United States
Department of
Agriculture

Forest
Service

Northern
Research Station

General Technical
Report NRS-P-15

SHORTLEAF PINE RESTORATION AND ECOLOGY IN THE OZARKS: PROCEEDINGS OF A SYMPOSIUM

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SHORTLEAF PINE RESTORATION AND ECOLOGY IN THE OZARKS: PROCEEDINGS OF A SYMPOSIUM

November 7-9, 2006
Springfield, MO

Edited by
John M. Kabrick
Daniel C. Dey
David Gwaze

Hosted by
The Missouri Department of Conservation

Published by
USDA Forest Service
11 Campus Blvd., Suite 200
Northern Research Station
Newtown Square, PA 19073-3294

September 2007

FOREWORD

The Shortleaf Pine Restoration and Ecology in the Ozarks Symposium was held at the University Plaza Hotel and Convention Center in Springfield, Missouri, on November 7-9, 2006. The purpose of the symposium was to communicate experiences, research, successes, challenges, and inspire inquiries into the ecology, management, and restoration of shortleaf pine communities and ecosystems in which shortleaf pine is prominent. The symposium brought together more than 200 registrants including private landowners, state and federal resource managers, consultants, members of conservation groups, and scientists from public and private institutions to exchange ideas and share knowledge about ecosystems containing shortleaf pine. Altogether, the symposium featured eight plenary presentations, 36 oral presentations, and nine poster presentations.

REVIEW PROCEDURES

Submitted manuscripts were peer-reviewed by two or more professionals familiar with the subject matter. The reviewed manuscripts were each assigned to one of the editors to render decisions about the review comments and to return the manuscripts. Revised manuscripts that were examined by the editors; satisfactory manuscripts were forwarded to the USDA Forest Service Northern Research Station for technical editing and publishing. Extended abstracts included herein were reviewed by the technical editors. The authors are responsible for the accuracy and content of their papers and extended abstracts.

LIST OF REVIEWERS

The editors sincerely appreciate the efforts of the following colleagues who reviewed one or more manuscripts. Their efforts greatly improved the content of this proceeding.

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CONTINUING FORESTRY EDUCATION

For attending this conference, each registrant was eligible for up to 19.5 hours of Continuing Forestry Education (CFE) Category 1 credit hours through the Society of American Foresters.

SYMPOSIUM ORGANIZING COMMITTEE

Missouri Department of Conservation:
David Gwaze (chair), Tom Nichols, Mike Huffman, Tom Kulowiec, Duane Parker, Larry Rieken, Rhonda Rimer, Matt Seek

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ACKNOWLEDGMENTS

The Symposium Organizing Committee gratefully acknowledges the conference sponsors:

Current River Pole Company
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CONTENTS

PLENARY

ECOLOGY OF SHORTLEAF PINE SYSTEMS

GENETICS AND TREE IMPROVEMENT OF SHORTLEAF PINE

REGENERATING AND MANAGING SHORTLEAF PINE

MAINTAINING PRODUCTIVITY AND PROTECTING WATER QUALITY

WILDLIFE DIVERSITY IN SHORTLEAF PINE FORESTS AND WOODLANDS

ECONOMICS OF MANAGING SHORTLEAF PINE

GROWTH AND YIELD OF SHORTLEAF PINE

RESTORING SHORTLEAF PINE COMMUNITIES

HISTORICAL AND SOCIAL FACTORS AFFECTING PINE MANAGEMENT IN THE OZARKS DURING THE LATE 1800s THROUGH 1940

Robert J. Cunningham[1]

ABSTRACT.—During the latter part of the 19th century, European descendents migrated to the Ozarks seeking employment with large pine-producing sawmills. Within a 30-year period, most of the pine resources across six million acres had been exploited and were largely replaced by oak-hickory forests. The era ended with residents struggling with economic challenges and limited natural resources. Differing values and management philosophies toward the forest, and attempts to restore pine communities by creating a system of forest management and recovery in Missouri, have been a legacy of conflict among people.

INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.) in the Missouri Ozarks has direct ties to the region's settlement, industrial exploitation, and the development of forest management in Missouri. Use of the forest resources have often resulted in struggles between the local citizens, wood industries, and politicians that benefited from the short-term exploitation, and citizen groups and agencies seeking long-term policies for maintaining the pine resource. Local economic conditions will continue to influence the extent of shortleaf pine and the acceptance of management schemes on both public and private lands.

MODEL FOR FORESTRY DEVELOPMENT

Throughout the world, the concepts of silviculture and forest management have been around for approximately 400 years. The development of modern forest management in the Missouri Ozarks is tied to activities throughout the past century and in particular to the industrial and political activities prior to 1940. Kimmins (1997) indicates that wherever and whenever forestry is developed, there has been a similar sequence of developmental stages:

- Stage 1: Unregulated exploitation of local forests.
- Stage 2: Regulation of forest exploitation through legal and political mechanisms or religious taboos.
- Stage 3: Development of an ecological approach to silviculture and timber management.
- Stage 4: Progression toward social forestry to be environmentally and ecologically sound but also responsive to diverse demands of society and local communities.

The history of forestry in the Ozarks and ultimately the history of forest management in Missouri largely follow the Kimmins model. The stages are not only continuous but are fluid, overlapping, and often repeating. Historic periods of the Ozarks have recorded progress towards the later stages of development only to be succeeded by a reversion to the primary stages as changes in economic conditions and emerging industries challenge the values that society places on the forest.

THE PINE RESOURCE

Even though forests covered 70 percent of Missouri prior to settlement, perhaps the most celebrated forest cover was the pine-covered hills of the southeastern Ozarks. Known as the Courtois Hills, this rugged area has steep-sided hills and chert-covered ridges (Fig. 1). The name Courtois Hills is derived from the Courtois Creek in Crawford County. Courtis Hills extend over all of Carter, Reynolds, and Shannon Counties, and parts of Crawford, Dent, Iron, Wayne, Oregon, Butler, Ripley, and Madison Counties (Hill 1949).

Presettlement pine was estimated to have occurred across 6.6 million acres in the Missouri Ozarks (Liming 1946). Not all of its range was limited to the Courtois Hills as pine was also found in some of Missouri's south-central and southwestern counties. The vast pine forests were distributed unevenly – some areas being heavily timbered with pine and some mixed with hardwoods, such as white oak (*Quercus alba* L.), post oaks (*Q. stellata* Wangenh.), black oak (*Q. velutina* Lam.), and blackjack oak (*Q. marilandica* Muenchh.). Pine occupied most of the sandy land, and part of the flint ridges. In the southern counties, pine grew profusely on the flat, clay uplands. White and black oak grew commonly on the ridges while post oak and blackjack grew on the dry, stony hillsides (Hill 1949).

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[1] Private Land Services Regional Supervisor (RJC), Missouri Department of Conservation, P. O. Box 138, West Plains, MO 65775: to contact call (417) 255-9561 x 225 or email at Bob.Cunningham@mdc.mo.gov

Figure 1.—Southeastern Missouri Ozark counties geographically known as the Courtois Hills.

Pine occurred mostly in clumps or groups, and occasionally formed pure stands. One of the most extensive areas was the Irish Wilderness in northeastern Oregon County. In general pine lands were fairly open, with little or no underbrush growing beneath the pines except for little bluestem grass (*Schizachyrium scoparium*) and an occasional oak sprout (Martin and Presley 1958). Pine volumes averaged 4,000 board feet per acre with occasional stands containing 25,000 board feet per acre (Hill 1949). Rare accounts of huge trees, some as large as 7 feet in diameter at the stump, have been collected through oral histories (Smith 1959).

THE PEOPLE

European descendents essentially poured into Missouri's agriculturally rich areas during the early 1800s. The hilly sections of the Ozarks were the state's last physical frontier and were largely bypassed due to poor transportation routes leading into the region and a general lack of fertile farm ground (Galloway 1961).

The first arrivals trickled into the Ozarks during the first half of the 19th century. Three-fourths of the early residents had migrated from Tennessee and Kentucky. For the most part, they were Scots-Irish descendents and possessed a true frontier spirit (Rafferty 1980).

Hammar (1935) typifies four aspects of frontier development that had an enduring effect on the Ozarks: (1) the dominance of agriculture in the conquest for the Middle West, and the corollary assumption that what was good for a rich agricultural section was equally good for the sections neither agricultural nor rich; (2) the race for acquisition based on the idea that he serves (and serves well) who merely acquires; (3) a fierce impatience with any government interference in "private" affairs and an almost complete disdain for public aspects of conservation; and (4) a faith in competition as a sufficient regulator of business, and a great willingness to give free rein to private initiative. Nearly 200 years later, these attitudes still embody the Ozark spirit.

The early settlers brought an outlook that all land was essentially agricultural land. Their primary occupation was subsistence farming; they were poor but nearly self-sufficient. The rugged and stony nature of the soils fought back against cultivation. When plowed, they were quickly worn out and vulnerable to erosion (Hammar 1935).

Most of the inhabitants were engaged in raising livestock on the open range. The pine forests were well suited to produce forage because they were naturally open with an understory of grasses. So long as the forest remained in its frontier or pristine condition, it could continue to support this form of agriculture and provide the basic needs for the people—but with limitations. As Hammar (1935) suggested, the region's thin and infertile soils were threatened with oversettlement.

A second phase of immigration started after the Civil War. Until this time, the Ozarks had been isolated from intensive settlement and commercial resource exploitation. The earliest pioneers had established small farms primarily in the valleys. It was during the second phase that persons employed by eastern capitalists penetrated and developed much of the region (Galloway 1961).

Since the demand for forest products was concentrated in the more populated eastern United States, Missouri's remote forests had remained uncut. Westward migration of people onto the treeless plains quickly drew attention to the Ozarks' forests. During the latter half of the 19th century, populations in the heavy pine-bearing counties increased from two to five times over the reported population of 1860 as lumber companies established large operations across the southeastern Ozarks (Shoemaker 1943). Carter, Oregon, Reynolds, Ripley, Shannon, and Wayne Counties best illustrates this since they were the center of the heaviest lumbering operations (Table 1).

Table 1.—Population trends in selected Missouri Ozarks counties.

County	1860*	1870	1880	1890	1900	1910	1920	1930	1940
Carter	1,215	1,455	2,168	4,659	6,706	5,505	7,482	5,503	6,226
Oregon	2,983	3,287	5,791	10,467	13,906	14,681	12,889	12,220	13,390
Reynolds	3,135	3,756	5,722	6,803	8,161	9,592	10,106	8,923	9,370
Ripley	3,669	3,175	5,377	8,512	13,186	13,099	12,061	11,176	12,606
Shannon	2,271	2,339	3,441	8,898	11,247	11,443	11,865	10,894	11,831
Wayne	5,368	6,068	9,096	11,927	15,309	15,181	13,012	12,243	12,794

*Figures reported for 1860 are listed as free men and do not include slave numbers.

THE EXPLOITATION

Even though the land in the Ozarks was characterized as rocky and unproductive, it had standing timber of both oaks and pine. Timber was a salable commodity, but it required a capital outlay that the ordinary farmer could not afford. As a result, much land became tax delinquent until it was picked up by speculators and lumbermen starting around the late 1860s (Hill 1949).

Missouri's pine lumber boom started in the late 1880s and ended in the 1920s. At its peak in 1899, lumber production in Missouri was 724 million board feet (Cunningham and Hauser 1989). The largest mills were the Missouri Lumber and Mining Company, first at Grandin and then later moved to West Eminence; the Holaday-Klotz Land and Lumber Company at Greenville; the Clarkson Sawmill at Leeper; the Cordz-Fisher Lumber Company at Birch Tree; the Ozark Land and Lumber Company at Winona; and the Bunker-Culler Lumber Company at Bunker (Fig. 2). Added to these larger mills were scores of smaller production sawmills.

Not all sawmills were engaged in the production of pine lumber. Between 1877 and 1898, Missouri had 184 stationary and 41 portable sawmills with a combined daily capacity that fluctuated between 2 million and 3.8 million board feet. Ten companies included logging railroads in their inventory (Fernow 1899).

The Missouri Lumber and Mining Company at Grandin, MO, was the first and largest company to begin large-scale lumbering in the Ozarks. Its operations were characteristic of the era and region with high-capacity milling facilities, huge labor forces and railroad logging. Its sawmilling operation began in 1887 and lasted until 1909 at Grandin. Operations moved to West Eminence in the fall of 1909 and continued until 1919. At its height of production, the Grandin-based sawmill consumed the timber resources from 70 acres per day. At the end of its fourteenth year of operation, it had cut more than 213,017 acres of forest land (Galloway 1961).

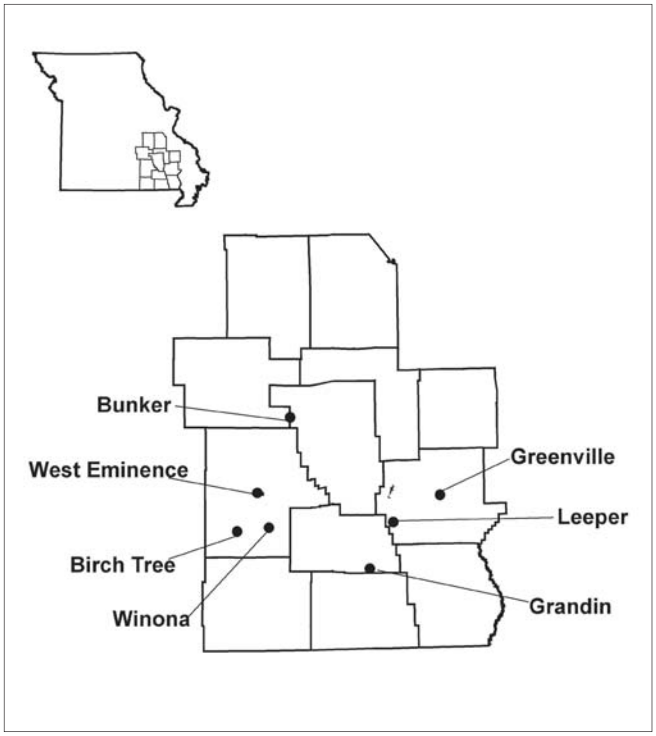

Figure 2.—Towns with large pine sawmilling operations between 1880 and 1920.

