treatments of the species of interest, it may be best to use models fit of other species that were also intensively managed. Here, we were not necessarily able to do that per se, although the VPI dataset was relatively intensive at the time of study establishment.

Finally, datasets of three datasets were created and used to fit equation 1. ETXVPI was combined with LL, further referred to as LLETXVPI and ALLVPI was combined with LL, further referred to as LLALLVPI. Datasets were combined to help determine if predictive ability is improved following calibration for the species of interest when there is more variability in the model fitting dataset (e.g., if there is more variability in the random effects, is that beneficial to produce better calibrated projections). Validation analyses were conducted for these models in a similar fashion as described above.

Additionally, for comparative purposes to the calibrated mixed-effects models, a fixed-effects model using only ages 6 to 11 of the longleaf pine data (LL) was fit. Additionally LSLL, which is loblolly and slash pine data ages 6, 7, 8, 9, 11, and 20 and the longleaf data from ages 6, 7, 8, 9, and 11 (excluding age 20), was used to fit a fixed-effects model. Parameter estimates of equation 1 for this additional model are shown in table 3.

RESULTS

Model Fitting

For most datasets, models with two random parameters (both a fixed and mixed component) achieved convergence criteria for equation 1 (table 2). There is some variability among the fixed-effects parameter estimates (b_0 , b_1 , and b_2) among the datasets. For all datasets the random-effect covariance was negative. For the VPI dataset, model fitting criteria could only be met when using one random

parameter. The model with b_0 random had better model fitting statistics but often predictive ability of an independent dataset doesn't necessarily agree with model fitting ability. Hence, both model forms were reported and tested.

Entirely fixed-effects models of equation 1 (table 3) had fairly different parameter estimates than mixed-effects models presented in table 2. Differences are likely due to the young nature of the data (table 1). Additionally, models presented in table 3 are technically not biologically correct because they ignore the behavior of individual stand trajectories when estimating parameters, often one of the advantages of mixed-effects models is their ability to account for individual stand behavior when estimating the population average (PA) trend, or the fixed-effect component of the model.

Model Testing

Most mixed-effects models, whether calibrated or not, underpredicted observed basal areas at age 20 (table 4). The best performing models in terms of both bias (*e*) and MSE was the age 11-only calibration and the PA of the VPI, Random b_2 model and the LLVPI model when calibrating using only ages 7, 8, and 9. However, based on the summation of MSE across all calibration age sets, the LLVPI model behaved the best followed by the VPI, Random b_2 model. Excluding the age 11-only calibrations, additional observations used in calibration substantially improved predictive ability for most models, the exception being the LLVPI model when age 11 was also used in calibration along with ages 7, 8, and 9. However, excluding the age 11-only calibrations, in many cases the PA model or uncalibrated model for a particular dataset performed the best. Models fit using some amount of the VPI dataset generally performed the best while models containing the ETX dataset generally performed the poorest (fig. 2).

In many cases the use of only age 11 in calibration improved predictive ability. The LL Fixed model greatly overpredicted stand development because the mid-rotation inflection point of the basal area trajectory was not yet observed (figs. 1 and 2).

Table 4—Model validation results following calibration of equation (1) by dataset and ages used in calibration, n = 4

Calibration ages	VPI, Random b0			VPI, Random b2			ALL			ETX		
	e	v	MSE	e	v	MSE	e	v	MSE	e	v	MSE
PA	-12.09	60.15	206.2	-3.44	55.88	67.7	-11.10	92.56	215.7	-35.09	133.31	1364.4
7	-53.03	60.13	2872.4	-40.70	49.50	1706.1	-46.58	65.42	2235.1	-72.69	97.67	5380.9
7, 8	-45.54	39.90	2114.0	-33.59	33.72	1162.2	-44.89	44.06	2059.4	-69.53	75.38	4909.9
7, 8, 9	-37.35	46.13	1441.0	-26.38	40.40	736.4	-39.96	49.86	1646.8	-63.82	77.69	4150.7
7, 8, 9, 11	-15.81	60.33	310.3	-7.03	58.33	107.8	-23.09	61.93	595.1	-47.11	78.19	2297.9
11	-9.22	63.12	148.2	-1.37	59.40	61.3	-10.13	68.67	171.3	-33.13	92.97	1190.4

Calibration ages	LLALL			ALLVPI			LLALLVPI			LLVPI		
	e	v	MSE	e	v	MSE	e	v	MSE	e	v	MSE
PA	-12.59	92.08	250.7	-12.67	68.29	228.8	-13.96	70.04	264.8	17.71	51.16	364.8
7	-49.14	64.77	2479.3	-52.69	66.78	2842.6	-54.58	67.96	3047.4	-14.96	73.04	297.0
7, 8	-45.49	43.69	2112.9	-46.71	39.05	2221.1	-48.27	40.04	2369.6	-11.54	40.81	174.0
7, 8, 9	-39.35	51.56	1599.8	-38.95	45.61	1562.8	-40.26	46.76	1667.5	-5.43	37.27	66.8
7, 8, 9, 11	-19.80	63.29	455.4	-14.17	52.39	253.3	-15.02	51.96	277.6	11.48	62.04	193.9
11	-11.45	70.14	201.2	-8.57	64.84	138.4	-10.20	64.71	168.7	18.99	77.83	438.5

Calibration ages	LLETX			ETXVPI			LLETXVPI			LL Fixed			
	e	v	MSE	e	v	MSE	e	v	MSE	e	v	MSE	
PA	-40.97	145.20	1824.0	-27.86	82.58	858.6	-28.78	84.98	913.5	Fixed	164.90	198.39	27388.9
7	-82.94	103.96	6983.3	-71.93	81.43	5255.7	-73.18	82.58	5438.5				
7, 8	-78.09	83.96	6181.6	-64.18	54.98	4173.5	-65.21	56.00	4308.0				
7, 8, 9	-71.01	88.32	5130.6	-55.09	62.28	3097.0	-55.94	63.32	3192.2				
7, 8, 9, 11	-51.47	89.83	2738.9	-27.95	58.83	840.0	-28.59	58.87	876.5	Fixed	-12.91	55.25	222.0
11	-39.78	103.72	1686.1	-23.71	67.66	629.7	-25.08	69.26	698.4				

PA = population average prediction for a model-fitting dataset where no calibration of the mixed-effects model occurred; e = residual, or the difference between the predicted and observed basal area; v = variance of residuals; MSE = mean square error (see equation 3); LL = longleaf pine age 11 and younger in Central Louisiana; LSL = all loblolly and slash pine ages, longleaf pine age 11 and younger in Central Louisiana; VPI = loblolly pine in the Atlantic Coastal Plain and Piedmont; ETX = loblolly pine in East Texas; ALL = ETX plus loblolly pine in Mississippi, ponderosa pine in the inland Northwest, and red pine in Ontario.

For the mixed-effect model, calibration ages are those ages used in calibration. For age 7, the previous measurement age and basal area was age 6.

For the LLVPI model when calibrated using ages 7, 8, and 9, the VPI, Random b_2 PA model, and the VPI, Random b_2 when calibrated using ages 7, 8, 9, and 11, and when calibrated using just age 11 data, absolute percent errors of 3.50 percent, 1.83 percent, 4.42 percent, and 3.81 percent, respectively were produced.

DISCUSSION

The VPI dataset likely performed best since the data consists of annual measurements by stand (plot) trajectory to common rotation ages which likely captures the entire biological behavior of a stand basal area trajectory. Plus, models fit using this dataset likely behaved well because of relatively greater early management activities and planting genetic stock (Amateis and others 1988) as compared to the ETX (Lenhart and others 1985) and ALL datasets. These observed longleaf pine trajectories are relatively productive

at age 20 for this species (table 1) (e.g., Cram and others 2010, Haywood 2015). Perhaps for less productive longleaf pine sites in this region the ETX dataset may perform better. Since loblolly has been shown to be relatively more productive than longleaf when previous generation management activities were used (numerous studies), at least early in the rotations, it was thought that the ETX dataset would be more appropriate for more recently established longleaf pine sites, since more recently established longleaf pine sites were thought to be more productive relative to longleaf plantations established using previous generation management activities. However, as stated earlier, these longleaf plots at age 20 are highly productive for this species and apparently more productive on average than previous generation loblolly from the Western Gulf. The observed basal areas at age 20 were 163, 191, 171, and 151 square feet per acre.

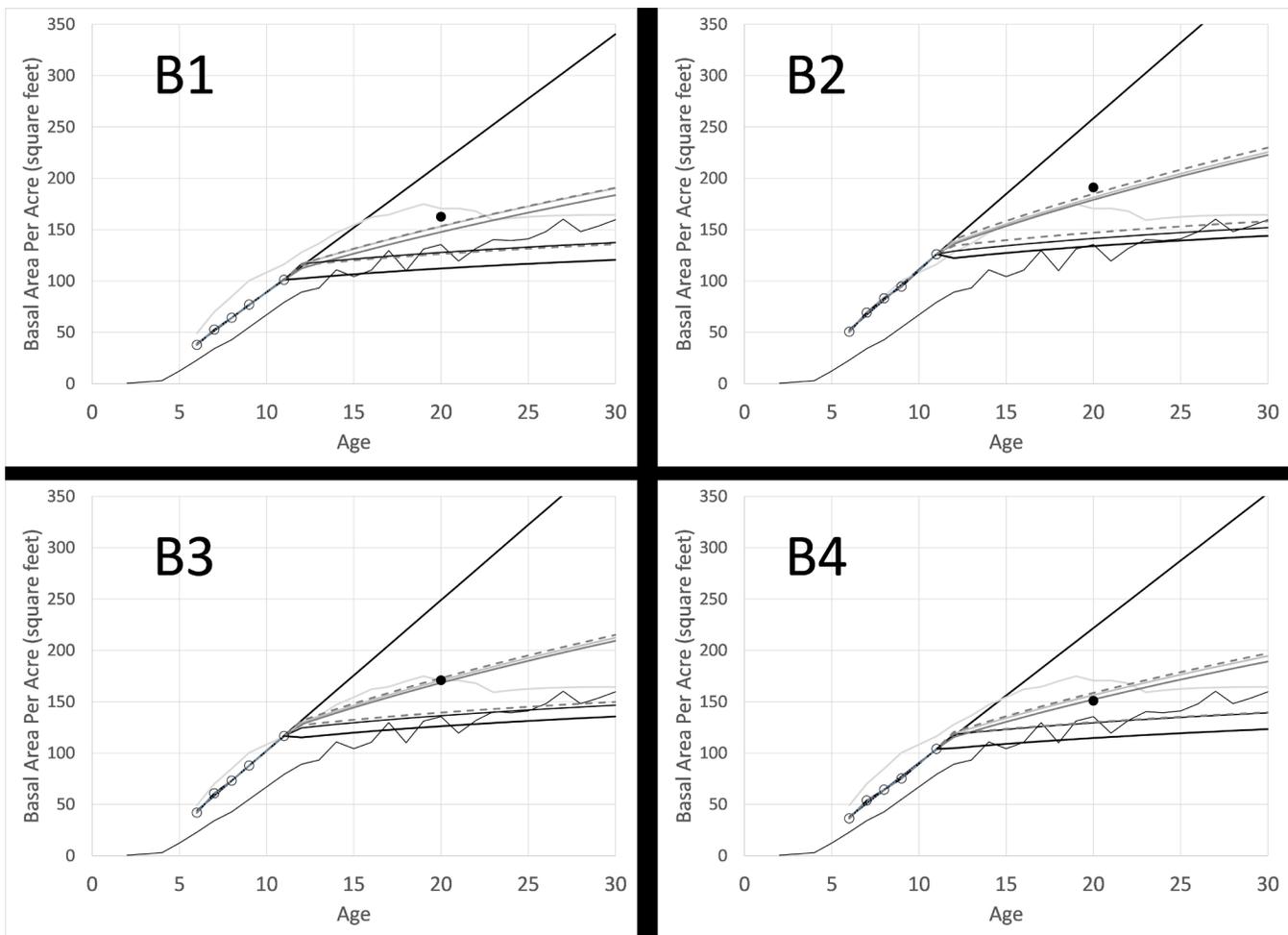


Figure 2—Observed and predicted longleaf pine basal area per acre by block (B). The gray and black unsmooth curves are the average basal areas by age from the VPI and ETX datasets, respectively—these curves ignore individual stand (or plot) behavior and merely are included to provide some indication of average predicted behavior across all stands. The black line is a linear regression using only ages 6 to 11 in model fitting, the upper and lower dashed lines are the VPI, Random b_2 , and ETX models calibrated using age 11-only observations, respectively. Bold gray and black curves are the VPI, Random b_2 , and ETX models, calibrated using ages 7 to 11, respectively. Light gray and black curves are the population average trends for the VPI, Random b_2 and ETX models, respectively. The white circles are observed basal areas and the black circles are observed basal areas at age 20. Curves extend to age 20, and beyond, by using age 11 observed basal area per acre as the regressor value in the equations (e.g., equation 1).

Following calibration, the PA behavior of the mixed-effects models added an inflection point to the predicted longleaf pine trajectories after age 11 basically remedying the substantial overprediction that would have occurred at age 20 if the general trend from ages 6 to 11 (LL) had been maintained (fig. 2). Hence, the calibration data and the PA behavior of the mixed-effect models are working in unison to produce a more biologically correct basal area trajectory for ages beyond those used in calibration. We are in a sense “borrowing” information from other species to produce a more likely basal area trajectory through time of our longleaf pine plantations.

In many studies where longleaf was established with loblolly and slash pine, the basal area trajectories of longleaf eventually caught up to those other species and in some cases exceeded production of those other species. Table 1 shows longleaf basal area per acre is starting to approach those of

loblolly and slash, having on average, the greatest basal area periodic increments from ages 9 to 11 and then 11 to 20. Most likely each species is going to have some range of calibration ages that is going to result in the calibration process producing relatively accurate future basal area trajectory estimates. For instance, perhaps the inclusion of age 15 (or by itself) into the calibration ages used for this dataset would produce better predictions for longleaf, but perhaps for ponderosa pine the “optimum” age for calibration may be around 25 or 30 since in general ponderosa pine has relatively longer biological and traditionally managed (e.g., for timber production) economic rotation ages.

How do we as managers optimize our resources in terms of time, costs, etc., to conduct inventories that will result in our ability to best predict future stand development? In order to get accurate results at ages 35 or 40, if desired, does spending money to conduct an inventory at age 10 help, or is

an inventory at age 20 sufficient, yet, you have to wait those additional 10 years to produce sufficient long-term estimates of stand development. This additional waiting time can be problematic if one is trying to project research studies such as silvicultural options and genetic selection to financially and biologically mature ages. Additionally, these “optimum” calibration ages may vary by site quality and management activity by species. Perhaps a longleaf pine dataset of relatively lower productivity at age 20 than that used here would have younger, or older, “optimum” ages.

For the VPI dataset models, generally the observed longleaf data were less than the average basal area per acre behavior across time, while for the ETX dataset the observed data were greater (fig. 2). Most likely, for the VPI datasets, the younger data resulted in underprediction at age 20 because it pulled the VPI PA trend down, while for the ETX datasets (and likely the ALL datasets), the average behavior (and/or model parameter estimates) were not flexible enough to allow the observed longleaf data to “pull it up.” In many cases the use of only age 11 in calibration improved predictive ability because of less underprediction (table 4, fig. 2). Perhaps for longleaf pine when calibrating these models using more observations, of younger ages, calibration can be problematic because of the observed data’s ability to pull the calibrated trajectory down.

Clearly, calibration is in a sense a “give-and-take”, or a “power struggle,” between the observed data, which is being used to calibrate, and the PA trend of the mixed-effects models. What is often referred to as “shrinkage” of the cluster-specific or plot/stand-specific behavior to the PA trend. The ability of the observed data to “mold” or “alter” the path of a PA trend likely greatly depends on the variability of the random effects, in addition to the calibration sample size. Even though a PA curve may be grossly incorrect for a plot of a particular species, if the random effects have large variances they will likely be flexible enough to be adjusted to the behavior of the calibration (or species of interest) species through the calibration process, particularly if the calibration sample size is large.

For this model form (e.g., equation 1), whether the oldest calibration age and basal area or, alternatively, predicted ages and basal areas, are used as the previous prediction age and basal area can influence projections (fig. 1). Based on these results, as utilized in figure 2, it appears best to always use the oldest calibration age and basal area (the last observed age and basal area) as the previous age and basal area (in this particular case the observed basal areas at age 11). This is in

opposition to using predicted basal areas to predict future basal areas.

Results here are promising but calibration among species may not be a complete panacea and without issues. It appears different trajectory shapes among species, and to some extent stands in general, reduces predictive ability. Further study needs to be conducted using ages of 15 and 20 in calibration and study needs to be conducted of other longleaf plantations. These longleaf pine plots were relatively productive for this species.

LITERATURE CITED

- Amateis, R.L.; Burkhart, H.E.; Zedaker, S.M. 1988. Experimental design and early analysis for a set of loblolly pine spacing trials. Gen. Tech. Rep. NC-120. U.S. Department of Agriculture Forest Service: 1058–1065.
- Arabatzi, A.A.; Burkhart, H.E. 1992. An evaluation of sampling methods and model forms for estimating height-diameter relationships in loblolly pine plantations. *Forest Science*. 38: 192–198.
- Baskerville, G.L. 1972. Use of logarithmic regression in the estimation of plant biomass. *Canadian Journal of Forest Research*. 2: 49–53.
- Cram, M.M.; Outcalt, K.W.; Zarnoch, S.J. 2010. Growth of longleaf and loblolly pine planted on South Carolina sandhill sites. *Southern Journal of Applied Forestry*. 34(2): 79–83.
- Haywood, J.D. 2015. Influence of herbicides and improvement cutting, fertilization, and prescribed fire on planted longleaf pine development. *Forest Science*. 61(2): 363–369.
- Haywood, J.D.; Sword Sayer, M.A.; Sung, S.S. 2015. Comparison of planted loblolly, longleaf, and slash pine development through 10 growing seasons in central Louisiana—an argument for longleaf pine. In: Holley, A.G.; Connor, K.F.; Haywood, J.D., eds. Proceedings of the 17th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-203, Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 383–390.
- Lenhart, J.D.; Hunt, Jr., E.V.; Blackard, J.A. 1985. Establishment of permanent growth and yield plots in loblolly and slash pine plantations in east Texas. In: Shoulders, E., ed. Proceedings of the third biennial southern silviculture Research Conference. Gen. Tech. Rep. SO-54. New Orleans: U.S. Department of Agriculture Forest Service: 436–437.
- VanderSchaaf, C.L.; Burkhart, H.E. 2012. Development of planting density-specific density management diagrams for loblolly pine. *Southern Journal of Applied Forestry*. 36(3): 126–129.
- VanderSchaaf, C.L.; Huang, S.; McConnell, T.E.; Yang, Y. 2020. Can a mixed-effects basal area equation fit using one species produce accurate estimates following calibration using data of another species? In: Bragg, D.C.; Koerth, N.E.; Holley, G.A., eds. Proceedings of the 20th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-253. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 31–41.

LINKAGE BETWEEN LONGLEAF PINE SEEDLING MORPHOLOGY AND GRASS STAGE EMERGENCE

Mary Anne S. Sayer and Shi-Jean Susana Sung

EXTENDED ABSTRACT

While the early survival of planted longleaf pine (*Pinus palustris* Mill.) is anticipated, the juvenile growth of longleaf pine may be hindered by grass stage duration, which is variable and may extend for several years (Crouch and others 2020, Haywood 2007). Variable grass stage duration causes irregular tree size and underutilizes site resources, representing setbacks to maximum economic return after planting. Interest in the dual purpose of restoring longleaf pine ecosystems and producing longleaf pine timber will increase when length and variation of the grass stage are minimized.

Positive correlation between grass stage emergence and seedling growth measured by root collar diameter is well documented (Knapp and others 2018, Wahlenberg 1946). Not only does root collar diameter represent overall seedling growth, but it also reflects the potential for root system acquisition of water (Grossnickle 2012). We proposed that sustained early growth and rapid, uniform grass stage emergence are tied to morphological relationships favoring water uptake. Our objective was to assess the growth and grass stage emergence of four types of greenhouse-grown longleaf pine seedlings. We hypothesized that root variables linked to water uptake are associated with grass stage emergence.

One longleaf pine seed source each from Alabama (AL) and Florida (FL) were grown for 7 months in two commercial cavity types in 2019 by the International Forest Company in Moultrie, GA. Six seedlings from each of the four seedling types were randomly chosen for pre-plant measurements. Twenty seedlings per seedling type were planted in 22.5-L pots, 50 cm deep, containing commercial peat-vermiculite medium and randomly placed on greenhouse benches. Seedlings were grown for 52 weeks under ambient conditions, watered twice per week, and fertilized once with 40 g Osmocote Plus 15-9-12 in September 2020. By the end of March 2020, 10 percent seedling mortality was attributed to *Fusarium* root disease and in April 2020, Root Shield Plus⁺ WP was applied as a root drench to remaining live seedlings. Seedlings were harvested in November 2020.

Among the pre-plant and harvested seedlings, root collar diameter (RCD) and root and shoot dry mass were measured and total dry weight (TDW) and root-to-shoot ratio (R:S) were calculated. Seedlings were further analyzed for stem length and number of sinker roots having a diameter >2 mm at the end of the taproot. Proximal ends of sinker roots were severed from the taproot and distal ends of sinker roots were severed at a 2-mm diameter. Taproot and sinker root top and end diameters and lengths were measured, top

Author Information: Mary Anne S. Sayer, Plant Physiologist, U.S. Department of Agriculture, Forest Service, Southern Research Station, Pineville, LA 71360, and Shi-Jean Susana Sung, Emeritus Scientist, U.S. Department of Agriculture, Forest Service, Southern Research Station, Pineville, LA 71360.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

and end areas were calculated, and volumes (cm³) were estimated by the conical frustum equation (1):

(1)

$$\frac{\pi h}{3} (r_1^2 + r_2^2 + r_1 r_2)$$

where

h (cm) is length, r_1 (cm) is top radius, and r_2 (cm) is end radius. Sums of sinker root top and end areas and volumes by seedling were calculated.

Means and standard deviations of pre-plant seedling RCD, tissue dry weights, TDW, and R:S were determined. Two-way factorial analyses of variance using a completely randomized experimental design were conducted on harvested seedling RCD, tissue dry weights, TDW, R:S, stem length, and sinker root (number, total and maximum lengths, total volume, top and end areas) and taproot (volume, top and end areas) variables. Main effects were seed source (AL, FL) and cavity type (1, 2). Statistical significance was established at an alpha-level of 0.05 for means comparisons with the Tukey-Kramer test.

Before potting, RCD and TDW of AL Type 2 seedlings were 17 and 11 percent greater, respectively, than means among the AL Type 1 and FL Type 1 and 2 seedlings. Across cavity types, the R:S of AL seedlings was 28 percent greater than that of FL seedlings.

Twelve months after potting, seedling RCD and TDW responses to seed source and cavity type differed from pre-plant values. The RCD of FL seedlings was significantly greater than that of AL seedlings, and the TDW of FL Type 2 seedlings was significantly greater (67 percent) than that of the other three seedling types (table 1).

Twelve months after planting in 22.5 L, deep pots, the pre-plant seed source effect on R:S was no longer apparent, and R:S increased 72 percent across all seedling types. This validates the need for a favorable planting environment to optimize longleaf pine root system development. Despite this observation, lower pre-plant R:S among the FL seedlings compared to the AL seedlings preceded a post-potting dry mass investment strategy that benefitted both the shoot and root system of FL seedlings compared to AL seedlings.

One year after potting, seedling stature was greater among the FL Type 2 seedlings compared to both types of AL seedlings and the FL Type 1 seedlings. We speculate that early growth of the FL seedlings was accelerated, in part, by a R:S that favored foliage mass. As greenhouse growth progressed, greater carbon fixation by the FL seedlings enhanced overall growth. The subsequent influence of cavity type on FL seedling taproot and sinker root growth led to superior root system development of the FL Type 2 seedlings. While the number of sinker roots emerged from the taproot end did not differ across the four seedling types, total volume and length as well as maximum depth of sinker roots were generally greater among the FL Type 2 seedlings and were positively related to taproot end area and volume.

In September 2020, 10 months after potting, 25 and 64 percent of FL Type 1 and 2 seedlings, respectively, had initiated height growth, whereas only 6 percent of AL Type 1 seedlings and none of the AL Type 2 seedlings had initiated height growth. Two months later, stem lengths indicative of grass stage emergence were observed in 36 percent of FL Type 2 seedlings but only 7 percent of the AL Type 1 seedlings and none of the FL Type 1 or AL Type 2 seedlings. Linkage between taproot and sinker root development and grass stage emergence are being investigated further.

Table 1—Mean longleaf pine seedling morphological variables 12 months after potting and placement in a greenhouse

Variable	AL seed source		FL seed source	
	Cavity type 1	Cavity type 2	Cavity type 1	Cavity type 2
Root collar diameter (mm) ^a	19.9 ± 1.1 b ^b	19.5 ± 0.8	21.0 ± 0.9	24.0 ± 0.7
Root dry weight (g) ^c	40.7 ± 5.4 b	29.5 ± 2.9 b	40.9 ± 3.8 b	64.3 ± 5.3 a
Shoot dry weight (g) ^c	40.5 ± 6.0 b	30.2 ± 2.9 b	42.7 ± 3.8 b	60.8 ± 5.3 a
Total dry weight (g) ^c	81.1 ± 11.2 b	59.7 ± 5.3 b	83.7 ± 7.4 b	125.1 ± 9.6 a
Root-to-shoot ratio ^e	1.04 ± 0.04	1.01 ± 0.06	0.97 ± 0.06	1.10 ± 0.06
Stem length (cm) ^a	4.2 ± 0.7	3.3 ± 0.3 a	5.2 ± 0.4	6.5 ± 0.8
Taproot top area (cm ²) ^a	3.3 ± 0.4	3.1 ± 0.2	3.6 ± 0.3	4.6 ± 0.3
Taproot end area (cm ²) ^c	1.1 ± 0.2 ab	0.6 ± 0.1 c	0.9 ± 0.1 bc	1.4 ± 0.2 a
Taproot volume (cm ³) ^c	20.4 ± 2.5 b	21.2 ± 1.7 b	24.0 ± 2.0 b	36.6 ± 2.2 a
Number of sinker roots ^d	1.9 ± 0.1 a	1.7 ± 0.2 a	1.4 ± 0.2 a	1.9 ± 0.2 a
Total sinker root top area (cm ²) ^c	0.9 ± 0.2 ab	0.5 ± 0.1 b	0.8 ± 0.1 ab	1.2 ± 0.2 a
Total sinker root end area (cm ²) ^e	0.07 ± 0.01	0.07 ± 0.01	0.05 ± 0.01	0.08 ± 0.02
Total sinker root volume (cm ³) ^c	24.1 ± 6.2 a	9.0 ± 1.2 b	17.4 ± 2.7 ab	31.1 ± 4.7 a
Total sinker root length (cm) ^c	97 ± 14 ab	64 ± 9 b	66 ± 8 b	106 ± 11 a
Maximum sinker root length (cm) ^c	57 ± 7 ab	40 ± 2 b	48 ± 3 b	66 ± 5 a

Note: Two seed sources, Alabama (AL) and Florida (FL), were grown in one of two cavity types for 7 months in a nursery before potting.

^a Seed source *P*-value < 0.05, FL greater than AL.

^b Standard error.

^c Seed source x cavity type *P*-value < 0.05; means within a row followed by a different lower case letter are significantly different by the Tukey-Kramer test at the 0.05 level.

^d Seed source x cavity type *P*-value < 0.05; means not significantly different by the Tukey-Kramer test at the 0.05 level.

^e No significant main or interaction effects.

LITERATURE CITED

- Crouch, C.D.; Knapp, B.O.; Cohen, S.A. [and others]. 2020. Site preparation for longleaf pine restoration on hydric sites: stand development through 15 years after planting. *Forest Ecology and Management*. 461: 117928. 11 p.
- Grossnickle, S.C. 2012. Why seedlings survive: influence of plant attributes. *New Forests*. 43: 711–738.
- Haywood, J.D. 2007. Influence of herbicides and felling, fertilization, and prescribed fire on longleaf pine establishment and growth through six growing seasons. *New Forests*. 33: 257–279.
- Knapp, B.O.; Pile, L.S.; Walker, J.L.; Wang, G.G. 2018. Fire effects on a fire-adapted species: response of grass stage longleaf pine seedlings to experimental burning. *Fire Ecology*. 14: 2–16.
- Wahlenberg, W.G. 1946. Longleaf pine its use, ecology, regeneration, protection, growth, and management. Washington, DC: Charles Lathrop Pack Forestry Foundation. 429 p.

SEASONAL BIENNIAL BURNING HAS NEGLIGIBLE EFFECTS ON LONGLEAF PINE BASAL AREA GROWTH

John L. Willis, Ajay Sharma, and John S. Kush

EXTENDED ABSTRACT

Historically, prescribed burning outside the dormant season has been avoided in the Southeastern United States (Ryan and others 2013). Part of the hesitancy to burn in the growing season derives from a fear of residual damage to valuable overstory trees. However, recognition of the ecological benefits of growing season burns, combined with a regional surge in prescribed burning demand, have increased interest in burning outside the dormant season (Knapp and others 2009, Outcalt 2008). To evaluate the potential impacts, we continued a long-term experiment examining the effects of seasonal biennial burning on longleaf pine (*Pinus palustris*) survival and productivity over 44 years at the Escambia Experimental Forest in southern Alabama (Boyer 1987).

The study was initiated in 1974 in three blocks of naturally regenerated longleaf pine. Each block contained 12 plots (0.4 acres) initially stocked at 500 trees per acre. In 1990, the plots were thinned to an average residual density of 70 square feet per acre to reduce intraspecific competition. Each plot was originally assigned a treatment combination of season of biennial burning (spring, summer, winter, or no burn) and non-fire hardwood control (mechanical removal of all woody stems >4.3 feet tall every 5 years, chemical treatment [2,4-D] at the start of the experiment, or no hardwood control) in a randomized complete block design. However, initial reports found no effect of the non-fire hardwood control methods prompting us to pool these treatments within burning treatments. Our study followed the plot-averaged basal area growth of 892 mature longleaf pines from 1995 through 2018. The corresponding stand age for this measurement interval was 37-60 years. The effects of biennial burning seasonality on cumulative basal area growth were investigated with a mixed-effects analysis of variance (ANOVA). The model included burn season as a fixed effect and block as a random effect. Treatments were considered significantly different at $\alpha = 0.05$.

Across all burning treatments, basal area growth averaged 8.71 square feet per acre. Overall, basal area growth was highest in the no burning treatment (9.96 square feet per acre) compared to all other seasonal burning treatments (fig 1). However, this difference was not statistically significant ($F = 0.33$, $P = 0.8083$). Among burning treatments, basal area growth was highest in summer burns (8.43 square feet per acre) followed by winter (8.32 square feet per acre) and spring burns (8.14 square feet per acre), but statistically significant differences were not detected (fig 1).

Collectively, our results demonstrate that spring or summer burning under a biennial regime will have minimal impact on longleaf pine growth (Willis and others 2021). The

Author Information: John L. Willis, Research Forester, U.S. Department of Agriculture, Forest Service, Southern Research Station, Auburn, AL 36849; Ajay Sharma, Assistant Professor, University of Florida, West Florida Research and Education Center, Milton, FL 32583; and John S. Kush, Retired Research Scientist, Auburn University School of Forestry and Wildlife Sciences, Auburn, AL 36849.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

lack of fire effects likely resulted from a combination of low fuel accumulation and existing bark thickness of the mature longleaf pine examined in this study. We suspect that the effects of fire frequency on fuel accumulation overwhelmed any potential negative effects of burning in the growing season. Future studies should explore these relationships at longer fire return intervals with younger trees.

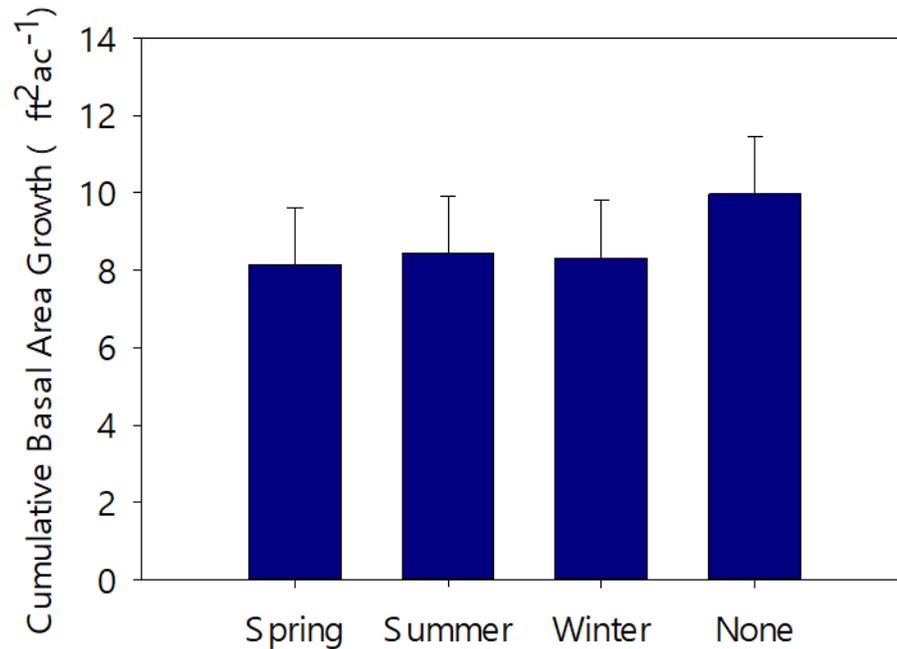


Figure 1—The estimated cumulative basal area growth (square feet per acre) of longleaf pine ± 1 standard error (SE) from 1995 through 2018 in winter, spring, and summer biennial burning and an unburned treatment.

LITERATURE CITED

- Boyer, W.D. 1987. Volume growth loss: a hidden cost of periodic prescribed burning in longleaf pine? *Southern Journal of Applied Forestry*. 11(3): 154–157.
- Knapp, E.E.; Estes, B.L.; Skinner, C.N. 2009. Ecological effects of prescribed fire season: a literature review and synthesis for managers. Gen. Tech. Rep. PSW-224. Albany, CA: U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station. 80 p.
- Outcalt, K.W. 2008. Lightning, fire, and longleaf pine: using natural disturbance to guide management. *Forest Ecology and Management*. 255(8–9): 3351–3359.
- Ryan, K.C.; Knapp, E.E.; Varner, J.M. 2013. Prescribed fire in North American forests and woodlands: history, current practice, and challenges. *Frontiers in Ecology and the Environment*. 11(s1): e15–e24.
- Willis, J.L.; Sharma, A.; Kush, J. 2021. Seasonality of biennial burning has no adverse effects on mature longleaf pine survival or productivity. *Frontiers for Forests and Global Change*. 4: 88.

UNDERSTANDING WIND RISK TO FORESTS: TOWARDS MECHANISTIC MODELS OF WIND RISK IN THE SOUTHEASTERN COASTAL PLAIN

Jeffery B. Cannon, Brandon T. Rutledge, R. Kevin McIntyre,
Angela M. Holland, and Steven B. Jack

EXTENDED ABSTRACT

Severe storms such as hurricanes alter the structure and function of forests and add economic and ecological uncertainty to the management of forest ecosystems of the Southeast. In 2018, Hurricane Michael affected over 25 percent of extant longleaf pine systems in a single event and damaged up to 80 percent of trees in some coastal stands (Zampieri and others 2020). Lower severity impacts also reached forests nearly 200 km (125 miles) inland (Rutledge and others 2021). Factors such as tree size, crown architecture, wood strength, stand density, soil type, elevation, and topographic position can influence stability (Cannon and others 2015, Garms and Dean 2019, Peterson and others 2019). Information on how these factors influence wind susceptibility can supply critical information to quantify and mitigate wind risk. Several studies rank longleaf pine (*Pinus palustris* Mill.) among the most wind-resistant species of the southeastern Coastal Plain, yet differences in size structure and association of species with varying soil types confounds a clear understanding of wind susceptibility rankings among southeastern pine species (Johnsen and others 2009). We aimed to rigorously test whether longleaf pine was more wind-resistant than associated pine species and investigate how tree, stand, and landscape factors affect tree stability in a longleaf pine forest.

We collected observations of over 3,000 trees stratified across 268 monitoring plots 0.1 ha (0.25 acre) in size (Holland and others 2018) at the Jones Center at Ichauway (31.21°N -84.45°W) following Hurricane Michael. The Jones Center is the site of 7300 ha (18,000 acres) of second growth longleaf pine woodlands that also contain minor components of other southern pines such as loblolly pine (*P. taeda* L.), slash pine (*P. elliottii* Englem.), shortleaf pine (*P. echinata* Mill.), and diverse hardwood species (Holland and others 2018). For each tree, we recorded whether trees were downed, and used previously collected diameter at breast height (d.b.h.) and stand density data. We derived information on soil type (excessively drained to poorly drained), distance from hurricane track, and wind exposure index (Plattner and others 2003) from publicly available data. Using a binomial generalized linear model, we tested how tree, stand, and landscape factors contributed to tree susceptibility (Zuur and others 2009). We also included two-way interactive effects (d.b.h. x species and species x soil type) to make inferences about wind risk among various size structures and soil types.

Author Information: Jeffery B. Cannon, Landscape Ecologist, The Jones Center at Ichauway, Newton, GA 39870; Brandon T. Rutledge, Conservation Coordinator, The Jones Center at Ichauway, Newton, GA 39870; R. Kevin McIntyre, Education Coordinator, The Jones Center at Ichauway, Newton, GA 39870; Angela M. Holland, Postdoctoral Research Associate, University of Delaware, Newark, DE 19716; and Steven B. Jack, Executive Director, Boggy Slough Conservation Area, T.L.L. Temple Foundation, Lufkin, TX 75901.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

Overall, we found that Hurricane Michael downed 16 percent of all trees sampled, accounting for a total basal area loss of 20 percent. We found that tree- and stand-level factors significantly influenced damage probability, but no landscape-scale factors were significantly correlated with treefall. Among pine species, we found that longleaf pine had the lowest damage (14.8 percent), followed by loblolly pine (24.1 percent), slash pine (28.1 percent), and shortleaf pine, which had the highest damage (39.8 percent). Though comparable to other studies (Johnsen and others 2009, Toulaiatos and Roth 1971), these species rankings should be interpreted with caution because there were significant interactions among species, soil type, and tree size, indicating that susceptibility rankings shift depending on soil type and tree size under consideration (fig. 1). Among pines, susceptibility increased with tree size, and shortleaf pine was most sensitive to changes in size, with probability of treefall increasing to 60-80 percent for large trees (60 cm d.b.h., 24 inches). Pines were more susceptible to windthrow in poorly drained soils, and slash pine and loblolly pine were most sensitive to changes in soil moisture (fig. 1). Longleaf pine did not have the lowest susceptibility in all cases (for example on excessively drained soils, large individuals of loblolly pine may be less vulnerable). However, longleaf pine was more resistant across a greater range of soil types and sizes than other pines. Full results, including those for oaks (*Quercus* spp.), are discussed further by Rutledge and others (2021).

In many southeastern forests, low-intensity fire is a prevailing theme in forest disturbance research. However, coastal pine forests also experience significant disturbance from hurricanes, and much less is known about how wind disturbance potentially shapes overstory structure, function, and competitive dynamics in fire-frequent forests. Wind disturbance is known to interact with and change fire behavior and effects, potentially leading to more complex feedbacks between these common disturbances (Cannon and others 2014, 2019; Gilliam and others 2006) that may shape community organization and function in fire-frequent forests and woodlands.

With several ongoing studies at the Jones Center, we are hoping to further address the role of hurricanes in shaping southeastern forests and conducting studies to develop a hierarchical model of wind risk that mechanistically incorporates tree, stand, and regional risk factors. Tree winching studies provide experimental means to measure tree susceptibility and provide information on the mechanisms and forces needed to topple trees of various species, sizes, and in different soil types. We are currently experimentally testing whether trunk and root strength in longleaf pine is greater than slash pine across a range of sizes and soil conditions using tree winching and experimental wetting (cf. Cannon and others 2015). Tree crowns create drag and convert wind torque on the trunk, and thus are important to understanding mechanisms of wind damage (Peterson and Cannon 2021). Simulation studies of wind damage usually assume that tree crowns have simple elliptical shapes (Gardiner and others 2000), and this assumption overestimates wind susceptibility. We are using terrestrial lidar to improve measurements of crown architecture in wind modeling. We are testing whether tree crowns or trunk strength drive observed post-hurricane patterns. We will incorporate results from tree crown measurements into wind simulation models (e.g., Peterson and others 2019) to refine estimates of wind susceptibility across a range of tree species, sizes, and stand densities. Using hurricane models, past studies have predicted the probability of hurricane-force winds at regional scales (Boose and others 2001, Zeng and others 2009). Borrowing a framework from wildfire-risk modeling (Scott and others 2013), upcoming work seeks to combine regional wind models with stand and tree level models of wind damage. Such hierarchical models can be critical for quantifying wind-risk and guiding management of southeastern landscapes.

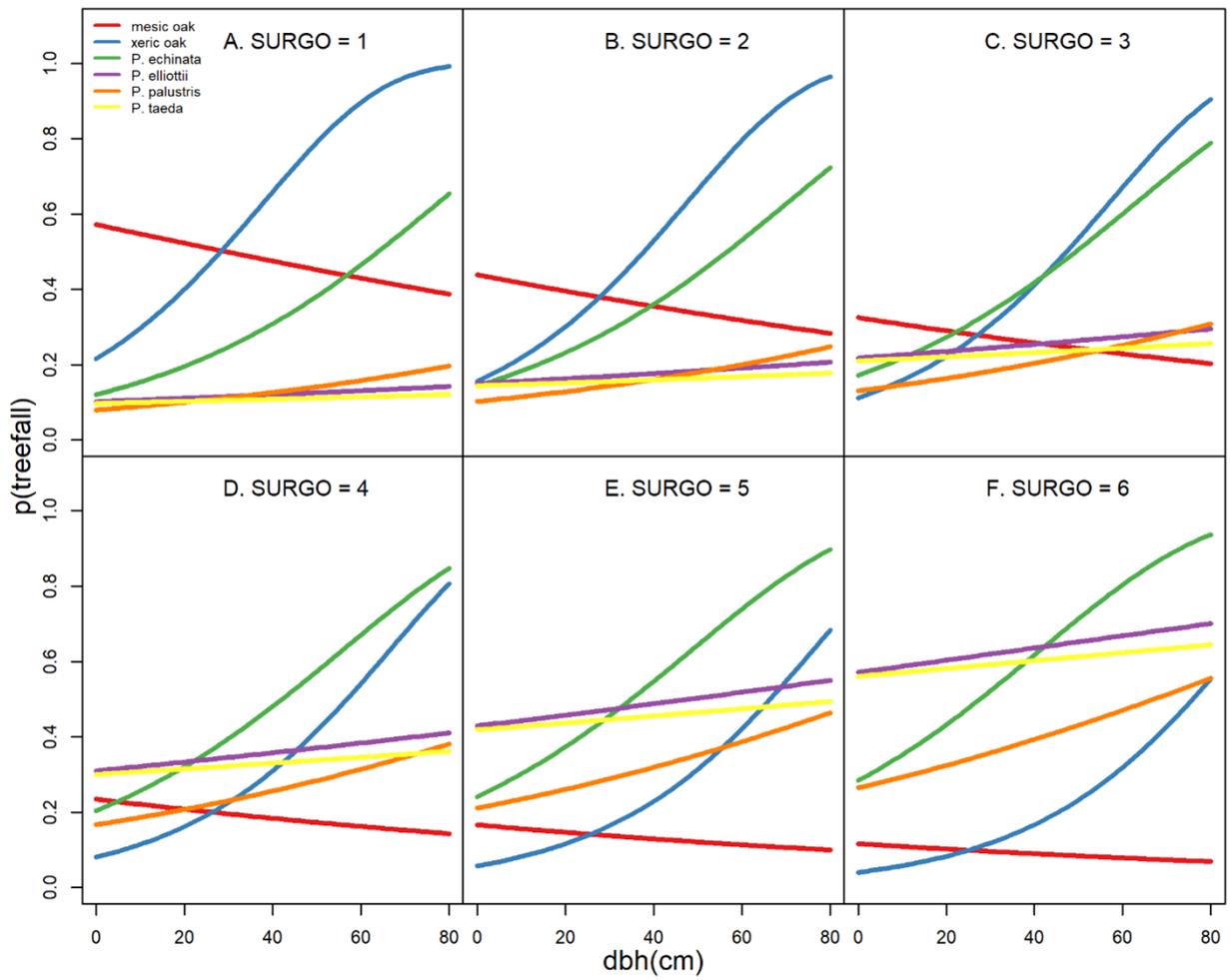


Figure 1—Model prediction indicating the relationship between tree size diameter at breast height (DBH) and estimated probability of treefall across five species and six soil types ranging from excessively drained (SURGO 1) to very poorly drained (SURGO 6). Figure from Rutledge and others (Rutledge and others 2021).

LITERATURE CITED

- Boose, E.R.; Chamberlin, K.E.; Foster, D.R. 2001. Landscape and regional impacts of hurricanes in New England. *Ecological Monographs*. 71: 27–48.
- Cannon, J.B.; Barrett, M.E.; Peterson, C.J. 2015. The effect of species, size, failure mode, and fire-scarring on tree stability. *Forest Ecology and Management*. 356: 196–203.
- Cannon, J.B.; Henderson, S.K.; Bailey, M.H.; Peterson, C.J. 2019. Interactions between wind and fire disturbance in forests: Competing amplifying and buffering effects. *Forest Ecology and Management*. 436: 117–128.
- Cannon, J.B.; O'Brien, J.J.; Loudermilk, E.L.L. [and others]. 2014. The influence of experimental wind disturbance on forest fuels and fire characteristics. *Forest Ecology and Management*. 330: 294–303.
- Gardiner, B.; Peltola, H.; Kellomäki, S. 2000. Comparison of two models for predicting the critical wind speeds required to damage coniferous trees. *Ecological Modelling*. 129: 1–23.
- Garms, C.; Dean, T.J. 2019. Relative resistance to breaking of *Pinus taeda* and *Pinus palustris*. *Forestry: An International Journal of Forest Research*. 92: 417–424.
- Gilliam, F.S.; Platt, W.J.; Peet, R.K. 2006. Natural disturbances and the physiognomy of pine savannas: A phenomenological model. *Applied Vegetation Science*. 9: 83–96.
- Holland, A.M.; Rutledge, B.T.; Jack, S.B.; Stober, J.M. 2018. The longleaf pine forest: Long-term monitoring and restoration of a management dependent ecosystem. *Journal of Nature Conservation*. 47: 38–50.
- Johnsen, K.H.; Butnor, J.R.; Kush, J.S. [and others]. 2009. Hurricane Katrina winds damaged longleaf pine less than loblolly pine. *Southern Journal of Applied Forestry*. 33: 178–181.
- Peterson, C.J.; Ribeiro, G.H.P. de M.; Negrón-Juárez, R. [and others]. 2019. Critical wind speeds suggest wind could be an important disturbance agent in Amazonian forests. *Forestry: An International Journal of Forest Research*. 92: 444–459.
- Peterson, C.J.; Cannon, J.B. 2021. Modelling wind damage to southeastern U.S. trees: effects of wind profile, gaps, neighborhood interactions, and wind direction. *Frontiers in Forest and Global Change*. 4: 719–813.
- Plattner, B.C.; Braun, L.N.; Brenning, A. 2003. Spatial variability of snow accumulation on Vernagtferner, Austrian Alps, in Winter 2003/2004. *Zeitschrift für Gletscherkd. und Glazialgeol.* 39: 43–57.
- Rutledge, B.T.; Cannon, J.B.; McIntyre, R.K. [and others]. 2021. Tree, stand, and landscape factors contributing to hurricane damage in a Coastal Plain forest: Post-hurricane assessment in a longleaf pine landscape. *Forest Ecology and Management*. 481: 118–724.
- Scott, J.H.; Thompson, M.P.; Calkin, D.E. 2013. A wildfire risk assessment framework for land and resource management. RMRS-GTR-315. U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. 83 p.
- Touliatos, P.; Roth, E. 1971. Hurricanes and trees: Ten lessons from Camille. *Journal of Forestry*. 69: 285–289.
- Zampieri, N.E.; Pau, S.; Okamoto, D.K. 2020. The impact of Hurricane Michael on longleaf pine habitats in Florida. *Scientific Reports*. 10: 1–11.
- Zeng, H.; Chambers, J.Q.; Negrón-Juárez, R.I. [and others]. 2009. Impacts of tropical cyclones on U.S. forest tree mortality and carbon flux from 1851 to 2000. *Proceedings of the National Academy of Sciences of the United States of America*. 106(19): 7888–7892.
- Zuur, A.F.; Ieno, E.N.; Walker, N.J. [and others]. 2009. *Mixed effects models and extensions in ecology with R*. *Page Statistics for Biology and Health*. New York: Springer. 574 p.

THE PERCENTAGE OF TREES BEARING CONES AS A PREDICTOR OF ANNUAL LONGLEAF PINE CONE PRODUCTION

Thomas W. Patterson

EXTENDED ABSTRACT

Longleaf pine (*Pinus palustris*) cone production has been documented for over six decades, beginning in Escambia County, Alabama in the late 1950s and currently at 11 locations throughout the species' range (Brockway 2019, Connor and others 2014). Data from the multi-decadal study have linked cone production to variations in environmental conditions, stand dynamics, and inherent masting complexity (Chen and others 2016, 2017, 2018, 2021; Guo and others 2016; Haymes and Fox 2012; Leduc and others 2016; Loudermilk and others 2016; Pederson and others 1999). The ability to analyze complex relationships for longleaf pine cone production relates to the methodology for counting cones—providing a good estimate using a scientific protocol (Brockway 2019). Alternatively, less precise, rapid mast assessments have been proposed in the literature, and these studies have documented a close relationship between the percentage of trees bearing mast and actual mast counts (Carevic and others 2014, Greenberg 2020, Nakajima and others 2015). At present, rapid cone assessments have not been tested for longleaf pine, yet rapid assessments can help land owners estimate crop size for successful, natural regeneration. In this study, I examined the relationship between the percentage of trees bearing cones (a rapid, binary measurement) to the estimated average cone crop to understand if simple visual surveys could approximate the results of the scientifically derived dataset.

Longleaf pine cone data were obtained from the Forest Service, U.S. Department of Agriculture, Southern Research Station, which included individual tree pine-cone production from 11 locations throughout the species' range (see Brockway 2019 for information on individual sites). Some locations contained sub-compartments where cones were counted separately, and each sub compartment was treated as a separate site for a total of 18 sites in this study. Data were incomplete for numerous sites, or individual trees, and therefore approximately 20 percent of the dataset were unusable and omitted from analyses. Digitized, individual-tree data were available from 1993 to present, and all analyses were limited to the last three decades. The raw cone data were not normally distributed; therefore, I transformed these data using a natural logarithm to use statistics that assume normality. The percentage of trees bearing cones (PBC) was computed for each year at each site:

Author Information: Thomas W. Patterson, Assistant Professor, The University of Southern Mississippi, Hattiesburg, MS 39406.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

$$PBC=(TBC/n)\times 100 \tag{1}$$

where

PBC = percentage of trees bearing cones

TBC = number of trees bearing cones

n = number of trees

and simple linear models were assembled that examined if PBC was a statistically significant ($p < 0.05$) predictor for log-average cone production for all sites. Next, PBC was examined as it related to the Failed–Bumper cone crop classification (Brockway 2019) for average number of cones per tree: Failed 0–9, Poor 10–24, Fair 25–49, Good 50–99, and Bumper ≥ 100 . Cone crop was averaged for each of the site and year observations ($n = 314$) and performed a one-way ANOVA test with a Tukey’s HSD post-hoc analysis to examine differences in mean PBC between the Forest Service cone-crop classes. Finally, the odds of correctly identifying a Fair or better cone crop (≥ 25 cones/tree) from the threshold identified by the ANOVA analysis using a diagnostic odds test was examined.

The percentage of trees bearing cones was a statistically significant predictor for log-average cone production (table 1), and PBC model explanatory power (r^2) ranged from 58 to 94 percent variance explained for the 18 sites. The median r^2 of all models was 78 percent variance explained, with a standard deviation of 10 percent. Significant differences in mean PBC existed between the five Failed–Bumper groups ($F = 139.8, p < 0.001$). No difference in mean PBC existed between the Fair–Bumper groups; however, mean PBC was significantly lower ($p < 0.01$) for the Poor group and the mean PBC for the Failed group was significantly lower ($p < 0.001$) than all other groups (fig. 1). Mean PBC for the lowest of the three not-significantly different groups (Fair, ≥ 25 cones per tree) equaled 89.47, which indicates PBC values ≥ 90 corresponded with Fair or better cone crops. I performed an odds ratio to examine the efficacy of correctly identifying a Fair or better cone crop using a PBC threshold of 90, and the results of the odds ratio indicated cone-count stands in this study would be at least 18.4 (95 percent CI 10.2–33.4) times more likely to have a Fair, Good, or Bumper crop when PBC ≥ 90 than when PBC is < 90 .

This study revealed two important findings that have implications for cone monitoring and forest regeneration. First, the percentage of trees bearing cones is a consistent and reliable predictor for log-average cone production throughout the species’ range. Models were statistically significant for all 18 sites in the study, and all models showed that PBC was a strong predictor of log-average cone production. Second, when average cone production was grouped by the Forest Service Failed–Bumper classification, there were convincing odds that a cone crop exceeding 25 cones per tree would occur when PBC was at or greater than 90. This unexpected finding has important implications for regeneration efforts, as cone crops classified as Fair or better represent good opportunities for natural regeneration (Brockway 2019). It is important to note that these results were obtained from a variety of stands throughout the longleaf pine range with data spanning the last three decades. Future studies should examine the reliability of PBC thresholds at new sites to understand how this relationship operates at different time scales, age classes, and topographic conditions.

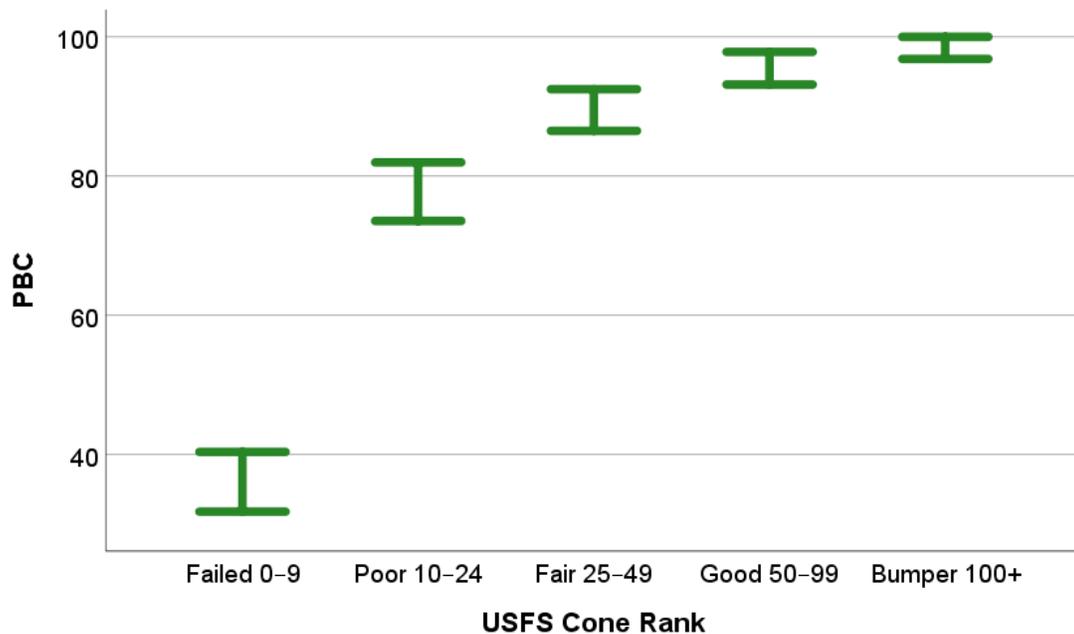


Figure 1—Error plot (i.e., 95 percent confidence intervals) from the one-way ANOVA analysis of PBC categorized by the U.S. Department of Agriculture, Forest Service cone-class ($F=139.8$, $p < 0.001$, $n=314$). Average number of cones per tree as follows: Failed=0-9, Poor=10-24, Fair=25-49, Good=50-99, and Bumper ≥ 100 .

LITERATURE CITED

- Brockway, D.G. 2019. Longleaf pine cone prospects for 2019 and 2020. Auburn, AL: U.S. Department of Agriculture Forest Service, Southern Research Station. 24 p.
- Carevic, F.S.; Alejano, R.; Fernández, M.; Martín, D. 2014. Assessment and comparison of the visual survey method for estimating acorn production in holm oak (*Quercus ilex* ssp. *Ballota*) open woodland of southwestern Spain. *Arid Land Research and Management*. 28(1): 102-108.
- Chen, X.; Brockway, D.G.; Guo, Q. 2021. Burstiness of seed production in longleaf pine and Chinese torreyia. *Journal of Sustainable Forestry*. 40(2): 188-196.
- Chen, X.; Guo, Q.; Brockway, D.G. 2016. Analyzing the complexity of cone production in longleaf pine by multiscale entropy. *Journal of Sustainable Forestry*. 35(2): 172-182.
- Chen, X.; Guo, Q.; Brockway, D.G. 2017. Power laws in cone production of longleaf pine across its native range in the United States. *Sustainable Agriculture Research*. 6(4): 64-73.
- Chen, X.; Guo, Q.; Brockway, D.G. 2018. Characterizing the dynamics of cone production for longleaf pine forests in the Southeastern United States. *Forest Ecology and Management*. 429: 1-6.
- Connor, K.F.; Brockway, D.G.; Boyer, W.D. 2014. Restoring a legacy: longleaf pine research at the Forest Service Escambia Experimental Forest. In: Hayes, D.C.; Stout, S.L.; Crawford, R.H.; Hoover, A.P., eds. U.S. Department of Agriculture Forest Service Experimental Forests and Ranges: Research for the long term. New York: Springer: 85-101.
- Greenberg, C.H. 2020. Modelling annual Southern Appalachian acorn production using visual surveys. *Wildlife Society Bulletin*. 44(2): 292-299.
- Guo, Q.; Zarnoch, S.J.; Chen, X.; Brockway, D.G. 2016. Life cycle and masting of a recovering keystone indicator species under climate fluctuation. *Ecosystem Health and Sustainability*. 2(6): e01226.
- Haymes, K.L.; Fox, G.A. 2012. Variation among individuals in cone production in *Pinus palustris* (Pinaceae). *American Journal of Botany*. 99(4): 640-645.
- Leduc, D.J.; Sung, S.-J. S.; Brockway, D.G.; Sayer, M.A.S. 2016. Weather effects on the success of longleaf pine cone crops. In: Schweitzer, C.J.; Clatterbuck, W.K.; Oswalt, C.M., eds. Proceedings of the 18th biennial southern silvicultural research conference; 2015 March 2-5; Knoxville, TN. e-Gen. Tech. Rep. SRS-212. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 535-541.
- Loudermilk, L.E.; Hiers, K.J.; Pokswinski, S. [and others]. 2016. The path back: Oaks (*Quercus* spp.) facilitate longleaf pine (*Pinus palustris*) seedling establishment in xeric sites. *Ecosphere*. 7(6): e01361.
- Nakajima, A.; Masaki, T.; Koike, S. [and others]. 2015. Estimation of tree crop size across multiple taxa: generalization of a visual survey method. *Open Journal of Forestry*. 5(7): 651-661.
- Pederson, N.; Kush, J.S.; Meldahl, R.S.; Boyer, W.D. 1999. Longleaf pine cone crops and climate: A possible link. In: Haywood, James D., ed. Proceedings of the 10th biennial southern silvicultural research conference; 1999 February 16-18, Shreveport, LA. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 255-258.

Table 1—Site information for location (latitude, longitude), the number of trees per site, years of data per site, the average and standard deviation of cones per tree per site, model explanatory power (r^2) and significance (p), and the model parameters

Site name	Latitude	Longitude	Number of trees	Number of years	Average cones per tree	Standard deviation cones	r^2	p	Model
Apalachicola National Forest	30.36	-84.30	10	25	19.5	46.1	0.773	<0.001	$y = 2.011x - 0.345$
Blackwater River State Forest	30.84	-86.81	10	15	43.6	93.9	0.838	<0.001	$y = 2.201x - 0.381$
Bladen Lakes State Forest	34.74	-78.54	14	23	18.5	32.6	0.841	<0.001	$y = 2.247x - 0.541$
Eglin Air Force Base - Rattlesnake Road Site	30.68	-86.59	9	24	28.3	57.5	0.816	<0.001	$y = 2.157x - 0.32$
Eglin Air Force Base - Old Sandhills #1 Site	30.61	-86.54	7	21	28.3	60.1	0.869	<0.001	$y = 2.239x - 0.334$
Eglin Air Force Base - Old Sandhills #2 Site	30.56	-86.42	8	21	18	42	0.765	<0.001	$y = 0.7x + 0.127$
Eglin Air Force Base - Brown Pond Site	30.56	-86.42	10	24	19.3	35.7	0.745	<0.001	$y = 1.938x - 0.257$
Escambia Experimental Forest - Compartment 156	31.02	-87.04	10	22	26.7	52.4	0.778	<0.001	$y = 1.818x - 0.14$
Escambia Experimental Forest - Compartment 107	31.02	-87.06	10	11	48	81.2	0.701	0.001	$y = 1.913x - 0.103$
Escambia Experimental Forest - Compartment 113	31.02	-87.04	10	9	53.2	80.3	0.788	0.001	$y = 2.279x - 0.418$
Escambia Experimental Forest - Compartment 71	31.02	-87.06	7	24	31.3	53.4	0.855	<0.001	$y = 2.054x - 0.289$
Escambia Experimental Forest - Compartment 118	31.02	-87.04	10	7	26.4	37.5	0.939	<0.001	$y = 1.925x - 0.164$
Escambia Experimental Forest - Compartment 103	31.02	-87.06	20	8	37.6	57.8	0.917	<0.001	$y = 2.176x - 0.226$
Fort Benning Military Base	32.36	-84.85	50	13	39.5	90.4	0.703	<0.001	$y = 2.315x - 0.333$
Jones Ecological Research Center - Turkey Woods	31.25	-84.47	11	16	43.6	103.2	0.837	<0.001	$y = 2.934x - 0.167$
Kisatchie National Forest	31.51	-92.47	15	20	34	69.3	0.592	<0.001	$y = 1.849x - 0.359$
Sandhills State Forest	34.55	-79.97	14	21	17.2	29.5	0.694	<0.001	$y = 1.767x - 0.35$
Tall Timbers Research Station	30.67	-84.22	9	10	10.6	17.4	0.575	0.01	$y = 1.67x - 0.352$

PLANTED LONGLEAF PINE STANDS IN THE FACE OF A TROPICAL CYCLONE

Seth W. Bigelow, Andrew W. Whelan, Jeffery B. Cannon, Gregory Starr,
Christina L. Staudhammer, Gavin R. Kenney, and Steven T. Brantley

EXTENDED ABSTRACT

Longleaf pine planting is widely recommended to southeastern landowners as an attractive practice that can provide income while helping to restore land to its historic ecological condition. Although longleaf pine is more wind resistant than other southern pines (Johnsen and others 2009, Rutledge and others 2021), planted stands can be vulnerable in tropical cyclones. These powerful windstorms may damage enough trees to result in substantial decreases in economic returns. A considerable body of knowledge exists on longleaf vulnerability in natural forests but means for predicting the vulnerability of plantations are not well developed. We surveyed planted longleaf pine stands throughout the area of greatest windspeeds of Hurricane Michael. Our goal was to develop a formula for predicting the proportion of damaged stems at a specified wind-speed, given knowledge about plantation development, soils, and landscape context.

Eighty-seven planted longleaf pine stands, age ca. 11 to 60 years, were assessed at locations in southwest Georgia and northwest Florida from 11 to 17 months after the passage of Hurricane Michael. The sample comprised 2,285 trees. We made a single visit to each plot, measuring diameter at breast height (d.b.h.), height, and damage of each tree in fixed radius plots to assess stand characteristics. We used aerial (NAIP) imagery from before the storm to identify proportion of each plot comprising adult or sub-adult trees within 300 m for a measure of wind exposure; tree cover was divided into arc segments corresponding to cardinal and ordinal directions. Maximum wind gust speed was estimated with the *Hurrecon* model based on data from the National Oceanic and Atmospheric Administration (Boose and others 2004). Estimated gust speed range was 26 to 96 m s⁻¹ (58-216 miles per hour).

A model of probability of tree damage was developed based on the data collected. Data were analyzed with a generalized linear mixed model, based on a binomial distribution with a logit transformation (response variable: undamaged and damaged). Damage types were any that would result in classification as “unacceptable growing stock” and included tip-ups, snapped trunks, and lean ≥ 10 degrees from vertical. Stand ($n=87$) was classified as a random effect. Statistical model terms included d.b.h., height, relative d.b.h. (d.b.h. relative to the plot mean d.b.h.), interaction between height and relative d.b.h., tall-tree cover in direction of maximum wind speed, and interaction between gust speed and d.b.h. The results indicated that, as expected, tree height and d.b.h. were strong predictors of

Author Information: Seth W. Bigelow, Assistant Scientist, The Jones Center at Ichauway, Newton, GA 39870, (current address) Tall Timbers Research Station and Land Conservancy, Tallahassee FL 32312; Andrew W. Whelan, Research Associate, The Jones Center at Ichauway, Newton, GA 39870; Jeffery B. Cannon, Assistant Scientist, The Jones Center at Ichauway, Newton, GA 39870; Gregory Starr, Professor, University of Alabama, Tuscaloosa, AL 35487; Christina L. Staudhammer, Professor, University of Alabama, Tuscaloosa, AL 35487; Gavin R. Kenney, Graduate Research Assistant, University of Alabama, Tuscaloosa, AL 35487; and Steven T. Brantley, Associate Scientist, The Jones Center at Ichauway, Newton, GA 39870.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

damage ($p < 0.001$ for both) but in opposite directions, taller trees were more likely to be damaged, but trees with large d.b.h. were less likely to be damaged. High gust speeds were correlated with damage ($p < 0.1$) and there was an interaction between gust speed and d.b.h. ($p < 0.01$) which indicated slightly increased probability of damage of smaller trees at high gust speeds (fig. 1A). Similarly, the largest trees within a stand (as indicated by relative d.b.h.) were less likely to be damaged than the smaller ones, but there was an interaction with height ($p < 0.01$) indicating that if the trees with largest d.b.h. within a stand are also the tallest trees they are likely to be damaged (fig. 1B). High windward cover from tall vegetation cover was correlated with decreased damage ($p < 0.05$; fig. 1C), and no effect of stand density was detected.

Attentive management of planted longleaf pine stands requires frequent thinning, which can be costly, so we scrutinized our results for support for the benefits of thinning. As a rule, removal of neighbors with thinning increases tree diameter growth but has little effect on height (Gonzalez-Benecke and others 2012). Although increased diameter should increase strength, stands have increased vulnerability to windthrow for up to 5 years after thinning (Dhôte 2005); we lacked data on thinning dates and were unable to test for this effect. The decrease in damage probability observed with larger d.b.h., and with larger relative d.b.h., supports the importance of thinning. Nevertheless, other studies show that the larger trees within a stand are most prone to damage and smaller trees within a stand are protected by larger ones (Hale and others 2012).

The observed increase in damage probability with increased height is a common finding in wind studies and is consistent with greater leverage exerted by taller trees with larger crowns (Gardiner and Quine 2000). We posit that frequent thinning may shrink the range of relative diameters in a stand and thereby provide some increased protection. Dhôte (2005) states that smoother canopies are advantageous for resisting windthrow, but he also found no clear improvement in tree stability in complex, uneven-aged canopies in comparison to even-aged monocultures (cf. Mason 2002). Our research suggests that row thinning should be combined with low thinning of overtopped and suppressed trees, along with limited crown thinning focusing on the tallest, emergent trees. Such trees are likely to have the highest turning moment and be most vulnerable to cyclonic winds.

Observations made in the aftermath of Hurricane Michael suggested that small-area pine stands (e.g., < 0.1 ha) surrounded by open fields were highly vulnerable, and our analysis confirmed these observations. Windward tall-tree cover had a protective effect, suggesting that large-area planted stands and/or those planted to leeward of existing stands will be better protected from damage (Lohmander and Helles 1987). We were surprised not to observe a stronger effect of gust speed in our analyses, given that sampling locations in the eye of the storm path near the Gulf coast had > 95 percent mortality. The relatively weak effect detected suggests the importance of multiple other factors such as stand and landscape effects that interact to determine damage to planted longleaf pine. Our research, which interprets field data via models, provides a basis for predicting damage probability which may be linked to geographic models of probability of experiencing cyclonic windspeeds near the Atlantic coast (Boose and others 2001, Zeng and others 2009). Our research also supports the role of professional management in creating planted longleaf pine stands that are resistant to cyclonic windstorms.

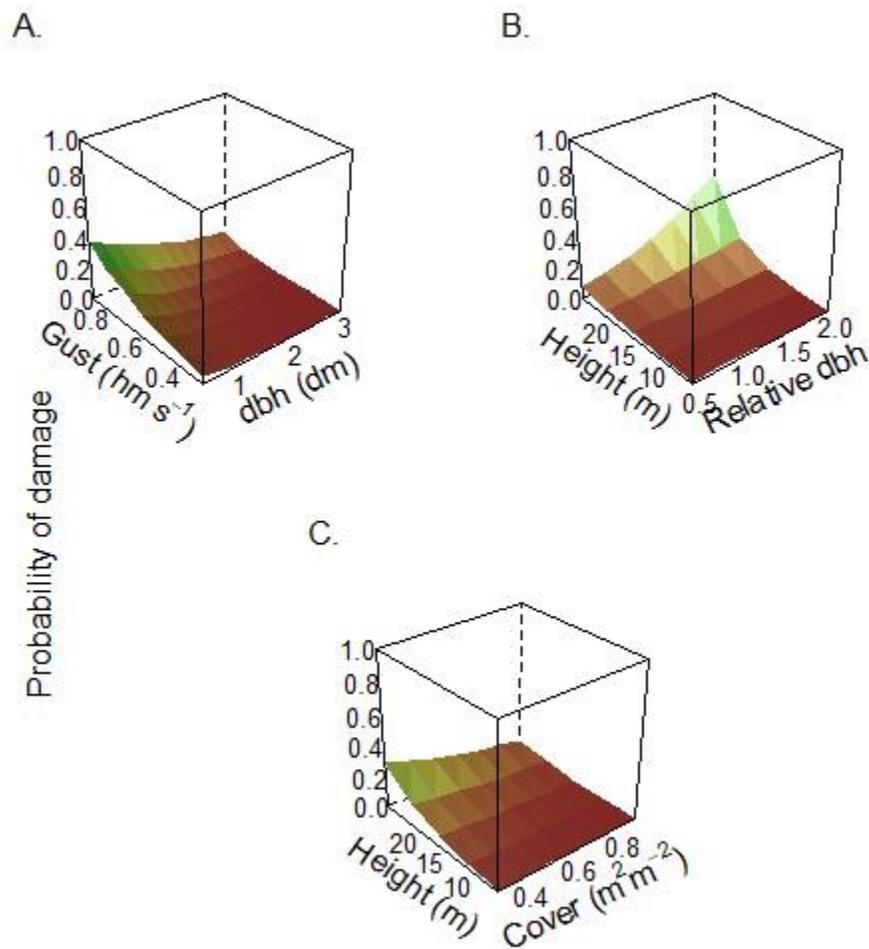


Figure 1—Predicted probability of damage to planted longleaf pines in windstorms (A) interactive effects of gust speed [100 m s⁻¹ (hectometer, hm s⁻¹) units] and diameter at breast height (d.b.h.) [10 cm (decimeter, dm) units] shown here for trees 15 m tall (B) interactive effect of tree height and relative d.b.h. (d.b.h. divided by mean stand d.b.h.) (C) effect of tall-tree cover (to 300 m windward of plot) in conjunction with target-tree height.

LITERATURE CITED

- Boose, E.R.; Chamberlin, K.E.; Foster, D.R. 2001. Landscape and regional impacts of hurricanes in New England. *Ecological Monographs*. 71: 27–48.
- Boose, E.R.; Serrano, M.I.; Foster, D.R. 2004. Landscape and regional impacts of hurricanes in Puerto Rico. *Ecological Monographs*. 74: 335–352.
- Dhôte, J.-F. 2005. Implication of forest diversity in resistance to strong winds. In: Scherer-Lorenzen, M.; Körner, C.; Schulze, E.-D., eds. *Forest diversity and function: temperate and boreal systems*. Berlin Heidelberg Germany: Springer-Verlag: 291–307.
- Gardiner, B.A.; Quine, C.P. 2000. Management of forests to reduce the risk of abiotic damage—a review with particular reference to the effects of strong winds. *Forest Ecology and Management*. 135: 261–277.
- Gonzalez-Benecke, C.A.; Gezan, S.A.; Leduc, D.J. [and others]. 2012. Modeling survival, yield, volume partitioning and their response to thinning for longleaf pine plantations. *Forests*. 3: 1104–1132.
- Hale, S.E.; Gardiner, B.A.; Wellpott, A. [and others]. 2012. Wind loading of trees: influence of tree size and competition. *European Journal of Forest Research*. 131: 203–217.
- Johnsen, K.H.; Butnor, J.R.; Kush, J.S. [and others]. 2009. Hurricane Katrina winds damaged longleaf pine less than loblolly pine. *Southern Journal of Applied Forestry*. 33: 178–181.
- Lohmander, P.; Helles, F. 1987. Windthrow probability as a function of stand characteristics and shelter. *Scandinavian Journal of Forest Research*. 2: 227–238.
- Mason, W.L. 2002. Are irregular stands more windfirm? *Forestry*. 75: 347–355.
- Rutledge, B.T.; Cannon, J.B.; McIntyre, R.K. [and others]. 2021. Tree, stand, and landscape factors contributing to hurricane damage in a Coastal Plain forest: Post-hurricane assessment in a longleaf pine landscape. *Forest Ecology and Management*. 481(118724): 1–13.
- Zeng, H.; Chambers, J.Q.; Negrón-Juárez, R.I. [and others]. 2009. Impacts of tropical cyclones on U.S. forest tree mortality and carbon flux from 1851 to 2000. *Proceedings of the National Academy of Sciences*. 106: 7888–7892.

Upland Hardwoods Management



NATURAL PRUNING VARYING WITH SWEETGUM VARIETY AND DENSITY

Joshua P. Adams, Michael Blazier, and Curtis L. VanderSchaaf

EXTENDED ABSTRACT

A sweetgum (*Liquidambar spp.*) study was installed at two sites in Louisiana in the winter of 2015-2016. Two taxa were planted including the native sweetgum, *L. styraciflua*, and a hybrid, *L. styraciflua x formosana*, in 25-tree block plots and have been measured for diameter and height each year. Crown closure appeared to begin during the mid-fourth year in blocks with near complete survival. By mid-growing season, some blocks of the faster growing hybrids began to both exhibit complete crown closure and begin the natural pruning process. We will explore the genetic and stocking effects on natural pruning. Overall, hybrids grew faster and had greater stocking than the native counterparts. The varying densities presented by the suite of hardwood genotypes presents a novel look at densities needed to stimulate limb fall.