The turn-of-the-century lumber boom had a devastating effect on the pine resource. Lumber company policies and practices virtually eliminated pine trees large enough for reseeding the forest. The Missouri Lumber and Mining Company had required all pines cut to a 12-inch stump (Hill 1949). Though not as severe, its competitor, the Ozark Land and Lumber Company at Winona, cut all pines to a 14-inch stump (Martin and Presley 1958).

Uncontrolled burning and timber thieves' cutting of the remaining pine as soon as it reached a minimum merchantable diameter further destroyed any chances of seed or seedlings to develop. As the timber resources diminished and the big mills closed, the remaining people returned to grazing the open range for an economic base. Hardwoods quickly replaced the pine and those trying to graze the cutover lands had to contend with regrowth. Without fire, the grass would dwindle. Fire killed pine seedlings and caused the hardwoods to vigorously resprout. Germinating pine seedlings were unable to survive under the prolific hardwood canopy (Cunningham and Hauser 1989). Prior to organized fire control in the 1930s, it was estimated that the total wooded area of the Ozarks burned over at least once every 3 years (Callison 1953).

The lumber companies were not interested in reforestation. Prior to purchase, much of their lands had been tax delinquent and was purchased with uncertain titles. Once the pine timber had been removed, the taxes would remain high. Cutover lands that could not be sold were abandoned and again auctioned at public tax sales (Cunningham and Hauser 1989).

The big mills had been an economic boon to the people living in the Ozarks. They had provided steady employment, improved transportation both into and away from the region, and enhanced the people's social connectivity. Without the benefits afforded by this extractive industry, the people remaining after the mills' closures were once again threatened with the prospects of impoverishment and the struggle for survival.

THE CALL FOR REGULATION

Long before Missouri's lumber boom, there were concerns from a few government and industry leaders expressed concern that the nation's timber supply was not inexhaustible and that there was a real threat of a timber famine (Galloway 1961). By the end of the 19th century, nation-wide attention was being drawn to a growing conservation movement in the United States.

The word "reforestation" appeared regularly in Missouri newspapers between 1910 and 1940. It was often used directly or indirectly in the context of the loss of the pine resource in the Ozarks stemming from the earlier lumber boom. Reforestation and forest fire control would become the rallying cause for the creation of both a state forestry program and establishment of a national forest in Missouri.

Citizen groups led the fight for reforestation in Missouri during the first third of the 1900s. This series of groundbreaking events was perhaps the most unrecognized yet important actions relating to Missouri's conservation movement in the 20th century. With each attempt however, the people of the Ozarks largely opposed the prospects of reforestation through government intervention, be it the institution of agencies, laws, or programs, because of the perceived threats they represented to their way of life.

By 1905, conservation leadership was coming from an unlikely source: John B. White, president and general manager of the Missouri Lumber and Mining Company. President Theodore Roosevelt had appointed White to investigate problems with lumbermen gaining control over valuable forest lands at Cass Lake, MN. White's ensuing recommendations quickly won favor with the President and the public. Two years later, the president appointed him to the forestry section of the National Conservation Commission (Galloway 1961).

During the May 1908 National Governors' Conference at Washington, D.C., Missouri Governor Joseph Folk addressed in his speech the issue of reforestation:

> The forestry question is our problem, and it is a problem that we must settle, and settle soon…. We want to put our forests in proper condition to preserve those we have, and to adopt a scheme of reforestation. In Missouri we have no state forester, but as soon as I go back I am going to appoint a State Forestry Commission. I believe every Governor ought to do the same thing, and I am sure that his State Legislature when he meets will ratify his action.
>
> We want to preserve our forests. Now, I hope I am not encroaching upon forbidden ground, but I have been wondering why, if it be so necessary to preserve our forests, it would not be a good idea to put lumber on the free list—make lumber free. I hope that is not heresy. It seems to me that for every foot of lumber brought here from another country we preserve a foot of lumber in our own forests. (Folk 1909).

Governor Folk appointed a four-man forestry commission in 1909. Since the rural-dominated General Assembly failed to appropriate funds, the members of the commission, which included John B. White, served without pay (Galloway 1961). A number of similar attempts by Folk's successors would fail as well (Flader 2004).

The U.S. Congress passed the Weeks Act in 1911 that authorized federal acquisition of lands for national forests in the eastern states. Suddenly Missouri was in line for a national forest, but the Missouri General Assembly would have to pass enabling legislation. In 1914, Clifford Hall, Forest Examiner for the U.S. Forest Service, completed his examination for the potential purchase of two national forest units around the St. Francis Mountains and the upper Current River drainage. The General Assembly voted against the legislation since its constituency was largely opposed to federal intervention and control of lands the residents were using to suit their needs (Flader 2004). The prospect of a "national forest reserve," or a "national park" as it was so often referred to at the time, would be delayed for several decades.

The Missouri Forestry Association (MFA) was formed in 1922. Its purpose as stated in its constitution was to advise the public of the importance of the timber crops in economic life so as to insure a supply of timber for future generations. Its leadership included President Dr. Hermann von Schrenck, timber engineer and plant pathologist for the Missouri Botanical Gardens; Vice-Presidents J. W. Fristoe, president of the Moss Tie and Timber Company of St. Louis; Marie Turner Harvey of the Porter School at Kirksville; and Secretary Frederick Dunlap, former head of the forestry department of the University of Missouri. The MFA also had an advisory council that included forest industry leaders such as John Himmelburger of Himmelberger-Harrison Lumber Company, Cape Girardeau; John B. White, former president of the Missouri Lumber and Mining Company, Grandin; and Mrs. W. W. Martin, president of the Missouri Federation of Women's Clubs (*Current Local*, 5 January 1922).

The MFA opposed regulation at any level but supported the formation of a state forestry board and encouraged the practice of forestry on private lands. Oddly, it opposed the creation of a national forest in Missouri and saw only a very limited role for state forests as demonstration areas (Flader 2004).

Forest restoration in Missouri would have to wait until 1924 when Congress passed the Clark-McNary Act. Matching federal funds were afforded to states with forestry programs and Missouri was ready for the opportunity. Due to a threatened veto by the Governor, the MFA agreed to provide the state's share of the matching funds (Flader 2004). After repeated attempts since 1909, the Missouri General Assembly finally created an office of state forester within the Department of Agriculture in 1925 (Keefe 1987).

Frederick Dunlap, former head of the forestry department of the University of Missouri and secretary of the MFA, was appointed State Forester and he in turn hired Paul Dunn to be his only district forester at Ellington. In 1926, Dunlap reported to the General Assembly that the bill for his office's services between Aug. 12, 1925 and Jan. 1, 1927, came to $12,817.75, paid with the private funds of the MFA. Chapter 1 of his report dealt with the issues of wildfire and fire protection. Four subsequent sections dealt with forest plantings of 70,000 seedlings across several counties, the State Nursery on the prison farm at Cedar City, model plantings, and appreciation of forestry (*Ellington Press*, 3 March 1927).

From 1925 through 1931, Dunlap and Dunn focused on organizing fire control efforts and reforestation through public outreach and education activities. Regular features originating from Dunlap's office appeared in newspapers throughout Missouri. These articles discussed forestry issues and outlined Dunn's activities in Reynolds County. With cooperative assistance from county extension agents, Dunn brought films entitled "Pines Will Come Back" and "What Forest Management Means to You" to local schools and communities (*Ellington Press*, 14 November 1929). Perhaps in an effort to heal the damage inflicted by the earlier timber boom, Dunlap promoted the collecting and marketing of shortleaf pine seed. The *Ellington Press* (11 September 1930) quoted Dunlap:

> People living close to Nature stands of shortleaf yellow pine in southern and eastern Missouri have a splendid opportunity, at this time, to profit by the sale of the seed of the desirable evergreen…all they need to do is to gather, clean, store and market this seed….The price last year (1929) was from $8.20 to $10 per pound and collectors have sometimes been paid up to $20…Such prices can be paid, because twenty-five acres of land can be seeded with one pound of seed.

There was no follow-up report to Dunlap's feature. One can only imagine this as another desperate and frustrating attempt to show the General Assembly the possibility for success—and all this done with only one field forester and a scant budget. Perhaps because of the Great Depression, the legislature neglected to appropriate funds for forestry in 1931 and the forestry division was abolished (Keefe 1987). As dejected as Frederick Dunlap and Paul Dunn may have felt with their dismissals, the venture was a success as it marked the true beginnings of reforestation and recovery in the Ozarks.

The public's interest in forestry in the 1920s was not limited to Dunlap's effort. By 1929, the General Assembly had finally passed an enabling act authorizing federal purchase of forest land in the state but had restricted acquisition to no more than 2,000 acres per county (Flader 2004). In 1930, the Missouri Ozarks Chamber of Commerce under the leadership of Lon Sanders passed a resolution "…pledging the continued agitation for a national park or a national forest reserve…" (*Ellington Press*, 1 May 1930). This Chamber of Commerce was an 11-county alliance dedicated to promoting the Ozark region (Fuchs 1978).

Throughout 1933, State Senator Carter M. Buford from Ellington campaigned on behalf of the national forest. At a gathering of 300 boosters at Howes Mill in Dent County, Buford was called upon to address the crowd. The *Ellington Press* (30 July 1933) recorded the moment:

> The Senator from his widespread experience in dealing in lands and timber in this section said that he heartily endorsed the proposed plan. He urged those present to go home and tell their neighbors about it and help to build up sentiment for the movement. Senator Buford stated that the counties were facing bankruptcy because the owners of

> so much of the cut-over lands were unwilling or unable to pay the taxes on this land, and were letting it sell for prices that will not even pay the cost of legal advertisement. He said that if the present conditions continue that taxes would be raised to an unbearable height on improved farms and on city and town property and that these would be finally sold for taxes.

(That same year, Senator Carter M. Buford's son, Wilbur C. Buford, became the last politically appointed director of the Missouri Game and Fish Commission. Wilbur Buford was named the first Commissioner of the newly formed Missouri Department of Conservation in 1937 [Keefe 1987].)

In August 1933, the National Forestry Commission announced plans to purchase 450,000 acres in four units that extended over 18 counties in the Missouri Ozarks (*Ellington Press*, 31 August 1933). Eventually the Missouri General Assembly removed all acreage limitations and "lands that nobody wanted" would become the Mark Twain National Forest (Flader 2004).

The final great act for securing both conservation and ultimately reforestation in the Ozarks would be the petition drive for Amendment 4, calling for the creation of the non-political Conservation Commission, as spearheaded by the Conservation Federation of Missouri. On Election Day, Nov. 3, 1936, Missouri voters passed the initiative by a margin of 897,213 for to 351,962 against. In March 1938, George O. White was hired as the state forester. Like his predecessor Frederick Dunlap, White saw fire control and landowner education as two of the most important needs (Keefe 1987).

Building citizen support for modern conservation in Missouri had taken nearly 40 years. Restoring the shortleaf pine component to the Ozarks would be a daunting task that continues into the 21st century.

Liming (1945) reported that the productivity of 5 to 6 million acres of Ozark forest land can be materially increased by raising the proportion of pine in the forest cover exclusive of about 1 million acres now adequately stocked with pine. He estimated that pine had been eliminated by misuse on approximately 3 to 4 million acres, and it would take 50 to 100 years to artificially reintroduce it. The age-old problems of the destruction of seed and seedlings by uncontrolled burning and the persistent cutting of pine at a minimum merchantable diameter were to blame. Fixing these problems would challenge both the Missouri Department of Conservation and the U.S. Forest Service for decades to come.

SOCIAL FORESTRY

Kimmins' (1997) developmental stages can be interpreted through psychologist Abraham Maslow's Hierarchy of Human Needs. Human beings are motivated by needs. Basic needs such as food, shelter, safety, and security must be satisfied first. Growth needs such as beauty, goodness, meaningfulness or perhaps an interest in natural resources conservation, and biodiversity are affordable only after the basic needs have been met (Kimmins 1997).

Limited resources, poor local economies, extractive industries and a historical trend of poverty have kept the Ozarks' inhabitants focused on their day-to-day existence. Since the people have depended on the lands that support forest resources, policies and regulations proposed or enacted by government agencies that invoke change are often perceived as threats to the satisfaction of their basic needs.

The Ozarks can no longer be regarded as the isolated frontier of the 1800s. Improved transportation and a higher standard of living are making the area more accessible for millions of people living well beyond its borders. As Missouri progresses toward the social forestry stage, public participation will play an increasingly important role in the development of forest policies.

CONCLUSION

The Ozarks' people were the primary benefactors of the lumber boom from 1880 to 1920. Nearly a century later, lumbering is still economically important to the region. Tourism and other forms of outdoor recreation, however, are poised to become the primary drivers of the local economies.

Today, Missouri's forests with pine and oak-pine stands cover approximately 600,000 acres (Hahn and Spencer 1991, Flader 2004). Perhaps the best and most extensive pine-bearing lands exist on state and federal ownerships, where management over the past 75 years has favored the re-establishment or protection of pine. These areas offer the best opportunities for creating pine woodlands on a landscape scale.

Pine on private lands in Missouri is often spotty or clumped into small, disconnected islands. Oaks and hickories have largely replaced most of the historically pine-bearing sites. Pine reforestation is critically limited by frequent changes in land ownership, lack of landowner knowledge about reforestation techniques, lack of pine timber markets, and a lack of financial resources available to landowners. Until these factors improve, the probability for developing landscape-scale pine woodlands on private lands is very remote.

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THE HISTORICAL ECOLOGY OF FIRE, CLIMATE, AND THE DECLINE OF SHORTLEAF PINE IN THE MISSOURI OZARKS

Richard P. Guyette, Rose-Marie Muzika, and Steven L. Voelker[1]

ABSTRACT.—We review studies that have shown reductions in the abundance of shortleaf pine (*Pinus echinata* Mill.) during the last century in the Ozark Highlands. These studies indicate that pine abundance is currently 15 to 53 percent of the pine abundance levels before major logging activity and fire suppression, activities dating from the mid- to late 19th century. Evidence of pine loss comes from General Land Office notes, the presence of pine remnants, and historical documentation that described pine forests. Selective removal of pine, followed by intense hardwood competition, reduced shortleaf pine abundance in the Ozarks over the past century. In addition, very short fire intervals (< 3 years) before and after logging reduced advanced pine regeneration. More recently (1940-2006), long fire intervals caused by fire suppression have contributed to a long-term decline in pine abundance. Under continuing fire suppression, vegetation dynamic models predict a decline in abundance that will stabilize in about 200 years. Additional, more recent threats to recruitment and maintenance of shortleaf pine populations may include global warming-induced insect outbreaks.