Hardwood trees are economically and ecologically important to many States in the United States of America, especially in the eastern half of the country. The Eastern United States is home to approximately 90 percent of the Nation's hardwood growing stock (Smith and others 2001). Hardwood timber production is a large industry in Louisiana. In 2002, 131 million cubic feet of hardwood trees were harvested in Louisiana and 43 percent of trees harvested in Louisiana were pulpwood or other industrial products like composite panels and mulch (Bentley and others 2002). Of these hardwoods, sweetgum (*Liquidambar styraciflua*) is one of the most prolific hardwood species in regard to site adaptability and growth. Sweetgum is commonly found on upland sites alongside pine in full sunlight but grows fastest on bottomland sites (Koch 1985).

Recently, efforts to hybridize *L. styraciflua* with another species in the genus, in this case Formosan Gum (*L. formosana*), have been undertaken to further increase its productivity. Hybrid sweetgum varieties may be able to produce more biomass than native sweetgums efficiently on upland, drier sites allowing harvests year-round. These new genotypes could open up a new sphere of possibilities for land managers and timber companies (Martin 2016). If hybrid sweetgum varieties are adaptable to diverse soil and water conditions, they may be able produce rapid, high quality growth patterns that would also make them amenable to forest products such as veneer lumber that necessitates a premium on quality, mainly lack of knots. Thus, this study quantifies effects on natural pruning from varieties of sweetgum and hybrid sweetgum.

Sweetgum varieties were grown at two sites in north Louisiana including Louisiana Tech South Campus in Ruston, LA and Louisiana State University Agricultural Center's Hill Farm Research Station in Homer, LA. The Louisiana Tech study site was largely on an Angie fine sandy loam soil, with a small portion on a Sacul very fine sandy loam, while the Hill Farm site was located on a Darley-Sacul complex, with Darley being on the ridgetop and down the hillside and Sacul being predominant in the bottom below the hill. The limiting

Author Information: Joshua Adams, Associate Professor, Louisiana Tech University, Ruston, LA 71272; Michael Blazier, Dean of the College of Forestry, Agriculture, and Natural Resources, University of Arkansas at Monticello, Monticello, AR 39759; and Curtis VanderSchaaf, Assistant Professor, Central MS Research and Extension Center, Raymond, MS 39154.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

factor at both sites was the presence of a hardpan; thus, both sites were subsoiled (ripped) to a 24-inch (0.6 m) depth in late summer prior to planting. One week before planting, 3 quarts per acre (7 L/ha) of glyphosate was applied (Accord XRTII® [Dow; Indianapolis, IN]) via ATV-mounted sprayer to remove any herbaceous vegetation present. Six Arborgen® sweetgum stocks were planted including two *Liquidambar styraciflua* half-sibling families and four sweetgum hybrid clones (*L. styraciflua* x *formosana*). All stock were planted as containerized 1-0 seedlings which were planted 8 feet apart along the row, while rows were 10 feet apart. Planting was conducted by hand with dibble bars on the upslope side of the rip. Planting was initiated and completed in early winter of 2015. The study was designed to have nine internal trees (3 tree x 3 tree) within each 5-tree x 5-tree plot.

Each year following the growing season, trees were measured for diameter at breast height (DBH) (when attaining 4.5 feet) and total height. In August and September of the 4th growing season, crown height (i.e., height to the lowest live branch) was measured as indicated by presence of leaves on the branch. Crown ratio was calculated from these measurements as the ratio of length of the live crown to total height of the tree. Though data were collected from all trees, analysis was done only on the internal trees from each plot. Pearson correlations were used to assess correlations among variables at the tree and plot level. Data were analyzed using the SAS Proc Glimmix. Fixed effects, site and planting stock, and random effect block were tested for effect on response variables crown height, crown ratio, total height, and DBH.

After four growing seasons, the total study height was 15.97 feet with an average DBH of 2.2 inches. Natural pruning was beginning to be evident for the internal trees and live limbs were not present below 3.99 feet above the ground. The average basal area of a plot was 32.2 square feet. At the tree level across the study, crown height was correlated with DBH and height at 0.43 and 0.62, respectively. As expected, crown ratio was negatively correlated with both traits with -0.24 and -0.43 for DBH and height, respectively. At the plot level, correlations of crown height with basal area per acre, stand density index, and trees per acre were 0.59, 0.58, and 0.22, respectively. Based on correlation strength with basal area per acre, this variable was included as a covariant in the Glimmix analysis and was found to significantly interact with the family effect to affect crown height ($p < 0.001$). Family also significantly affected ($p < 0.01$) DBH and height.

Interaction effect estimates on crown height differed among the families and was expressed by families having varying slopes across varying basal areas (fig. 1A). The two native sweetgum families (AGH25 and AGH2) both had negative though non-significant slopes, while AGHS2 and AGHS1 both had significantly greater slopes. These two hybrid families were also in the top three families for DBH growth (fig. 1B) and were the top two tallest average families (fig. 1C).

Hybrid sweetgum families outperformed native sweetgum families at two sites in Louisiana after four years of growth. Careful selection within the taxa may be needed for future production of high-quality lumber. While all four hybrids were superior to the native families, two taxa greatly outperformed the others in regard to self-pruning and demonstrated that they were affected by stand level basal area greatly. On the other hand, two hybrids as well as the two native families did not express a significant interaction with stand level basal area to effect self-pruning. These effects did not totally agree or differentiate with the single-tree growth patterns. This study demonstrates genetic differences among families contribute to the natural pruning promoting future high-quality lumber.

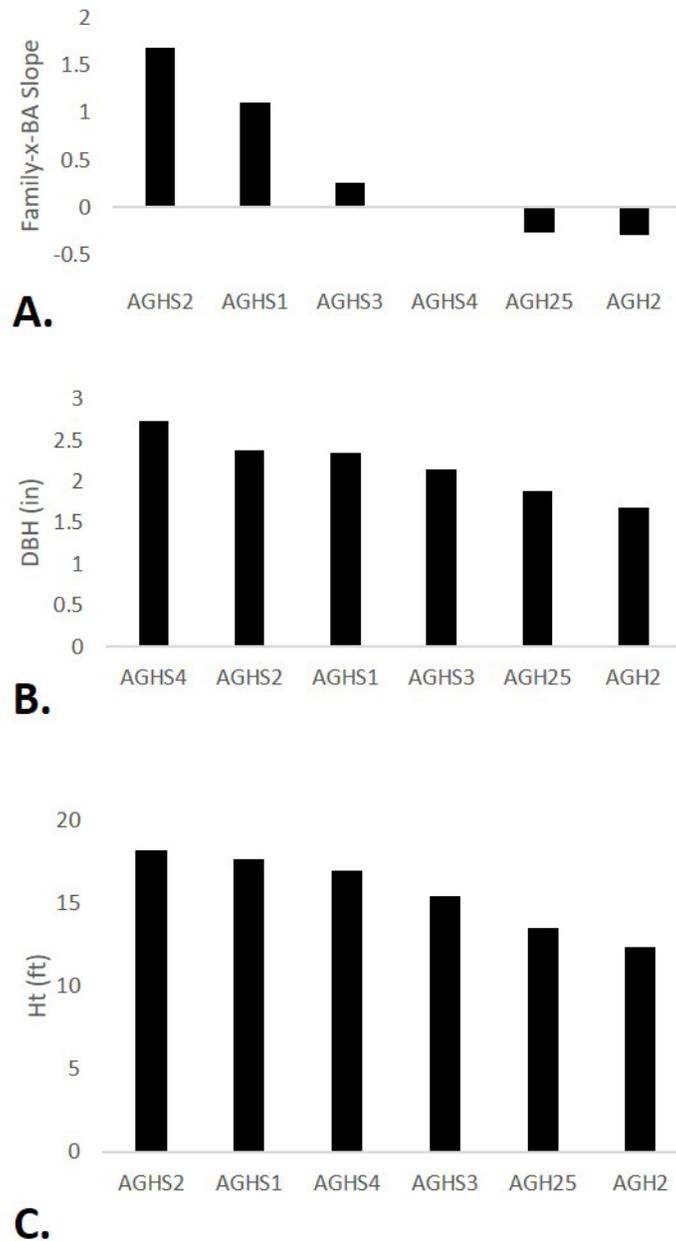


Figure 1—End of the year-5 growing season produced (A) slope estimates of basal area interacting with family to effect year-5 crown height (Ht), and the previous year growth as expressed by (B) average DBH (inches) across family and (C) average Ht (feet) across family.

LITERATURE CITED

- Bentley, J.W.; Howell, M.; Johnson, T.G. 2002. Louisiana's Timber Industry—an assessment of timber product output and use, 1999. Resour. Bull. SRS-81. U.S. Department of Agriculture Forest Service, Southern Research Station. 39 p.
- Koch, P. 1985. Utilization of hardwoods growing on southeastern pine sites—volume 1. Agric. Handb. SFES-AH-605. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station: 1419–2542.
- Martin, S. 2016. New hybrid sweetgum trees could boost paper, bioenergy production. UGA Today. July 12: Athens, GA, July 12.
- Smith, W.B.; Vissage, J.S.; Darr, D.R.; Sheffield, R.M. 2001. Forest Resources of the United States, 1997. Gen. Tech. Rep. NC-219. St. Paul, MN: U.S. Department of Agriculture Forest Service, North Central Station. 198 p.

THIRTY YEARS OF COOPERATIVE OAK RESEARCH AND TECHNOLOGY DEVELOPMENT IN THE SOUTHERN REGION

Stacy L. Clark, Scott E. Schlarbaum, Barbara Crane, and Tom Tibbs

EXTENDED ABSTRACT

Southeastern North American forests have a tremendous diversity of oaks (*Quercus* L.), consisting of over 30 different species. These species provide wood, habitat, mast, and ecosystem and aesthetic values integral in consumptive and non-consumptive industries and lifestyles. By the late 1980s, oak recruitment failures and decline were widely recognized, and planting was seen as a potential solution (Crow 1988). Despite the common occurrence of oak and the long history of planting in this country, artificial regeneration protocols remain largely unrefined. The majority of previous research and technology transfer regarding planting oak was generated in central and northeastern forests on sites generally devoid of fast-growing competition like tulip-poplar (*Liriodendron tulipifera* L.) (Dey and others 2008). Additionally, seedlings used in southeastern plantings were generally from unpedigreed seed sources and were small in size (e.g., <2 feet in height), which may not be locally adapted and can be quickly overtopped by competing vegetation (Loftis 1979).

In 1992, a long-term partnership was initiated among three parties: (1) The University of Tennessee's Tree Improvement Program (UT-TIP); (2) the Southern Region, Genetic Resources Program (Region 8) of the Forest Service, U.S. Department of Agriculture (USDA); and (3) the Southern Research Station (SRS) of the Forest Service. Personnel from these participating programs pooled together associated expertise and resources to develop and test artificial regeneration protocols for oak species. The approach involved using high-quality, pedigreed seedlings for restoration and enrichment of the oak component in Southern Appalachian forests, following the pioneering research of Dr. Paul P. Kormanik and associates at the SRS Institute of Tree Root Biology (ITRB). For background, the ITRB began work in the 1980s to improve hardwood planting stock and establish baseline fertility and irrigation guidelines for nurseries that grow oak species (Kormanik and others 1994). These protocols were designed to grow hardwood seedlings in 1 year (i.e., 1-0 bare-root nursery seedlings) to their maximum growth. The oak seedlings were stimulated to flush up to seven times during a growing season, instead of the usual one or two flushes under traditional nursery practices. Because of the inherent variability in oak seedlings, approximately 50 percent of the best quality seedlings could be visually selected through commercial grading practices (Kormanik and others 1995). Resultant seedlings not only had increased above-ground stature, but the root systems showed a corresponding increase

Author Information: Stacy L. Clark, Research Forester, U.S. Department of Agriculture, Forest Service, Southern Research Station, Knoxville, TN 37996-4563; Scott E. Schlarbaum, Professor and Director, The University of Tennessee, Tree Improvement Program, Knoxville, TN 37996-4563; Barbara Crane, Regional Genetist (Retired), U.S. Department of Agriculture, Forest Service, Southern Region, Atlanta, GA 30309; and Tom Tibbs, Regional Genetist (Retired), U.S. Department of Agriculture, Forest Service, Southern Region, Atlanta, GA 30309.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

in size, particularly the tap roots. The number of first-order lateral roots were shown to be a heritable trait and correlated well to seedling height and root-collar diameter (Kormanik and others 1997).

When the ITRB began working with oaks, they found that pedigreed oak seedlings were a rarity in Southern States, as there were very few seed orchards. Acorn collections from naturally occurring trees could have been made from individual trees, but were problematic. The collections depended on masting years, and most of the naturally occurring oaks in forests had relatively small crowns and did not produce many acorns. Availability and quality of acorns were also affected by mammalian and bird predation or damage from a variety of insects. To partially avoid these problems, Regional Geneticist, James L. McConnell, had the foresight to convert a large northern red oak progeny test on the Watauga Ranger District of the Cherokee National Forest to a seedling seed orchard in the mid-1980s. The resulting orchard (Watauga Northern Red Oak Seed Orchard) is the largest oak orchard (16 acres) in North America and is now capable of producing enough acorns to meet seedling demands on Southern Appalachian National Forests.

Acorn production in the Watauga Orchard was noted as early as 1984, when the orchard was still an 11-year-old progeny test. In 1990, UT-TIP began to study reproductive maturation in the orchard and to characterize acorn production in individual trees (Schlarbaum and others 1994). Eventually, UT-TIP become responsible for managing the orchard in the late 1990s and continues to manage the orchard in conjunction with the Southern Region. Acorn production was found to progressively increase as the trees become reproductively mature in the years after the orchard was created. The first significant crop occurred in 1993 (age 20) and was collected by pedigree for use by the above partnership to initiate a large-scale project to establish progeny tests and seed production areas across the Southern Region. The partnership was initially distinguished from other research programs by integrating genetics, baseline nursery protocols, characterization of seedling quality, and geography of planting sites (mesic sites in the Southern Appalachians) in widespread experimental field plantings. Over time, the partnership has evolved to test high-quality, genetically improved seedlings across various silvicultural settings; further refine nursery protocols for using pedigreed acorns (fig. 1); characterize variation in seedling quality among mother trees; test the effects of top pruning on seedling development; and develop northern red oak seed orchard management protocols, which can be applied to other oak species (Clark and Schlarbaum 2018, Clark and others 2000, 2015).

Technology transfer to Federal and State agencies and private landowners has been an important part of the partnership since its inception. Results from the varied experiments have been transferred via various publications, meetings, workshops, presentations, and press interviews. Technology transfer opportunities will increase in the future, as the older studies continue to yield results and newer studies are established that build on the knowledge gained over the history of the partnership.

The acorn crops from the Watauga Orchard continue to be a nexus for the partnership, while other recent studies are using acorns and seedlings from other Southern Region and UT-TIP seed orchards of different oak species. Since 2013, the partnership has been formally recognized through a series of Memorandums of Understanding. Despite changes in personnel and scarcity of dedicated long-term funding during the 30-year history of the partnership, the goal of developing successful and economically feasible artificial regeneration of oaks species still remains at the core of this group's efforts.

ACKNOWLEDGMENTS

The authors thank David Mercker and Belinda Esham-Ferro for reviews. The authors thank Forest Service personnel: Glen Beaver, Jim Cunningham, Paul Kormanik, Taryn Kormanik, Jim McConnell, Bill Ostrosina, Susana Sung, and Mike Thompson; Georgia Forestry Commission personnel: Russell Ayres, Wayne Bellflower, Johnny Brannan, Jeff Fields, Russ Pohl, Greg Seabolt, and Jerry Scott; Tennessee Division of Forestry personnel: John Conn, Paul Ensminger, and Gina Sowders; UT-TIP personnel: David Casey, David Griffin, Jason Hogan, Gene Johnson, Allison Mains, Mark Miller, Ken Proffitt, and Ami Sharp; and the U.S. Department of Labor Older Americans Program.



Figure 1—U.S. Department of Agriculture (USDA) Forest Service personnel from the Southern Region and Southern Research Station and The University of Tennessee personnel gather at the Georgia Forestry Commission's (GFC) State Nursery to process and sort seedlings for reforestation and research plantings (top). Dr. Paul Kormanik at the GFC nursery (bottom). (USDA Forest Service photo by Barbara Crane).

LITERATURE CITED

- Clark, S.L.; Schlarbaum, S.E. 2018. Effects of acorn size and mass on seedling quality of northern red oak (*Quercus rubra*). *New Forests*. 49(4): 571–583.
- Clark, S.L.; Schlarbaum, S.E.; Kormanik, P.P. 2000. Visual grading and quality of 1-0 northern red oak seedlings. *Southern Journal of Applied Forestry*. 24: 93–97.
- Clark, S.L.; Schlarbaum, S.E.; Schweitzer, C.J. 2015. Effects of visual grading on northern red oak (*Quercus rubra* L.) seedlings planted in two shelterwood stands on the Cumberland Plateau of Tennessee, USA. *Forests*. 6: 3779–3798.
- Crow T.R. 1988. Reproductive mode and mechanisms for self-replacement of northern red oak (*Quercus rubra*)—a review. *Forest Science*. 34(1): 19–40.
- Dey, D.C.; Jacobs, D.F.; McNabb, K. [and others]. 2008. Artificial regeneration of major oak (*Quercus*) species in the Eastern United States—a review of the literature. *Forest Science*. 54(1): 77–106.
- Kormanik, P.P.; Sung, S.J.S.; Kormanik, T.L. 1994. Towards a single nursery protocol for oak seedlings. In: Lantz, C.W.; Moorhead, D.J., comps. *Proceedings of the 22nd Southern Forest Tree Improvement Conference*, Atlanta, GA. [Place of publication unknown]: Southern Forest Tree Improvement Centre: 89–98.
- Kormanik, P.P.; Sung, S.J.S.; Kormanik, T.L.; Zarnoch, S.J. 1995. Oak regeneration—why big is better. In: Landis, T.D.; Cregg, B., tech. coords. *National Proceedings, Forest and Conservation Nursery Associations*. Gen. Tech. Rep. PNW-GTR365. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station: 117–723.
- Kormanik, P.P.; Sung, S.J.S.; Kormanik, T.L. [and others]. 1997. Heritability of first-order lateral roots in five *Quercus* species: effect on 1-0 seedling quality evaluation. In: Steiner, K.C., ed. *Diversity and adaptation in oak species. Proceedings of the second meeting of working party 2.08.05, Genetics of Quercus, of the International Union of Forest Research Organizations*. University Park, PA: Pennsylvania State University: 194–200.
- Loftis, D.L. 1979. Northern red oak performs poorly in North Carolina planting. Res. Note SE-277. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. [Number of pages unknown].
- Schlarbaum, S.E.; McConnell, J.L.; Barber, L.R. [and others]. 1994. In: Lantz, C.W.; Moorhead, D.J., comps. *Proceedings of the 22nd Southern Forest Tree Improvement Conference*, Atlanta, GA. [Place of publication unknown]: Southern Forest Tree Improvement Centre: 52–58.

EFFECTS OF FOREST MANAGEMENT PRACTICE (PRESCRIBED BURNING) ON MERCURY TRANSPORT: A CASE STUDY IN A PAIRED EXPERIMENTAL WATERSHED IN THE LOWER COASTAL PLAIN OF SOUTH CAROLINA

Peijia Ku, Martin Tsui, Troy Farmer, Huan Chen, Devendra Amatya, Carl C. Trettin, and Alex Chow

EXTENDED ABSTRACT

Land use changes and forest management practices (e.g., prescribed burning, mechanical thinning, etc.) are known to alter ecosystem structure and water quality. However, little is known about their short- and long-term impacts on the biogeochemical cycling of mercury (Hg), a global pollutant that can be bioaccumulated and biomagnified in natural food webs, posing a threat to the health of top predators and humans through fish consumption. Forest ecosystems are significant “sinks” for atmospheric Hg, due to the stomatal uptake by leaves. However, silvicultural practices such as prescribed burning and mechanical thinning interferes with Hg storage in forests and potentially increase its export to downstream environment, where it can be a hotspot for transformation into methylmercury (MeHg) production by different anaerobic microbes. Therefore, a better understanding is needed for the impacts of the forest management on Hg bioaccumulation and its export in forested watersheds.

We conducted this study in a paired experimental watershed (WS77 and WS80) with similar size (~150-160 ha) at Santee Experimental Forest on the Atlantic Coastal Plain of South Carolina managed by the Forest Service, U.S. Department of Agriculture, Southern Research Station (as shown in fig. 1). WS77 has been managed for various silvicultural treatments and recently burned in March 2018. WS80 serves as an unburned control. The burn severities were mostly considered as light to moderate burn, with 33 percent light burned area, 66 percent moderate burned area, and ~1 percent not burned area. We collected surface water samples biweekly before and after burning from the outlet of both gauged watersheds from September 2017 to August 2020. We determined the general water quality and total Hg and MeHg concentrations in both watersheds before and after burning in March 2018 and compared total Hg and MeHg export from the watersheds 1- and 2-years post burn. The annual loadings and yields of total suspended solid (TSS), dissolved organic carbon (DOC), total Hg and MeHg in the first year after the burning in

Author Information: Peijia Ku, Postdoctoral Research Associate, Oak Ridge National Laboratory, Oak Ridge, TN 37831; Martin Tsui, Associate Professor, University of North Carolina at Greensboro, Greensboro, NC 27402; Troy Farmer, Assistant Professor of Fisheries Ecology, Clemson University, Clemson, SC 29634; Huan Chen, Research Assistant Professor, Clemson University, Clemson, SC 29634; Devendra Amatya, Research Hydrologist, U.S. Department of Agriculture Forest Service, Southern Research Station, Cordesville, SC 29434; Carl C. Trettin, Team Leader and Supervisory Research Soil Scientist, U.S. Department of Agriculture Forest Service, Southern Research Station, Cordesville, SC 29434; and Alex Chow, Professor, Clemson University, Georgetown, SC 29442.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture, Forest Service Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

the paired watershed were calculated and compared. We also examined MeHg in stream biota in both watersheds, including biofilm, macroinvertebrates, and fish from several collection campaigns.

Results showed TSS concentrations in streamwater were higher at the burned site than the control site in the first year post burning ($p < 0.05$, t-test), but no difference in the second year post burning. Total Hg and MeHg concentrations in the streamwater did not show statistical differences in either the first year or second year post burning. On an annual basis, as shown in table 1, TSS yield in the WS77 (burned) were 1.6 times higher than TSS yield in the WS80 (control) (6.66 tons Y⁻¹ km⁻² at WS77 compared to 4.17 tons Y⁻¹ km⁻² at WS80). Not surprisingly, the prescribed burning reduced DOC yield considerably (6.28 tons Y⁻¹ km⁻² at WS77 compared to 9.55 tons Y⁻¹ km⁻² at WS80). There was no obvious difference in the total Hg yield between the two watersheds, but much higher MeHg yield (1.71 times higher) in WS77 (burned) than WS80 (control).

We observed much higher MeHg levels in eastern mosquitofish (*Gambusia holbrooki*) (~4 folds) and dollar sunfish (*Lepomis marginatus*) (~2 folds) in WS77 than those in WS80, with similar trends in macroinvertebrates (crayfish [order *Decapoda*], dragonfly larvae [order *Odonata*], water scorpions [family *Nepidae*]), but we found no difference in MeHg levels in streamwater and biofilm samples between the paired watersheds. The higher MeHg contents in fish and macroinvertebrates may be attributed to the different food web structure and organismal growth rate. Further studies are needed to better understand the underlying mechanisms.

In summary, we found there was no significantly ($\alpha = 0.05$) elevated total Hg export to the downstream watershed but higher MeHg annual yield in the burned watershed than the control in the short-term. However, we should be aware that repeated prescribed burning may exaggerate this trend and lead to more Hg bioaccumulation in aquatic food webs. Meanwhile, long-term prescribed burning may reduce water use by vegetation, potentially leading to a higher water table in the forested watershed. This would promote a more reducing environment favoring the anaerobic microbes and Hg methylating groups (i.e., promoting more Hg methylation). This study provides new insights into how a forest management practice such as prescribed burning affects the amount and bioavailability of Hg in the downstream aquatic environment and has implication on Hg bioaccumulation in the managed forested watersheds.

Table 1—Comparison of annual loading and annual yield of TSS, DOC, total Hg and MeHg in the watersheds in the first year post-burning

	Annual loading				Annual yield			
	TSS (tons Y ⁻¹)	DOC (tons Y ⁻¹)	THg (g Y ⁻¹)	MeHg (g Y ⁻¹)	TSS (tons Y ⁻¹ km ⁻²)	DOC (tons Y ⁻¹ km ⁻²)	THg (g Y ⁻¹ km ⁻²)	MeHg (g Y ⁻¹ km ⁻²)
WS77 (Prescribed burned)	10.32	9.73	4.71	0.094	6.66	6.28	3.04	0.060
WS80 (Control)	6.67	15.28	5.41	0.056	4.17	9.55	3.38	0.035

TSS = total suspended solid; DOC = dissolved organic carbon.

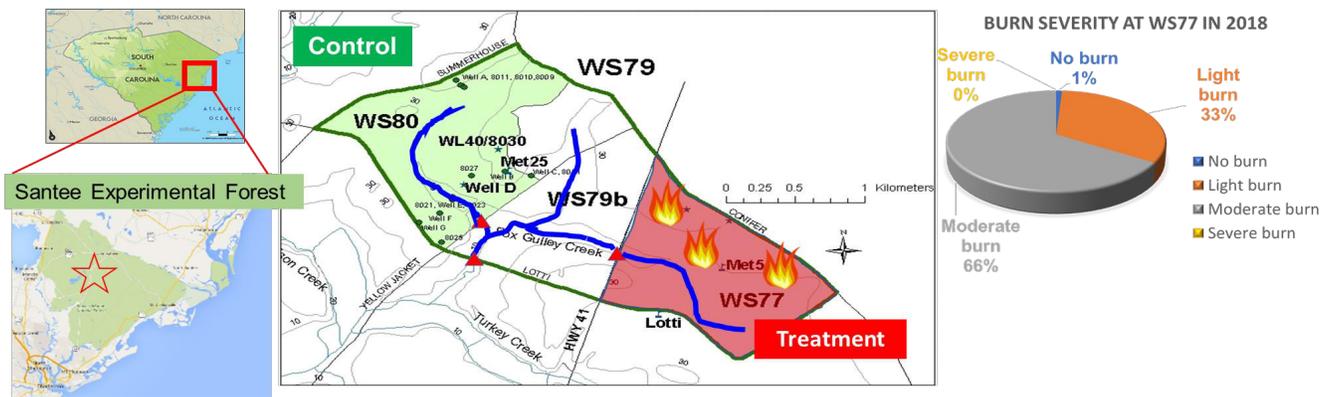


Figure 1—Site map of Santee Experimental Forest, South Carolina. Prescribed burning was conducted at WS77 (red), the managed first order watershed. WS80 (green) is paired unmanaged first order watershed. WS79 is the second order watershed. The burn severity at WS77 in March 2018 was shown on the right.

FIFTH YEAR DEVELOPMENT OF NATURAL REGENERATION FOLLOWING PRE-COMMERCIAL HERBICIDE RELEASE TREATMENTS

Stephen E. Peairs and Wayne K. Clatterbuck

ABSTRACT

Land managers have a challenging time attempting to maintain the competitive status of oak reproduction following clearcutting. Early herbicide applications have the potential to assist oak reproduction in reaching competitive status at crown closure. Yellow-poplar, red oak, and white oak seedlings and saplings were re-measured for change in height and groundline diameter five growing seasons following early herbicide applications conducted immediately after clearcutting. Prior (May and August 2014) treatments around the reproduction included radial sprays using glyphosate, post-emergent release with sulfometuron methyl, and an untreated control. Though 2-year growth responses were statistically different between treatments, after 5 years no statistical difference existed between the herbicide treatments and control. A numerical difference existed for red oak change in height growth however, as chemical release did increase the mean. Findings from this study suggest that additional competition sources may be reduced by glyphosate applications around favored reproduction. The seedling growth gains from the release treatment may assist in promoting red oak establishment and improve the probability that red oak reaches dominant crown positions at crown closure.

INTRODUCTION

Clearcutting is a commonly utilized silvicultural technique to perpetuate stands of oak (*Quercus* spp.) and yellow-poplar (*Liriodendron tulipifera*). Clearcutting can promote desirable natural hardwood regeneration compared to other regeneration methods (Clatterbuck and others 1999, Jensen and Kabrick 2008, Ward and Stephens 1999), and usually results in a high reproduction establishment rate between 10,000–40,000 stems per acre (Johnson and Krinard 1988, Romagosa and Robison 2003). Yellow-poplar is proficient at seed production and can potentially occupy a clearcut site with greater than 50,000 seedlings per acre (Beck 1990). This species can also establish dominance in crown position and species composition as the stand develops following clearcutting (Brashers and others 2004, McGee and Hooper 1970). Ward and Stephens (1994) suggested that oaks showing early dominance have the best chance to survive and establish a place of prominence in the upper crown classes once the stand reaches maturity. The difficulty lays in developing and maintaining the competitive status of oak reproduction when plant competition is high. Typically, competing plants will suppress the preferred oak regeneration though yellow-poplar will normally maintain dominance within the stand. Research findings have suggested that previous stand composition changes after disturbance with shade tolerant species replacing some of

the shade intolerant and intermediate species (McGee and Hooper 1970, Zedaker and others 1989). This response is most common on higher productivity sites.

Early silvicultural tending operations such as herbaceous release and weeding may prolong a more competitive status and enhance growth for desired natural reproduction (Peairs 2018, Schuler and Robison 2006). These management actions are necessary as managers have had adversity in maintaining adequate oak reproduction on many sites following greater severity disturbances. Though a wealth of small seedlings may be present after timber removal, simply having a multitude of reproduction is not adequate to ensure oak regeneration success to form the future stand (Smith 1986, Stringer 2005). The primary reason for oak regeneration failure is likely attributed to the abundant establishment and persistence of post-disturbance competing vegetation.

Chemical vegetation control has been suggested to improve the competitive status of oaks in hardwood stands. In particular, enhanced seedling diameter and height growth may result from chemical release. Hilt and Dale (1987) concluded that increased intensity of pre-commercial thinning resulted in greater diameter growth in stands 13, 17, and 21 years of age. A study by Thompson and Nix (1993) observed that early crop tree release within a 4-year-old clearcut significantly decreased herbaceous and woody plant competition. This reduction in competition resulted

Author Information: Stephen E. Peairs, Assistant Professor, Clemson University, Clemson, SC 29634; and Wayne K. Clatterbuck, Professor, University of Tennessee, Knoxville, TN 37996.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

in increased seedling groundline diameter growth but did not improve height growth over untreated controls. Nix (2004) remeasured the released natural oak 10 years after the initial chemical release treatments and reported that four herbicide treatments significantly increased diameter growth of released oak seedlings. Likewise, circumspectly applied post-emergent herbicide applications utilizing glyphosate has improved height growth in hardwood species (Hopper and others 1993) in addition to oak seedling survival.

Competition control around oak reproduction is often an ongoing process requiring more than one application within the first decade. Adjacent woody stems will be a persistent factor limiting crop tree growth whether due to ineffective control by the chemical application or as subsequent invasion of new seed. Continued silvicultural upkeep, beyond pre- or post-harvest site preparation, will often be needed as the proliferation of light-seeded species will invade or establish from seed already present in the soil herbicide treated areas (Clatterbuck and Schubert 2007).

Previous studies (Self and others 2014, Thompson and Nix 1993) suggested that early herbaceous release can improve select species of oak's growth. Two-year measurement analyses (Peairs 2018) previously indicated significant change in height growth existed between sulfometuron methyl, glyphosate radial spray, and control plots. A difference in diameter growth was found for the sulfometuron methyl treatment versus the control and radial glyphosate release (latter two did not differ) after two growing seasons.

OBJECTIVES

This study is a continuation of a previous study that examined the impacts of chemical release applications on height and diameter growth of natural oak and yellow-poplar reproduction. Analyses aimed to determine if (1) a significant difference still exists for absolute change in seedling height growth, after five complete growing seasons, among chemical treatments applied post-harvest to clearcuts conducted in 2014; (2) a difference has become evident for absolute change in groundline diameter for natural regeneration; and (3) derive estimates of stem density creating competition for resources around the sample trees.

METHODS

Study Site

The study site was located on a private landholding in the Western Highland Rim-highly dissected plateau physiographic ecoregion of west-central Tennessee (Smalley 1984). The soils on the study site were Bodine gravelly silt loams (5 to 40 percent slopes). Site index value for white oak (*Quercus alba*) was 75 feet at base age 50.

Most undisturbed forestland in the region was dominated (80 percent or greater) by oak species. The study site was covered by a mixed-mesophytic forest, with white oak, southern red oak (*Q. falcata*), chestnut oak (*Q. montana*), black oak (*Q. velutina*), hickory (*Carya* spp.), blackgum (*Nyssa sylvatica*), red maple (*Acer rubrum*), sugar maple (*A. saccharum*), black cherry (*Prunus serotina*), and yellow-poplar forming the majority of the overstory species composition. Midstory and understory canopy layers also contained flowering dogwood (*Cornus florida*), sourwood (*Oxydendrum aboreum*), sassafras (*Sassafras albidum*), eastern hophornbeam (*Ostrya virginiana*), elms (*Ulmus* spp.), white ash (*Fraxinus americana*), and American beech (*Fagus grandifolia*). As indicated by residual stumps, one or more diameter-limit harvests probably occurred within the area (the most recent harvest likely occurred between 1990 and 1995). The research blocks had experienced five full growing seasons since clearcutting. The majority of trees within the replicated blocks have reached large seedling to sapling size class. A heavy abundance of *Rubus* spp. still exists on at least 75 percent of the research area. The heavy abundance of broomsedge (*Andropogon virginicus*) previously on site at year 2 has been displaced by shading from the developing vegetation. Large seedlings and saplings were tallied by species. The stand has not reached crown closure but is expected to do so in 2 to 3 years.

Study Design

The study incorporated a randomized complete block sampling design. Three individual blocks were replicated on sites with uniform site productivity, and these blocks were clearcut in the early spring of 2014. Six individual treatment units, approximately 0.75 acres in size, were initially installed within each block. Only three treatments were re-measured for 5-year growth response due to travel and budget restrictions. These included broadcast sulfometuron methyl, radial glyphosate sprays, and control treatment units. Eight of the nine treatment units were sampled during the winter and an adequate number of sample trees were re-measured. An attempt was made to remeasure samples in the ninth treatment unit in July of 2020. Due to a lack of sample data (previously tagged trees could not be found) the aforementioned control treatment unit in one block was dropped from the analysis. More descriptive narratives of the treatments analyzed include:

1. Chemical seedling release treatments utilizing the equivalent of 2 ounces per acre of sulfometuron methyl (SFM75[®] by Alligare LLC) only,
2. Radial spray release utilizing foliar sprays of glyphosate (5 percent solution), and
3. Untreated control.

The three sulfometuron methyl treatment units received applications in May-June of 2014. Glyphosate radial spray applications were conducted between July and August of 2014. Radial sprays treated vegetation in the surrounding area of approximately a 5-foot radius from the sample seedling. A stove pipe apparatus covered the seedling being released to protect foliage from incidental contact with herbicide solution. The final treatment unit (untreated control) did not receive any herbicide applications.

Approximately 150 naturally regenerated seedlings (approximately half oak species and half yellow-poplar) in each treatment unit in the three replicated blocks were measured in the fall of 2014 for overall height and ground line diameter. A total of 2,653 seedlings were initially measured. Height measurements were taken with a standard retractable ruler to the nearest half inch. Diameter was measured at groundline using handheld digital calipers. Seedlings were measured again after five full growing seasons had elapsed in December 2019 to January 2020. Stem density data was collected at the aforementioned time and in July 2020. The same methods were used to gather height and groundline diameter data. The final data collection was later in the growing season due to ramifications with the Covid-19 pandemic. Only 378 seedlings (of the 1,550 relocated during the 2017 measurement period to gather second year growth) were relocated, on 8 out of the 18 total treatment units, for measurement.

Stem density tallies were summarized by individual treatments and combined treatments. Stem density within a 5-foot radius around 155 of the sample trees in the study were collected. The 5-foot radius was representative of the distance treated in the radial glyphosate sprays. Percentages of individual species were calculated for each summarization. Overall stem density per tree as well as stem density per tree by treatments were also derived from the data.

Statistical Analyses

The experimental design was a randomized complete block with sampling using height and diameter measurements taken from white oak, red oak, and yellow-poplar seedlings. The white oak group included post oak (*Quercus stellata*), chestnut oak, and white oak species. All red oak species

(primarily black oak and southern red oak) had been designated as “red oak” since initial measurements. Analyses were run for each species group and for all seedlings combined to determine any differences between treatments. Treatment was considered a fixed variable. Random variables included blocks and seedlings. Statistical analyses were performed using linear mixed models (PROC Glimmix; SAS version 9.4) (SAS Institute 2013) with a normal distribution. The least squares means were separated using Tukey’s significant difference test. The significance level was set at alpha = 0.05. A degrees of freedom test using the Kenward-Roger method was also performed.

RESULTS

The type III tests indicated no significant differences were calculated amongst treatments when all seedlings were combined for diameter ($F_{2,425} = 0.12, p < 0.8939$) or height ($F_{2,425} = 0.051, p < 0.6815$). There were no statistical differences for change in diameter growth for red oak ($F_{2,163} = 1.11, p < 0.5947$), white oak ($F_{2,161} = 5.158, p < 0.6458$), or yellow-poplar ($F_{2,99} = 3.42, p < 0.8053$). There were also no statistical differences (at alpha = 0.05) for change in height growth for red oak ($F_{2,163} = 2.85, p < 0.0611$), white oak ($F_{2,161} = 3.721, p < 0.3961$), or yellow-poplar ($F_{2,99} = 3.227, p < 0.5105$). Though no statistical difference was found, a numerical difference exists between red oak height growth in control and sulfometuron methyl treatments with means of 59.97 inches and 78.19 inches, respectively (table 1). Red oak mean height growth was also greater than white oak for radial glyphosate and sulfometuron methyl released red oak having 13.44 inches and 8.44 inches greater growth over white oak species, respectively. There was minimal difference in height growth between red oak and white oak in the control. A similar trend existed for change in diameter among species and treatments. Red oak means for radial and sulfometuron methyl were 0.952 and 0.953 inches, respectively (table 2). Control had a lower mean of 0.778 inches. The white oak mean for the sulfometuron methyl treatment was highest at 0.834 inches.

Table 1—Least squares mean estimates for change in height (inches) of natural reproduction by species groups and treatments for the herbicide seedling release study on the Western Highland Rim of Tennessee

Treatment	Red oak			White oak			Yellow-poplar			Combined		
	n	LS Mean	SE	n	LS Mean	SE	n	LS Mean	SE	n	LS Mean	SE
Control	54	59.97	5.33	45	59.50	8.75	22	155.53	34.23	121	75.52	9.27
Radial	60	69.44	5.01	60	56.00	6.72	25	123.37	27.55	145	73.81	8.39
SFM 75	50	78.19	5.48	57	69.35	6.86	53	106.39	26.18	160	80.18	8.26

Treatments had no statistical difference by tree group or for all reproduction combined.

n = number of seedlings; LS Mean = least squares means; SE = standard error; Control = no treatment; SFM75 only = 2 ounces per acre rate of sulfometuron methyl only; Radial = Radial spray release utilizing foliar sprays of glyphosate (5 percent solution).

Table 2—Least squares mean estimates for change in basal diameter (inches) of natural reproduction by species groups and treatments for the herbicide seedling release study on the Western Highland Rim of Tennessee

Treatment	Red oak			White oak			Yellow-poplar			Combined		
	n	LS Mean	SE	n	LS Mean	SE	n	LS Mean	SE	n	LS Mean	SE
Control	54	0.778	0.137	45	0.697	0.107	22	1.967	0.540	121	0.952	0.142
Radial	60	0.952	0.115	60	0.781	0.090	25	1.620	0.415	145	1.010	0.110
SFM 75	50	0.953	0.118	57	0.834	0.092	53	1.526	0.391	160	1.032	0.108

Treatments had no statistical difference by tree group or for all reproduction combined.

Table 3—Competing live stem density (large seedlings and saplings) within 5 feet of sample trees within treatment units for the herbicide seedling release study on the Western Highland Rim of Tennessee

Treatment	Density	Samples	YLP	OAK	ASH	HIC	BLC	LOB	SYCA	GUM	SUMA	ELM	BASS	RBUD	HOP	DOG	Other	Totals
Control	5.23	62	89	26	41	22	7	1	12	8	36	5	17	22	29	4	5	324
			<i>27.47</i>	<i>8.02</i>	<i>12.65</i>	<i>6.79</i>	<i>2.16</i>	<i>0.31</i>	<i>3.70</i>	<i>2.47</i>	<i>11.11</i>	<i>1.54</i>	<i>5.25</i>	<i>6.79</i>	<i>8.95</i>	<i>1.23</i>	<i>1.54</i>	
Radial	2.98	45	35	19	5	19	1	6	1	1	2	3	7	5	21	4	5	134
			<i>26.12</i>	<i>14.18</i>	<i>3.73</i>	<i>14.18</i>	<i>0.75</i>	<i>4.48</i>	<i>0.75</i>	<i>0.75</i>	<i>1.49</i>	<i>2.24</i>	<i>5.22</i>	<i>3.73</i>	<i>15.67</i>	<i>2.98</i>	<i>3.73</i>	
SFM75	5.27	48	83	35	62	13	6	2	3	3	4	9	12	13	0	1	7	253
			<i>32.81</i>	<i>13.83</i>	<i>24.51</i>	<i>5.14</i>	<i>2.37</i>	<i>0.79</i>	<i>1.19</i>	<i>1.19</i>	<i>1.58</i>	<i>3.56</i>	<i>4.74</i>	<i>5.14</i>	<i>0.0</i>	<i>0.40</i>	<i>2.77</i>	
Totals	4.59	155	207	80	108	54	14	9	16	12	42	17	36	40	50	9	17	711
			<i>29.11</i>	<i>11.25</i>	<i>15.19</i>	<i>7.59</i>	<i>1.97</i>	<i>1.27</i>	<i>2.25</i>	<i>1.69</i>	<i>5.91</i>	<i>2.39</i>	<i>5.06</i>	<i>5.63</i>	<i>7.03</i>	<i>1.27</i>	<i>2.39</i>	

YLP = yellow-poplar; OAK = all oaks; HIC = hickory; BLC = black cherry; LOB = loblolly pine; SYCA = sycamore; SUMA = sumac spp.; BASS = basswood; RBUD = redbud; HOP = hophornbeam; DOG = dogwood; OTHER includes sassafras, persimmon, eastern redcedar, sugar maple, and miscellaneous species (all <1 percent of competing stem population); Density = the average number of competing stems surrounding a sample tree inside of a 5-foot radius; Samples = number of flagged/marked trees within a particular treatment; stems within the 5-foot radius were tallied around these trees.

Italicized numbers are species percentages of the total competing stem count.

Bold font is the overall combined species percentages (all treatment counts combined for individual species) for the entire population.

Stem density of competing stems around the sampled measured trees in the control and sulfometuron methyl treatments were similar at 5.23 and 5.27 stems per tree, respectively (table 3). The radial glyphosate spray treatment was substantially lower at 2.98 stems per tree. Yellow-poplar (29.1 percent) and ash (15.2 percent) were the most abundant competitors to the sample trees surveyed (table 3). Unmarked oak species comprised 11.3 percent of the competing stem population.

DISCUSSION

The lack of data in one of the control units likely did not impact analysis results for either red or white oak as sample sizes were of similar values to both the radial and sulfometuron methyl treatments. Due diligence was applied to find seedlings, but efforts were futile with dense, actively growing vegetation (July 2020). Yellow-poplar sample size was low due to difficulty determining if most of the yellow-poplars on site were previously sampled. It is possible that some tags may have grown into the trees themselves or were removed by wildlife. Flagging was evident at the base of some trees where it had become detached from tree growth, but a tag may not have been found making it unidentifiable. Future

studies will likely require biennial or annual upkeep to avoid loss of sample stems.

The findings regarding the gained absolute change in height growth for red oaks in response to the sulfometuron treatment is notable and would most likely be statistically significant at a lower level of significance, alpha level of 0.10. This herbicide treatment yielded a mean enhancement in height of 18.22 inches over the control. The suppression of herbaceous competition using sulfometuron methyl during the inchoate development of sample red oak likely accelerated early height growth (Peairs 2018). Likewise, the radial glyphosate release treatment improved height growth 10.11 inches which may also be attributed to both herbaceous and woody plant control in the immediate growing area around the crop trees. This response is especially noteworthy as sample trees within the radial glyphosate treatment appeared to have produced a “stunted” change in height growth compared to the control after the first two growing seasons (Peairs and Clatterbuck 2020). Thus, the sample trees appear to have recuperated from previous deleterious effects caused by glyphosate release during late summer of the first growing season.

The increased height growth resulting from release treatments may place red oaks in a more competitive position for maintaining dominance and higher vigor until

crown closure in the next few years as compared to the poorer performing red oaks found in the control treatment. Untreated vegetation around red oak in the control units may suppress preferred oak trees prior to crown closure potentially leading to mortality or lower vigor (Romagosa and Robison 2003). For the first few years, the presence of herbaceous vegetation may have also reduced potential growth of the oak seedlings (Romagosa and Robison 2003). Within any treatment, red oak will certainly have the advantage over white oak in this situation given the family's faster growth rate (Burns and Honkala 1990, Johnson and others 2009). Red oaks' faster growth rate has also been evident during the course of this study (Peairs 2018).

Adjacent competing woody stem density will also be a factor in determining if oak will be successful in maintaining dominance over time. The lower average density around crop trees in the radial sprays may continue to yield greater gains in subsequent years. Lower density equates to less competition for available resources including canopy/ root expansion growing space, water, and nutrients. Less competitor stems may also lead to decreased costs (labor time) should a crop tree release application be applied after crown closure. The sulfometuron methyl treatment stem density was similar to that of the control but is an anticipated response given the active ingredient, when applied at 2 ounces per acre, does not have injurious effects on oak or yellow-poplar. The abundant prevalence of competitors (especially yellow-poplar) around oak stems will likely lead to suppression of oak in the developing stand (Beck 1990, Brashears and others 2004). It will be imperative that some additional silvicultural management, such as crop tree release, be applied to the stand to continue oak prominence. Yellow-poplar will continue to dominate (Beck and Hooper 1986) and will not likely experience stagnated growth (Beck and Sims 1983).

CONCLUSIONS

Early attempts to control competing vegetation around preferred, higher-value species is common practice to establish hardwood stands. Few studies have investigated the efficacy of chemical applications to promote natural regeneration in recently disturbed stands. Though a statistical difference was not found at $\alpha=0.05$, a numerical difference appears evident to suggest that early release may promote red oak competitiveness in regard to height growth by using sulfometuron methyl and competition reduction using glyphosate applied as foliar sprays. The observance of height stunting by glyphosate after two growing seasons was previously observed, however, results from this study suggest that seedlings had recuperated and height is now greater than that of untreated seedlings.

LITERATURE CITED

- Beck, D.E. 1990. *Liriodendron tulipifera* L. Yellow-poplar. In: Burns, R.M.; B.H. Honkala, eds. Silvics of North America. Volume 2. Hardwoods, Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture Forest Service: 406–416.
- Beck, D.E.; Hooper, R.M. 1986. Development of a Southern Appalachian hardwood stand after clearcutting. *Southern Journal of Applied Forestry* 10(3): 168–172.
- Beck, D.E.; Sims, D.H. 1983. Yellow-poplar. In *Silvicultural systems for the major forest types of the United States*. Agric. Handb. 445. Washington, DC: U.S. Department of Agriculture Forest Service: 180–182.
- Brashears, M.B.; Fajvan, M.A.; Schular, T.M. 2004. An assessment of canopy stratification and tree species diversity following clearcutting in Central Appalachian Hardwoods. *Forest Science*. 50(1): 54–64.
- Burns, Russell M.; Honkala, B.H., tech. coords. 1990. *Silvics of North America: 1. Conifers; 2. Hardwoods*. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture Forest Service. 877 p. Vol. 2.
- Clatterbuck, W.K.; Blakley, P.; and Yielding, P. 1999. Development of oak regeneration nine years after shelterwood cutting and clearcutting on the Coastal Plain of west Tennessee. Gen. Tech. Rep. SRS-24. Proceedings of 12th central hardwood forest conference. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 189–194.
- Clatterbuck, W.K.; Schubert, M.R. 2007. Effects of pre- and post-harvest site preparation treatments on natural regeneration success in a mixed hardwood stand after 10 years. In: Stanturf, J.A., ed. Proceedings of the 14th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-121. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 451–454.
- Hilt, D.E.; Dale, M.E. 1987. Effects of precommercial thinning on diameter growth in young central hardwood stands. In: Hay, R.L.; Woods, F.W.; DeSelm, H., eds. Proceedings of the 6th central hardwood forest conference. Knoxville, TN: University of Tennessee: 179–187.
- Hopper, G.M.; Buckner, E.R.; Mullins, J.A. 1993. Effects of weed control and fertilization on plantation establishment and growth of green ash, sweet gum, and loblolly pine: four-year results. In: Brisette, J.C., ed. Proceedings of the seventh biennial southern silvicultural research conference. Gen. Tech. Rep. SO-93. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 357–360.
- Jensen, R.G.; Kabrick, J.M. 2008. Comparing single-tree selection, group selection and clearcutting for regenerating oaks and pines in the Missouri Ozarks. USDA General Technical Report NRS-P-24. Proceedings of the 16th central hardwood forest conference. Newtown Square, PA: U.S. Department of Agriculture Northern Research Station: 38–49.
- Johnson, P.S., Shifley, S.R.; Rogers, R. 2009. The ecology and silviculture of oaks, 2nd addition. Wallingford, Oxfordshire, UK: CABI International. 580 p.
- Johnson, R.L.; Krinard, R.M. 1988. Growth and development of two sweetgum-red oak stands from origin through 29 years. *Southern Journal of Applied Forestry*. 12(2): 73–78.
- McGee, C.E.; Hooper, R.M. 1970. Regeneration after clearcutting in the Southern Appalachians. Res. Pap. SE-70. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experimental Station: 520–523.
- Nix, L.E. 2004. Herbicide release of 4-year-old, naturally regenerated bottomland oaks—10 year results. In: Connor, K.F., ed. Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 520–523.
- Peairs, S.E. 2018. Oak and yellow-poplar response to pre-commercial chemical applications after clearcutting a high-graded hardwood stand on the Western Highland Rim of Tennessee. Knoxville, TN: University of Tennessee. 155 p. Ph.D. dissertation. https://trace.tennessee.edu/utk_graddiss/5083. [Date accessed: August 2018].

- Peairs, S.E.; Clatterbuck, W.K. 2020. Potential detrimental effects of using glyphosate for hardwood seedling release. In: Bragg, D.C.; Koerth, N.E.; Holley, A.G., eds. Proceedings of the 20th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 302–308.
- Romagosa, M.A.; Robison, D.J. 2003. Biological constraints on the growth of hardwood regeneration in upland Piedmont forests. *Forest Ecology and Management*. 175: 545–561.
- SAS Institute. 2013. SAS/STAT 13.1 user's guide. Version 9.4. Cary, NC: SAS Institute. [Not paged].
- Schuler, J.L.; Robison, D.J. 2006. Stand development and growth responses of 1- and 3-year-old natural upland hardwoods to silvicultural treatments. *Forest Ecology and Management*. 232(1–3): 124–134.
- Self, A.; Ezell, A.W.; Rowe, D. 2014. Performance of oak seedlings grown under different Oust® XP regimes. *Forests*. 5(6): 1331–1340. <https://doi.org/10.3390/f5061331>.
- Smalley, G.W. 1984. Classification and evaluation of forest sites on the northern Cumberland Mountains. Gen. Tech. Rep. SO-50. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 84 p.
- Smith, D.M. 1986. *The practice of silviculture*, eighth edition: New York: John Wiley and Sons. 527 p.
- Stringer, J. 2005. Harvest survivability of oak advanced regeneration. In: Weigel, D.R.; Van Sambeek, J.W.; Michler, C.H., eds. Ninth workshop on seedling physiology and growth problems in oak plantings. 2004 October 18-20; West Lafayette, IN. Gen. Tech. Rep. NC-262. St. Paul, MN: U.S. Department of Agriculture Forest Service, North Central Research Station: 26–27.
- Thompson, J.F., Jr.; Nix, L.E. 1993. Early release of naturally-regenerated cherrybark and shumard oak seedlings with herbicides. In: Brisette, J.C., ed. Proceedings of the seventh biennial southern silvicultural research conference. General Technical Report SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 445–451.
- Ward, J.S.; Stephens, G.R. 1994. Crown class transition rates of maturing northern red oak (*Quercus rubra* L.). *Forest Science*. 40(2): 221–237.
- Ward, J.S.; Stephens, G.R. 1999. Influence of cutting methods on 12-year-old hardwood regeneration in Connecticut. Gen. Tech. Rep. SRS-24. Proceedings, 12th central hardwood forest conference. Asheville, NC: U.S. Department of Agriculture, Southern Research Station: 204–208.
- Zedaker, S.M.; Smith, D.W.; Kreh, R.E.; Fredericksen, T.S. 1989. The development of five-year-old mixed upland hardwood-pine stands. In Proceedings of pine-hardwood mixtures: A symposium on management. Gen. Tech. Rep. SE-58. Atlanta: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station: 100–106.

IS THERE HOPE FOR HYBRID POPLARS IN THE SOUTHERN UNITED STATES?

Randall J. Rousseau, Kiah M. Smith, Mark Murphy, and Taylor Bowling

ABSTRACT

Early-age results of hybrid poplars showed promise with higher survival rates than eastern cottonwood and rapid growth rates that rivaled that of eastern cottonwood (*Populus. deltoides* Bartr. ex Marsh.) when grown on the newly developing and highly fertile soils of the Lower Mississippi Alluvial Valley (LMAV). But as the tests aged so did the susceptibility to the fungus (*Sphaerulina musiva*) which resulted in mortality. This fungus is both a leaf disease as well as a canker disease that manifests itself on both stem and limbs of hybrid poplars. Although eastern cottonwood is not resistant to the leaf spot disease of the fungus, it is resistant to the canker formation. Between 2010 and 2013, a total of four test sites was established by Mississippi State University with two in the LMAV and two on Upland sites in Mississippi. This document examines only the common varieties included for all four sites. Comparison between the LMAV and Upland sites revealed patterns that were unexpected for both eastern cottonwood and hybrid poplar varieties.

INTRODUCTION

The term “hybrid” always catches one’s interest, with forest researchers and landowners being no different. The term is taken to mean that a hybrid will be superior to the native species because it conveys a dramatic improvement in growth or other characteristic over whatever species is common to that specific environment. In agriculture, hybrids are planted widely, and farmers rely on new genotypes to increase crop yields. In forestry, most tree improvement programs employ a recurrent selection system focused primarily on general combining ability where repeated cycles of mating, testing, and selection within each generation provides genetic gain (Isik and McKeand 2019). However, in *Populus* emphasis is placed on inter-specific matings to produce hybrid vigor, which is then followed by vegetative propagation to take advantage of the full potential of genetic gain.

Populus hybridization work which began in the Northern United States has involved numerous species and has seen varying success across poplar-growing regions. In the Midwest, there has also been considerable hybridization work including the mating of *P. deltoides* x *P. nigra* (DN) and *P. deltoides* x *P. maximowiczii* (DM). In the Pacific Northwest, work at the University of Washington and Washington State University in the late 1970s and early 1980s led to the development of *P. x generosa* which results from matings of *P. trichocarpa* x *P. deltoides* (TD). In the 1990s and 2000s, GreenWood Resources began a large inter-specific breeding program that produced a variety of *Populus* taxa for their

landholdings in Oregon and Washington (Bergusson and others 2010).

In the 1960s through the mid-1980s, the *Populus* program in the South centered around eastern cottonwood (*P. deltoides* Bartr. ex Marsh.) (CTW) and was designed by the U.S. Department of Agriculture Forest Service Laboratory located at Stoneville, MS. Pulp and paper companies operating along the Mississippi River quickly added CTW plantations on alluvial soils both inside and outside the levee system from Cairo, IL to Baton Rouge, LA. The Stoneville Laboratory provided information on a variety of disciplines including tree improvement, silviculture, biometrics, pathology, and entomology. While little breeding was done during this period, the groundwork was well laid to build a significant population for immediate and future use. The Stoneville Laboratory examined a limited number of hybrid poplars (HYB) but found them unsuitable for use in the Lower Mississippi Alluvial Valley (LMAV) (Maisenhelder 1970). It was not until mid-1980 that the Westvaco central region, located just south of the confluence of the Mississippi and Ohio Rivers, would venture from the norm, and examine newly developed HYB in the LMAV. In a series of trials that spanned from 1987 to 1989, various HYB varieties within the TD taxon were tested on batture sites along the Mississippi River, south of the confluence of the two rivers. Varieties of *P. x generosa* were provided by Dr. Reinhard Stettler, (Geneticist, University of Washington) and included in variety trials with selected CTW in 1987, 1988, and 1989. It was obvious from these tests that the HYB varieties rooted

Author Information: Randall J. Rousseau, Extension/Research Professor (Retired), Mississippi State University, Mississippi State, MS 39762-9681; Kiah M. Smith, Research Associate (Former), Mississippi State University, Mississippi State, MS 39762-9681; Mark Murphy, Research Associate, Mississippi State University, Mississippi State, MS 39762-9681; and Taylor Bowling, Graduate Assistant, Mississippi State University, Mississippi State, MS 39762-9681.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

better and exhibited excellent first-year height growth. However, by age 2 growth rates slowed and disease in the form of stem and limb cankers, identified as resulting from *Septoria musiva* (now known as *Sphaerulina musiva*), became prominent. By age 3, the hybrids were riddled with cankers resulting in excessive mortality and by age 5 not a single hybrid ramet remained alive. It was unclear if the mortality was due to disease, annual flooding, or a combination of both factors. Regardless, further work with HYB varieties in the LMAV was discontinued (Westvaco Central Region 1991).

From mid-1990 to about 2005, there was a resurgence of research among a few industrial programs (e.g., James River and Westvaco) aiming to develop new and faster growing intra-specific CTW varieties for use in the LMAV and testing of inter-specific HYBs for upland sites in the South. Concurrently, short rotation woody crops (SRWCs), including poplar, were garnering more interest as feedstock for biofuels and bioenergy. Hybrid poplars were envisioned as the answer for rapid growth, thin bark, good coppice regeneration, and the ability to perform well across a wide range of sites.

This study focuses on the Department of Energy (DOE)—SunGrant Regional Biomass Feedstock Partnership entitled “Consolidated Populus Feedstock Trials” where the goal was to test the most current *Populus* material available from tests in different geographic areas to determine what species or taxa and varieties would perform best. This document covers only trials established by Mississippi State University (MSU).

PROCEDURES

The Consolidated *Populus* Feedstock testing began in 2010 and included the University of Minnesota (UMN), MSU, ArborGen (AG), and Greenwood Resources (GWR), each of which provided 20 varieties. Varieties from the UMN and GWR were HYBs while most of the material provided by AG and MSU were CTW genotypes (table 1). A total of four trials was established between 2010 and 2013 by MSU. The original design called for two trials in 2010 and 2011, with one trial each year placed in the LMAV and the other to be placed on an Upland site in Mississippi. The 2010 trials were established as expected with one trial established on an Upland site of the Upper Gulf Coastal Plain near Pontotoc, MS and the other in the LMAV near New Madrid, MO. In 2011, only the Upland site was established because flooding along the Mississippi River, which reached historic levels, prevented establishment. The LMAV test site was selected because a cooperative study between Westvaco and the University of Kentucky identified a number of races of cottonwood leaf rust (*Melampsora medusae* THÜM), some of which were very aggressive in this area (Prakash and Heather 1986, Prakash

and Thielges 1987). The spring of 2013 was the earliest that the second LMAV trial could be established on this site.

As per the Consolidated Populus Feedstock study, the trials were designed as varietal screening trials where minimum copies (ramets) were tested per varietal. This allows screening of many varieties, but selections should be further tested. The design consisted of a compact varietal block design (i.e., split-plot) consisting of three blocks, with each block having four sub-blocks, consisting of 20 varieties per sub-block, arranged in two tree-row plots, and planted at a spacing of 6 x 9 feet. The summer prior to the respective planting sites was disked and sub-soiled in two perpendicular directions to a depth of 16 inches. Cutting length varied depending on the contributor, with HYB cuttings between 9 to 12 inches and CTW cuttings between 16 to 18 inches. In 2010, both sites were planted during April and immediately treated with a broadcast application of Goal 2XL (Oxyfluorfen) at a 64 ounce per acre rate. When the herbicide lost effectiveness, the sites were mechanically disked and, if needed, hoed around the trees. Disking was maintained, as needed, during the first summer and once at the start of the second growing season. Insect control was conducted on an as-needed basis during biweekly checks. Any infestation of cottonwood leaf beetles (*Chrysomela scripta* F.) or Japanese beetles (*Popillia japonica* Newman) was treated with Admire® Pro (Imidacloprid). Total height (THT) and diameter at breast height (DBH) were measured at ages 1, 3, 5, and 10 for the 2010 trials, ages 1, 3, and 5 for the 2011 Trial and ages 1, 5, and 8 for the 2013 Trial.

The 2011 Upland test site was planted in April, but as previously noted the companion LMAV site was not planted until March of 2013. Varietal material intended for the 2011 LMAV site was placed into a stoolbed and held until the spring of 2013. This LMAV Trial is located in Mississippi County, Missouri and like the 2010 LMAV Trial, the test site is just outside of the Mississippi River levee system. Unfortunately, the 2013 LMAV Trial did not include all the HYB varieties that were included in the 2011 Upland Trial. Eleven HYB varieties were not included because they exhibited disease in the stoolbed. The 11 varieties excluded from the 2013 Trial included five HYB varieties (6320, 6329, 99007115, 1428, and 12804) that were part of the 21 common clones to be placed in each trial (table 1).

Our analysis focused on measurements taken at ages 1, 3, and 5 for all sites except the 2013 LMAV Trial that was not measured at age 3. These measurements included:

2010 LMAV Trial	Age 1 THT, Ages 3, 5, and 10 DBH and THT
2010 Upland Trial	Age 1 THT, Ages 3, 5, and 10 DBH and THT
2011 Upland Trial	Age 1 THT, Ages 3 and 5 DBH and THT
2013 LMAV Trial	Age 1 THT, Ages 1, 5, and 8 DBH and THT

Table 1—Varietal identification, taxa, agency of varietal, test location and age of the 21 common genotypes planted in the four SunGrant Consolidated Populus Feedstock trials established by Mississippi State University

Varietal ID	Taxa	Agency	Trial locations
110412	DD	MSU ^b	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
110804	DD	MSU	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
111234	DD	MSU	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
AG414	DD	AG ^c	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
AG437	DD	AG	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
S7C1	DD	MSU	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
ST66	DD	MSU	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
ST244	DD	MSU	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
1428 ^a	TD	GWR ^d	2010 LMAV, 2010 Upland, 2011 Upland
6018	TD	GWR	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
6198	DT	GWR	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
6320 ^a	DM	GWR	2010 LMAV, 2010 Upland, 2011 Upland
6329 ^a	DM	GWR	2010 LMAV, 2010 Upland, 2011 Upland
9732-31	DN	UMN ^e	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
12804 ^a	TD	GWR	2010 LMAV, 2010 Upland, 2011 Upland
22021048	DN	UMN	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
99007115 ^a	DN	UMN	2010 LMAV, 2010 Upland, 2011 Upland
AG187	TD	AG	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
AG188	TD	AG	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
AG229	TD	AG	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV
DN5	DN	UMN	2010 LMAV, 2010 Upland, 2011 Upland, 2013 LMAV

^aVarietals omitted from the 2013 LMAV Trial.

^bMSU varietals provided by Mississippi State University.

^cAG varietals provided by ArborGen.

^dGWR varietals provided by GreenWood Resources.

^eUMN varietals provided by the University of Minnesota.

When possible, individual tree volume calculations were derived for ages 3, 5, 8, and 10 using an equation developed for small CTW plantation grown trees (Mohn and Krinard 1971):

$$\text{Total volume outside bark} = 0.21099 + (0.00221(\text{DBH}^2 \times \text{THT}))$$

where

$$D = \text{DBH}$$

$$\text{THT} = \text{Total height.}$$

Though disease was not measured, it was noted when mortality appeared to be specific to a known disease.

The data were analyzed using Proc MIXED and Proc GLIMMIX model procedures in SAS Proprietary Software 9.4 (TS1M6) (SAS Institute 2016). Blocks and varietals within species and taxa were considered random. We conducted a combined analysis of all four sites and separate analyses combining like and different geographic areas. Additionally, each test site was subjected to Proc GLIMMIX producing

Pearson correlations to identify trait and age relationships for making effective selections.

RESULTS

Survival

Patterns of survival emerged for varietal groups (CTW versus HYB) when analyzed across all test sites, as well as when analyzed between LMAV and Upland sites. When combining all four test locations, the HYB group exhibited higher age 1 survival (92.9 percent) as compared to the CTW group (89.6 percent). This trend continued to age 3, when survival of the HYB and CTW groups were 84.6 percent and 80.5 percent, respectively. By age 5, survival of the HYB group dropped to 56.0 percent, while survival of the CTW group held at 80.2 percent (table 2). Although not shown in table 2, age 10 survival for the CTW group on the 2010 LMAV site was 72.9 percent, while the HYB group was zero. However, age 10

Table 2—Mean survival for the eastern cottonwood (CTW) and the hybrid poplar (HYB) groups at ages 1, 3, and 5 and least square means for total height, diameter at breast height (DBH), and volume at ages 1, 3, and 5

Mean survival				Total height			DBH		Volume	
<i>percent</i>				<i>feet</i>			<i>inches</i>		<i>cubic feet</i>	
All trials combined^a:										
Type	Age 1	Age 3	Age 5	Age 1	Age 3	Age 5	Age 3	Age 5	Age 3	Age 5
CTW	89.6	80.5	80.2	8.5a	20.4a	36.8a	2.4a	4.3a	0.6185a	2.2474a
HYB	92.9	84.6	56.0	7.7a	16.4b	27.0b	1.7b	3.0b	0.3774b	1.2218b
2010 LMAV Trial^b:										
Type	Age 1	Age 3	Age 5	Age 1	Age 3	Age 5	Age 3	Age 5	Age 3	Age 5
CTW	83.3	83.3	83.3	14.3a ^d	28.6a	44.1a	3.8a	5.6a	1.1855a	3.4307a
HYB	87.2	74.4	16.7	11.3b	19.7b	30.4b	2.4b	3.7b	0.4845b	1.3026b
2010 Upland Trial^b:										
Type	Age 1	Age 3	Age 5	Age 1	Age 3	Age 5	Age 3	Age 5	Age 3	Age 5
CTW	89.6	85.4	83.3	4.9b	17.2a	28.6a	1.6a	3.1a	0.3704a	1.0069a
HYB	93.6	93.6	91.0	6.4a	16.9a	22.8b	1.5a	2.5a	0.3390a	0.6577b
2011 Upland Trial^b:										
Type	Age 1	Age 3	Age 5	Age 1	Age 3	Age 5	Age 3	Age 5	Age 3	Age 5
CTW	91.7	72.9	60.4	6.0a	15.7a	23.7a	1.7a	3.0a	0.3340a	0.7749a
HYB	93.6	85.9	65.4	6.0a	13.1a	17.6b	1.3a	2.0b	0.2867a	0.4647b
2013 LMAV Trial^b:										
Type	Age 1	Age 3	Age 5	Age 1	Age 3	Age 5	Age 3	Age 5	Age 3	Age 5
CTW	93.8	N/A ^c	93.8	8.9a	N/A	49.1a	N/A	5.4a	N/A	3.6355a
HYB	100.0	N/A	47.9	6.9b	N/A	32.0b	N/A	3.3b	N/A	1.1342b

^aCombined analyses included all four trials between the various varieties grouped into either the CTW or HYB group and shown under the first heading of all four trials combined.

^bIndividual analyses represents only the data from the specific trial shown.

^cAge 3 data were not available for the 2013 LMAV Trial.

^dTotal height, DBH, and volume at specific ages with the same letter are not significantly different at P < 0.05 level.

survival for the CTW group on the 2010 Upland site was 79.2 percent, while the HYB group was 56.4 percent.

When combining the LMAV trials of 2010 and 2013, age 1 survival for the HYB group was 92.1 percent, while the CTW group was 88.5 percent. At age 3 the 2010 LMAV site and age 5 for the 2010 and 2013 LMAV sites, survival between the two groups began to diverge with the HYB group showing 74.3 percent at age 3 and 28.5 percent at age 5, while survival of the CTW group remained near constant from ages 1 to 5. Age 1 survival for 4 of the 13 HYB varieties exhibited no mortality in the 2010 and 2013 LMAV sites. By age 5, no single HYB variety exhibited 100-percent survival over both sites, but variety 6198 (DT) ranked as the highest surviving genotype at 83.3 percent (table 3). Later age survival (ages 8 and 10) revealed little difference after age 5. The CTW varieties particularly 110412, 111234, AG414, and S7C1 showed a loss of no more than one or two ramets.

Analysis of the combined 2010 and 2011 Upland sites revealed a different survival pattern between the two groups.

Age 1 survival for the HYB group was similar to the previous combinations (93.6 percent), but survival of the CTW group (90.6 percent) was higher than expected. Survival for both groups fell at ages 3 and 5, with the HYB group being 89.7 and 78.2 percent, respectively, while the CTW group was 79.2 and 71.9 percent, respectively.

Survival of individual varieties shows the extent of variability among the groups (table 3). Variety 12804 suffered extensive mortality and was the main contributor to the 3.8-percent drop in survival of the HYB group between ages 1 and 3. A 9-percent drop in the HYB group survival occurred between ages 3 and 5 due to varieties 6320, DN5, and 12804. Thus, age 5 survival ranged from 100 percent (Varieties 6329 and AG229) to 33.3 percent (Variety 12804). Similarly, the CTW group showed a drop of approximately 10 percent between ages 3 and 5 driven by mortality of varieties 110804 and S7C1. By age 5, only one CTW variety, AG414, maintained 100-percent survival. Age 10 measurements were only taken

Table 3—Mean survival of 21 common varieties at ages 1, 3, 5, and 10 for the 2010 LMAV and Upland sites, at ages 1, 3, and 5 for the 2011 Upland site, and ages 1, 5, and 8 for the 2013 LMAV site

2010 LMAV site Eastern cottonwood					2010 Upland site Eastern cottonwood				
Varietal ID	Percent survival				Varietal ID	Percent survival			
	1	3	5	10		1	3	5	10
110412 (DD)	100.0	100.0	100.0	100.0	110412 (DD)	100.0	100.0	100.0	100.0
110804 (DD)	83.3	83.3	83.3	50.0	110804 (DD)	100.0	100.0	100.0	100.0
111234 (DD)	100.0	100.0	100.0	100.0	111234 (DD)	100.0	83.3	83.3	83.3
AG414 (DD)	100.0	100.0	100.0	83.3	AG414 (DD)	100.0	100.0	100.0	66.7
AG437 (DD)	33.3	33.3	33.3	16.7	AG437 (DD)	50.0	33.3	33.3	33.3
S7C1 (DD)	100.0	100.0	100.0	100.0	S7C1 (DD)	100.0	100.0	83.3	83.3
ST66 (DD)	83.3	83.3	83.3	83.3	ST66 (DD)	83.3	83.3	83.3	83.3
ST244 (DD)	50.0	50.0	50.0	50.0	ST244 (DD)	83.3	83.3	83.3	83.3
Hybrid Poplars:					Hybrid Poplars:				
1428 (TD)	83.3	83.3	00.0	00.0	1428 (TD)	100.0	100.0	100.0	100.0
6018 (TD)	50.0	50.0	00.0	00.0	6018 (TD)	66.7	66.7	66.7	33.3
6198 (DT)	83.3	66.7	66.7	00.0	6198 (DT)	100.0	100.0	100.0	66.7
6320 (DM)	83.3	50.0	00.0	00.0	6320 (DM)	100.0	100.0	66.7	00.0
6329 (DM)	83.3	66.7	66.7	00.0	6329 (DM)	100.0	100.0	100.0	83.3
12804 (DT)	100.0	66.7	16.7	00.0	12804 (DT)	66.7	66.7	66.7	33.3
9732-31 (DN)	100.0	83.3	50.0	00.0	9732-31 (DN)	100.0	100.0	100.0	66.7
22021048 (DN)	100.0	66.7	00.0	00.0	22021048 (DN)	100.0	100.0	100.0	00.0
99007115 (DN)	100.0	100.0	00.0	00.0	99007115 (DN)	100.0	100.0	100.0	83.3
AG187 (TD)	100.0	100.0	16.7	00.0	AG187 (TD)	100.0	100.0	100.0	50.0
AG188 (TD)	66.7	66.7	00.0	00.0	AG188 (TD)	83.3	83.3	83.3	83.3
AG229 (TD)	83.3	83.3	00.0	00.0	AG229 (TD)	100.0	100.0	100.0	100.0
DN5 (DN)	100.0	83.3	00.0	00.0	DN5 (DN)	100.0	100.0	100.0	00.0

continued

on the 2010 Upland Trial revealing that AG414 lost two trees between ages 5 and 10, both due to mechanical injury.

Growth Traits

The LMAV sites showed better growth than the Upland sites for all traits examined between ages 1 and 5 (table 2). Analysis of the four sites combined revealed site differences for all traits when sites were grouped by geographic areas, the differences were no longer apparent. The combined analysis of the sites indicated location differences for all age 3 traits (DBH, THT, and volume) with the 2010 LMAV site performing better than the 2010 and 2011 Upland sites (table 2).

Age 1 height of the 2010 site was significantly taller (12.5 feet) than the 2013 LMAV Trial (7.9 feet) (table 4). Age 1 heights for the 2010 and 2011 Upland sites were significantly shorter than the LMAV sites but did not differ significantly from each other at 6.0 and 5.7 feet. Age 3 volume of the 2010 LMAV site was greater than twice the volume produced by

the 2010 Upland site and 2.5 times greater than the 2011 Upland site. DBH followed the trend seen for volume with the LMAV site being about double the DBH of each of the Upland sites. Age 3 THT of the 2010 LMAV site was 23.1 feet versus 16.5 feet and 14.1 feet for the 2010 Upland and 2011 Upland sites, respectively. Analysis indicated highly significant effects site, site by type, varietal within type, and site by varieties of the age 5 traits of DBH, THT, and volume. Age 5 volume of the 2010 LMAV site was the highest at 2.5608 cubic feet and the 2013 LMAV site at 2.5505 cubic feet. Age 5 volume of the 2010 and 2011 Upland sites were much lower at 0.7979 cubic feet and 0.5338 cubic feet, respectively.