THE ABUNDANCE AND LOSS OF SHORTLEAF PINE

Estimates of shortleaf pine occurrence and loss in Ozark forests come from several quantitative and qualitative sources, and are best presented in the context of the contemporary forest. Among the most recent studies, Voelker (2004) measured the diameter and age class distribution (Fig. 1) of oak and pine in the Current River Hill subsection of Missouri (Nigh and Shroeder 2002), and determined their current relative abundance. Shortleaf pine has a greater frequency in older age classes due to its greater maximum age relative to red oaks. The age class distribution of pine on these 1200 randomly chosen plots indicates that about 15 percent of the shortleaf pine in this region is over 90 years in age. Only two studies have evaluated the age structure of successional forests of the Ozarks left after the exploitation period, both of which were based in single stands in order to test silvicultural definitions of even-aged versus multi-aged forests (Loewenstein and others 2000; Shelton and Murphy 1990). It is common knowledge that many of the mature oak-pine stands are relatively even aged, but knowledge of the actual age distributions across the landscape is lacking.

The most recent forest inventory data indicate that the shortleaf pine forest type occurs on approximately 72,000 hectares or 1 percent of the forested land in Missouri (Moser and others 2006). Historically, shortleaf pine was estimated to have covered 2.7 million hectares in Missouri (Fletcher and McDermott 1957). Using landuse-landcover maps and comparing these with General Land Office (GLO) survey notes, Hamilton's (2003) analysis indicated that forests with a shortleaf pine component currently occupy about 36 percent of the landscape that was originally described as shortleaf pine forest in the Current and Eleven Point rivers region. An estimate by Cunningham and Hauser (1989) states that shortleaf pine forest types currently occur on approximately 162,000 hectares in Missouri. Despite considerable range in data describing current distribution, several studies have documented that the abundance of shortleaf pine in the Missouri Ozarks has diminished (Table 1). Batek and others (1999) quantified GLO note data in the Current River watershed of the Missouri Ozarks and identified 53 percent of the landscape as having supported a shortleaf pine component. Guyette and Dey (1997) documented the loss of pine by quantifying long-lasting pitch filled pine remnants such as stumps, snags and pine knots, and comparing that to current overstory composition. Additionally, Voelker (2004) found that the red oak group, primarily black oak (*Quercus velutina*) and scarlet oak (*Q. coccinea*) replaced the original shortleaf pine forest in the Ozark Highlands as evidenced by current distribution patterns of black and scarlet oak relative to occurrence of identifiable shortleaf pine remnants. The current diameter distribution of overstory shortleaf pines consists of a preponderance of small size classes, in contrast with the estimated historic distribution of shortleaf pine in the plots sampled in the Current River Hills Subsection (Fig. 2).

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[1] Research Professor (RPG), and Associate Professor (RMM), Department of Forestry, 203 ABNR, University of Missouri, Columbia, MO 65211, and Ph.D. Candidate (SLV), Department of Wood Science and Engineering, Oregon State University, Corvallis, Oregon 97339. RPG is the corresponding author: to contact call (573) 882-7741 or email guyetter@missouri.edu or muzika@missouri.edu

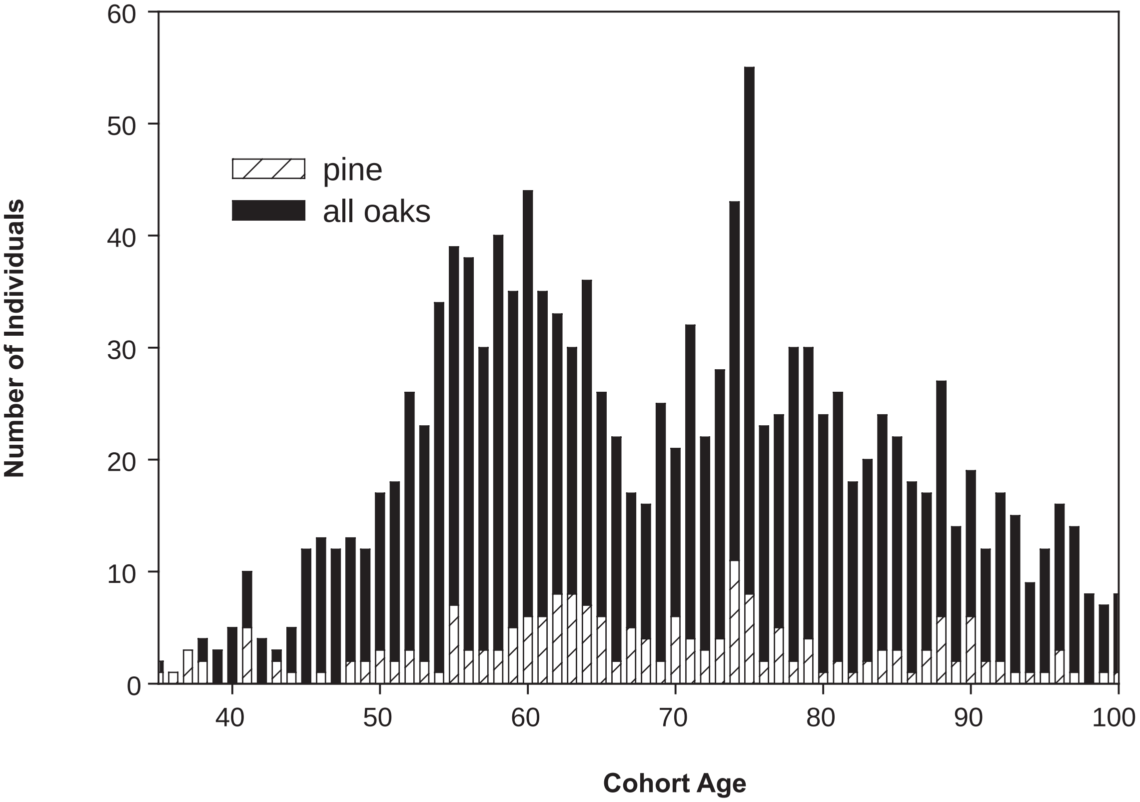

Figure 1.—The age class distribution of pine and upland scarlet and black oaks in the Current River Hill subsection of the Ozark Highlands of Missouri (Voelker 2004).

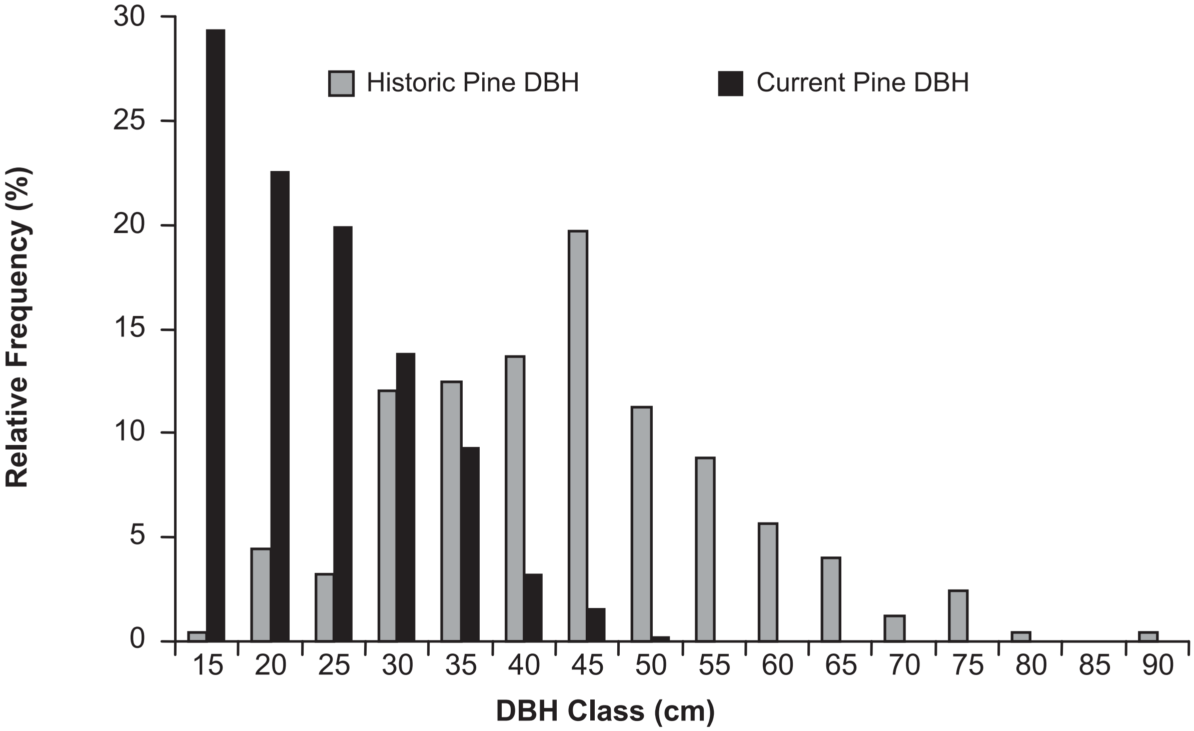

Figure 2.—Current and Historic Diameter Distributions of Shortleaf Pines on MOFEP Site 8. The historic diameter distribution was recreated by measuring diameter at root collar of all remaining pine stumps on plots at MOFEP site 8 and converting them to DBH from a linear regression model relating diameter at root collar to DBH (Voelker 2004).

Table 1.—Studies and estimates of shortleaf pine loss in the Missouri Ozarks. The percent of historic condition is the quantity of pine or pine forest pre-logging[a] divided by a post-logging quantity times 100. MOFEP 8 is on the Peck Ranch Conservation area near Van Buren, Missouri. Integrated moisture index (IMI)[b] and land use land cover (LULC) present indices of pine abundance.

Measure	Scale	Location	Historic	Current and future	Percent of historic conditions	Source
Area	Ozark oak pine forests	Missouri Ozarks	1.1 million ha^{2}	0.17 million ha	15%	Cunningham and Hauser (1989)
Stem density, no plantations	335 ha	MOFEP 8 SE MO	17,143 stems ha^{-1}	5,744 stems ha^{-1}	34%	Guyette & Dey (1997)
Stem density with plantations	335 ha	MOFEP 8 SE MO	17,381 stems ha^{-1}	9,239 stems ha^{-1}	53%	Guyette & Dey (1997)
Spatial occurrence	29,000 km^{2}	Oak-pine region of MO	47 % (IMI)	9.6 % (LULC)	20%[c]	Hamilton (2003)
Wood volume	2 ac cut over oak-pine forest	Reynolds Co. MO.	11.4 m^{4}	1.5 m^{3}	13%	Record (1910)
Predicted % of landscape with pine	century model estimate[d]	Oak-hickory pine forests	60% (with fire)	10% (with no fire)	17%	Guyette and others (2004)
Basal area	335 ha	MOFEP 8 ridge tops	2.3 m^{2} ha^{-1}	0.83 m^{2} ha^{-1}	35%	Voelker (2004)
Mean					22% without plantations	

[a] IMI was developed by Iverson and others (1997) and used by Hamilton (2003) to evaluate Ozark shortleaf pine occurrence relative to simulated historic occurrence.

[b] The historic area of forests with pine is from Liming (1946) and is adjusted from 1.7 million ha by 0.53 (Batek and others 1999) to 2.3 and from 1 million ha by 0.20 to 194,250 ha and summed.

[c] Estimate is calculated based on approximate scales and areas used in this analysis.

[d] VDDT modeling results of percent of landscape with a pine component.

Given all estimates (Table 1), the present abundance of shortleaf pine in the Missouri Ozarks is probably between 20 and 50 percent of the abundance immediately prior to the mid 19th century. Much of the accumulated evidence suggests that about 50 to 80 percent of Missouri forests with a substantial pine component have such a dramatically different species composition such that shortleaf pine no longer dominates. Moreover, some of the “loss” can be attributed to a distinct loss of forested land through conversion and shifts in land use. Depending on the parameter used, losses of shortleaf pine can be considered approximately 15-20 percent of the area once occupied by forests dominated by shortleaf pine, while basal area was calculated to have been reduced by 35 percent in the past 150 years.

The reduction in shortleaf pine abundance can be attributed hypothetically to the removal of seed source by logging and a fire regime with fire intervals too frequent for optimum pine recruitment. Overall, fire frequency and logging resulted in the removal of seed and advanced pine regeneration. For roughly 80 years prior to extensive logging of the pine resource (1880 to 1920), very frequent fires occurred in this shortleaf pine-dominated forest type of the Ozarks (Mean fire interval [MFI] < 3 years, Guyette and others 2002). The recurrent fire removed small diameter advanced pine regeneration. Logging, especially selective pine logging, removed seed sources. Selective pine logging in mixed oak pine stands was particularly important in favoring succession to hardwoods. Frequent fire (MFI < 3 years) inhibited seedling survival, since a vigorously conditioned layer of oak root grubs outcompeted pine seedlings for light and nutrients. Finally, and more recently, fire suppression has promoted closure of canopy gaps, build-up of a deep litter layer, which all but eliminates bare mineral soil necessary for epigeous germination of pine seeds (Baker 1992, Stambaugh 2001).

The historic fire frequency (1880 to 1920), in conjunction with xeric sites in higher landscape positions such as upper slope or ridges, may have increased the advantage of pines once they were in larger diameter classes. Large pines have a suite of characteristics that convey advantages over most oaks and other hardwoods in the Ozarks. They have thick, insulating bark, resistance to rot induced by fire scars, resistance to drought conditions, longer available growing season (pines can photosynthesize later in the fall and earlier in the spring than deciduous hardwoods in temperate climates), and considerable longevity of 250 years or more. However, establishment of pine is limited by the proximity and timing of seed source as well as the potential seedbed conditions (Grano 1949, Lawson 1990, Cain 1991, Shelton and Cain 2000, Stambaugh 2001).