The combined site analysis of the CTW versus HYB groups indicated that these groups differed for all traits except age 1 height (table 3). But analysis of each site indicated a somewhat different pattern for DBH, total height, and volume. Results of the 2010 and 2013 LMAV sites followed

Table 3—Mean survival of 21 common varieties at ages 1, 3, 5, and 10 for the 2010 LMAV and Upland sites, at ages 1, 3, and 5 for the 2011 Upland site, and ages 1, 5, and 8 for the 2013 LMAV site (continued)

2013 LMAV site Eastern cottonwood				2011 Upland site Eastern cottonwood			
Varietal ID	Percent survival			Varietal ID	Percent survival		
	1	5	8		1	3	5
110412 (DD)	83.3	83.3	66.7	110412 (DD)	83.3	50.0	50.0
110804 (DD)	100.0	100.0	66.7	110804 (DD)	100.0	33.3	33.3
111234 (DD)	100.0	100.0	83.3	111234 (DD)	83.3	33.3	33.3
AG414 (DD)	100.0	100.0	66.7	AG414 (DD)	100.0	100.0	100.0
AG437 (DD)	100.0	100.0	100.0	AG437 (DD)	100.0	100.0	100.0
S7C1 (DD)	100.0	100.0	83.3	S7C1 (DD)	83.3	83.3	50.0
ST66 (DD)	100.0	100.0	33.3	ST66 (DD)	83.3	83.3	83.3
ST244 (DD)	66.7	66.7	33.3	ST244 (DD)	100.0	100.0	66.7
Hybrid Poplars:				Hybrid Poplars:			
1428 (TD)		<i>Not planted</i>		1428 (TD)	100.0	100.0	83.3
6018 (TD)	100.0	16.7	00.0	6018 (TD)	100.0	83.3	83.3
6198 (DT)	100.0	100.0	00.0	6198 (DT)	83.3	66.7	66.7
6320 (DM)		<i>Not planted</i>		6320 (DM)	100.0	100.0	66.7
6329 (DM)		<i>Not planted</i>		6329 (DM)	100.0	100.0	100.0
12804 (DT)		<i>Not planted</i>		12804 (DT)	66.7	33.3	00.0
9732-31 (DN)	100.0	83.3	00.0	9732-31 (DN)	100.0	100.0	83.3
22021048 (DN)	100.0	50.0	00.0	22021048 (DN)	100.0	50.0	16.7
99007115 (DN)		<i>Not planted</i>		99007115 (DN)	100.0	66.7	50.0
AG187 (TD)	100.0	00.0	00.0	AG187 (TD)	83.3	83.3	83.3
AG188 (TD)	100.0	00.0	00.0	AG188	83.3	83.3	83.3
AG229 (TD)	100.0	83.3	00.0	AG229	100.0	100.0	100.0
DN5 (DN)	100.0	50.0	00.0	DN5	100.0	100.0	33.3

Table 4—Mean height, diameter at breast height (DBH), and volume by site location at ages 1, 3, and 5 for the four SunGrant test sites established by Mississippi State University

Location	Total height			DBH		Volume	
	Age 1	Age 3	Age 5	Age 3	Age 5	Age 3	Age 5
	-----feet-----			----- inches -----		----- cubic feet -----	
2010 LMAV	12.5a ^a	23.1a	36.7b	3.0a	4.6a	0.7528a	2.5608a
2010 Upland	5.9c	16.5b	25.0c	1.5b	2.7b	0.3484b	0.7979b
2011 Upland	6.0c	14.1c	20.0d	1.4b	2.3b	0.3002bc	0.5338bc
2013 LMAV	7.9b	N/A	40.9a	N/A	4.4a	N/A	2.5505a

^aTotal height, DBH, and volume means at specific ages with the same letter are not significantly different at P < 0.05 level.

a pattern similar to that of the combined four site analysis, but the 2010 and 2011 Upland sites showed the CTW group differed from the HYB group until age 5, though trends leading to these differences were obvious at age 3. By age 5, the CTW group averaged approximately 6 feet taller, an inch larger in diameter, and 1.5 times greater in volume than the HYB group. No site by varietal interactions were found when sites of similar geographic area were combined. However, site by varietal interactions was found when combining locations of different geographic areas (i.e., LMAV vs. Upland).

Though CTW varieties exhibited the highest volume production on the 2010 LMAV site at ages 3 and 5 as well as age 5 on the 2013 LMAV site, there was considerable variation in this trait among the CTW varieties. Volume of the CTW varieties continued to increase based on the later age measurements of 8 and 10 years. Examination of the two Upland sites where volume for CTW varieties was approximately less than one-half of what was observed on the LMAV sites, reveals a different picture than described above. There was a considerable lack of variability in age 3 volume among the eight CTW and the 13 HYB varieties as compared to the findings on the LMAV site. Additionally, some varieties, such as AG437 (DD), showed puzzling volume yields in the Upland sites with poor volume production in the 2010 site and good volume in the 2011 site (table 2).

To determine performance differences, the common varieties were compared to the entire varietal test populations at each test site. Selecting the top 20 percent of the test population for volume at ages 3 and 5 gives an indication of potential gains via varietal selection. The top 16 volume producing varieties for the 2010 LMAV site at ages 3 and 5 consisted of 15 CTW varieties and a single HYB varietal 13317 (TN). Performance of the CTW varieties were in the upper one-half of the test population whereas HYB varieties were in the bottom half of the test population. For age 3 volume, six of the common varieties (all CTW varieties) 110412, 110804, 111234, AG414, ST66, and ST244 were among the top 16. Age 5 results were nearly identical with 110804 and 111234 dropping out and only five common CTW varieties 110412, AG414, S7C1, ST66, and ST244. For the 2010 Upland site, the top performing varieties at age 3 were a mixture of HYB and CTW varieties, seven of which were HYB varieties, six were DM varieties of which two (6320 and 6329) are common varieties. The nine CTW varieties included two common varieties, AG414 and 110412. The HYB varietal 8019 was the top volume performer at ages 3 and 5. Age 5 volume included three HYB varieties in the top 20 percent of the entire test population and two common CTW varieties, AG414 and 110412, are among the best performing varieties. The 2010 and 2011 Upland sites showed a similar trend as age increased, fewer HYB varieties remained in the top 20 percent of the test population. The top 20 percent of the 2011

Upland site for age 3 volume included eight CTW varieties and eight HYB varieties, of which AG414 was a common CTW varietal. The common HYB varieties were 6198, 6329, and AG229. Age 5 top volume producers included 5 HYB and 11 CTW varieties of which AG414 and S7C1 were common CTW varieties. Varietal rankings for age 5 volume of the 2013 LMAV site was similar to the 2010 LMAV site in that the upper half of the test population was comprised primarily of CTW varieties and AG414 was the only common varietal in the top 20 percent of the test population.

Age 1 height was poorly correlated with age 3 ($r = 0.51$) and age 5 height ($r = 0.23$). Age 3 height was strongly correlated with age 5 height and volume at 0.90 and 0.87, respectively.

DISCUSSION

The genus *Populus* is well known for possessing some of the fastest growing tree species in the world and its ease of vegetative propagation, thus allowing for varietal use to capture total genetic gains. This document focused partially on survival primarily for three reasons:

1. Variability in early survival when using dormant unrooted stock is often associated with rooting. Can selection for enhanced rooting, especially among CTW varieties lead to improved overall survival during the establishment phase?
2. Disease limits advancement of improved HYB *Populus* varieties. Selection for disease resistance that conveys long-term survival plays a foundational role in defining the landscape conducive for *Populus* species and hybrids in the Southeastern United States.
3. Yield is maximized when high survival is combined with exceptional growth. Effective selections combine these field performance traits to maximize area-basis yields.

Although marginal agriculture sites are often suggested as likely areas for biomass production with SRWCs, the 2016 Billion Ton update does not actually state marginal but rather the use of cropland (Langholtz and others 2016). A marginal agriculture site would be an area limited by either accessibility or by capability of supporting a suitable return from agriculture. In the case of the LMAV, this is often in the batture where flooding impairs agricultural crops, or soil types are unsuited for agriculture. In uplands of the South, soils are typically limiting to agriculture due to inherently low nutrient status. The LMAV sites, in general, possess the inherent soil fertility as shown by the mean volume production of the 2010 and 2013 LMAV sites and could play a major role in biomass production. Currently, a limitation centers around the inability to use inter-specific hybrids due to disease.

In respect to uplands, poor soil fertility does not limit age 1 survival of either CTW or HYB varieties but greatly affects volume production. Thus, it is imperative that specific varietal selections must be found that are capable of not only high survival and disease resistance, but capable of capturing specific inputs to maximize volume production. This study provides some insight into these possibilities, but increased effort must be devoted to the Southeastern United States to make this a possibility.

Survival and growth variables of the 21 common clones included in this study indicated that all three of the previously mentioned reasons certainly were borne out for the LMAV and the nearby lands of Arkansas, Kentucky, Louisiana, Missouri, and Tennessee. One of most critical issues is disease resistance and especially *Sphaerulina musiva* (Peck) Quaedv., Verkley and Crous (Syn. *Septoria musiva* (Peck) limb, and stem-canker resistance (Newcombe and Ostry 2001, Ostry and McNabb 1985). The necessary resistance to this disease cannot be overstated especially for the use of HYB varieties in a wide geographic area of the LMAV. The 2010 and 2013 LMAV sites clearly demonstrate that HYB varieties of any taxa should not be used in this region. This does not come as a complete surprise as Maisenhelder (1970) alluded to the same finding in 1970. It appears possible that the amount and perhaps virulence level from the array of strains or races of *Sphaerulina* in the LMAV overwhelms the low HYB varietal resistance. A typical case in point is the 2013 site. In this trial, the common HYB varieties exhibited 100-percent survival at the end of the first growing season, confirming their excellent rooting ability. However, by age 5 the disease impacted the HYB population such that only three varieties remained at a survival rate suitable for further examination. This was not to be because not a single HYB ramet remained alive at age 8. The LMAV is certainly still an area unsuitable for current HYB varieties.

Upland sites have been recommended as areas where biomass could be produced given suitable production rates. The 2010 and 2011 Upland sites show that *Populus* will certainly grow on these sites, but the resulting volume production was far less than the volume production shown on LMAV sites. A good performance of some CTW varieties on Upland sites was unexpected. It was also unexpected to observe *Sphaerulina* in the Upland sites, thus suggesting that HYB varieties must be thoroughly screened prior to deployment. A previous study conducted by Rousseau and others (2013), on an upland site some 65 miles east of the Mississippi River showed that *Sphaerulina* limb and stem cankers resulted in extensive mortality to varieties of TD, TDxD, TM, TMxM, and TN taxa at age 9, even though age 2 data indicated no incidence of cankers. In that study survival dropped from 92.4 percent at age 2 to 23.9 percent at age 9, considerably

lower than the 56.4 percent at age 10 recorded for 2010 Upland site of the current study. Both studies indicated the negative effect on growth by *Sphaerulina*. However, the current study does not answer the question of the effects of *Sphaerulina* as sites are located east of the Mississippi.

Newcombe and Ostry (2001) who studied *Sphaerulina* resistance in *Populus*, noted stem cankers present on all the F₁ TD hybrids following the third growing season, but found no cankers on CTW varieties. The results of the study appear very similar to observations from the 2010 and 2011 Upland sites. The 2010 and 2011 Upland sites were located in a pine region of northeast Mississippi about 61 miles east of the Mississippi River, thus it is uncertain if *Sphaerulina* would play a significant role in affecting survival and growth. *Sphaerulina* cankers were first noticed in these trials during the third-year measurements, but their appearance seemed inconsequential. However, this was not the case with the more susceptible HYB genotypes exhibiting increased mortality. There were some HYB genotypes that were capable of walling off the disease to a certain extent, but this led to slower growth. Similar results were shown by Niemczyk and Thomas (2020) where growth rates and mortality resulted from genotype selection that included *Sphaerulina musiva* resistance. *Sphaerulina* cankers were also observed in a *Populus* planting of the Integrated Biomass Supply System (IBSS) study located just south of Columbus, MS. In this location, the disease affected growth of the HYB varietal 7388 (DM) prior to coppice regeneration harvest at age 2, while varietal 6329 (DM) only revealed stem cankers following the coppice regeneration harvest. Additionally, varieties 5077 (TD) and 8019 (DM) at the Columbus, MS IBSS site exhibited some ability to wall off cankers. The IBSS sites near Columbus, MS and Raleigh, NC were compared for incidence of stem cankers and found that the HYBs were more susceptible at Columbus, MS. However, at Raleigh, NC there was no difference between the CTW and HYBs, even though the canker scores for the HYBs were the same. Kaczmarek and others (2013) examined 23 CTW varieties and eight HYB varieties grown on sandy soils near Aiken, SC. The authors did not observe limb or stem cankers; thus, it appears that this particular environment was not conducive to the fungus *Sphaerulina*.

Rooting in *Populus* is a strongly inherited genetic trait, so careful selection for this trait should provide gains needed to increase rooting at establishment for improved age 1 survival. Zalesny and Zalesny (2009) showed that adventitious roots, termed basal roots, typically form near the callus tissue that develops on the cut surfaces created when whips are cut into segments for planting stock. However, more importantly are the adventitious roots, termed lateral roots which are from either preformed or induced primordia above the callus tissue. Survival and growth are greatly improved

when numerous lateral roots develop along the length of the cutting. Additionally, Zalesny and others (2005) showed that position of the cutting along the parent whip influenced rooting. They showed that rooting was best when the cutting originated from the lower portion of the whip and its diameters was greater than 0.6 inches. The CTW material produced by MSU as well as the HYB cuttings produced by MSU for the 2013 LMAV site followed the protocol shown by Zalesny and others (2005). The HYB cuttings for the 2010 and 2011 trials were grown at the various locations of the owners and then shipped to MSU. Prior to 2012, all the cuttings received by MSU were stored in a cooler at 36 °F to 38 °F. This changed in the 2013 Trial with all of the CTW and HYB varieties cuttings being grown, processed, and graded at MSU. Storage of the processed dormant unrooted cuttings for the 2013 Trial was in a walk-in freezer at 28 °F prior to planting. This change in handling and storage may account for the perfect survival of the eight HYB varieties established in the 2013 LMAV Trial. In this study we used age 1 survival as a surrogate for rooting ability. Cottonwood varieties such as AG414 (DD) and S7C1 (DD) showed excellent survival over both site types whereas varieties AG437 (DD) and 12804 (DT) varied greatly among the four sites questioning their rooting ability and thus the inclusion into further testing.

The combined analysis of all four locations revealed consistency with earlier studies that found age 1 height to be more dependent upon on planting stock quality and weed control rather than species or hybrid background. This remained true even though nearly one-fourth of the tested genotypes originated from colder climates than that of the sites used in this study. Interestingly, as age increased so did difference between CTW and HYB groups. This appears to result from an inability by the HYB group to tolerate LMAV site conditions, which included periodic flooding. The ability of the CTW group to exhibit growth like the HYB group when planted on upland sites was unexpected, with the assumption being that the HYB group would be far superior to CTW. This expectation was based on the superior rooting of the *Populus* hybrids shown by the literature (Kaczmarek and others 2013, Rousseau and others 2013).¹ Given that there are CTW varieties that root well, there is an opportunity to advance this trait in the future. In essence, the 21 common varieties represent a microcosm of the overall larger test population. The lack of significant differences for all age 3 growth traits clearly indicates that selected CTW varieties are capable of good growth on Upland sites. This is shown by the age 3 volume performance of the CTW variety AG414 which exhibited similar or better than the top performing variety 6329 (DM) on the 2010 and 2011 Upland sites.

SUMMARY

Common CTW and HYB varieties were examined in four trials of the SunGrant Consolidated *Populus* Feedstock program established by MSU on two test sites in the LMAV of southeast Missouri and two test sites on upland soils of northeast Mississippi. Survival and growth traits were analyzed for differences among sites, types, and varieties. Genotype by environmental interactions were only significant when sites of different geographic areas were combined, as in the case of LMAV versus Upland sites. The common varieties represented a microcosm of the entire test population, showing that except for age 1, CTW survival was generally higher than HYB survival except on Upland sites at age 5. Additionally, age 3 volumes began trending larger for CTW such that volume of the CTW group was greater than that of the HYB group on all sites by age 5. An important finding is that no HYB varieties will survive in the LMAV, but some CTW varieties performed well on the uplands, especially when held longer than 5 years. Survival of the HYB varieties diminished through time due to *Sphaerulina* susceptibility. As the trees aged, stem cankers increased resulting in lower survival or greater mortality.

These SunGrant trials illustrate the great need to test other *Populus* taxa to determine their viability for growth in southern environments. At MSU we began this process with test numerous *P. nigra* varieties at multiple locations. Recent selections were made to be mated with highly selected CTW varieties for the purpose of generating a F₁ population appropriate for the Southern United States. This procedure is only a first step, but the example could be replicated for a variety of other *Populus* species such as *P. simonii* and *P. yunnanensis*.

Although, the use of hybrid poplars outside of a 100-mile radius of the Mississippi River seems very likely, it is still appropriate to test for *Populus* diseases, especially *Sphaerulina*, prior to any commercial deployment in the South. In addition, the development of a rapid screening technique to use on specific genotypes for resistance/susceptibility to *Sphaerulina musiva* would greatly aid in the selection process for breeding and deployment. Also, there is no doubt that *Sphaerulina* should be further examined to determine the extent and virulence of the disease throughout the South.

¹ Personal communication. 2016. Brian Stanton, GreenWood Resources, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831.

REFERENCES

- Berguson, B.; Eaton, J.; Stanton, B.J. 2010. Development of hybrid poplar for commercial production in the United States: The Pacific Northwest and Minnesota Experience. Proceedings of the sustainable feedstocks for advanced biofuels workshop. Sustainable alternative fuel feedstock opportunities, challenges, and roadmap for six U.S. regions. Soil and Water Conservation Society: 282–299. Chapter 17.
- Isik, F.; McKeand, S.E. 2019. S.E. Fourth cycle breeding and testing strategy for *Pinus taeda* in the N.C. State university cooperative tree improvement program. *Tree Genetics and Genomes*. 15(70): 1–12. <https://doi.org/10.1007/s11295-019-1377-y>.
- Kaczmarek, D.J.; Coyle, D.R.; Coleman, M.D. 2013. Survival and growth of a range of *Populus* clones in central South Carolina USA through age ten: do early assessments reflect longer-term survival and growth trends. *Biomass and Bioenergy*. 49: 260–272. <https://doi.org/10.1016/j.biombioe.2012.12.005>.
- Langholtz, M.H.; Stokes, B.J.; Eaton, L.M. 2016. 2016 Billion Ton report: Advancing domestic resources for a thriving bioeconomy, Volume 1: Economic availability of feedstock. ORNL/TM-2016/160. Oak Ridge, TN: U.S. Department of Energy. Oak Ridge National Laboratory. 411 p.
- Maisenhelder, L.C. 1970. Eastern cottonwood selections outgrow hybrids on southern sites. *Journal of Forestry*. 68: 300–301.
- Mohn, C.S.; Krinard, R.M. 1971. Volume tables for small cottonwoods in plantations. Res. Note. SO-RN-113. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 4 p.
- Newcombe, G.; Ostry, M.E. 2001. Recessive resistance to *Septoria* stem canker of hybrid poplar. *Phytopathology*. 91: 1081–1084.
- Niemczyk, M.; Thomas, B.R. 2020. Growth parameters and resistance to *Sphaerulina musiva*-induced canker are more important than wood density for increasing genetic gain from selection of *Populus* spp. hybrids for northern climates. *Annals of Forest Science*. 77: 26. <https://doi.org/10.1007/s13595-020-0931-y>.
- Ostry M.E.; McNabb, H.S. 1985. Susceptibility of *Populus* species and hybrids to disease in the North Central United States. *Plant Disease*. 69: 755–757.
- Prakash, C.S.; Heather, W.A. 1986. Inheritance of resistance to races of *Melampsora medusae* in *Populus deltoides*. *Silvae Genetica*. 35(2,3): 74–77.
- Prakash, C.S.; Thielges, B.A. 1987. Pathogenic variation in *Melampsora medusae* leaf rust of poplars. *Euphytica*. 36: 563–570. <https://doi.org/10.1007/BF00041503>.
- Rousseau, R.J.; Adams, J.P.; Wilkerson, D.W. 2013. Nine-year performance of a variety of *Populus* taxa on an upland site in western Kentucky. In: Guldin, James M., ed. 2013. Proceedings of the 15th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-GTR-175. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 299–305.
- SAS Institute. 2016. SAS Proprietary Software 9.4 (TS1M6). https://documentation.sas.com/doc/en/pgmsascdc/9.4_3.4/statug/statug_mixed_syntax.htm. [Date accessed: March 14, 2022].
- Westvaco Central Forest Research Center, Central Region. 1991. Unpublished research report. On file with: Westvaco Central Region Research, Hwy. 121, Wickliffe, KY 42087.
- Zalesny, R.S.; Hall, R.B.; Bauer, E.O.; Riemenschneider, D.E. 2005. Soil temperature and precipitation affect the rooting ability of dormant hardwood cuttings of *Populus*. *Silvae Genetica*. 54(2): 47–58.
- Zalesny, R.S., Jr.; Zalesny, J.A. 2009. Selecting *Populus* with different adventitious, root types for environmental benefits, fiber, and energy. In: Niemi, K.; Scagel, C., eds. Adventitious root formation of forest trees horticulture plants—from genes to applications. Research Signpost: 359–384. Chapter 18.

WATER USE, EFFICIENCY, AND STOMATAL SENSITIVITY IN EASTERN COTTONWOOD AND HYBRID POPLAR VARIETALS ON CONTRASTING SITES IN THE SOUTHEASTERN UNITED STATES

Heidi J. Renninger, Leah F. Stewart, and Randall J. Rousseau

EXTENDED ABSTRACT

The Southeastern United States has widescale potential to achieve high productivity from elite eastern cottonwood (*Populus deltoides* W. Bartram ex Marshall) and hybrid poplar varieties to produce renewable bioenergy and bioproducts (U.S. Department of Energy 2016). In order to determine their impact to groundwater supplies and streamflow and maintain growth during drought periods, varieties that use water efficiently and/or tolerate water stress conditions are needed to make planting recommendations across a variety of sites (Petzold and others 2011, Zalesny and others 2016). Poplars have been shown to exhibit a range of water use strategies with some exhibiting a conservative (isohydric) strategy in which they restrict water use and, in turn, productivity under water stress conditions and others exhibiting a more risky (anisohydric) strategy in which they continue to function under increasing water stress (Attia and others 2015, Navarro and others 2020). In addition, inoculation with nitrogen-fixing endophytic bacteria may improve water stress tolerance (Rho and others 2018) by increasing root biomass and reducing damage from reactive oxygen species (Khan and others 2016, Rogers and others 2012). This research sought to address the following objectives: (1) Determine water use strategies for six *Populus* varieties (three eastern cottonwood and three hybrid poplars) planted on the Upper Gulf Coastal Plain (Coastal Plain) and the Lower Mississippi Alluvial Valley (LMAV) and determine if strategies differ depending on planting site, (2) Determine if inoculation with diazotrophic endophyte bacteria impacts growth and water use strategies in these tested varieties and if site conditions impact the endophyte effect, and (3) Determine two-year aboveground biomass production for all varieties at both sites and identify physiological parameters that are most correlated with growth.

Tested varieties consisted of three eastern cottonwood varieties (*P. deltoides* × *P. deltoides*, “D×D”) including 110412, S7C8, ST66, and three hybrid poplar varieties, two of which were *P. deltoides* × *P. maximowiczii* (A. Henry) crosses (“D×M”; 6329 and 8019) and one *P. trichocarpa* (Torr. & Gray ex Hook.) × *P. deltoides* cross (“T×D”; 5077) supplied by Greenwood Resources Inc. (Portland, OR, USA). Individuals were planted as cuttings in 15-tree blocks at a 6 by 9 feet spacing in 2018 on a Gulf Coastal Plain site in northeastern Mississippi and a site in the Mississippi Delta portion of the LMAV. The LMAV site was

Author Information: Heidi J. Renninger, Associate Professor, Mississippi State University, Mississippi State, MS 39762; Leah F. Stewart, Graduate Research Assistant, Mississippi State University, Mississippi State, MS 39762; and Randall J. Rousseau, Extension/Research Professor, Mississippi State University, Mississippi State, MS 39762.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

more poorly drained and had a history of row crop production compared with the Coastal Plain site. Half of the blocks were inoculated with diazotrophic endophyte bacteria from Intrinsyx Bio (Moffett Federal Airfield, CA, USA). In the second growing season, Granier heat dissipation sapflow sensors (Granier 1987) were installed into two or three trees per varietal and endophyte treatment. Half-hourly sapflow rates (J_s) were combined with environmental data, tree-level sapwood and leaf areas (see below) to calculate canopy stomatal conductance (canopy G_s) as follows:

$$\text{Canopy } G_s = \frac{K_G \times \frac{J_s \times A_s}{A_L}}{VPD} \quad (1)$$

where

K_G is a conductance coefficient, A_s is tree sapwood area, A_L is tree leaf area, and VPD is atmospheric vapor pressure deficit.

Canopy G_s was plotted vs. the natural log of VPD at both low and average to high soil moisture conditions (θ) to determine reference stomatal conductance (G_{sref} at VPD = 1 kPa), stomatal sensitivity (m; slope of the G_s vs. VPD relationship) and scaled stomatal sensitivity (m/G_{sref}) (Oren and others 1999). At the end of the second growing season but before leaf fall, trees were harvested to estimate sapwood area, leaf area and total dry woody biomass. Biomass at the end of the first growing season was estimated from tree heights and diameters. Whole-tree water use efficiency (WUE) was calculated as the ratio of dry biomass accumulated during the second growing season and water used during that time period for each individual.

We found that, at the Coastal Plain site, varietal 8019 (D×M) used more water during the early portion of the growing season with water use declining after June while other varietals, including S7C8 (D×D), ST66 (D×D), and 6329 (D×M) increased water use during the growing season using the most water in August or used similar amounts of water for most months of the growing season (fig. 1A). At the LMAV site, S7C8 (D×D) and 5077 (T×D) used the most water in June and July, while other varietals either maintained or increased water use throughout the growing season (fig. 1B). Biomass was significantly higher across varietals at the Coastal Plain site compared with the LMAV site. At the Coastal Plain site, biomass was greatest in 8019 (D×M) and S7C8 (D×D) and greatest for all eastern cottonwoods at the LMAV site (fig. 1C, D). We found that whole-tree WUE was similar across varietals at 5.2 g biomass per kg water used and that water use scaled positively with tree size. In terms of the relationship between canopy G_s and $\ln VPD$, we found that water use strategies in terms of scaled stomatal sensitivity converged across varietals under stressful soil water conditions (low soil moisture at the Coastal Plain site, high soil moisture at the LMAV site), but that varietal 8019 (D×M) and 110412 (D×D) tended to exhibit the highest plasticity in stomatal sensitivity under different soil moisture conditions. We found that inoculation with endophytes caused significant impacts at the more nitrogen limited, LMAV site leading to increased biomass production, whole-tree WUE, and scaled G_s sensitivity under low soil moistures. Across sites and varietals, tree leaf area and whole-tree WUE were positively correlated with woody biomass production while plasticity in scaled G_s sensitivity was important with lower sensitivity under high soil moisture as well as higher sensitivity under low soil moisture being positively correlated with biomass. Overall, these findings can be used to model hydrologic impacts of large-scale *Populus* biofuel production as well as to recommend varietals with efficient water use strategies. More information and results from this study can be found in Renninger and others (2021).

Table 1— Analysis of variance results presenting significant effects of site (S), varietal (V) and endophyte inoculation (E), as well as their interaction (×) on productivity, water use, and canopy stomatal conductance (G_s) parameters under low and average to high soil moisture (θ)

Parameter	Site	Varietal	Endophyte	S×V	S×E	V×E	S×V×E
Biomass	**	**	-	-	*	-	-
Specific gravity	*	***	**	-	*	-	-
Leaf area	-	***	-	-	*	-	-
Seasonal water use	**	***	*	*	*	-	-
Whole-tree WUE	-	-	-	-	-	-	-
G_{sref} low θ	-	***	**	*	-	-	*
G_s sensitivity, low θ	-	***	-	**	-	-	-
Scaled G_s sensitivity, low θ	-	*	***	**	***	**	-
G_{sref} high θ	-	**	-	**	-	-	-
G_s sensitivity, high θ	-	*	-	**	-	-	-
Scaled G_s sensitivity, high θ	-	**	*	**	-	-	-

* = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$; WUE = water use efficiency; G_{sref} = reference canopy conductance; - = not significant.

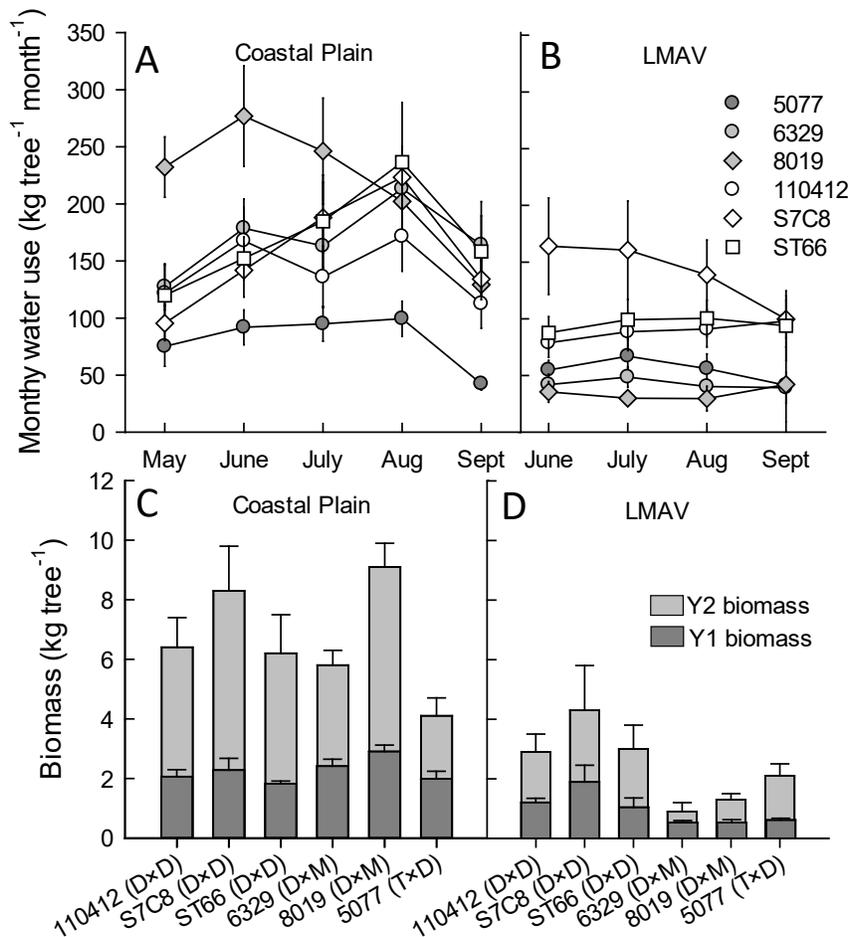
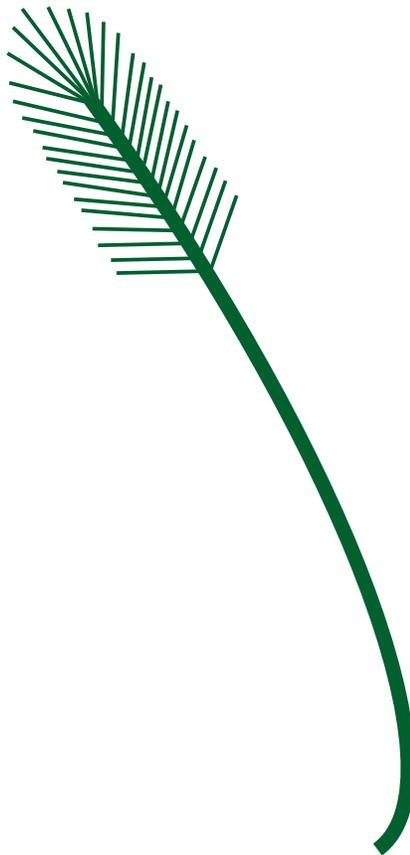


Figure 1—Total monthly water use (kg water tree⁻¹ month⁻¹) in the second growing season at (A) the Coastal Plain site and (B) the LMAV site for eastern cottonwoods including varietals 110412 (white circles), S7C8 (white diamonds) and ST66 (white squares) and hybrid poplars in the *P. deltoides* × *P. maximowiczii* taxa including 6329 (light gray circles) and 8019 (light gray diamonds) and the *P. trichocarpa* × *P. deltoides* taxa including varietal 5077 (dark gray circles) and biomass (kg tree⁻¹) for the first growing season (Y1; dark gray) and second growing season (Y2; light gray) at the (C) Coastal Plain, and (D) LMAV sites.

LITERATURE CITED

- Attia, Z.; Domec, J.C.; Oren, R. [and others]. 2015. Growth and physiological responses of isohydric and anisohydric poplars to drought. *Journal of Experimental Botany*. 66(14): 4373–4381. <https://doi.org/10.1093/jxb/erv195>.
- Granier, A. 1987. Evaluation of transpiration in a Douglas-fir stand by means of sap flow measurements. *Tree Physiology*. 3: 309–320.
- Khan, Z.; Rho, H.; Firrincieli, A. [and others]. 2016. Growth enhancement and drought tolerance of hybrid poplar upon inoculation with endophyte consortia. *Current Plant Biology*. 6: 38–47.
- Navarro, A.; Portillo-Estrada, M.; Ceulemans, R. 2020. Identifying the best plant water status indicators for bioenergy poplar genotypes. *Global Change Biology Bioenergy*. 12: 426–444.
- Oren, R.; Sperry, J.S.; Katul, G.G. [and others]. 1999. Survey and synthesis of intra- and interspecific variation in stomatal sensitivity to vapour pressure deficit. *Plant Cell and Environment*. 22: 1515–1526.
- Petzold, R.; Schwärzel, K.; Feger, K.H. 2011. Transpiration of a hybrid poplar plantation in Saxony (Germany) in response to climate and soil conditions. *European Journal of Forest Research*. 130: 695–706.
- Renninger, H.J.; Stewart, L.F.; Rousseau, R.J. 2021. Water use, efficiency, and stomatal sensitivity in eastern cottonwood and hybrid poplar varieties on contrasting sites in the southeastern United States. *Frontiers in Forests and Global Change*. 4: 1–16. <https://doi.org/10.3389/ffgc.2021.704799>.
- Rho, H.; Hsieh, M.; Kandel, S.L. [and others]. 2018. Do endophytes promote growth of host plants under stress? A meta-analysis on plant stress mitigation by endophytes. *Microbial Ecology*. 75: 407–418.
- Rogers, A.; McDonald, K.; Muehlbauer, M.F. [and others]. 2012. Inoculation of hybrid poplar with the endophytic bacterium *Enterobacter* sp. 638 increases biomass but does not impact leaf level physiology. *Global Change Biology Bioenergy*. 4: 364–370.
- U.S. Department of Energy. 2016. 2016 Billion-Ton Report: Advancing domestic resources for a thriving bioeconomy, Volume I: Economic availability of feedstocks. ORNL/TM-2016/160. Oak Ridge, TN: Oak Ridge National Laboratory. 448 p. [s://doi.org/10.2172/1271651](https://doi.org/10.2172/1271651).
- Zalesny, R.S.; Stanturf, J.A.; Gardiner, E.S. [and others]. 2016. Ecosystem services of woody crop production systems. *Bioenergy Research*. 9: 465–491.

Shortleaf Pine Management



DEVELOPMENT AND COMPETITIVE STATUS OF SHORTLEAF PINE SEEDLING SPROUTS AFTER PRESCRIBED BURNING IN A MID-ATLANTIC MIXEDWOOD FOREST

Matthew G. Olson

EXTENDED ABSTRACT

Shortleaf pine (*Pinus echinata*) possesses multiple adaptations for persistence in fire-prone ecosystems. Arguably, the most interesting of these adaptations is the basal crook, a trait that develops during the seedling stage (Little and Somes 1956). The basal crook insulates dormant buds at the base of the stem, which helps preserve the plant's ability to form basal sprouts after being damaged or top-killed by fire (Stone and Stone 1954). Public land in the New Jersey Pine Barrens (NJPB) is periodically treated with prescribed burning, mainly for fuels reduction and wildfire mitigation, yet prescribed burning is also conducted for maintenance of fire-dependent plant communities. Prescribed burning may be important for maintaining fire-adapted shortleaf pine in pine-hardwood communities of the NJPB due to their successional nature. However, there is a lack of information on the impacts of controlled fire on shortleaf pine sprouting and competitive dynamics in Mid-Atlantic Coastal Plain pine-hardwood forests.

A prescribed burn in March 2020 provided an opportunity to assess fire effects on shortleaf pine sprouting in a Mid-Atlantic Coastal Plain pine-hardwood forest (hereafter mixedwood). The purpose of this investigation was two-fold: (1) evaluate factors related to shortleaf seedling sprouting after a single prescribed burn, and (2) assess how a single fire impacted competitive status of shortleaf pine seedlings. The study site was a 0.2-ha natural canopy opening in a mixedwood forest located on Wharton State Forest in Shamong Township, Burlington County, New Jersey. Shortleaf pine was the dominant pine species in the study area. The hardwood component was a mix of oak species (*Quercus spp.*), hickory species (*Carya spp.*), blackgum (*Nyssa sylvatica*), black cherry (*Prunus serotina*), and persimmon (*Diospyros virginiana*).

The size, fire damage, and competitive status of natural pine reproduction was assessed shortly after the burn. This effort included tagging shortleaf pine seedlings 30-150 cm tall with >25 percent of the crown scorched. Additionally, seedlings were selected based on size and damage severity across the gap area to limit potential confounding with gap position. The initial measurement was taken immediately after the burn, which was assumed to represent pre-burn seedling size. A total of 40 pine seedlings were tagged for monitoring basal crook sprouting and competitive status during the 2020 growing season. It was later determined that four of these seedlings were Virginia pine (*Pinus virginiana*). This study focused mainly on the 36 tagged shortleaf pine seedlings. The main response variables were survival, number of basal sprouts (sprout number), and height of the dominant basal

Author Information: Matthew G. Olson, Assistant Professor, Stockton University, Galloway, NJ 08205.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

sprout (dominant sprout height). A backward step-wise procedure was performed to construct the best model for predicting sprout number and dominant sprout height using ordinary least squares regression. This process included pre-burn seedling ground-line diameter and total height, percent crown scorch, height of stem charring, sprout number (included in the model for dominant sprout height), and dominant sprout height (included in the model for sprout number) as potential explanatory variables. Statistical analysis was performed in R 4.0.4.

All tagged shortleaf pine seedlings survived to the end of the first season after burning: 28 by basal crook sprouting (sprouters), 2 resisting top-kill (resisters), and 6 through a mixture of sprouting and resistance (mixed). Sprouters were nominally smaller prior to the burn (mean ground-line diameter and mean top height of 12.2 mm and 83.8 cm, respectively) than resisters (19.8 mm and 125.5 cm) and mixed (20.1 mm and 125.8 cm). Sprouters also had nominally greater crown scorch (mean of 87.9 percent) than resisters and mixed seedlings (62.5 and 66.7 percent, respectively). By the end of the first season, sprouting shortleaf seedlings (sprouters and mixed) supported on average 15 sprouts, with a dominant sprout height of 26.6 cm (maximum of 39 sprouts and 49.5 cm, respectively). All four Virginia pine seedlings, ranging in size from 47-131 cm tall and 5.2-21.4 mm diameter, were killed by fire. These results confirm shortleaf pine's tolerance to fire at the seedling stage. Furthermore, they also support the importance of the basal crook as a fire adaptation in pine species, since none of the Virginia pine, a species without this trait, survived the burn. Collectively, this suggests that prescribed burning can be used to favor shortleaf pine reproduction over Virginia pine, similar to what has been observed in areas with loblolly pine (*Pinus taeda*) and shortleaf pine reproduction (Bradley and others 2016, Stewart and others 2015, Williams 1998).

Step-wise regression yielded models with pre-burn seedling size variables and the sprouting variables as predictors (table 1). The model for estimating sprout number retained pre-burn ground-line diameter and dominant sprout height as predictors, while pre-burn total height and sprout number were retained as predictors in the model for dominant sprout height. Both models were statistically significant at an alpha-level of 0.05. Positive slopes (significant at alpha=0.05) for pre-burn seedling size variables in both models suggests seedling sprout production is positively associated with pre-disturbance seedling size. Negative slopes were estimated when regressing the response variables with each other (significant at alpha=0.10). This result suggests a possible tradeoff in the number of sprouts produced and the growth of individual sprouts.

Prior to the March 2020 burn, most of the tracked shortleaf seedlings were either overtopped (16) or intermediate between over-topped and free-to-grow (19), while only one seedling was deemed free-to-grow (fig. 1). By the end of the first season following the burn, two-thirds of the seedlings were classified as overtopped (24), which was largely due to eight pre-burn intermediate seedlings being reclassified as over-topped in October 2020. Competitors of pine were mostly sprout-origin woody broadleaf species, including heath shrubs (Ericaceae), oaks, hickories, black cherry, and persimmon. The two post-burn seedlings classed as free-to-grow were mixed seedlings (resisted top-kill and sprouted) and greater than 110 cm tall. These results indicate a single prescribed burn may have negatively affected the competitive status of shortleaf pine reproduction, particularly the smaller seedlings, in this mixedwood canopy gap. Continued monitoring will help test this hypothesis.

Table 1—Results of ordinary least squares regression models for sprout number and dominant height based on 34 shortleaf pine seedlings that sprouted after a single prescribed fire in March 2020

Response variable	Explanatory variable	Slope	Intercept	Adjusted R-squared
Sprout number	Pre-burn GLD	1.643 ^a	3.315	0.547 ^a
	Dominant sprout height	-0.344 ^b		
Dominant height	Pre-burn seedling height	0.209 ^a	15.372 ^a	0.355 ^a
	Sprout number	-0.318 ^b		

GLD = ground-line diameter.

^aStatistical significance at an alpha-level of 0.05.

^bStatistical significance at an alpha-level of 0.10.

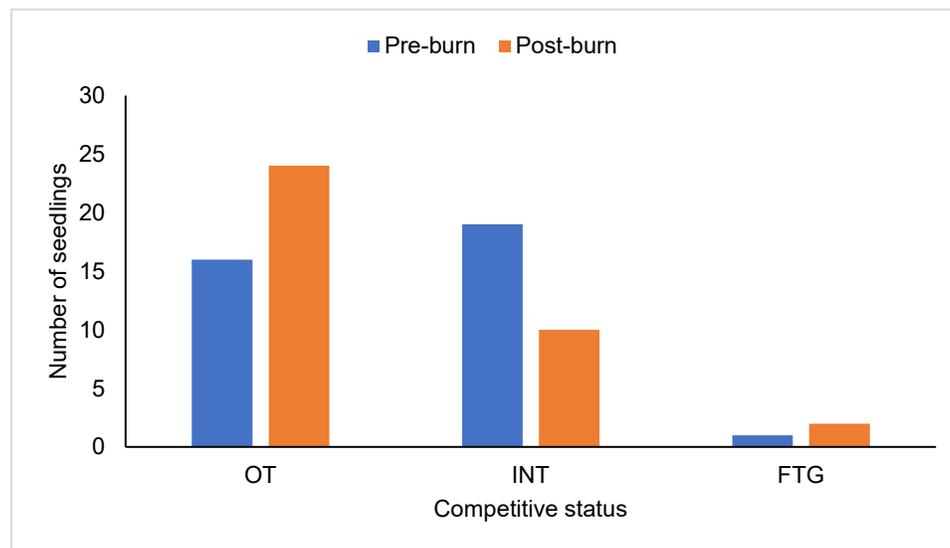


Figure 1—Competitive status of tracked shortleaf pine seedlings (n=36) before and after the first growth season following a single prescribed burn. Status categories are OT = over-topped, INT = intermediate, and FTG = free-to-grow.

LITERATURE CITED

- Bradley, J.C.; Will, R.E.; Stewart, J.F. [and others]. 2016. Post-fire resprouting of shortleaf pine is facilitated by a morphological trait but fire eliminates shortleaf x loblolly hybrid seedlings. *Forest Ecology and Management*. 379: 146–152.
- Little, S.; Somes, H.A. 1956. Buds enable pitch and shortleaf pines to recover from injury. Station Paper NE-81. Upper Darby, PA: U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station. 14 p.
- Stewart, J.F.; Will, R.E.; Robertson, K.M. [and others]. 2015. Frequent fire protects shortleaf pine (*Pinus echinata*) from introgression by loblolly pine (*P. taeda*). *Conservation Genetics*. 16: 491–495.
- Stone, E.L., Jr.; Stone, M.H. 1954. Root collar sprouts in pine. *Journal of Forestry*. 52: 487–491.
- Williams, R.A. 1998. Effects of fire on shortleaf and loblolly pine reproduction and its potential use in shortleaf/oak/hickory ecosystem restoration. In: Waldrop, T.A., ed. Proceedings of the ninth biennial southern silviculture research conference. Gen. Tech. Rep. SRS-20. Washington, DC: U.S. Department of Agriculture Forest Service: 321–325.

ARE LOCAL SEED SOURCES STILL RECOMMENDED FOR PLANTING SHORTLEAF PINE IN SOUTHERN NEW JERSEY AND CENTRAL PENNSYLVANIA?

Grant Gallagher and Matthew G. Olson

ABSTRACT

Artificial regeneration could help offset the decline of shortleaf pine (*Pinus echinata*) populations, yet also address concerns related to climate change resilience. Provenance experiments are uniquely positioned to inform decisions regarding where to source seed for out-plantings designed to enhance regeneration success and climate resilience. Research from the late 1960s indicated that local seed sources should be used for shortleaf pine plantings in the Mid-Atlantic Region. The purpose of this research was to determine if recommendations for sourcing shortleaf pine seed in the Mid-Atlantic Region made over 50 years ago still apply. We revisited two shortleaf pine common garden trials in 2020, one in southern New Jersey (NJ) and the other in central Pennsylvania (PA), to evaluate performance of seed sources in their seventh decade after establishment. Our analysis indicated that local seed sources are still among the top-performers but that a few southern sources have closed the performance gap noted in the past at the NJ common garden. Therefore, some southern sources may be suitable for out-planting in southern NJ. The poor performance of all sources at the PA site, including the local source, support an earlier recommendation for more research on shortleaf seedling planting in central PA.

INTRODUCTION

Shortleaf pine (*Pinus echinata*) is a tree species found primarily in the Southeastern United States yet occurs as far inland as the lower Midwest (Oklahoma and Missouri) and as far north as the Mid-Atlantic (New Jersey and Pennsylvania) (Little 1971). Shortleaf pine grows on a wide range of sites and in association with a diversity of tree taxa, including oaks (*Quercus*), hickories (*Carya*), other southern pines (loblolly pine (*P. taeda*) and Virginia pine (*P. virginiana*), and more northern pines ([pitch pine, *P. rigida*] and eastern white pine [*P. strobus*]) (Lawson 1990). Although the species can occur on a range of landforms, shortleaf pine is most often associated with dry, well-drained to excessively well-drained soils or sites with a history of frequent burning (Lawson 1990). Because of shortleaf pine's tolerance of drought and frequent fire, the species is considered well adapted to projected future climate over the next century (Butler-Leopold and others 2018).

In recent decades, this species has undergone a population decline throughout its native range (Oswalt 2012). Research suggests that over much of shortleaf pine's range, regeneration and recruitment of new individuals is insufficient to replace senescent adult trees, contributing to the decline (Alberto and others 2013, Oswalt 2012). This shortleaf pine decline has been linked to several factors both historical and environmental, including exploitative timber harvesting,

wildfire suppression, insect pests (e.g., southern pine beetle [*Dendroctonus frontalis*]), and autogenic succession (Cunningham and Hauser 1989, Guyette and others 2007, Hanberry and others 2013). Currently, there is a concerted effort in conserving shortleaf pine to help counteract its range-wide decline (Anderson and others 2016).

Because of diminishing adult shortleaf pine abundance and seed sources, artificial regeneration, either direct seeding or seedling planting, may be the best option for reversing shortleaf pine population decline. Seedling planting can increase the probability of regeneration success as it bypasses uncertainties associated with earlier life stages. Planting nursery-grown shortleaf seedlings holds promise as a means to regenerate the species under a range of overstory structures (Kabrick and others 2015).

In the 1950s, the Southwide Pine Seed Source Study (SPSSS) was established to test the capacity to move seedlings across the distributions of southern pine species (Bragg and Hossain 2020). The SPSSS created a network of common garden experiments for the four major southern pine species, including shortleaf, installed across the Southeastern United States. As part of this larger effort, common garden trials for shortleaf pine were established on the Atlantic Coastal Plain near the northern edge of its native range at Green Bank, New Jersey (NJ) and outside of the species' range in the Central Appalachians at Blain, Pennsylvania (PA). Early results of the

Author Information: Grant Gallagher, Undergraduate Student, Stockton University, Galloway, NJ 08205; and Matthew G. Olson, Assistant Professor, Stockton University, Galloway, NJ 08205.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

experiment at Green Bank indicated that local seed sources should be considered when planting shortleaf pine in NJ, but shortleaf pine may not be ideal for planting at sites north of its range in PA (Little 1969). At both sites, poor performance of southern provenances was linked to elevated winter injury, presumably due to lower winter hardiness (e.g., tolerance to low temperatures and heavier snow and ice loading).

Climate change has raised concerns about where to source seedlings. Local seed sources have been recommended for parts of shortleaf's range (Little 1969); however, this suggestion was made over 50 years ago and under a different climate. Updated recommendations are needed to support shortleaf pine conservation efforts where seedling planting is being considered. The Green Bank, NJ and Blain, PA common garden studies are uniquely positioned to help inform shortleaf pine conservation efforts involving artificial regeneration on contrasting sites in the Mid-Atlantic Region (i.e., Coastal Plain vs. Appalachians).

The purpose of this research was to evaluate the performance of shortleaf pine provenances planted at the Green Bank and Blain sites in year 62 and 66, respectively, of these experiments. Based on an early report linking performance to latitude of seed origin (Little 1969), we hypothesized that the southern seed sources originating farther from the planting sites will have lower survival and growth rate than seed sources closer to the planting or those better adapted to climate at the study sites. By revisiting these long-term studies, we hope our results will aid future managers and researchers to make informed decisions on where to source shortleaf pine seedlings for enhanced regeneration success in southern New Jersey and central Pennsylvania.

METHODS

Study Site Description and Design

The study site at Green Bank, NJ (Burlington County) is located in the Outer Coastal Plain (OCP) Physiographic Province. The OCP has flat to slightly undulating topography and is underlain by unconsolidated marine deposits dominated by sand. Climate at Green Bank is predominantly humid continental with mean January low temperature, mean July high temperature, and mean annual precipitation of -3.9 °C, 29.4 °C, and 119.4 cm, respectively (Arguez and others 2010). The Green Bank common garden was planted in a former seedling nursery in the Wharton State Forest. The study site is underlain by two soil types (USDA Soil Survey Staff 2021). The dominant (75 percent of the area) is mapped as Galloway sand with 0 to 5-percent slope. The second is mapped as Downer loamy sand with 0 to 5-percent slopes.

The study site at Blain, PA (Perry County) is in the Ridge and Valley Physiographic Province of the Central Appalachians.

Climate at the Blain site is humid continental with mean annual precipitation as rain, mean July high temperature, and mean January low temperature of 109.6 cm, 28.9 °C, and -6.1 °C, respectively (Arguez and other 2010). The planting location is flat to gently sloping and somewhat poorly drained. The dominant soil series is Blairton silt loam formed within silty colluvium derived from shale and siltstone over acid, silty residuum weathered from shale and siltstone (USDA NRCS Soil Survey Staff 2021).

At both sites, multiple seed sources were planted in a randomized block design. Seed sources from seven States were planted in 1958 at Green Bank, NJ: New Jersey (NJ), Virginia (VA), South Carolina (SC), Tennessee (TN), Georgia (GA), Missouri (MO), and Louisiana (LA). At Blain, six seed sources were planted in 1954: PA, TN, Arkansas-Stone County (AR-S), Arkansas-Ashley County (AR-A), Oklahoma (OK), and Texas (TX). Seed was collected from at least 20 trees at each geographic source (Wells and Wakeley 1970). All seed sources were replicated four times (i.e., four blocks). The seed sources were randomly assigned to planting units within each block. Every planting unit representing a seed source had 121 trees planted as 11 rows with 11 trees within each row. Trees were planted on a 1.8 m x 1.8 m spacing. In order to minimize edge effects with adjacent plantings, the interior 49 trees (seven rows with seven trees per row) were tagged for long-term monitoring.

2020 Remeasurement

We revisited Green Bank and Blain test sites in the summer of 2020 to obtain updated data on the monitored trees. Our measurements at Green Bank focused primarily on the stem diameter, total height, and survival assessment of the trees. We measured the diameter at breast height (DBH; 1.4 m above the ground) with diameter tapes and recorded to the nearest tenth of a centimeter. Tree top height (height) was measured to the nearest tenth of a meter from at least two angles approximately one tree height from the subject tree using the ultrasound function of a Haglof Vertex Laser Geo unit. Only the number of live trees was recorded at the Blain study site.

Statistical Analysis

Our analysis evaluated shortleaf pine responses at stand and tree levels. The experimental unit (ExU) is the 49 tagged trees planted for each replicate of the seed source experiment (n=28 and n=24 at Green Bank and Blain study sites, respectively). Two response variables were used for testing stand-level patterns: survival and basal area. Survival (SURV) was estimated as the percent of original 49 tracked trees tallied as live in 1962, 1967, 1972, and 2020. Basal area (BA) was calculated by summing the basal area of live trees in each ExU based on the 2020 measurement, which was then expanded to the area per hectare. Tree-level responses

were tested using top height and DBH of live trees from the 2020 inventory summarized by ExU. Tree-level means for height and DBH were calculated based on all trees (mHT and mDBH, respectively). The maximum DBH (xDBH) and height (xHT) in each ExU were also included as tree-level responses. Analysis of the Blain study site was based on descriptive summaries of 2020 survival only.

Statistical tests were performed on the Green Bank data using RStudio version 1.1.456. We tested our hypothesis using analysis of variance (ANOVA) and correlation analysis. We used one-way ANOVA for a randomized block design to evaluate the effect of seed source on several response variables. The LA seed source was excluded from ANOVA models testing for seed source effects on tree-level attributes since only two of the four blocks had surviving trees in 2020. When significant seed source effects were detected by ANOVA, all pairwise comparisons of seed source means were performed using Tukey’s Honest Significant Difference method. We used correlation analysis (Pearson’s product-moment correlation) to test for associations between the response variables and geographic and climatic variables related to seed source origin (table 1). Statistical significance was assessed when $p \leq 0.05$.

Table 1—Descriptions of geographic and climatic variables used in Pearson product moment correlation tests based on year 62 data from Green Bank

Distance from seed source to planting site (DIST): Euclidean distance from center of origin county to the Green Bank site; kilometers
Latitude (LAT): Universal Transverse Mercator latitude for center of origin county; meters
Longitude (LON): Universal Transverse Mercator longitude for center of origin county; meters
Altitude (ALT): Elevation in meters above sea level for center of origin county
Annual precipitation (PREC): Mean annual precipitation for origin county; centimeters
Annual temperature (TEMP): Mean annual temperature for origin county; Celsius
Mean January low temperature (JALO): Mean of the low temperatures in January for origin county; Celsius

Note: Climatic variables are 30-year averages for 1981–2010.
Source: Arguez and others 2010.

RESULTS

Seed Source Effects

Survival variation among seed sources was evident early in the experiment at Green Bank (fig. 1). Mean survival at year 5 (1962) ranged from a high of 94 percent for the NJ source to a low of 22 percent in the LA source. By year 15 (1972), all out-of-State seed sources averaged <67 percent survival, while mean survival of the local NJ source remained above 90

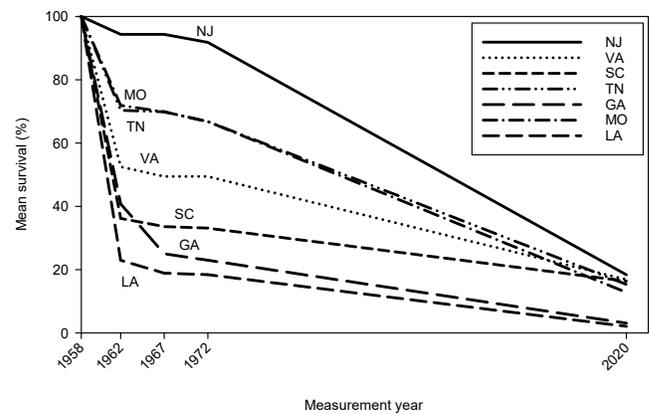


Figure 1—Mean survival of seven shortleaf pine provenances over a 62-year period of the common garden experiment in Green Bank, NJ. Survival in 1958 represents seedlings at the time of planting (late winter), while others are estimates from either during or the end of that year’s growing season.

percent. In 2020, mean survival of all seed sources fell below 20 percent and the LA seed source survived in just two of the four original blocks. Seed sources formed two groupings based on 2020 mean survival. The low survival grouping at year 62 consisted of LA and GA sources, both with mean survival below 5 percent. Mean survival of sources falling in the higher survival grouping ranged from 13 percent for the MO source to 18 percent for the NJ source. Based on survival rankings, the SC source went from the third lowest at age 15 (33 percent) to the third highest at age 62 (16 percent).

Compared to the Green Bank study, 2020 survival was substantially lower in the 66-year-old common garden planting near Blain, PA (table 2). No provenance exceeded 10 percent survival. Although not tested statistically, the PA seed source had the highest survival, followed by TN. Both the PA and TN planting were the only ones with survivors in all four of the original blocks.

Table 2—Mean percent survival and number of experimental units (ExU) with at least one survivor for six seed sources in year 66 of the common garden planting at Blain, PA

Seed source	Mean survival	Surviving ExUs
	percent	number
PA	9.3	4
TN	7.2	4
AR-S	3.1	3
OK	1.5	2
AR-A	0.5	1
TX	0.5	1

Note: Seed sources are listed in ascending order of proximity to the Blain site (i.e., closest to farthest).

Seed source was a significant source of variation in the ANOVA model for 2020 survival ($p < 0.001$). Tukey's HSD test detected significantly greater survival in NJ, VA, and SC sources than in GA and LA sources (fig. 2A). No differences in survival were detected between GA and LA sources or MO with any of the seed sources. Seed source was a significant factor in the ANOVA model for 2020 BA ($p < 0.001$). Tukey's HSD detected significantly lower BA in the GA plantings compared to both SC and VA (fig. 2B). The BA of the LA plantings were significantly lower than NJ, SC, TN, and VA according to Tukey's HSD. According to ANOVA, seed

source was a significant factor in the model for 2020 mDBH ($p = 0.002$), but not in the model for xDBH. Tukey's HSD test determined that the mDBH of the GA trees was significantly greater than trees sourced from NJ, MO, and TN (fig. 2C). An effect of seed source was detected in ANOVA models for 2020 mHT ($p = 0.010$) and xHT ($p = 0.004$). Tukey's HSD tests for mHT determined that trees sourced from GA were on average taller than trees sourced from NJ and MO (fig. 2E). Tukey's HSD test revealed the mean xHT of MO trees was significantly less than trees from several sources, including NJ, VA, SC, and GA (fig. 2F).

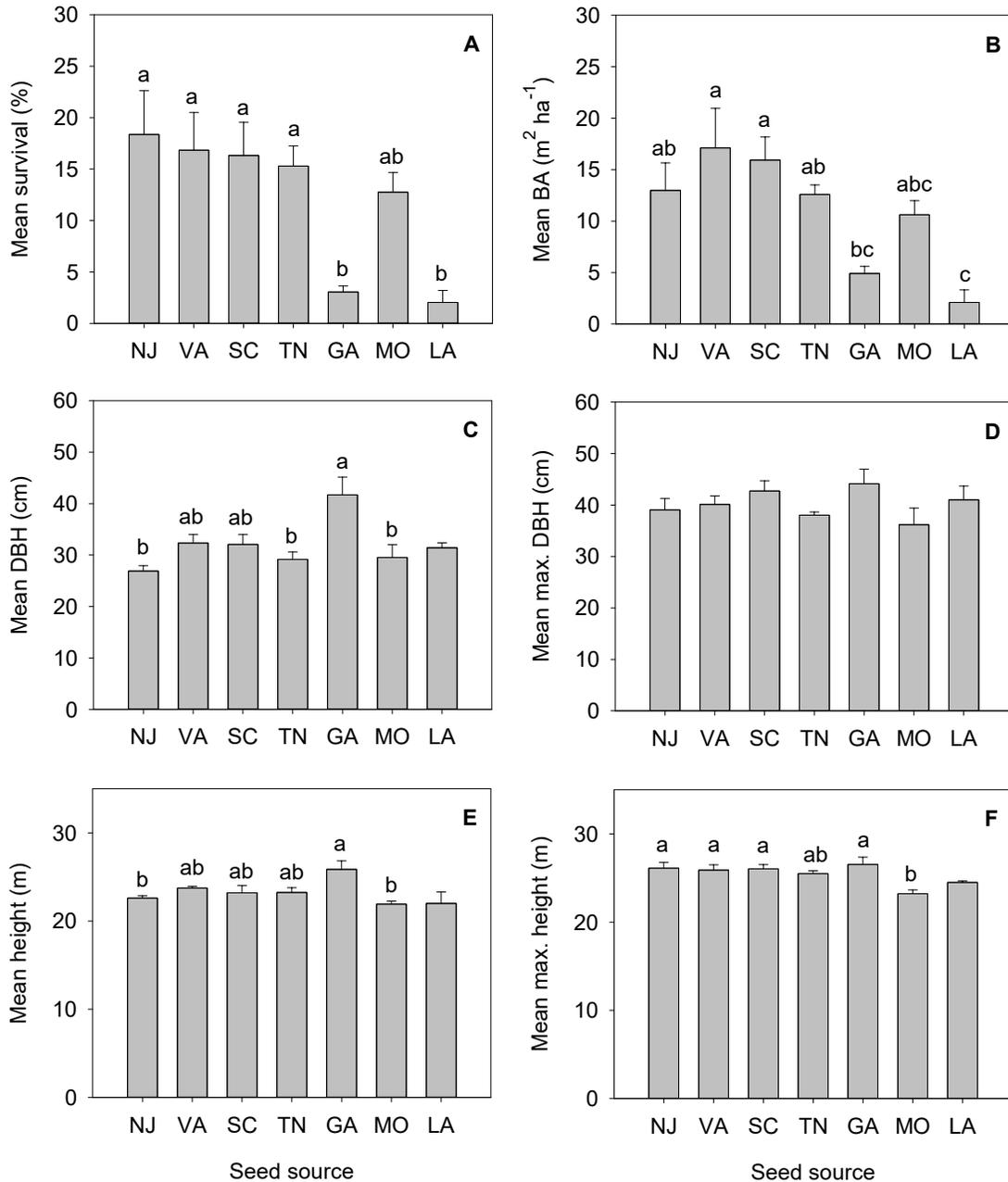


Figure 2—Mean survival (A), BA (B), DBH (C), maximum DBH (D), height (E), and maximum height (F) of shortleaf pine in year 62 (2020) of the common garden experiment in Green Bank, NJ. Seed sources are ranked from left to right based on increasing distance from county of origin to Green Bank. Seed source was a significant factor in ANOVA models for variables where lowercase letters are present (except D). State means with the same letter are not statistically different according to Tukey's HSD. Louisiana not included in ANOVA models for variables shown in figures C-F. Error bars equal one standard error.

Table 3—Pearson product-moment correlations and test results for associations between the six response variables and seven geographic and climatic variables based on year 62 data collected at Green Bank

Response variables	Geographic and climatic variables						
	DIST	LAT	LON	ALT	PREC	TEMP	JALO
SURV	-0.631 ^b	0.696 ^b	0.524 ^b	-0.003	-0.529 ^b	-0.606 ^b	-0.580 ^b
BA	-0.604 ^b	0.577 ^b	0.533 ^b	-0.030	-0.574 ^b	-0.474 ^a	-0.437 ^a
mDBH	0.283	-0.590 ^b	-0.134	-0.042	0.031	0.571 ^b	0.584 ^b
xDBH	0.005	-0.392 ^a	0.123	-0.264	0.079	0.477 ^a	0.494 ^a
mHT	-0.023	-0.389 ^a	0.157	-0.164	-0.073	0.435 ^a	0.465 ^a
xHT	-0.438 ^a	-0.128	0.555 ^b	-0.501 ^b	-0.040	0.319	0.363

^aStatistically significant at $p \leq 0.05$.

^bStatistically significant at $p \leq 0.01$.

Influence of Geography and Climate

According to Pearson correlation tests (table 3), all but one significant correlation was moderate in strength (i.e., $|r|=0.334-0.667$). Survival and BA were significantly correlated with nearly all geographic and climatic variables, except altitude of the county of seed origin. Correlations between distance from source county to the planting site with both survival and BA were negative. The only strong correlation ($|r|>0.667$) detected was between survival and latitude, a positive correlation. Survival and BA were negatively correlated with all climatic variables. Of the climatic variables, survival was most strongly associated with mean annual temperature of the county of origin, while BA was most strongly associated with mean annual precipitation of the county of origin. Correlations with mean January low temperature were stronger for survival than BA. Latitude of origin was the only geographic variable significantly correlated with mDBH, xDBH, and mHT, which were negative. The tree-level variable xHT was negatively correlated with both distance from origin and altitude of origin and positively correlated with longitude of origin. The variables mDBH, xDBH, and mHT were positively correlated with both mean annual and January low temperatures.

DISCUSSION

A geographic pattern in survival and growth of shortleaf pine seed sources was evident at years 10 and 14 of the Green Bank (NJ) and Blain (PA) common garden trials, respectively, which was linked to variation in winter injury among the seed sources (Little 1969). Partly because of these early results, we hypothesized that seed sources originating farther from the study sites, especially those from southern-most sources, would have lower survival and growth than local seed sources or ones better adapted to the climate of the planting site. The results presented for stand-level attributes (i.e., survival and basal area) at both common gardens

supported this hypothesis. Our analysis showed that the southern-most sources (LA and GA) had substantially lower survival and basal area than central and northern sources over the 62-year study at Green Bank. Interestingly, LA and GA sources had the poorest survival out to stand age 15 in a Missouri common garden comparing the same seed sources as the Green Bank study (Gwaze and others 2007). Our hypothesis was also supported by correlation tests revealing associations between geographic variables and the stand-level attributes of the NJ common garden in year 62. Positive correlations with latitude of origin and stand-level attributes are likely more indicative of adaptation to climate, while negative correlations with distance from origin county to Green Bank may reflect local adaptation in the shortleaf pine seed sources more generally. Gwaze and others (2007) also detected a north-to-south trend to shortleaf pine seed source performance in two common garden trials in Missouri with more northern sources out-performing the local MO source.

Most of the results for tree-level attributes (i.e., top height and stem diameter) did not support our hypothesis. For example, the GA seed source out-performed several others based on average diameter and height in 2020, including the local NJ source. However, the GA source also had one of the lowest survival rates during the 62-year study. By stand age 15, the mean survival rate for GA-sourced trees was just 22 percent. Therefore, the GA specimens surviving to 2020 have grown in low-density stand conditions for nearly a half century. We surmise that the larger size of surviving GA-sourced trees is more of a reflection of density-dependent growth than inherent growth superiority over the local seed source. Furthermore, the higher survival of the NJ source (>90 percent out to age 15) maintained stands with high tree density, intense competition, and less growing space per capita, which, in turn, yielded smaller trees on average after 62 years.

A tree-level result that did support our hypothesis was the negative correlation between distance from source county and maximum top height, suggesting a decrease in tree performance with increasing distance the seed was moved. Since the height of free-to-grow trees is more responsive to physical site conditions (e.g., site quality) than stand density (Avery and Burkhart 2002), this negative association could be linked to an increased mismatch between shortleaf genotypes and the planting site with increasing seed transportation distance. Winter injury (e.g., snow and ice loading) was cited as a factor to help explain poor performance of southern genotypes out to year 10 at Green Bank (Little 1969). Shoot injury caused by late frosts could have also disproportionately affected development of southern genotypes growing in Green Bank, a site near the northern limit of shortleaf's natural range.

The NJ source was the undisputed top-performer out to year 10 of the Green Bank study. Based on the 10-year results, Little (1969) recommended local seed sources for planting in southern NJ. Our results suggest that the local NJ source is no longer the top-performer after 62 years. By 2020, the VA, SC, and TN sources closed the performance gap with the local source. Although statistical differences were not detected among these 4 sources at age 62, the nominally greater basal area and tree size for VA and SC sources implies that Coastal Plain sources south of NJ may be suitable for planting in southern NJ. Several other common garden studies have also suggested that moving seeds a modest distance northward may be preferable to deploying local sources for southern pine artificial regeneration (Schmidting 1995, Tauer 1980, Wells and Wakeley 1970).

The 64-year results of the common garden study near Blain, PA, albeit limited to just survival, indicate that local sources will likely yield best results for shortleaf pine plantings in central PA. However, the poor performance of all sources at the Blain test site also suggest that shortleaf pine may not be suitable for planting at similar sites (i.e., sites with similar soil, topography, and climate) north of the species' current range. Early results clearly show how poorly shortleaf pine performed out to year 14. For example, survival ranged from 1 percent in the southern-most source (TX) to 35 percent in the local PA source. Winter injury was likely the main culprit explaining poor performance at Blain, but deer browse may have also contributed (Little 1969). Some have posited that planting shortleaf pine in the PA Ridge and Valley should prioritize south-facing sites underlain by sandstone at elevations less than 305 m above sea level, especially where frost pockets are unlikely to form (Little 1969). We concur with the early recommendation that shortleaf pine planting should be experimental in central PA until results indicate otherwise.

CONCLUSIONS

Results of the Green Bank and Blain common gardens out to the seventh decade continue to support the early recommendation to source shortleaf pine seedlings from populations best adapted to planting sites in southern NJ and central PA. However, the poor performance of all sources at Blain, PA indicates that additional experimental research is likely needed to determine appropriate genetics to deploy and site types to select when planting shortleaf pine north of its natural range in central PA. Although local sources are still viable options for shortleaf artificial regeneration in southern NJ, our study suggests that some southern sources are also suitable for out-planting on NJ Coastal Plain sites. This finding has implications not only for shortleaf pine artificial regeneration in NJ, but for climate change adaptation strategies at the northern edge of shortleaf pine's natural range. Since a warming climate is expected to favor genotypes adapted to warmer conditions, the deliberate northward movement of southern shortleaf pine seed may help enhance resilience of NJ Coastal Plain forests to future climate. Artificial regeneration would also create an opportunity for deployment of genetically improved shortleaf pine planting stock. However, one must also anticipate winter injury and associated performance setbacks in more southern sources, especially in the first few decades before climate has ameliorated for a given seed source. For example, the SC source went from one of the poorest performers to one of the top-performing sources in year 62. This suggests the performance of the SC source may have improved as climate warming ameliorated growing conditions at Green Bank. Future research at these common garden trials could investigate seed source variation in climate sensitivity based on the radial growth of individual trees over the last seven decades.

LITERATURE CITED

- Alberto, F.J.; Aitken, S.; Alia, R. [and others]. 2013. Potential for evolutionary responses to climate change—evidence from tree populations. *Global Change Biology*. 19: 1645–1661.
- Anderson, M.; Hayes, L.; Keyser, P.D. [and others]. 2016. Shortleaf pine restoration plan: restoring an American forest legacy. Shortleaf Pine Initiative. 57 p. <https://shortleafpine.net/shortleaf-pine-initiative/shortleaf-pine-restoration-plan/shortleaf-pine-restoration-plan>. [Date accessed: May 1, 2021].
- Arguez, A.; Durre, I.; Applequist, S. [and others]. 2010. NOAA's U.S. Climate Normals (1981-2010). NOAA National Centers for Environmental Information. *American Meteorological Society*. 93(11): 1687–1697.
- Avery, T.E.; Burkhart, H.E. 2002. *Forest measurements*, fifth edition. New York: McGraw-Hill. 456 p.
- Bragg, D.C.; Hossain, S.M. 2020. Revisiting shortleaf outplantings of the Southwide Pine Seed Source Study on the Crossett Experimental Forest. In: Bragg, D.C.; Koerth, N.E.; Holley, A.G., eds. *Proceedings of the 20th biennial southern silvicultural research conference*. e-Gen. Tech. Rep. SRS–253. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 318–324.

- Butler-Leopold, P.R.; Iverson, L.R.; Thompson, F.R., III [and others]. 2018. Mid-Atlantic forest ecosystem vulnerability assessment and synthesis: a report from the Mid-Atlantic Climate Change Response Framework project. Gen. Tech. Rep. NRS-181. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station. 294 p.
- Cunningham, R.J.; Hauser, C. 1989. The decline of the Missouri Ozark forest between 1880 and 1920. In: Waldrop, T.A., ed. Proceedings of pine-hardwood mixtures: a symposium on management and ecology of the type. Gen. Tech. Rep. SE-58. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station: 34-37.
- Guyette, R.P.; Muzika, R.; Voelker, S.L. 2007. The historical ecology of fire, climate, and the decline of shortleaf pine in the Missouri Ozarks. In: Kabrick, J.M.; Dey, D.C.; Gwaze, D., eds. Shortleaf pine restoration and ecology in the Ozarks: proceedings of a symposium. Gen. Tech. Rep. NRS-P-15. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station: 8-18.
- Gwaze, D.; Myszewski, J.; Kabrick, J. 2007. Performance of shortleaf pine provenances in Missouri. In: Kabrick, J.M.; Dey, D.C.; Gwaze, D., eds. Shortleaf pine restoration and ecology in the Ozarks: proceedings of a symposium. Gen. Tech. Rep. NRS-P-15. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station: 89-94.
- Hanberry B.B.; Kabrick, J.M.; He, H.S. 2013. Densification and the state transition across the Missouri Ozarks landscape. *Ecosystems*. 17(1): 66-81.
- Kabrick, J.M.; Knapp, B.O.; Dey, D.C. [and others]. 2015. Effect of initial seedling size, understory competition, and overstory density on the survival and growth of *Pinus echinata* seedlings underplanted in hardwood forests for restoration. *New Forests*. 46: 897-918.
- Lawson, E.R. 1990. *Pinus echinata* Mill. shortleaf pine. In: Burns, R.M.; Honkala, B.H., tech. coords. *Silvics of North America*. Volume 1, Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture Forest Service: 316-326.
- Little, E.L., Jr. 1971. Atlas of United States trees: conifers and important hardwoods. Misc. Publ. 1146. Washington, DC: U.S. Department of Agriculture Forest Service. 320 p. Vol. 1.
- Little, S. 1969. Local seed sources recommended for loblolly pine in Maryland and shortleaf pine in New Jersey and Pennsylvania. Res. Pap. NE-134. Upper Darby, PA: U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station. 16 p.
- Oswalt, C.M. 2012. Spatial and temporal trends of the shortleaf pine resource in the Eastern United States. Special Rep. 11. In: Kush, J.; Barlow, R.J.; Gilbert, J.C., eds. Proceedings of the shortleaf pine conference: east meets west. Auburn, AL: Alabama Agricultural Experiment Station: 33-37.
- Schmidtling, R.C. 1995. Seed transfer and genecology in shortleaf pine. In: Boyd, E.M., comp. Proceedings of the eighth biennial southern silvicultural research conference; 1994 November 1-3. Auburn, AL. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 373-378.
- Tauer, C.G. 1980. Twenty-year results of a shortleaf pine seed source study in Oklahoma. Agricultural Experiment Station Bull. B-752. Stillwater, OK: Oklahoma State University. 12 p.
- United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), Soil Survey Staff. 2021. Web Soil Survey. <https://websoilsurvey.sc.egov.usda.gov/>. [Date accessed: February 15, 2021].
- Wells, O.O.; Wakeley, P.C. 1970. Variation in shortleaf pine from several geographic sources. *Forest Science*. 16: 415-423.

HEIGHT OF PITCH AND SHORTLEAF PINE IS INCREASED BY INTRASPECIFIC COMPETITION 13 YEARS AFTER PLANTING IN THE SOUTHERN APPALACHIANS

W. Henry McNab

ABSTRACT

Predicted total height of surviving pitch pine (*Pinus rigida*) and shortleaf pine (*P. echinata*) was evaluated in response to intraspecific and interspecific competition 13 years after seedlings were row planted in a clearcut, oak (*Quercus* spp.) dominated, mixed hardwood stand on a dry ridge site. Surviving pines of each species occurring in groups of greater than or equal to two crown-touching trees (intraspecific competition) were significantly taller compared with single pines surrounded entirely by hardwood saplings (interspecific competition). Shortleaf pines in large groups (greater than or equal to three trees) were taller than those in small groups of two crown-touching trees. Grouped pines of each species were typically codominant with yellow-poplar (*Liriodendron tulipifera*), the primary competitor in the hardwood reproduction, but individual pines were generally shorter. If further studies confirm the increased height growth of pine seedlings planted in groups of two to five trees, resource managers can reduce supply and labor costs of ecological restoration of hardwood-pine communities on dry ridge sites by planting seedlings in scattered groups in small clearcut openings.

INTRODUCTION

Shortleaf pine (*Pinus echinata*) is not regenerating as a minor component of mixed hardwood stands on dry slopes and ridges in the Southern Appalachians (Elliott and others 1999), primarily because the historical occurrence of wildland fires has been reduced during the 20th century (Guldin and Black 2019). Restoration of shortleaf pine and other southern yellow pines, such as pitch pine (*P. rigida*), is desirable to maintain ecological diversity for wildlife habitat (Masters 2007). Prescribed burning, however, has not been successful for recruiting natural pine reproduction (Elliott and Vose 2005, Vose and others 1999). Planting pine seedlings can be successful for restoration of hardwood-pine communities in the North Carolina Piedmont (Schnake and others 2021), Georgia Piedmont (Waldrop 1997) and Arkansas (Brissette and Barnett 2004).

Tree communities on dry sites (typically ridges and upper west-facing slopes) consist of a mixed composition of overstory oaks (*Quercus* spp.), hickory (*Carya* spp.) and scattered shortleaf pine, a midstory of shade tolerant hardwood species, and an understory of advance reproduction (Elliott and others 1999). Because root systems and stems of most hardwood species sprout vigorously when cut or damaged during harvesting, site preparation of some form (e.g., herbicide, mechanical, burning) is necessary

to temporarily reduce interspecific competition from hardwoods while the newly planted pine seedlings become established and begin height growth (Baker and others 1996, Knowe 1992, Phillips and Abercrombie 1987). In addition to intensive site preparation for pines in commercial plantings seedlings are typically planted in uniformly spaced rows, not only for mechanical operational efficiency, but also to quickly occupy growing space to exclude hardwood competition (Fox and others 2007). Applying the principle of growing space occupation on a smaller scale, European foresters have demonstrated that planting small groups of closely spaced seedlings can be successful for establishing European oak (*Q. robur*) (Jensen and Lof 2017, Saha and others 2012) and European cherry (*Prunus avium*) (Saha 2018) in regenerated stands. Except study of site preparation methods and large group plantings (64 trees) of closely spaced shortleaf pine seedlings in central Tennessee (Clabo and Clatterbuck 2020), information is not available on the growth of yellow pines in small groups in response to hardwood competition after crown closure.

A chance observation in a restoration planting of shortleaf pine seedlings suggested the configuration of surviving trees in small groups had influenced their size after 13 years of growth (McNab 2021). Initially planted in rows, high mortality of seedlings in that study resulted in a mosaic of surviving pines occurring either as individuals surrounded

Author Information: W. Henry McNab, Research Forester, U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC 28806.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

by hardwood reproduction or small groups of two to five pines, also surrounded by hardwoods. Casual observations elsewhere in the study area revealed that pines appeared to be larger when present in groups compared with pines not in groups (fig. 1), which conflicts with the much-studied Darwinian theory that intraspecific competition between individuals of the same species is greater compared to interspecific competition between species (Becker 2000, Darwin 1859, Harper 1967). Based on that rationale, pines in groups should have been smaller than pines occurring as individuals. However, if pines in groups can compete better with hardwoods and gain a size advantage compared to single trees, this information could have practical application when seedlings are planted for biological restoration projects.

The purpose of this unplanned follow-up study as a component of the parent study was to investigate effects of intraspecific competition among surviving 13-year-old pines planted for restoration. My primary objective was to test for height differences of trees occurring as individuals compared with pines in groups. If a significant group response was found, a second objective was to test for the effect of group size on tree height. The scope of this investigation was restricted to observations in an existing study that had



Figure 1—Example of intraspecific competition between two, 13-year-old crown-touching yellow pines and their interspecific competition with surrounding hardwoods, which have smaller diameters compared to the pines but have similar heights (USDA Forest Service photo by W. Henry McNab).

been installed to evaluate clearcutting and planting as a regeneration method for ecological restoration of pitch and shortleaf pine in a mixed hardwood stand.

METHODS

Study Site

The study was conducted in the Bent Creek Experimental Forest compartment of the Pisgah Ranger District, in the Pisgah National Forest (35.4915° N, -82.6383° W). The mean annual temperature of this mountainous watershed is 12.5 °C and the seasonally uniform precipitation averages 1,200 mm. Geologic formations consist of Precambrian gneisses and schists that have weathered to form soils that are generally deep (>100 cm) and predominantly acidic (pH ≤ 6.0). The study was situated on the southwest-facing slope of a broad ridge crest with an elevation of 775 m. Forest vegetation was a multilayered stand structure of deciduous hardwoods. The overstory was dominated by two species of xerophytic, shade-intolerant oaks: chestnut oak (*Q. prinus*) and scarlet oak (*Q. coccinea*). Until recently, a minor component of yellow pines (pitch pine and shortleaf pine) was also present but had been eliminated resulting from wind throw, insects, or lightning strikes or other types of disturbance. The midstory consisted of shade-tolerant red maple (*Acer rubrum*), black gum (*Nyssa sylvatica*), and sourwood (*Oxydendron arboretum*). The tall (>3 m) shrub layer was dominated by shade-tolerant mountain laurel (*Kalmia latifolia*). Advance regeneration under the shrub layer was predominantly hardwood tree species. Basal area composition of the preharvest stand was distributed as 67 percent in the canopy consisting primarily of two oak species (chestnut and scarlet); 26 percent in the shade-tolerant midstory consisting of black gum, red maple and sourwood; and 7 percent in the mountain laurel shrub layer (table 1). The large stems of mountain laurel were an indication of a lack of fire, probably since about 1915 when the Bent Creek watershed was purchased for inclusion in the Pisgah National Forest. An area of 0.57 ha, extending across the upper and into the middle slope position, was harvested in fall 2005 by clearcutting merchantable trees and felling residual trees >2.54 cm diameter at breast height (d.b.h.). Site preparation consisted of spraying cut stumps of undesirable species (primarily shade tolerant) within an hour of felling with a 50:50 ratio of triclopyr amine and water to reduce basal sprouting.

Study Design and Field Data

The study design consisted of two, 0.10-ha blocks located along the narrow upper slope of the southwest facing ridge crest. Each block was subdivided into two 0.05-ha plots for planting with bare-root, nursery grown seedlings of either pitch pine or shortleaf pine. In spring 2007, each plot was hand planted in a rectangular grid pattern with seedlings

Table 1— Mean preharvest basal area and 13 years postharvest stem density (stem den.), basal area (BA), and quadratic mean diameter at breast height (qdbh) by species in the restoration study area

Species	Shade tolerance	Preharvest			Postharvest		
		BA	Stem den.	(SD)	BA	(SD)	qdbh
		<i>m²/ha</i>	<i>n/ha</i>		<i>m²/ha</i>		<i>cm</i>
Pitch pine	Intolerant	0	150	(483)	0.448	(1.694)	6.2
Shortleaf pine	Intolerant	0	250	(707)	0.836	(2.706)	6.5
Yellow-poplar	Intolerant	0	2,300	(2,736)	2.094	(2.549)	3.4
Oaksa	Intolerant	17.45	4,550	(2,104)	1.596	(1.176)	2.1
Sassafras	Intolerant	0.46	700	(1,129)	0.310	(0.731)	2.4
Minor species^b	Intolerant	0	500	(560)	0.362	(0.488)	3.0
Black gum	Tolerant	0.46	1,750	(1,410)	1.183	(2.237)	2.9
Red maple	Tolerant	3.21	4,200	(3,592)	1.800	(3.181)	2.3
Sourwood	Tolerant	3.21	350	(933)	0.542	(1.974)	4.4
Mountain laurel	Tolerant	1.84	4,600	(5,355)	0.394	(0.520)	1.0
All species	NA	26.63	19,350	(2,538)	9.565	(1.672)	2.5

SD = standard deviation; NA = not applicable.

^aOak species were primarily chestnut and scarlet.

^bMinor species: black cherry, American chestnut, serviceberry, black birch.

spaced 1.83 m within rows and 2.44 m between rows. The (approximately) 112 seedlings planted in each 0.05-ha plot were released from hardwood competition in May 2011 using a streamline basal spray of 20 percent triclopyr ester herbicide mixed with mineral oil. Mean second-year survival was about 95 percent for each pine species.

All living planted pines in the two blocks were inventoried by species and d.b.h. in fall 2019. Each pine was classified by the type of competition surrounding it as either interspecific or intraspecific. Interspecific competition was present when the subject pine was surrounded entirely by hardwoods and its foliage was not touching that of another pine. Competition was classified as intraspecific when the subject pine was surrounded mostly by hardwoods, but its foliage was touching that of one or more adjacent pines. Intraspecific competition occurred typically from adjacent pines in the same planted row but occasionally from one or more pines in an adjoining parallel row. Therefore, because all planted pines (the experimental units) experienced interspecific competition from adjacent hardwoods, the treatment applied to each living planted pine was the presence or absence of intraspecific competition resulting from one or more adjacent crown-touching pines. For pines experiencing intraspecific competition, a second treatment on pine size was effect of the amount, or level, of intraspecific competition, which was quantified by the number of crown-touching pines in each group. The level of intraspecific competition was classified as either low, if the group of pines consisted of two trees, or high, if the group consisted of three or more trees. In summary, each pitch or shortleaf pine was an experimental

unit, the intraspecific competition treatment consisted of two factors: absent or present, and the amount of intraspecific competition treatment was evaluated at two levels: low or high. The treatment of each living pine (presence or absence of an adjacent pine) had been applied over a period of 13 years as random events causing natural mortality of the uniformly planted seedlings, which resulted in a mosaic of variously spaced single and grouped pine trees in the study area. Duration of the intraspecific competition for grouped pines varied depending on mortality of adjacent trees and was unknown because the study was inventoried only once, at 13 years of age. Treatment response differences between the two pine species were not a study objective and were not evaluated.

The treatment response variable was height of each surviving pine. Because of time constraints, tree heights were not measured when the study was initially inventoried in fall 2019. Height data were obtained later, however, to supplement treatment responses initially assessed using d.b.h. (McNab 2021) and to better evaluate present structure and future stand development (see Acknowledgments). In April 2021, d.b.h. and height were sampled across the range of tree sizes present for each pine species and three selected hardwood species groups or individual species. The three hardwoods included pooled oak species, yellow-poplar (the predominant shade-intolerant hardwood), and red maple (the predominant shade-tolerant hardwood) (table 2).

Data Analysis

Linear regression was used to quantify the relationship between tree d.b.h. and total height for each of the two

species of pine, pooled oaks, yellow-poplar, and red maple. The curvilinear relationship between d.b.h. and height was transformed using natural logarithms (Meyer 1940). I used a covariance form of linear regression to test for differences between the pitch and shortleaf pine height-d.b.h. models to determine if species could be pooled (Gujarati 1987). Predicted tree heights were used to evaluate the response of each pine species to the two competition treatments. Pine single and group sample sizes and their locations in the study site were determined by natural mortality occurring over 13 years within the grid of 112 seedlings initially planted in each plot. One-way ANOVA was used to test first for a significant difference of mean heights in response to the two competition treatments (interspecific vs. interspecific and intraspecific) by each pine species. If a significant response to competition type was evident, a second ANOVA was then used to test for effects of the level of intraspecific competition (low vs. high) on mean predicted height of each pine species. Tree d.b.h. was not tested for differences because it was used to predict height and therefore the responses to competition type would be similar. Treatment response differences between the two pine species were not tested because the study objectives were to evaluate competition effects on pines and not to decide which species to plant for restoration. Version 3.5.1 of R was used for data analysis (R Core Team 2020); significance was determined at the $P = 0.05$ level.

RESULTS AND DISCUSSION

Regenerated Stand Characteristics

Thirteen years postharvest basal area was distributed as 17 percent oaks, 37 percent midstory species, and 4 percent shrubs (table 1). Basal area composition of new species in the postharvest stand included 13 percent yellow pines, 22 percent yellow-poplar, and 7 percent other species. The reproduction stem density was dominated by oaks, red maple, and mountain laurel. Composition changes following the harvest, particularly for yellow-poplar, were similar to results reported elsewhere in the Southern Appalachians (Elliott

and others 1999, Shure and others 2006). Additional detail on composition and diameter structure of the hardwood reproduction is provided elsewhere in these proceedings.

Height—Diameter Models

The ranges of d.b.h. and height were sampled for 15 trees of each pine species and 10 trees each for pooled oak species, yellow-poplar, and red maple (table 2). The pooled oak species consisted primarily of chestnut and scarlet, yellow-poplar was the predominant shade-intolerant species, and red maple represented the shade-tolerant species. Predicted heights across the range of d.b.h. present for each sampled species are shown in figure 2. The slope coefficients for the prediction models for height of pitch and shortleaf pines were significantly different ($P = 0.041$), which did not allow further testing of common

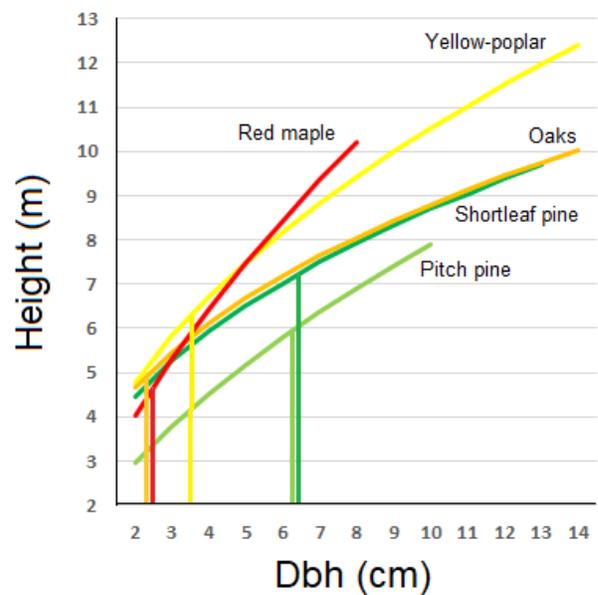


Figure 2—Predicted height in relation to diameter at breast height (d.b.h.) of planted pitch and shortleaf pines and three species of predominant hardwood regeneration 13 years after clearcutting. Length of the height curve for each species represents the range of tree sizes occurring and sampled in the regenerated stand (table 2). The vertical line projecting from each curve to the horizontal axis indicates the quadratic mean d.b.h. of that species in the regenerated stand (table 1).

Table 2—Number (n), ranges of diameter at breast height (d.b.h.), and total height (ht) of trees sampled and parameter estimates (standard error [SE]) of d.b.h.-based models for total height of selected species in a 13-year-old mixed hardwood clearcut stand on a dry site in the Pisgah National Forest, NC

Species	N	Range		Parameter		R ²	RMSE
		d.b.h. (cm)	ht (m)	Intercept (SE)	Slope (SE)		
Pitch pine	15	2.2–9.5	3.1–8.3	0.6624 (0.146)	0.6100 (0.077)	0.83	0.671
Shortleaf pine	15	3.6–11.7	5.5–9.5	1.1999 (0.090)	0.4183 (0.043)	0.88	0.440
Yellow-poplar	10	2.6–14.0	5.8–12.5	1.2225 (0.079)	0.4921 (0.041)	0.95	0.533
Oaks ^a	10	2.6–14.7	4.9–10.5	1.2635 (0.784)	0.3954 (0.046)	0.90	0.420
Red maple	10	1.0–7.3	2.1–8.9	0.9340 (0.111)	0.6681 (0.078)	0.90	0.713

Note: all model formulations are natural logarithm of height (m) = $a + (b \cdot \ln(\text{dbh-cm}))$; RMSE: Root mean square error.

^aOak species are *Quercus coccinea* and *Q. montana*.

intercepts between models or for pooling species data for a single model. Although allometric models were available for predicting biomass of small pines and hardwoods, I found no similar height-d.b.h. models for comparisons.

Competition Type

A total of 29 (26 percent) pitch and 46 (41 percent) shortleaf pines survived 13 years after planting (fig. 3). For the 29 pitch pine seedlings, 18 (62 percent) were single trees and 11 (38 percent) were in groups of greater than two conspecific trees. Fifteen (33 percent) of the surviving shortleaf pines occurred as individuals; 31 (67 percent) trees were in conspecific groups. Single compared to group survival could not be tested for either species because of the study design. Although second-year survival was high (95 percent) for both pine species, growing season precipitation was 60 percent of normal for both years, which probably affected planted seedling height growth and competition with the natural hardwood seedlings and sprouts. Other factors that could have affected seedling performance include seed provenance, nursery practices, genetic variability, and insect damage, such as defoliation by pine sawflies (*Neodiprion* spp.) (Hallgren and others 1993, Leland and others 2016, Schnake and others 2021).

Predicted mean height of the 18 pitch pines responding to interspecific competition (single trees) was 4.68 m (sd = 1.88 m) and 6.19 m (sd = 1.05 m) for the 11 trees responding to intraspecific competition (grouped trees). The difference in mean height (1.51 m) was significant ($P = 0.02$). For the 46 shortleaf pines, mean height of the 15 trees occurring singly was 6.39 m (sd = 1.67 m) and 7.96 m (sd=1.02 m) for trees in groups (fig. 3). The difference in mean height of 1.57 m between single and grouped shortleaf pines was significant ($P < 0.01$).

A reasonable explanation for the increased height of both pine species in response to intraspecific competition can only be speculated because environmental and competition data were not collected. A previous analysis of the pine competition data based on d.b.h. suggested no differences in soil moisture or fertility as indicated by hardwood competition (McNab 2021). A plausible explanation for taller trees being associated with groups could result from the combined effects of crown and foliage architecture. For example, branches of grouped pines could decrease shading from hardwood foliage on one or more sides of the trees by physically restricting the presence of broadleaf foliage leaves. The needle-like foliage of pines allows near maximum penetration of light into their crowns to reach earlier flushes of seasonal growth (McGarvey and others 2014) and lower branches (Baker and others 1996).

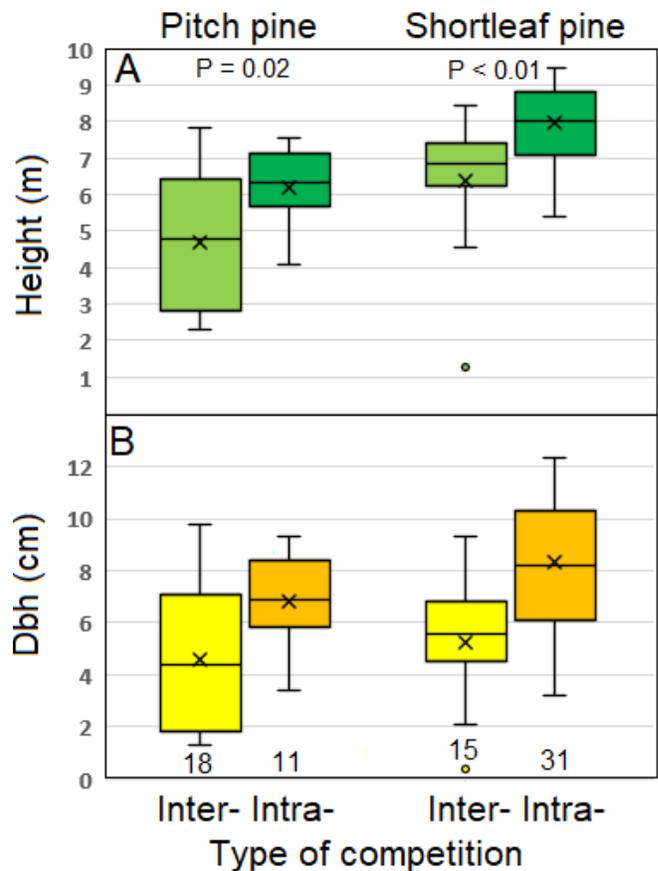


Figure 3—Distributions of diameter breast height (d.b.h.) and predicted height of surviving pitch and shortleaf pines in relation to interspecific (Inter-; single tree) competition or intraspecific (Intra-; grouped trees) competition of trees 13 years after row-planting of 1-year-old seedlings. The number of trees in each competition category is provided above the x-axis of panel B. Above the pair of whiskers in panel A is the probability (P) of significant height differences between single and groups of trees. Each box represents the interquartile range of data and shows the median (horizontal line), mean ("x"), and range (whiskers); data outliers are represented by small open circles.

Intraspecific Competition Level

The effects of the level (group size) of intraspecific competition were evaluated using heights for 11 pitch pine groups and 31 shortleaf pine groups (fig. 4). Mean pitch pine heights of the low and high levels of intraspecific competition were 6.02 m (sd = 1.29 m) and 6.47 m (sd = 0.44 m) respectively, resulting in a difference of 0.45 m, which was not significant ($P = 0.52$). For the effects of level size on shortleaf pines, mean height was 7.27 m (sd = 1.14 m) for low (n = 2) and 8.29 m (sd = 0.78 m) for the high level (n ≥ 3) of intraspecific competition. The difference of mean tree heights was 1.02 m, which was significant ($P < 0.01$). Results of this analysis agree with and extend the results for competition type, indicating that the effects of intraspecific competition on tree height increased with larger numbers of trees present in groups of shortleaf pines. Because the effects of competition type were similar for both pine species, the small sample size (n = 11) available for pitch pine level of competition was probably a factor contributing to its lack of significance.

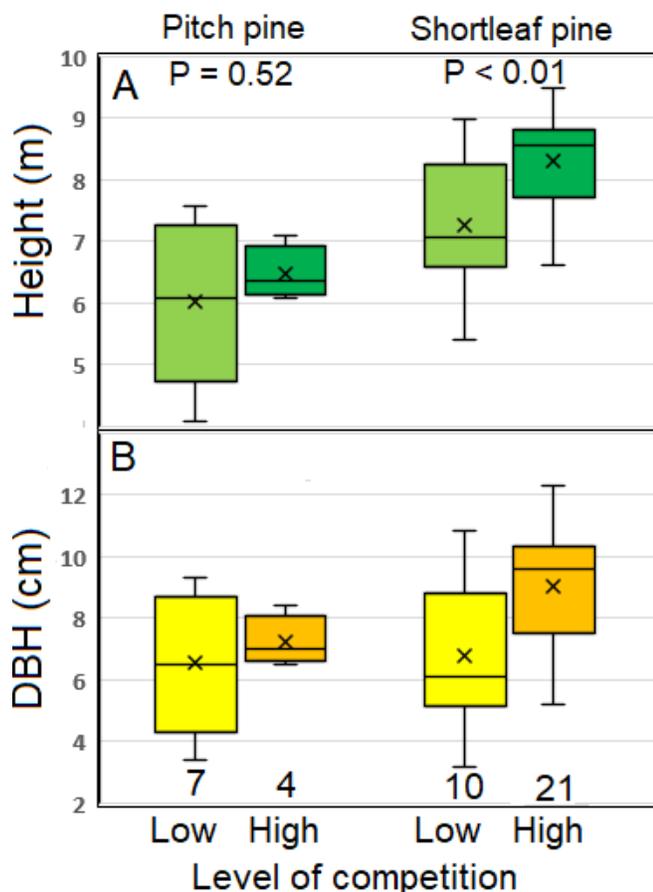


Figure 4—Distributions of diameter at breast height (d.b.h.) and predicted height of surviving pitch and shortleaf pines in relation to the level (low, group size, $n = 2$ trees; high, $n \geq 3$ trees) of intraspecific competition for trees 13 years after row-planting of 1-year-old seedlings. The number of trees sampled by level of intraspecific competition is shown above the x-axis of panel B. Note that the total trees of each pine species is equal to the number of intraspecific competition sample trees in figure 3. Above the pair of whisker boxes in panel A is the probability (P) of significant height differences between low and high levels of intraspecific competition. Each box represents the interquartile range of data and shows the median (horizontal line), mean ("x"), and range (whiskers).

Because my study involved two unusual silvicultural topics in the Southern Appalachians: (i) species restoration by clearcutting and planting yellow pines and (ii) intraspecific competition of pines and hardwoods, I found no other studies for direct comparison of results. Clabo and Clatterbuck (2020) planted shortleaf pine seedlings in large clusters (64 trees) following four site preparation methods but did not include a non-cluster treatment for comparison. The closest comparisons were from several studies of interspecific competition in Germany where *Quercus robur* and *Q. petraea* seedlings were planted in small groups to facilitate their establishment in competition with other species of hardwoods (Jensen and Lof 2017, Saha and others 2012) and improve form of a central crop tree (Skiadaresis and others 2016). Results from my study provide a meager test of the effects of intraspecific competition as proposed by Darwin (1859), which he based primarily on population dynamics

rather than size of individuals (Becker 2000, Howler and others 2019).

Size differences of pines occurring singly compared with groups could have resulted primarily from foliage competition for light and somewhat from root competition for water and nutrients. Competition for light was enhanced by physical exclusion of hardwood foliage by the touching pine branches, which allowed increased light transmittance through the thin needle-like conifer foliage to lower levels of interior branches (Baker and others 1996, Guo and Shelton 1998). Also, the rapid rate of height growth of stump sprouts compared to that of seedlings could have been a retarding influence on height of some individual pines compared to groups of trees (Wendel 1975). Because ectomycorrhiza are beneficial (and perhaps essential) for survival and growth of planted pine seedlings in competition with other vegetation, the degree of nursery and subsequent natural colonization by fungi of root systems was likely a factor affecting the early survival of pines on the study site (Jorgensen and Shoulders 1967, Ruehle and others 1981, Wright 1957). As the regenerated stand matured, development of mycorrhizal networks between roots of closely spaced pine trees could have allowed sharing of moisture and nutrients during droughts, thereby benefitting growth of pines in groups compared to individuals (Booth and Hoeksema 2010, Simard and others 2012, Teste and Simard 2008). Also, the wide host range of ectomycorrhizal fungi increases the possibility that pines could share networks with some hardwood species, particularly oaks (Rasmussen and others 2017).

This opportunistic study had several weaknesses. Perhaps the most important was insufficient replication and lack of data on progressive pine mortality and development of pines in competition with hardwoods as the study aged. Unfortunately, the only suitable site available for this study did not allow space for additional replication. Because the regenerated stand consisted of many hardwood species (table 1), detailed data on the composition of species competing with each planted pine would have provided useful information for targeted application of the herbicide release treatment following planting (Canham and others 2004). More important for the study objectives, however, would have been analysis of the measured height of each pine, rather than predicted heights. A minor strength of the study was evaluation of the response of pines in relation to competition after crown closure, when the effects of early juvenile growth differences among species had largely passed (Gauthier and others 2013).

MANAGEMENT IMPLICATIONS AND CONCLUSIONS

Although cumulative seedling mortality was high for both species, the population of large surviving pines (mostly in groups) was equivalent to 110 and 310 trees/ha for pitch and shortleaf pines, respectively, which could be considered adequate to meet the ecological objective of restoring a conifer component in the regenerated stand. Most of the pines in groups were in a codominant or dominant crown position and should continue their upper canopy position as the stand develops. Study results showed that heights of pitch and shortleaf pines in groups greater than or equal to two trees were significantly taller compared to individual pines not in groups when planted on a dry ridge site following clearcut harvesting. With further study to confirm and refine those findings, resource managers could decide that extensive use of herbicides for site preparation and release treatments may not be needed for ecological restoration, thereby resulting in cost savings and reduction of possible environmental impacts. In summary, the significant height response of planted pines growing in groups provides a logical reason for additional investigation of intraspecific competition of conifers for conifer restoration on dry sites in the Southern Appalachians.

ACKNOWLEDGMENTS

I am grateful for the constructive comment by a person attending my virtual webinar presentation of results from this study in March 2021, which were based only on tree d.b.h. That person said pine heights would provide a better evaluation of competition compared to diameter. Consideration of that comment prompted my return to the study site in April for data to develop diameter-height regression models (while continuing to observe Forest Service, U.S. Department of Agriculture (USDA), guidelines for field work during the ongoing Covid-19 pandemic). Funding was provided by the Forest Service, Southern Research Station. I thank Erik Berg and Theodore Oprean for their reviews of a previous draft of this manuscript. I particularly appreciate a comment by Ted Oprean on the importance of ectomycorrhiza for successful establishment of conifer regeneration. This article was written and prepared by a U.S. Government employee on official time, and it is therefore in the public domain. The findings and conclusions in this publication are those of the author and should not be construed to represent any official USDA or U.S. Government determination or policy.

LITERATURE CITED

- Baker, J.B.; Cain, M.D.; Guldin, J.M. [and others]. 1996. Uneven-aged silviculture for loblolly and shortleaf pine forest cover types. Gen. Tech. Rep. SO-118. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 65 p.
- Becker, P. 2000. Competition in the regeneration niche between conifers and angiosperms: Bond's slow seedling hypothesis. *Functional Ecology*. 14: 401–412.
- Booth, M.G.; Hoeksema, J.D. 2010. Mycorrhizal networks counteract competitive effects of canopy trees on seedling survival. *Ecology*. 91(8): 2294–2302.
- Brissette, J.C.; Barnett, J.P. 2004. Stock type affects performance of shortleaf pine planted in the Ouachita mountains through 10 years. In: Connor, K.F., ed. Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 420–422.
- Canham, C.D.; LePage, P.T.; Coates, K.D. 2004. A neighborhood analysis of canopy tree competition: effects of shading versus crowding. *Canadian Journal of Forest Research*. 34: 778–787.
- Clabo, D.C.; Clatterbuck, W.K. 2020. Restoration of shortleaf pine (*Pinus echinata*)-hardwood mixtures in low quality mixed upland hardwood stands using cluster planting and natural regeneration. *Forests*. 11: 457. <https://doi.org/10.3390/f11040457>.
- Darwin, C. 1859. The origin of species. London: John Murray [reprinted 1999, Bantam Books, New York.] 400 p. Chapter 3.
- Elliott, K.J.; Vose, J.M. 2005. Effects of understory prescribed burning on shortleaf pine (*Pinus echinata* Mill.)/mixed-hardwood forests. *The Journal of the Torrey Botanical Society*. 132: 236–251.
- Elliott, K.J.; Vose, J.M.; Swank, W.T.; Bolstad, P.V. 1999. Long-term patterns in vegetation-site relationships in a southern Appalachian forest. *The Journal of the Torrey Botanical Society*. 126: 320–334.
- Fox, T.R.; Jokela, E.J.; Allen, H.L. 2007. The development of pine plantation silviculture in the Southern United States. *Journal of Forestry*. 105(7): 337–347.
- Gauthier, M.-M.; Zellers, K.E.; Lof, M.; Jacobs, D.F. 2013. Inter- and intra-specific competitiveness of plantation-growth American chestnut (*Castanea dentata*). *Forest Ecology and Management*. 291: 289–299.
- Gujarati, D. 1987. Use of dummy variables in testing for equality between sets of coefficients in two linear regressions: a note. *The American Statistician*. 24: 50–52.
- Guldin, J.M.; Black, M.W. 2019. Restoration of shortleaf pine in the Southern United States—strategies and tactics. In: Kirschman, Julia E., comp. 2018. Proceedings of the 19th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-234. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 281–287.
- Guo, Y.; Shelton, M.G. 1998. Canopy light transmittance in natural stands on upland sites in Arkansas. In: Waldrop, T.A., ed. 1998. Proceedings of the ninth biennial southern silvicultural research conference; 1997 February 25–27, Clemson, SC. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 618–622.
- Hallgren, S.W.; Tauer, C.G.; Weeks, D.L. 1993. Cultural, environmental, and genetic factors interact to affect performance of planted shortleaf pine. *Forest Science*. 39: 478–498.
- Harper, J.L. 1967. A Darwinian approach to plant ecology. *Journal of Ecology*. 55(2): 247–270.
- Howler, K.; Vor, T.; Seidel, D. [and others]. 2019. Analyzing effects of intra- and interspecific competition on timber quality attributes of *Fagus sylvatica* L.—from quality assessments on standing trees to sawn boards. *European Journal of Forest Research*. 138: 327–343.
- Jensen, A.M.; Lof, M. 2017. Effects of interspecific competition from surrounding vegetation on mortality, growth, and stem development in young oaks (*Quercus robur*). *Forest Ecology and Management*. 302: 176–183.

- Jorgensen, J.R.; Shoulders E. 1967. Mycorrhizal root development vital to survival of slash pine nursery stock. *Tree Planters' Notes*. 18(2): 7–11.
- Knowe, S.A. 1992. Predicting the impact of interspecific competition in young loblolly pine plantations with diameter distribution models. *Forest Ecology and Management*. 55: 65–82.
- Leland, C.; Hom, J.; Skowronski, N. [and others]. 2016. Missing rings, synchronous growth, and ecological disturbance in a 36-year pitch pine (*Pinus rigida*) provenance study. *PLoS ONE*. 11(5): e0154730. <https://doi.org/10.1371/journal.pone.0154730>.
- Masters, R.E. 2007. The importance of shortleaf pine for wildlife and diversity in mixed oak-pine forests and in pine-grassland woodlands. In: Kabrick, J.M.; Dey, D.C.; Gwaze, D., ed. 2006. Proceedings of the shortleaf pine restoration and ecology in the Ozarks: Proceedings of a symposium, 2006 November 7-9, Springfield, MO. Gen. Tech. Rep. NRS-P-15. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station: 35–45.
- McGarvey, R.C.; Martin, T.A.; White, T.L. 2014. Integrating within-crown variation in net photosynthesis in loblolly and slash pine families. *Tree Physiology*. 24: 1209–1220.
- McNab, W.H. 2021. Preliminary evidence that intraspecific competition increases size of restoration-planted pitch and shortleaf pines in a mixed hardwood clearcut in the Southern Appalachians. *Forest Science*. 67: 374–379. <https://doi.org/10.1093/forsci/xfab011>.
- Meyer, H.A. 1940. A mathematical expression for height curves. *Journal of Forestry*. 38: 415–420.
- Phillips, D.R.; Abercrombie, J.A. 1987. Pine-hardwood mixtures—a new concept in regeneration. *Southern Journal of Applied Forestry*. 11(4): 192–197.
- R Core Team. 2020. A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.r-project.org/>. [Date accessed: August 19, 2021].
- Rasmussen, A.L.; Busby, R.R.; Hoeksema, J.D. 2017. Host preference of ectomycorrhizal fungi in mixed pine-oak woodlands. *Canadian Journal of Forest Research*. 48(2): 153–159.
- Ruehle, J.L.; Marx, D.H.; Barnett, J.P.; Pawuk, W.H. 1981. Survival and growth of container-grown and bare-root shortleaf pine seedlings with *Pisolithus* and *Thelephora ectomycorrhizae*. *Southern Journal of Applied Forestry*. 5(1): 20–24.
- Saha, S. 2018. Group planting of cherry (*Prunus avium* L.) fosters growth and tree quality is superior to conventional row planting in Germany. *Journal of Forestry Research*. 29(4): 1099–1110.
- Saha, S.; Kuehue, C.; Kohle, U. [and others]. 2012. Growth and quality of young oaks (*Quercus robur* and *Quercus petraea*) grown in cluster plantings in central Europe: a weighted meta-analysis. *Forest Ecology and Management*. 283: 106–118.
- Schnake, D.K.; Roberts, S.D.; Willis, J.L. [and others]. 2021. Overstory retention and stock type impact survival and growth of underplanted shortleaf pine beneath a hardwood canopy. *Forest Science*. 67(2): 219–230.
- Shure, D.J.; Phillips, D.L.; Bostick, P.E. 2006. Gap size and succession in cutover southern Appalachian forests: an 18 year study of vegetation dynamics. *Plant Ecology*. 185: 299–318.
- Simard, S.W.; Beiler, K.J.; Bingham, M.A. [and others]. 2012. Mycorrhizal networks: mechanisms, ecology and modelling. *Fungal Biology Reviews*. 26: 39–60.
- Skiadareisis, G.; Saha, S.; Bauhus, J. 2016. Oak group planting produces a higher number of future crop trees, with better spatial distribution than row planting. *Forests*. 7: 289. <https://doi.org/10.3390/f7110289>.
- Teste, F.P.; Simard, S.W. 2008. Mycorrhizal networks and distance from mature trees alter patterns of competition and facilitation in dry Douglas-fir forests. *Oecologia*. 158: 193–203.
- Vose, J.M.; Swank, W.T.; Clinton, B.D. [and others]. 1999. Using stand-replacement fires to restore southern Appalachian pine-hardwood ecosystems: effects on mass, carbon, and nutrient pools. *Forest Ecology and Management*. 114: 115–126.
- Waldrop, T.A. 1997. Four site-preparation techniques for regenerating pine-hardwood mixtures in the Piedmont. *Southern Journal of Applied Forestry*. 21(3): 116–122.
- Wendel, G.W. 1975. Stump sprout growth and quality of several Appalachian hardwood species after clearcutting. Res. Pap. NE-329. Upper Darby, PA: U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station. 9 p.
- Wright, E. 1957. Importance of mycorrhizae to ponderosa pine seedlings. *Forest Science*. 3(3): 275–280.

RESTORATION PLANTING OF PITCH AND SHORTLEAF PINES AFTER CLEARCUTTING A MIXED HARDWOOD STAND ON A RIDGE SITE IN THE SOUTHERN APPALACHIANS: LESSONS LEARNED AFTER 13 YEARS

W. Henry McNab

ABSTRACT

Southern yellow pines (*Pinus* spp.) are not regenerating in formerly mixed hardwood—pine stands on low elevation ridges in the Southern Appalachians, resulting in loss of biodiversity. The purpose of this study was to evaluate clearcutting and planting as a regeneration method for restoring a pine component in a mixed hardwood stand on a ridge site. The study objective was to test for differences of stocking, diameter breast height (d.b.h.), and basal area between pitch (*P. rigida*) and shortleaf (*P. echinata*) pines at crown closure, 13 years after planting. One year after clearcut harvesting the mature mixed oak (*Quercus montana*, *Q. coccinea*) stand, 1-0 bare-root seedlings were bar planted 1.83 m apart in rows spaced 2.44 m (2,220 trees/ha) in four, 0.05 ha plots. All pine and hardwood reproduction ≥ 0.1 cm was inventoried by d.b.h. class on 5, 1/1000 ha sample subplots on each plot. The regenerated stand basal area of 9.56 m²/ha was distributed among yellow pines 13 percent, oaks 17 percent, yellow-poplar (*Liriodendron tulipifera*) and other shade intolerant species (29 percent), red maple (*Acer rubrum*) and other shade tolerant species 37 percent and mountain laurel (*Kalmia latifolia*) 4 percent. There were no differences in reproduction between the two pine species. The most surprising result of this study was the dominance of yellow-poplar reproduction on the dry, southwest facing ridge summit, a species that was absent in the preharvest stand. The surviving dominant and codominant pines, which tended to occur in scattered small groups of two-to-five trees, will likely be a continuing canopy component of the maturing stand. Preliminary results from this study suggest that clearcutting small patches of mixed hardwoods and planting yellow pine seedlings provides resource managers with a low-cost option for restoring habitat biodiversity on dry, oak-dominated sites.

INTRODUCTION

Within the predominantly, hardwood dominated oak-hickory (*Quercus-Carya*) forests of the Southern Appalachian Mountains, vegetative communities on low-to-moderate elevation (<1060 m) dry ridges typically include a minor component of several species of southern yellow pines (*Pinus* spp.), particularly shortleaf pine (Harmon 1982, Jenkins 2007) (fig. 1). Periodic wildland fire was previously a common disturbance on these sites, which created conditions favorable for natural reproduction of pines (Barden and Woods 1976, DeVivo 1991, Welsch 1999). The combination of fire suppression during the 1900s and periodic outbreaks of the endemic southern pine beetle (*Dendroctonus frontalis*) has resulted in composition changes from mixed hardwood-pine communities to predominantly hardwood dominated stands in the Southern Appalachians and throughout the interior uplands of the Southeastern United States (Guldin and Black 2018). The associated reduction of biodiversity resulting from loss of yellow pines affects habitat for birds and mammals

(Eddleman and others 2007, Masters 2007), including Indiana bats (*Myotis sodalis*) (O’Keefe and Loeb 2017).

Restoration of pines as a minor component of hardwood communities in the Southern Appalachians has typically involved prescribed burning to create conditions favorable for natural reproduction (Elliott and others 2012, Vose and others 1999). Prescribed burning for natural reproduction has not been effective because low intensity, controlled fires do not reduce leaf litter on the forest floor sufficiently for establishment of seedlings or reduce shade from hardwoods (Elliott and others 1997, Elliott and Vose 2005). Direct seeding to supplement natural production by onsite trees is usually not successful because of predation by birds and rodents (Barnett 2014). Planting seedlings following harvests can be successful for pine restoration, but intensive site preparation and competition control of advance hardwood reproduction is usually necessary for establishment of well stocked stands for commercial management (Clabo and Clatterbuck 2020). However, on sites where the objective is

Author Information: W. Henry McNab, Research Forester, U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC 28806.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.



Figure 1—A remnant group of mature pitch and shortleaf pines surrounded by mixed oaks on the ridge crest opposite the study area at Boyd Gap, Bent Creek Experimental Forest. A 124-year-old shortleaf pine in this group likely indicates the most recent date of a stand replacing fire. Natural yellow pine reproduction is absent in the stand but abundant in grasses on the south-facing road bank. The three yellow circles indicate resprouting shortleaf pine saplings following periodic cutting of vegetation on the right-of-way beside Boyd Branch Road. The two white arrows identify eastern white pine saplings that have regenerated in the stand (USDA Forest Service photo by W. Henry McNab).

to establish a component of pines in the new stand, rather than a high density for management, a minimal level of site preparation may be adequate, such as herbicide treatment of cut stumps of readily sprouting species, including red maple (*Acer rubrum*) and sourwood (*Oxydendrum arboretum*) (Kochenderfer and others 2012, Zedaker and others 1987). Clabo and Clatterbuck (2015) reported increased growth of loblolly pine seedlings planted after clearcutting and prescribed burning a hardwood site in eastern Tennessee. In the North Carolina Piedmont, restoration of shortleaf pine on an upland hardwood site was successful by planting following site preparation by prescribed burning (Schnake and others 2021). Information is lacking, however, for restoration of yellow pines on hardwood sites that have not been burned.

The purpose of this study was to determine the potential for ecological restoration of yellow pines by planting seedlings on a clearcut mixed hardwood site with minimal site preparation. The objective was to compare performance of pitch and shortleaf pine. This is the first report of results from this long-term study of pine restoration.

METHODS

Study Site

The study was installed at Boyd Gap (35.4915o N, -82.6383o W) in the Bent Creek Experimental Forest, in the Southern Appalachian Mountains of western North Carolina. Annual temperature averages 12.5 oC; precipitation averages 1200 mm and is uniformly distributed among seasons. The 0.57-ha study site was the southwest-facing slope of a broad

Table 1—Mean preharvest basal area and 13 years postharvest stem density (stem den.), basal area (BA), and quadratic mean diameter at breast height (qdbh) by species in the restoration study area

Species	Shade tolerance	Preharvest		Postharvest			
		BA	Stem den.	(SD)	BA	(SD)	qdbh
		<i>m²/ha</i>	<i>n/ha</i>		<i>m²/ha</i>	<i>cm</i>	
S. yellow pine	Intolerant	0	400	(598)	1.284	(2.233)	6.4
Yellow-poplar	Intolerant	0	2,300	(2,736)	2.094	(2.549)	3.4
Oaks^a	Intolerant	17.45	4,550	(2,104)	1.596	(1.176)	2.1
Sassafras	Intolerant	0.46	700	(1,129)	0.310	(0.731)	2.4
Minor species^b	Intolerant	0	500	(560)	0.362	(0.488)	3.0
Black gum	Tolerant	0.46	1,750	(1,410)	1.183	(2.237)	2.9
Red maple	Tolerant	3.21	4,200	(3,592)	1.800	(3.1815)	2.3
Sourwood	Tolerant	3.21	350	(933)	0.542	(1.974)	4.4
Mountain laurel	Tolerant	1.84	4,600	(5,355)	0.394	(0.520)	1.0
All species	NA	26.63	19,350	(2,538)	9.565	(1.672)	2.5

SD = standard deviation; NA = not applicable.

^aOak species were primarily chestnut and scarlet.

^bMinor species: black cherry, American chestnut, serviceberry, black birch.

ridge crest at 775 m elevation. Soils are deep (>100 cm) and predominantly Ultisols of the Evard-Cowee complex. The preharvest canopy of the of the study site was dominated by two species of shade-intolerant oaks: chestnut and scarlet (table 1). The midstory consisted primarily of red maple, black gum (*Nyssa sylvatica*), and sourwood. Also present were sassafras (*Sassafras albidum*) and occasional sprouts of American chestnut (*Castanea dentata*). Mountain laurel (*Kalmia latifolia*), a shade-tolerant evergreen shrub common on xeric sites, dominated the understory. The single remaining mature shortleaf pine (approximately 30 cm d.b.h.) had died from unknown causes and was windthrown in 2004. Site index (50-year base age) estimated from a nearby 124-year-old shortleaf pine in the stand shown in figure 1, was 17.4 m.

This site occupies the ecotone between landscapes typically occupied by two species of southern yellow pine species: shortleaf pine on gentle slopes of lower elevations up to 900 m and pitch pine on steeper slopes of higher elevations to about 1370 m. Forest composition of the study site was typical of xeric oak-pine communities on mid-elevation ridges that have been maintained historically by periodic disturbance from low-intensity wildland fires (Elliott and Vose 2005). There was no evidence of timber harvest although historical records suggest the area was likely used as a woodlot and had been burned periodically to promote browsing for livestock before 1900, when the tract was purchased by George Vanderbilt as part of his Pisgah Forest properties (Nesbitt 1941). The presence of a dense, tall (>3 m) shrub layer of mountain laurel is an indication of the absence of recent fire, probably before acquisition by the Forest

Service, U.S. Department of Agriculture, for the Pisgah National Forest in 1914.

Study Design and Field Data

Timber on the study site was harvested in fall 2005. The merchantable parts of tree stems were skidded to a log deck next to a logging road outside of the study area. Large branches of unmerchantable treetops were cut in place to increase ground contact and promote decomposition. All residual trees and shrubs larger than 2.54 cm d.b.h. were cut. Cut stumps of undesirable species were sprayed with a 50:50 ratio of triclopyr amine and water. Undesirable species included red maple, sourwood, black gum, sassafras, and mountain laurel. Basal sprouting from stumps of these species can occupy a large proportion of growing space soon after harvest (Fei and Steiner 2009). Herbicide treatment of cut stumps was a method of site preparation commonly used by national forests for low-impact site preparation (Kochenderfer and others 2012).

The study site within the larger harvested area consisted of two, 0.10-ha blocks, which extended parallel with the ridge crest across the upper slope position and down to the middle slope. Each 0.10-ha block (approximately 36 m x 28 m) was subdivided into two 0.05-ha treatment plots. Study treatments consisted of planting (spring 2007) each plot with unimproved 1-0 seedlings of either pitch pine or shortleaf pine from state nurseries in Tennessee and North Carolina, respectively. Seedlings were bar-planted 1.83 m apart in rows extending down slope across contours; rows were spaced 2.44 m apart for an average of 2,220 seedlings/ha. Control (unplanted) plots were not established because the objective

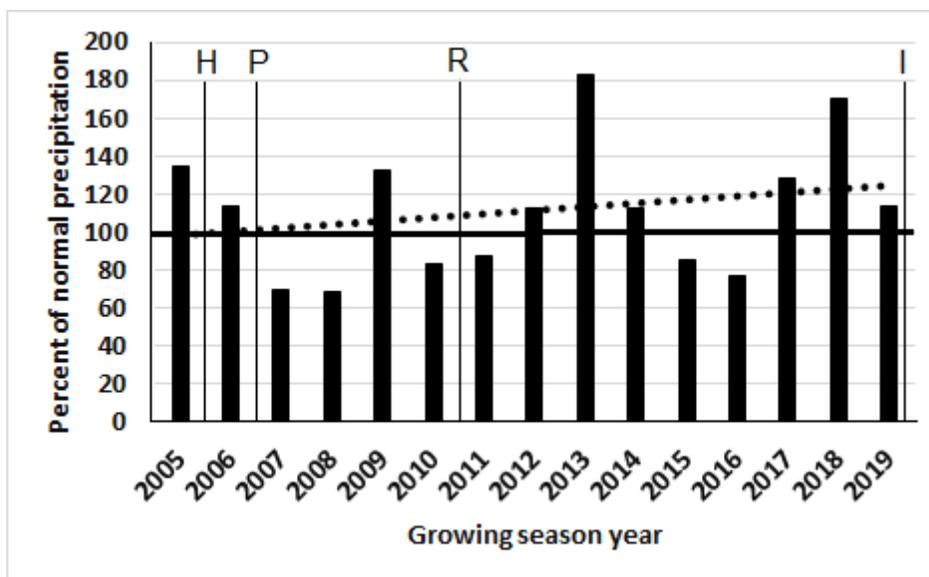


Figure 2—Growing season (April–September) precipitation during the 13 years of the study displayed as percentage of normal (613.7 mm) recorded at the Asheville Regional Airport, about 8 km southeast of the study area. The horizontal solid line represents 100 percent of normal growing season precipitation; the dotted line represents the trend of growing season precipitation during the study period. The letters H, P, R, and I represent harvest, planting, release, and inventory events occurring during the study, respectively.

was to compare performance of two species of pine seedlings. Mean second-year survival of each pine species was >95 percent. In May 2011, both pine species were released from competition using streamline basal spray application of 20-percent triclopyr ester herbicide mixed with mineral oil.

Pine and hardwood reproduction were inventoried in fall 2019, on five systematically located, circular 0.001-ha sample subplots in each treatment plot. Tree and shrub (mountain laurel) stems ≥ 1.37 m tall were inventoried by species and d.b.h. and recorded in approximately 2-cm classes (<0.5 cm, 0.6–1.9 cm, 2.0–3.9 cm, etc.). The first size class was subdivided primarily to better describe stand structure associated with mountain laurel, which consisted entirely of small stems. Calculated response variables were basal area and quadratic mean d.b.h. (qd.b.h.). Mean stocking of sample plots by ≥ 1 pine tree was calculated for each species. Pine survival percent by species was based on a potential planting density of 2,220 seedlings per ha. The 30-year normal (1980–2010) and measured growing season (April–September) precipitation were obtained from the National Oceanic and Atmospheric Administration (NOAA) site at the Asheville Regional Airport (35.4361° N, -82.5083° W; 660 m elevation), located about 8 km southeast of the study area (fig. 2).

Data Analysis

Treatment response variables were stem density and basal area and their relative values as a percentage of total tree basal area in each sample plot. All sample plots were stocked with hardwoods, but pines were missing from more than half of the sample plots, resulting in negatively skewed data for analysis. Shapiro-Wilks tests confirmed non-normal distributions for all treatment response variables. Therefore, the non-parametric Kruskal-Wallis one-way ANOVA was used for analysis of treatment (pine species) differences.

Version 3.5.1 of R was used for data analysis (R Core Team 2020); significance was determined at the $\alpha = 0.05$ level.

RESULTS AND DISCUSSION

Basal area composition of the preharvest stand was distributed as 66 percent in the canopy consisting of two oak species (scarlet and chestnut); 26 percent in the shade-tolerant midstory of black gum, red maple and sourwood; and 8 percent in the mountain laurel shrub layer (table 1). Thirteen years postharvest, basal area was distributed as 17 percent oaks, 37 percent midstory species, and 4 percent shrubs. Basal area of new species in the postharvest stand included 13 percent southern yellow pines and 22 percent yellow-poplar. The sapling reproduction stem density was dominated by oaks, red maple, and mountain laurel. Composition changes following the clearcut harvest, particularly for yellow-poplar, were similar to results reported elsewhere in the Southern Appalachians (Elliott and others 1997, Shure and others 2006).

Stem density of the even-aged pine and hardwood reproduction in the study area followed a negative exponential relationship (fig. 3). The majority of stems in the smallest qd.b.h. class (0.1–0.5 cm) were mountain laurel, followed by red maple and chestnut oak (table 2). Except for the planted pines, species with the largest mean qd.b.h. were stump sprouts of shade-tolerant species, particularly black gum and sourwood. Chestnut oak, yellow-poplar, and red maple stems were abundant across all qd.b.h. size classes. Although mean basal area in the study area was less than reported by Elliott and others (1997) on a more mesic site, the size class distribution and composition of stems were similar.

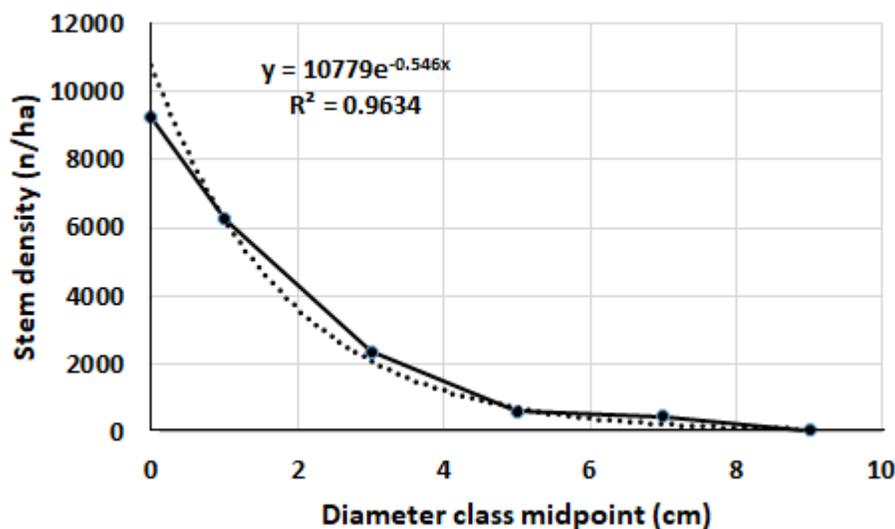


Figure 3—A negative exponential model describes the relationship between stem density and diameter at breast height (d.b.h.) class midpoints of pine and hardwood reproduction inventoried in the study site 13 years after planting.

Table 2—Stem density of reproduction by species and diameter at breast height (d.b.h.) classes 13 years postharvest

Species	Stem density (<i>n/ha</i>)						Total
	d.b.h. class (<i>cm</i>)						
	0.1–0.5	0.6–1.9	2.0–3.9	4.0–5.9	6.0–7.9	8.0–9.9	
Pitch pine	0	0	50	50	50	0	150
Shortleaf pine	0	0	50	100	100	0	250
Chestnut oak	1650	1100	150	50	100	0	3050
Scarlet oak	350	450	50	0	0	0	850
Minor oaks ^a	300	300	50	0	0	0	650
Yellow poplar	250	1000	800	200	50	0	2300
Sassafras	150	400	150	0	0	0	700
Minor intolerants ^b	200	100	150	50	0	0	500
Red maple	1750	1750	550	100	50	0	4200
Black gum	700	700	250	0	50	50	1750
Sourwood	50	100	100	50	50	0	350
Mountain laurel	3850	750	0	0	0	0	4600
All species	9250	6650	2350	600	450	50	19350

^aMinor oak species: black, northern red, white.

^bMinor intolerant species: black birch, American chestnut, serviceberry, black cherry.

Table 3—Mean (standard deviation [SD]) stand characteristics of pine reproduction by species and probability (P) that the difference is significant 13 years after planting

Pine reproduction	Pitch pine		Shortleaf pine		P
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	
Sample subplot stocking (%)	30	(48.3)	40	(51.6)	0.65
Stem density (<i>n/ha</i>)	300	(483.0)	500	(707.1)	0.47
Relative stem density (%) ^a	1.615	(2.6)	2.451	(3.6)	0.56
Stem basal area (<i>m</i> ² / <i>ha</i>)	0.897	(1.7)	1.672	(2.7)	0.45
Relative stem basal area (%) ^a	6.551	(11.7)	15.448	(22.3)	0.28

^aPine relative density and basal area calculated as percentage of total (pine and hardwood) stem density and basal area.

Analysis of variance indicated no difference between the two blocks for pitch pine stem density ($P=0.51$) and basal area ($P=0.37$) or shortleaf pine density ($P=0.81$) and basal area ($P=0.64$) (data not shown). Sample data for the two plots of each block were then merged for species comparisons. Stocking percent of the sample plots did not differ ($P=0.65$) between pitch (30 percent) and shortleaf pine (40 percent) (table 3). Also, there was no significant differences between pitch and shortleaf pines for density ($P=0.56$), relative density ($P=0.56$), basal area ($P=0.45$), or relative basal area ($P=0.28$). Survival after 13 years was low for each pine species: 13.5 percent for pitch pine and 22.58 percent for shortleaf. Competition as the stand aged was the likely cause for the low survival (Baker and others 1996, Shelton and Murphy

1992). Growing season precipitation was below average for the 2 years after planting (fig. 2), but the high early survival of both pine species during that period (>95 percent) suggests viable seedlings were planted. The subsequent low survival of pitch seedlings (from a Tennessee nursery) as the stand aged may be a result of environmental differences between the seed source provenance and the planting site (Leland and others 2016).

Two naturally established pine saplings were observed in the study area, a pitch pine (d.b.h. 12 cm) and a shortleaf pine (d.b.h. 10.5 cm). The seed source for both saplings was likely a small group of mature, mixed-pine species approximately 50 m north of the study site (fig. 1). These two trees originated from wind disseminated seeds that germinated on disturbed

soil soon after logging and therefore were a year older than the planted seedlings, which were established one growing season following harvest. These two volunteer trees, which were dominant in comparison with surrounding hardwoods and larger than the planted pines, demonstrate the growth potential of natural pine reproduction in competition with hardwoods on dry ridge sites.

The low survival (approximately 20 percent) of planted pines on my study sites was similar to the 23-percent survival reported by Clabo and Clatterbuck (2015) on clearcut, unburned sites with similar species composition in eastern Tennessee. In that study, however, survival of planted pines was nearly two times higher on burned plots. In central North Carolina, Schnake and others 2021 reported good 5-year survival of shortleaf following clearcut and burning for site preparation. Phillips and Abercrombie (1987), in the Piedmont of South Carolina, reported high survival and growth of shortleaf pines following prescribed burning of logging debris. Based on results from studies elsewhere, survival of pines in my study would probably have been higher if the area had been prescribed burned for site preparation.

Except for scattered chestnut oak and black gum stump sprouts, yellow-poplar was visually the tallest hardwood species in the sample plots, which made it the primary competitor with both the pines and other hardwoods, including red maple. Domination of the regenerated stand by yellow-poplar was a surprising result because it was absent before the harvest and is a mesophytic species that logically should not flourish on the dry southwest slope of the study area. Generally higher-than-average years of growing season precipitation during the period of study probably compensated for the dry characteristics of the site (fig. 2). The high density of yellow-poplar reproduction probably originated from the seed bank (Clark and Boyce 1964) when the forest floor litter was disturbed during logging (Beck and Della-Bianca 1981). Above average precipitation after harvest (2005) likely aided germination of yellow-poplar seeds and establishment of seedlings. Source of the stored seeds was likely from mature trees on the backside (northeast facing) slope of the ridge crest study area. Wind disseminated yellow-poplar seeds can be transported up to 100 m from the mother tree (Engle 1960). About half of the surviving pine species were visually equal or taller than the surrounding hardwoods and will probably remain a canopy component as the stand ages. Although yellow-poplar could be a lasting component of this stand on a dry site, it will likely undergo self-thinning during periods of drought (Hilt 1985). Prescribed burning can reduce stem density of juvenile yellow poplar (Barnes and VanLear 1998), but as the stand matures, wildland fire could be more harmful to oaks, particularly scarlet oak (*Q. coccinea*), than to yellow-poplar

(Brose and VanLear 1999, Nelson and others 1933), probably because of differences in bark thickness (Hare 1965).

The pattern of pine survival resulting from the row planting could be a factor influencing variation of their size, which ranged from 2 to 8 cm d.b.h. In the only sample subplot where two planted shortleaf pines were inventoried, their d.b.h. differed by 3 cm. The smaller of the two inventoried pines was solitary, but the other (larger) was near several other planted pines outside of the sample plot boundary, which collectively formed a small group of crown-touching trees. All pines in the group appeared larger than other nearby pines occurring singly. Casual observations elsewhere in the study area revealed a similar apparent greater size of trees in groups compared to those occurring as single trees surrounded by hardwoods. Detailed study appears warranted of this apparent size difference associated with intraspecific competition among pines in groups.

CONCLUSION

Reduction of wildland fire in the Southern Appalachians during the early 1900s has resulted in a lack of southern yellow pine reproduction and increasing loss of tree species diversity in mixed hardwood stands on dry ridges. Results from this study show that a conifer component can be restored on dry ridge sites by clearcut harvesting small patches (<0.5 ha) in mixed hardwood stands and planting pitch or shortleaf pines. Although herbicide was used for site preparation to reduce sprouting of undesirable species in this study, it may not be necessary if the objective is to establish a minor component of yellow pines for biodiversity rather than a high density of pines for management.

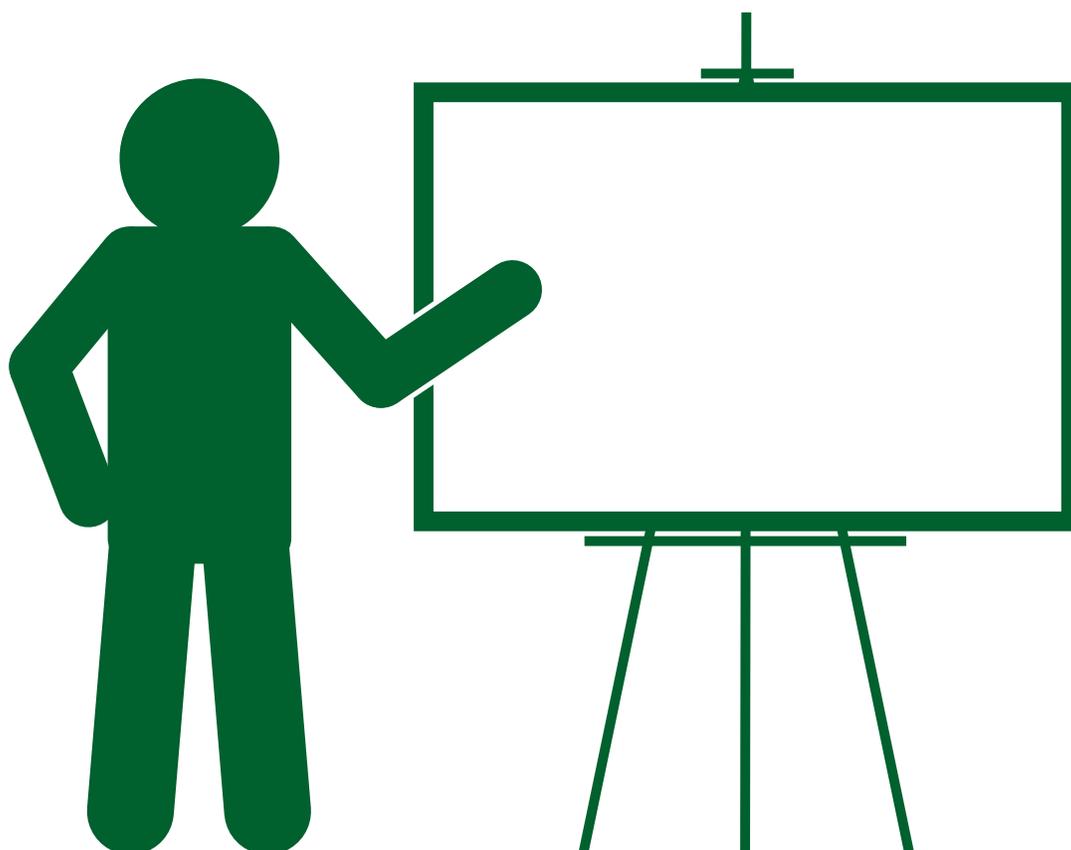
ACKNOWLEDGMENTS

David Loftis suggested locating this demonstration study next to an abandoned logging road as partial justification for its reconstruction to allow vehicular access by visiting university classes. Ted Oprean designed the harvested area following the Forest Service stand regeneration guidelines. Funding was provided by the Forest Service, Southern Research Station. The findings and conclusions in this publication are those of the author and should not be construed to represent any official USDA or U.S. Government determination or policy. This article was written and prepared by a U.S. Government employee on official time, and it is therefore in the public domain. I thank Ted Oprean and Erik Berg for reviewing an earlier draft of this manuscript.

REFERENCES

- Baker, J.B.; Cain, M.D.; Guldin, J.M. [and others]. 1996. Uneven-aged silviculture for loblolly and shortleaf pine forest cover types. Gen. Tech. Rep. SO-118. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 65 p.
- Barden, L.S.; Woods, F.W. 1976. Effects of fire on pine and pine-hardwood forests in the Southern Appalachians. *Forest Science*. 22(4): 399–403.
- Barnes, D.A.; VanLear, D.H. 1998. Prescribed fire effects on advanced regeneration in mixed hardwood stands. *Southern Journal of Applied Forestry*. 22(3): 138–142.
- Barnett, J.P. 2014. Direct seeding southern pines: history and status of a technique developed for restoring cutover forests. Gen. Tech. Rep. SRS-187. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 35 p.
- Beck, D.E.; Della-Bianca, L. 1981. Yellow-poplar: characteristics and management. Agric. Handb. 583. Washington, DC: U.S. Department of Agriculture Forest Service. 92 p.
- Brose, P.; VanLear, D. 1999. Effects of seasonal prescribed fires on residual overstory trees in oak-dominated shelterwood stands. *Southern Journal of Applied Forestry*. 23(2): 88–93.
- Clabo, D.; Clatterbuck, W. 2020. Restoration of shortleaf pine (*Pinus echinata*)-hardwood mixtures in low quality mixed upland hardwood stands using cluster planting and natural regeneration. *Forests*. 11(4): 457–475. <https://doi.org/10.3390/f11040457>.
- Clabo, D.; Clatterbuck, W.K. 2015. Site preparation techniques for the establishment of mixed pine-hardwood stands: 22-year results. *Forest Science*. 61(4): 790–799.
- Clark, F.B.; Boyce, S.G. 1964. Yellow-poplar seed remains viable in the forest litter. *Journal of Forestry*. 62: 564–567.
- DeVivo, M.S. 1991. Indian use of fire and land clearance in the Southern Appalachians. In: Nodvin, S.C.; Waldrop, T.R., eds. *Fire and the environment: ecological and cultural perspectives*. Gen. Tech. Rep. SE-69. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station: 306–312.
- Eddleman, W.R.; Clawson, R.L.; Eberly, J. 2007. Birds of shortleaf pine forests in Missouri: an historical and contemporary perspective. In: Kabrick, J.M.; Dey, D.C.; Gwae, D., eds. *Shortleaf pine restoration and ecology in the Ozarks: proceedings of a symposium; 2006 November 7–9; Springfield, MO*. Gen. Tech. Rep. NRS-15. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station: 168–175.
- Elliott, K.J.; Boring, L.R.; Swank, W.T.; Haines, B.R. 1997. Successional changes in plant species diversity and composition after clearcutting a Southern Appalachian watershed. *Forest Ecology and Management*. 92: 67–85.
- Elliott, K.J.; Vose, J.M. 2005. Effects of understory prescribed burning on shortleaf pine (*Pinus echinata* Mill.)/mixed-hardwood forests. *The Journal of the Torrey Botanical Society*. 132: 236–251.
- Elliott, K.J.; Vose, J.M.; Knoepp, J.D.; Clinton, B.D. 2012. Restoration of shortleaf pine (*Pinus echinata*)-hardwood ecosystems severely impacted by the southern pine beetle (*Dendroctonus frontalis*). *Forest Ecology and Management*. 274: 181–200.
- Engle, L.G. 1960. Yellow-poplar seedfall pattern. Station Note 143. Columbus, OH: U.S. Department of Agriculture Forest Service, Central States Forest Experiment Station. 2 p.
- Fei, S.; Steiner, K.C. 2009. Rapid capture of growing space by red maple. *Canadian Journal of Forest Research*. 39: 1444–1452.
- Guldin, J.M.; Black, M.W. 2018. Restoration of shortleaf pine in the Southern United States—strategies and tactics. In: Kirschman, J.E., comp. *Proceedings of the 19th biennial southern silvicultural research conference*. e-Gen. Tech. Rep. SRS-234. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 281–287.
- Hare, R.C. 1965. Contribution of bark to fire resistance of Southern trees. *Journal of Forestry*. 63: 248–251.
- Harmon, M.E. 1982. Fire history of the westernmost portion of the Great Smoky Mountains National Park. *Bulletin of the Torrey Botanical Club*. Torrey Botanical Society: 109: 74–79.
- Hilt, D. 1985. Where has all my yellow-poplar gone? *Northern Journal of Applied Forestry*. 2: 67–69.
- Jenkins, M.A. 2007. Vegetation communities of Great Smoky Mountains National Park. *Southeastern Naturalist*. 6: 35–56.
- Kochenderfer, J.D.; Kochenderfer, J.N.; Miller, G.W. 2012. Manual herbicide application methods for managing vegetation in Appalachian hardwood forests. Gen. Tech. Rep. NRS-96. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station. 59 p.
- Leland, C.; Hom, J.; Skowronski, N. [and others]. 2016. Missing rings, synchronous growth, and ecological disturbance in a 36-year pitch pine (*Pinus rigida*) provenance study. *PLoS ONE*. 11(5): e0154730. <https://doi.org/10.1371/journal.pone.0154730>.
- Masters, R.E. 2007. The importance of shortleaf pine for wildlife and diversity in mixed oak-pine forests and in pine-grassland woodlands. In: Kabrick, J.M.; Dey, D.C.; Gwae, D., eds. *Shortleaf pine restoration and ecology in the Ozarks: proceedings of a symposium; 2006 November 7–9; Springfield, MO*. Gen. Tech. Rep. NRS-15. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station: 35–46.
- Nelson, R.M.; Simms, I.H.; Abell, M.S. 1933. Basal fire wounds on some Southern Appalachian hardwoods. *Journal of Forestry*. 31(7): 829–837.
- Nesbitt, W.A. 1941. History of early settlement and land use on the Bent Creek Experimental Forest, Buncombe County, NC. Unpublished paper. 78 p. On file with: U.S. Department of Agriculture Forest Service, Southern Research Station, Bent Creek Experimental Forest, 1577 Brevard Rd., Asheville, NC 28806.
- O’Keefe, J.M.; Loeb, S.C. 2017. Indiana bats roost in ephemeral, fire-dependent pine snags in the Southern Appalachian Mountains, USA. *Forest Ecology and Management*. 391: 264–274.
- Phillips, D.R.; Abercrombie, J.A., Jr. 1987. Pine-hardwood mixtures—a new regeneration concept. *Southern Journal of Applied Forestry*. 11(4): 192–197.
- R Core Team. 2020. A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. <https://www.R-project.org/>. [Date accessed: August 5, 2021].
- Schnake, D.K.; Roberts, S.D.; Willis, J.L. [and others]. 2021. Overstory retention and stock type impact survival and growth of underplanted shortleaf pine beneath a hardwood canopy. *Forest Science*. 67(2): 219–230.
- Shelton, M.G.; Murphy, P.A. 1992. Pine regeneration and understory vegetation 1 year after implementing uneven-aged silviculture in pine-hardwood stands of the silty uplands of Mississippi. In: Brissette, J.C., comp. *Proceedings of the seventh biennial southern silvicultural research conference 1992 November 17–19, 1992; Mobile, AL*. Gen. Tech. Rep. SO-93. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station: 333–341.
- Shure, D.J.; Phillips, D.L.; Bostick, P.E. 2006. Gap size and succession in cutover Southern Appalachian forests: an 18-year study of vegetation dynamics. *Plant Ecology*. 185: 299–318.
- Vose, J.M.; Swank, W.T.; Clinton, B.D. [and others]. 1999. Using stand-replacement fires to restore Southern Appalachian pine-hardwood ecosystems: effects on mass, carbon, and nutrient pools. *Forest Ecology and Management*. 114: 115–126.
- Welsch, N.T. 1999. Occurrence of fire in Southern Appalachian yellow pine forests as indicated by macroscopic charcoal in soil. *Castanea*. 64(4): 310–317.
- Zedaker, S.M.; Lewis, J.B.; Smith, D.W.; Kreh, R.E. 1987. Impact of season of harvest and site quality on cut-stump treatment of Piedmont hardwoods. *Southern Journal of Applied Forestry*. 11(1): 46–49.

Poster Sessions



HEDONIC ANALYSIS OF LOBLOLLY PINE PLANTATION FIRST THINNING COSTS

T. Eric McConnell

ABSTRACT

Revenues from pine plantation harvests have increasingly struggled to adequately support the wood supply system. A model was developed to better understand how three timber tract characteristics—acreage, site index, and trees planted per acre—can affect loblolly pine plantation first thinning costs. A growth and yield model provided yield data when basal area reached 110 square feet per acre. The Auburn Harvest Analyzer determined harvest system costs for multiple tract sizes. Variable stand ages at thinning required converting costs to equivalent annual costs (EAC), \$/ton per year. The cost implicitly associated with each independent variable was calculated from the predicted EAC when holding all predictors at their mean levels, which was \$3.16/ton per year. Each 10-foot increment of site index added \$0.43 to system EAC. Planting 10 additional trees at stand establishment increased system EAC \$0.03. Conversely, EAC was reduced by \$0.76 for each additional 10 acres of tract size. Managers can use these findings to better gauge the relationship between physical attributes of timber stands and the prices payable for standing timber.

INTRODUCTION

Long-term cost reductions driven by increased productivity and technical efficiencies in the logging industry ended in the 1990s, with costs subsequently trending upward since that time (Baker and others 2014, Cubbage and others 1988, Dodson and others 2015). Harvest systems in the U.S. South generally consist of varying quantities of rubber-tired feller bunchers, grapple skidders, and trailer-mounted loaders. Tractor trucks and trailers hauling timber products to wood-using mills may be company owned or contracted for their services from independent firms. Each piece of in-woods equipment previously listed can easily eclipse \$100,000 each, and equipment investments exceeding \$1 million is a norm rather than an exception.

Logging costs ultimately impact the prices paid for standing timber. One logging cost estimation technique assesses a system's productivity via time and motion study, where a value is then placed on that productivity (Conrad IV and Dahlen 2019). Productivity studies alone, though, cannot reveal the latent values physical attributes possess to influence harvesting costs. Tree and tract sizes are two key factors impacting logger productivity and costs (Cubbage and others 1989). The former is linked to the typical increase in production, and the latter is related to economies of forest tract size in operations. An alternative perspective considers the values the market places on these and other timber sales characteristics because the timber market will consider

adjustments resulting from the levels of these factors (Munn and Palmquist 1997).

The hedonic function is well suited to discovering the characteristic values that comprise a forest-based product or service that themselves may not possess a market derived worth. Kennedy and others (2011) assessed north Louisiana timberland values, finding paved road access (+), distance from a city (-), and the potential for future development (+) played roles in determining sale values¹. Puttock and others (1990) found stumpage prices were influenced by segregating standing volumes further according to species, scale (+), quality (+), and tract distance to mill (-). Stand volume (+) and age (+) were significant determinants of Chinese fir (*Cunninghamia lanceolata*) stumpage price (Chen and others 2020). Wood quality declines in British Columbia softwood logs were disaggregated into two effects, species mix and grade mix, and how their proportional contributions to timber product output affected final product value (Constantino and Haley 1988). Alzamora and Apiolaza (2010) concluded log scaling diameter (+), taper (-), and length between branch internodes on the values of radiata pine (*Pinus radiata*) impacted butt and upper-log values, but branch-specific variables did not.