The Influence of Site on Shortleaf Pine Abundance

In the southeast Missouri Ozarks, Liming (1946), Fletcher and McDermott (1957), Batek and others (1999), and Voelker (2004) considered soils and bedrock stratigraphy, specifically residuum over the Roubidoux formation, to be the most important factor influencing the pre-settlement extent of shortleaf pine on the landscape scale. A number of mechanisms working at multiple scales, however, can select for the success of pines and other tree species at any site, i.e., neighborhood effects. Neighborhood effects are defined here as those influences in which the rate or probability of change depends on the condition or behavior of sites surrounding the site of interest. For example, local disturbance history, or the last time a site burned (as well as its intensity and magnitude), has a complex interaction with prior and present species composition, which in turn is influenced by edaphic factors. For example, the relation of the site on the landscape to elevation, site quality, shape of the landform, and local topography all must be considered at the appropriate spatial scale. Moreover, the dynamics of neighborhood effects, as mediated by the canopy, may be significant at a smaller scale. The landscape to elevation ratio can be up to 100,000 m^2, whereas the scale of influence of site quality or local topography could be as small as 10 m^2.

Shortleaf pine remnants are the only direct evidence indicating the extent of pine dominance in forest structure before the exploitation era of logging. Using remnant stumps, and estimating the pre-logging relative occupation of a site by shortleaf pine, Voelker (2004) found that soils derived from the Roubidoux formation have more stumps than other geologic strata (Fig. 3), indicating that historically this soil-pine relationship was important. However, geologic strata are also correlated with slope position and elevation, or percent of local relief. The Roubidoux was disproportionately associated with upper landscape positions (Voelker 2004). At a certain scale relative topographic position may influence the presence of pines due to its relationship with fire frequency and topographic roughness (Guyette and Dey 1997). The interrelationship between parent material, topographic position, and pine remnants is complex, and cannot be easily disentangled.

There is no definitive explanation for what constitutes a “pine site.” Xeric, exposed conditions on rocky, acid soils lead to consistently high evapotranspirative demand and water-stress in which shortleaf pine becomes more competitive with the hardwoods in the Ozarks. Shortleaf pine competes better with oaks on xeric sites, yet it is strongly associated with soils of lower base saturation in the Missouri Ozarks (Nigh and Schroeder 2002) and appears to be found exclusively on sites with acidic soil. Although there is no quantitative data clearly show this pattern, ecological evidence and strong anecdotal evidence support the local and edaphic site association with shortleaf pine in the Ozarks.

Radial Variability in Shortleaf Pine Growth

Shortleaf pine growth rates vary greatly in time and space. Radial growth rates between trees range widely, from as low as 100 rings per 2.5 cm (0.25 mm per year) to higher than 3 rings per cm (8 mm per year). The oldest, slow-growing small trees are found on sandstone outcrops with little soil volume while some of the fastest growing shortleaf pines grow in deep, acid, and variable depth soils derived from sandstone, chert, and igneous bedrocks. The relationship

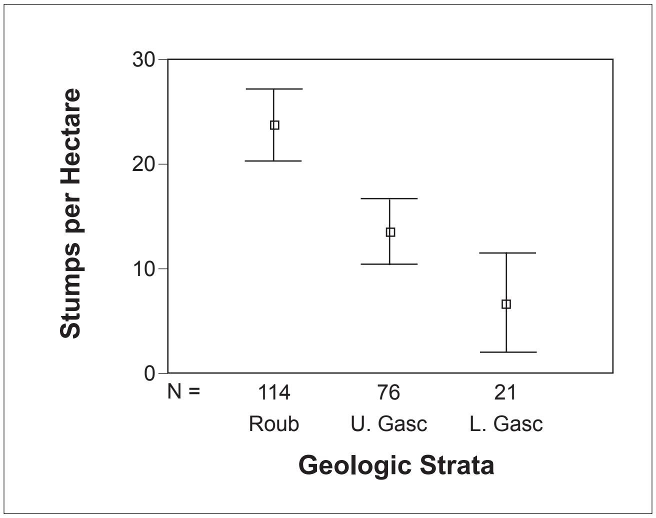

Figure 3.—The abundance of pine remnants (mean and 95 percent confidence intervals) on different geologic strata in the Current River Hill subsection. Geologic strata are Roubidoux, Upper Gasconade, and Lower Gasconade (from Voelker 2004).

between the diameter of shortleaf pine and age is strong (Voelker 2004), but only for young trees (Fig. 4). For trees over 100 years, diameter was not significantly related to age (Fig. 5). Additionally, tree-ring width series of shortleaf pine often show large abrupt changes in growth within a tree. Abrupt, frequent, and persistent growth reductions in shortleaf pine growth suggest that these evergreens are particularly vulnerable to canopy disturbances, especially when tree age is greater than 100 years. Canopy openings resulting from fire, climate, or wind result in radial growth declines, and likely mortality. When trees are less than 100 years, however, canopy openings provide opportunities for trees to respond competitively, and radial growth, as well as height growth in many cases, increases in response to canopy openings of varying sizes, regardless of cause. Recruitment and patterns of stand development of shortleaf pine, therefore, are strongly influenced by dominant cohort age and ability to respond to canopy openings.

Shortleaf Climate Response and Climate Change

The relationship between drought and temperature and the growth of shortleaf pine has been documented by Stambaugh and Guyette (2004). When winter temperatures are favorable, evergreen trees such as eastern redcedar and shortleaf pine can photosynthesize, and thus demonstrate a physiological—and competitive—advantage over deciduous trees. With increasing winter temperature, and possibly accompanying drying in summers, forest evergreens such as shortleaf pine may express a growth advantage. Thus, shortleaf pines, unlike many deciduous tree species, may be able to compensate for hot dry summers if conditions provide for warmer winters with more soil moisture.

Higher concentrations of atmospheric CO_2 are thought to have fertilization effects on shortleaf pine, which consequently shows an increased growth rate. Although deciduous trees may capitalize on increases in CO_2 during the summer, pines would benefit from higher CO_2 in winter as well as summer. Voelker and others (2006) used an extensive tree ring data set from the Ozarks to demonstrate an increase in pine and oak growth that is hypothesized to be the result of putative CO_2 fertilization. This study and another (Stambaugh and Guyette 2004) showed increased growth rates, especially for younger pines, over the last century. These findings have substantial implications for tree growth of a younger cohort of shortleaf pine (Fig. 2), specifically that the growth rates may be increasing.

Shortleaf Pine Growth and Climate Cycles

The growth of shortleaf pine has been shown to be cyclical and related to bi-decadal oscillations in climate (Stambaugh and Guyette 2004). This cyclical growth response can be further quantified by dating abrupt growth reductions in shortleaf pine ring-width series. We used 68 late successional shortleaf pines from near the Current and Big Piney Rivers to examine growth reductions associated with climate (Fig. 6). We calculated abrupt growth declines as 10-year exponentially weighted growth means divided by the prior 10-year weighted growth means. Abrupt growth reductions in shortleaf pine occurred on a bi-decadal frequency (Fig. 6). This cycle is broken by a 35-year hiatus in the 300-year-long record of abrupt growth reductions circa 1784 to 1820. The most extreme clustering of growth reductions usually approximately coincided with extreme drought years. Additionally, there were 14 years over the

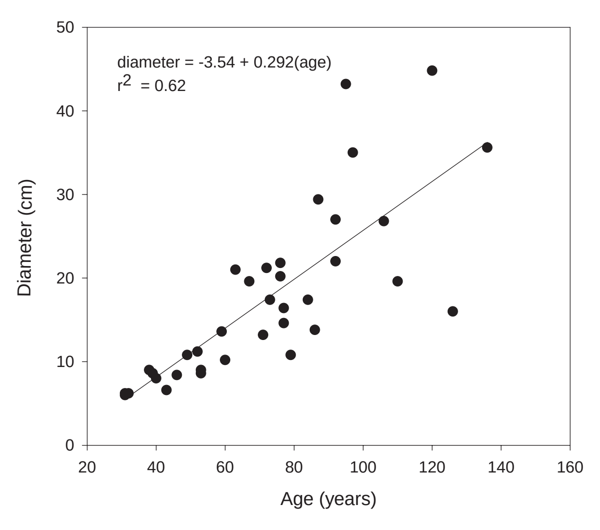

Figure 4.—The relationship between tree age and diameter for shortleaf pine trees less than about 100 years in age (unpublished data, Guyette and Stambaugh).

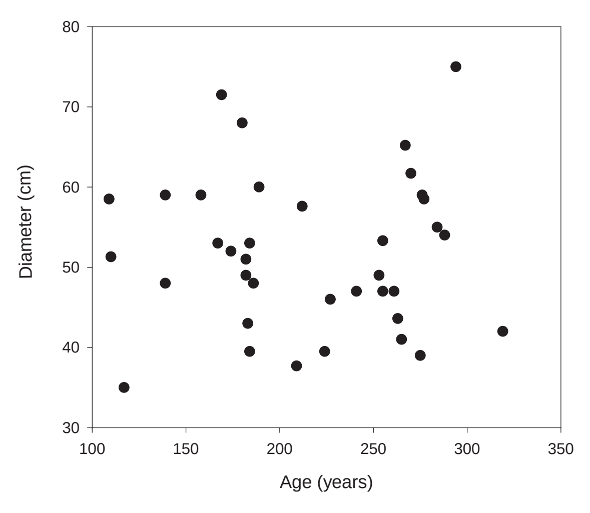

Figure 5.—The relationship between tree age and diameter for shortleaf pine trees greater than about 100 years in age (unpublished data, Guyette and Stambaugh).

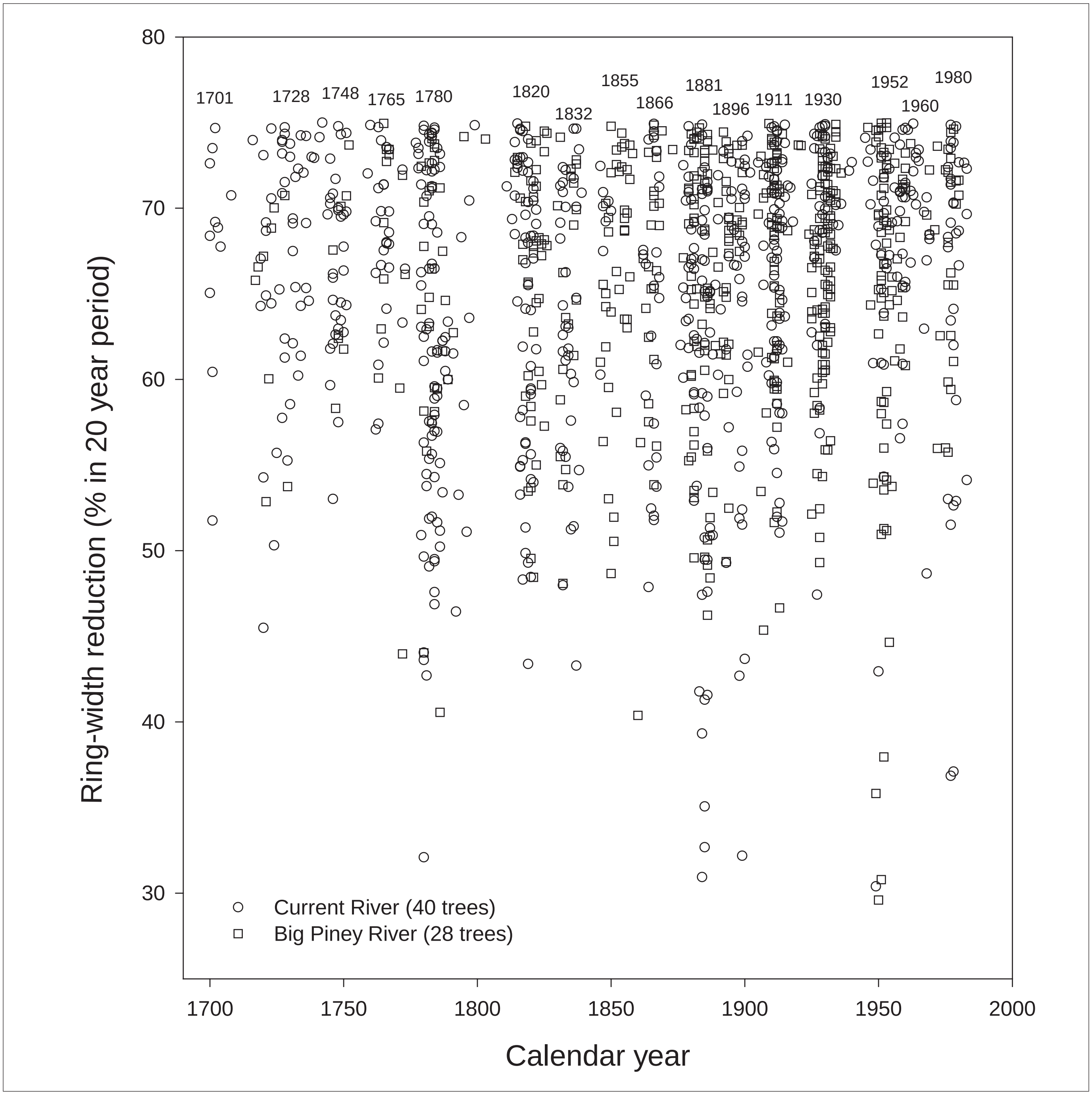

Figure 6.—The date and magnitude of ring-width reductions greater than 75 percent at two shortleaf pine sites in the Missouri Ozarks. Ring width reductions are calculated as the ring-width mean for 10 years before each date divided by the ring width mean after that date (unpublished data, Guyette and others).

last 300 years (Fig. 7) in which more than 30 percent of the trees had abrupt growth suppressions (> 25 percent growth reduction). These years tended to be drought years and drought transitions, but winter weather, snow, and early or late freezing events may be responsible for some of these growth setbacks.

In the context of stand development of shortleaf-dominated forests in the Ozarks, patterns of response to climate likely played a significant role. Although we cannot exclude the importance of a range of climate effects, there is a strong association of development and growth with drought years (Guyette and others 2006a). Drought years also co-occur with fires, which may also result in regeneration events and recruitment potential. Growth reduction events that influence the overstory may conincide with development events in the understory.