Even though the hedonic function has wide acceptance in the forest economic literature, a gap was identified regarding its application in harvesting economics. Loblolly pine plantation first thinnings are largely composed of smaller diameter pulpwood-sized stems, although some trees do

¹ The symbols (+) and (-) denote significant positive or negative effects observed in the cited studies.

Author Information: T. Eric McConnell, Assistant Professor, Mississippi State University, Mississippi State, MS 39762.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

reach small sawtimber “chip-n-saw” size. This type of operation typically removes all trees within every fourth or fifth row, and another 20 to 25 percent are selectively removed from between the rows due to poor size, form, etc. (Dickens and Moorhead 2015). Thus, most of the value received at the mill gate is paid to cover the logger’s costs, risk, and profit. For example, the harvest margin paid to loggers for pine pulpwood in Mississippi, on average, comprises 70 percent of the mill delivered product value versus 25 percent for pine sawtimber (Norris Foundation 2020).

Loggers as a tradeoff for the first thinning’s smaller average tree size require plantations of greater acreage that increase the tract’s total harvestable volume. This is because of the large, fixed costs tied to the equipment as well as transporting it to establish the harvest operation. Foresters typically time the thinning operation to coincide with the plantation’s reaching a designated stocking benchmark. When considered from the perspective of basal area (BA), this may range from 110 to 120 square feet per acre. Two physical characteristics that impact the time required to reach this level are a tract’s site index (SI) and its stand density. A higher site-indexed tract will, all else being equal, be more productive than a lower-indexed site. Consequently, production can be regulated within each of those sites by strategically planning the number of trees per acre to plant at establishment. This study’s goal was to apply hedonic modeling techniques to study timber tract characteristics—specifically acreage, SI, and trees per acre (TPA) planted at establishment—that can influence harvesting costs for loblolly pine plantation first thinnings.

METHODS

The Cutover Loblolly Growth and Yield Model (CoLob) (Matney 1996) provided timber yield data for the following tract variables and levels: SI (60, 65, 70, 75, and 80 feet at 25 years) and TPA (485, 585, and 685) at establishment. Thinning occurred only when stand BA surpassed 110 square feet per acre and yields of at least 25 tons per acre would result from harvesting every fifth row coupled with selective thinning of lower-sized classes between the harvested rows. Fifth row thinning was selected over more aggressive row removals because of the better quality that will result from selectively thinning over more TPA (Harrington 2001). Loblolly pine density outside bark was assumed as 63 pounds per cubic foot (Miles and Smith 2009). Remaining BA was set to 60 square feet per acre (Gallagher and others 2017). This was deemed the minimum to maintain full stocking for timber production (Dickens and Moorhead 2015). These were consistent across all possible treatment combinations. Results from CoLob were incorporated into a spreadsheet modeled on the Auburn Harvest Analyzer (Tufts and others 1985) that provided stump-to-mill costs for a balanced system.

The harvest system consisted of two rubber-tired feller bunchers, two grapple skidders, and two trailer-mounted loaders. One operator ran each machine along with one foreman on site. Machine rates were calculated using equipment costs obtained from a regional John Deere dealer of \$365,000 for the feller bunchers (John Deere 843L-II), \$365,000 for the skidders (John Deere 748L-II), and \$322,000 for the loaders (John Deere 437E). Operator wages were \$17 per hour (U.S. Department of Labor Bureau of Labor Statistics 2019) plus 45-percent fringe benefits. Machine availabilities were assumed to be a constant 90 percent as were operator efficiencies.

The feller bunchers were assumed to possess a capacity 5.2 square feet of area. Average skid distance was set to 400 feet. Average turn tonnage was set to center around 2.85 tons for the skidders, with variation around that value due to the treatment combinations’ mean tree weights by diameter class, which were determined at the time of thinning (Holtzschler and Lanford 1997). Four minutes of prep time was assumed for the loaders. Haul costs were based on the first quarter 2020 incremental haul rate published by Timber Mart-South for the U.S. South, \$0.15/ton per loaded mile (Norris Foundation 2020). Payload and distance were held constant at 27 tons and 50 miles, respectively. Moving time (4 hours) and distance (40 miles) were held constant. Unit costs, \$/ton, were calculated and recorded for each treatment combination.

Stand ages at the designated thinning times differed due to the variables analyzed (table 1). As SI and TPA increased, time to thinning decreased. A preliminary model that included age as a predictor returned high variance inflation factors for that variable, SI, and TPA. Therefore, costs at each factor and level combination were instead converted to their respective equivalent annual cost (EAC) at the time of thinning (years) so valid comparisons could be performed using equation 1

$$EAC = C_t * \frac{R(1+R)^t}{(1+R)^t - 1} \quad (1)$$

where

EAC is equivalent annual cost of the first thinning’s system costs (fell, skid, load, and haul); C is the first thinning’s system costs at thinning time; t is thinning time; and R is the real discount rate. The level of R was set to a constant 10-percent rate, which approximated the percent residual after subtracting historic logging costs and stumpage from pine pulpwood delivered price in Louisiana and Mississippi (McConnell 2020). Tract size was studied at six levels (P: 25, 50, 100, 250, 500, and 1,000 acres).

Table 1—Stand age at first thinning for the site index and trees planted per acre at establishment treatment combinations

Site index	Trees per acre	Age at first thinning years
60	485	28
60	585	22
60	685	19
65	485	22
65	585	19
65	685	17
70	485	19
70	585	16
70	685	15
75	485	17
75	585	14
75	685	13
80	485	15
80	585	13
80	685	12

The hedonic model's form was equation 2 (Hussain and others 2013, Kennedy and others 2011)

$$\ln EAC = \ln \beta_0 + \beta_1 \ln P + \beta_2 SI + \beta_3 TPA + \varepsilon \quad (2)$$

where

SI is modeled as a continuous variable, TPA is a discrete variable, ε is the error terms, and $\beta_0, \beta_1, \beta_2, \beta_3$ are model parameters. Tract size P was logged due to the intuitively nonlinear between P and EAC (Cubbage 1983). As P increased from the smallest tract size, average EAC decreased at a greater rate before leveling off at the highest levels of P , which was similar to results seen in land valuation studies (Hussain and others 2013, Kennedy and others 2011). Normality was tested using the Shapiro-Wilk test. Heteroskedasticity was examined using the Breusch-Pagan test.

Marginal implicit costs for each independent variable were determined at the predicted EAC from equation 2 when the independent variables were entered at their mean levels (Hussain and others 2013). The regression coefficients of tract size and SI (equations 3 and 4) represented their marginal costs and were multiplied by average EAC . The earlier transformation of the tract size to its natural logarithm required adjusting the model coefficient for tract size in equation 3 by one over the average tract size across all observations (Hussain and others 2013, Kennedy and others 2011). The discrete nature of TPA required an error adjustment per equation 5 (Hussain and others 2013), where the term was one-half of the standard error associated with the coefficient

$$ImpP_{EAC} = \widehat{\beta}_1 / \bar{P} * \widehat{EAC} \quad (3)$$

$$ImpSI_{EAC} = \widehat{\beta}_2 * \widehat{EAC} \quad (4)$$

$$ImpTPA_{EAC} = \left[e^{\left(\widehat{\beta}_3 - \frac{S\beta_3}{2} \right)} - 1 \right] * \widehat{EAC} \quad (5)$$

RESULTS AND DISCUSSION

Average system costs at the time of thinning and their EAC s are provided in table 2 at each level of the independent variables. As mentioned previously, system costs decreased with tract size, therefore EAC decreased as well. A higher level of SI led to an increasing average EAC , but the trend was interestingly not consistent. This was due to improved site conditions that promoted tree growth, which allowed the stand to reach the target BA at an earlier age. Higher levels of TPA at establishment were associated with higher average EAC s. While the targeted stand BA was reached at earlier ages for increasing levels of SI and TPA in CoLab, the tree of average BA was smaller at higher levels of SI and TPA than at lower levels. However, total stand volume in those cases was greater.

Table 2—Average system costs, \$/ton, and equivalent annual costs, EAC \$/ton per year, at the various levels of independent variables

P	Average system costs \$/ton	Average EAC , \$/ton per year
25	\$34.34	\$4.36
50	\$28.01	\$3.56
100	\$24.70	\$3.14
250	\$22.61	\$2.87
500	\$21.80	\$2.77
1,000	\$21.35	\$2.71
SI	Average system costs \$/ton	Average EAC , \$/ton per year
60	\$24.39	\$2.78
65	\$24.99	\$2.99
70	\$25.80	\$3.26
75	\$26.57	\$3.56
80	\$25.59	\$3.58
TPA	Average system costs \$/ton	Average EAC , \$/ton per year
485	\$23.87	\$2.86
585	\$25.54	\$3.27
685	\$26.99	\$3.58

Equation 1 was applied to calculate EAC .

EAC = equivalent annual costs; P = logged tract size; SI = site index; TPA = trees per acre at establishment.

Table 3—Hedonic regression results, where the dependent variable was logged equivalent annual harvesting costs EAC, and marginal implicit costs associated with the independent variables

Independent variables	Coefficient	Standard error	t Statistic	p-value	Predicted EAC at mean P, SI, and TPA	Marginal implicit cost	10-unit incremental cost
Intercept	0.1416	0.0893	1.5849	0.1167			
P	-0.1220	0.0054	-22.5728	< 0.0001		-\$0.08	-\$0.76
SI	0.0138	0.0010	14.0309	< 0.0001	\$3.16/ton/year	\$0.04	\$0.43
TPA	0.0011	0.0001	13.3478	< 0.0001		< \$0.01	\$0.03

P = logged tract size; SI = site index; TPA = trees per acre.

Independent variables are logged tract size P, site index SI, and trees per acre at establishment TPA.

The marginal implicit cost represents the monetary value one unit of an independent variable carries at the predicted EAC when all predictors are at their mean levels.

The 10-unit incremental cost is the marginal implicit cost multiplied by 10.

Regression normality ($W = 0.9854, p = 0.4138$) was satisfied; the constant variance assumption ($F_{3,86} = 3.8288, p = 0.0126$) was not deemed extreme. The results are provided in table 3. The SI produced the greater positive influence statistically ($t = 14.0309, p < 0.0001$) followed by TPA ($t = 13.3478, p < 0.0001$). Tract size P was the lone variable to possess a negative effect on equivalent annual thinning costs ($t = -22.5728, p < 0.0001$). Additional findings included adjusted $R^2 = 0.9083$, Akaike Information Criterion = -485.9130 (lower is better), and variance inflation factors equal to 1.0000.

Marginal implicit costs were calculated based upon the predicted EAC when all independent variables are measured at their mean levels, which was \$3.16/ton per year². The marginal implicit cost is an estimate of how EAC changes, given a unit change in tract size, SI, or TPA per acre at establishment. A characteristic that exhibits a positive marginal implicit cost indicates that increasing that variable's level subsequently raises the per ton harvesting cost of loblolly pine plantation first thinnings. For example, increasing pine plantation acreage by a 1-acre lowered EAC by 8 cents, holding other factors constant. Marginal implicit costs ranged from -\$0.08/ton per year for P to \$0.04/ton per year for SI. Thought of another way, incremental implicit costs are provided in table 3 at 10-unit intervals. Each 10-foot increment of SI at 25 years thus increased average EAC by \$0.43/ton per year, while EAC rose \$0.03/ton per year due to planting 10 additional trees at stand establishment. Conversely, each additional 10 acres reduced EAC by -\$0.76/ton per year.

This study was a first step to differentiating the costs that timber stand characteristics carry for loggers. The reader should be aware these data were simulated; they were not obtained completely random. Therefore, the regression only provided indications of relationships. Similar type analyses will be conducted by studying other species and compositions, timber product and log-quality mixes, along with additional tract characteristics for different

types of forest operations. Perhaps by including additional characteristics, stand age can be incorporated into future analyses as well. Moreover, the challenging southern pine timber market in recent years has led some to consider greater thinning intensities that boost individual tree growth, so sawtimber size requirements are reached at earlier stand ages. Huang and Kronrad (2004) concluded a pine sawtimber price premium would be required in many of their hypothesized scenarios for an aggressive, low-density management regime to be financially feasible. This was due to the additional pruning operation required to maintain tree quality that impacted the net present value of the forest investment. A second stage bid function would be needed to understand this and other economic considerations. Future efforts intend to build on this concept.

Still, the results trended in expected directions as past logging cost studies (Cubbage and others 1989). As tree size, volume per acre, tract size, and total volume increased, EAC decreased. The contribution of this work to the literature went beyond hypothesis testing and system cost prediction by placing market derived costs on loblolly pine plantation characteristics. Like Branman and others (1981), this study demonstrated hedonic modeling can provide measures of change in harvesting cost due to the variability of a differentiated product's physical attributes, which in this case was a logging operation. Logging and forest managers can use this study to better gauge the relationship between timber stands' physical characteristics, the costs required to harvest and haul to market, and ultimately the prices payable for pine plantation first thinnings in their market regions.

² This equated to an actual cost of \$24.72/ton.

ACKNOWLEDGMENTS

This publication is a contribution of the Forest and Wildlife Research Center at Mississippi State University. This material is based upon work that is supported by the U.S. Department of Agriculture, National Institute of Food and Agriculture, McIntire-Stennis project under accession number 1025007. Bruno Kanieski da Silva, Brady Self, Shaun Tanger, and Curtis VanderSchaaf kindly reviewed earlier versions of this manuscript.

REFERENCES

- Alzamora, R.M.; Apiolaza, L.A. 2010. A hedonic approach to value *Pinus radiata* log traits for appearance-grade lumber production. *Forest Science*. 56(3): 281–289.
- Baker, S.A.; Mei, B.; Harris, T.G.; Greene, W.D. 2014. An index of logging cost changes across the U.S. South. *Journal of Forestry*. 112(3): 296–301.
- Branman, L.; Buongiorno, J.; Fight, R. 1981. Quality adjusted price indices for Douglas-fire timber. *Western Journal of Agricultural Economics*. 259–272.
- Chen, H.; He, Z.; Hong, W.; Liu, J. 2020. An assessment of stumpage price and index of Chinese fir timber forests in southern China using a hedonic price model. *Forests*. 11(4): 36.
- Conrad IV, J.L.; Dahlen, J. 2019. Productivity and cost of processors in whole-tree harvesting systems in southern pine stands. *Forest Science*. 65(6): 767–775.
- Constantino, L.F.; Haley, D. 1988. Trends in wood quality for the British Columbia coast and the United States Pacific Northwest, Westside. *Forest Science*. 34(1): 176–189.
- Cubbage, F. 1983. Tract size and harvesting costs in southern pine. *Journal of Forestry*. 81(7): 430–433, 478.
- Cubbage, F.W.; Greene, W.D.; Lyon, J.P. 1989. Tree size and species, stand volume, and tract size: effects on southern harvesting costs. *Southern Journal of Applied Forestry* 13(3): 145–152.
- Cubbage, F.W.; Stokes, B.J.; Granskog, J.E. 1988. Trends in southern forest harvesting equipment and logging costs. *Forest Products Journal*. 38(2): 6–10.
- Dickens, E.D.; Moorhead, D.J. 2015. A guide to thinning pine plantations. Georgia Forest Productivity Publication Series. Publication number 0010. Athens, GA: University of Georgia. 13 p.
- Dodson, E.; Hayes, S.; Meek, J.; Keyes, C.R. 2015. Montana logging machine rates. *International Journal of Forest Engineering*. 26(2): 85–95.
- Gallagher, T.V.; Kantavichai, R.; Teeter, L.D. 2017. An economic analysis of incorporating biomass thinning into loblolly pine plantations in Alabama. *Open Journal of Forestry*. 7(2): 172–187.
- Harrington, T.B. 2001. Silvicultural approaches for thinning southern pines: method, intensity, and timing. Publication number FSP002. Macon, GA: Georgia Forestry Commission. 17 p.
- Holtzschner, M.A.; Lanford, B.L. 1997. Tree diameter effects on cost and productivity of cut-to-length systems. *Forest Products Journal*. 47(3): 25–30.
- Huang, C.-H.; Kronrad, G.D. 2004. Economic analysis of pruning and low-density management compared to traditional management of loblolly pine plantations in east Texas. *Southern Journal of Applied Forestry*. 28(1): 12–20.
- Hussain, A.; Munn, I.A.; Brashier, J. [and others]. 2013. Capitalization of hunting lease income into northern Mississippi forest land values. *Land Economics*. 89(1): 137–153.
- Kennedy, G.A.; Vandever, L.R.; Henning, S.A. [and others]. 2011. Estimating tract value relationships in the north Louisiana timberland market. *Southwestern Economic Review*. 29: 123–134.
- Matney, T. 1996. Cutover loblolly plantation growth and yield model. Mississippi State, MS: Mississippi State University, Forest and Wildlife Research Center. <https://www.fwrc.msstate.edu/software.php>. [Date accessed: July 12, 2020].
- McConnell, E. 2020. Timber price trends for western Gulf States. 20 p. Unpublished data. On file with: Mississippi State University, 75 B.S. Hood Road, Mississippi State, MS 39762.
- Miles, P.D.; Smith, W.B. 2009. Specific gravity and other properties of wood and bark for 156 tree species found in North America. Res. Note NRS-38. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station. 35 p.
- Munn, I.A.; Palmquist, R.B. 1997. Estimating hedonic price equations for a timber stumpage market using stochastic frontier estimation procedures. *Canadian Journal of Forest Research*. 27: 1276–1280.
- Norris Foundation. 2020. Timber Mart-South quarterly price data for Mississippi. Athens, GA: University of Georgia. 15 p.
- Puttock, G.D.; Prescott, D.M.; Meilke, K.D. 1990. Stumpage prices in Southwestern Ontario: a hedonic function approach. *Forest Science*. 36(4): 1119–1132.
- Tufts, R.A.; Lanford, B.L.; Greene, W.D.; Burrows, J.A. 1985. Auburn harvesting analyzer. *Compiler*. 3(2): 14–15.
- U.S. Department of Labor Bureau of Labor Statistics. 2019. Occupational employment statistics. <https://www.bls.gov/oes/home.htm>. [Date accessed: July 15, 2020].

PROBABILISTIC ESTIMATES OF COSTS FOR TREATING SOUTHERN PINE BEETLE INFESTATIONS BY CUT-AND-LEAVE SUPPRESSION MEASURES DURING AN OUTBREAK

Curtis L. VanderSchaaf, T. Eric McConnell, Michael K. Crosby, Jason J. Holderieath, James R. Meeker, Chris A. Steiner, Brian Strom, Crawford (Wood) Johnson

ABSTRACT

The Bienville National Forest (BNF) in central Mississippi was affected by a southern pine beetle (SPB; *Dendroctonus frontalis* Zimmermann) outbreak between 2015 and 2019. In 2017, cut-and-leave treatments were applied to many of the actively enlarging infestations within the forest in an attempt to mitigate the spread and damages due to SPB. Contractors treated 330 different spots on the BNF (out of a total of 1,660 recorded SPB spots, or approximately 20 percent of all spots), at an average cost of \$645 per acre. The spot and cost data were obtained in an effort to provide a probabilistic assessment of cut-and-leave treatment costs for the forest. A two-parameter Weibull distribution was ultimately selected to model the probabilities of observing a particular spot size. The spot size-density probabilities from 2017 can be combined with an estimate of the likely total number of SPB infestation spots, and an estimate of per unit (e.g., acre) treatment costs, to estimate the total treatment cost for a particular region within a desired length of time. This information could be used to inform cost estimates for planning and mitigation efforts for future outbreaks on this or comparable forests.

INTRODUCTION

The southern pine beetle (SPB), (*Dendroctonus frontalis* Zimmermann), is the most destructive insect pest of pine in the Southern United States (Duerr and Mistretta 2013). Pye and others (2011) state SPB outbreaks occurred, on average, every 5 to 10 years from 1977 to 2004, while others report slightly shorter intervals of every 5 to 7 years beginning in the 1960s up to the 1990s (Asaro and others 2017, Clarke and Nowak 2009). The last widespread outbreak occurred in the late 1990's and early 2000's (e.g., Oswalt and others 2016). These beetles are short-legged, stout, and about one-eighth inch long (Frank and others 2019) and occur in a generally continuous distribution across the Southern and Southeastern United States, roughly coinciding with the distribution of loblolly pine (*Pinus taeda* L.). Its range extends from New Jersey to Florida to Texas to Illinois (Clarke and Nowak 2009). Southern yellow pines are the primary hosts of SPB (Duerr and Mistretta 2013). Shortleaf (*Pinus echinata* Mill.), loblolly, Virginia (*Pinus virginiana* Mill.), and pitch (*Pinus rigida* Mill.) pines appear to be the preferred hosts. SPB

usually attack trees that are at least 15 years old. The SPB must kill its host pines to reproduce, and attacks trees *en masse*.

Pye and others (2011) reported short-run impacts to timber producers around \$1.2 billion, or about \$43 million per year from the 1980s to 2010. While SPB geographic "hotspots" are found annually in local areas and woodsheds, the last widespread outbreak in the late 1990's and early 2000's (e.g., Oswalt and others 2016) resulted in an estimated \$1.5 billion dollars of economic damage (Clarke and Nowak 2009, Duerr and Mistretta 2013). The volume of timber killed annually by SPB from 1973 through 2004 ranged from 3 to 417 million cubic feet (Pye and others 2011). They show there have been eight outbreaks of varying intensity from 1973 to 2003, each geographically spanning only portions of the region.

Mississippi has a comprehensive program for SPB prevention (Kushla and others 2019) that includes educational efforts and thinning cost shares. Kushla and others (2019) essentially estimated that this SPB outbreak prevention program can have around a \$5.5 to 12.0-million-dollar impact annually on the economy. This program is in conjunction with the Southern Pine Beetle Prevention Program (SPBPP) (a joint

Author Information: Curtis L. VanderSchaaf, Assistant Professor, Mississippi State University, Raymond, MS 39154; T. Eric McConnell, Assistant Professor, Mississippi State University, Mississippi State, MS 39762; Michael K. Crosby, Assistant Professor, Louisiana Tech University, Ruston, LA 71272; Jason J. Holderieath, Assistant Professor, Louisiana Tech University, Ruston, LA 71272; James R. Meeker, Entomologist, U.S. Department of Agriculture, Forest Service, Southern Research Station, Pineville, LA 71360; Chris A. Steiner, Biological Science Technician, U.S. Department of Agriculture, Forest Service, Southern Research Station, Pineville, LA 71360; Brian Strom, Research Entomologist, U.S. Department of Agriculture, Forest Service, Southern Research Station, Pineville, LA 71360; and Crawford (Wood) Johnson, Entomologist, U.S. Department of Agriculture, Forest Service, Southern Research Station, Pineville, LA 71360.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

effort of the Forest Service, U.S. Department of Agriculture and Southern Group of State Foresters) that is designed to encourage and provide cost-share assistance for silvicultural treatments to reduce stand and forest susceptibility to SPB.

Studies have actually proposed insuring forests to protect against loss due to SPB (Chen and others 2019). Pye and others (2011) state that southern pine forests periodically experience large SPB outbreaks somewhere in the region on relatively short cycles. Although damages southwide have not been found to exceed 8 percent of typical sawtimber or pulpwood harvests in any given year, the concentration of mortality to subregions suggests that impacts to local timber markets would be more severe. This could be true most especially for those markets containing a relatively larger amount of Forest Service national forest land (e.g., Carter and others 1991). Mississippi has had relatively minor outbreaks compared to other States, with the largest one occurring in the late 1970's and early 1980's (Pye and others 2011). Relatively smaller acreages compared to other States were infested during the last regionwide outbreak occurring in the late 1990's and early 2000's.

When beetle populations are low (endemic), attacks are generally restricted to senescent, stressed or damaged pines; however, epidemics periodically occur (Thatcher and others 1980). During epidemics, SPB infestations often begin in weakened or injured trees, but the high beetle populations can invade and overcome healthy vigorous trees by attacking in large numbers over a short period of time (Thatcher and others 1980). Widespread and severe tree mortality can occur during epidemics, SPB spots (groups of infested trees) may expand at rates up to 50 feet per day, and uncontrolled infestations may grow to thousands of acres in size (Billings 2011). SPB attacks subsequently encourage attack by other insects, including Ips bark beetles (Clarke and Hartshorn 2021) and eastern subterranean termites (Little and others 2012).

Over the last 15 to 20 years (1996–2016), major SPB outbreaks spanning more than a county/parish or two and persisting for longer than a year have largely failed to materialize across most of the Piedmont and Coastal Plain regions, where intensive pine plantation culture is most common. This has occurred despite that from the 1950s through the present day, a 20-fold increase in pine plantation area has been observed across this region (Asaro and others 2017). They believe substantial changes to the management and condition of the southern pine resource in the form of plantations that are genetically improved, younger, faster growing, less overstocked, and more fragmented is a robust explanation for regional declines in SPB outbreak activity. However, the Bienville National Forest (BNF) in central Mississippi was affected by a SPB outbreak between 2015 and 2019. Thus, as evidenced by this outbreak, SPB attacks still do occur and we as natural resource managers should expect them to occur.

In a disturbance event, response is often important to prevent further damage and impacts in a forest. In events like SPB outbreaks, resource planning for treatment and mitigation are vital to prevent additional and undesirable losses. In 2017, cut-and-leave treatments were applied to many actively enlarging infestations within the BNF that posed an imminent threat to active red-cockaded woodpecker (*Dryobates borealis*) clusters, and neighboring and susceptible private property, in an attempt to mitigate the spread of and losses due to SPB. Contractors treated 330 different spots on the BNF (out of a total of 1,660 recorded SPB spots, or approximately 20 percent of all spots), at an average cost of \$645 per acre. The treated locations on the BNF during 2017 provide prior information to leverage into a means of estimating infestation spot sizes and associated costs with future outbreaks. The majority of the treated locations are smaller in acreage, and thus skew the distribution towards smaller areas. To develop a means of estimating the likelihood of areas to be treated, the spot size and number, and the associated treatment cost, data was obtained in an effort to provide a probabilistic assessment of cut-and-leave treatment costs for the forest, this will be accomplished by testing various probability distributions and eventually employing a particular probability distribution.

METHODS

Weibull Distribution

The Weibull distribution is widely used in forestry and natural resources applications (Cao 2004, Evans and others 2019, VanderSchaaf 2015) as it is effective in the characterization of a variety of distributions of a variable of interest, in this case, SPB cut-and-leave treatment areas, or spot size. The distribution can be found by:

$$f(x) = \left(\frac{c}{b}\right) \left(\frac{x-a}{b}\right)^{c-1} \exp\left[-\left(\frac{x-a}{b}\right)^c\right] \quad (1)$$

where

x is the SPB cut-and-leave treatment area spot size (in acres) and the parameters for location (a) represents the minimum value, and scale (b) and shape (c) are often estimated using maximum likelihood estimators (MLE). The per acre cost is applied to this value to estimate the probability of treatment costs. When the location parameter (a) is set to 0 the three-parameter Weibull distribution reduces to the two-parameter Weibull distribution.

For this study, several initial attempts were conducted to fit the three-parameter Weibull distribution using maximum likelihood estimation (MLE) of the observed spot size (acres)-density relationship shown in figure 1. A variety of software was used. Additionally, the exponential distribution and

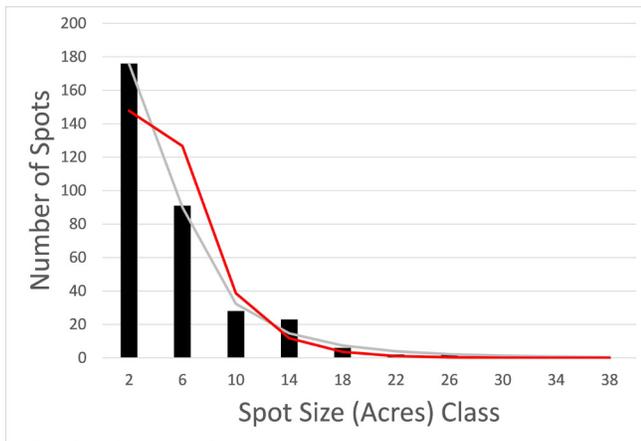


Figure 1—Observed number of southern pine beetle (SPB) cut-and-leave treated spots by size-class in acres, the two-parameter Weibull probability distribution function (PDF) as estimated using Solver in Microsoft Excel (gray curve), and a maximum likelihood estimation (MLE) exponential PDF (red curve).

a PERT-based beta distribution approach were examined. However, results were unsatisfactory, largely underpredicting the number of smaller spot sizes (acres), the exponential probability distribution function (PDF) is depicted in figure 1. Parameter estimation attempts were made by both separating the number of spots by size class (acres) into individual observations (e.g., 330 observations—hence $n = 330$) as well as just using the total number of spots within each of the 9 (hence $n = 9$) observed size (acres) classes (e.g., 2, 6, 10, 14, 18, 22, 26, 30, and 34) (fig. 1).

Thus, due to the unsatisfactory results, after initially setting the location (a) parameter to 0, the two parameter Weibull distribution was fit by using the Solver application within Microsoft Excel (2013). The scale (b) and shape (c) parameters were estimated by minimizing the sum of square errors (SSE) from the observed and predicted number of spots by area (acres) class. Similar concepts of estimating Weibull parameters by minimizing SSEs were described by Cao (2004), Cao and McCarty (2006), and Evans and others (2019), what Evans and others (2019) described as linear estimators. Parameter estimates for the Solver estimated two-parameter Weibull distribution and the exponential MLE estimates are shown in table 1 along with their associated SSEs.

Table 1—Parameter estimates of the two-parameter Weibull probability distribution function (PDF) using the Solver application within Microsoft Excel and maximum likelihood estimates (MLE) of the exponential PDF

PDF	n	Location	Scale (b)	Shape (c)	SSE
Weibull	9	-	2.959727	0.697766	95.56
Exponential	330	1.989795	3.367781	-	2,318.12

SSE = sum of square errors.
Sample sizes differ because parameters were estimated both following grouping spot sizes (acres) into groups (e.g., binning) and as separate observations.

	A	B	C	D	E	F	G	H
2	Enter number of predicted SPB spots for a given year:						1200	
3	Enter cost per treated acre:						\$200.00	
4							\$1,136,800.00	
5	Spot	Size	Cost					
6	1	2	\$400				New estimate:	1
7	2	6	\$1,200					
8	3	10	\$2,000				Spot Size Class	Number
9	4	2	\$400				(Acres)	of Spots
10	5	10	\$2,000				2	500
11	6	2	\$400				6	303
12	7	2	\$400				10	99
13	8	22	\$4,400				14	51
14	9	2	\$400				18	17
15	10	6	\$1,200				22	12
16	11	2	\$400				26	9
17	12	6	\$1,200				30	3
18	13	2	\$400				34	1
19	14	2	\$400				38	2
20	15	2	\$400				42	0
21	16	2	\$400				46	1
22	17	26	\$5,200				50	1
23	18	14	\$2,800				54	0
24	19	2	\$400				58	0
25	20	2	\$400				62	1
26	21	2	\$400				66	0
27	22	2	\$400				70	0
28	23	10	\$2,000				74	0
29	24	2	\$400				Total	1000
30	25	6	\$1,200					
31	26	2	\$400					
32	27	6	\$1,200					
33	28	10	\$2,000					
34	29	6	\$1,200					
35	30	2	\$400					
36	31	2	\$400					

Figure 2—Partial screenshot of the spreadsheet application developed using the two-parameter Weibull distribution to estimate southern pine beetle (SPB) cut-and-leave control costs for a particular region over time, in this example for a period of 1 year. Individual spot-size (acres) predictions (Columns A and B) are binned into the summary spot size (acres) classes found in cells G8:H29.

RESULTS AND DISCUSSION

The Solver estimated two-parameter Weibull distribution produced a much more meaningful and useful depiction of the likely number of treated SPB infestations by spot size (acres), including a substantial reduction in SSE as compared to the other parameter estimation techniques for the exponential (table 1) and Weibull distributions.

An Excel-based application was developed using the two-parameter Weibull distribution to estimate SPB cut-and-leave control costs for a particular region and length of time, for example, 1 year (fig. 2). Users can use the default parameter estimates presented here in table 1 or can manually change them to represent any likely amount of SPB infestations requiring cut-and-leave suppression measures by treatment acre size-class. For example, the Weibull PDF depicted in figure 1 can be modified to produce a more representative probability of treatment spot size-density distributions for a particular region and time.

Users then can enter the number of likely total SPB infestations (or spots) requiring cut-and-leave treatment for a particular

length of time (e.g., 1,660 spots annually for the BNF in 2017) and the SPB control costs per acre. The application then provides 25 estimates of the likely total treatment costs across the particular region and length of time depending on the user-specified number of likely spots requiring treatment, the estimated SPB control costs per acre, and the Weibull PDF of the likely relative amounts of SPB spot sizes (acres). The application then calculates the average estimated control costs for the region and length of time across the 25 estimates and determines the minimum and maximum estimated costs. These upper and lower cost estimates provide the user some idea of the potential range in total SPB treatment costs for cut-and-leave suppression measures.

Variability in the total cut-and-leave treatment costs is produced through the use of list sampling. List sampling involves using some type of randomization process to select observations given the probability of their occurrence (Husch and others 2003). As seen in table 2, given the estimates of the scale (*b*) and shape (*c*) parameters presented in table 1,

the probabilities of cut-and-leave treatment spot sizes (acres) can be determined. A convenient finding provided by the Weibull distribution itself is that for the scale parameter (*b*). This value approximates the 63rd percentile for the response variable (Bailey and Dell 1973). The approximate spot size located at the 63rd percentile from this study was found to be 2.96 acres (table 2).

Note, there is a greater probability of a treated spot size being 2 acres than 22 or 34 acres in size. To randomly assign a spot size (acres) to a particular spot given the probabilities in table 2, a random number between 0 and 1 can be generated, and the spot size (acres) assigned will depend on where that random number falls within the cumulative spot size probabilities (CDF) (table 2, fig. 3). Hence, there is a wider interval for assigning a value of 2 acres than 22 acres, and hence there is a greater probability of any random number from 0 to 1 falling within the 2-acre range and thus that acreage being assigned to an SPB spot. There is a 53.27 percent chance of a SPB spot treated by cut-and-leave being 2

Table 2—Number of sampled observed spots by size (acres) of cut-and-leave treatment from the Bienville National Forest (BNF) in 2017

Spot size <i>acres</i>	Observed spots <i>number</i>	CDF	Probability	Spot size acre interval
2	176	0.5327	0.5327	213.1
6	91	0.8055	0.2728	322.2
10	28	0.9035	0.0980	361.4
14	23	0.9480	0.0445	379.2
18	6	0.9705	0.0225	388.2
22	2	0.9826	0.0121	393.1
26	2	0.9895	0.0068	395.8
30	1	0.9935	0.0040	397.4
34	1	0.9959	0.0024	398.4
38	0	0.9974	0.0015	398.9
42	0	0.9983	0.0009	399.3
46	0	0.9989	0.0006	399.5
50	0	0.9992	0.0004	399.7
54	0	0.9995	0.0002	399.8
58	0	0.9997	0.0002	399.9
62	0	0.9998	0.0001	399.9
66	0	0.9998	0.0001	399.9
70	0	0.9999	0.0000	400.0
74	0	0.9999	0.0000	400.0
78	0	0.9999	0.0000	400.0

CDF = cumulative probability distribution function.

Weibull two-parameter cumulative probability distribution function (CDF) using parameter estimates given in table 1, probability distribution function (Probability) for the Weibull two-parameter estimates given in table 1, and the spot size (acres) interval, for illustrative purposes, assuming 400 spots requiring cut-and-leave treatment in a particular region and length of time, in this case 1 year.

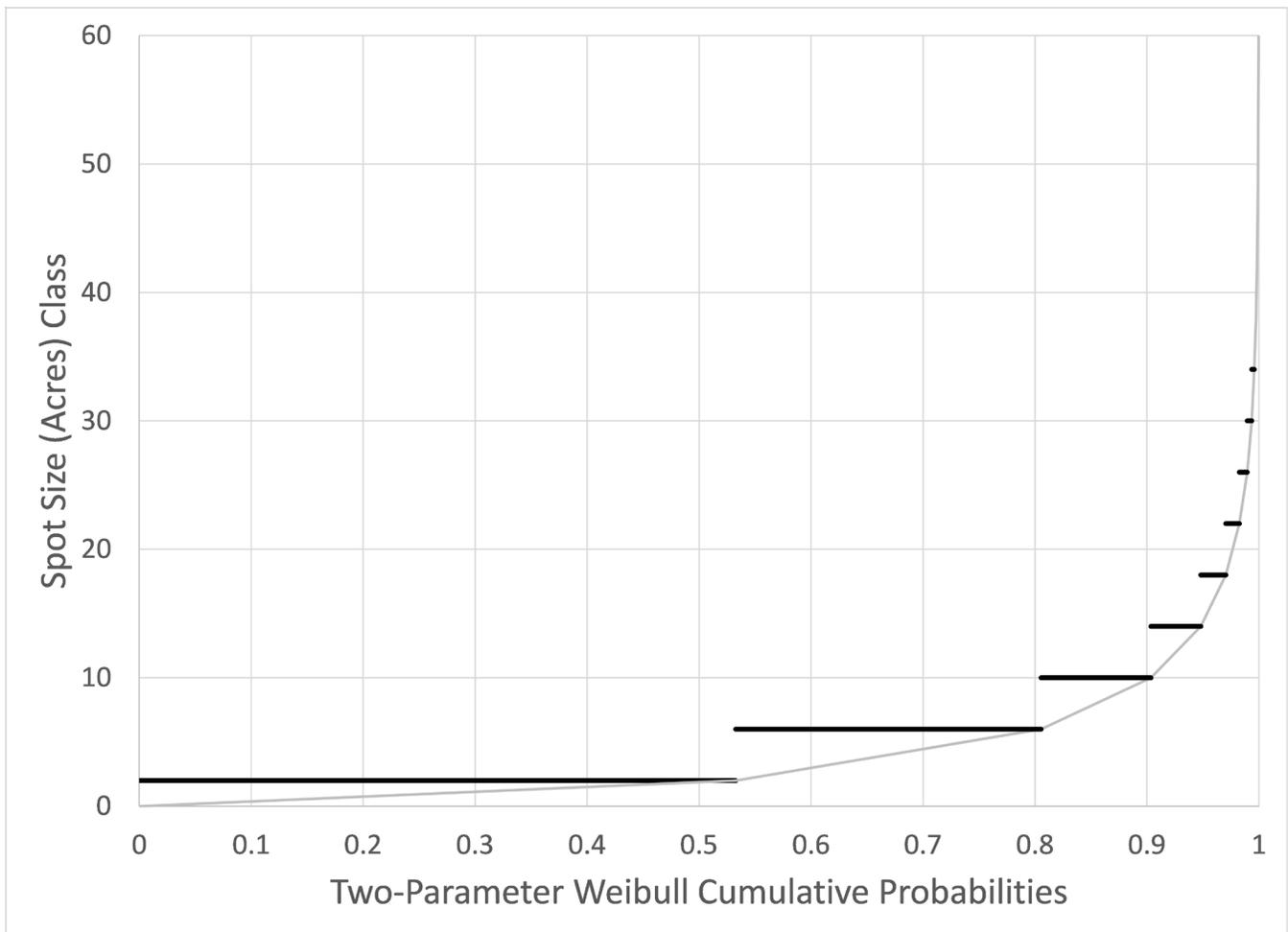


Figure 3—Two-parameter Weibull cumulative probability along with spot size (acres) assignment intervals (bold black lines). To assign an acreage to a particular future southern pine beetle (SPB) spot, a random number is generated from 0 to 1 (e.g., Rand() within Microsoft Excel), and if that random number is 0.5327 or less that SPB spot is assigned an acreage of 2 acres. If that random number is from 0.5328 to 0.8055, the SPB spot is assigned an acreage of 6 acres, and so forth. Consistent with the observed data ($n = 330$)—Table (2), a future SPB spot has a much greater probability of being assigned an acreage of 2 acres (a large interval) than being assigned an acreage of 30 acres (a small interval).

acres, while there is only a 1.21-percent chance of a similarly treated SPB spot being assigned a size of 22 acres. Thus, whenever a random number between 0 and 1 is 0.5327 or less, a SPB spot is assigned a spot size of 2 acres, while if that random number falls between 0.9706 and 0.9826 the spot is assigned an acreage of 22 acres.

Alternatively, we can multiply the 0 to 1 random number by the number of expected SPB spots requiring cut-and-leave suppression measures, for a given region within a particular length of time, and whenever that numerical product falls within a particular SPB spot size acre interval that corresponding acreage is assigned to the SPB spot. Thus, if we expect 400 spots requiring cut-and-leave treatment in the BNF in 2021, for example, we can generate 400 random numbers between 0 and 1, multiply each of the 400 random numbers by 400, and then determine what spot size acre

interval those numerical products are within to assign a spot size (acres). The spot size acre intervals correspond to the random number intervals from CDF, and the use of either approach will produce the same treated spot size acreage being assigned to a particular spot. Once again, given the current treated spot size probability distribution (tables 1 and 2, fig. 1), smaller spot sizes (acres) have a wider interval (fig. 3) and hence should be assigned a greater number of times to SPB spots.

As stated earlier, users can alter the spot size (acres) probability distribution in the Excel application if desired, to better tailor the estimates to their particular region of interest and length of time. The Excel application will automatically adjust spot size (acres) assignments.

LITERATURE CITED

- Asaro, C.; Nowak, J.T.; Elledge, A. 2017. Why have southern pine beetle outbreaks declined in the southeastern U.S. with the expansion of intensive pine silviculture? A brief review of hypotheses. *Forest Ecology and Management*. 391: 338–348.
- Bailey, R.L.; Dell, T.R. 1973. Quantifying diameter distributions with the Weibull function. *Forest Science*. 19(2): 97–104.
- Billings, R.F. 2011. Mechanical control of southern pine beetle infestations. In: Coulson, R.N.; Klepzig, K.D., eds. *Southern Pine Beetle II*. Gen. Tech. Rep. SRS-140. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 512 p.
- Cao, Q.V. 2004. Predicting parameters of a Weibull function for modeling diameter distribution. *Forest Science*. 50: 682–685.
- Cao, Q.V.; McCarty, S.M. 2006. New methods for estimating parameters of weibull functions to characterize future diameter distributions in forest stands. Gen. Tech. Rep. SRS-92. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 338–340.
- Carter, D.R.; O’Laughlin, J.; McKinney, C. 1991. Southern pine beetle impacts and control policy in the 1982-1986 Texas epidemic. *Southern Journal of Applied Forestry*. 15(3): 145–153.
- Chen, X.; Goodwin, B.K.; Prestemon, J.P. 2019. How to fight against southern pine beetle epidemics: An insurance approach. *Canadian Journal of Agricultural Economics/Revue canadienne d’agroeconomie*. 67(2): 193–213. <https://doi.org/10.1111/cjag.12186>.
- Clarke, S.R.; Hartshorn, J. 2021. Contrasting competitor and predator responses to a short-lived southern pine beetle outbreak: A case study. *Forest Science*. 67(1): 22–29.
- Clarke, S.R.; Nowak, J.T. 2009. Southern pine beetle. *Forest Insect and Disease Leaflet 49, FS-R6-RO-FIDL49*. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Region. 8 p.
- Duerr, D.A.; Mistretta, P.A. 2013. Invasive pests—insects and diseases. In: Wear, D.N.; Greis, J.G., eds. *The Southern Forest Futures Project: technical report*. Gen. Tech. Rep. SRS-GTR-178. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 457–508.
- Evans, J.W.; Kretschmann, D.E.; Green, D.W. 2019. Procedures for estimation of Weibull parameters. Gen. Tech. Rep. FPL–GTR–264. Madison, WI: U.S. Department of Agriculture Forest Service, Forest Products Laboratory. 17 p.
- Frank, S.; Baker, J.; Bambara, S. 2019. Southern Pine Beetle. *Entomology Insect Notes*. Raleigh, NC: North Carolina State University, N.C. State Extension. <https://content.ces.ncsu.edu/southern-pine-beetle>. [Date accessed: May 12, 2022].
- Husch, B.; Beers, T.W.; Kershaw, J.A., Jr. 2003. *Forest Mensuration*. Hoboken, NJ: John Wiley and Sons. 443 p.
- Kushla, J.D.; Dicke, S.G.; Henderson, J.E. [and others]. 2019. Economic impact of a large-scale, collaborative forest health project: a model for making a difference. *Journal of Extension*. 57(3): 1–12.
- Little, N.S.; Riggins, J.J.; Schultz, T.P. [and others]. 2012. Feeding preference of native subterranean termites (Isoptera: Rhinotermitidae: Reticulitermes) for wood containing bark beetle pheromones and blue-stain fungi. *Journal of Insect Behavior*. 25: 197–206.
- Oswalt, C.M.; Oswalt, S.N.; Meade, J.R. 2016. Species composition and succession in yellow pine stands following southern pine beetle outbreaks in Tennessee—preliminary results. In: Schweitzer, C.J.; Clatterbuck, W.K.; Oswalt, C.M., eds. *Proceedings of the 18th biennial southern silvicultural research conference*. e-Gen. Tech. Rep. SRS–212. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 1–6.
- Pye, J.M.; Holmes, T.P.; Prestemon, J.P.; Wear, D.N. 2011. Economic impacts of the southern pine beetle. In: Coulson, R.N., and K.D. Klepzig, eds. *Southern Pine Beetle II*. Gen. Tech. Rep. SRS-140. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 512 p.
- Thatcher, R.C.; Searcy, J.L.; Coster, J.E.; Hertel, G.D., eds. 1980. *The southern pine beetle*. Tech. Bull. 1631. Washington, DC: U.S. Department of Agriculture Forest Service, Science and Education Administration. 265 p.
- VanderSchaaf, C.L. 2015. Modeling aspen cover type diameter distributions in Minnesota. In: Stanton, S.M.; Christensen, G.A., comps. *Pushing boundaries: new directions in inventory techniques and applications: Forest Inventory and Analysis (FIA) symposium 2015*. Gen. Tech. Rep. PNW-GTR-931. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station: 381–386.

PROJECTING STAND DEVELOPMENT AND ECONOMICS OF LONGLEAF PINE PLANTED OUTSIDE ITS KNOWN HISTORICAL RANGE

Curtis L. VanderSchaaf, Michael A. Blazier, Joshua P. Adams

ABSTRACT

As part of a regional study of new longleaf pine (*Pinus palustris* Mill.) genotypes, a trial was established at the Louisiana State University Agricultural Center Hill Farm Research Station in northwest Louisiana. The goal was to determine growth and development of genotypes planted north of the species' known historical range. This location is within the projected potential range of longleaf pine under moderate to severe climate change scenarios.

In January 2016, the site was hand-planted with 1-0 containerized longleaf pine seedlings in a 10-foot by 10-foot spacing using genotypes of diverse geographic origin (Alabama, North Carolina, east Texas); 17 genotypes were half-sibling and 2 were full-sibling crosses. Summary statistics and stand tables were calculated by genotype at age 5 and used to conduct projections using a variety of model systems. These projections were used to estimate future economic values, rotation ages, and to see how projections varied among model systems.

INTRODUCTION

Given advances in genetics, better quality seedlings, and an increase in the knowledge of how to transport, store, and plant longleaf pine seedlings (South 2006), and the fact that we now know it is essential to control non-crop tree vegetation early in the life of the stand (Haywood 2005, Nelson and others 1985), longleaf pine (*Pinus palustris* P. Mill.) plantations are a viable economic alternative compared to loblolly (*Pinus taeda* L.) or slash (*Pinus elliottii* Engelm. var *elliottii*) pine. This is especially true when accounting for the significantly greater number of poles found in longleaf pine stands (South 2006). Prices in east Texas during 2016 varied but sawtimber on the stump averaged \$27/ton while pine poles averaged \$50/ton (Stottlemeyer and others 2017). Concerns about the lost ecosystem services associated with the reduction in longleaf pine ecosystems prompted restoration efforts; the improved seedling quality and yield potentials bolster those efforts.

Longleaf pine is relatively resilient to droughts, severe storms, fire, and pest outbreaks anticipated to occur with greater frequency with climate change in the Southeastern United States (Boyer 1990, Clark and others 2018). Prasad and others (2019) consequently predicted expansion potential of longleaf pine far north of its historical range, extending under high climate change scenarios into Arkansas and Missouri in the western portion of its range and Massachusetts in the eastern

Table 1—Description of genotypes established during this study

Genotype	Geographic origin	Code
1	East Texas	ETX
2	South Alabama	SAL1
3	South Alabama	SAL2
4	South Alabama	SAL3
5	North Alabama–Montane	NAL1
6 ^a	North Carolina ^a	NC1 ^a
7	South Alabama	SAL4
8	South Alabama	SAL5
9	South Alabama	SAL6
10	North Carolina	NC2
11	North Carolina	NC3
12	North Carolina	NC4
13	South Alabama	SAL7
14 ^a	North Carolina ^a	NC5 ^a
15	North Alabama–Montane	NAL2
16	North Alabama–Montane	NAL3
17	North Carolina	NC6
18	North Carolina	NC7
19	South Alabama	SAL8

^aFull-sibling genotypes; all others are half-sibling.

Author Information: Curtis L. VanderSchaaf, Assistant Professor, Mississippi State University, Raymond, MS 39154; Michael A. Blazier, Professor, Louisiana State University Agricultural Center, Homer, LA 71040; and Joshua P. Adams, Associate Professor, Louisiana Tech University, Ruston, LA 71272.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

portion of its range. This projected climatic resilience as well as longleaf pine's sawtimber, pine straw, and wildlife habitat production potential has increased its attractiveness to landowners (Jose and others 2006). Hence, it is important to know if longleaf pine can be established effectively beyond its northern range as encountered by Europeans (Boyer 1990). Genotypes may vary in their adaptability to sites outside its range as well as in their productivity, so it is important to explore these genetic differences.

In this study, 19 genotypes of longleaf pine (table 1) drawn from diverse portions of its native range were established at a drought-prone site approximately 25 miles north of the northwestern most portion of the longleaf pine historical range. The objective of this study was to explore observed individual tree and stand development at age 5 years and long-term predicted stand development in terms of survival, basal area (BA), volume, and economic returns.

METHODS

Data Modeled

The study was conducted at the Louisiana State University Agricultural Center Hill Farm Research Station in northwest Louisiana (32°44'N, 93°03'W). Soils were classified as a gravelly fine sandy loam Darley-Sacul soil (an association of a fine, kaolinitic, thermic Hapludult and a fine, mixed, active, thermic Aquic Hapludult) common in upland forests of northwestern Louisiana, southwestern Arkansas, and eastern Texas (USDA SCS 1989). The Darley portion of the association occurs on upper slopes, and the Sacul portion is found within lower-slope positions. Droughts are common in the study area because late summer precipitation (USDA SCS 1989) is often below potential evapotranspiration during the same period; the moderately well- and well-drained soils of the site likely exacerbate impacts of drought.

Prior to establishment, the site was a loblolly pine plantation for 46 years. The native forest ecosystem of the region is loblolly pine, shortleaf pine (*Pinus echinata* Mill.), and southern red oak (*Quercus falcata* Michx.) mixtures (USDA NRCS 2000, 2015). After the plantation was clearcut-harvested in 2007, the site was replanted with loblolly pine in 2009 and 2010. Both replanting attempts were unsuccessful due to drought-related mortality of 50 to 70 percent. After 2010, the site naturally regenerated with loblolly pine and a mixture of hardwoods primarily of coppice origin. To foster replanting of the site, an aerial broadcast application of saflufenacil (Detail), imazapyr (Chopper Gen2), and glyphosate (Accord XRT) herbicides at 0.7, 10.1, and 57.1 fluid ounces active ingredient (a.i.) per acre, respectively, was conducted in June 2015. In July 2015, the study site was operationally mulched to comminute the vegetation killed by the herbicide application. In September 2015, the site

was subsoiled to a 2.62-foot depth. In the same month, 250 pounds per acre of diammonium phosphate was broadcast-applied by a tractor-mounted spreader to supply, respectively, 50 and 45 pounds per acre of P and N.

In January 2016, the site was hand-planted with container-grown seedlings in a 10-foot by 10-foot spacing. Treatments consisted of 19 genotypes of diverse geographic origin; 17 genotypes were half-sibling and 2 were full-sibling crosses (table 1). Each experimental unit was a row of six trees all of the same genotype; each genotype was replicated six times. Treatments were applied in a randomized complete block design with gradual changes in slope (which was associated with soil type change within the Darley-Sacul association) as the blocking factor; each genotype was represented one time per block. For this analysis, the six replicates of six trees were combined ($n = 36$ trees), and the survival, and diameter and height characteristics, across the 36 trees of a genotype were considered to be representative of stand behavior for a particular genotype.

After planting, non-crop vegetation was suppressed to better isolate genotype effects. Rotary mowing was carried out two times per year (late spring and mid-summer) in 2016 and 2017. In 2018, the site was mowed one time, in mid-summer. In March 2016, 11.3 ounces per acre of Oustar herbicide was applied to supply 7.2 and 1.3 ounces a.i. per acre of hexazinone and sulfometuron methyl for competing vegetation suppression. The Oustar was applied via tractor-mounted sprayer within a 6.0-foot wide band along the tree rows. In July 2017, Velpar L herbicide was spot-applied via backpack sprayer at 16.4 fluid ounces a.i. per acre of hexazinone; a circular spot 2.95 feet in diameter was sprayed around each seedling. Table 2 contains individual tree summary data and table 3 contains estimated per acre summary data by genotype.

Modeling

Approach One—forest vegetation simulator (FVS)

The Southern variant (SN, version 1860) of FVS covers forest areas in the Southern United States including Louisiana, east Texas, and Mississippi (Keyser 2008). This is a distance-independent individual tree model. Individual tree data ($n = 36$) at age 5 by genotype were entered into FVS and projections were conducted annually until age 40. The "MANAGED" keyword was selected within FVS to inform the modeling system that projections are for plantations. This keyword is used within FVS since in general plantations have greater diameter growth rates relative to natural, or "unmanaged" stands.

Approach Two

The second approach used a stand-level volume equation presented in VanderSchaaf (2022c). Data used in model development were obtained from the Forest Service, U.S. Department of Agriculture Forest Inventory and Analysis (FIA) annual surveys of Alabama, Florida, Louisiana, Mississippi, and Texas.

Per-acre volume at a particular age (A_2) was predicted using equation 1:

$$Vol_2 = Vol_1[(1 - \exp^{-0.104124A_2}) / (1 - \exp^{-0.104124A_1})]^{(1 - 0.746766)^{-1}} \quad (1)$$

where Vol is volume of trees of d.b.h. 5.0 inches and greater from a 1-foot stump to a 4-inch top diameter outside-bark (essentially trees merchantable for pulpwood, sawtimber, veneer, etc.).

For Approach Two, merchantable volume was estimated by taking the ratios of pulpwood, chip-n-saw, and sawtimber to total merchantable volume as predicted by FVS for each genotype by age. The predicted total merchantable volumes from equation (1) were then multiplied by the ratio associated with a particular product class.

Approach Three

This approach uses equations developed by Gonzalez-Benecke and others (2012). Stand-level equations predicting dominant height, trees per acre, BA per acre, and total and merchantable volumes were fit using data from across the Gulf region of the Southeastern United States. This system of equations was incorporated into an Excel spreadsheet-based Timber Decision Support System (TDSS) entitled *LongGulf* (available from Curtis VanderSchaaf). To be consistent with the definition of dominant height by Gonzalez-Benecke and others (2012), at age 5 the average height of all trees taller than the upper 25th percentile tree height were used for each genotype (table 3).

Approach Four

The fourth approach used a stand-level, nonlinear, mixed-effects Chapman-Richards (Zeide 1993) BA equation to predict BA per acre.

$$BA_j = (199.14 + u_{0i}) * (1 - \exp[-0.1854 * Age_j])^{2.8210 + u_{2j}} \quad (2)$$

where BA is basal area (square feet per acre); the variances of u_{0i} and u_{2j} are 222.08, and 0.3984, respectively, there is also a covariance of -5.2133, and the constant random error variance is 6.0568; i indexes a specific plot or stand and j

Table 2—Individual tree d.b.h. and total tree height (Ht) summary statistics by genotype at age 5^a

Genotype	Code	D.b.h.					nD	Ht				
		Stdev.	Min.	Max.				Stdev.	Min.	Max.	nH	
		inches						feet				
1	ETX	2.44	0.68	1.00	3.71	26	10.4	3.3	2.3	16.2	26	
2	SAL1	2.62	0.52	1.30	3.50	30	10.5	2.4	5.8	15.0	31	
3	SAL2	2.36	0.51	1.00	3.20	27	9.8	2.1	5.0	13.9	28	
4	SAL3	2.54	0.42	1.40	3.20	31	10.6	1.6	7.8	14.0	31	
5	NAL1	2.57	0.64	1.30	3.71	27	10.4	2.5	6.0	15.6	27	
6	NC1	2.90	0.52	2.00	4.00	25	11.7	1.8	8.8	14.0	25	
7	SAL4	2.71	0.56	1.00	3.60	32	11.4	2.0	8.0	15.7	32	
8	SAL5	2.57	0.46	1.80	3.50	30	10.9	1.8	7.1	14.5	30	
9	SAL6	2.77	0.38	2.00	3.30	33	12.2	2.4	2.9	15.6	34	
10	NC2	2.18	0.53	1.00	3.00	31	9.3	2.6	3.0	13.5	32	
11	NC3	2.54	0.58	1.30	4.00	27	10.6	2.2	6.0	15.0	27	
12	NC4	2.41	0.62	1.00	3.60	31	9.9	2.9	4.0	15.8	31	
13	SAL7	2.66	0.50	1.90	4.00	28	11.2	2.3	3.1	15.1	29	
14	NC5	2.74	0.64	1.40	4.00	29	11.1	2.2	7.0	15.0	29	
15	NAL2	2.35	0.72	1.00	3.30	31	10.2	2.5	4.0	14.7	32	
16	NAL3	2.77	0.43	1.90	3.40	26	10.4	2.6	3.8	13.7	29	
17	NC6	2.72	0.55	1.50	3.70	26	10.7	2.3	4.4	15.0	27	
18	NC7	2.62	0.50	1.30	3.50	34	11.0	2.1	5.6	15.5	34	
19	SAL8	2.86	0.61	1.21	4.00	32	11.2	2.0	5.2	14.1	32	

D.b.h. = diameter at breast height; nD = d.b.h. tree number; Ht = total tree height; nH = Ht tree number.

^aNumber of trees planted per genotype was n = 36. If Ht tree number (nH) exceeds d.b.h. tree number (nD) by genotype, then not all trees had yet reached d.b.h.

Table 3—Stand-level summary statistics by genotype at age 5

Genotype	Code	DomG	DomHt	D _q	Percent survival	TPA	TPA _d	BAA	VAA
		<i>feet</i>	<i>feet</i>					<i>square feet</i>	<i>cubic feet</i>
1	ETX	14.8	15	2.53	72	315	315	11.0	82
2	SAL1	13.5	13	2.67	86	375	363	14.1	99
3	SAL2	12.6	11	2.41	78	339	327	10.4	68
4	SAL3	12.7	12	2.57	86	375	375	13.5	92
5	NAL1	13.0	13	2.65	75	327	327	12.5	87
6	NC1	13.9	13	2.95	70	303	303	14.3	108
7	SAL4	14.1	12	2.76	89	387	387	16.1	117
8	SAL5	13.3	13	2.61	83	363	363	13.4	94
9	SAL6	14.6	13	2.79	94	411	399	17.0	137
10	NC2	12.1	12	2.24	89	387	375	10.3	68
11	NC3	13.2	13	2.60	75	327	327	12.0	86
12	NC4	13.1	13	2.49	86	375	375	12.7	86
13	SAL7	13.5	12	2.70	81	351	339	13.5	103
14	NC5	14.2	12	2.82	81	351	351	15.2	111
15	NAL2	13.3	12	2.45	89	387	375	12.3	87
16	NAL3	12.8	12	2.80	81	351	315	13.5	94
17	NC6	13.3	12	2.77	75	327	315	13.1	96
18	NC7	13.7	14	2.67	94	411	411	16.0	113
19	SAL8	13.4	12	2.93	89	387	387	18.1	131

DomG = average height of the upper 25th percentile of heights (feet); DomHt = the dominant height calculated using FVS (feet); D_q = quadratic mean diameter (inches); Percent Survival = percent survival of all trees (TPA); TPA = trees per acre; TPA_d = trees per acre with a d.b.h.; BAA = basal area per acre (square feet, 4.5 feet); VAA = volume per acre (cubic feet) from FVS.

indexes the current age. Calibration of the mixed-effects model was accomplished using each genotype’s age 5 BA per acre (table 3). Data used in model fitting were obtained from loblolly pine, slash pine, and longleaf pine container-stock plantations established in central Louisiana.

Modeling systems presented for cutover and old-field sites in southwestern Georgia were also examined (Brooks and Jack 2016). However, they greatly over-predicted BA per acre (e.g., 450 to 750 square feet per acre at age 25) or volume per acre (7,100 to 31,000 cubic feet per acre at age 25). Large overpredictions occurred because our observed values at age 5 exceed the data used in model fitting at this age and the plots used in model fitting had very little observed mortality (self-thinning) through time.

Volume Modeling Assumptions

For the three approaches that estimated merchantable cubic foot volume (Approaches One, Two, and Three), minimum merchantability limits were essentially consistent with standard FVS SN protocol and stump height was set to 0.5 feet. Minimum merchantable pulpwood diameter at breast height (DBH, 4.5 feet above ground level) was 4.0 inches, and upper-stem diameter outside bark (DOB) was 4.0 inches.

Chip-n-saw specifications were minimum DBH of 8.0 inches to 11.0 inches, and an upper-stem DOB of 4.0 inches. Sawtimber specifications were minimum DBH of 11.0 inches and an upper-stem DOB of 7.0 inches. For FVS projections, volumes were calculated using the “SpMcDBH” keyword within FVS. Topwood, or upper-stem pulpwood on chip-n-saw and sawtimber merchandized trees, was included in the pulpwood class. The default FVS max stand density index of 332 was changed to 400 (Reineke 1933, Shaw and Long 2007, VanderSchaaf and others 2007).

Cubic feet volumes were converted to green tons assuming 62 pounds per cubic feet (Baldwin and Saucier 1983). Stumpage values per green ton for pine pulpwood, chip-n-saw, and sawtimber were \$9, \$19, and \$25, respectively, and were obtained from the 2nd quarter, 2019 Louisiana Timber Market Report (Tanger 2019). An interest rate of 6 percent was used.

RESULTS AND DISCUSSION

Despite being established north of the species historical range in Louisiana, the genotypes on this site are relatively productive, and some are extremely productive for this species. Our study consisted of early herbaceous weed

control, which has been known for some time now to be essential for longleaf pine growth and survival (Dickens and others 2010, Haywood 2005, Nelson and others 1985). There is some separation in DBH among the genotypes, but there are more meaningful differences in height among the genotypes (table 2). At comparative ages, these observed DBHs were within the range of, or exceeded, many other container-grown studies within its historical range (Cram 2019, Creighton and Bitoki 2011, Dickens and others 2010, South and others 2012) and the heights as well (Cram 2019, Creighton and Bitoki 2011, Dickens and others 2010, Haywood and others 2015, South and others 2012). Our average DBHs and total heights at age 5 are comparable to those in southwestern Virginia at age 7 (Creighton and Bitoki 2013). Of surviving trees, all genotypes had >90 percent with a DBH (TPA_d and TPA) at age 5 (table 3).

Our percent survivals (table 3) were within the range, and often exceeded, many other container-grown studies within the species historical range (Cram 2019, Creighton and Bitoki 2011, Dickens and others 2010, South and others 2012). The lowest genotype survival rate in this study was 70 percent. These percent survivals exceed countless bare-root studies.

Genotypes 9 (SAL6) and 19 (SAL8) exhibited the greatest BA and volume per acre measurements while genotypes 10 (NC2) and 3 (SAL2) exhibited the lowest BA and volumes per acre (table 3). Based on Goelz and Leduc (2001) for plantations established within its native range in the Western Gulf, observed volumes per acre for genotypes 9 (SAL6) and 19 (SAL8) would be considered High, while all other genotypes would be considered Medium at a minimum. The 435 per acre planting density is relatively low, and yet all genotypes can be considered of Medium productivity using Goelz and Leduc (2001), hence, it can be said that all genotypes at age 5 are exhibiting good rates of growth for this species. Their Medium- and High-BAs and total volumes per acre at age 5 were 5 and 14 square feet per acre and 43 and 156 cubic feet per acre, respectively. However, most of their data are from older generation longleaf pine plantations (established prior to 1980) that likely were established using bare-root stock and used less intensive regeneration practices. Nonetheless, our plantations, planted outside longleaf pine's historical range, are productive and it currently appears that longleaf pine can be successfully grown in this region of Louisiana, although their tolerance to extreme weather events such as ice storms must be evaluated as well.

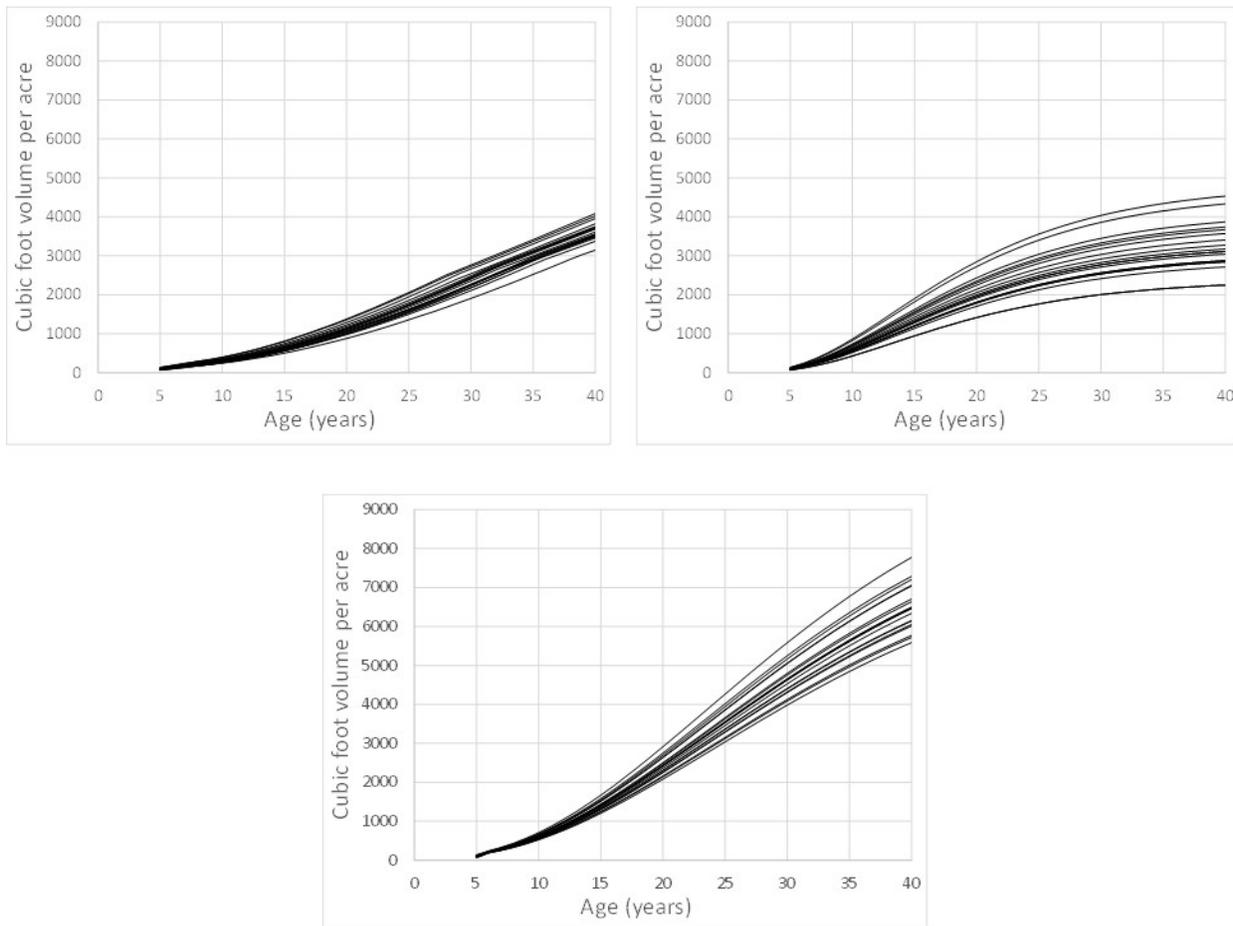


Figure 1—Approach One—Forest Vegetation Simulator (FVS) (upper left), Approach Two (equation 1) (upper right), and Approach Three [LongGulf—Gonzalez-Benecke and others (2012)] (lower) projected unthinned standing cubic foot volume per acre trajectories by genotype.

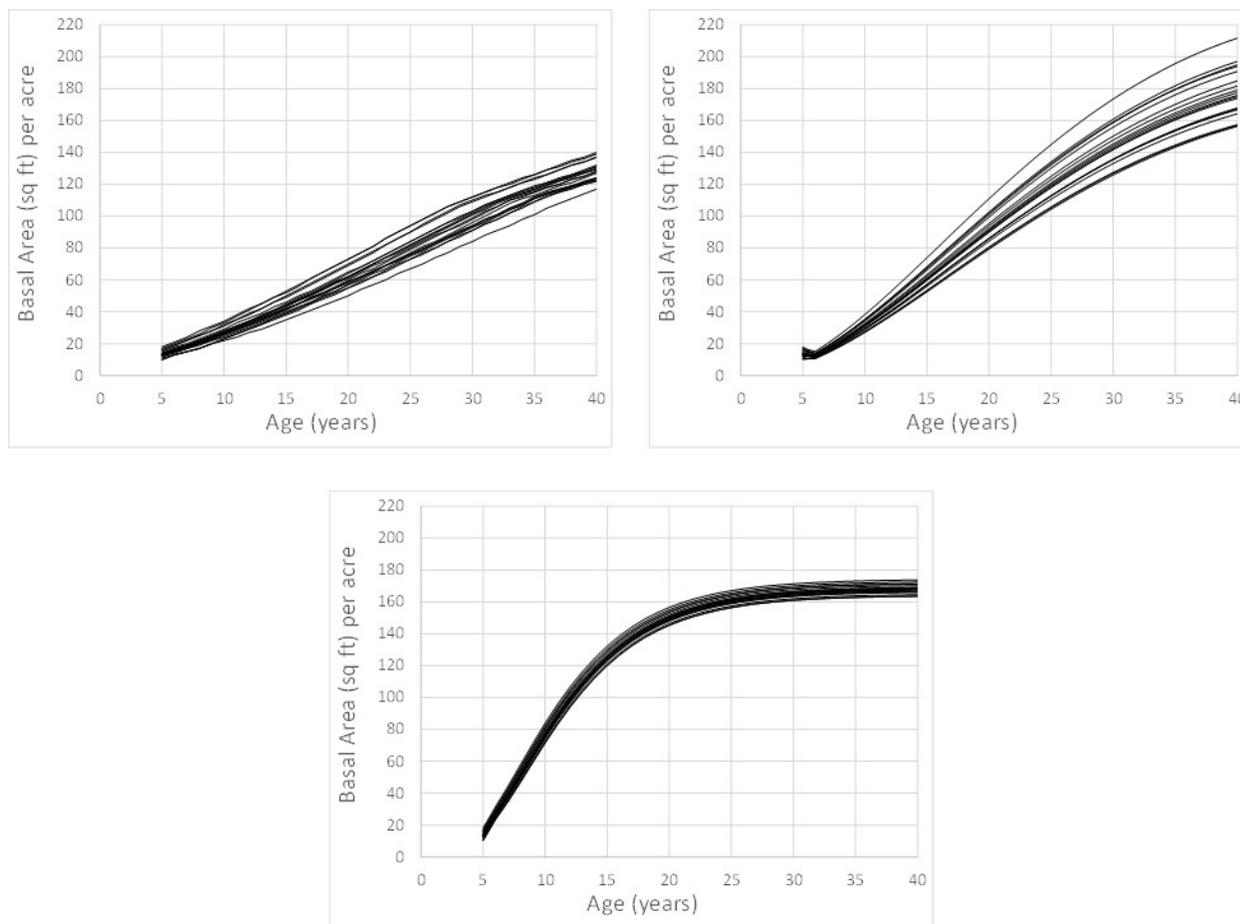


Figure 2—Approach One—Forest Vegetation Simulator (FVS) (upper left), Approach Three [*LongGulf*—Gonzalez-Benecke and others (2012)] (upper right), and Approach Four [mixed effects—equation (2)] (lower) projected unthinned standing basal area per acre trajectories by genotype.

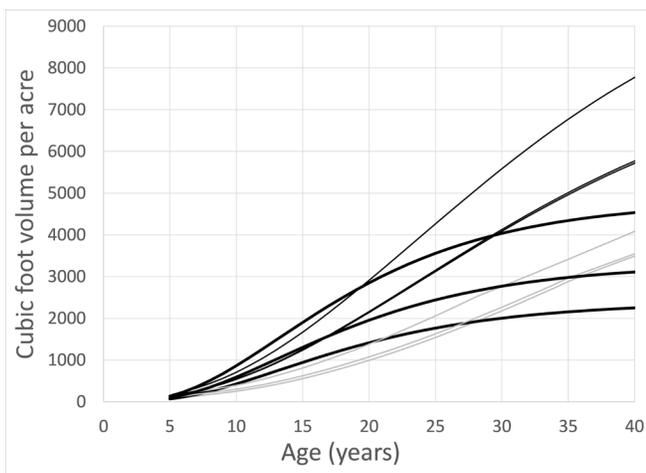


Figure 3—Approach One—Forest Vegetation Simulator (FVS) (gray lines), Approach Two [equation (1)]—bold black lines, and Approach Three [*LongGulf*—Gonzalez and others (2012)] (light black lines) projected standing cubic foot volume per acre trajectories for the lowest (genotype 3-SAL2), median (genotype 16-NAL3), and greatest volume (genotype 9-SAL6) genotypes, observed at age 5. For Approach Three, the lowest and median trajectories are nearly identical.

Volume and BA per acre projections differed substantially by model system both in terms of carrying capacity and trajectory shape through time (figs. 1 through 3). For volume (figs. 1 and 3), Approach Two [equation (1)] produced the most sigmoidal trajectories while Approach One (FVS) had little sigmoidal shape. The variability among the projection approaches demonstrates uncertainty regarding projections from young ages to rotation ages. The intent of this study is merely to have some idea of the likely behavior in the future and to obtain relative values among the genotypes.

Figure 3 provides the clearest indication of projected volume behavior among the approaches. For all three genotypes, respectively, Approach Three (*LongGulf*) predicts substantially more volume. The Approach One-FVS projected trajectories show very little sigmoidal shape and generally the relatively lowest productivity levels across time, respectively by genotype.

Projected volumes are comparable and, in some cases, exceed those from published studies, particularly Approach Three (*LongGulf*). Our projected yields at age 25 generally exceed those observed on a cutover site in southern Mississippi of relatively the same planting density and receiving various cultivation and NPK fertilization treatments

(Schmidting 1987, VanderSchaaf 2022a). Our projected yields are comparable to those presented in yield tables from plantations in Louisiana and Texas (Lohrey and Bailey 1977), and South (2006) as predicted using the SiMS03 growth and yield model (ForesTech 2005). Based on site class productivities in Goelz and Leduc (2001), at age 25 most genotypes for all three volume approaches are projected to be of Medium-site quality (3,057 cubic feet per acre), with just a few being of Low- (956 cubic feet per acre) and High- (4,331 cubic feet per acre) site qualities.