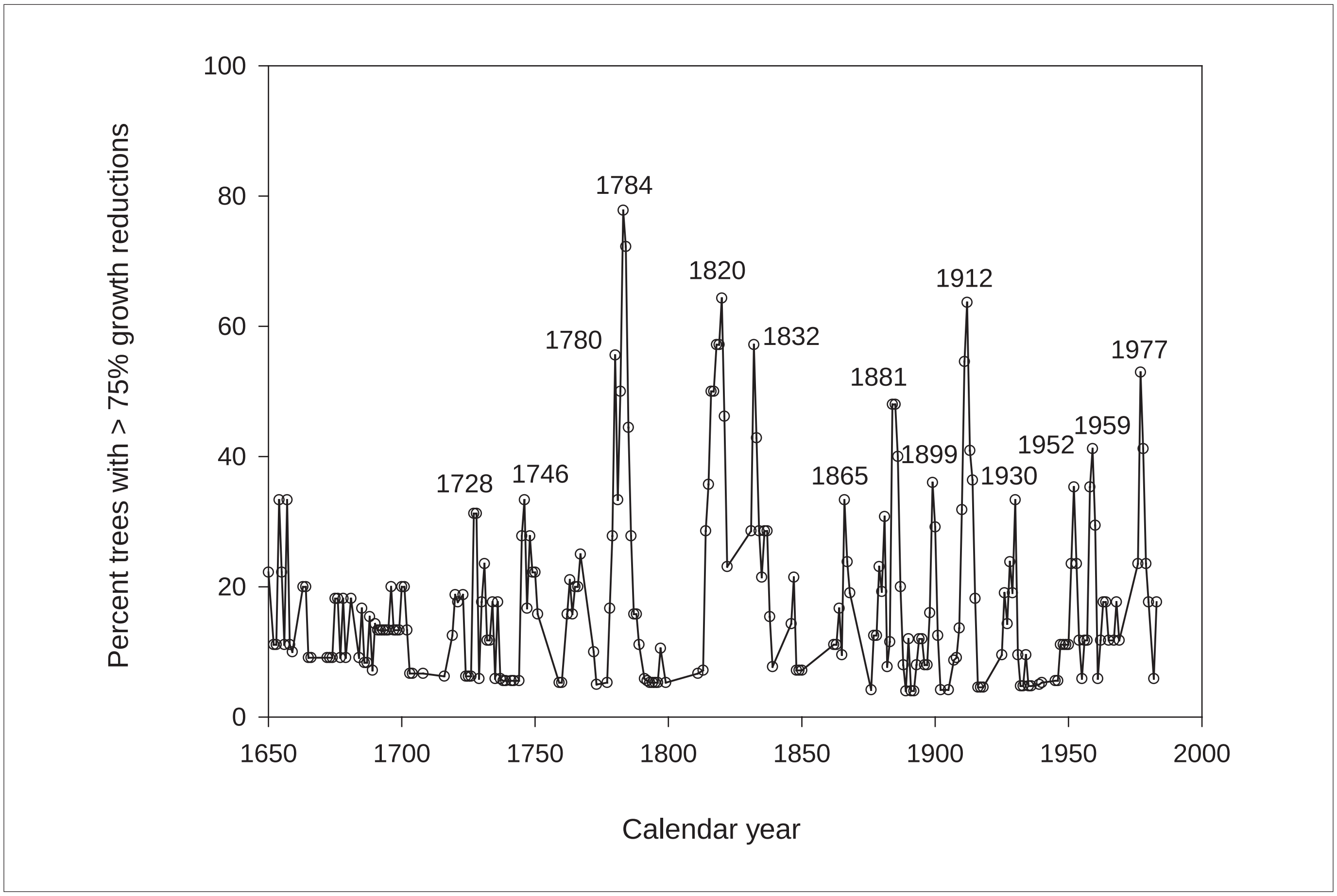

Figure 7.—The percent of shortleaf pine trees with abrupt growth declines over the last 350 years (unpublished data, Guyette and others).

Dendroecological Inferences on Historical Stand Development

The rings of the well preserved wood of shortleaf pine have been used to study climate variations, the growth response of the species to sites and events, and wildland fires. Thousands of dated fire scars on shortleaf pine trees, cut stumps, and natural snags have led to a detailed, and quantitative understanding of Ozark fire history (Batek and others 1999, Guyette and others 2002, Stambaugh and others 2005, Guyette and others 2006a). Through the use of fire scars, we have dated fire occurrence since the 1500s in the Missouri Ozarks. Fire scars have been cross-dated on the thousands of well preserved pine stumps that have survived logging and fire. These scars, combined with those on natural remnants and living pines in the Ozarks, have led to a greater understanding of Ozark fire regimes. This knowledge in turn has helped us understand how humans, climate, and fire have interacted to produce the contemporary distribution and structure of Ozark oak and pine forests (Guyette and others 2002).

In Missouri, there is dendrochronological evidence for both even-aged and mixed-age shortleaf pine regeneration (Stambaugh and others 2002). Canopy dominants at two late successional, old-growth shortleaf pine forests (Highway 19 Virgin Pine Forest [HVP] and the Eck Natural Area [ECK]) illustrate even-aged and mixed-age regeneration (Fig. 8). A historically relevant question may focus on which type of regeneration predominated. Data from the ECK site suggest that small and large disturbances to the canopy allowed both mixed-age and even-aged regeneration, leading to shortleaf pine cohorts within a stand. Data from HVP suggest that very few events gave rise to regeneration at this site, creating essentially an even-aged forest. Both small- and large-scale disturbance events were probably important in the Ozarks, and there may be no consistent interpretation of how ecological site conditions relate to disturbance. The HVP and ECK are in similar, albeit not identical, ecological landtypes, however the association of Roubidoux strata is more evident at ECK. The difference in the effects of scale of disturbance may simply relate to fire interval and intensity. Above all, it is important to understand that fire

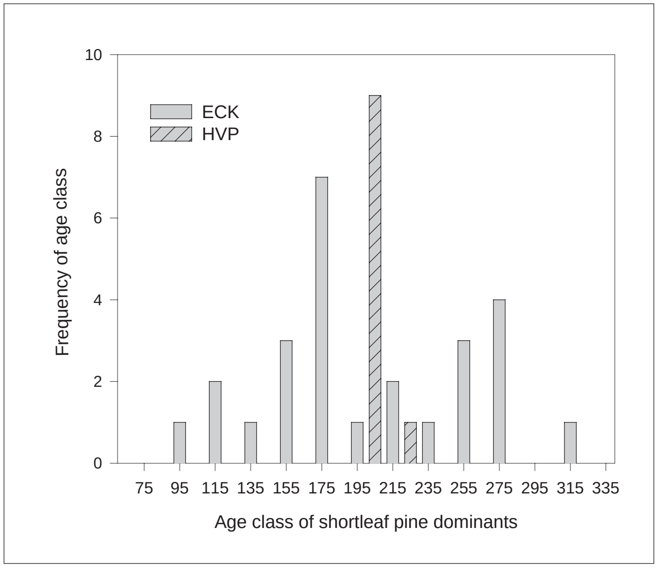

Figure 8.—Frequency distribution of pith dates at 1.3 m on shortleaf pine canopy dominates at the Eck Conservation Area (ECK) (solid bars) and the Highway 19 Virgin Pine Natural Area (HVP) (diagonally filled bars) (Stambaugh and others 2002).

contributes to stand initiation through stand replacing events and also results in mixed age classes of shortleaf pine through small-scale, perhaps surface fires.

Some support for the role of fire in shortleaf pine recruitment comes from fire history studies. Evidence suggests that the Ozarks had very frequent rotation intervals for large-scale fires (Guyette and others 2006b). Between 1748 and 1810 fire scars in Arkansas and Missouri indicate that over 310 percent of the landscape burned in 60 years. This yields a rotation interval of about 20 years for very large fires that occurred under moderate or severe drought conditions. In other words, an area the size of the Ozarks (129,500 km^2) burned about every 20 years. Unlike the typical characterization of Ozark fire regimes as having frequent low intensity surface fires, this landscape had fires that occurred over large sections of the Ozarks during moderate to extreme drought years. Because of the strong association between fire size and severity, these fires probably caused many small (1 to 10 hectare) stand-replacement events in the rough and broken topography of the Ozarks.

Given the large area of the Ozarks under consideration, the types of fires occurring between 1748 and 1810 were highly variable and likely dictated by topography as well as climate (Guyette and others 2002). The frequency of fire was in part attributable to the discontinuous nature of fuel, varying by landform and landscape position. Moreover, a steep, highly dissected landscape lends itself to small-scale events because fires are not perpetuated in topographically complex areas.

FUTURE ISSUES AND THREATS

The restoration potential for shortleaf pine in part resides in selecting the appropriate site and providing necessary conditions for regeneration, recruitment, and development given the current forest condition. Successional trends in extant Ozark forests, even in the absence of management, suggest only limited potential for pine regeneration and recruitment into the overstory. Following extensive logging of the shortleaf pine resource, scarlet oak and black oak quickly regenerated many sites. These 90- to 120-year-old cohorts of oak have experienced decline since the 1980s, supported by ring-width studies from the Missouri Ozarks that have shown a pattern of a protracted decrease in growth increment, ending in the death of the tree (Dwyer et al. 1995, Jenkins and Pallardy 1995, Pederson 1998, Voelker 2004). By examining site conditions and shortleaf pine remnants, we have established that sites previously dominated by shortleaf pine often have the greatest dieback and mortality (Voelker 2004, Voelker and others 2007). This situation was particularly true on exposed slopes and ridges. Characterizing these sites by species composition and structure, we found that the successional trends indicate that without major disturbance, white oak, not shortleaf pine, will gradually replace much of the recent red oak dominance within the historic shortleaf pine range in Missouri (Voelker and others 2007).

In recreating historic shortleaf pine distribution using remnants, we found that many of the areas with the greatest number of shortleaf pine remnants also have the greatest amount of shortleaf pine in basal area, although many of the individuals are small and may not develop into the overstory. Appropriate management of these stands, then, can promote existing, developing shortleaf pine. An overall directive toward a greater composition of longer-lived, drought resistant species, shortleaf pine and white oak, is suggested and is already in place on some public lands. A specific and prerequisite consideration for the regeneration and success of shortleaf pine would include prescribed burning or some kind of site preparation that disturbs and reduces the litter layer (Grano 1949, Stambaugh 2001). Increasing the overall vigor of the shortleaf pine and shortleaf pine-oak forests of the Ozarks will surely require a flexible combination of even-aged and uneven-aged silvicultural techniques for the local site conditions and levels of advance regeneration present. Unless silvicultural regimes change drastically, shortleaf pine's inability to establish and compete with oaks following cutting, will quickly account for its displacement as a significant overstory presence in the Ozarks (Stambaugh 2001).

Despite the current presence of scarlet oak and black oak in the Ozarks, these oaks historically were probably limited by frequent fire on many sites (Batek and others 1999). It is hypothesized, however, that some of the same exogenous and endogenous factors (e.g., *Armillaria*, xeric conditions, drought, and longevity of pines versus red oaks) which selected against oaks in pre-settlement times may also select against red oaks currently on pine sites. As an example, Bruhn and others (2000) indicated that *Armillaria* root disease is present in almost every case of red oak mortality.

Owing to the relative scarcity of extensive stands of shortleaf pine, little is known about pests of shortleaf pine, nor has there been much opportunity to examine them in the Ozarks. Admittedly, the challenges are greater for restoring rather than protecting the shortleaf pine resource. However, as shortleaf pine stands develop, it will be critical to understand and evaluate the role of biotic challenges to the species and forests. Such concerns could include southern pine beetle (*Dendroctonus frontalis*), the most damaging insect in eastern pine forests. Southern pine beetle outbreaks have increased recently and spread into previously uninfested territory, such as the southern Appalachians, a phenomenon explained in part by climatic conditions (Ungerer and others 1999). Other beetles occurring in the Ozarks and for which shortleaf pine serves as a host are small southern pine engraver (*Ips avulsus*) and black turpentine beetle (*Dendroctonus terebrans*). Additional pests include insects that target regeneration, e.g., pine webworm (*Pococera robustella*), a defoliating caterpillar known to occur in the Ozarks. Annosum root disease (*Heterobasidion annosum*) and littleleaf disease (*Phytophthora cinnamomi*) are persistent diseases of shortleaf pine in the southern United States.

The potential interaction of climate change and insect and pest population relative to increasing shortleaf pine on the landscape must be considered when managing and promoting shortleaf pine. Similarly, the importance of a comprehensive understanding of the role of climate in determining fire frequency and severity requires further investigation to improve models describing fire occurrence and consequence across the Ozark landscape.

CONCLUSION

Dendroecological approaches describing shortleaf pine growth, climate response, and fire history provide a long-term perspective on this species' development, success, and sustainability in the Ozarks. We have developed an understanding of shortleaf pine life history traits, particularly regarding growth and age relationship, and the role of fire in influencing stand initiation and development. Shortleaf pine trees can live for more than 350 years, but such ages are rare. As with most tree species, shortleaf pine growth is negatively affected by drought, but unlike other deciduous Ozark hardwoods, the growth may be increased by winter warming. Shortleaf pine growth can be as little as 20 rings per cm or as great as 1 ring per cm. Radial pine growth exhibits a 22-year cycle that is tied to drought and solar cycles. Although global warming may favor shortleaf pine, fire history in oak-pine forests shows that litter accumulation, dense canopies, and hardwood sprouting continue to be impediments for recruitment and successful regeneration.

Historic shortleaf pine distribution was associated with parent material, fires, and climate. Parent material, soil residuum, and landscape position all seem to play a role in explaining historic shortleaf distribution across the landscape. We corroborated older findings by close examination and analysis of shortleaf pine remnants. An extensive size class/age class distribution revealed that most contemporary shortleaf pine have developed within the last 80 years.

Abundance of shortleaf pine has resulted from large drought-driven mixed severity fires in the Ozarks occurring every 10-20 yrs. Both multiple and single cohort development of shortleaf pine occurred in the Ozarks. We have shown that the remnant late-successional shortleaf pine forests in the Missouri Ozarks have developed from a mixed disturbance regime. Therefore, a consistent or uniform management approach may not satisfactorily reestablish shortleaf pine communities. Such findings support earlier research such as Brinkman and Liming (1961) and Brinkman and Smith (1968).