Projected BAs at age 20 using Approach Four are comparable to those from Haywood and others (2015) and as reported in VanderSchaaf (2022b), a container-stock study located in central Louisiana. The data from that study was in part used to fit the mixed-effects equation [equation (2)] that was calibrated to produce the BA projections presented in figure 2. However, basal area projections using Approaches One and Three are vastly less than those presented in Haywood and others (2015), which averaged 169 square feet of BA per acre at age 20. However, their (Haywood and others 2015) site was found to be relatively productive for longleaf pine.

For Approaches One and Two, given current regeneration costs and the assumed stumpage values, growth rates will not be enough to offset those costs such that a financial profit will be produced (fig. 4). However, economics of Approach Three (*LongGulf*) projections show that establishing many genotypes at this site will produce a financial profit. Our analysis fails to include any stumpage being sold as poles. For southern yellow pines, pole stumpage is often twice that of sawtimber stumpage (LDAF 2019, South 2006, Stottlemeyer and others 2017, Tanger 2019). Mills and Stiff (2013) for east Texas showed that having as little as 25 percent of sawtimber stumpage sold as poles can substantially enhance economic returns, and these greater revenues make longleaf pine much more competitive with loblolly pine and in some cases actually producing greater returns than loblolly pine.

Plus, we did not include potential returns for pine straw production. Several studies, South (2006), Mills and Stiff (2013), and Dickens and others (2014), have demonstrated that the sale of pine straw can substantially increase financial returns and/or make longleaf pine financial returns much more comparable to loblolly and slash pine. Future work can examine how varying stumpage values and interest rates will

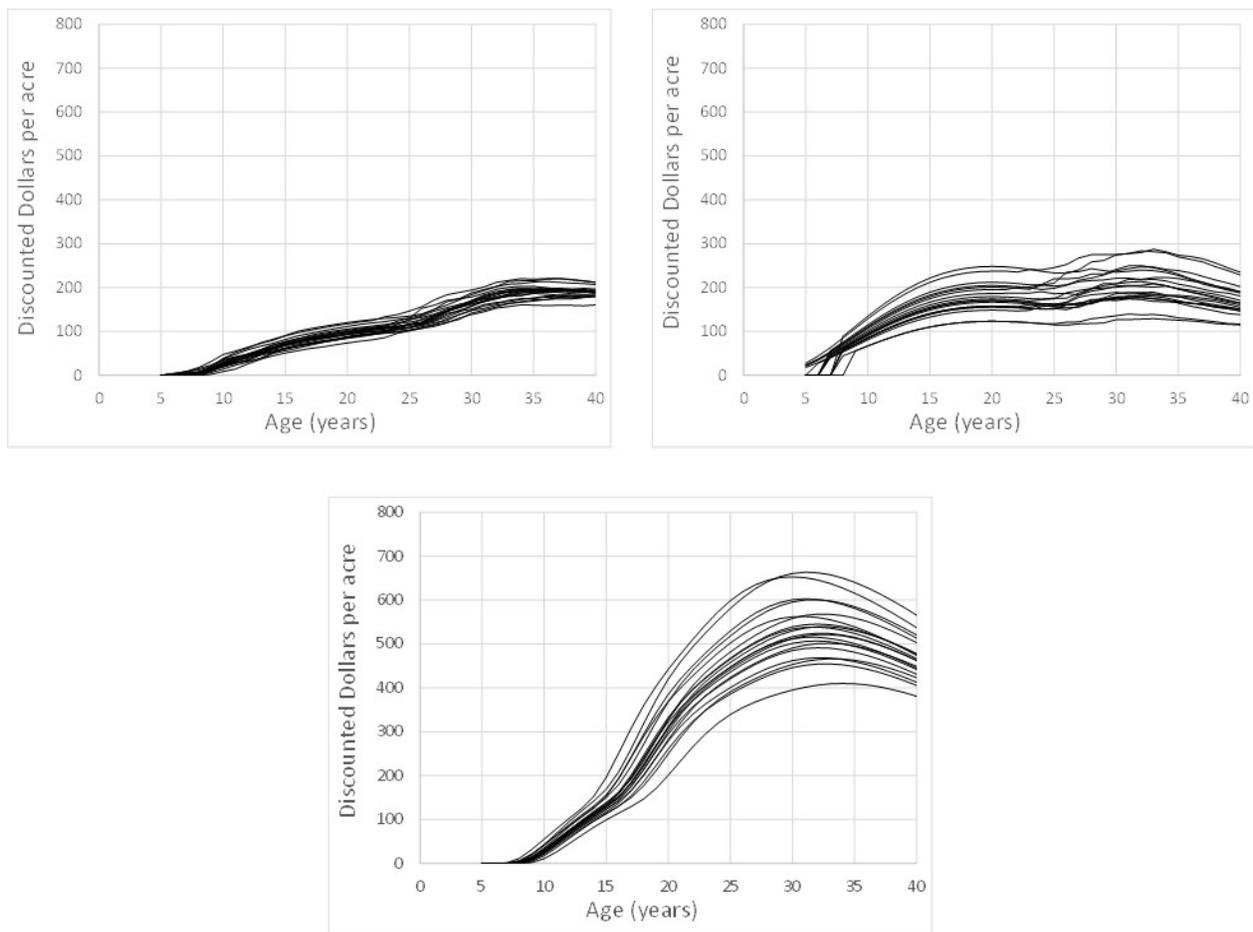


Figure 4—Approach One—Forest Vegetation Simulator [FVS] (upper left), Approach Two (equation 1) (upper right), and Approach Three [*LongGulf*—Gonzalez-Benecke and others (2012)] (lower) projected discounted revenue per acre trajectories by genotype. Stumpage values were \$9, \$19, and \$25/ton for pulpwood, chip-n-saw, and sawtimber, respectively (Tanger 2019). An interest rate of 6 percent was used.

impact projected financial returns. Additionally, as future measurements are made, a clearer depiction of even further future stand development should be observed such that we can obtain a more meaningful projection of when an initial thinning should be conducted, if desired. Timely thinning treatments might improve financial returns.

REFERENCES

- Baldwin, V.C., Jr.; Saucier, J.R. 1983. Aboveground weight and volume of unthinned, planted longleaf pine on West Gulf forest sites. Res. Pap. SO-191. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 25 p.
- Boyer, W.D. 1990. Longleaf pine: *Pinus palustris* Mill. In: Silvics of North America. Agric. Handb. 654. U.S. Department of Agriculture Forest Service: 405–412.
- Brooks, J.R.; Jack, S.B. 2016. An updated whole stand growth and yield system for young longleaf pine plantations in southwest Georgia. In: Schweitzer, Callie J.; Clatterbuck, Wayne K.; Oswalt, Christopher M., eds. Proceedings of the 18th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-212. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 258–263.
- Clark, K.E.; Chin, E.; Peterson, M.N. [and others]. 2018. Evaluating climate change planning for longleaf pine ecosystems in the Southeast United States. Journal of the Southeastern Association of Fish and Wildlife Agencies. 5: 160–168.
- Cram, M.M. 2019. Effect of *Pisolithus tinctorius* nursery treatment on long-term loblolly and longleaf pine survival and growth in the South Carolina sandhills. Tree Planters' Notes. 62: 58–66.
- Creighton J.; Bitoki, O. 2011. 2006 longleaf pine provenance study. Charlottesville, VA: Virginia Department of Forestry. https://dof.virginia.gov/wp-content/uploads/FRR-2011-05_pub.pdf. [Date accessed: April 25, 2022].
- Creighton J.; Bitoki, O. 2013. Longleaf pine provenances in Virginia: age seven update. Charlottesville, VA: Virginia Department of Forestry. https://dof.virginia.gov/wp-content/uploads/FRR-2013-08_pub.pdf. [Date accessed: April 25, 2022].
- Dickens, E.D.; McElvany, B.C.; Moorhead, D.J. [and others]. 2010. Stand dynamics of an old-field longleaf pine stand following herbicide application, poor survival, and subsequent replanting. In: Stanturf, John A., ed. Proceedings of the 14th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-121. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 219–222.
- Dickens, E.D.; Sunday, J.; Moorhead, D.J. 2014. Economics of growing loblolly, longleaf, and slash pine to various rotation ages with three stumpage price sets, four establishment cost sets, four discount rates, with and without pine straw—soil expectation value. Series paper number 8. Athens, GA: University of Georgia, Daniel B. Warnell School of Forestry and Natural Resources. 28 p. <https://bugwoodcloud.org/bugwood/productivity/pdfs/SeriesPaper8.pdf>. [Date accessed: April 25, 2022].
- ForesTech. 2005. SiMS2003. Athens, GA: ForesTech International LLC. <http://www.foresstech.us/>. [Date accessed: October 8, 2022].
- Goelz, J.C.G.; Leduc, D.J. 2001. Long-term studies on development of longleaf pine plantations. Longleaf Alliance Report No. 5. In: Proceedings of the third longleaf alliance conference. Auburn University, AL: Longleaf Alliance: 116–118.
- Gonzalez-Benecke, C.A.; Gezan, S.A.; Leduc, D.J. [and others]. 2012. Modeling survival, yield, volume partitioning and their response to thinning for longleaf pine plantations. Forests. 3: 1104–1132.
- Haywood, J.D. 2005. Effects of herbaceous and woody plant control on *Pinus palustris* growth and foliar nutrients through six growing seasons. Forest Ecology and Management. 214: 384–397.
- Haywood, J.D.; Sayer, M.A.; Sung, S.S. 2015. Comparison of planted loblolly, longleaf, and slash pine development through 10 growing seasons in central Louisiana—an argument for longleaf pine. In: Holley, A. Gordon; Connor, Kristina F.; Haywood, James D., eds. Proceedings of the 17th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-203. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 383–390.
- Jose, S.; Jokela, E.J.; Miller, D.L. 2006. The longleaf pine ecosystem: ecology, silviculture, and restoration. New York: Springer. 450 p.
- Keyser, C.E., comp. 2008 (revised November 2020). Southern (SN) Variant Overview—Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Forest Management Service Center. 80 p.
- Lohrey, R.E.; Bailey, R.L. 1977. Yield tables and stand structure for unthinned longleaf pine plantations in Louisiana and Texas. Res. Pap. SO-133. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 53 p.
- Louisiana Department of Forestry (LDAF). 2019. Louisiana timber market report. Baton Rouge, LA: <http://www.ldaf.state.la.us/wp-content/uploads/2020/02/4th-qtr-2019.pdf>. [Date accessed: April 11, 2022].
- Mills, S.D.; Stiff, C.T. 2013. Financial performance of loblolly and longleaf pine plantations. In: Guldin, James M., ed. 2013. Proceedings of the 15th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-GTR-175. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 183–191.
- Nelson, L.R.; Zutter, B.R.; Gjerstad, D.H. 1985. Planted longleaf pine seedlings respond to herbaceous weed control using herbicides. Southern Journal of Applied Forestry. 9: 236–240.
- Prasad, A.M.; Iverson, R.; Matthews, S.; Peters, M. 2019. Longleaf pine. In: a climate change atlas for 134 forest tree species of the eastern United States. [Database]. Delaware, OH: U.S. Department of Agriculture Forest Service, Northern Research Station. <https://www.fs.fed.us/nrs/atlas/tree/121>. [Date accessed: April 11, 2022].
- Reineke, L.H. 1933. Perfecting a stand-density index for even-aged forests. Journal of Agricultural Research. 46: 627–638.
- Schmidting, R.C. 1987. Relative performance of longleaf compared to loblolly and slash pines under different levels of intensive culture. In: Philips, D.R., comp. Proceedings of the 4th biennial southern silvicultural research conference. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station: 395–400.
- Shaw, J.D.; Long, J.N. 2007. A density management diagram for longleaf pine stands with application to red-cockaded woodpecker habitat. Southern Journal of Applied Forestry. 31(1): 28–38.
- South, D.B. 2006. Planting longleaf pine at wide spacings. Native Plants. 7(1): 79–88.
- South, D.; Johnson, E.E.; Hains, M.J.; Vanderschaaf, C.L. 2012. Restoring longleaf pine on an agricultural site by planting alternating rows of slash pine: a case study. Southern Journal of Applied Forestry. 36(3): 118–125.
- Stottlemyer, A.; Dougal, E.; Parajuli, R. [and others]. 2017. Harvest Trends 2016. College Station, TX: Texas A&M Forest Service. 24 p.
- Tanger, S.M. 2019. Louisiana timber market report. Baton Rouge, LA: Louisiana State University Agricultural Center. <https://lsuagcenter.com/profiles/lblack/articles/page1563895865132>. [Date accessed: April 11, 2022].
- United States Department of Agriculture, Natural Resource Conservation Service (USDA NRCS). 2000. Darley series. National Cooperative Soil Survey. https://soilseries.sc.egov.usda.gov/OSD_Docs/D/DARLEY.html. [Date accessed: April 11, 2022].
- United States Department of Agriculture, Natural Resource Conservation Service (USDA NRCS). 2015. Sacul series. National Cooperative Soil Survey. https://soilseries.sc.egov.usda.gov/OSD_Docs/S/SACUL.html. [Date accessed: April 11, 2022].
- United States Department of Agriculture, Soil Conservation Service (USDA SCS). 1989. Soil Survey of Claiborne Parish, Louisiana. 147 p.

- VanderSchaaf, C.L. 2022a. Ability of site index to differentiate merchantable yield in southern yellow pine plantations. In: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. Proceedings of the 21st biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 222-230 p.
- VanderSchaaf, C.L. 2022b. Can longleaf pine plantations be modeled by calibrating mixed-effects models of other species. In: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. Proceedings of the 21st biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 115-122 p.
- VanderSchaaf, C.L. 2022c. Developing a simple longleaf pine plantation growth and yield model for the Gulf region. In: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. Proceedings of the 21st biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 231-240 p.
- VanderSchaaf, C.L.; Mehdahl, R.S.; Kush, J.S. 2007. Preliminary density management diagram for naturally regenerated longleaf pine. In: Proceedings of the 6th longleaf alliance conference. Longleaf Alliance Rep. No. 10. Auburn University, AL: Longleaf Alliance: 137-140.
- Zeide, B. 1993. Analysis of growth equations. *Forest Science*. 39(3): 594-616.

BREAST LEVEL HEIGHT DISPLACEMENT: DO STANDING TREES SINK INTO THE SOIL

Curtis L. VanderSchaaf, Boris Zeide, and William B. Patterson

ABSTRACT

Increases in the above-ground biomass (bole, crown) may result in trees sinking due to gravity and the corresponding decrease in the original diameter at breast height (d.b.h.) level, further referred to as displacement. Below-ground increases in biomass (roots) push the soil up and out and may result in raising the ground level. Both forces may be at work and partially offset one another. These phenomena may produce errors when estimating volume as a function of d.b.h. Remeasuring diameter at the same level across time removes this complication. Lines placed at d.b.h. at age 12 and periodically remarked in a 43-year-old pine (*Pinus taeda* L.) plantation are lower than 4.5 feet above the ground level, especially for larger trees. The objective of this study is to determine whether the d.b.h level of loblolly pine trees at 43 years of age have changed because of displacement and/or ground-raising.

There is some force that has caused these trees to rise over time from ground level at the time of planting, most likely roots pushing the tree up because of a high clay content which provides resistance to root expansion. Part of this soil "rise" around trees is offset by the tree sinking due to weight. To prevent volume estimation errors, d.b.h. should be permanently marked during the establishment of research studies.

INTRODUCTION

Forest research is vital to obtain optimal operational management scenarios. Often, research is conducted on a limited number of individuals and then information from this sample is used to infer about the behavior of the population as a whole. Therefore, it is important to obtain accurate measurements during research operations and to understand all aspects of processes that may ultimately be used when making management decisions. Growth and yield models are a tool regularly used to produce optimal management scenarios. It is imperative that the data used to develop these systems are accurately and consistently measured across time. One important measurement is the diameter at breast height (d.b.h.) level which in the United States is 4.5 feet above the ground line.

As trees grow, their weight and size increases. It is known that as the above-ground component of a tree becomes larger so does its root volume (Kapeluck and Van Lear 1995, Pehl and others 1984). An increase in the above-ground biomass of a tree (bole, crown) may result in the tree sinking due to gravity and the corresponding decrease in the original breast height level, further referred to as displacement. Below-ground increases in biomass (roots) push the soil up and out and may result in raising the ground level. It is our belief that both forces may be at work and to some extent offset one another. These forces likely differ among sites depending

upon factors such as soil type, slope, climate, perhaps even due to the presence or lack thereof of fragipans, etc. and likely among species, stand densities, and even factors such as genetics (e.g., crown structure and density, wood density, and so forth), and other factors. Displacement and ground-raising may increase for larger trees since their above-ground weights and root volumes are greater.

These phenomena may result in errors when estimating volume. Perhaps there are several ways, but we believe one way is that displacement and ground-raising can impact the d.b.h. level over time, and hence the measurement of d.b.h. that is often used to produce volume (weight or biomass, etc.) estimates. Remeasuring diameter at the same level across time removes this complication. If the d.b.h. line is not marked at the time of study establishment, volumes and diameter increments will be underestimated. We noticed that lines (stripe of white paint) initially placed at age 12 and periodically remarked on trees in a 43-year-old loblolly pine (*Pinus taeda* L.) plantation in southeastern Arkansas are lower than 4.5 feet above the ground level, especially for larger trees (and subsequently in the unthinned portion of the study as well). To document this minor process of stand dynamics and explain it, we conducted the following investigation.

The objective of this study is to determine whether the d.b.h. level of loblolly pine trees at 43 years of age has changed because of displacement and/or ground-raising.

Author Information: Curtis L. VanderSchaaf, Assistant Professor, Mississippi State University, Raymond, MS 39154; Boris Zeide, (Deceased), Professor, University of Arkansas at Monticello, Monticello, AR 71656; and William B. Patterson, Associate Professor, Louisiana Tech University, Ruston, LA 71272.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

METHODS

Hypotheses

To find an explanation of the observed change in the diameter at breast-height level, referred to as displacement, we formulated these four hypotheses:

1. Sinking due to gravity caused by an increase in the above-ground biomass of a tree
2. Ground elevation resulting from the increase of below-ground volume of roots, which pushes the soil out and up
3. Combination of these two forces
4. The extent of both forces is related to tree weight and volume

Approach

The measurements of displacement, D , and ground elevation increase, G , are sufficient to test these hypotheses. We assumed no error during the initial establishment of d.b.h. at age 12 (and at age 27 for the unthinned portion). There are two apparent cases:

1. $D = G$. This would mean that the sole reason for displacement is ground elevation.
2. $D > G$. In this case the tree sank into the soil.

Monticello Thinning and Pruning Study

The stand was established in the winter of 1958-1959 in a row-cropped old field at a spacing of 8 feet by 8 feet using 1-0 seedlings obtained from a State nursery located in Arkansas. Genetic stock was of a local-seed source. Plots were originally established in 1970 when the trees were 12 years old. Four levels of thinning, three levels of pruning, and all their combinations were included in the study design. Each combination had three replications within a randomized complete block design. Four plots were also established for each of the four thinning treatments without pruning for a total of 40 plots. Each plot had a gross size of 132 feet by 132 feet and contained an inner plot of 66 feet by 66 feet where all trees were individually numbered. Thus, the 0.1-acre measurement plot (inner plot) was surrounded by a similarly treated (including pruning) 0.3-acre buffer zone one-half chain wide. Site index (base age 25 years) was determined to be near 62 feet.

Originally, no unthinned plots were established. The need for such plots was later recognized, and at the age of 27 (in the summer of 1984) five control plots (without thinning or pruning) were established on the adjacent untreated part of the plantation. The size and arrangement of each plot was the same as that of the 40 original plots. To make growth comparable, hardwood competition was controlled on the plots by injecting Tordon® 101 R. For more detailed information, see General and others (2013).

Soil Description

The study area is located on Tippah silt loam, 1 to 3 percent slopes (USDA NRCS 2021). Tippah is classified as a fine-silty, mixed, active, thermic Aquic Paleudalf, and is situated on toeslopes of stream terraces. Tippah has a silt loam surface over a silty clay loam argillic subsoil that becomes clay by 31 inches depth. It is moderately well drained, with a seasonal high-perched water table of 18-30 inches depth in the late winter and early spring. Tippah has a slow infiltration rate, low runoff, and moderate permeability in the upper subsoil, but low permeability in the clay, lower subsoil.

The soil erodibility of the Tippah silt loam is high, with a moderate erosion hazard (off-road, off-trail) and it has zero initial and total subsidence, and low soil slippage potential. Bulk density is 1.50 g/cm^3 in the surface, and 1.48 g/cm^3 in the subsoil down to 30 inches depth and there is a medium potential for soil compaction. Restrictive soil layers are deeper than 6.6 feet from the surface. Organic matter content is low (1.25 percent) but the available water capacity of the soil is high (24 percent). Tippah silt loam is rated as somewhat favorable for aerobic soil organisms, with low organic matter, favorable bulk density, and somewhat favorable soil moisture and clay content.

Measurements

Measurements were conducted on inner plot trees that had their d.b.h. marked with a white paint stripe at age 12 (and age 27 in the unthinned portion). Careful examination resulted in the selection of trees that had level ground at 5 feet from their base to avoid measuring dips and logging activity soil displacements. After trees were selected using these criteria, the three largest-diameter and smallest-diameter trees throughout all plots were selected. All other trees were selected based on an attempt to get an even distribution of diameters. Litter and understory vegetation were cleared at the base of each tree in two general directions: north and east. A measuring stick was used to determine the height (in feet) from the existing ground-base (ground level at the base of the tree) to the white paint stripe (fig. 1), D is the difference from that height and 4.5 feet. The measuring stick was then carefully dropped on a pin and straightened by use of a level (fig. 2). Height from the ground level to the bottom of the measuring stick was made at a distance of 5 feet from the base of the tree by a ruler and defined as G . Table 1 contains summary statistics of data used in model fitting and model validation.



Figure 1—The top pictures are of tree 252, which is in plot 27, which is a 30 square feet per acre thinning plot with no pruning. The tree has a d.b.h. of 25.2 inches, and an average displacement (D) of 7.8 inches. This tree had the largest measured d.b.h. and average displacement (D). The ruler in front of the tree depicts how the ground level has increased (G) around the base of the tree, which is an average of 7.4 inches. The red line on the measuring stick is d.b.h., or 4.5 feet, while the yellow tape shows where the original white stripe d.b.h. line was placed at age 12. The bottom pictures are of tree 595, which is in plot 45, which is an unthinned and unpruned plot. The tree has a d.b.h. of 7.6 inches and had no displacement (D). The tree had an average of 0.75 inches of ground elevation (G), the lowest amount of any measured tree. The yellow tape shows where the original white stripe d.b.h. line was placed at age 27.



Figure 2—Tree 252 with a ground elevation (G) of 8.4 inches (east direction) and tree 595 with a ground elevation (G) of 0.7 inches (east direction). These pictures show how a stick was located from the base point on the tree, used to locate d.b.h., in a due east direction, a level used to ensure the stick was straight, and a ruler used to measure the amount of ground elevation (G).

Table 1—Summary statistics of data used in model fitting and model validation

Measurement	Mean	Minimum	Maximum	SD
D (inches)				
t	3.864	1.800	7.800	1.450
u	0.900	0.000	3.000	1.140
G (inches)				
t	4.896	2.900	7.400	1.237
u	2.500	0.750	5.250	1.367
D.b.h. (inches)				
t	18.7	13.7	25.2	3.27
u	11.7	7.1	17.8	4.14

SD = standard deviation; subscript t refers to observations from thinned treatments; subscript u refers to observations from unthinned treatments. For thinned, n = 25, and unthinned, n = 10.

ANALYSIS AND RESULTS

The relationships between D, G, and d.b.h. were analyzed using regression. Several models were examined for each dependent variable (D and G). Selection of a particular model depended both on statistical and biological criteria. For all linear models, the y-intercept was forced to zero assuming that the ground level at the study site would not sink.

A linear relationship was found between D and G (fig. 3). As ground level at the base of a tree rises, D gets larger. Linear regression was used to quantify the effects of d.b.h. on D (fig. 4) and the relationship between G and d.b.h. (fig. 5). There is a direct relationship between d.b.h. and both D and G. In all cases, linear correlations were found to be significant at least at $p < 0.0099$.

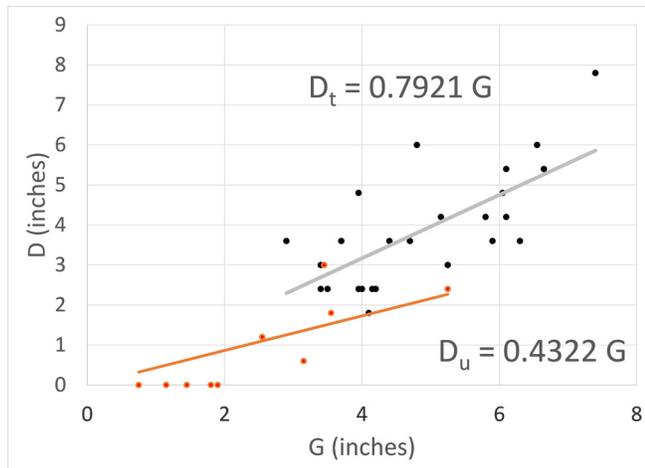


Figure 3—Relationship between D–d.b.h. displacement (inches) and G–ground-raising (inches). Subscript t refers to observations from thinned treatments and subscript u refers to observations from unthinned treatments. For thinned, n = 25, and unthinned, n = 10.

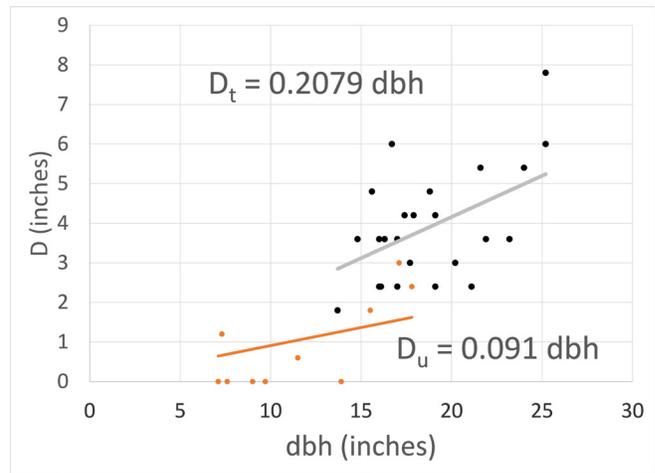


Figure 4—Relationship between D–d.b.h. displacement (inches) and d.b.h. (inches). Subscript t refers to observations from thinned treatments and subscript u refers to observations from unthinned treatments. For thinned, n = 25, and unthinned, n = 10. For thinned observations, d.b.h. is the diameter of the tree at the white stripe line originally established at age 12 while for unthinned observations, d.b.h. is the diameter of the tree at the white stripe line originally established at age 27.

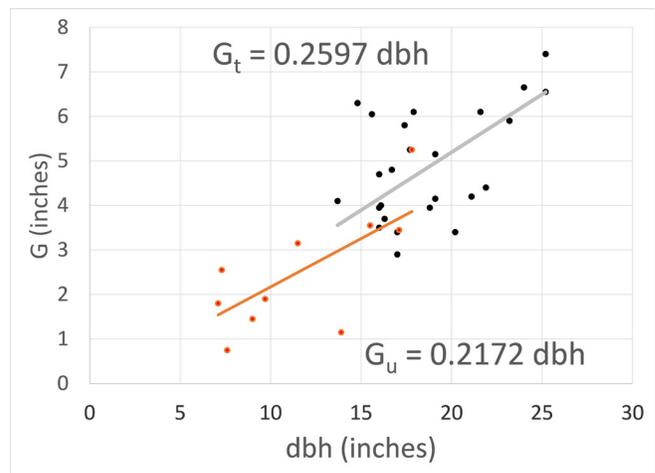


Figure 5—Relationship between G–ground-raising (inches) and d.b.h. (inches). Subscript t refers to observations from thinned treatments and subscript u refers to observations from unthinned treatments. For thinned, n = 25, and unthinned, n = 10. For thinned observations, d.b.h. is the diameter of the tree at the white stripe line originally established at age 12 while for unthinned observations, d.b.h. is the diameter of the tree at the white stripe line originally established at age 27.

DISCUSSION

It appears there is some force that causes loblolly pine trees to rise over time from ground level at the time of planting. This force is probably roots pushing the tree up (figs. 1 and 2) because of a high clay content which provides resistance to root expansion. It is known that as the above-ground component of a tree becomes larger so does its root volume (Kapeluck and Van Lear 1995, Pehl and others 1984). A lot of humus was also present in the upper 2 inches of the soil mound at the base of the study trees also resulting in the soil rising. Naturally, over a 43-year period a lot of litter accumulated.

Alternatively, this apparent rise around the tree, may in fact, slightly develop because of a corresponding decrease in soil in the distant vicinity from the base of a tree due to transpiration, where the diameter of that vicinity depends on the size, and likely species (in this case loblolly pine), of that tree. This could potentially be a third factor contributing to d.b.h. displacement. We believe this could be a potential contributor despite this site having a Tippah silt loam soil series and thus inherently low soil subsidence. The uptake of soil moisture by the tree roots and ultimate moisture transfer to the atmosphere (transpiration), plus factors such as decaying dead soil woody material, producing voids in the soil that collapse, and subsistence of microorganisms may also contribute to the soil within a vicinity of larger trees decreasing over time as a result of tree growth. Soil erosion is another potential factor that may lead to soil decrease in the distant vicinity from the base of a tree, making it appear that the tree base rose in height. This may be true given the soil properties of Tippah silt loam (soil erodibility is high, with a moderate erosion hazard) (USDA NRCS 2021). A related factor, may be some accumulation of the displaced soil around the base of a tree, causing the soil around the base of a tree to increase, and changing the point along the stem at which d.b.h. occurs through time.

Part of this soil “rise” around trees is offset by the tree sinking. Evidence for this is the fact that the increase in G is not totally accounted for by D (table 1, fig. 3). Large trees contain a lot of weight. Despite this, apparently the expansion force of roots is greater than the force of gravity pushing the tree downward.

Long-term research studies should be concerned about D. The d.b.h. of trees should be permanently marked during the establishment of studies. This will prevent errors from being made when determining both d.b.h. and volume. The decrease in d.b.h. could also, to a minor degree, result in some inconsistencies in forest inventories across rotations and theoretically total height. However, the impacts resulting from the loss in height are probably negligible, since the loss in height is probably minimal compared to the error associated with determining height for larger trees.

This may be the last publication produced by Dr. Zeide. The majority of this work was conducted when the lead author was a Research Specialist and Dr. Zeide was a professor at the University of Arkansas at Monticello.

This is a tribute to him, a person who was highly influential in the understanding of self-thinning patterns of forests and the understanding of growth equations, among other topics. He produced several highly influential papers on the self-thinning rule but his paper “Analysis of Growth Equations” (Zeide 1993) may have been his most influential work. It is currently the most cited paper in the history of Forest Science. Dr. Zeide was a very influential part of the lead author’s career.

LITERATURE CITED

- General, D.R.; VanderSchaaf, C.L.; Zeide, B. 2013. The longest active thinned and pruned loblolly pine permanent plots: the last measurement. In: Guldin, James M., ed. 2013. Proceedings of the 15th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-GTR-175. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 479–486.
- Kapeluck, P.R.; Van Lear, D.H. 1995. A technique for estimating below-stump biomass of mature loblolly pine plantations. *Canadian Journal of Forest Research*. 25: 355–360.
- Pehl, C.E.; Tuttle, C.L.; Houser, J.N.; Moehring, D.M. 1984. Total biomass and nutrients of 25-year-old loblolly pines (*Pinus taeda* L.). *Forest Ecology and Management*. 9: 155–160.
- U.S. Department of Agriculture, Natural Resources Conservation Service (USDA NRCS). 2021. Web soil survey. <https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>. [Date accessed: April 15, 2021].
- Zeide, B. 1993. Analysis of growth equations. *Forest Science*. 39: 594–616.

ABILITY OF SITE INDEX TO DIFFERENTIATE MERCHANTABLE YIELD IN SOUTHERN YELLOW PINE PLANTATIONS

Curtis L. VanderSchaaf

ABSTRACT

This study examines if site index (SI) temporally consistently ranks a site's ability to produce a particular product for loblolly, slash, and longleaf pine. Each plot by species was considered as representative of a different stand. Total height and diameter at breast height were measured and yield in tons were subsequently estimated at ages 8, 25, and 39. The SI of each plot and product yields by plot were ranked and examined for correlations at a particular age and for consistency across time. Total yield and SI rankings were strongly linearly related within a particular age. Loblolly pine had the least amount of variability. Correlations of yields in tons and SI rankings for total and pulpwood tons generally decreased across time, particularly for slash pine. However, sawtimber production correlations increased across time. Loblolly showed the most consistency among SI and yield rankings across time for a particular product and age. Longleaf showed less variability relative to slash for all product classes but sawtimber.

INTRODUCTION

Including site quality in growth and yield models is essential for the prediction of future yields. Site quality estimates are used to help identify the applicability of management actions, or to determine the ability of a site to meet management objectives. Commonly used measures of site quality are site index (SI) (e.g., King 1966), ecological classification systems such as habitat typing, and more direct measures of soils and climate (e.g., Graney 1977, Harrington 1991). Conceptually, for a particular species, SI is a collective influence of soil factors and climatic conditions and when excluding extremes, SI is thought to be independent of stand density. However, studies have shown that genetics and stand density can greatly influence SI (e.g., Boyer 1983). Unless accounted for, factors such as genetics (McKeand and others 2006, Zhai and others 2015), fertilization (Subedi and others 2014, Tiarks and Haywood 1996), planting density (Akers and others 2013, Anto'n-Ferna'ndez and others 2011, MacFarlane and others 2000), and thinning (Ritchie and others 2012) all contribute to reducing the effectiveness of SI to differentiate sites as to their ability to produce yields of a particular species. Hence, SI is both advantageous and non-advantageous because it is a function of the existing trees—thus the existing genetics and management practices of the current rotation and previous rotations. However, it is often non-advantageous because it does not provide a direct explanation of site growing conditions. These issues associated with SI are widely known.

There are numerous definitions of trees to be included in the calculation of SI for tree species across the world (Anto'n-Ferna'ndez and others 2011, Burkhart and Tennent 1977, Cao and others 1997, Lenhart and others 1986, Ritchie and others 2012, Sharma and others 2002). Different definitions of dominant height have been proposed for southern yellow pines (*Pinus taeda* L.) in the Southeastern United States (Lenhart and others 1986) including the tallest 50 percent of trees per acre (Boyer 1983, Golden and others 1981), the tallest 55 percent of trees per acre (McTague 2008), and dominants and co-dominants (Amateis and Burkhart 1985, Cao and others 1997, Zarnoch and Feduccia 1984). Two of the three former definitions calculate dominant height using a fixed proportion of trees (sometimes referred to as predominant height) while the other estimates dominant height based on crown classes (often dominants and co-dominants). Top height, or some percent of the largest diameter trees, has also been used as a definition (Sharma and others 2002). Placing trees into crown classes requires additional inventory time and for some research datasets may not have been conducted (Golden and others 1981). Thus, it may be necessary to use a definition of dominant height other than crown class.

Others have noted problems with the consistency of SI across time. Sharma and others (2002) found that correlation with the initial SI measurement decreased as time passed. However, studies examining the consistency of SI across time to rank the productivity of plots to produce common commercial product classes have been minimal—particularly

Author Information: Curtis L. VanderSchaaf, Assistant Professor, Mississippi State University, Raymond, MS 39154.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

in relation to product classes such as pulpwood, chip-n-saw, and sawlogs.

The primary objective of this study was to determine how consistently SI ranks the productivity of plots for common southern yellow pine product classes across time. Loblolly pine (*Pinus taeda* L.), longleaf pine (*Pinus palustris* Mill.), and slash pine (*Pinus elliottii* Engelm. var *elliottii*) were analyzed.

METHODS

Data

Data used during this assessment is from a study located on the Harrison Experimental Forest, near Saucier, MS, about 25 miles north of Gulfport, MS. It had been stocked with second-growth longleaf pines before being clearcut in 1958-1959. The soils are well-drained upland, fine sandy loams in the Poarch series and the Saucier-Susquehanna complex. Slope varies from 0 to 8 percent on the gently rolling land (Schmidting 1984, 1987).

One-year-old seedlings of loblolly, longleaf, and slash pine were planted at 10- by 10-foot spacing in 1960. Within each plot, there were 10 subplots, five cultural treatments applied to high specific gravity populations and five to average specific gravity populations. Four replications (or blocks) were established, each plot contained 100 measured trees, for a total of:

$$3 \text{ species} \times 4 \text{ blocks} \times 10 \text{ subplots} \times 100 \text{ trees per plot} = 12,000 \text{ trees in the study}$$

The five cultural treatments were:

- U-0—check, no cultivation and no fertilizer;
- F-0—cultivation, but no fertilizer;

F-1—cultivation and a single application of 100, 21, and 42 pounds per acre of N, P, and K, respectively;

F-2—cultivation and a single application of 200, 42, and 84 pounds per acre of N, P, and K, respectively; and

F-4—cultivation and a single application of 400, 85, and 167 pounds per acre of N, P, and K, respectively.

Cultivated plots were cleared of all stumps and slash, then plowed and disked. Stumps, soil, and competing vegetation were not disturbed on check plots. Cultivation consisted of disking three times each season for 3 years after planting and mowing in the 4th and 5th seasons. Fertilizer was distributed with an agricultural spreader and disked into the soil in May 1961, 1 year after planting.

Tree height and diameter at breast height (DBH) were measured in 1968 (age 8), 1985 (age 25), and 1999 (age 39). Height was measured during the commonly used SI base age of 25 years—allowing for a direct estimate of SI at base age 25.

Calculation of Dominant Height and Weights

Since dominants and co-dominants were not classified in this study, SI was specified using one predominant height (the tallest half of surviving trees). A base age of 25 years was selected and since heights were measured at age 25, excluding measurement error, there is an estimate of the true SI for each plot.

Equations found in Lenhart and others (1987) were used to predict total and merchantable weights for loblolly and slash pines while those in Baldwin and Saucier (1983) were used for longleaf pine. Upper stem diameter outside bark (DOB)s of 8 inches, 4 inches, and 2 inches were assumed to represent sawtimber, chip-n-saw, and pulpwood merchantable classes, respectively. Minimum DBHs were 12 inches, 9 inches, and 4 inches for sawtimber, chip-n-saw, and pulpwood

Table 1—Summary characteristics of loblolly, longleaf, and slash pine plantations located in Mississippi planted at a spacing of 436 seedlings per acre

Species	Age	Total tons per acre				Pulpwood tons per acre				Chip-n-saw tons per acre				Sawtimber tons per acre				Tallest 50 percent (feet)			
		Min	Mean	Max	SD	Min	Mean	Max	SD	Min	Mean	Max	SD	Min	Mean	Max	SD	Min	Mean	Max	SD
Loblolly	8	1	15	32	9.7	0	13	32	10.2	0	0	0	0	0	0	0	0	17	32	43	7.62
	25	6	33	69	19.0	5	33	68	19.1	0	17	50	16.3	0	4	20	5.6	38	56	74	10.71
	39	6	50	104	28.0	6	50	103	28.0	1	39	96	28.6	0	18	60	17.5	48	71	92	12.18
Longleaf	8	0	7	15	4.7	0	5	13	4.5	0	0	0	0	0	0	0	0	8	22	30	6.60
	25	6	42	90	19.4	6	41	89	19.3	0	16	40	13.4	0	1	8	2.2	47	60	69	5.72
	39	16	71	149	30.6	16	71	149	30.5	4	53	120	28.3	0	15	49	13.7	58	75	86	6.19
Slash	8	3	12	24	6.4	0	10	24	7.4	0	0	0	0	0	0	0	0	19	30	37	5.30
	25	20	41	63	10.8	20	41	62	10.9	0	16	43	12.5	0	1	9	2.8	47	62	72	5.80
	39	25	64	99	17.3	25	64	98	17.3	12	48	87	18.0	0	17	65	14.7	60	79	92	7.40

SD = standard deviation; Min = minimum; Max = maximum.

Pulpwood tons is to an upper stem diameter outside bark (DOB) of 2 inches for diameter at breast height (DBH)s of 4 inches and larger, chip-n-saw tons is to a DOB of 4 inches for DBHs of 9 inches and larger, and sawtimber tons is to a DOB of 8 inches for DBHs of 12 inches and larger. *n* = 40 for all three species and ages.

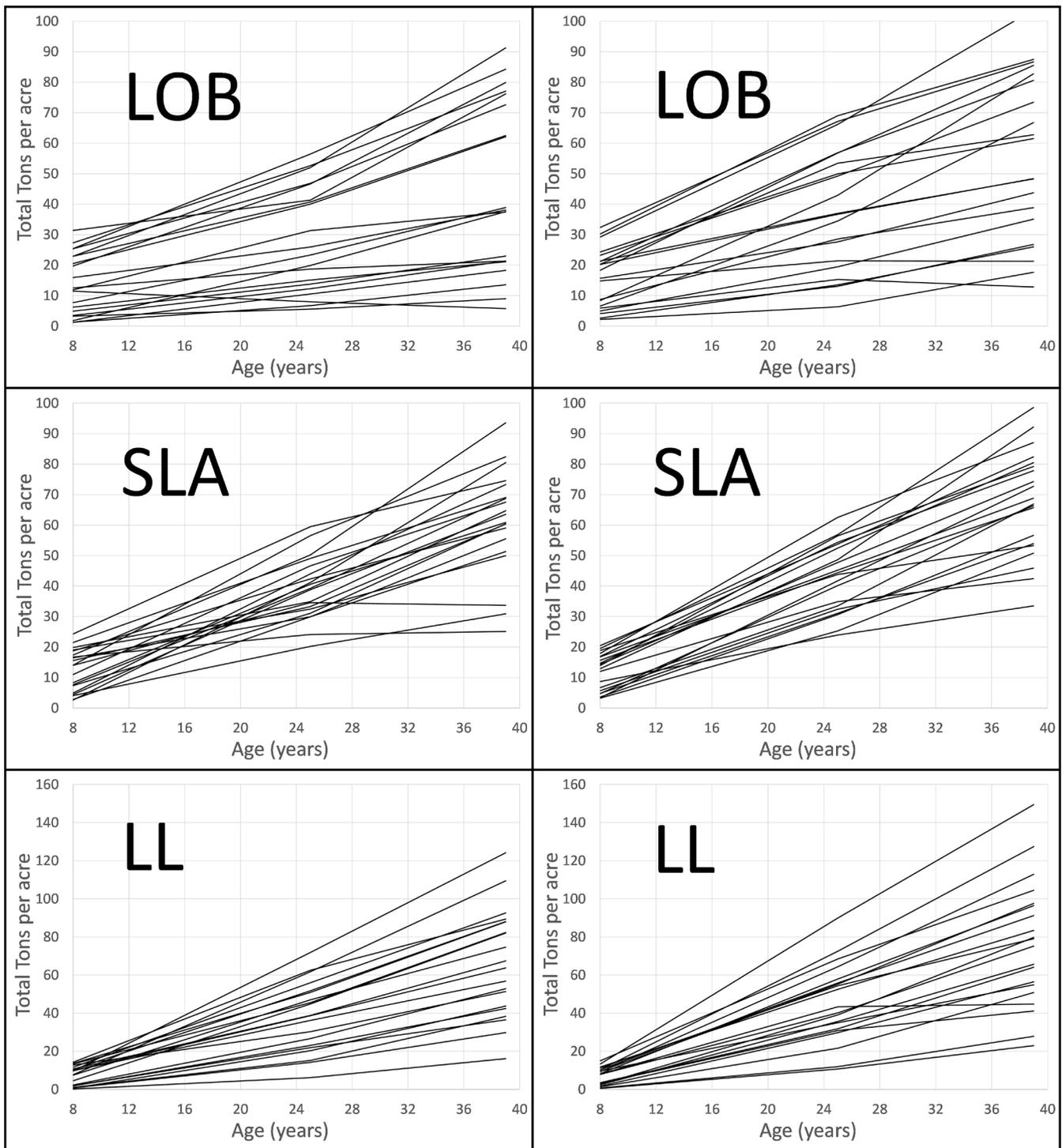


Figure 1—Total tons per acre at ages 8, 25, and 39, each subfigure contains 20 trajectories. The subfigures on the left are for blocks 1 (n = 10) and 2 (n = 10) by species, and the figures on the right are for blocks 3 (n = 10) and 4 (n = 10) by species. Note the different y-axis scales among the three species.

merchantable classes, respectively. Table 1 presents summary statistics and figure 1 contains total yield trajectories.

It could be argued that results in this paper are dependent to some extent on the particular volume or weight equations used—different equations may result in some differences in allocating total volume or weight among product classes. However, if this truly was an operational growth and yield

study or the specific purpose was to estimate volume or weight, these sets of equations would be reasonable choices.

For this study the total predicted amounts of pulpwood, chip-n-saw, and sawtimber were analyzed separately, determined based only on minimum DBH and upper stem diameter specifications. Hence, no attempt was made to sort trees into various product classes that would be done

during an actual timber harvest, and thus there was no need to calculate upper-stem pulpwood (topwood) on chip-n-saw and sawtimber “trees.” For this analysis (table 1), for example, the pulpwood yield includes portions that could be merchandized as chip-n-saw or sawtimber. This approach is thought to be advantageous to determining the ability of SI to differentiate the capability of stands to produce a particular product class. For instance, are we interested in differentiating the ability of sites to produce pulpwood, or to produce upper-stem pulpwood (topwood)?

Analytical Procedures

It is desired of SI to rank stands based on their ability to produce merchantable weights. Merchantable weights were estimated at ages 8, 25, and 39 (since total tree heights and DBH were available). At each age, the relative ranking of each plot’s total, pulpwood, chip-n-saw, and sawtimber weights was calculated, as well as the relative ranking of each plot’s SI at age 25 (or predominant height at age 25). A ranking of 1 is the greatest value, or most productive, plot and a ranking of 40 is the smallest value, or least productive, plot for a particular variable.

For each plot, the yield ranking by product class at any age and its SI (predominant height at age 25) can be considered as being paired. The relative rankings of the plot yields across the different ages can be examined to see if indeed the predominant height rankings provide consistent information about merchantable volumes and tons throughout a rotation. The concept here is that if indeed SI (predominant height) across time is strongly correlated with the ability of stands and plots to produce a particular product throughout a rotation, then the relative rankings of the plot yields should be consistent across time. However, if a plot has a relatively poor yield ranking (for this study a larger numerical ranking represents lower site quality) at age 8, but a relatively good yield ranking (for this study a smaller numerical ranking represents better site quality) at age 39, then SI (predominant height) is not a temporally consistent measure of the inherent productivity level of a site.

RESULTS AND DISCUSSION

Plot yield ranks were generally strongly linearly related to SI ranks (table 2). Thus, greater SIs generally indicated greater yields. Longleaf and slash pines had more variability in their correlations for a particular age than loblolly pine. Pulpwood production at age 8 is not overly meaningful. However, correlations at common potential rotation ages, particularly at age 25, are important. Correlations of yields and SI plot rankings for total and pulpwood yields generally decreased across time, particularly for slash pine. Loblolly pine total and pulpwood correlations remained high at ages 25 and 39.

Table 2—Correlation matrix of plot-level product class and site index (base age 25) ranks by age and species of loblolly, longleaf, and slash pine plantations located in Mississippi planted at a spacing of 436 seedlings per acre

Age	Product	Loblolly	Longleaf	Slash
8	Total	0.92364	0.78743	0.88968
	Pulpwood	0.92008 (39) ^a	0.83752 (27) ^a	0.89268
	Chip-n-saw	-	-	-
	Sawtimber	-	-	-
25	Total	0.94371	0.55366	0.47992
	Pulpwood	0.94390	0.56735	0.49550
	Chip-n-saw	0.94522 (34) ^a	0.88931 (35) ^a	0.92364 (37) ^a
	Sawtimber	0.72233 (20) ^a	0.24353*(11) ^a	0.40356 (10) ^a
39	Total	0.89193	0.49925	0.28368**
	Pulpwood	0.89869	0.50432	0.29287***
	Chip-n-saw	0.90807	0.73096	0.63077
	Sawtimber	0.87186 (33) ^a	0.78518 (34) ^a	0.87842 (32) ^a

- = no ranking of plots.

^aNumber of plots with values greater than 0 for a particular product class.

Pulpwood tons is to an upper stem diameter outside bark (DOB) of 2 inches for diameter at breast height (DBH)s of 4 inches and larger, chip-n-saw tons is to a DOB of 4 inches for DBHs of 9 inches and larger, and sawtimber tons is to a DOB of 8 inches for DBHs of 12 inches and larger. *n* = 40 for all three species and ages by product. All correlations are significant at a *p* < 0.0098 level, except *significant at *p* < 0.1300, **significant at *p* < 0.0761, ***significant at *p* < 0.0667.

However, as expected sawtimber production correlations increased across time. Chip-n-saw correlations decreased from age 25 to 39, but of the three product classes, this class had the strongest correlations at age 25. To some extent the correlations may be artificially inflated because yield was not directly measured, but rather estimated using equations, which are a function of the observed heights. However, these correlation coefficients and this study do provide some indication of the relative ranking at one point in time in terms of management—which is useful.

Table 3 shows the average deviation by product class, age, and species between the SI and product class yield rankings of a particular plot. Except for sawlog tons at age 39, loblolly always had the lowest average difference and standard deviation. Consistent with the correlation results seen in table 2, loblolly pine generally had the strongest relationships between product class yield and SI rankings. For longleaf relative to loblolly pine, this seems logical given that longleaf pine survival and growth rates can often be erratic due to the “grass stage” and its particular biology (e.g., Haywood and others 2015)—perhaps important is that all seedlings in this study were bareroot, but given current regeneration practices, such as planting with container stock and better herbicides for weed control, longleaf may have reduced variability. The coefficient of variation is variable among the species, but it is uncertain if this measure of dispersion is of utility for this type of analysis.

Table 3—Average absolute (direction was ignored) difference in rank by product class, age, and species from the site index (base age 25) rank of a particular plot to that plot's product yield rank (Mean)

Product	Age	Loblolly			Longleaf			Slash		
		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
Total	8	3.6	2.8	76.5%	6.2	4.4	71.5	4.0	3.7	92.7
	25	2.9	2.7	93.2%	8.9	6.4	71.7	9.2	7.4	80.9
	39	4.6	2.8	60.9%	9.8	6.2	63.2	11.5	7.8	67.4
Pulpwood	8	3.7 (39) ^a	2.8	75.5%	5.2 (27) ^a	4.1	78.5	4.0	3.6	89.9
	25	2.9	2.6	92.9%	8.8	6.3	72.0	9.0	7.4	82.3
	39	4.4	2.8	63.6%	9.8	6.2	63.2	11.5	7.7	67.0
Chip-n-saw	8	-	-	-	-	-	-	-	-	-
	25	3.1 (34) ^a	2.3	76.4%	4.1 (35) ^a	3.6	88.0	3.2 (37) ^a	3.3	103.8
	39	4.1	2.9	71.2%	6.6	5.4	81.4	7.8	6.3	80.9
Sawtimber	8	-	-	-	-	-	-	-	-	-
	25	6.5 (20) ^a	5.7	87.8%	11.5 (11) ^a	8.5	74.3	10.1 (10) ^a	7.6	75.7
	39	4.9 (33) ^a	3.2	65.8%	5.7 (34) ^a	5.0	88.4	4.8 (32) ^a	3.1	64.5

-- = no ranking of plots; SD = standard deviation; CV = coefficient of variation.

^aNumber of plots with values greater than 0 for a particular product class.

Pulpwood tons is to an upper stem diameter outside bark (DOB) of 2 inches for diameter at breast height (DBH)s of 4 inches and larger, chip-n-saw tons is to a DOB of 4 inches for DBHs of 9 inches and larger, and sawtimber tons is to a DOB of 8 inches for DBHs of 12 inches and larger. *n* = 40 for all three species and ages, and hence correlation ranks.

We may also be interested in the consistency between plot yield and SI rankings across time (fig. 2–4, table 4). For planning purposes, foresters are often interested in having a measure of site productivity that consistently ranks and differentiates sites across time. If there is substantial variability in yield production rankings among plots across time given their SI, then, in operation, a site's capability to produce yield at a particular age may be incorrectly determined to be relatively high or low because of its relative SI value being high or low.

Loblolly showed the most consistency among SI and yield rankings across time for a particular product and age (figs.

2–4, table 4) with the exception of total and pulpwood weights from ages 25 to 39. Longleaf pine showed less variability relative to slash for all product classes but sawtimber. For ages 25 to 39, sawtimber production showed the most variability across time. For total and pulpwood weights, ages 8 to 25 showed more variability in yield and SI-paired rankings relative to ages 25 to 39. Unfortunately, these results are tainted by relatively low production across all three species, many plots did not even have sawtimber at age 25 (table 2), and even some plots did not produce sawtimber at age 39, and hence, it is difficult to “define” their changes in ranks.

Table 4—Average absolute (direction was ignored) change in yield ranks by product class and species from ages 8 to 25 and from ages 25 to 39

Species	Projection	Total	All plots			Only plots with product yields		
			Pulpwood	Chip-n-saw	Sawtimber	Pulpwood	Chip-n-saw	Sawtimber
Loblolly	8 to 25	4.4	4.5	-	-	4.5 (39)	-	-
	25 to 39	3.0	2.8	2.7	6.3	-	2.5 (34)	3.5 (20)
Longleaf	8 to 25	5.8	7.3	-	-	8.2 (27)	-	-
	25 to 39	2.2	2.2	4.3	10.7	-	4.8 (35)	5.9 (11)
Slash	8 to 25	8.7	8.8	-	-	8.8 (40)	-	-
	25 to 39	4.8	4.9	6.6	10.0	-	6.6 (37)	5.0 (10)

-- = no ranking of plots.

Pulpwood tons is to an upper stem diameter outside bark (DOB) of 2 inches for diameter at breast height (DBH)s of 4 inches and larger, chip-n-saw tons is to a DOB of 4 inches for DBHs of 9 inches and larger, and sawtimber tons is to a DOB of 8 inches for DBHs of 12 inches and larger. *n* = 40 for all three species and projections for the “All plots” average changes. For the Only plots with product yields average changes, numbers in parentheses are the number of observations used in the correlation analysis.

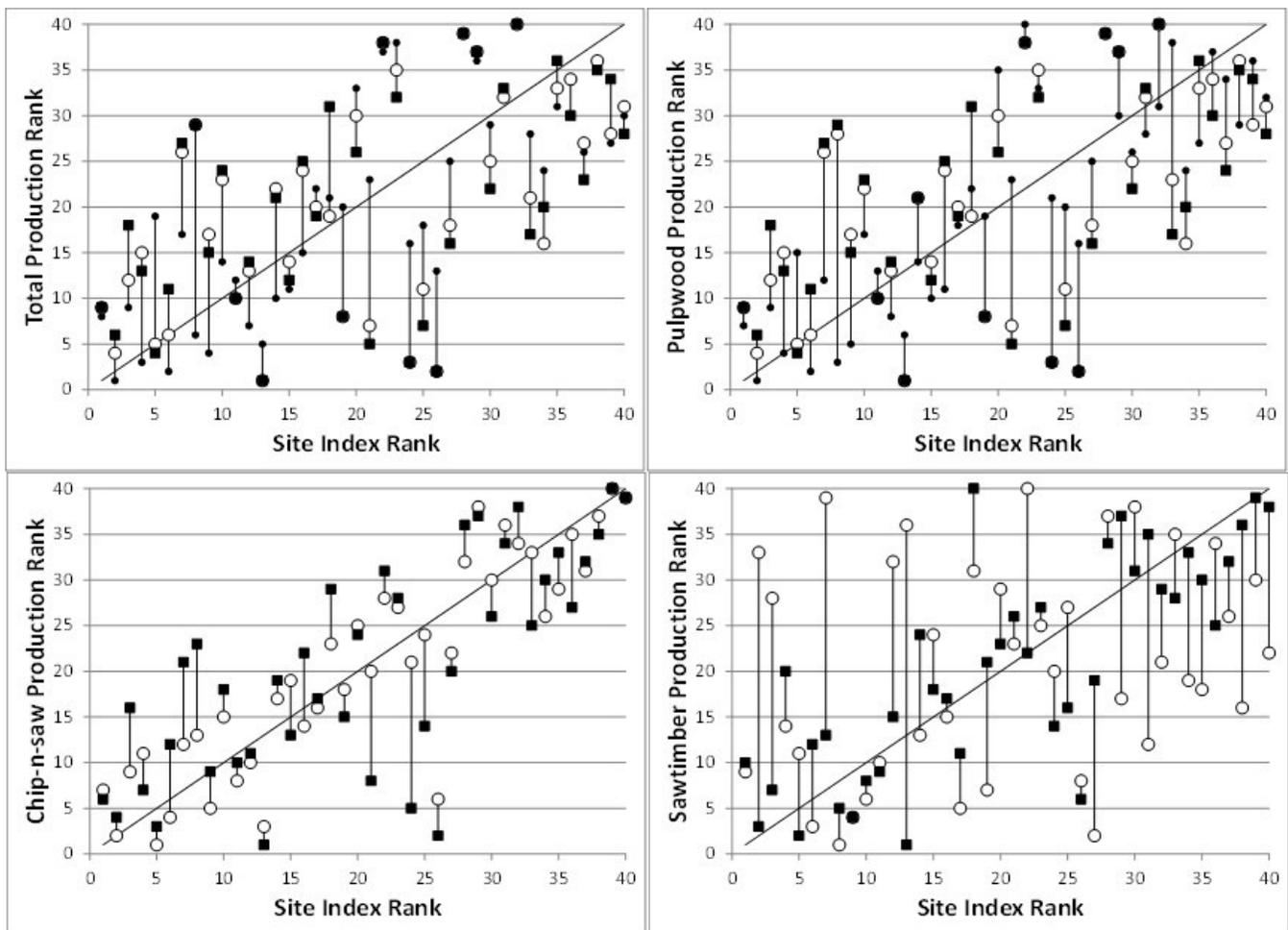


Figure 2—Ranks of the 40 longleaf pine plots by total, pulpwood, chip-n-saw, and sawtimber tons at ages 8, 25, and 39 over site index (base age 25) rank. The most productive site is 1, least productive is 40. Black filled circles are age 8, unfilled circles are age 25, and black filled squares are age 39. There are no age-8 values for chip-n-saw and sawtimber classes. $n = 40$ for each product and age. The black line is a one-to-one line.

One could analyze only those plots that had sawtimber at both ages 25 and 39, but that could eliminate the impacts of some, unidentified, biological limitation to using SI, such as why lower productivity sites eventually produced sawtimber at age 39. Table 4 also includes the change in yield rank across time for only those plots that had produced a particular product class at the younger age (Only plots with product yields). Although conducting this analysis had little impact on the relative relationship differences among species, when compared to the “All plots” analysis, absolute value changes in the relationships between sawtimber yield rankings (and hence SI) were substantially reduced for each species. For longleaf pine pulpwood at age 8, the change in ranks actually increased (7.3 to 8.2). This indicates that SI does distinguish low from high productivity sites, but, for example, does not always accurately distinguish the ability among sites that are considered to be highly productive. These results suggest that SI can essentially only tell you if a site has low or high productivity.

Self-thinning or the lack of self-thinning may play a part in the variability among paired rankings of yield and SI at

ages 25 and 39. More productive sites may start competing with each other sooner for limited site resources, and if self-thinning does not occur, then chip-n-saw and sawlog production at older ages may not be as high as if self-thinning occurred. The lack of self-thinning may allow lower-quality sites to “catch-up” to the yields of the higher-quality sites with time; this could cause some variability in the relative status in yield production of stands across time relative to their SI ranking. The paired rankings may be more consistent through time if a thinning treatment(s) was applied. However, productivity was low for many plots on this site, regardless of species, likely due in part to a relatively low planting density, and it is difficult to say whether self-thinning occurred or not, and if it did, had any meaningful impact on results from this analysis.

There are a variety of SI definitions (Anto'n-Ferna'ndez and others 2011, Burkhart and Tennent 1977, Cao and others 1997, Lenhart and others 1986, Ritchie and others 2012, Sharma and others 2002). The ability to differentiate the capability of sites to produce a particular product may differ by SI definition. For example, perhaps for sawtimber

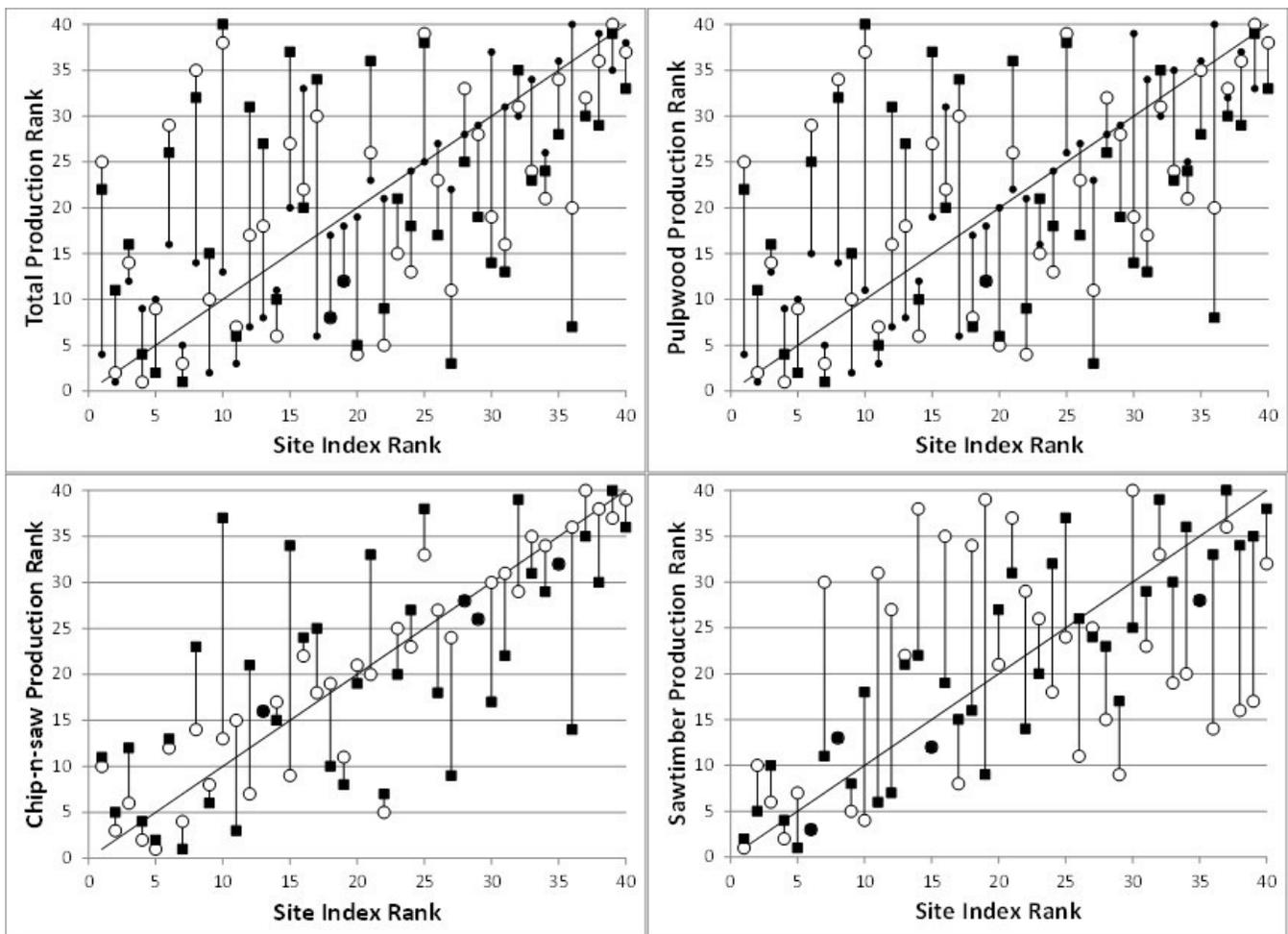


Figure 3—Ranks of the 40 slash pine plots by total, pulpwood, chip-n-saw, and sawtimber tons at ages 8, 25, and 39 over site index (base age 25) rank. The most productive site is 1, least productive is 40. Black filled circles are age 8, unfilled circles are age 25, and black filled squares are age 39. There are no age-8 values for chip-n-saw and sawtimber classes. $n = 40$ for each product and age. The black line is a one-to-one line.

yield, top height, or the average height of some amount of the largest diameter trees, may be better than using some type of height selection definition (e.g., predominant height or dominants and co-dominants). Further, top height may be better for sawtimber because of some artificially inflated correlation between sawtimber yield and different definitions of site quality since we are predicting yields (a yield equation) as a function of measured diameters and most often measured heights—sometimes even heights are predicted as a function of diameters. Future work should concentrate on seeing if different SI definitions have varying capabilities of determining the competitive status of plots and stands for a particular product class. As just noted, in most studies at least (except those where volume and weight are directly observed), a problem will be that stand volume and weight, or individual tree volume and weight, are predicted as a function of the observed heights, and thus there will likely be some artificially inflated correlation between those SI measures that are calculated using a larger number of tree heights, and volume and weight.

Oddly, determining the ability of SI, at a base age of 25, to rank the productive ability of sites is in part confounded with the impact of various management activities on other variables, such as survival and diameter growth. For instance, Haywood and Tiarks (2002), reported that dominant heights ranged from 39.4 to 40.2 feet and 45.6 to 45.9 feet at age 15, while cubic foot volume per acre ranged from 2,568 to 3,102 and 2,912 to 3,402, differing in levels due to varying mechanical site preparation, for loblolly and slash pine, respectively. In some ways it is good that dominant height was little affected by the mechanical site preparation treatments (disking and disking with bedding) because we have a consistent measure to compare this site to others, but since these treatments impacted survival, basal area, and ultimately volume, dominant height at age 15 (and SI at base age 25 estimated from it) is actually not a good measure of differentiating site productivity in this case. Kyle and others (2005) also showed inconsistencies to some degree for SI and volume production for sites receiving different site preparation and fertilization treatments. Bedding had the lowest SI (61 feet) and the lowest volume per acre (3,880

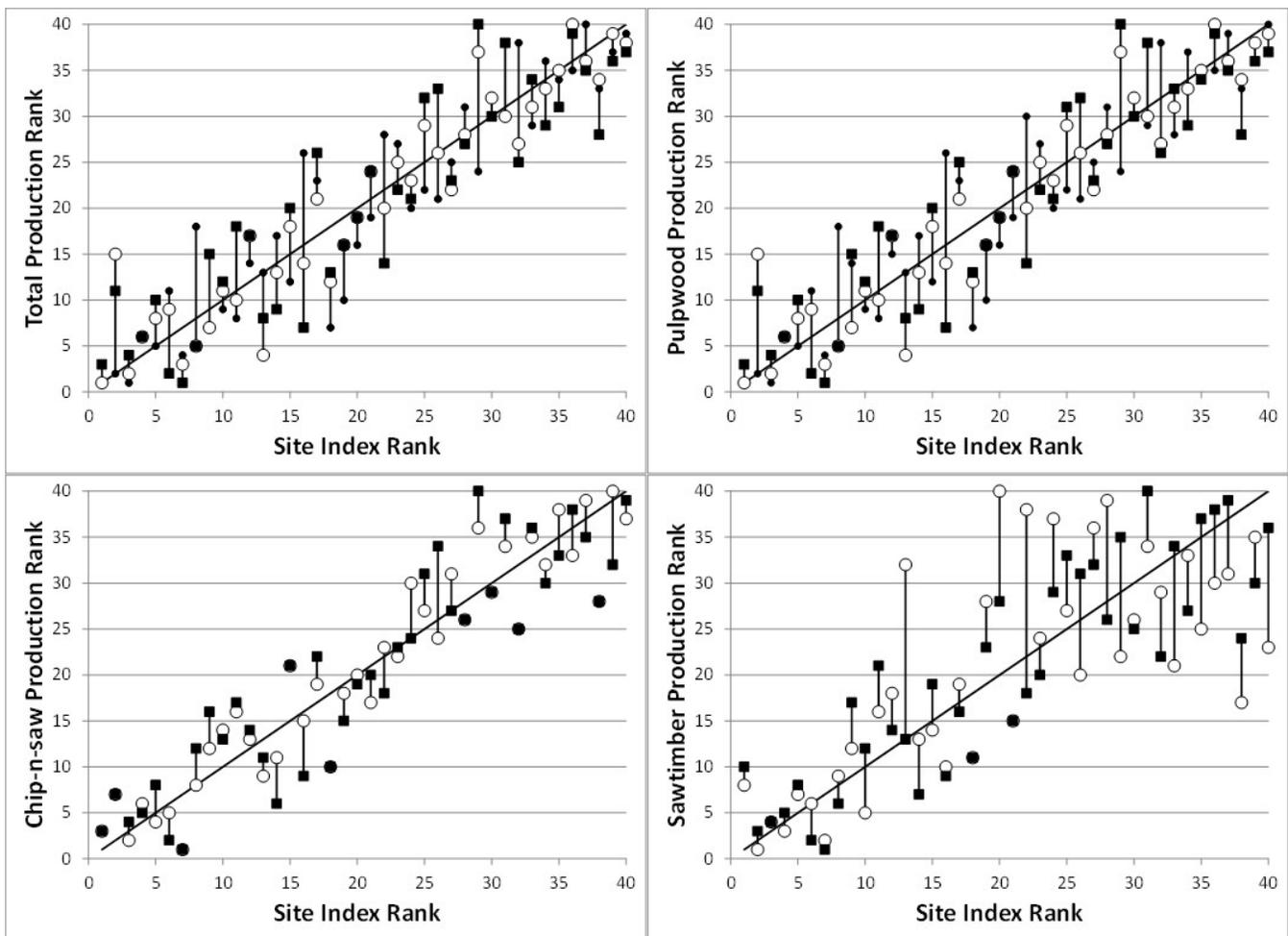


Figure 4—Ranks of the 40 loblolly pine plots by total, pulpwood, chip-n-saw, and sawtimber tons at ages 8, 25, and 39 over site index (base age 25) rank. The most productive site is 1, least productive is 40. Black filled circles are age 8, unfilled circles are age 25, and black filled squares are age 39. There are no age-8 values for chip-n-saw and sawtimber classes. $n = 40$ for each product and age. The black line is a one-to-one line.

cubic feet) at age 33, which is good, but chopping had a lower SI (66 feet) but higher volume production (4,846 versus 4,749) relative to ditching (68 feet). Some inconsistencies also occurred in the average volume and dominant height behavior across fertilization treatments.

One could argue that SI is a good measure of inherent site productivity, but not necessarily a good, or perhaps a better word is strong, measure of site productivity following the application of various silvicultural techniques. However, this is a whole other topic of study, and it may greatly depend on the definition of SI. For this study, it would be important to examine how the nitrogen, phosphorus, potassium (NPK) and cultivation treatments impacted the consistency of SI (base age 25) to rank the ability of plots to produce common product classes. However, we can view the experimental treatments in this study (e.g., NPK fertilization and disking) as creating different sites, and that we are in a way examining productivity on many different sites (while actually being at only one site). Hence, the results of this study are likely tainted because of the conflating (and thus confounding) impact of inherent versus enhanced site productivities, and

which one of these site productivities do we want to use in specifying one site is more productive than another.

Longleaf pine eventually attained similar productivity levels as loblolly and slash pine and often exceeded their production (table 1, fig. 1). Similar results were seen in Outcalt (1993), and some treatments of this study at age 50 (Samuelson and others 2012). In terms of the utility of SI to differentiate among stands for a particular species, SI better differentiates longleaf pine than slash pine, but SI appears best for loblolly pine. Obviously, this conclusion is site dependent, and is likely even SI-definition dependent.

CONCLUSIONS

This study shows SI is not always consistent across time to differentiate a site's ability to produce certain products. Most of the results were as expected, but this study provides quantification of the errors, and hence quantitative evidence. The greatest variability was observed in slash pine while the least was observed in loblolly pine. This study is unique in that all three species essentially existed on the same site,

and that the site exists in historic areas of all three species. Of course, different definitions of product classes, planting density, thinning, etc., would likely impact the results, as well as different definitions of SI. This study is another example of the importance of selecting a SI-base age that corresponds with the timing of management goals, such as final harvest, for SI to be a useful tool to differentiate the ability of sites to produce common wood products, particularly for longleaf and slash pine (table 2). Further study is needed to determine if SI (base age 25) always consistently ranks loblolly pine volume and weight productivity better throughout a rotation relative to longleaf and slash pine. Relative results in relation to SI's effectiveness among species on the same site may very well be dependent on genetic stock selected, planting density, thinning regimes, soil type, nutritive status, and control of undesirable vegetation.

ACKNOWLEDGMENTS

The author would like to thank Drs. Ralph Meldahl and John Kush of Auburn University for sharing the data.

LITERATURE CITED

- Akers, M.K.; Kane, M.; Zhao, D. [and others]. 2013. Effects of planting density and cultural intensity on stand and crown attributes of mid-rotation loblolly pine plantations. *Forest Ecology Management*. 310: 468–475.
- Amateis, R.L.; Burkhart, H.E. 1985. Site index curves for loblolly pine plantations on cutover site-prepared lands. *Southern Journal of Applied Forestry*. 9: 166–169.
- Anto'n-Ferna'ndez, C.; Burkhart, H.E.; Strub, M.; Amateis, R.L. 2011. Effects of initial spacing on height development of loblolly pine. *Forest Science*. 57: 201–211.
- Baldwin, V.C., Jr.; Saucier, J.R. 1983. Aboveground weight and volume of unthinned, planted longleaf pine on West Gulf forest sites. Res. Pap. SO-191. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 25 p.
- Boyer, W.D. 1983. Variations in height-over-age curves for young longleaf pine plantations. *Forest Science*. 29: 15–27.
- Burkhart, H.E.; Tennent, R.B. 1977. Site index equations for radiata pine in New Zealand. *New Zealand Journal of Forest Science*. 7: 408–416.
- Cao, Q.V.; Baldwin, V.C., Jr.; Lohrey, R.E. 1997. Site index curves for direct-seeded loblolly and longleaf pines in Louisiana. *Southern Journal of Applied Forestry*. 21: 134–138.
- Golden, M.S.; Meldahl, R.; Knowe, S.A.; Boyer, W.D. 1981. Predicting site index for old-field loblolly pine plantations. *Southern Journal of Applied Forestry*. 5: 109–114.
- Graney, D.L. 1977. Site index predictions for red oaks and white oak in the Boston Mountains of Arkansas. Res. Pap. SO-139. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 9 p.
- Harrington, C.A. 1991. PTSITE—A new method of site evaluation for loblolly pine: model development and user's guide. Gen. Tech. Rep. SO-81. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 28 p.
- Haywood, J.D.; Tiarks, A.E. 2002. Response of second-rotation southern pines to fertilizer and planting on old beds—fifteenth-year results. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 497–502.
- Haywood, J.D.; S-Sayer, M.A.; Sung, S.S. 2015. Comparison of planted loblolly, longleaf, and slash pine development through 10 growing seasons in central Louisiana—an argument for longleaf pine. In: Holley, A.G.; Connor, K.F.; Haywood, J.D., eds. Proceedings of the 17th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-203. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 383–390.
- King, J.E. 1966. Site index curves for Douglas-fir in the Pacific Northwest. Weyerhaeuser Forest Paper 8. Centralia, WA: Weyerhaeuser Company, Weyerhaeuser Forestry Research Center. 49 p.
- Kyle, K.H.; Andrews, L.J.; Fox, T.R. [and others]. 2005. Long-term effects of drainage, bedding, and fertilization on growth of loblolly pine (*Pinus taeda* L.) in the Coastal Plain of Virginia. *Southern Journal of Applied Forestry*. 29(4): 205–214.
- Lenhart, J.D.; Hackett, T.L.; Laman, C.J. [and others]. 1987. Tree content and taper functions for loblolly and slash pine trees planted on non-old fields in east Texas. *Southern Journal of Applied Forestry*. 11: 147–151.
- Lenhart, J.D.; Hunt, E.V., Jr.; Blackard, J.A. 1986. Site index equations for loblolly and slash pine plantations on non-old fields in east Texas. *Southern Journal of Applied Forestry*. 10: 109–112.
- MacFarlane, D.W.; Green, E.J.; Burkhart, H.E. 2000. Population density influences assessment and application of site index. *Canadian Journal of Forest Research*. 30: 1472–1475.
- McKeand, S.E.; Jokela, E.J.; Huber, D.A. [and others]. 2006. Performance of improved genotypes of loblolly pine across different soils, climates, and silvicultural inputs. *Forest Ecology and Management*. 227: 178–184.
- McTague, J.P. 2008. Modelling the response of loblolly pine to juvenile fertilization. *The Open Forest Science Journal*. 1: 80–88.
- Outcalt, K.W. 1993. Southern pines performance on sandhill sites in Georgia and South Carolina. *Southern Journal of Applied Forestry*. 17: 100–102.
- Ritchie, M.; Zhang, J.; Hamilton, T. 2012. Effects of stand density on top height estimation for ponderosa pine. *Western Journal of Applied Forestry*. 27: 18–24.
- Samuelson, L.J.; Stokes, T.A.; Johnsen, K.H. 2012. Ecophysiological comparison of 50-year-old longleaf pine, slash pine and loblolly pine. *Forest Ecology and Management*. 274: 108–115.
- Schmidting, R.C. 1984. Early intensive culture affects long-term growth of loblolly pine trees. *Forest Science*. 30: 491–498.
- Schmidting, R.C. 1987. Relative performance of longleaf compared to loblolly and slash pines under different levels of intensive culture. In: Phillips, D.R. comp. Proceedings of the 4th biennial southern silvicultural research conference, Atlanta, Georgia, 4-6, 1986. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station: 395–400.
- Sharma, M.; Amateis, R.L.; Burkhart, H.E. 2002. Top height definition and its effects on site index determination in thinned and unthinned loblolly pine plantations. *Forest Ecology and Management*. 168: 163–175.
- Subedi, P.; Jokela, E.J.; Vogel, J.G.; Martin, T.A. 2014. Inter-rotational effects of fertilization and weed control on juvenile loblolly pine productivity and nutrient dynamics. *Soil Science Society of America Journal*. 78(S1): S152–S167.
- Tiarks, A.E.; Haywood, J.D. 1996. Site preparation and fertilization effects on growth of slash pine for two rotations. *Soil Science Society of America Journal*. 60: 1654–1663.
- Zarnoch, S.J.; Feduccia, D.P. 1984. Slash pine plantation site index curves for the West Gulf. *Southern Journal of Applied Forestry*. 8: 223–225.
- Zhai, L.; Jokela, E.J.; Gezan, S.A.; Vogel, J.G. 2015. Family, environment and silviculture effects in pure-and mixed-family stands of loblolly (*Pinus taeda* L.) and slash (*P. elliottii* Engelm. Var. *elliottii*) pine. *Forest Ecology and Management*. 337: 28–40.

DEVELOPING A SIMPLE LONGLEAF PINE PLANTATION GROWTH AND YIELD MODEL FOR THE GULF REGION

Curtis L. VanderSchaaf

ABSTRACT

The longleaf pine (*Pinus palustris* P. Mill.) forest ecosystem was one of the most extensive in North America. This species produces valuable wood products but has the stigma of slow growth and hence was often not replanted following harvest. Thus, despite its timber value, only a few growth and yield models have been developed. This study examined the ability of four different modeling approaches to estimate merchantable volume of plantations in the Gulf region. Data used in model development are from the Forest Service, U.S. Department of Agriculture, Forest Inventory and Analysis (FIA) annual surveys conducted in Alabama, Florida, Louisiana, Mississippi, and Texas. Based on independent validation data from four different studies, one each in Mississippi and Alabama and two in Georgia, the approach predicting volume as a function of initial volume and age and the approach that first predicts basal area and then volume produced the best predictive statistics. However, neither approach was consistently best across all four validation studies. Based on these analyses, a single superior modeling approach was not identified.

INTRODUCTION

When using cross-sectional data to estimate future yields per acre (e.g., volume or tons), or using many observations of stands varying in age at the same point of measurement time, one of three growth and yield projection approaches to estimate yields are commonly used. The first is to predict future yield from a single equation based on calibrating the equation using currently observed yields (fig. 1). This is further referred to as Approaches One and Two where the same approach was used but differing in equation form. Fixed-effects regression predicts the average behavior of a dependent variable given regressors. By adjusting the average behavior given current, or local, stand conditions, the future estimate should be more responsive to local site conditions and practices impacting the yield trajectory of a stand through time.

A second method is similar to the first. However, to predict future yield, first another variable is calibrated (e.g., basal area per acre) as described above and then the future value of the other variable is used to predict the future yield. This is further referred to as Approach Three. This approach may be advantageous to One and Two if the equation used to predict basal area has superior model fit statistics relative to simply predicting yield, and then only if basal area has a strong relationship with the yield variable. Since basal area must first be predicted, and then the predicted basal area is used to predict yield, the error involved in predicting basal area is

“passed” to the equation to predict yield, and thus the first two approaches will likely be superior predictors of future yields (e.g., volume or tons).

The objective of this study was to examine the ability of these three different modeling approaches to estimate merchantable volume per acre of longleaf pine plantations in the Gulf region. This study will eventually lead to the development of a simple TDSS for longleaf pine plantations in the Gulf region.

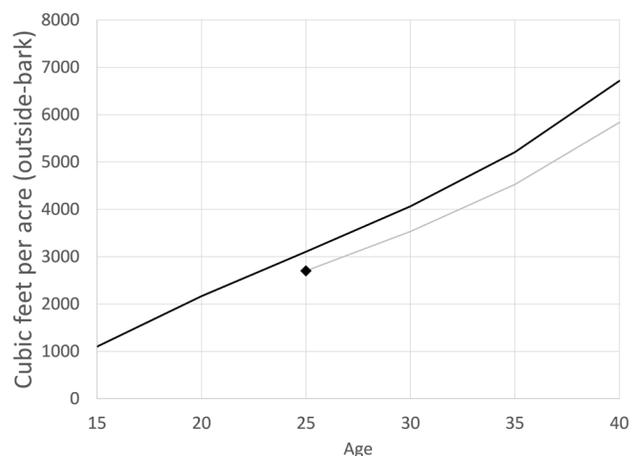


Figure 1—Example of calibrating an individual stand-level growth trajectory of a stand inventoried at age 25. Assuming the black line represents the average behavior for a site of stand conditions, the gray curve is generated by “calibrating” the average trajectory for this individual stand by taking the ratio of the predicted behavior at age 25 from the average curve to the volume based on an inventory at age 25. This ratio is then maintained throughout the rest of the projection.

Author Information: Curtis L. VanderSchaaf, Assistant Professor, Mississippi State University, Raymond, MS 39154.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

METHODS

The Forest Service, U.S. Department of Agriculture, Forest Inventory and Analysis (FIA) (Miles 2016) plots designated as longleaf pine plantations are located in the Western Gulf but concentrated in the Eastern Gulf region (fig. 2). According to FIA there are 245,227 acres in Alabama, 223,870 acres in Florida, 18,215 acres in Louisiana, 39,868 acres in Mississippi, and 17,761 acres in Texas.

The data used in model development were obtained from FIA annual surveys. The FIA panels used varied by State. Panels from 2006 to 2015, 2010 to 2014, 2001 to 2013, 2006 to 2014, and 2004 to 2012 were used for Alabama, Florida, Louisiana, Mississippi, and Texas, respectively. Data were obtained from the FIA database website (USDA Forest Service 2016).

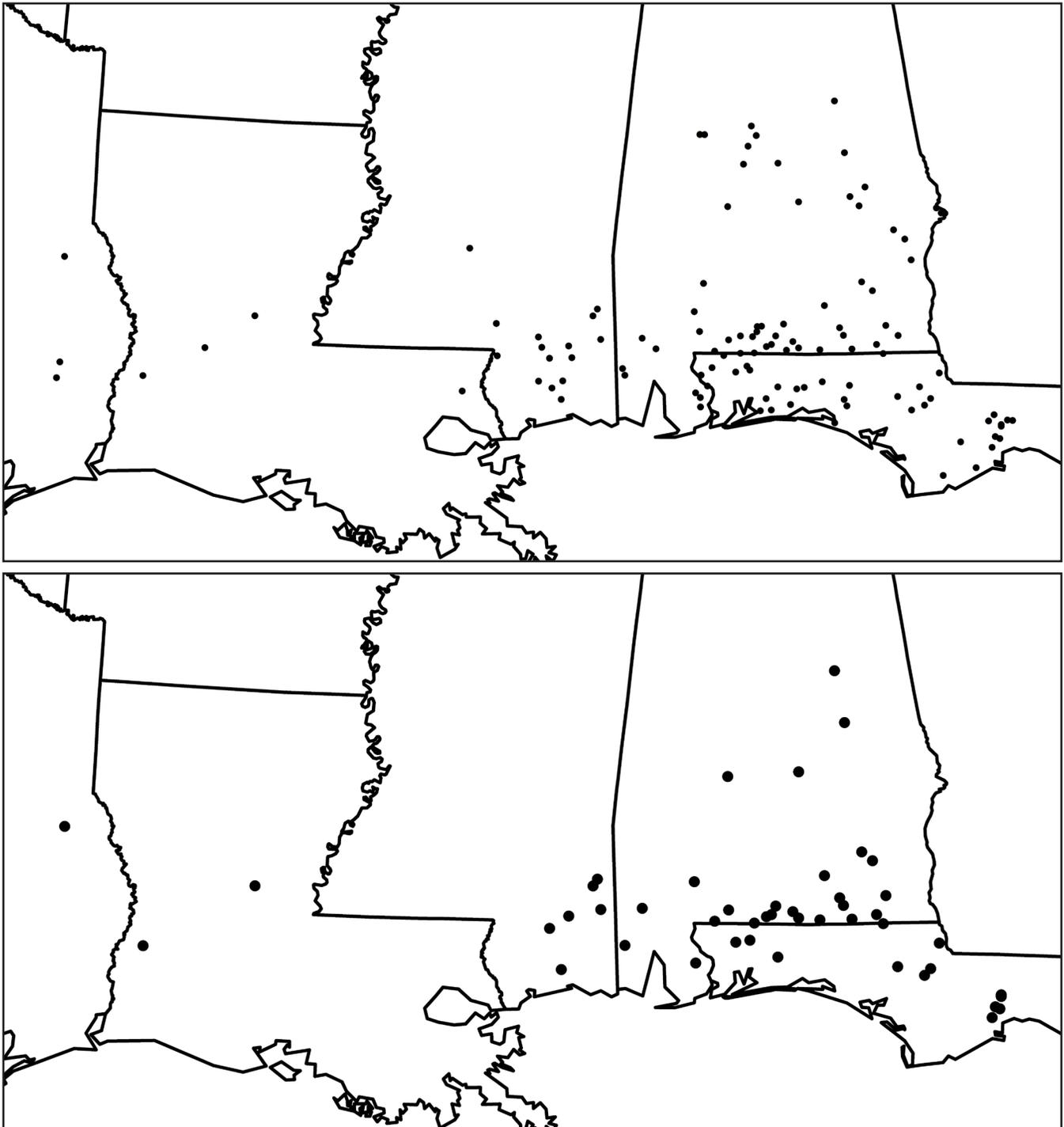


Figure 2—Spatial location of the 116 Forest Inventory and Analysis (FIA) plots designated as longleaf pine plantations (upper). Spatial location of the 47 FIA plots used in model development (lower).

Model Fitting Data

Only those plots considered plantations by FIA (STDORGCD = 1 in the FIA Condition table) were used, as these plots have sufficient evidence to be classified as plantations. Only living trees were included (STATUSCD = 1 in the FIA Tree table), all tree classes were included (TREECLCD within the FIA Tree table was not used to filter the data), all ownerships were included (OWNCD in the FIA Condition table was not used to filter the data), and FIA timberland was used (SITECLCD from 1 to 6 in the FIA Condition table). Table 1 presents summary data for the plots used in model development and figure 2 graphically locates the plots.

Dominant height of a particular plot for model development was defined as the average height of the tallest 50 percent of all surviving longleaf pine trees—consistent

with the definition of Boyer (1980). All plots of age less than 5 were removed due to concerns about the reliability of volume estimates and all plots with four or fewer longleaf pine trees used to calculate dominant height were removed because sample sizes are likely too low to provide a reliable estimate of dominant height. Plots that had a ratio of dominant height and stand age (STDAGE in the FIA Condition table) less than 1.22 were removed (two plots), because dominant heights were 30 feet and 46 feet at ages 27 and 38, respectively. One plot greater in age than 70 was deleted. One observation was deleted because after initially calculating site index (base age 25) using equation 2, the estimated site index exceeded 100 feet. The observed dominant height for this stand at age 8 was 45 feet. Following deletion of this observation, the

Table 1—Summary statistics (upper table) by State and across the entire model fitting dataset for the Forest Inventory and Analysis (FIA) plots used in model development (n = 47). Summary statistics (lower table) for the four validation datasets

State	n	Stand age				Basal area per acre (square feet)				Cubic feet per acre				Dominant height (feet)				Site index (feet, base age 25)			
		M	S	Min.	Max.	M	S	Min.	Max.	M	S	Min.	Max.	M	S	Min.	Max.	M	S	Min.	Max.
Alabama	25	18	8	10	45	88	40	40	236	1,185	804	188	3,217	48	13	27	80	59	7	43	70
Florida	13	23	10	11	40	61	29	27	113	786	636	210	2,058	49	12	34	69	54	9	38	66
Louisiana	2	34	10	27	41	111	17	99	123	2,489	341	2,248	2,730	73	3	71	75	67	9	61	73
Mississippi	6	26	6	17	32	108	41	56	167	1,859	712	605	2,670	59	7	46	66	59	4	55	66
Texas	1	28	-	28	28	100	-	100	100	1,989	-	1,989	1,989	65	-	65	65	62	-	62	62
All	47	21	9	10	45	84	39	27	236	1,233	831	188	3,217	51	13	27	80	58	8	38	73

State	n	Stand age				Basal area per acre (square feet)				Cubic feet per acre				Dominant height (feet)			
		M	SD	Min.	Max.	M	SD	Min.	Max.	M	SD	Min.	Max.				
Mississippi	40	8	17	11	1	35	38	51	0	192	22	7	8	30			
	40	25	48	21	8	98	963	486	142	2163	60	6	47	69			
	40	39	69	28	17	133	1,782	784	407	3,799	74	6	58	85			
Alabama	6	7, 8, 10, 11	33	11	19	46	130	128	8	285	22.8	5.1	17.0	29.0			
Cuthbert, GA	5	7	19	5	12	23	240	82	112	313			
	5	9	32	6	24	38	460	101	315	561	20.6	1.6	18.3	22.2			
Tift, GA	3	17	118	8	113	127	3,368	414	3,096	3,845	56.9 ^a	0.4	56.4	57.3			
	3	21	134	11	126	146	4,634	532	4,261	5,243	66.5 ^a	0.1	66.4	66.5			

M = mean; SD = standard deviation; Min. = minimum; Max. = maximum; - = no reported height.

^aFor Tift, GA, dominant height was calculated by multiplying reported average height by 1.0939390541.

parameters of equation 2 were then re-estimated. The final sample size used in model fitting was $n = 47$ observations.

Merchantable volume as defined by FIA (VOLCFNET within the FIA Tree table) was used as the dependent variable. Essentially, this is the merchantable volume of trees with diameter at breast height (d.b.h.) of 5.0 inches and greater, from a 1-foot stump to a minimum 4.0 inches top diameter.

Stand-Level Model Development

Equations were selected based on both biological and statistical considerations. Parameter estimates were checked to make sure they were consistent with biological theory (e.g., with age volume per acre should increase). Additionally, predicted values of stand development were examined to determine whether a particular equation or sets of equations produced reasonable estimates across a range of ages and values of the regressors. After accounting for biologically meaningful variables, the function with the highest Adjusted $R^2(s)$ was selected. Residuals were examined for trends. Proc Model (SAS 1989) and the Gauss-Newton algorithm were used to estimate parameters of all equations.

Dominant Height Equation

A widely accepted site index equation for longleaf pine plantations does not exist. Hence, an equation was developed. A simple anamorphic guide curve approach was selected using equation 1:

$$Ht_D = e^{\beta_0 + \beta_1 A^{-1}} \quad (1)$$

where

Ht_D = dominant height (feet), defined as the average height of the tallest 50 percent of surviving longleaf pine trees (other species were not selected), within a FIA plot

A = plot age (STDAGE in the FIA Condition table)

β_0, β_1 = parameters to be estimated

After removing plots of young ages and low numbers of trees, a total of 47 FIA plots were used in model development. After fitting (Adjusted $R^2 = 0.7312$) and algebraic manipulation, equation 1 becomes:

$$SI = Ht_D e^{(25^{-1} - A^{-1}) \cdot 10.7364} \quad (2)$$

where

SI = dominant height at a reference base age of 25 years, and others as previously defined.

Equation 3 is used to predict dominant height:

$$Ht_D = SI e^{(25^{-1} - A^{-1}) \cdot 10.7364} \quad (3)$$

Predicting Volume

Approach One—For Approach One, equation 4 was used to estimate volume per acre:

$$Vol = \beta_2 (1 - e^{-\beta_3 A})^{1 - \beta_4} \quad (4)$$

where

Vol = volume of trees of d.b.h. 5.0 inches and greater from a 1-foot stump to a 4-inch top diameter outside-bark (essentially trees merchantable for pulpwood, sawtimber, veneer, etc.). Within FIADB, the variables VOLCFNET and TPA_UNADJ are used to estimate individual tree volume on a plot basis, merchantable trees of all species,

$\beta_2, \beta_3, \beta_4$ = parameters to be estimated, and others as previously defined.

Approach Two—Alternatively, equation 5 contains an estimate of site quality–dominant height:

$$Vol = \beta_5 (1 - e^{-\beta_6 A})^{1 - \beta_7 Ht_D} \quad (5)$$

where

$\beta_5, \beta_6, \beta_7$ = parameters to be estimated, and others as previously defined.

To project a stand trajectory forward, after algebraic manipulation, equation 4 becomes:

$$Vol_2 = Vol_1 \left[\frac{1 - e^{-\beta_3 A_2}}{1 - e^{-\beta_3 A_1}} \right]^{1 - \beta_4} \quad (6)$$

where

A_1 = plot age at the current time; A_2 = desired future plot age, and others as previously defined.

And, to project a stand trajectory forward, after algebraic manipulation, equation 5 becomes:

$$Vol_2 = Vol_1 \left[\frac{1 - e^{-\beta_6 A_2}}{1 - e^{-\beta_6 A_1}} \right]^{1 - \beta_7 Ht_D} \quad (7)$$

Hence, we can “calibrate” equations 4 or 5 to local site conditions and practices such as site preparation, herbaceous weed control treatments, planting density, etc., through the use of Vol_1 .

Approach Three—For this approach the following equation was used to first estimate basal area per acre:

$$BA = e^{\beta_8 + \beta_9 A^{-1}} \quad (8)$$

where

BA = square feet of basal area per acre of all surviving trees (trees of all species, and whether the trees are merchantable or not) within the plot; β_8, β_9 = parameters to be estimated, and others as previously defined.

After algebraic manipulation of equation 8 similarly to equation 1, equation 9 is produced:

$$BA_2 = BA_1 e^{(A_2^{-1} - A_1^{-1}) \beta_9} \quad (9)$$

Equation 10 is then used to predict volume:

$$Vol = \beta_{10} BA Ht_D \quad (10)$$

For Approach Three, to avoid potential simultaneous equation bias and to account for potential cross-equation correlation of the residuals, a simultaneous parameter

estimation methodology (Borders 1989) was used to estimate parameters of equations 8 and 10.

Validation Data

To gain insight into which approach will produce the most accurate and precise estimates of future growth and yield, predictions were made using unthinned plantations established in southern Mississippi (Schmidting 1987). All individual tree data were obtained from longleaf pine growing on the Harrison Experimental Forest near Saucier, MS. This study consisted of testing whether plowing and discing combined with a single application of NPK fertilizer disced into the soil 1 year after planting increased yield. Seed sources differing in whether specific gravity was low or high were also tested. Cultivated plots were cleared of all stumps and slash, then plowed and disced. Cultivation consisted of discing 3 times each season for 3 years after planting and mowing in the 4th and 5th seasons. All seedlings were 1-0 bareroot stock of a local seed source planted in 1960 at a 10 feet by 10 feet spacing. There were four replications consisting of 10 plots. Each plot contained 100 trees. Total tree height and d.b.h. measurements were conducted at ages 8, 25, and 39, and volumes were predicted for ages 8, 25, and 39. Dead trees after the first growing season were replanted.

The definition of volume was consistent with FIA's definition as defined for Vol in equation 4. Volume of trees of d.b.h. 5.0 inches and greater from a 1-foot stump to a 4-inch top diameter outside-bark (essentially trees merchantable for pulpwood, chip-n-saw, sawtimber, etc.). Individual tree volumes were estimated using equations found in Gonzalez-Benecke and others (2014). For this study, age 8 data were used as the initial measurement for predictions at age 25 and age 25 data were used as the initial measurement for predictions at age 39. These long predictive intervals will likely impact predictive ability. For Approaches Two and Three, the observed dominant heights at ages 25 and 39 were used. In practice, these dominant heights would need to be predicted using equation 3. This study is further referred to as the Mississippi study. Table 1 presents summary data for the plots used in model validation.

Farrar and White (1983) provided the second unthinned validation dataset. They state that all site preparation treatments essentially resulted in complete destruction of woody vegetation and thus removal of all sources of brownspot needle blight (*Scirrhia acicola* Dearn. Siggers) infection. All planting stock was 1-0 bareroot, machine-planted, and densities ranged from 1,132 to 1,271 seedlings per acre. No additional cultural treatments were conducted beyond site preparation, thus there was no first-year herbaceous weed control treatment. Study sites were located within Escambia County, AL. Initial measurement data at sites were ages 7 and 8 while the predictive ages were either 10 or

11, respectively. For Approaches Two and Three, the observed dominant heights at ages 10 or 11 were used. In practice, these dominant heights would need to be predicted using equation 3. This study is further referred to as the Alabama study.

The second published source was obtained from an unthinned plantation established near Cuthbert, GA (Creighton 1987, Knowe 1982, Lauer 1990). Previous land use was a 20-year-old slash pine plantation and site preparation consisted of chopping and discing. Planting density was 726 seedlings per acre (5 feet by 12 feet), machine planted (likely bareroot stock). This study examined how varying number and application method (either banded or broadcast) of annual herbaceous weed control treatments affected yield. Treatments consisted of no control, first-year, or first- and second-year herbicide applications to control herbaceous weeds. The initial measurements were conducted at age 7 while age 9 measurements were predicted. For Approaches Two and Three, the observed dominant heights at age 9 were used. In practice, these dominant heights would need to be predicted using equation 3. This study is further referred to as the Cuthbert, GA study.

The third published source was obtained from an unthinned plantation established on a former old-field in Tift County, GA (Dickens and others 2012). Site preparation consisted of chisel plowing, followed by Oust sprayed in years 1 and 2 post-plant and the site was burned in year 2. Planting density was 605 bareroot seedlings per acre (6 feet by 12 feet). This study examined how NPK fertilization would impact growth rates. Measurements were conducted at ages 17 and 21. The initial measurement age was 17 and the predictive age was 21. Dominant height was not reported, but average height was presented. To estimate dominant height, dominant height was calculated using the reported average heights and the ratio between the average and dominant heights at age 25 from the Mississippi study, a value of 1.0939390541. Dominant height was defined as the average height of the tallest 50 percent of surviving longleaf pine trees, consistent with equation 3. The value of 1.0939390541 (used for internal calculations) is similar to the ratio between reported dominant height and average height at age 9 in the Cuthbert, GA study of 1.114031. The Mississippi ratio was used since the data was similar in age and to some degree planting density to the Tift, GA study. This study is further referred to as the Tift, GA study.

Validation Analyses

Validation analyses follow those presented in Trincado and others (2007). The difference between the predicted (Vol_{pred}) and observed volumes (Vol_{obs}) for the four modeling approaches was calculated ($e = Vol_{pred} - Vol_{obs}$) for each validation plot/observation within a particular study. The mean residual (\bar{e}) and the sample variance (v) of residuals were computed by study and age for each modeling approach

and considered to be estimates of bias and precision, respectively. An estimate of mean square error (MSE) was obtained by study for each modeling approach by combining the bias and precision measures using the following formula:

$$MSE = \bar{e}^2 + v \quad (11)$$

RESULTS AND DISCUSSION

Parameter estimates and model fitting results are presented in table 2. For the Mississippi study, all modeling approaches underpredicted volumes (figs. 3 and 4, table 3). In some cases, predictions were consistently severely low. Once again this is likely in part due to the extremely long prediction intervals. All modeling approaches use current inventory data to in a sense “calibrate” the models for that plots specific growing conditions. Hence, it may be that 3- or 5-year intervals would produce better predictions. Additionally, volumes on this site are inherently low. Perhaps the model fitting data in general will not produce adequate predictions for this site. However, that is the purpose of the initial measurement—to help “calibrate” the models. Modeling

Approach Three, although not satisfactory, clearly produced the best predictive statistics. A problem with Approaches One and Two is that if the previous volume was 0, there will be no predicted future volume, this can be seen for $n = 16$ observations in figure 3. This is an advantage of Approach Three, when applying this model to most stands at ages 5 and older, some amount of basal area will exist, and hence some amount of volume will be predicted since volume is predicted (equation 10) as a function of basal area from equation 9 and the dominant height.

Similarly, Approach Three produced the best predictive results in the Alabama study (fig. 5, table 3). Approach Three actually produced reasonable predictions that may be acceptable by users. The predictive intervals were only 3 years which may have resulted in the better predictive ability relative to the Mississippi study.

For the two Georgia studies of common approaches, Approach One produced the best predictive statistics by meaningful amounts. Approach Three did not produce acceptable results. The Tift, GA site is an old-field, this could have had some impact on predictions.

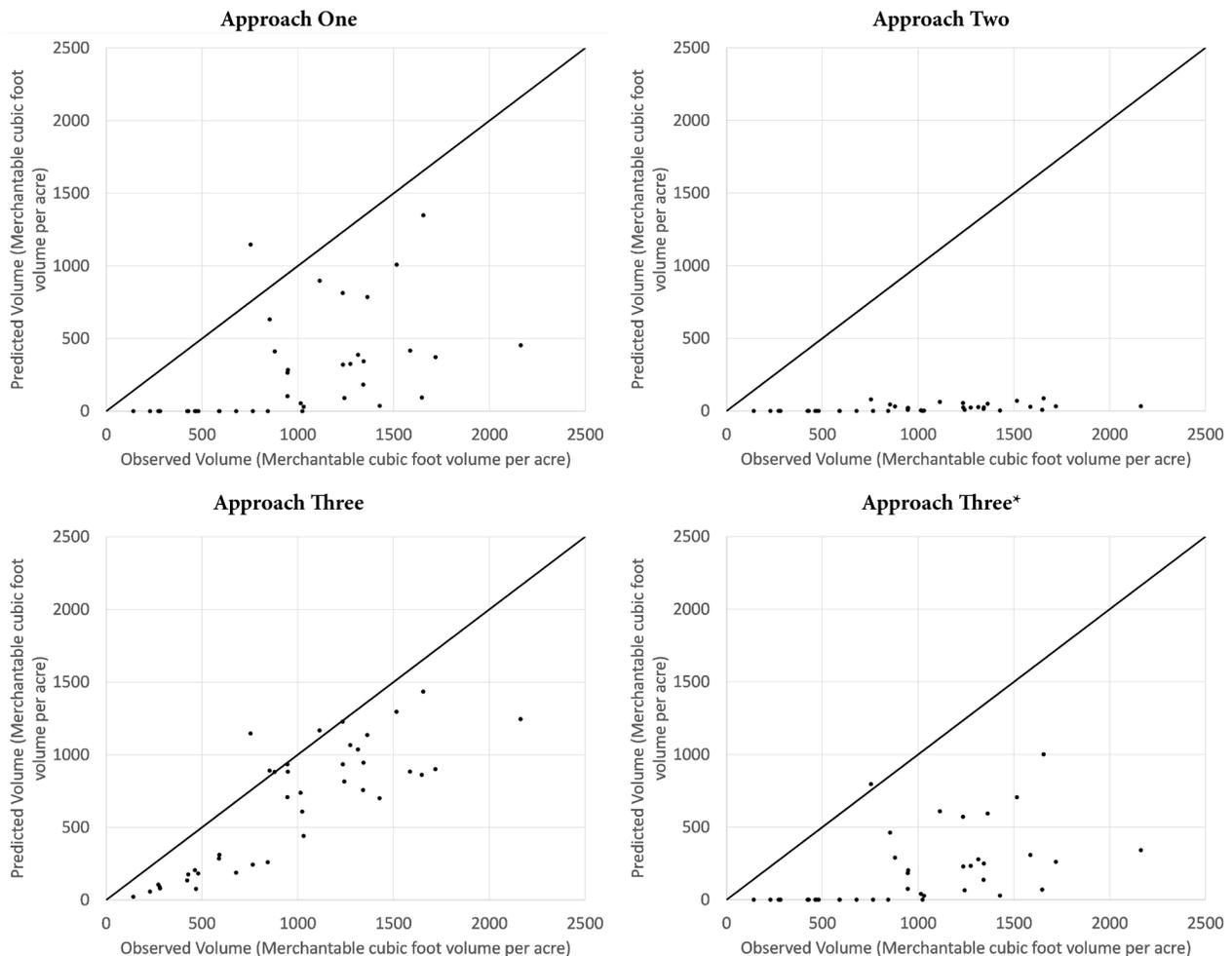


Figure 3—Model validation results of the four approaches from the Mississippi study at age 25. Black lines are one-to-one predictions. $n = 40$.

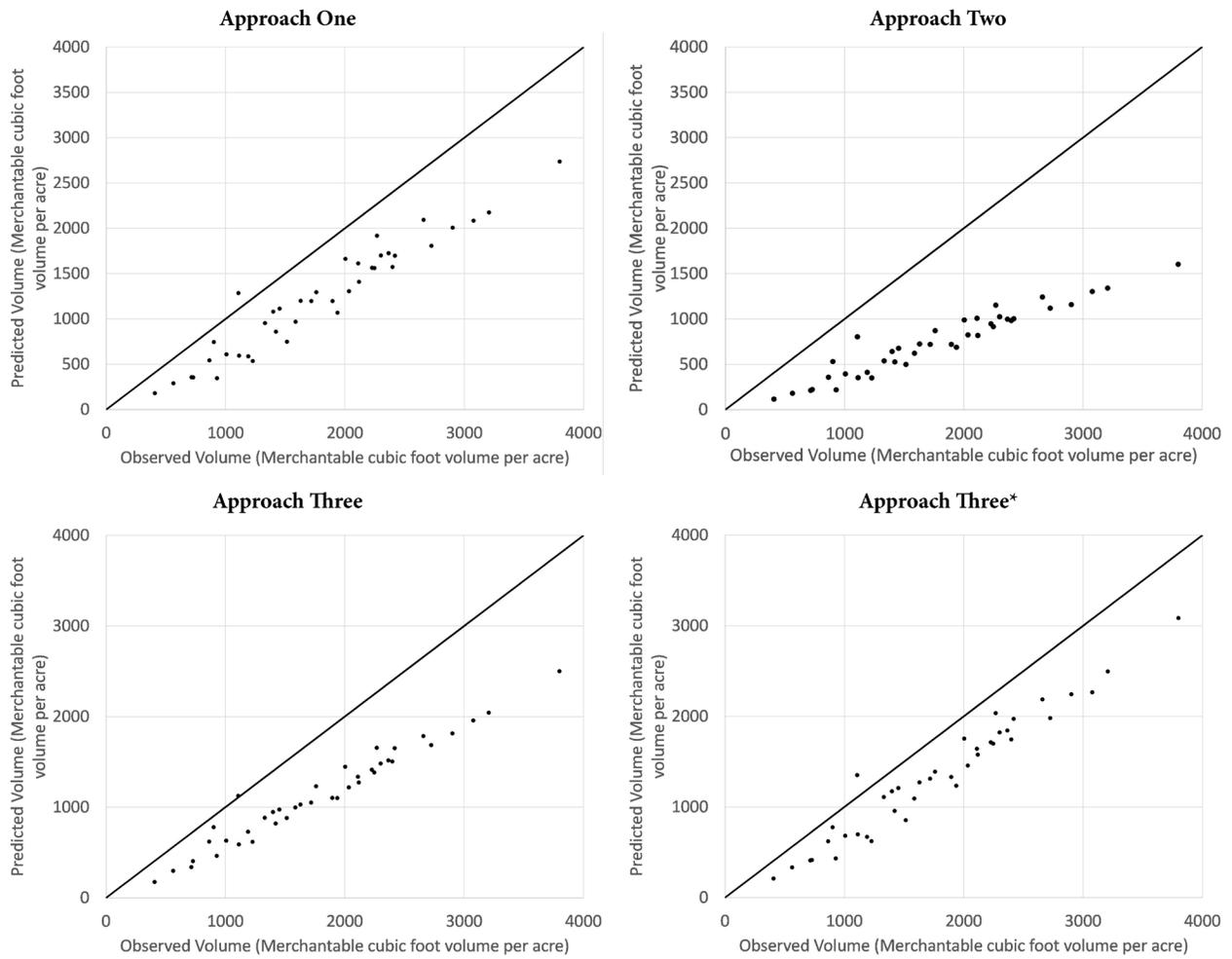


Figure 4—Model validation results of the four approaches from the Mississippi study at age 39. Black lines are one-to-one predictions. $n = 40$.

Table 2—Parameter estimates of equations 4, 5, 8, and 10 ($n = 47$)

Equation	Adj. R_2	Parameters	Estimate	Approximate Standard Error	t -value	$Pr > t $
4	0.3806	β_2	2178.996	480.3	4.54	<.0001
		β_3	0.104124	0.0675	1.54	0.1298
		β_4	0.746766	0.2465	3.03	0.0041
5	0.6809	β_5	650.7229	293.5	2.22	0.0318
		β_6	0.007	0.00163	4.30	<.0001
		β_7	0.025319	0.00448	5.65	<.0001
8	0.1055	β_8	4.905399	0.1652	29.70	<.0001
		β_9	-9.00891	3.1934	-2.82	0.0071
10	0.8463	β_{10}	0.277065	0.00880	31.49	<.0001

Table 3—Model validation results of cubic foot volume and square feet of basal area per acre using the three modeling approaches for the four validation datasets

Mississippi, Schmidting (1987), $n = 80$, $n = 40$ within parentheses				
Approach	Error			MSE
	\bar{e}	v	$\bar{e}\%$	
One	-628 (-693 & -564)	128581	-45.8 (-72.0 & -31.6)	523255 (665552 & 384042)
Two	-1028 (-944 & -1113)	233584	-74.9 (-98.0 & -62.5)	1291260 (1115083 & 1473062)
Three	-478 (-312 & -645)	105535	-34.9 (-32.4 & -36.2)	334462 (167983 & 502220)
Three*	-604 (-769 & -440)	132919	-44.0 (-79.9 & -24.7)	498178 (761742 & 236634)

Alabama, Farrar and White (1983), $n = 3$				
Approach	Error			MSE
	\bar{e}	v	$\bar{e}\%$	
One	-211	1436	-86.2%	45917
Two	-229	1357	-93.6%	53688
Three	19	2911	7.8%	3264
Three*	-214	1480	-87.5%	47122

Cuthbert, GA, Knowe (1982), Creighton (1987), Lauer (1990), $n = 5$				
Approach	Error			MSE
	\bar{e}	v	$\bar{e}\%$	
One	-7	3289	-1.5%	3336
Two	-192	386	-41.7%	37104
Three	-313	3078	-68.0%	101355

Tift, GA, Dickens and others (2012), $n = 3$				
Approach	Error			MSE
	\bar{e}	v	$\bar{e}\%$	
One	-236	13003	-5.1%	68492
Two	-1691	37115	-36.5%	2897480
Three	-2230	143684	-48.1%	5117889
Three*	-285	9449	-6.1%	90851

Basal area per acre study	Error			MSE
	\bar{e}	v	$\bar{e}\%$	
Mississippi ($n = 80$)	-12.3 (-10.6 & -14.0)	147	-21.1 (-22.2 & -20.3)	298 (349 & 250)
Alabama ($n = 3$)	-7.7	25	-18.2%	85
Cuthbert, GA ($n = 5$)	-6.7	2	-21.0%	47
Tift, GA ($n = 3$)	-3.1	8	-2.3%	18

\bar{e} , v , $\bar{e}\%$, and MSE are the mean error, variance of the errors, percent mean error, and mean square error, respectively, for a particular study and approach, as expressed in equation 11. For Approach Three* rather than using the parameter estimate for β_{10} of 0.277065 in equation 10, an observation-specific ratio using equation 12 was used, calculated using data from the previous (or current) measurement. For the Mississippi study, the first number in parentheses corresponds to age 25 results and the second number corresponds to age 39 results.

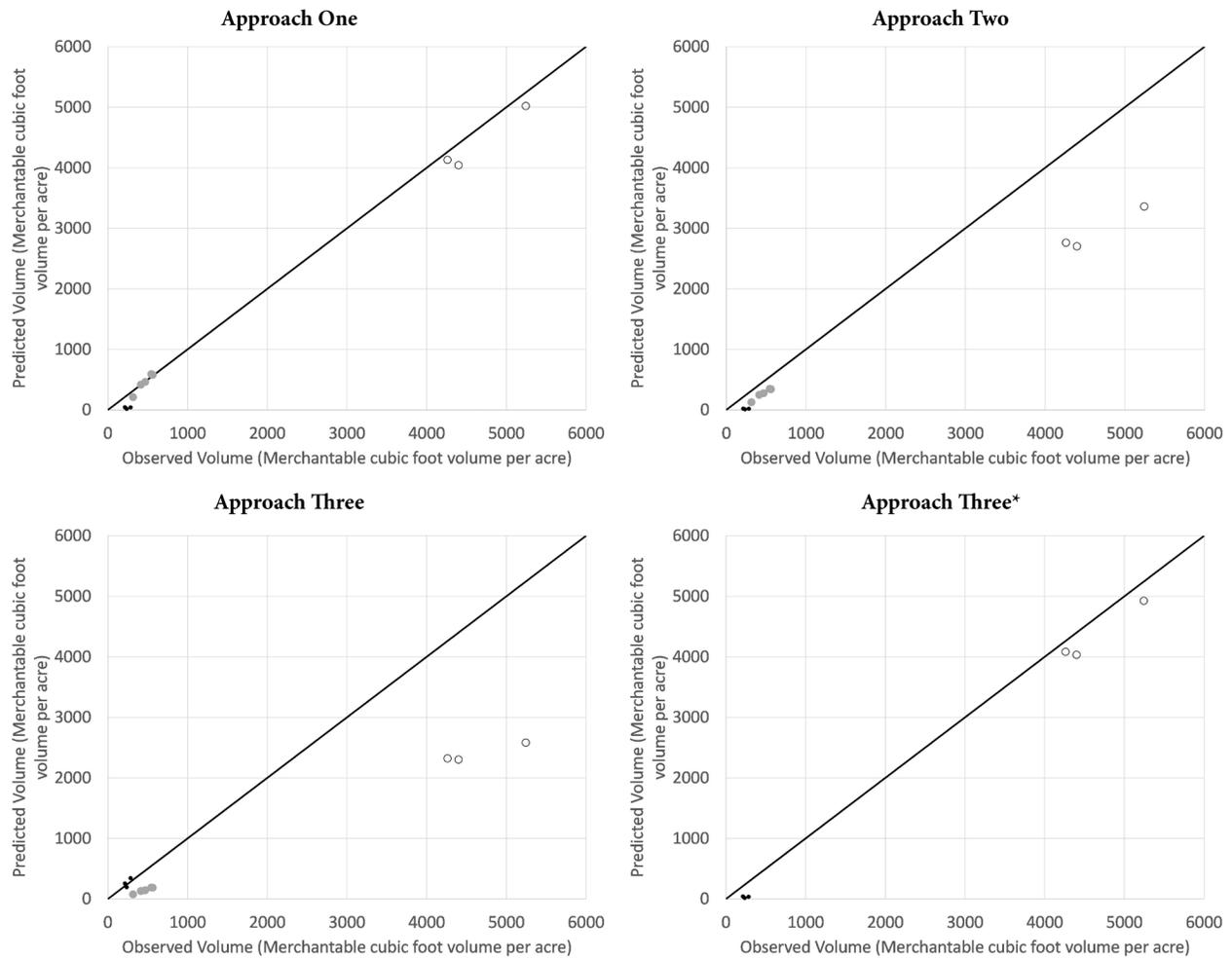


Figure 5—Model validation results of the four approaches from the Alabama (black circles $n = 3$), Cuthbert, GA (gray circles $n = 5$), and Tift, GA (unfilled circles $n = 3$) studies. Black lines are one-to-one predictions.

Equation 9 produced good estimates of basal area for the Tift, GA site (table 3), a percent error of 2.3 percent. However, Approach Three did not produce very good volume estimates, likely because the estimated value of β_{10} is not appropriate for the Tift, GA dataset. Therefore, equation 12 was used to determine a mathematically-derived value of β_{10} using previous measurement age observations. This allows a user to produce an estimate of β_{10} that is more indicative of the local genetic stock, stand densities, and their impacts on form and taper rates when estimating merchantable volume.

$$Vol_{A_i} / [BA_{A_i} * H_{D_{A_i}}] = \beta_{10i} \quad (12)$$

where

β_{10i} = parameter mathematically-derived for each stand/plot (i) at a particular age using the previous (or current) measurement age (A_i) volume, basal area per acre, and dominant height.

This approach, further referred to as Approach Three*, substantially improved volume estimates at the Tift, GA site relative to Approach Three, but they were still not as good as

Approach One. Approach Three* did not produce acceptable results at the Mississippi site as a whole and the Alabama site. At the Mississippi site, overall, this likely resulted in part from the long prediction intervals, making the previous value of β_{10i} not applicable for the estimated age. However, for volume, when predicting from age 25 to 39 the lowest percent error at the Mississippi site was observed (-24.7 percent). At both the Mississippi and Alabama sites, basal area was not accurately predicted, equation 9 produced percent errors of 21.1 percent and 18.2 percent at the Mississippi and Alabama sites, respectively. These relatively poor results likely were produced at the Mississippi site because of the long prediction intervals and the sporadic survival, producing in some cases low basal areas, and the young previous ages (ages 7 or 8) and low productivities, likely due to minimal vegetation control after establishment, at the Alabama site. There was no reported previous dominant height (at age 7) at the Cuthbert, GA site. Similar to Approaches One and Two, a problem with Approach Three* is that if the previous volume was 0 there

will be no predicted future volume (see equations 10 and 12). This can be seen for $n = 16$ observations in figure 3.

Validation analyses show substantial variability. Based on these results it is difficult to suggest a particular prediction approach across all four validation studies. Approach One produced the best results for two studies, while Approach Three produced the best results at the two other studies. And while Approach Three* never produced the best results, it was second, or nearly so, in the three studies where the approach was used. Additionally, it produced the lowest percent error when predicting from age 25 to age 39 at the Mississippi site. Approach One, since it has a means to in a sense “calibrate” the volume predictions to that site’s specific characteristics through Vol_1 , is likely the method that should be suggested. However, the use of equation 12 to produce a stand-specific estimate of β_{10} , or β_{10}^* , produced solid predictions when using Approach Three* for initial measurement ages greater than 10, which were the Tift, GA study and when predicting volume at age 39 using age 25 observed volumes at the Mississippi study. For younger initial ages, it often did not produce satisfactory results. Approaches Three and Three* also have an advantage of providing a basal area per acre estimate. Approach Two consistently produced unsatisfactory prediction statistics.

These validation studies were purposefully chosen because they vary widely in their ages, site conditions (e.g., old-field versus cutover), planting densities, and prediction intervals. Young ages, such as those less than 10 years old, seem to have relatively poorer prediction results. This is particularly true of low productivity sites such as the Alabama study. Vegetation control is essential for longleaf survival and productivity during the first year or two following establishment (Lauer 1990, Nelson and others 1985). The Alabama study only consisted of site preparation treatments (Farrar and White 1983) and that likely contributed to the low productivity, and likely the poor prediction results. In general, relatively poorer results were observed for the Mississippi study when predicting from age 8 to 25 than from age 25 to 39 (figs. 3 and 4, table 3). It appears that when young previous measurement age data (e.g., less than 10) is used to estimate β_{10} (equation 12), that the ratios are not applicable to older ages and hence generally result in poor prediction results when using Approach Three*.

Projection intervals should be no greater than 5 years. Longer projection intervals will likely result in poor predictions. Unfortunately, at this time, a consistently best modeling approach was not identified. If these equations are used, managers should use these tools along with other available tools when making management decisions.

LITERATURE CITED

- Borders, B.E. 1989. Systems of equations in forest stand modeling. *Forest Science*. 35(2): 548–556.
- Boyer, W.D. 1980. Interim site-index curves for longleaf pine plantations. Research Note SO-261. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 5 p.
- Creighton, J.L. 1987. 1980 herbaceous vegetation control pine growth response studies: 1986 growing season results. Auburn University Silvicultural Herbicide Cooperative 87-1. Auburn, AL: Auburn University. 5 p.
- Dickens, E.D.; Moorhead, D.J.; McElvany, B.C.; Hicks, R. 2012. Longleaf pine wood and straw yields from two old-field planted sites in Georgia. In: Butnor, J.R., comp. Proceedings of the 16th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-156. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 93–97.
- Farrar, R.M., Jr.; White, J.B. 1983. Early development of longleaf pine planted on prepared sites in the East Gulf. In: Jones, E.P., Jr. ed. Proceedings of the second biennial southern silvicultural research conference. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station: 109–117.
- Gonzalez-Benecke, C.A.; Gezan, S.A.; Martin, T.A. [and others]. 2014. Individual tree diameter, height, and volume functions for longleaf pine. *Forest Science*. 60: 43–56.
- Knowe, S. 1982. Second year results for longleaf growth impact. Auburn University Silvicultural Herbicide Cooperative 82-1. Auburn, AL: Auburn University. 2 p.
- Lauer, D. 1990. Seventh year results of the 1983 and ninth year results of the 1980-1981 herbaceous weed control growth impact studies. Auburn University Silvicultural Herbicide Cooperative 90-2. Auburn, AL: Auburn University. 26 p.
- Miles, P.D. 2016. Forest Inventory EVALIDator web-application Version 1.8.0.01. St. Paul, MN: U.S. Department of Agriculture Forest Service, Northern Research Station. <https://apps.fs.usda.gov/Evalidator/evalidator.jsp>. [Date accessed: May 13, 2022].
- Nelson, L.R.; Zutter, B.R.; Gjerstad, D.H. 1985. Planted longleaf pine seedlings respond to herbaceous weed control using herbicides. *Southern Journal of Applied Forestry*. 9: 236–240.
- SAS Institute. 1989. SAS/ETS user’s guide. Version 6. 4th edition. Cary, NC: SAS Institute, Inc. [Not paged].
- Schmidtling, R.C. 1987. Relative performance of longleaf compared to loblolly and slash pines under different levels of intensive culture. In: Phillips, D.R., comp. Proceedings of the fourth biennial southern silvicultural research conference. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station: 395–400.
- Trincado, G.; VanderSchaaf, C.L.; Burkhart, H.E. 2007. Regional mixed-effects height-diameter models for loblolly pine (*Pinus taeda* L.) plantations. *European Journal of Forest Research*. 126: 253–262.
- U.S. Department of Agriculture (USDA) Forest Service. 2016. FIA DataMart 1.6.0.02. https://apps.fs.usda.gov/fia/datamart/CSV/datamart_csv.html. [Date accessed: May 25, 2016].

GROWTH RESPONSE OF MATURE LONGLEAF PINE TO DROUGHT AND THINNING AT THE HARRISON EXPERIMENTAL FOREST IN SOUTH MISSISSIPPI

John R. Butnor, Robert J. Eaton, and C. Dana Nelson

ABSTRACT

We explored the diameter growth of longleaf pine (*Pinus palustris*) planted in 1961, during the years following disturbances from Hurricane Katrina (2005) and thinning (2011) at the Harrison Experimental Forest in southern Mississippi. Winds from Hurricane Katrina destroyed 7 percent of the longleaf pine and damaged much more, while the thinning was variable based on existing density, with 29 percent of trees being removed. In April 2017, a total of 180 trees were sampled with an increment borer and analyzed to quantify basal area increment (BAI). After Hurricane Katrina impacted the site in 2005, BAI declined an average of 23 percent during the next 6 years. Immediately after thinning, growth markedly increased in 2012 (50 percent) and 2013 (30 percent). Without any other context, the interannual variation in BAI could be interpreted as being driven primarily by disturbance. However, the site had experienced prolonged drought during the years following Hurricane Katrina which was eventually alleviated in 2012. Using a suite of climate variables (monthly precipitation, air temperature, solar radiation, and vapor pressure deficit), we found that 79 percent of the annual variation in BAI could be explained by the amount of precipitation during the growing season (partial $R^2 = 0.59$) and warm winter nights in January (partial $R^2 = 0.05$) and February (partial $R^2 = 0.15$). The 50-year-old longleaf pine trees were unresponsive to thinning, and variation in interannual growth rates was primarily dependent on climate. It seems the trees of that age have limited ability to exploit additional light, moisture, and nutrient resources. If the goal of thinning is to increase the growth rate of residual trees, it should be implemented at an earlier age or perhaps be combined with fertilization.

INTRODUCTION

Longleaf pine (*Pinus palustris*) is a long-lived tree that is well suited to extended rotations in the Gulf Coast, where it is grown for commercial purposes or to create wildlife habitat. Thinning is often employed in young plantations to remove undesirable trees and increase resource availability (i.e., soil nutrients and water and access to light) to residual trees. When timed appropriately, thinning can maximize tree growth and improve stem quality. Early studies with longleaf pine focused on thinning dense natural regeneration beginning at age 15 (Gaines 1951), and positive diameter growth responses were observed from thinning as late as 37 years (Farrar 1968). These early studies recommended frequent thinning (every 5 years) on average sites, retaining no more than $14 \text{ m}^2 \text{ ha}^{-1}$ (60 square feet per acre) of residual basal area (BA) to maximize volume growth (Farrar 1968). In an effort to more broadly restore longleaf pine across the landscape, nursery stock was deployed in the form of plantations, even though the principal benefits of biodiversity, disturbance resistance, and natural regeneration are derived through uneven-aged management, frequent burning, and maintenance of relatively low canopy tree BA

(Mitchell and others 2006). The first commercial thinning of planted stock typically occurs between 13 and 18 years depending on site productivity (Nebeker and others 1985). However, many overstocked plantations exist that were planted at low density and never thinned. Little is known about the response of these overstocked mature trees to natural and silvicultural disturbances. Exposure to decades of intraspecific competition without thinning may lead to trees with narrow crowns, low live crown length, and elevated height-to-diameter at breast height ratios that make them more susceptible to breakage (Harrington 2020).

Longleaf pine is known to be resistant to blowdowns and breakage from hurricanes that occur frequently in the Southern United States (Johnsen and others 2009). Prior to settlement and widespread destruction from conversion to farmland, land areas along the Coastal Plain and Piedmont favored longleaf pine ecosystems due to their resistance to wind damage from hurricanes coupled with adaptation to periodic fires (Rutledge and others 2021). There are several recent reports that categorize and quantify the wind firmness and resistance to wind damage among southern tree species (Bigelow and others 2020, Johnsen and others 2009, Rutledge and others 2021, Zampieri and others 2020), though

Author Information: John R. Butnor, Research Plant Physiologist, U.S. Department of Agriculture, Forest Service, Southern Research Station, Burlington, VT 05405; Robert J. Eaton, Biologist, U.S. Department of Agriculture, Forest Service, Southern Research Station, Research Triangle Park, NC 27709; and C. Dana Nelson, Research Geneticist and Project Leader, U.S. Department of Agriculture, Forest Service, Southern Research Station, Lexington, KY 40506.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

lingering effects of damage in subsequent years have been less studied. Hurricanes topple and break trees, akin to a chaotic thinning, but what cost to future growth results from branch, foliage, and partial crown loss?

The primary purpose of this study was to evaluate whether mature longleaf pines at the Harrison Experimental Forest near Saucier, MS, exhibit a growth response to thinning. The story is complicated by tree mortality due to intraspecific competition and damage from hurricanes that reduced the initial 3-m x 3-m spacing (1,075 trees/ha [TPH]). While the site was planted at low density (1,075 TPH), it was only thinned after 50 years of growth, which is a departure from standard silvicultural practices. We explored diameter growth at both the tree and plot level using increment cores in the years following disturbances from Hurricane Katrina (2005) and thinning (2011).

MATERIALS AND METHODS

Site

The study was conducted at the Harrison Experimental Forest near Saucier, MS, on a large experimental planting known as “section 36” and the “species by culture experiment” (30.65° N, 89.04° W, elevation 50 m), which examined the effects of intensive silviculture on the growth of longleaf, loblolly (*P. taeda*), and slash (*P. Elliottii*) pines (Schmidting 1973). The soils are highly variable and classified as the Poarch and Saucier series (coarse loamy, siliceous, semiactive, thermic Plinthic Paleudults) and the Saucier-Susquehanna complex, which are well drained with

slopes ranging from 1 to 4 percent. The soil is characterized as being phosphorus deficient, with relatively low carbon and nitrogen contents, and consequently has no history of agriculture (Butnor and others 2012). The plantation was heavily damaged by Hurricane Katrina in 2005 and mortality varied by pine species: 7 percent of longleaf pine, 14 percent of slash pine, and 26 percent of loblolly pine (Johnsen and others 2009). A major harvest of 12 gaps and thinning of the remaining plots were implemented in 2011.

Experimental Design and Measurements

The original experiment was composed of 120 plots: 4 blocks, 3 species (longleaf, slash, loblolly pine), and 10 treatments planted with 3-m x 3-m spacing (Schmidting 1973). During the 2011 harvest, 12 gaps (55 x 55 m) were created by removing trees in 4 contiguous blocks, reducing the number of plots to 72. Of the remaining longleaf pine plots, 22 were deemed to be suited for continued study. The original 100-tree measurement plots were collapsed to 10-m-radius plots from plot center. In 2006, they ranged in stand density from 95 to 637 TPH and BA from 8 to 39 m² ha⁻¹. The thinning was conducted by a contractor, using a BA target of 14 m² ha⁻¹ for one-half of the plots and 23 m² ha⁻¹ for the other half. In 2017, 180 trees were cored from two directions (south and north) and the annual increment or radius was measured using ImageJ version 1.54h software after being scanned on an Epson® Expression 11000XL scanner (fig. 1). Of the 180 trees, 116 were from the 23 m² ha⁻¹ thinned plots and 64 from the 14 m² ha⁻¹ plots. Annual area growth per tree (cm²) or basal area increment (BAI) was calculated, summed for each plot, and also expressed as BA in m² ha⁻¹. As there were no inventories

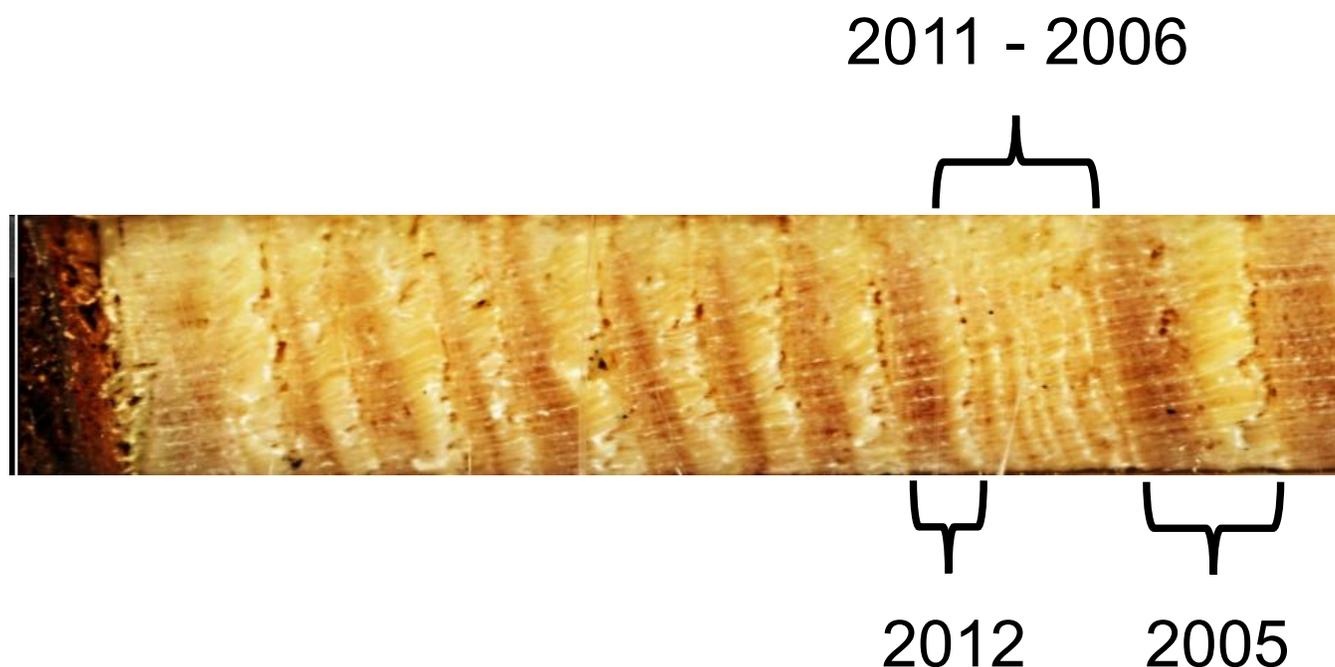


Figure 1—Representative core showing large radial growth in 2005, followed by 6 years of stagnant growth following Hurricane Katrina. After thinning in 2011, radial growth increased dramatically (USDA Forest Service photo by Robert J. Eaton).

prior to the harvest and increment data were only available for live residual trees, the growth rate of residual trees in each plot was determined for years 2006 through 2011 and applied to the trees that were harvested in 2011. By “growing out” the trees since the inventory, an accurate assessment of the BA harvested was computed. Since the entire plantation was impacted by thinning, a nearby longleaf pine plantation with the same establishment year and similar hurricane exposure with no history of thinning was used as a control. The site is described in detail by Snyder and Namkoong (1978) and commonly referred to as the “longleaf pine diallel study” at the Harrison Experiment Forest. We randomly selected 6 plots that varied in BA from 12.7 to 29.0 m² ha⁻¹ for a total of 51 trees and 2 cores per tree were collected in January 2021. When necessary to predict bark thickness to compute stand-level BA, an equation by Cao and Pepper (1986) was applied. Daily estimates of climate variables (maximum [Tmax] and minimum [Tmin] air temperature, precipitation, solar radiation, and vapor pressure) were accessed via DAYMET (<https://daymet.ornl.gov/>) for years 1998 through 2016 and monthly means were calculated. Growing season precipitation was computed for each year as the sum of rainfall from March through October. The data were analyzed using a completely randomized plot design,

utilizing correlation, linear regression, and stepwise linear regression with SAS 9.14 (SAS Institute 2015).

RESULTS

Hurricane Katrina impacted the Harrison Experimental Forest, in late August 2005, killing 7 percent of the longleaf pine in the section 36 study (Johnsen and others 2009). By comparison, the 2011 thinning operation removed 29 percent of the longleaf pine that survived Hurricane Katrina. After Hurricane Katrina, BAI declined an average of 23 percent during the next 6 years (fig. 2). Immediately after thinning, growth markedly increased in 2012 (50 percent) and 2013 (30 percent). The thinning removed four times as many trees as the hurricane and large increases in growth were observed the following year (fig. 2). Without any other context, the interannual variation in BAI could be interpreted as being driven primarily by disturbance. Hurricane Katrina only killed 7 percent of trees in 2005 but likely caused loss of foliage and branches that compromised the photosynthetic machinery of the stand resulting in suppressed growth for years. However, it is readily apparent that precipitation and BAI are closely related, and the alleviation of drought in 2012 was related to the uptick in individual tree growth (figs. 3 and 4). When the full suite of monthly climate variables was

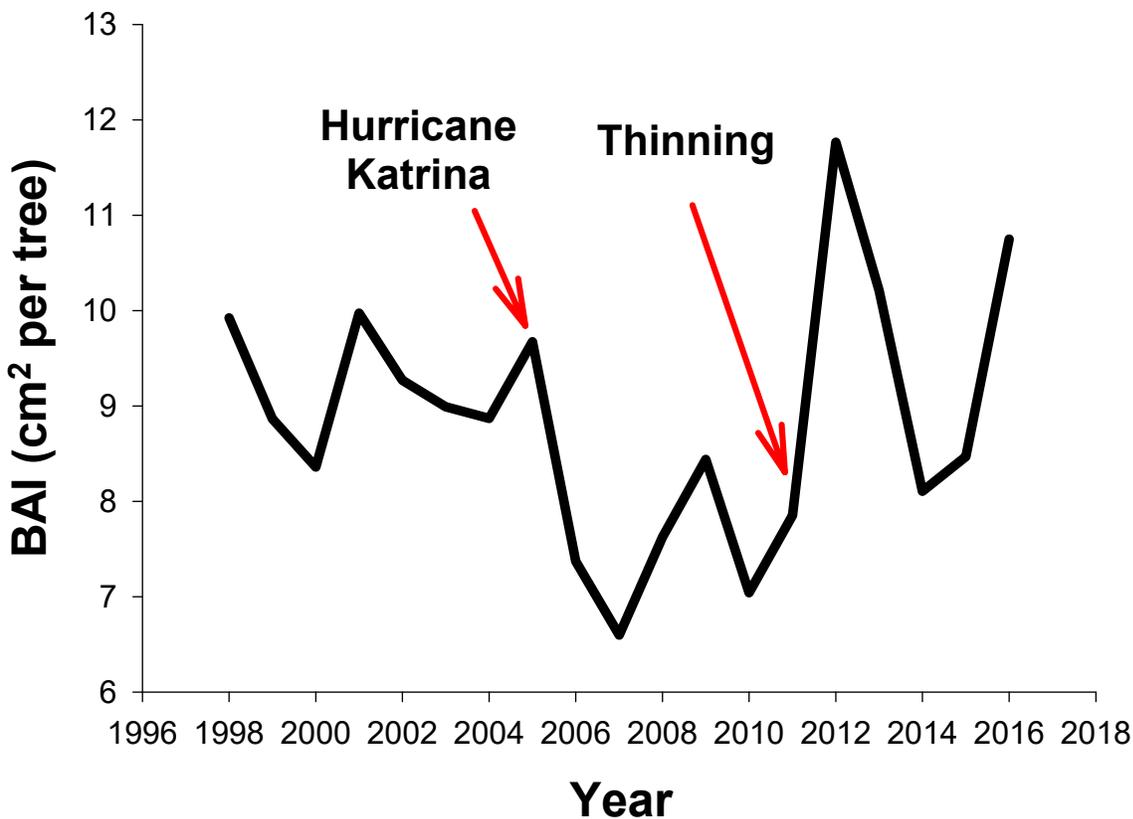


Figure 2—Mean basal area index (BAI) (per tree) of 180 longleaf pine trees located in the section 36 study at the Harrison Experimental Forest for years 1998 through 2016. Arrows denote major disturbance events from Hurricane Katrina (2005) and thinning (2011).

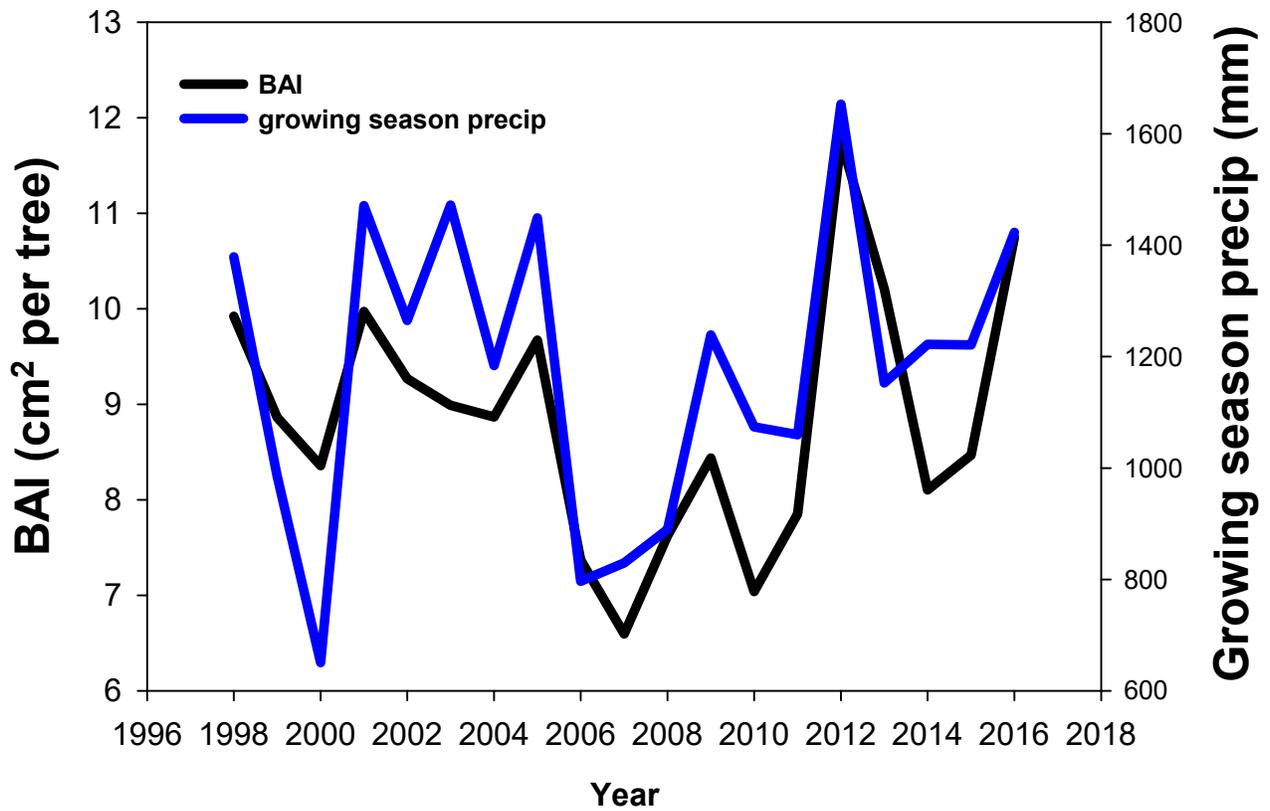


Figure 3—Overlay of basal area index (BAI) (per tree) and growing season precipitation (March through October) for years 1998 through 2016.

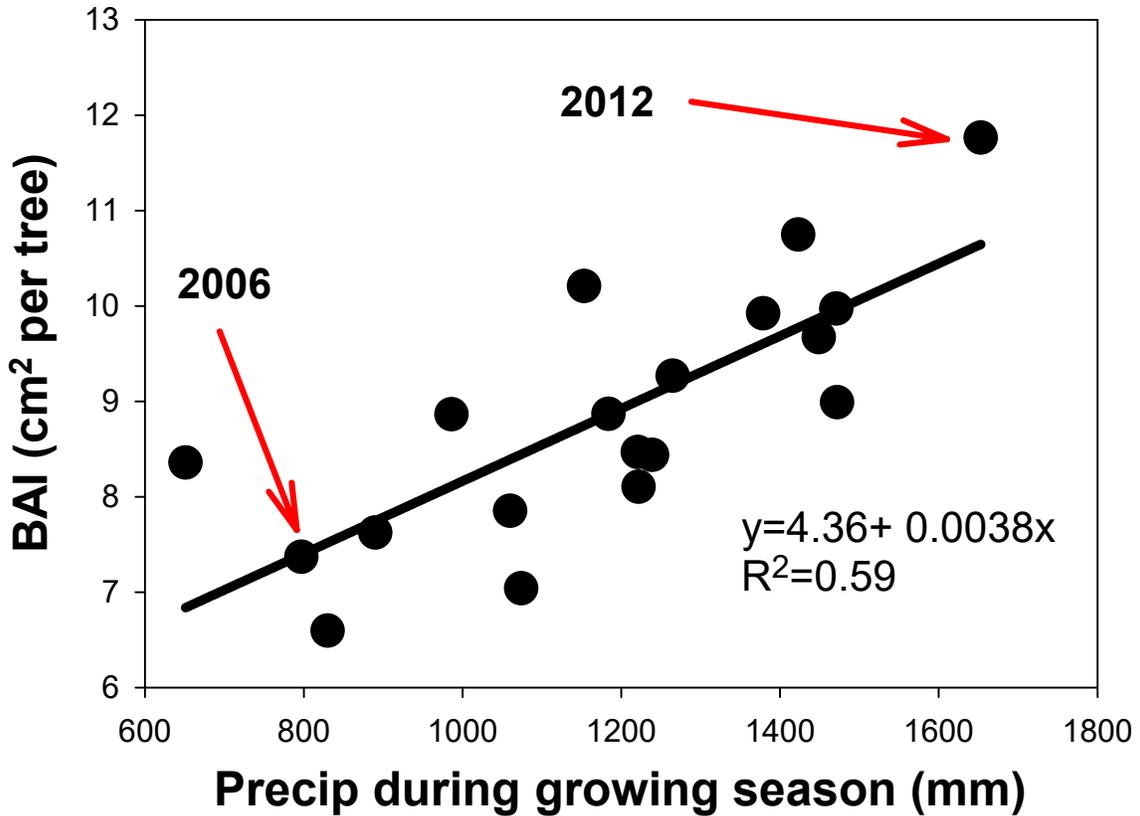


Figure 4—Linear regression of mean basal area increment (BAI) (per tree) and growing season precipitation (March through October) for years 1998 through 2016. Arrows denote the year after major disturbance events: hurricane impact (2006) and thinning (2012).

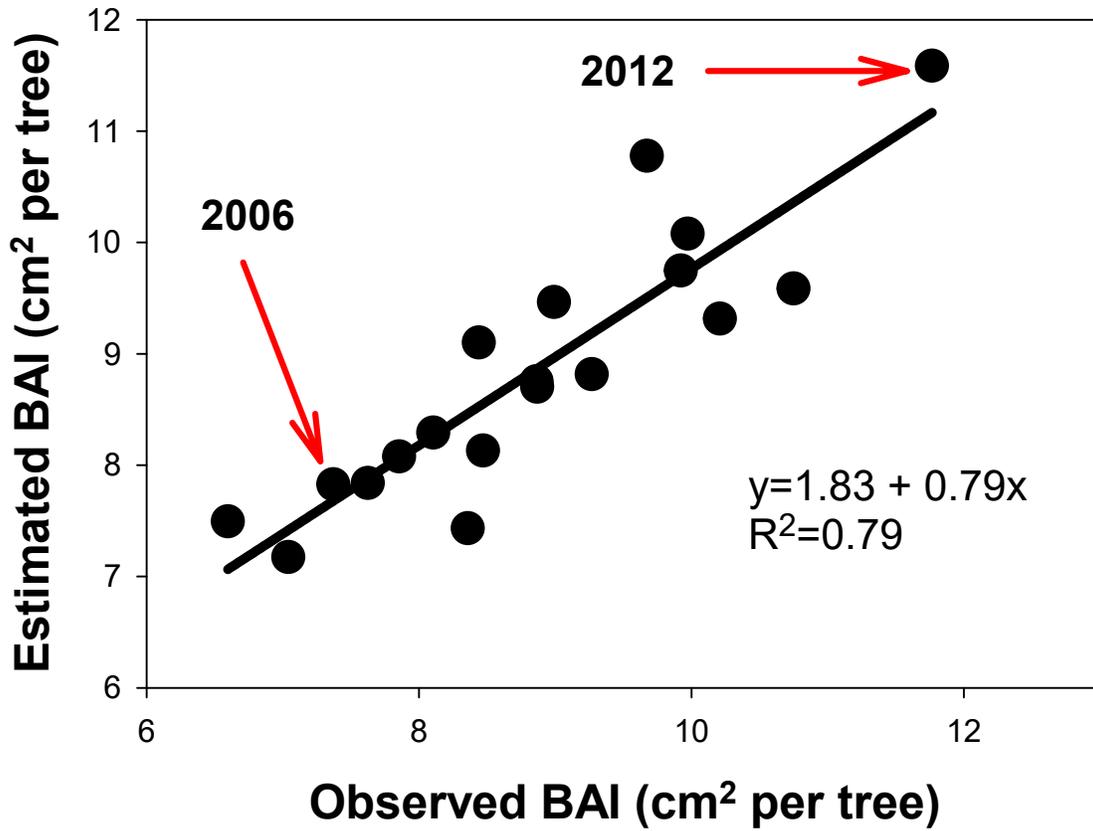


Figure 5—Multivariate model of basal area index (BAI) [equation (1)] versus observed BAI.

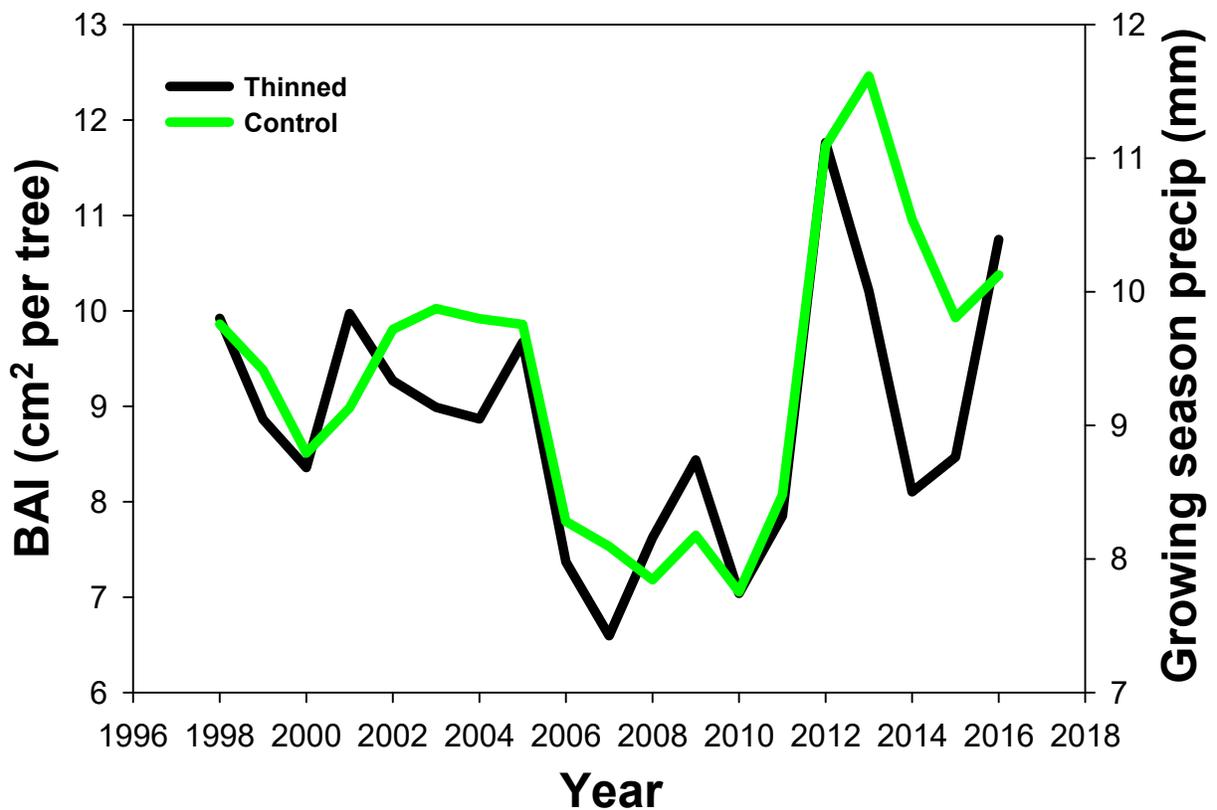


Figure 6—Mean basal area index (BAI) (per tree) for thinned and control plots for years 1998 through 2016.

considered, warm minimum temperatures in January and February were also found to contribute to BAI. The combined model [equation (1)] explained 79 percent of the variation in BAI (partial R^2 s: growing season precipitation = 0.59; January T_{min} = 0.05, February T_{min} = 0.15). Viewed through this analysis, warm late winter nights and plentiful rainfall during the growing season appear to be the main drivers of BAI variation in mature longleaf pines (fig. 5).

$$\text{Annual BAI} = 2.94289 + 0.15326 * \text{January } T_{min} (\text{°C}) + 0.18889 * \text{February } T_{min} (\text{°C}) + 0.00358 * \text{growing season precipitation (mm)} \quad (1)$$

Both thinned and control plots follow similar growth patterns, which is closely linked to the amount of rainfall

during the growing season (fig. 6). Prior to thinning, the BAIs of control and thinned plots are highly correlated ($R^2 = 0.70$), but in the years after thinning, the treated plots lagged in growth ($R^2 = 0.21$). To more closely examine if there was any thinning response, we compared the amount of BA harvested and the residual BA to the change in BAI before (2011) and after the harvest (2012). The same analysis was repeated comparing the BAI in 2011 with the mean of the next 5 years. There were no significant effects of the amount of BA harvested or residual BA on growth, as gauged by BAI either in the following year (data not shown) or the mean of the next 5 years (fig. 7).