Shortleaf pine growth setbacks occur frequently in the Ozarks, as evidenced by the dendrochronological record of radial growth patterns. Climatic conditions, such as drought, and canopy opening disturbance, including fire, disease, insects, or windthrow, can influence radial growth. However, the growth response strongly relates to tree age, and a general threshold of about 100 years indicates the species age when the tree may either respond positively, or be vulnerable to damage or abiotic conditions. This vulnerability is expressed by growth losses and an overall lack of response occurring in general in trees more than 100 years old.

Challenges include proper management, restoration of site conditions, and re-establishment of missing seed source. Although the pine plains supported areas of nearly 100 percent shortleaf pine, much of the Ozarks supported a pre-settlement mixed pine-oak forest, particularly in the topographically complex landscape of the river hills and breaks. The ecological benefits of increased overstory diversity in Ozark forests are manifold; therefore, promotion of shortleaf pine in oak-dominated landscapes addresses concerns of sustainability and ecological integrity. Mixed oak-pine forests create a diverse successional, structural, and habitat conditions in Ozarks forests. Attributes such as canopy cover, wood chemistry and life history help explain shortleaf pine's unique ecological role in oak-pine forests. Evergreen canopies provide nesting sites, roosting, and primary productivity in the winter and early spring. Toxic oleoresins preserve wood and cavities for long periods of time relative to other woody debris. Shortleaf pines may be less susceptible to crown fires and insect attacks in mixed oak-pine stands than in pure pine stands or plantations.

Shortleaf pine components of oak-hickory-pine forests are predicted to diminish without fire by a coarse-scale, state transition model (Guyette et al. 2004). These models are validated with Ozark fire history data (Shlisky and others 2005) and indicate that without fire, forests with a shortleaf pine component will occupy less than 10 percent of the landscape within a few centuries. Thus, in the absence of intervention, forests with a shortleaf pine component, which once covered more than 53 percent of parts of the Ozark landscape (Batek and others 1999) may be confined to 10 percent of the landscapes. Those few sites are characterized by xeric condition and soils with low base saturation. The silvicultural and ecological challenges of restoring the mixed pine-oak forests require attention, time, and evaluation.

ACKNOWLEDGMENT

The authors would like to thank D.C. Dey and M.C. Stambaugh for their support and work on numerous shortleaf pine projects that have contributed to this work.

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SHORTLEAF PINE COMPOSITION AND STRUCTURE IN THE UNITED STATES

W. Keith Moser, Mark Hansen, William H. McWilliams, and Raymond M. Sheffield[1]

ABSTRACT.—Although shortleaf pine currently occupies a prominent position in many eastern forests, particularly on upland sites, many scientists and managers have expressed concern about the future of this species in the absence of the disturbance patterns that facilitated its establishment up to now. Reductions in timber harvesting and fire, in particular, may give the advantage to competitors such as oaks, sweetgum, and maples. Commercial owners have favored the faster-growing loblolly pine over shortleaf pine. Using data from the Forest Inventory and Analysis program of the U.S. Forest Service, we looked at current data and temporal trends to gauge the trajectory of shortleaf pine forests in the eastern United States. The shortleaf pine volume per acre of timberland has decreased over the last two to three decades. The shortleaf pine basal area component on forestland has decreased in absolute terms and also represents a decreasing proportion of the total basal area, suggesting that associated species are increasing in their share of the overstory. The total number of shortleaf pine seedlings/saplings in the understory of stands has been decreasing and the proportion of all seedlings/saplings that are shortleaf pines has been declining over the last 20 or so years. The declining proportion of regeneration represented by shortleaf pine suggests a future eastern U.S. forest with substantially reduced proportions of the species in the overstory. Reintroducing disturbances, such as fire, is essential to maintain shortleaf pine's overstory presence and associated biological and economic benefits.

INTRODUCTION AND METHODS

Southern pines, including shortleaf pine, have had a prominent role in eastern U.S. forests for thousands of years. While current pine forests evolved through a combination of ecological and human-influenced factors, changes in disturbance patterns are altering both the species mix and the structure of the nation's pineries. Other authors at this conference present their interpretation of shortleaf pine stand dynamics and influences; in this paper, we examine trends, status, and implications of the structure and composition of shortleaf pine forests in the eastern United States.

We examined data from the national Forest Inventory and Analysis Program (FIA) of the U.S. Forest Service (Frayer and Furnival 1999). The FIA program conducts comprehensive forest inventories to estimate the area, volume, growth, and removal of forest resources in the United States, in addition to taking measurements on the health and condition of these resources. The program's sampling design has a base of one plot per approximately 6,000 acres, which provides a consistent, unbiased sample across the entire landscape. The national FIA program consists of four regional programs that provide estimates of forest area, volume, change, and forest health throughout the United States (McRoberts 1999). We used data from two of these regional FIA programs—the Northern and Southern FIA programs—to depict forest conditions for the eastern United States. For historical data, we use data generated from past FIA reports for states in the eastern U.S. and data generated by the FIA Mapmaker program (Miles 2006). For current structure and regeneration, we used data generated by the FIA database. The states and inventory dates we used in our analysis are listed in Table 1.

Shortleaf pine is found throughout the southeastern quadrant of the United States and is the second most important southern pine (McWilliams et al. 1986). The species is most prevalent in two groups: loblolly-shortleaf pine and oak-pine. The loblolly-shortleaf pine forest-type group is the predominant forest type group of the southern pine region (Walker 2001). As defined by the FIA, the two forest-type groups included eight detailed types within the oak-pine group and eight pine types within the loblolly-shortleaf pine group. These groups are defined by the proportion of total stocking represented by various pine species and their associates. The shortleaf pine type is defined as forests in which pines accounts for at least 50 percent of the stocking of all live trees, with shortleaf pine the most common

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[1] Research Forester (WKM and MHH), Northern Research Station, Forest Inventory and Analysis Program, U.S. Forest Service, 1992 Folwell Ave., St. Paul, MN 55108; Supervisory Research Forester (WMW), Northern Research Station, Forest Inventory and Analysis Program, U.S. Forest Service, 200 Campus Blvd, Suite 200, Newtown Square, PA, 19073; Supervisory Research Forester (RMS), Southern Research Station, Forest Inventory and Analysis Program, 200 W.T. Weaver Blvd., Asheville, NC, 28804. WKM is corresponding author: to contact, call (651) 649-5155 or email at wkmoser@fs.fed.us

Table 1.—FIA statewide inventories used in this study.

	Annual Inventories		Periodic Inventories			
State	Year	Number of Timberland Plots	Year	Number of Timberland Plots	Year	Number of Timberland Plots
Alabama	2004	3298	2000	4399	1990	3917
Arkansas	2005	3353	1995	3135		
Florida	2005	1756	1995	5506	1987	5583
Georgia	2004	5209	1997	7045	1989	7522
Illinois	2004	767	1998	1671	1985	1095
Indiana	2005	958	1998	1546	1986	1998
Kansas	2004	374	1994	1676	1981	937
Kentucky	2004	3286	1988	1927		
Louisiana	2005	2443	1991	2413		
Maryland	2004	68	1999	525	1986	653
Mississippi			1994	3185		
Missouri	2004	3706	1989	4673		
New Jersey	2004	56	1999	383	1987	250
North Carolina	2002	3913	1990	5921	1984	5580
Ohio	2004	963	1991	1652		
Oklahoma			1993	1090		
Pennsylvania	2004	3061	1989	2971		
South Carolina	2005	1989	1993	4446	1986	4382
Tennessee	2003	2134	1999	2732	1989	2275
Texas	2005	3066	1992	2056		
Virginia	2003	3151	1992	4399	1984	4432
West Virginia	2004	309	2000	2153		

pine. Mixed pine-hardwood stands are those in which pine accounts for 25 to 50 percent of total stocking. Of the major forest types in the eastern United States, shortleaf pines are common associates of loblolly pine, oaks, hickories, and gums.

RESULTS

Shortleaf pine is found in 22 states and 85 forest-type groups. It is most often found in the loblolly-shortleaf pine forest-type group, but is also found in such types as longleaf-slash pine, pine-oak and several other upland hardwood forest types. The latest estimates from each of the states in the historic shortleaf pine range add up to 12.9 billion cubic feet of the species on timberland. Shortleaf pine volume has generally decreased across the region over time, sometimes at a rapid rate.

Although the species is present from Pennsylvania to Texas and Florida (Fig. 1), it is the most prevalent in the forests of the south-central states of Arkansas, Oklahoma, Mississippi, and Missouri.

The FIA stand-size variable can provide some indication of the stages of stand development (Oliver and Larson 1996), but the correlation with stand or tree age is less robust, because the classification is based solely on tree diameter (McWilliams et al. 2002). Each FIA plot has two to three "age" trees that are used to develop productivity equations. Because only the most dominant overstory trees are sampled, the ages may not represent all plot trees, and age data will not be considered here. Using the most recent data, shortleaf pine timberland area had a stand size distribution of 8 percent seedling-sapling, 23 percent poletimber, and 69 percent sawtimber. The shortleaf pine-oak forest-type group had a slightly more balanced stand structure, with 13 percent of the area in seedling-saplings, 31 percent in poletimber, and 56 percent in sawtimber. The predominance of larger trees has implications for calculations of growth and mortality, as we will see later.

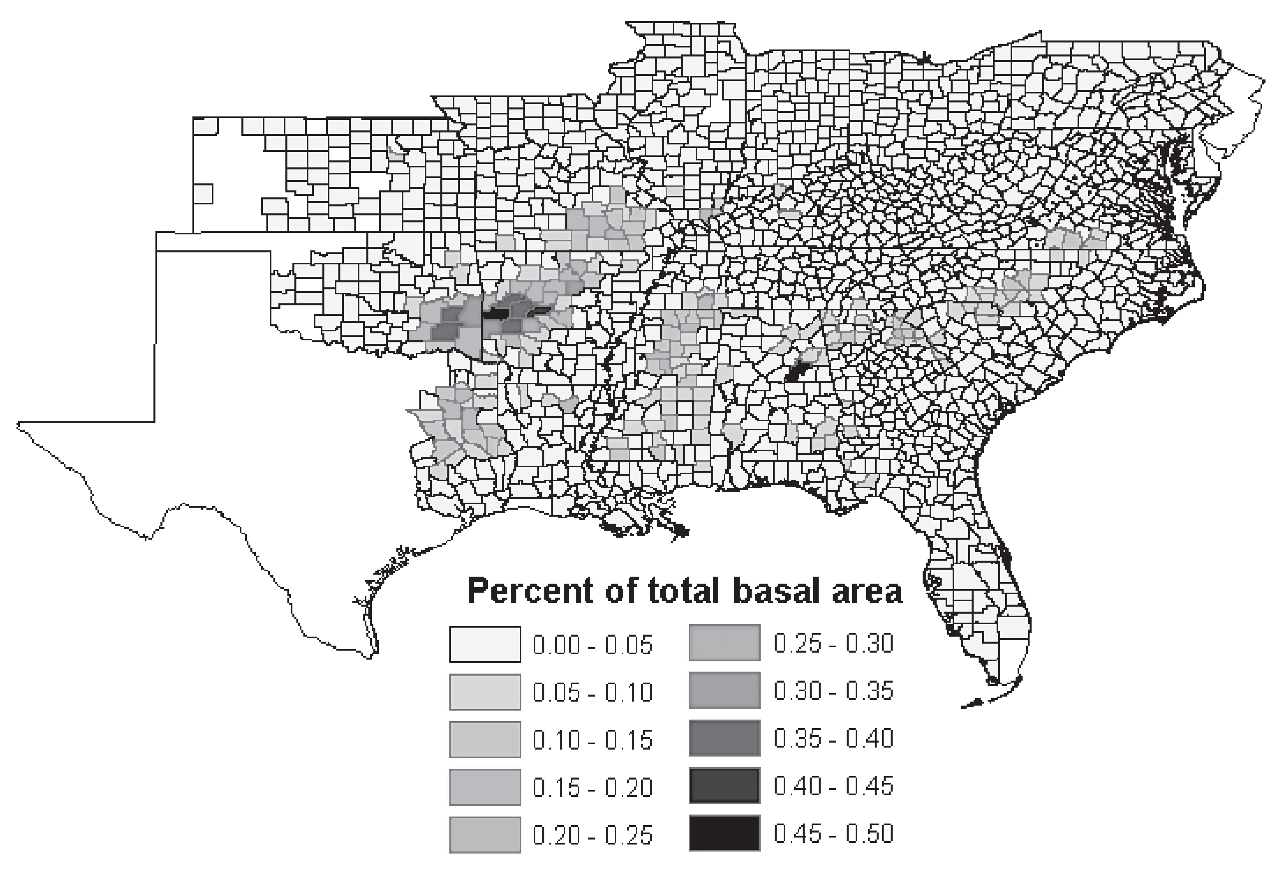

Figure 1.—Shortleaf pine as a percentage of total timberland basal area, based on the most recent FIA inventories from each state.

Shortleaf Pine Overstory: Status and Trends

Area

Out of approximately 241 million acres of timberland in the 22 states of the shortleaf pine range, shortleaf pine and shortleaf pine-oak forest types occupy over 7.4 million acres (Table 2). Over 4.7 million acres (64 percent) are in large-diameter stands and about 738,000 acres (10 percent) are in small-diameter stands, with the remaining 2 million acres in medium-diameter stands.

Number of trees

Of the 1.9 billion shortleaf pine trees, 791 million, or 42 percent, are found in the shortleaf pine forest type (Table 3). Another 335 million, or 18 percent of all shortleaf pine trees, are in the shortleaf pine-oak forest type. Beyond these two forest types, shortleaf pine trees do not have a prominent presence in any forest type in the United States.

The five top states, based on number of trees are Arkansas, Oklahoma, Mississippi, Alabama, and Georgia (Table 4). There are 1.9 billion shortleaf pine trees in the states in the species' range: 785 million are in large-diameter stands, 685 million in medium-diameter stands and 414 million in small-diameter stands. All things being equal, we would expect more trees per acre in small-diameter stands than in other size classes, so the fact that there are proportionally more trees in the large-diameter class reinforces the observation that the bulk of shortleaf pine forests are in large-diameter stands.