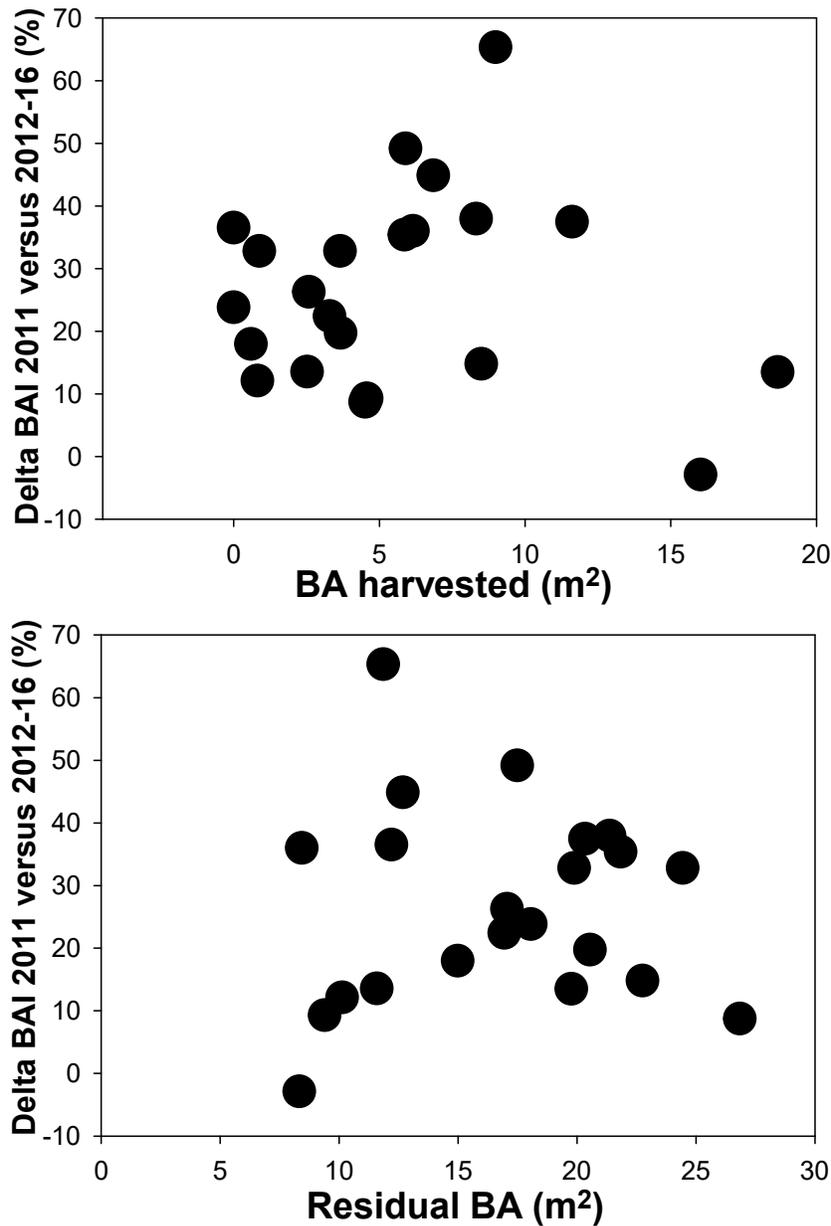


Figure 7—Effect of basal area removal and residual basal area on basal area index (BAI).

DISCUSSION

While the intent of this study was to examine the growth response of mature longleaf pine to disturbance either from natural events or harvesting, it served to quantify the sensitivity of growth to annual variation in temperature and rainfall. Longleaf pine can persist in very well drained sandy soils, but growth is highly sensitive to moisture availability during the growing season. Under extreme drought conditions, longleaf pine is able to exert stomatal control over water loss and cease transpiration for extended periods (Samuelson and others 2019). This affords a degree of climate resilience, where trees may persist until drought conditions are alleviated. Curtailing transpiration sharply limits photosynthesis, leading to declines in growth. In a precipitation exclusion experiment conducted in a 13-year-old plantation, Samuelson and others (2019) found that a 40-percent reduction in throughfall led to a 21-percent reduction in longleaf pine volume growth during three growing seasons with little mortality. By way of comparison with the present study (50-year-old longleaf pine), growing season precipitation in 1999 was 40 percent lower than 2012 and BAI was 25 percent lower. Obviously, there are multiyear effects of drought that need consideration, but the scale of drought sensitivity seems commensurate across these disparate age classes.

We did not observe any effects of BA removed or residual BA on BAI during the 5 years after harvesting. This differs from prior longleaf pine studies that aimed to keep growth rates near maximum, by employing multiple thinnings at earlier stand ages (Farrar 1968, Gaines 1951). Younger trees in the exponential growth phase have greater opportunity to take advantage of additional light resources. Sword Sayer and others (2004) found that loblolly pines that were thinned at age 7 and 14 years developed greater live crown length and had increased BA relative to control stands. It seems likely that canopy architecture and the development of tall trees with narrow crowns (Harrington 2020) limits the ability to refit the photosynthetic apparatus of the tree to take advantage of more light at age 50. Observing the plantation 5 years post-harvest, the holes in the canopy created by thinning are largely unchanged and the crowns of residual trees do not appear to have enhanced growth adjacent to gaps. The relatively nutrient-poor condition of the soil, especially phosphorus (Butnor and others 2012, 2020), likely mutes any potential enhancement in leaf area and growth (Sword Sayer and others 2004). Although somewhat complicated by the onset of extended, multiyear drought after Hurricane Katrina in 2005, there was little effect of this disturbance on growth of residual trees. This is not surprising when the extent of BA removed by the hurricane was 7 percent and the thinning was 29 percent.

CONCLUSIONS

The 50-year-old longleaf pine trees were unresponsive to thinning, and variation in interannual growth rates was primarily dependent on weather. Thinning likely has positive effects on biodiversity, wildlife, understory development, and regeneration, but it seems the mature trees have limited ability to exploit additional light, moisture, and nutrient resources for accelerated growth. If the goal of thinning is to increase the growth rate of residual trees, it should come at an earlier age or perhaps be combined with fertilization.

ACKNOWLEDGMENTS

We appreciate the efforts of Steven Flurry and Chance Parker (U.S. Department of Agriculture Forest Service, Southern Research Station, Harrison Experimental Forest) to collect the dendrochronology cores. Drs. Dale Brockway and Chris Maier reviewed an earlier version of the manuscript and offered advice for improving the presentation.

LITERATURE CITED

- Bigelow, S.W.; Looney, C.E.; Cannon, J.B. 2020. Hurricane effects on climate-adaptive silviculture treatments to longleaf pine woodland in southwestern Georgia, USA. *Forestry: An International Journal of Forest Research*. 94(3): 395–406.
- Butnor, J.R.; Johnsen, K.H.; Maier, C.A.; Nelson, C.D. 2020. Intra-annual variation in soil C, N and nutrients pools after prescribed fire in a Mississippi longleaf pine (*Pinus palustris* Mill.) plantation. *Forests*. 11: 1–14.
- Butnor, J.R.; Johnsen, K.H.; Sanchez, F.G.; Nelson, C.D. 2012. Impacts of pine species, stump removal, cultivation, and fertilization on soil properties half a century after planting. *Canadian Journal of Forest Research*. 42: 675–685.
- Caio, Q.V.; Pepper, W.D. 1986. Predicting inside bark diameter for shortleaf, loblolly, and longleaf pines. *Southern Journal of Applied Forestry*. 10: 220–224.
- Farrar, R.M. 1968. Thinning longleaf pine on average sites. *Journal of Forestry*. 66: 906–909.
- Gaines, E.M. 1951. A longleaf pine thinning study. *Journal of Forestry*. 49: 790–792.
- Harrington, T.B. 2020. Long-term effects of thinning and woody control on longleaf pine plantation development, understory abundance, and tree damage from an ice storm. *Forest Ecology and Management*. 459(117846): 1–11.
- Johnsen, K.H.; Butnor, J.R.; Kush, J.S. [and others]. 2009. Hurricane Katrina winds damaged longleaf pine less than loblolly pine. *Southern Journal of Applied Forestry*. 33: 178–181.
- Mitchell, R.J.; Hiers, J.K.; O'Brien, J.J. [and others]. 2006. Silviculture that sustains: the nexus between silviculture, frequent prescribed fire, and conservation of biodiversity in longleaf pine forests of the Southeastern United States. *Canadian Journal of Forest Research*. 36: 2724–2736.
- Nebecker, T.E.; Hodges, J.D.; Karr, B.K.; Moehring, D.M. 1985. Thinning practices in southern pines-with pest management recommendations. *Tech. Bull. 1703*. New Orleans: U.S. Department of Agriculture Forests Service. Southern Forest Experiment Station. 36 p.
- Rutledge, B.T.; Cannon, J.B.; McIntyre, R.K. [and others]. 2021. Tree, stand, and landscape factors contributing to hurricane damage in a Coastal Plain forest: Post-hurricane assessment in a longleaf pine landscape. *Forest Ecology and Management*. 481(118724): 1–13.

- Samuelson, L.J.; Stokes, T.A.; Ramirez, M.R.; Mendonca, C.C. 2019. Drought tolerance of a *Pinus palustris* plantation. *Forest Ecology and Management*. 451(117557): 1–10.
- SAS Institute. 2015. SAS/STAT® 9.4 user's guide. Cary, NC: SAS Institute Inc. 440 p.
- Schmidtling, R.C. 1973. Intensive culture increases growth without affecting wood quality of young southern pines. *Canadian Journal of Forest Research*. 3: 565–573.
- Snyder, E.B.; Namkoong, G. 1978. Inheritance in a diallel crossing experiment with longleaf pine. Res. Pap. S0-140. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 38 p.
- Sword Sayer, M.A.; Goelz, J.C.G.; Chambers, J.L. [and others]. 2004. Long-term trends in loblolly pine productivity and stand characteristics in response to thinning and fertilization in the West Gulf region. *Forest Ecology and Management*. 192: 71–96.
- Zampieri, N.E.; Pau, S.; Okamoto, D.K. 2020. The impact of Hurricane Michael on longleaf pine habitats in Florida. *Scientific Reports*. 10(8483): 1–11.

A PHOTOGRAPHIC RECORD OF THE FIRST SILVICULTURAL RESEARCH BY THE SOUTHERN FOREST EXPERIMENT STATION

Don C. Bragg

ABSTRACT

On July 1, 1921, researchers from the new Southern Forest Experiment Station (SOFES) took over what would become the Station's first silvicultural research project in young, even-aged, old-field pine stands on Urania Lumber Company lands in central Louisiana. While few records of this pioneering thinning study remain, a collection of images, reports and plans, and some publications can help with its reconstruction. With this study, the SOFES sought to quantify the response of young overstocked stands to "German" and "French" thinning approaches at different levels of intensity ("grades"). The quarter-acre plots (which included unthinned "checks") established in 1915 were supplemented with others in the 1920s and maintained until the study closed in 1961. Installed before the widespread use of probabilistic statistics, hypothesis testing, and effective study design, this poorly replicated and inadequately controlled effort would today be considered more demonstration than research. Nevertheless, the Urania thinning study produced multiple publications that supported targeted density reductions in overstocked pine stands and helped train numerous SOFES silviculture researchers.

INTRODUCTION

When the U.S. Department of Agriculture (USDA) Forest Service established their Branch of Research under Earle Clapp in 1915, the Federal agency had no formal research program outside of a few small and isolated field stations in the Western United States and the Forest Products Laboratory in Madison, WI (Williams 2005). Otherwise, any Forest Service science conducted outside of those Government-owned locations was done on the lands of others. In 1915, the Forest Service found one of those "others" in Louisiana lumberman Henry Hardtner. That year, Hardtner approached the Forest Service for help with his nascent forest management efforts on the pineywoods of his Urania Lumber Company. In response, that same year the Forest Service sent Samuel Trask Dana and several others (fig. 1) from the Washington Office to establish a series of small plots in young, even-aged, naturally regenerated old-field stands of loblolly (*Pinus taeda*) and shortleaf pine (*P. echinata*) for a thinning study (Mauder and Fry 1966, Wyman 1922).

With openings of the Southern Forest Experiment Station (SOFES) and the Appalachian Forest Experiment Station on July 1, 1921, the Forest Service initiated a formal research program in the Southern United States. The SOFES took over the agency's thinning project and other studies at Urania (Dana and the others had also installed plots to consider the effects of fire and hogs on longleaf [*P. palustris*]

and loblolly pine reproduction [Chapman and Bickford 1932, Mauder and Fry 1966]). Although poorly designed by today's standards, this first silvicultural research of the SOFES proved to be a useful research and demonstration tool to help foresters and landowners learn to effectively manage the even-aged, pine-dominated forests of the South.

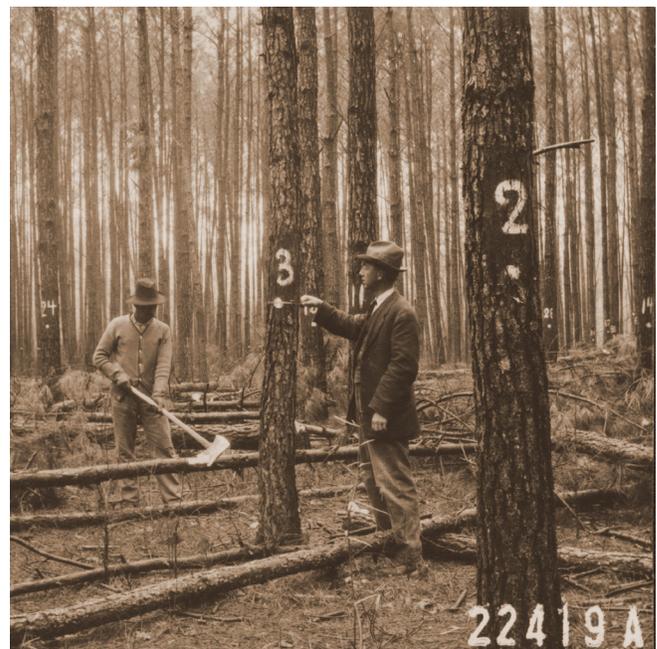


Figure 1—Heavily thinned 20- to 22-year-old loblolly pine-dominated old-field stand in LaSalle Parish, LA, January 27, 1915. USDA Forest Service photo (image number 22419A) by Samuel Trask Dana.

Author Information: Don C. Bragg, Project Leader and Research Forester, U.S. Department of Agriculture, Forest Service, Southern Research Station, Monticello, AR 71656.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

Such work was critical, as the studied condition—young, naturally regenerated old-field pine—was increasingly common and silviculturists had few management options for this type. As the old timber was cleared, even the mighty southern pine industry in Louisiana began to fail (Garrison 1952). However, a rapidly growing pulp and paper industry in Louisiana after 1920 provided a ready market for small-diameter trees, low-grade larger logs, and less commercially viable species, and thus provided new management options for landowners.

This paper does not present new research on or a new analysis of the original Urania thinning study. Rather, it presents a series of photographs taken between 1915 and 1951 as an encapsulation of some of the people, places, and projects that were involved in this first silviculture study of the SOFES.

MATERIALS AND METHODS

Original Thinning Study and Later Modifications

The Urania thinning study consisted of four sets of plots (called “Holly,” “Maxwell,” “Mayes,” and “Castor”), with additional plots added during the next 10–15 years (Bull 1936, Chapman and Bickford 1932). All of the plots were relatively small (0.2–0.25 acres), unreplicated, and lacked a good experimental design. Unfortunately, when the Urania thinning study was originally installed and then expanded upon, the foundational work of R.A. Fisher on more robust statistical analyses and the factorial design of experiments was still years in the future (Fisher 1925, 1935). Such deficiencies were recognized almost immediately, but the SOFES considered the plots established at Urania as valuable nevertheless. According to Chapman and Bickford (1932: 28), “Although many of these experiments were begun without adequate planning and were carried on under the handicap of inexperienced and frequently changing personnel, it is felt that they have furnished a variety of miscellaneous information as well as serving to train the staff.” Chapman and Bickford (1932) believed the first results of this Urania thinning study were inconclusive (in part because of the design flaws) but held out hope they would later demonstrate the influence of thinning in these young pine stands.

The thinning treatments used were consistent with the concepts and terminology of that time (Barrett and Righter 1929). When first installed, these were called “German” (“thinning from below”) and “French” (“thinning from above”). In addition, different thinning intensities (“grades”) were applied, ranging from light (“A”) to heavy (“D”) removals. Later researchers (for example, Bull [1935]) eschewed the German and French designs for a more “American” approach to managing these even-aged stands

with stocking levels based on the number of residual (target) trees or basal area per acre.

Over the years, the plots were periodically remeasured, rephotographed, and thinned (when feasible). As these plots matured, a few were destroyed by fire, insects, wind, or inadvertent logging, and some had new studies implemented to consider other treatments. For instance, later researchers looked at pruning or growth and yield in some of these plots, while others changed the thinning approach (Bull 1935) or added pruning and timber stand improvement components. Not surprisingly, such changes to these small plots contributed to problems as the study aged, with some planned treatments not being possible in later years as too few pines remained. Ultimately, this prompted F.W. Whitmore, then the researcher in charge of the study, to formally close the last Urania thinning study plots in the early 1960s (Whitmore 1961a, 1961b).

Current Approach

A large collection of historical photographs, negatives, maps, and some documents from the Urania thinning study were stored at the Crossett Experimental Forest (CEF). As a part of the 100th anniversary of the founding of the Forest Service Southern Research Station (the successor to the SOFES), many of these old images have been digitized and permanently archived in the Forest Service Research Data Archive (RDA) as a part of the Southern Research Station Historical Documents and Images collection (Bragg 2020; digital versions of these public domain images and many others can be downloaded from <https://doi.org/10.2737/RDS-2020-0047>).

This paper is based on 15 of the 190 photographs currently in this collection, each chosen because they clearly demonstrated an objective or interesting facets of this study. All photographs were digitized with a flatbed scanner at a resolution of at least 300 dots per inch. Available metadata (for example, Forest Service negative number, date picture was originally taken, photographer, location, image content) for each scanned image was also recorded. Additional information on the Urania thinning study has been extracted from several published articles and information from a series of unpublished establishment, progress, and closing reports. This included material from the “Urania Bible,” an unpublished account of the Forest Service work on the Urania Lumber Company lands up to 1932 (Chapman and Bickford 1932).

RESULTS AND DISCUSSION

Check Plots

In the Urania thinning study, a series of “check plots” served as the unmanaged (uncut) controls for the thinning



Figure 2—Loblolly pine-dominated unthinned old-field stand in LaSalle Parish, LA, March 1920. USDA Forest Service photo (image number 45632A).

treatments, and at least one was established for each old-field set of plots. Figure 2 is a 1920 picture of a check plot, a clear example of an overstocked pine stand. Check plots were compared to other treatments to help evaluate their effectiveness. As mentioned earlier, the check plot comparison to unreplicated treatment plots failed to control for several relevant initial conditions. This provided inherent logical challenges with unsatisfactory outcomes; for example, see the work of Righter (1929) based in part on these *Urania* thinning studies and Mulloy's (1929) response. Such limitations affected the inferences and statistical power of the analysis (Gevorkiantz 1935). Based in part on their experiences with the *Urania* thinning study, a later treatment of a proposed experimental design offered by Barrett and Righter (1929: 786) suggested the replication of thinning treatments across a range of sites for a more robust evaluation. Barrett and Righter (1929) included uncut controls, but they also felt that check plots were needed only if time and money were available, and that a single check would suffice.

Although unreplicated for their paired treatment and therefore lacking the capacity to identify the contributions of site, initial stocking, and other factors, the check plots helped demonstrate to landowners some of the consequences of overstocked, even-aged southern pine stands. Figures



Figure 3—Maxwell check plot number 1, LaSalle Parish, LA, January 1925. USDA Forest Service photo (image number 194734) by E.N. Munns.



Figure 4—Maxwell check plot number 3, LaSalle Parish, LA, April 1931. USDA Forest Service photo (image number 254794) by R.A. Chapman.

3 and 4, although not of the same plot shown in figure 2, reflected the high mortality and slow individual tree growth of these unthinned stands. The *Urania* thinning study also documented that more productive sites responded sooner to overstocking, consistent with the principles of self-thinning (Reineke 1933) and at the expense of considerable volumes of small (but often usable) wood lost to mortality (Bull 1935, Mann 1952).

Thinning Approaches

As mentioned earlier, the original study was intended to compare two different approaches to thinning at several levels of thinning intensity. Figure 5 shows a “light” (Grade A) German thinning. This approach, better known today as thinning from below (or sometimes “low thinning”), first targeted the removal of dead, dying, or suppressed trees. At the lightest (or Grade A) thinning intensity, these would be the only trees removed. With progressively higher degrees of removal (B, C, and D), a greater proportion of the smaller trees would be taken until at Grade D, when many codominant stems were cut (Barrett and Righter 1929, Hawley 1929).

The second thinning approach, French (now generally called “thinning from above” or “high thinning”), approached harvests differently. As can be seen in figure 6, French thinnings were designed to release the most prominent crop trees from the beginning, with increasing intensity (grades



Figure 5—Recently thinned 20-year-old shortleaf and loblolly pine old-field stand in Winn Parish, LA, January 1915. USDA Forest Service photo (image number 22421A) by S.T. Dana.



Figure 6—Light French thinning plot U-65, Winn Parish, LA, December 1928. USDA Forest Service photo (image number 232355) by L.I. Barrett.



Figure 7—"Shortwood" (for pulp) stacked following a light French thinning, December 1928. USDA Forest Service photo (image #232350) by L.I. Barrett.

targeting a greater proportion of the remaining tree classes for removal (Barrett and Righter 1929, Hawley 1929). In practice, more intense German and French thinnings could be difficult to distinguish from each other. While their targeting approaches may have differed, the end results would not: under heavy thinnings of both, all but a few of the best crop trees would be removed.

Regardless of the system employed, the earliest thinnings in these even-aged southern pine stands were largely noncommercial because Louisiana lacked good markets for small-diameter pine. It would be the development of the pulp and paper industry that soon provided such a market. After 1920, a series of new pulp mills that used southern pine opened in Louisiana and immediately changed the dynamics of management practices (Garrison 1952). Now, the quantity of usable volume became the issue; figure 7 demonstrates the amount of pulpwood produced by a single light French thinning on this study plot. The mixture of bolt diameters is a good indicator of French thinning, with some larger stems from felled codominant trees.

Thinning Results

As the study progressed, the effectiveness of the different treatments became increasingly apparent. Most noticeably,



Figure 8—Loblolly pine-dominated unthinned old-field stand in LaSalle Parish, LA, November 1929. USDA Forest Service photo (image number 241513) by R.A. Chapman.



Figure 9—Light German thinning of shortleaf pine stand, Winn Parish, LA, April 1929. USDA Forest Service photo (image number 254806) by R.A. Chapman.

in the check plots (such as the one in fig. 8), individual tree diameter growth was noticeably less, there was a greater amount of mortality, and the closed canopy of these unthinned stands produced a sparse groundcover typical of the low-light understory environment (Bull 1935).

Light thinnings of either German or French styles released a few pines and started opening the canopy, allowing for increasing numbers of hardwoods in the understory (fig. 9). In German-style light thinnings, some of the pines that were of poor form, undesired species, unhealthy, or likely to



Figure 10—Heavy French thinning, LaSalle Parish, LA, December 1928. USDA Forest Service photo (image number 232351) by L.I. Barrett.

die from suppression were utilized for timber production, but only limited growth in the residual pines resulted from their removal. In a light French thinning, most of these subordinate or poor trees were retained (many of which would soon die or continue to decline or degrade), yet too few crop trees were sufficiently released to provide much of a response from the residual pines. Bull (1935) favored heavier thinnings that included competitors to crop trees at relatively early stages of these even-aged southern pine stands to provide a stronger growth response from the residual, thereby producing sawtimber sooner (fig. 10).

Other Lessons Learned

Bull (1935) also noted that if the market for pulpwood or other small-diameter products was a major driver for the thinning treatments, other recommendations could be justified. For example, sometimes thinnings could be made later in the rotation and would not need to be as intensive to improve outcomes. In areas where both pulpwood and sawtimber markets were viable (fig. 11), thinning should be tiered towards the most profitable product. Even modest thinnings in areas with good small-diameter markets were often profitable and offered landowners a chance to earn income while putting their crop trees in a better position to get to sawtimber size sooner. From the Urania thinning study, Mann (1952) concluded that stand-level cordwood production at 35 years was maximized by not thinning but at the cost of no early income. Light thinnings were best when both pulpwood and sawtimber were desired, and heavy thinnings favored faster sawtimber production at the expense of lower total volume yield.

The realization of other ecological consequences would influence silvicultural practices. For example, it became quickly apparent (fig. 12) that the moderate to heavy thinnings that opened the canopy to best release crop pines also triggered the greatest hardwood understory response, especially when fire was suppressed (Chapman 1953). Later research work elsewhere further documented the impacts of



Figure 11—Over three cords of pulpwood from a quarter-acre plot following a heavy French thinning in LaSalle Parish, LA, December 1928. USDA Forest Service photo (image number 232352) by L.I. Barrett.



Figure 12—Hardwood understory response after a heavy thinning in LaSalle Parish, LA, early 1940s. USDA Forest Service photo (image number 443391).

these hardwood competitors and the value of their control in improving pine volume production (Grano 1970, Korstian and Bilan 1957).

...And the Rest of the Story

The evolution of a robust system of experimental design, sampling, and statistical analysis in the late 1920s into the 1930s made it apparent how inadequate the original Urania thinning study was, but this does not mean that the effort was in vain. Rather, the utility of such a project to help train new agency researchers while still producing some reasonable, fact-based silvicultural recommendations was considerable. Other lessons were drawn from this original work. For instance, rather than focusing just on a relative assessment of heavily stocked, even-aged stands of a species such as loblolly pine, researchers learned that site conditions can play a major role in determining thinning responses and that site quality can vary remarkably from one stand to the next. Figure 13 provides an example of one of the Urania thinning plots on a former longleaf pine site that was inherently less productive than most of their other sites. In this photograph, the presence of the old longleaf pine stumps indicated that this location likely had not been row cropped (perhaps just grazed), making it even more different than plots on more productive sites that had been farmed.



Figure 13—Loblolly pine plot in the "Deer Pasture" site near Urania, LA, with original longleaf pine stumps remaining, April 1924. USDA Forest Service photo (image number 185985) by W.R. Hine.

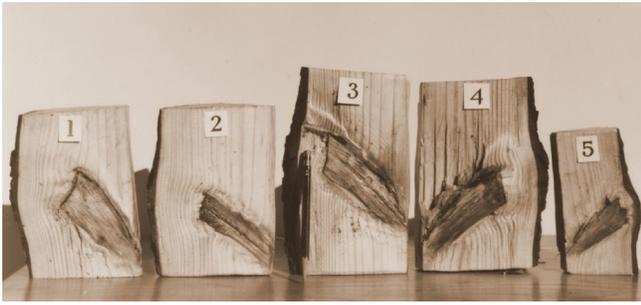


Figure 14—View of branch stubs from pruned trees in 1951, 18 years post-thinning. USDA Forest Service photo by Wilbur F. Mattoon.

Such design considerations would be incorporated into future studies as suggested in Barrett and Righter (1929). As this study matured, investigators had other questions, leading to the layering of new research on the existing design. For example, young, heavily thinned stands had much less natural branch loss as the trees aged, producing knottier wood of lower value. This suggested that pruning may benefit such treated stands by removing the branches to improve the quality of the lower bole (fig. 14). However, some of the studies imposed upon the existing Urania thinning study reduced the ability of an already design-limited study to address the original objectives. Not all of these lessons learned were negative. Knowledge gained across a range of thinning intensities led to a better understanding of stand development and individual tree growth patterns, which were later adapted to develop other approaches to intermediate treatments such as timber stand improvement that targeted low-quality individual trees (fig. 15). Over the years, the SOFES researchers also produced multiple publications on this work (Bond and others 1937; Bull 1935, 1936; Mann 1952; Righter 1929; Wyman 1922).

CONCLUSIONS

This collection of historical photographs and documents covers an interesting period in the South where even limited studies by the SOFES helped shape a “new” timber industry and the practice of forestry. Once the industry was convinced that second-growth pine forests had the potential to produce adequate wood (and new pulp and paper markets developed), interest in these increasingly common old-field stands grew (Bragg 2021). Not surprisingly, then, a remarkable amount of useful silvicultural information arose from the Urania thinning study. Between 1915 and 1961, this effort also helped the SOFES develop new researchers and the forestry profession benefited from a suite of treatment recommendations for this often-undervalued forest type. Furthermore, future research projects learned from the mistakes and limitations of this initial effort. Though these stands have long since been cleared, the legacy of the Urania old-field thinning study continues to live on.



Figure 15—A crooked loblolly pine marked as a part of a timber stand improvement experiment in LaSalle Parish, LA, August 1937. USDA Forest Service photo (image number 352080) by C.A. Bickford and T.T. Kohara.

ACKNOWLEDGMENTS

In addition to the early agency researchers who designed, implemented, maintained, and monitored these treatments—and those who preserved these records over the decades—I would like to thank the following for their assistance in this project: John Willis, Curtis VanderSchaaf, Jim Guldin, Jim Barnett, and Kirby Sneed. This work was funded by the USDA Forest Service (with early support by the Urania Lumber Company and Henry Hardtner). The findings and conclusions in this publication are those of the author(s) and should not be construed to represent an official USDA, Forest Service, or U.S. Government determination or policy.

REFERENCES

- Barrett, L.I.; Righter, F.I. 1929. Working plan for experimental thinnings in shortleaf and loblolly pines. *Journal of Forestry*. 27(7): 782–803.
- Bond, W.E.; Wahlenberg, W.G.; Kirkland, B.P. 1937. Profitable management of shortleaf and loblolly pine for sustained yield. Occasional Paper 70. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 37 p.
- Bragg, D.C. 2020. A century of Forest Service research and development in the Southern United States: historical documents and images. Fort Collins, CO: U.S. Department of Agriculture Forest Service Research Data Archive. <https://doi.org/10.2737/RDS-2020-0047>.
- Bragg, D.C. 2021. The first silvicultural study of the Southern Forest Experiment Station. *Journal of Forestry*. 119(4): 432–435.
- Bull, H. 1935. Thinning loblolly pine in even-aged stands. *Journal of Forestry*. 33(5): 513–518.
- Bull, H. 1936. Pulpwood yields from experimental thinnings in old-field stands of loblolly and shortleaf pines. Occasional Paper 57. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 9 p.
- Chapman, H.H. 1953. Effects of thinning on yields of forest-grown longleaf and loblolly pines at Urania, LA. *Journal of Forestry*. 51(1): 16–26.
- Chapman, R.A.; Bickford, C.A. 1932. Forestry history of Urania Lumber Company's holdings in northern Louisiana. Unpublished manuscript. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 215 p. On file with: Crossett Experimental Forest, 4472 Highway 133 South, Crossett, AR 71635.
- Fisher, R.A. 1925. Statistical methods for research workers. Edinburgh, UK: Oliver and Boyd. 319 p.
- Fisher, R.A. 1935. The design of experiments. Edinburgh, UK: Oliver and Boyd. 248 p.
- Garrison, P.M. 1952. Building an industry on cut-over land. *Journal of Forestry*. 50(3): 185–187.
- Gevorkiantz, S.R. 1935. The statistical method in forest research. *Journal of Forestry*. 33(12): 974–978.
- Grano, C.X. 1970. Small hardwoods reduce growth of pine overstory. Res. Pap. SO-66. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 9 p.
- Hawley, R.C. 1929. The practice of silviculture. 2d ed. New York: John Wiley and Sons. 335 p.
- Korstian, C.F.; Bilan, M.V. 1957. Some further evidence of competition between loblolly pine and associated hardwoods. *Journal of Forestry*. 55(11): 821–822.
- Mann, W.F. 1952. Response of loblolly pine to thinning. *Journal of Forestry*. 50(6): 443–446.
- Mauder, E.R.; Fry, A. 1966. Samuel Trask Dana: the early years. *Forest and Conservation History*. 10(2): 2–13.
- Mulloy, G.A. 1929. "A more scientific method of experimental thinnings". *Journal of Forestry*. 27(5): 582–584.
- Reineke, L.H. 1933. Perfecting a stand-density index for even-aged forests. *Journal of Agricultural Research*. 46(7): 627–638.
- Righter, F.I. 1929. A more scientific method of experimental thinnings. *Journal of Forestry*. 27(3): 280–281.
- Whitmore, F.W. 1961a. Maxwell thinning study. Unpublished final office report. Crossett, AR: U.S. Department of Agriculture Forest Service, Crossett Research Center. 6 p. On file with: Crossett Experimental Forest, 4472 Highway 133 South, Crossett, AR 71635.
- Whitmore, F.W. 1961b. Mayes thinning study. Unpublished final office report. Crossett, AR: U.S. Department of Agriculture Forest Service, Crossett Research Center. 5 p. On file with: Crossett Experimental Forest, 4472 Highway 133 South, Crossett, AR 71635.
- Williams, G.W. 2005. The USDA Forest Service—the first century. FS-650. Washington, DC: U.S. Department of Agriculture Forest Service, Office of Communication. 156 p.
- Wyman, L. 1922. Results from sample plots in southern pines experiments. *Journal of Forestry*. 20(7): 780–787.

EFFECTS OF PLANTING STOCK ON GROWTH AND SURVIVAL IN AN ARTIFICIALLY REGENERATED SHORTLEAF PINE FOREST IN THE SOUTHERN APPALACHIAN MOUNTAINS

Tara L. Keyser and Amelia L. MacDonald

ABSTRACT

Shortleaf pine (*Pinus echinata* Mill.) is a widely distributed species and was historically a prominent component of southern Appalachian forests but has continued to decline throughout the region. The objectives of this case study were to examine how survival and growth of artificially regenerated shortleaf pine seedlings varied between planting stocks (containerized versus bareroot) and quantify and characterize competition from hardwood species following two-aged regeneration harvests that included site preparation activities and release treatments. Three-year survival was high for both containerized (100 percent) and bareroot stock (96 percent), while 3-year height and ground line diameter were greater for bareroot stock. The regeneration harvest stimulated the growth and recruitment of mesophytic hardwood species that will compete with shortleaf pine and likely influence future growth and survival. Efforts to successfully regenerate and restore mixed shortleaf pine/oak stands necessitate the reintroduction of disturbance via silvicultural treatments that include harvesting, site-preparation, chemical or mechanical release treatments, and/or prescribed fire over a long period of time.

INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.) is the most widely distributed southern yellow pine species. Found in 22 states in a variety of forest types and geographic conditions, shortleaf pine was historically a prominent component of southern Appalachian forests (Anderson and others 2016, Oswalt 2012). It is estimated that prior to the European colonization of North America, shortleaf pine and shortleaf pine/oak forest types covered roughly 24 to 28 million hectares (Anderson and others 2016). However, shortleaf pine has declined dramatically throughout the region (Guldin and Black 2018). Today, these forest types only cover 2.5 million hectares, with shortleaf pine forest types covering an estimated 1.3 million hectares and shortleaf pine/oak forest types covering 1.2 million hectares (Guldin and Black 2018, Oswalt 2012). Factors such as land use change, conversion to high-yield plantations, southern pine beetle (*Dendroctonus frontalis*) outbreaks, and changes in the historic disturbance regime, including fire suppression, are the leading causes associated with the decline throughout the range (Guldin 2007).

The abundance, dominance, and relative importance of shortleaf pine varies widely across its natural range. In the western portion of the range (e.g., Arkansas), pure shortleaf pine stands are common, while in the Southern Appalachian

Mountains, shortleaf pine exists primarily as a component of mixed pine/oak (*Quercus* L.) forest types, with common associates including pitch pine (*P. rigida* Mill.) and dry oak species, including scarlet (*Q. coccinea* Menchh.), chestnut (*Q. montana* L.), white (*Q. alba* L.), and black (*Q. velutina* Lam.) oak. In the Southern Appalachian Mountains, shortleaf pine and shortleaf pine/oak forests are primarily found on exposed, convex landforms at low elevations as well as upper slopes that are low in fertility and experience a deficit in soil moisture during the growing season (Simon and others 2005). Similar to upland oak forests prevalent across much of the Eastern United States, shortleaf pine/oak forests are successional, with persistence at the stand- and landscape-level dependent on frequent low- to moderate-severity disturbance (Brose and others 2001). Without disturbance to the upper and lower canopy layers, these xeric pine/oak forests transition to forests dominated by oaks and eventually shade-tolerant, mesophytic species (Harrod and others 1998, Nowacki and Abrams 2008).

The regeneration and restoration of shortleaf pine/oak forests in the Southern Appalachians is complicated by competition from fast-growing hardwood species, such as sweetgum (*Liquidambar styraciflua* L.), red maple (*Acer rubrum* L.), and yellow-poplar (*Liriodendron tulipifera* L.) (Clabo and Clatterbuck 2020a, Jensen and others 2007, Schnake

Author Information: Tara L. Keyser, Research Forester and Director of the Center for Forest Restoration and Management, U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC 28806; and Amelia L. MacDonald, Student Trainee, U.S. Department of Agriculture, Forest Service, Forest Management Service Center, Asheville, NC 28806.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

and others 2021). As such, site preparation and release treatments are likely needed to ensure shortleaf pine remains competitive and to facilitate recruitment into the canopy over time (Clabo and Clatterbuck 2020b). Further complicating restoration efforts is that existing pine/oak stands in the Appalachians contain few shortleaf pine seed trees. This sparse shortleaf pine overstory is unlikely to provide for the timely and sufficient seed source necessary to secure natural regeneration, making artificial regeneration a necessary component of shortleaf pine/oak restoration treatments.

Artificial regeneration of shortleaf pine is usually conducted after manipulating the density and stocking of the overstory (Clabo and Clatterbuck 2020a, Kabrick and others 2015, Waldrop and others 1989). Combined across species, southern pines regenerated from containerized stock have better performance on poor sites, but differences in performance between planting stocks are ameliorated on sites of higher productivity (Barnett and Brissett 2004, Barnett and McGilvray 1993, Boyer 1988, Ruehle and others 1981, South and others 2012). Root systems of containerized seedlings are often less damaged than bareroot seedlings during lifting operations at the nursery, which should confer an advantage (both survival and growth) over bareroot stock during outplanting (Barnett and Brisette 1986). Although containerized seedlings are preferred to artificially regenerate longleaf pine (*P. palustris* Mill.) (Barnett and McGilvray 1997), information on the potential advantages and disadvantages of the different planting stocks specific to shortleaf pine is sparse, especially across a wide range of environmental conditions.

Restoration of shortleaf pine and shortleaf pine/oak forests in the mountainous regions east of the Mississippi River, will be challenged by myriad factors, including strong and complex topographic, edaphic, and climatic gradients, all of which influence species composition, competitive dynamics, and post-disturbance stand dynamics. Although literature that guides the ecology and management of shortleaf pine forests in the western portion of its range is abundant (Guldin 2019, Kabrick and others 2007), comparatively few studies have been conducted in the Appalachian Region (Clabo and Clatterbuck 2020a, 2020b; Waldrop 1997). As such, basic information that guides the restoration of shortleaf and shortleaf pine/oak forests, including efficacy of natural and artificial regeneration methods, across a wide range of environmental gradients and stand conditions in the eastern portion of shortleaf pine's range is lacking. The objectives of this observational study are to examine how the survival and growth of artificially regenerated shortleaf pine seedlings varied between planting stocks (containerized verses bareroot) and quantify and characterize competition from hardwood species following a two-aged regeneration

harvested in a degraded shortleaf pine/oak stand in the Southern Appalachians.

MATERIALS AND METHODS

Study Area

This study was conducted on two sites on the Grandfather Ranger District on the Pisgah National Forest in western North Carolina. The Grandfather Ranger District lies within the Blue Ridge Escarpment, where the Blue Ridge Mountains meet the Piedmont. The landscape is characterized by the southwest to northeast aspects typical of the Blue Ridge Mountains. Elevations ranged from 400 to 550 m and slopes ranged from 11 to 47 percent. The climate is characterized as generally warm and humid, with annual precipitation averaging (1991-2020, Old Fort AG 3W climate station) 1421 mm and minimum and maximum temperatures averaging 6.1 °C and 20.2 °C, respectively (<https://www.ncei.noaa.gov/access/us-climate-normals/>).

TREATMENTS, DATA COLLECTION, AND DATA SUMMARY

Six stands ranging in size between 4.6 and 14.6 ha were identified in the Roses Creek (RC) area (four stands) and Miller Mountain (MM) area (two stands). The stands were all even-aged, mature (>80 years) white pine (*P. strobus* L.) upland hardwood forest types with white oak site index (base-age 50) values ranging from 17.7 to 20.1 m.

Between March of 2013 and August of 2014 all six stands were regenerated through a shelterwood with reserves harvest. Post-harvest residual basal area at the MM and RC sites averaged 4.4 and 3.1 m²/ha, respectively. Reserve trees were dispersed relatively evenly throughout the stands. Merchantable white pine, scarlet oak, Virginia pine (*P. virginiana* Mill.), and black oak were harvested, while white oak, chestnut oak, shortleaf pine, pitch pine, and hickory (*Carya* Nutt.) were retained as reserves. Site preparation activities were similar to that described in the “fell and burn” approach to regenerate mixed pine-hardwood stands (Waldrop 1997, Waldrop and others 1989). Following harvest, all non-merchantable material between 5.1 and 20.3 cm diameter at breast height (dbh) was felled, and a cut stump herbicide treatment (50 percent triclopyr amine in water) was applied to prevent sprouting of mesophytic species (e.g., red maple, blackgum, sourwood [*Oxydendrum arboreum*], sweetgum). Prescribed fires were conducted 6 to 12 months following harvest in all six stands to prepare the sites for planting.

In March of 2015, the four stands in the RC site were artificially regenerated with shortleaf pine using bareroot

1-0 stock planted on a 4.3-m x 4.3-m spacing (treatment = bareroot). During the same time period, the two stands in the MM site were artificially regenerated with shortleaf pine using containerized 1-0 stock planted on a 6.1-m x 6.1-m spacing (treatment = containerized). Unfortunately, because of the opportunistic nature of this study, we were unable to obtain information related to the type of container used or plug size of containerized seedlings. Seedlings that were severely damaged or displayed excessive dieback were culled during planting. All seedlings were produced in one nursery in North Carolina using the same North Carolina Southern Appalachian seed source identified as “superior” (Seed lot SH-50-1-110-1-09-01). In the winter of 2016, a streamline herbicide release treatment consisting of 17 percent triclopyr ester with 1.5 percent adjuvant mixed in basal oil, was conducted on both sites that targeted single stems and sprout clumps of red maple, yellow-poplar, and other undesirable, mesophytic species.

A 30-m buffer was established between each stand and the surrounding undisturbed forest. Random sampling points were then generated at a rate of two plots per hectare. Within all stands, sampling points were ≥ 20 m apart. Data were collected at the end of one (YR1) and three growing seasons (YR3) after planting. At each sampling location, one artificially regenerated shortleaf pine seedling was tagged and ground line diameter (cm) was measured and recorded as the average of two measurements using a digital caliper. Height (m) of the artificially regenerated shortleaf pine

seedling was also measured and recorded. Using a 0.002 ha plot, all competing woody vegetation < 3.8 cm dbh was inventoried by species and size classes. Size classes were based on height and diameter and included: stems < 0.6 m, stems ≥ 0.6 m and < 0.9 m, stems ≥ 0.9 m and < 1.4 m, stems ≥ 1.4 m and < 3.8 cm dbh.

Survival (%), average height (m), and average ground line diameter (cm) of the artificially regenerated shortleaf pine seedlings were calculated and compared for each site/ planting stock. Regeneration data were divided into species subgroups, and average stems per ha were calculated by species subgroup and size class per site for each sampling period. Species subgroups included oak/hickory (OH), red maple (RM), yellow-poplar (YP), southern yellow pine (shortleaf, which included the one planted shortleaf per plot, pitch, Table Mountain [*P. pungens* Lamb.], and Virginia pine) (SYP), and other (OT).

RESULTS

In YR1, bareroot and containerized shortleaf pine seedlings each had 100-percent survival. Survival remained high, regardless of planting stock, with YR3 survival of containerized and bareroot seedlings averaging 100 percent and 96 percent, respectively.

At the end of the first growing season, height of bareroot seedlings averaged 0.26 m, while height of containerized seedlings averaged 0.28 m. After three growing seasons,

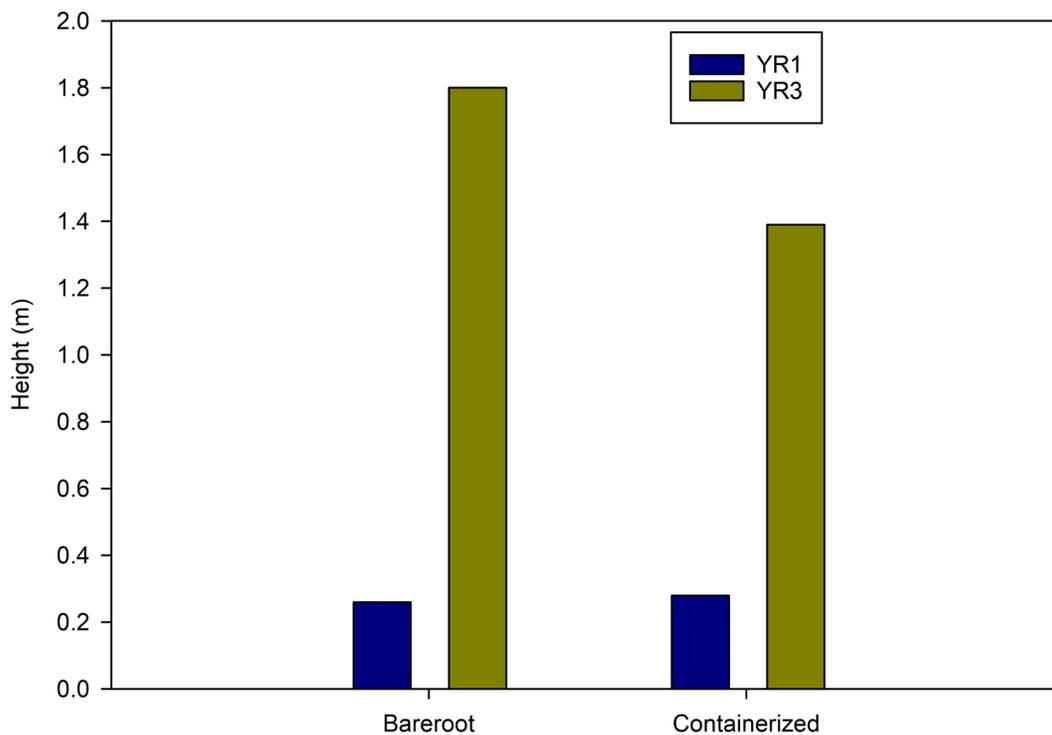


Figure 1—Average height (m) of artificially regenerated shortleaf pine seedlings one (YR1) and three (YR3) growing seasons post-establishment.

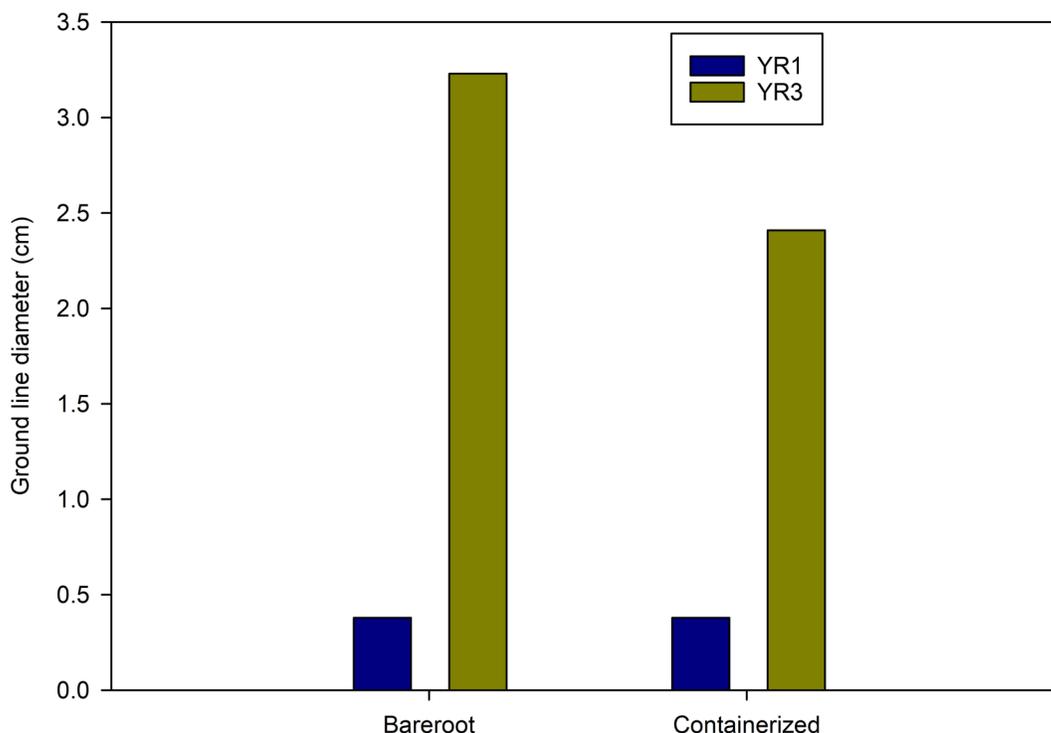


Figure 2—Average ground line diameter (cm) of artificially regenerated shortleaf pine seedlings one (YR1) and three (YR3) growing seasons post-establishment.

height increased to an average 1.80 m and 1.39 m for bareroot and containerized seedlings, respectively (fig. 1). In YR1, ground line diameter of both the bareroot and containerized seedlings averaged 0.38 cm (fig. 2). By YR3, differences in ground line diameter between the planting stocks were observed, with bareroot seedlings averaging 3.23 cm and containerized seedlings averaging 2.41 cm.

Competing woody vegetation, which included both hardwood and conifer species, was diverse and abundant at both the MM and RC sites. After one growing season, woody competition at both sites was dominated by stems <0.6 m (fig. 3), with few stems of any species in the largest two size classes. Although OH and SYP were abundant in the smallest size class (average OH and SYP across the two sites was 1,105

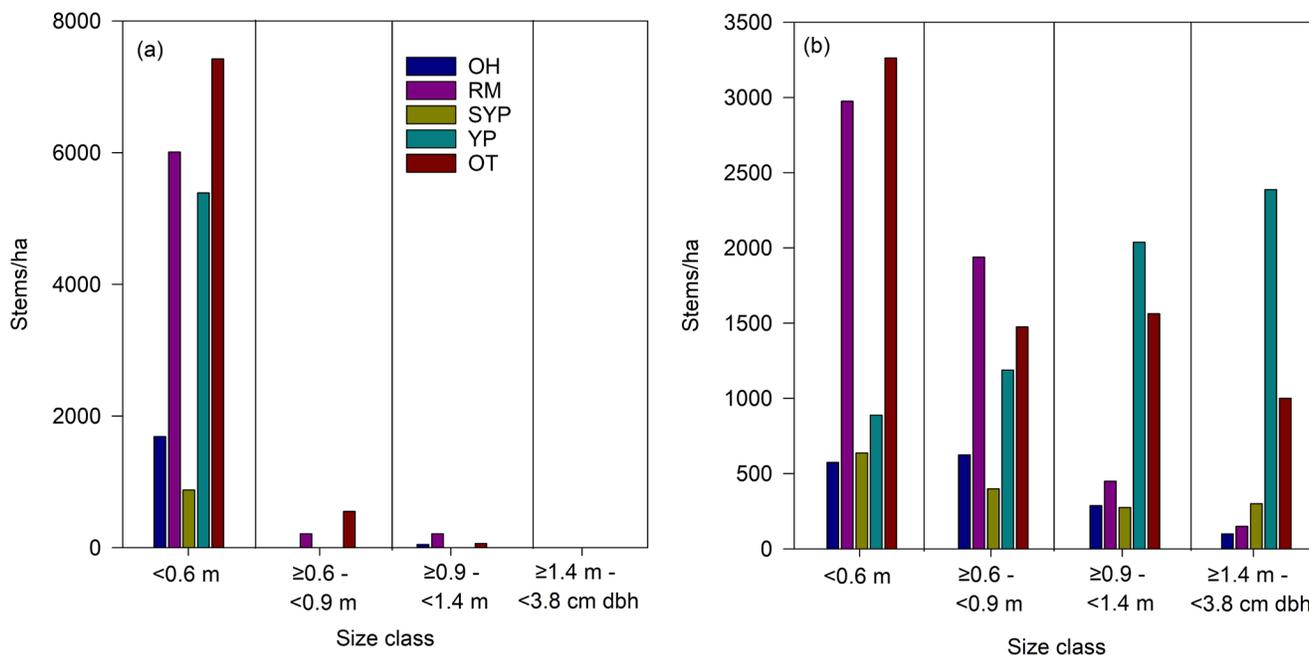


Figure 3—Density (stems/ha) by species group and size class of the competing woody vegetation <3.8 cm dbh (a) one (YR1) and (b) three (YR3) growing seasons post-establishment in the MM (containerized) site. OH=oak/hickory, RM=red maple, SYP=southern yellow pine, YP=yellow-poplar, OT=other.

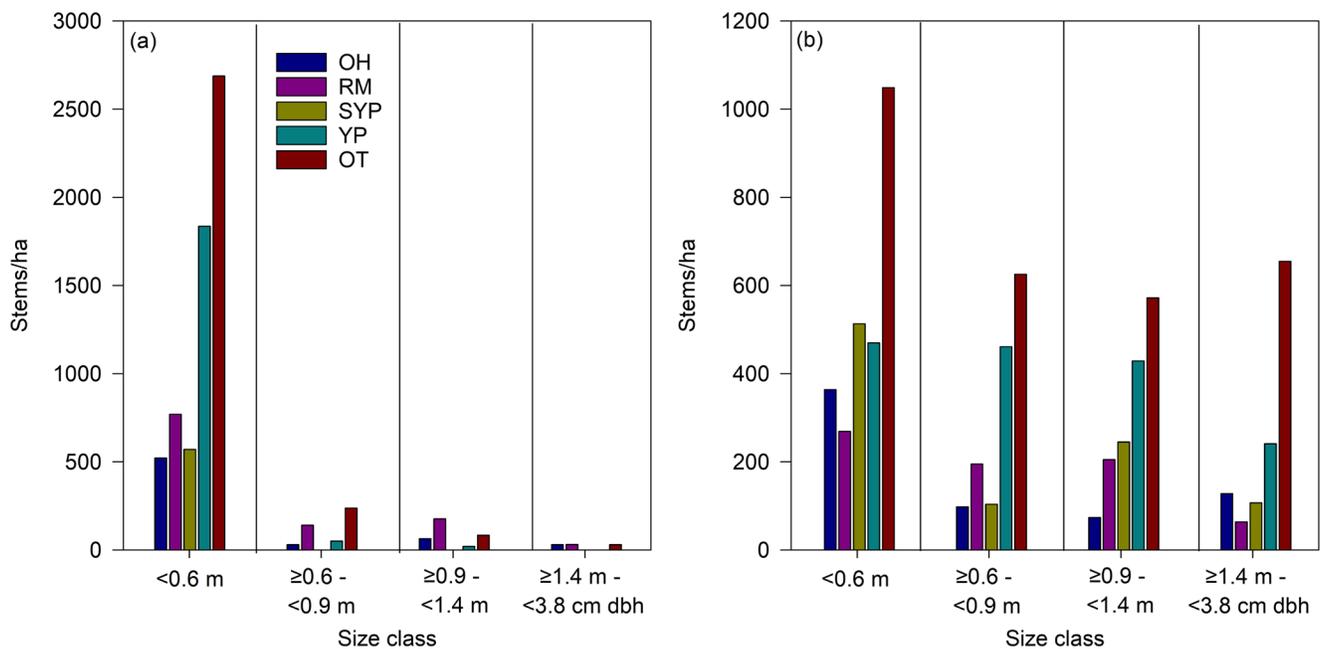


Figure 4—Density (stems/ha) by species group and size class of the competing woody vegetation <3.8 cm dbh (a) one (YR1) and (b) three (YR3) growing seasons post-establishment in the RC (bareroot) site. OH=oak/hickory, RM=red maple, SYP=southern yellow pine, YP=yellow-poplar, OT=other.

and 723 stems/ha, respectively), their relative abundance was low, as the density of YP, OT, and RM across the two sites exceeded 3,300 stems/ha.

There were substantial changes in the size distribution and composition of competing woody vegetation between YR1 and YR3, with recruitment into the largest two size classes evident in both the MM and RC sites (fig. 4). In the largest size class (stems ≥ 1.4 and <3.8 cm dbh), which represents the individuals most likely to successfully compete and form the dominant and co-dominant canopy layer at crown closure (Loftis 1990), there was an increase of approximately 100 stems/ha of OH between YR1 and Y3 in both the MM and RC sites. Similarly, there was an increase in the density of SYP stems ≥ 1.4 and <3.8 cm dbh of 300 and 107 stems/ha in the MM and RC sites, respectively. Although both OH and SYP, desirable species from a pine/oak restoration perspective, increased, less desirable species also increased in the largest seedling size class between YR1 and YR3, including an increase of (on average across the two sites) 91, 1,315, and 812 stems/ha of RM, YP, and OT species, respectively.

DISCUSSION

The level of residual basal area in this study can affect growth of planted shortleaf pine seedlings relative to conditions following a clearcut (Kabrick and others 2015, Schnake and others 2021). However, because residual overstory density was similar between the two sites, it is unlikely a direct factor influencing the response of artificially regenerated shortleaf pine in this case study. Survival of planted shortleaf pine seedlings was high, with 100 percent and 96 percent

of containerized and bareroot seedlings surviving through YR3, respectively. The negligible difference in survival between the two planting stocks is in contrast with Schnake and others (2021) who report that survival of containerized seedlings was up to 37 percent greater than bareroot seedlings on dry upland hardwood sites in the Piedmont region of North Carolina.

Although data on seedling size at the time of planting were lacking, both height and ground line diameter of bareroot and containerized seedlings were similar after YR1 (figs. 1 and 2), suggesting any differences at planting were likely minor. By YR3, however, relative to containerized seedlings, bareroot seedlings were, on average, 0.43 m taller and possessed ground line diameters that were, on average, 0.82 cm greater. Reports that detail growth and competitiveness of containerized versus bareroot seedlings are conflicting. For example, our results support the findings of Gwaze and others (2006) who report stem diameter of bareroot seedlings was significantly greater than containerized seedlings after two growing seasons. However, the authors did not report any significant differences in height between the two stock types. On the other hand, Schnake and others (2021) found containerized seedlings with large plugs (plug volume = 113.1 mL) outperformed bareroot seedlings, with bareroot seedlings being no taller than containerized seedlings with small (plug volume = 93.4 mL) plugs. It is worth noting that nursery records indicate the bareroot and containerized seedlings utilized in this study were likely from the same seed and nursery as the “large plug” seedlings used by Schnake and

others (2021), indicating that, at least in this study area, this particular seed source performs as well as either stock type.

CONCLUSION AND FUTURE MANAGEMENT IMPLICATIONS

The response of undesirable hardwood species to a variety of regeneration methods, including two-aged methods (Miller and others 2006), will hamper restoration success without follow-up treatments (Anup and others 2016). Despite the herbicide release (conducted in 2016), the density of hardwood stems in the largest size class (stems ≥ 1.4 and < 3.8 cm dbh) remained high, with that pool of woody regeneration dominated by species that are not necessarily desirable (e.g., YP, OT) from a mixed pine/oak restoration perspective. Although OH stems were present in the largest size class, relative abundance was low, highlighting the need to conduct silvicultural treatments (chemical or mechanical cleaning or release treatments) that encourage the regeneration and recruitment of both shortleaf pine as well as oak and hickory species. If shortleaf pine seedlings are suppressed beyond 5 to 8 years (Kenefic and others 2021, Lyczak 2019) and oak seedlings beyond 8 years (Weigel and Johnson 2000), mortality significantly increases.

Although release of individual seedlings can be accomplished mechanically or chemically, shortleaf pine/oak forests were historically developed and maintained by a variety of disturbances, including fire (Brose and others 2001). Shortleaf pine is well-adapted to fire, as seedlings and saplings can resprout from a basal crook following topkill (Stewart and others 2016). Similarly, oaks, with their conservative growth strategy, maintain high root:shoot and exhibit hypogeal germination; traits linked to increased resprout ability relative to non-oak species (Brose and others 2014). Using fire to control competition has the benefit of being able to treat large areas with relatively low economic cost (Wade 1989). To reduce the risk of mortality to planted shortleaf, prescribed fire should be withheld during the first 3 years after planting, with low-intensity burns repeated every 5 to 8 years to promote pine recruitment and temporarily reduce hardwood competition (Kenefic and others 2021). However, all hardwoods, including red maple and yellow-poplar and various oak species, can resprout vigorously following fire-induced topkill, with the probability of desirable oak species (e.g., white oak) sprouting being lower than that of red maple and yellow-poplar (Keyser 2019).

Like oak systems in the Appalachians, efforts to successfully regenerate and restore mixed shortleaf pine/oak stands necessitate the reintroduction of disturbance via silvicultural treatments that include harvesting, site-preparation, chemical or mechanical release treatments, and/or prescribed fire over a long period of time (Guldin 2007, Kenefic and others 2021).

Shortleaf pine habitat covers approximately 1,139,595 km² and is found as far west as eastern Texas and west up to the eastern seaboard of New Jersey. The ecological complexity associated with the range of shortleaf pine suggests no single prescription will be applicable to the range of conditions in which shortleaf pine is found. Genetics (Gwaze and others 2006), environmental conditions, silvicultural methods, including fire and release treatments, and planting methods (South and others 2012) along with other factors, including competition from faster growing hardwoods, will interact to influence the success of planting shortleaf pine (Gwaze and others 2006, Hallgren and others 1993, South and others 2012) and eventual restoration efforts.

This observational (opportunistic) study lacked an experimental design and quantitative descriptors of shortleaf pine seedlings at the time of planting (e.g., plug size, seedling height, root collar diameter, root:shoot, etc.) which limited our ability to make statistically-based inferences related to the effects of planting stock on growth, development, and competitiveness of planting shortleaf pine. Despite these limitations, the results presented provide basic information that can help refine avenues of future research associated with restoring mixed shortleaf pine/oak forests across the Southern Appalachians.

ACKNOWLEDGMENTS

We thank Kenny Frick and Marcus Wood for assistance with field data collection, and staff (Matt Keyes, Owen Reed, and Chad Keyser (on detail at the time of the study) of the Pisgah Ranger District, Pisgah National Forest for facilitating this study. David Schnake and Dr. Stacy Clark improved an earlier version of the manuscript with their comments and edits. This paper was written and prepared by a U.S. Government employee on official time, and therefore it is in the public domain and not subject to copyright. This research was supported in part by the U.S. Department of Agriculture (USDA) Forest Service. The findings and conclusions in this publication are those of the author(s) and should not be construed to represent an official USDA, Forest Service, or U.S. Government determination or policy.

LITERATURE CITED

- Anderson, M.; Hayes, L.; Keyser, P.D. [and others], principal contributors. 2016. Shortleaf Pine Restoration Plan: restoring an American forest legacy. Shortleaf Pine Initiative. 67 p. <http://shortleafpine.net/tools-and-resources/restoration-plan/shortleaf-pine-restoration-plan>. [Date accessed: April 28, 2022].
- Anup, K.C.; Lynch, T.B.; Guldin, J.M. 2016. Shortleaf pine (*Pinus echinata* Mill.) and hardwood regeneration after thinning natural shortleaf pine forests in southern United States. In: Schweitzer, Callie J.; Clatterback, Wayne K.; Oswalt, Christopher M., eds. Proceedings of the 18th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-212. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 553–554.

- Barnett, J.P.; Brisette, J.C. 1986. Producing southern pine seedlings in containers. Gen. Tech. Rep. SO-59. New Orleans: U.S. Department of Agriculture Forest Service, Southern Research Station. 71 p.
- Barnett, J.P.; Brisette, J.C. 2004. Stock type affects performance of shortleaf pine planted in the Ouachita Mountains through 10 years. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 420–422.
- Barnett, J.P.; McGilvray, J.M. 1993. Performance of container and bareroot loblolly pine seedlings on bottomlands in South Carolina. Southern Journal of Applied Forestry. 17: 80–83.
- Barnett, J.P.; McGilvray, J.M. 1997. Practical guidelines for producing longleaf pine seedlings in containers. Gen. Tech. Rep. SRS-15. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 28 p.
- Boyer, W.D. 1988. Effects of site preparation and release on the survival and growth of planted bare-root and container grown longleaf pine. Georgia Forest Research Paper 76. [Place of publication unknown]. Georgia Forestry Commission, Research Division: 1–7.
- Brose, P.H.; Dey, D.C.; Waldrop, T.A. 2014. The fire-oak literature of eastern North America: synthesis and guidelines. Gen. Tech. Rep. NRS-135. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station. 98 p.
- Brose, P.; Schuler, T.; Van Lear, D.; Berst, J. 2001. Bringing fire back: the changing regimes of the Appalachian mixed-oak forests. Journal of Forestry. 99: 30–35.
- Clabo, D.; Clatterbuck, W. 2020a. Restoration of shortleaf pine (*Pinus echinata*)-hardwood mixtures in low quality mixed upland hardwood stands using cluster planting and natural regeneration. Forests. 11: 457. <https://doi.org/10.3390/f11040457>.
- Clabo, D.C.; Clatterbuck, W.K. 2020b. Establishment and early development of even-aged shortleaf pine-hardwood mixtures using artificially regenerated shortleaf pine and various site preparation release treatments. Forest Science. 66: 351–360.
- Guldin, J.M. 2019. Restoration of native fire-adapted southern pine-dominated forest ecosystems: Diversifying the tools in the silvicultural toolbox. Forest Science. 65: 508–518.
- Guldin, J.M. 2007. Restoration and management of shortleaf pine in pure and mixed stands—science, empirical observation, and the wishful application of generalities. Gen. Tech. Rep. NRS-P-15. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station: 47–58.
- Guldin, J.M.; Black, M.W. 2018. Restoration of shortleaf pine in the Southern United States—strategies and tactics. e-Gen. Tech. Rep. SRS-234. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 281–287.
- Gwaze, D.; Melick, R.; Studyvin, C.; Hoss, G. 2006. Survival and growth of container and bareroot shortleaf pine seedlings in Missouri. In: Riley, L.E.; Dumroese, R.K.; Landis, T.D., tech. coords. National proceedings: Forest and Conservation Nursery Associations—2005. RMRS-P-43. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station: 123–126.
- Hallgren, S.W.; Tauer, C.G.; Weeks, D.L. 1993. Cultural, environmental and genetic factors interact to affect performance of planted shortleaf pine. Forest Science. 39: 478–498.
- Harrod, J.C.; White, P.S.; Harman, M.E. 1998. Changes in xeric forests in western Great Smoky Mountains National Park, 1936–1995. Castanea. 63: 346–360.
- Jensen, J.; Smith, C.; Johanson, J.; Gwaze, D. 2007. Underplanting shortleaf pine in the Missouri Ozarks. Gen. Tech. Rep. NRS-P-15. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station: 112–116.
- Kabrick, J.M.; Dey, D.C.; Gwaze, D. 2007. Shortleaf pine restoration and ecology in the Ozarks: proceedings of a symposium. Gen. Tech. Rep. NRS-P-15. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station. 215 p.
- Kabrick, J.M.; Knapp, B.O.; Dey, D.C.; Larsen, D.R. 2015. Effect of initial seedling size, understory competition, and overstory density on the survival and growth of *Pinus echinata* seedlings underplanted in hardwood forests for restoration. New Forests. 46: 897–918.
- Kenefic, L.S.; Kabrick, J.M.; Knapp, B.O. [and others]. 2021. Mixed wood silviculture in North America: the science and art of managing for complex, multi-species temperate forests. Canadian Journal of Forest Research. 51(7): 921–924. <https://doi.org/10.1139/cjfr-2020-0410>.
- Keyser, T.L. 2019. Resprouting by seedlings of four North American deciduous broadleaved tree species following experimental burning. Oecologia. 190: 207–218.
- Loftis, D.L. 1990. Predicting post-harvest performance of advance red oak reproduction in the Southern Appalachians. Forest Science. 36: 908–916.
- Lyczak, S.J. 2019. The survival and growth of shortleaf pine systems in the Missouri Ozarks: effects of competition, genetics, and site preparation. Oxford, MS: University of Missouri. 125 p. M.S. thesis.
- Miller, G.W.; Kochenderfer, J.N.; Fekedulegn, D.B. 2006. Influence of individual reserve trees on nearby reproduction in two-aged Appalachian hardwood stands. Forest Ecology and Management. 224: 241–251.
- Nowacki, G.J.; Abrams, M.D. 2008. The demise of fire and “Mesophication” of forests in the Eastern United States. Bioscience. 58: 213–138.
- Oswalt, C.M. 2012. Spatial and temporal trends of the shortleaf pine resource in the Eastern United States. In: Kush, J.; Barlow, R.J.; Gilbert, J.C., eds. Proceedings of the shortleaf pine conference: east meets west, bridging the gap with research and education across the range. Special Report No. 11. Huntsville, AL: Alabama Agricultural Experiment Station: 33–37.
- Ruehle, J.L.; Marx, D.H.; Barnett, J.P.; Pawuk, W.H. 1981. Survival and growth of container-grown and bare-root shortleaf pine seedlings with *Pisolithus* and *Thelephora Ectomycorrhizae*. Southern Journal of Applied Forestry. 5: 20–24.
- Schnake, D.K.; Roberts, S.D.; Willis, J.L. [and others]. 2021. Overstory retention and stock type impact survival and growth of underplanted shortleaf pine beneath a hardwood canopy. Forest Science. 67: 219–230.
- Simon, S.A.; Collins, T.K.; Kauffman, G.L. [and others]. 2005. Ecological zones in the Southern Appalachians: first approximation. Res. Pap. SRS-41. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 41 p.
- South, D.B.; Jackson, D.P.; Starkey, T.E.; Enebak, S.A. 2012. Planting deep increases early survival and growth of *Pinus echinata* seedlings. The Open Forest Science Journal. 5: 33–41.
- Stewart, J.F.; Will, R.E.; Crane, B.S.; Nelson, C.D. 2016. The genetics of shortleaf pine (*Pinus echinata* mill.) with implications for restoration and management. Tree Genetics and Genomes. 12: 98.
- Wade, D.D. 1989. A guide for prescribed fire in southern forests. Tech. Pub. R8-TP-11. U.S. Department of Agriculture Forest Service, Southern Region. 57 p.
- Waldrop, T.A. 1997. Four site-preparation techniques for regenerating pine-hardwood mixtures in the Piedmont. Southern Journal of Applied Forestry. 21: 116–122.
- Waldrop, T.A.; Lloyd, F.T.; Abercrombie, J.A., Jr. 1989. Fell and burn to regenerate mixed pine-hardwood stands: an overview of research on stand development. Gen. Tech. Rep. SE-58. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station: 75–82.
- Weigel, D.R.; Johnson, P.S. 2000. Planting red oak under oak/yellow-poplar shelterwoods: A provisional prescription. Gen. Tech. Rep. NC-210. St. Paul, MN: U.S. Department of Agriculture Forest Service, North Central Research Station. 16 p.

Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

The 21st Biennial Southern Silvicultural Research Conference (BSSRC) was held on March 16-17, 2021, in a virtual format. The BSSRC is designed as a forum to exchange silvicultural information between researchers, land managers, forest industry, and graduate students. From the 64 oral presentations and 22 posters offered at the conference, 26 papers and 24 extended abstracts were submitted to these proceedings. The submissions were organized into seven topics, which include Prescribed Fire; Bottomland and Riparian Forests; Loblolly Pine Management; Natural Disturbances and Climate Change; Longleaf Pine Management; Upland Hardwoods Management; and Shortleaf Pine Management. Collectively, the work presented in this manuscript provides a synopsis of the latest silvicultural research conducted in the Southeastern United States.

KEYWORDS: Climate change, disturbance ecology, forest mensuration, genetics, hardwoods, herbicides, hybrid poplar, invasive species, loblolly pine, longleaf pine, modeling, oak, plantations, physiology, prescribed fire, shortleaf pine, silviculture, soil.



In accordance with Federal civil rights law and U.S. Department of Agriculture (USDA) civil rights regulations and policies, the USDA, its Agencies, offices, and employees, and institutions participating in or administering USDA programs are prohibited from discriminating

based on race, color, national origin, religion, sex, gender identity (including gender expression), sexual orientation, disability, age, marital status, family/parental status, income derived from a public assistance program, political beliefs, or reprisal or retaliation for prior civil rights activity, in any program or activity conducted or funded by USDA (not all bases apply to all programs). Remedies and complaint filing deadlines vary by program or incident.

Persons with disabilities who require alternative means of communication for program information (e.g., Braille, large print, audiotape, American Sign Language, etc.) should contact the responsible Agency or USDA's TARGET Center at (202) 720-2600 (voice and TTY) or contact USDA through the Federal Relay Service at (800) 877-8339. Additionally, program information may be made available in languages other than English.

To file a program discrimination complaint, complete the USDA Program Discrimination Complaint Form, AD-3027, found online at http://www.ascr.usda.gov/complaint_filing_cust.html and at any USDA office or write a letter addressed to USDA and provide in the letter all of the information requested in the form. To request a copy of the complaint form, call (866) 632-9992. Submit your completed form or letter to USDA by: (1) mail: U.S. Department of Agriculture, Office of the Assistant Secretary for Civil Rights, 1400 Independence Avenue, SW, Washington, D.C. 20250-9410; (2) fax: (202) 690-7442; or (3) email: program.intake@usda.gov.

USDA is an equal opportunity provider, employer, and lender.