Table 2.—Timberland area of shortleaf pine, shortleaf pine-oak, and all forest types in those regions in the eastern United States with shortleaf pine forest type, in millions of acres and from the most recent inventory.[2] The most recent inventories for Maryland and New Jersey are not complete; completed panels do not list any shortleaf pine volume, so those states were not included in calculations. For West Virginia, the 2000 periodic inventory data was used.

Forest type and region	Total	Large diameter	Medium diameter	Small diameter
Shortleaf pine				
Central states[a]	218,293	162,375	50,654	5,264
Mid-Atlantic states[b]	7,884	-	-	7,884
Atlantic states[c]	573,995	341,224	174,667	58,104
Gulf states[d]	3,138,664	2,230,161	686,749	221,754
Total	3,938,836	2,733,760	912,070	293,006
Shortleaf pine-oak				
Central states[a]	382,805	252,923	120,704	9,178
Mid-Atlantic states[b]	106,312	69,046	29,484	7,782
Atlantic states[c]	693,560	428,763	171,387	93,410
Gulf states[d]	2,315,348	1,239,695	740,687	334,966
Total	3,498,025	1,990,427	1,062,262	445,336
All forest types				
Central states[a]	21,974,818	12,978,559	6,872,589	2,031,029
Mid-Atlantic states[b]	16,046,291	9,467,123	4,743,453	1,745,410
Atlantic states[c]	97,347,847	44,207,968	27,071,852	24,975,568
Gulf states[d]	105,688,465	48,557,114	30,751,469	25,842,126
Total	241,057,421	115,210,764	69,439,363	54,594,133

[2] a – Illinois, Indiana, Missouri (Kansas has shortleaf pine volume but no shortleaf pine forest type); b – Pennsylvania (Maryland and New Jersey not included due to incomplete inventories); c – Florida, Georgia, Kentucky, North Carolina, South Carolina, Virginia, and West Virginia; d – Alabama, Arkansas, Louisiana, Mississippi, Oklahoma, Tennessee, and Texas.

Table 3.—Number of shortleaf pine trees by forest type, using the most recent inventories from each state.

Forest type	Number of Growing Stock Trees (millions)	Percent of all Trees in the Type	Percent of all Shortleaf Pine Trees in the Region	Million Acres
Shortleaf pine	791.1	49.4%	42.1%	3.9
Shortleaf pine/oak	335.4	26.7%	17.8%	3.5
Loblolly pine	325.3	1.4%	17.3%	45.6
White oak/red oak/hickory	137.8	1.0%	7.3%	43.0
Loblolly pine/hardwood	63.1	1.1%	3.4%	13.7
Post oak/blackjack oak	41.3	2.1%	2.2%	6.1
Mixed upland hardwoods	39.5	0.6%	2.1%	24.9
Virginia pine	25.3	2.1%	1.3%	2.3
Sweetgum/yellow poplar	17.8	0.7%	0.9%	7.7
White oak	14.6	0.8%	0.8%	5.2
Other types	89.7	0.0%	4.8%	111.7

Table 4.—Number of shortleaf pine growing stock trees on timberland, by State and stand size class. The most recent inventories for Maryland and New Jersey are not complete; completed panels do not list any shortleaf pine volume. For West Virginia, the 2000 periodic inventory data was used.

State	Total	Large diameter	Medium diameter	Small diameter	Nonstocked
Alabama	167,247,530	50,916,318	70,360,118	45,971,094	–
Arkansas	509,819,996	228,566,160	197,829,315	83,424,521	–
Florida	5,941,473	4,193,999	193,772	1,553,702	–
Georgia	141,542,129	63,466,096	51,397,764	26,678,269	–
Illinois	8,582,649	8,300,201	282,448	–	–
Indiana	1,297,227	1,258,092	39,135	–	–
Kansas	311,943	311,943	–	–	–
Kentucky	13,220,721	6,846,929	4,057,996	2,315,795	–
Louisiana	33,386,094	24,248,403	3,554,730	5,582,960	–
Mississippi	195,436,442	76,413,093	42,631,002	76,392,347	–
Missouri	134,082,175	69,945,736	49,252,301	14,884,139	–
North Carolina	86,577,023	37,559,019	25,508,996	23,509,008	–
Ohio	135,537	135,537	–	–	–
Oklahoma	313,421,254	75,708,912	153,153,603	84,558,740	–
Pennsylvania	4,173,670	–	36,719	4,136,952	–
South Carolina	59,302,378	24,593,186	27,251,995	7,457,197	–
Tennessee	32,287,953	18,093,002	11,196,273	2,998,678	–
Texas	127,593,640	71,912,480	26,795,401	28,845,757	40,002
Virginia	43,827,211	19,144,117	20,917,245	3,765,850	–
West Virginia	5,676,645	2,892,416	425,163	2,359,066	–
Total	1,883,863,691	784,505,639	684,883,974	414,434,076	40,002

Volume

Growing stock volume of shortleaf pine in the latest inventories was almost 13 billion cubic feet (Table 5). Arkansas led the way with 3.4 billion cubic feet, followed by Mississippi, Texas, Alabama, and Oklahoma. The state with the smallest estimated shortleaf pine volume was Pennsylvania with 801 thousand cubic feet. Nationally, shortleaf pine volume is much lower compared to historical times. Figure 2 displays the nearly universal decline in the species' volume over the last three decades.

Net Growth and Removals

For those states where recent data exist, shortleaf pine averaged 428 million cubic feet per year in net growth, which is defined as gross growth less mortality. This number represents less than 4 percent of current volume for those states (Table 5). The values ranged from -3.4 percent in West Virginia to more than 6 percent in Oklahoma. For the states where we have removals data, removals represent less than 6 percent of current volume, and ranged from 0 percent of volume in several states to more than 15 percent in Louisiana.

The presence of a particular species is influenced not only by environmental considerations, but also by how human activity impacts the species. Along these lines, a useful indicator of shortleaf pine resource dynamics is the net growth to removals ratio. Ratios less than 1.0 indicate removals exceed growth, while values above 1.0 indicate inventory expansion. We examined the latest estimates of net volume growth and removal volume for the species. The gross growth to removals ratio was 0.58, indicating that our estimated removals exceeded the net growth. Among states with both positive growth and removals, the ratio ranged from 0.23 in Georgia to 4.96 in Missouri.

Table 5.—Growing stock volume, mortality, growth and removals, in cubic feet, of shortleaf pine in the eastern United States. Data is based on the latest inventory for each state, as of Sept. 1, 2006. Maryland and New Jersey are not listed because these inventories are only partially completed and completed panels do not list any shortleaf pine volume. For West Virginia, the 2000 periodic inventory data was used for all estimates. For Virginia, North Carolina, Alabama, South Carolina, Tennessee, Georgia, Ohio, and Pennsylvania mortality, growth, and removals estimates were taken from most recent periodic inventories.

State	Total Growing Stock Volume	Mortality	Mortality Percentage	Net Growth	Growth to Removals	Ratio
Alabama	1,098,283,367	26,291,884	2.4	46,197,186	106,398,925	0.43
Arkansas	3,410,072,606	39,214,174	1.1	101,416,898	112,978,627	0.90
Florida	59,225,060	0	0.0	2,982,499	4,818,029	0.62
Georgia	940,083,263	31,900,953	3.4	19,178,706	82,881,734	0.23
Illinois	74,826,427	339,968	0.5	1,787,358	0	--
Indiana	29,960,121	400,852	1.3	748,674	0	--
Kansas	1,889,991	0	0.0	0	0	--
Kentucky	164,265,225	3,685,351	2.2	2,572,188	1,290,085	1.99
Louisiana	371,289,865	4,081,610	1.1	18,133,050	57,278,885	0.32
Mississippi	1,529,628,337	20,996,813	1.4	72,883,929	165,796,601	0.44
Missouri	798,489,530	3,477,856	0.4	25,093,884	5,058,655	4.96
North Carolina	716,936,742	0	0.0	198,984	0	--
Ohio	2,796,283	241,087	8.6	-10,598	17,257	-0.61
Oklahoma	1,019,164,707	2,854,448	0.3	62,573,293	48,419,185	1.29
Pennsylvania	801,685	0	0.0	3,577	0	--
South Carolina	356,902,941	11,228,537	3.1	7,873,755	27,191,035	0.29
Tennessee	437,310,556	8,440,432	1.9	17,588,975	18,070,517	0.97
Texas	1,511,567,329	23,648,948	1.6	45,364,165	88,023,443	0.52
Virginia	351,939,107	7,955,820	2.3	3,971,042	15,794,677	0.25
West Virginia	12,841,996	540,975	4.2	-436,636	0	--
Total	12,888,275,138	185,299,708	1.4	428,120,928	734,017,654	0.58

Status of Proportion of Shortleaf Pine in Eastern U.S. Forest Overstory

As the underlying theme of this paper is “Where is shortleaf pine going?”, we examined trends in the percentage of total basal area that is in shortleaf pines (Table 6). We looked at changes between inventories in the 1980s, 1990s, and 2000s. All states showed an overall decline during this period.

Regeneration is heavily influenced by the size and composition of the forest overstory (Smith et al. 1996). We have seen a declining trend in the proportion of total timberland in shortleaf pine overstory, with a few exceptions, throughout the eastern United States. Given the relative longevity of shortleaf pine, much of the current shortleaf pine overstory is likely a reflection of disturbance conditions far in the past. Shortleaf pine regeneration, however, should reflect more recent disturbances. Accordingly, we looked at shortleaf pine seedling/sapling data from the last one to three inventories in each state to gain some insight into the future of shortleaf pine forests (Table 6 and Fig. 3).

The eastern U.S. forests are not lacking for tree regeneration (Fig. 3). In most states, we have observed the presence of shortleaf pine regeneration, although not in large quantities, except for Arkansas and Oklahoma. Like overstory basal area, shortleaf pine regeneration was also flat or declining over this period. While these numbers do not indicate particular areas in the state where regeneration is successfully replacing shortleaf pine overstory, the overall trends – particularly the smaller proportion of regeneration versus overstory basal area – point to a decline in the species’ presence in future forests.

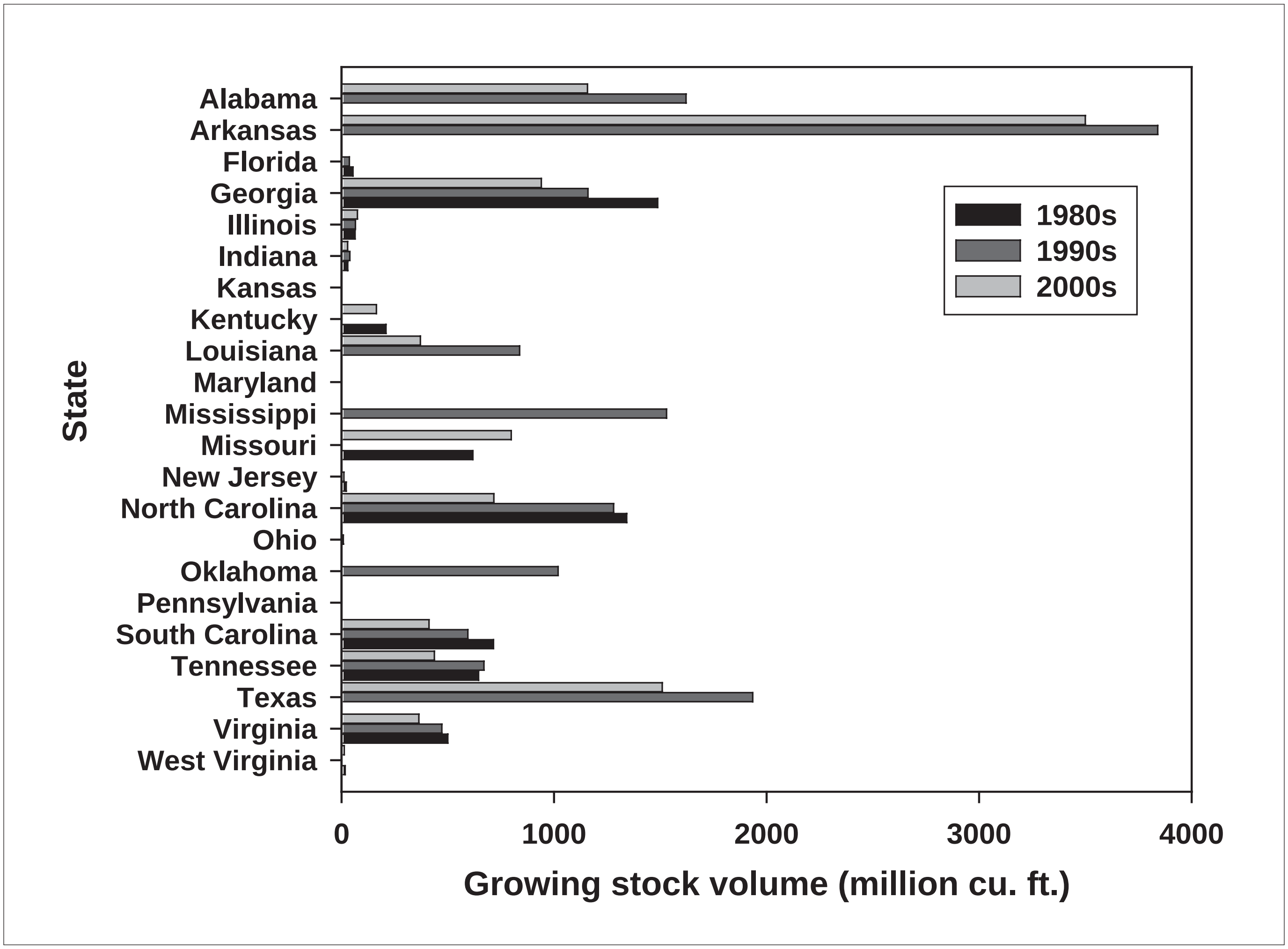

Figure 2.—Shortleaf pine growing stock volume by inventory decade and state. For each state, the bars progress (where data exist) from the 1980s on the bottom to 2000s on the top.

Table 6.—Percentage of total basal area in shortleaf pine basal area (“x/”) and shortleaf pine seedlings/saplings as a percentage of all seedlings/saplings (“/x”), by state and inventory period. All percentages rounded to nearest whole percent. Percentages less than 0.5 percent are shown as “0”.

State	1980s	1990s	2000s	State	1980s	1990s	2000s
Alabama		5/2	4/1	Missouri	4/1		5/1
Arkansas		13/4	11/3	New Jersey	1/1	0/0	
Florida	0/0	0/0	0/0	North Carolina	4/1	3/1	2/0
Georgia	4/1	1/0	2/1	Ohio		0/0	0/0
Illinois	1/0	1/0	1/0	Oklahoma		15/9	
Indiana	1/0	1/0	1/0	Pennsylvania	0/0		0/0
Kansas	0/0	0/0	0/0	South Carolina		3/2	2/1
Kentucky	1/1		0/1	Tennessee	3/1	2/0	1/0
Louisiana		3/1	1/0	Texas		10/2	6/1
Maryland	0/0	0/0		Virginia	2/0	2/0	2/0
Mississippi		5/1		West Virginia	0/0		0/0

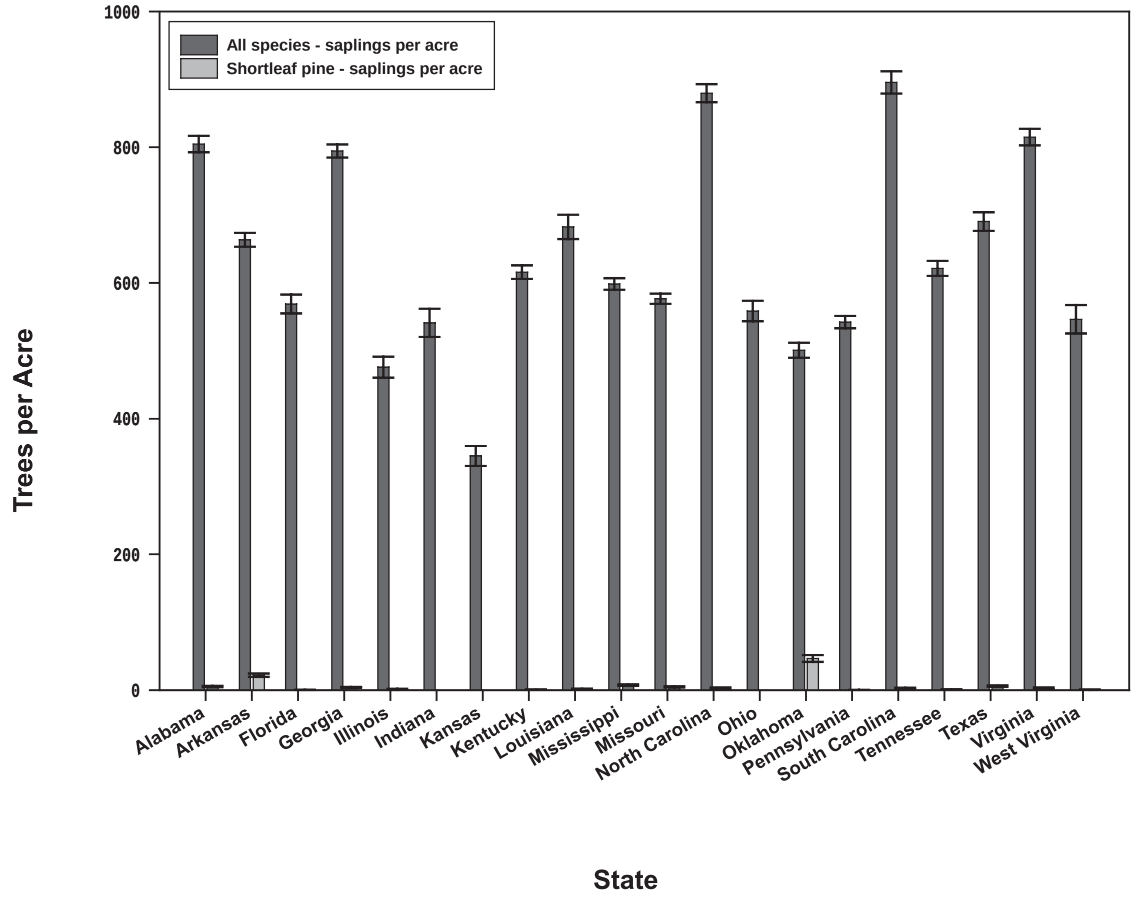

Figure 3.—Seedlings and saplings of all species and shortleaf pine, per acre, by state. The most recent inventories for Maryland and New Jersey are not complete; completed panels do not list any shortleaf pine volume.

CONCLUSIONS

After reaching a low point in the 1960s and 1970s, timberland in the eastern U.S. has recently started to increase. Shortleaf pine, however, has been decreasing in the number of trees and volume over the last several decades. Although we did find shortleaf pine regeneration in several states, the proportion was less than shortleaf pine's proportion of overstory basal area. The species is largely concentrated in large-diameter stands throughout its range. Such stands are likely older; older trees are frequently slower growing, which is, in turn, reflected in turn a smaller growth-to-removals ratio.

Johnson et al. (2002) emphasize the importance of accumulating oak regeneration in the understory and outlines the disturbances, anthropogenic and natural, that encourage this accumulation. The same principles apply to species such as the southern pines, particular shortleaf pine and longleaf pine (Moser 2003). Such disturbances promote two processes: the concentration of early growth on the pine seedling/sapling root system resulting from dieback of the above-ground component, and the elimination of less fire-resistant species that would otherwise compete successfully for resources. Two of the most prominent disturbances are harvesting and fire. Increasing urbanization and regulation have put pressure on both of these disturbance types. Furthermore, where shortleaf pine has been harvested, it has frequently been replaced by planted loblolly pine.

The declining proportion of regeneration represented by shortleaf pine is particularly disquieting, as it provides a foretelling of forest overstory composition. It is hard to imagine a future eastern U.S. forest landscape with the current proportion of shortleaf pine in the overstory, given these regeneration trends. While re-instituting large-scale disturbances will pose problems in a settled landscape such as the South, they should be considered part of the toolbox that resource managers use as they seek to maintain this important species.

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GENETIC VARIATION IN THE SOUTHERN PINES: EVOLUTION, MIGRATION, AND ADAPTATION FOLLOWING THE PLEISTOCENE

Ronald Schmidtling[1]

ABSTRACT.—Climate has certainly changed over time, requiring genetic change or migration of forest tree species. Little is known about the location of the southern pines during the Pleistocene glaciation, which ended around 14,000 years ago. Macrofossils of spruce (*Picea* spp.) dating from the late Pleistocene, which are typical of climates much cooler than presently occupied by the southern pines, have been found within the current range of the southern pines, indicating that the climate was considerably colder at that time. From this discovery it is reasonable to assume that the southern pines were situated south of their present range during the Pleistocene and migrated to their current location after the glaciers receded. Variation in adaptive and non-adaptive traits of the southern pines suggests that loblolly pine (*Pinus taeda*) existed in two refugia, one in south Texas/north Mexico, and one in south Florida. Longleaf pine (*P. palustris*) probably existed only in the western refugium. Slash pine (*P. elliottii*), on the other hand, presumably resided only in the Florida refugium, whereas shortleaf pine (*P. echinata*) is cold-hardy enough to have existed in a continuous distribution across the Gulf Coast. Implications of climate warming on the future of southern pines are discussed.

INTRODUCTION

There has been a great deal of discussion about "global climate change". An increase in CO_2 in the atmosphere since industrialization has been well documented and is apparently causing an increase in average temperatures. A consensus is developing that global temperatures are on the increase. Changes in climate, however, are not new, but have occurred many times in geological history.

The most drastic climatic changes during the long history of the pines have been relatively recent, during the Pleistocene Ice Ages. During the 1.6 million years of the Pleistocene, large fluctuations in temperature resulted in the advance and retreat of glaciers with a periodicity of a little more than 100,000 years. The interglacial periods were short compared to the glaciated periods. The current interglacial period, the Holocene, began from 10,000 to 14,000 years before present (BP); the last interglacial, the Eemian, from 130,000 to 107,000 years BP (Critchfield 1984). The large fluctuations in climate, which resulted in lengthy migrations, undoubtedly affected the population structure of temperate forest tree species.

Climate during the height of the last of these glaciations, the Wisconsin (c. 18,000 years BP), was colder than at present in the southeastern United States. The glaciation extended as far south as southern Ohio (40°N), overlapping the current northern distribution of the most temperate of the southern pines (Fig. 1). The southern pines were certainly situated south of their current location. The postulated palaeovegetation maps of Delcourt and Delcourt (1981) show oak, hickory, southern pine as far north as Tennessee (36°N). The maps of Webb et al. (1987), on the other hand, show southern pines absent at this time, and appearing in south Florida only at 12,000 years BP. Palynological evidence is difficult to interpret. Not only can pine pollen travel large distances, but it may be impossible to identify to the species level.

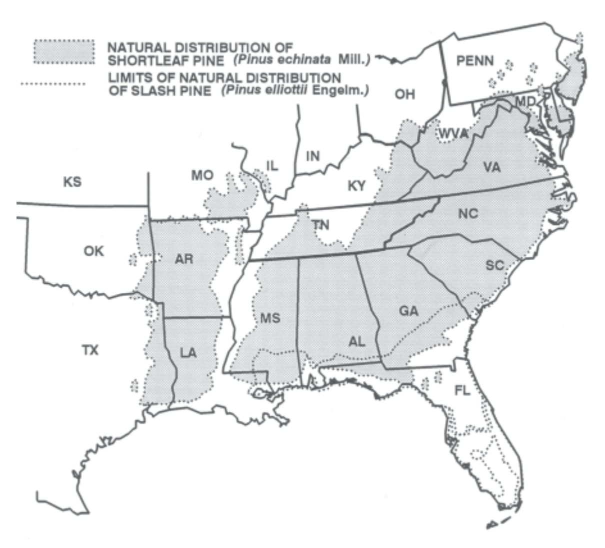

Figure 1.—Map of the Southeastern United States showing the current natural distribution of shortleaf and slash pines.

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[1] Scientist Emeritus, USDA Forest Service, Southern Institute of Forest Genetics, SRS, 23332 Hwy 67, Saucier, MS 39574. Email: rschmidtling@fs.fed.us

Macrofossils (including cones and needles) of boreal species, spruce (*Picea* sp.) and jack pine (*Pinus banksiana*) have been identified from several Wisconsin deposits (c. 14,000 years BP), one as far south as Louisiana (31°N) (Critchfield 1984). These locations are within the current natural ranges of even the more austral of the southern pines (Fig. 2). The current natural range of shortleaf pine (*Pinus echinata*) extends as far north as Ohio and New Jersey, but is several hundred kilometers south of the nearest jack pine in northern Michigan. Shortleaf pine overlaps the natural range of red spruce (*Picea rubens*) in the Appalachian Mountains, but shortleaf pine does not occur above 910 m, whereas red spruce does not occur below 1370 m (USDA 1990). Spruce and shortleaf pine do not currently grow on the same sites, but "disharmonious" associations could have existed during the Pleistocene (Wright 1989).

GENETIC VARIATION IN THE SOUTHERN PINES

Genetic variation in the more commercial southern pines is well known, especially for the adaptive traits of growth, survival, and pest resistance (summarized in Schmidtling 2001). The results of common-garden experiments as well as allozyme studies are available for shortleaf, longleaf (*P. palustris*), loblolly (*P. taeda*) and slash (*P. elliottii*) pines. These four species exhibit four different patterns of variation. The first three occur on both sides of the Mississippi River, but the last occurs only to the east of the river. This is an important factor in the evolution of the species.

Longleaf Pine

Provenance tests have shown that substantial variation in growth, survival, and disease incidence exists in longleaf pine (Wells and Wakeley 1970). Growth is generally related to latitude or temperature at the seed source (Schmidtling and Sluder 1995). Geographic variation in longleaf pine parallels that of other forest tree species; seedlings from warmer climates grow faster than those from colder climates, if they are not transferred to greatly differing climates.

In longleaf pine there are no differences in adaptive traits among sources east of the river versus those west of the river, after the minimum temperature at the seed source is taken into consideration (Schmidtling 1999). Given the lack of such differences in adaptive traits, it was surprising to find a linear decrease in variability from west to east in allozyme diversity (Schmidtling and Hipkins 1998). Sixty percent of the variation in expected heterozygosity was explained by longitude of the seed source (Fig. 3).

The most attractive explanation for the observed trend in variation is that longleaf pine originated from a single, limited refugium in southeast Texas or northeast Mexico, resulting in a reduced level of genetic variability as the rapidly migrating population was affected by stochastic events (Fig. 2).

Loblolly Pine

Like longleaf pine, loblolly pine occurs on both sides of the Mississippi River Valley (Fig. 4). Provenance tests have shown that substantial geographic variation in growth, survival, and disease susceptibility exists in loblolly pine (Wells and Wakeley 1966). Growth is generally related to latitude or temperature at the seed source (Schmidtling 1997). Geographic variation parallels that of longleaf pine; seedlings from warmer climates grow faster than those from colder climates, if they are not transferred to very different climates.

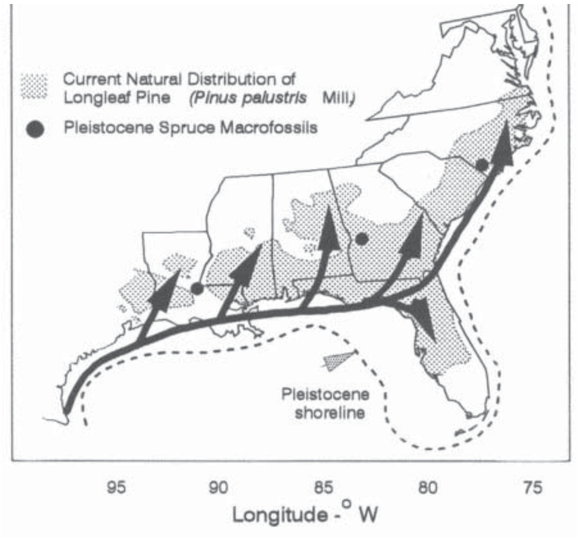

Figure 2.—Post-Pleistocene migration route accounting for the variation. Adapted from Schmidtling and Hipkins (1998).

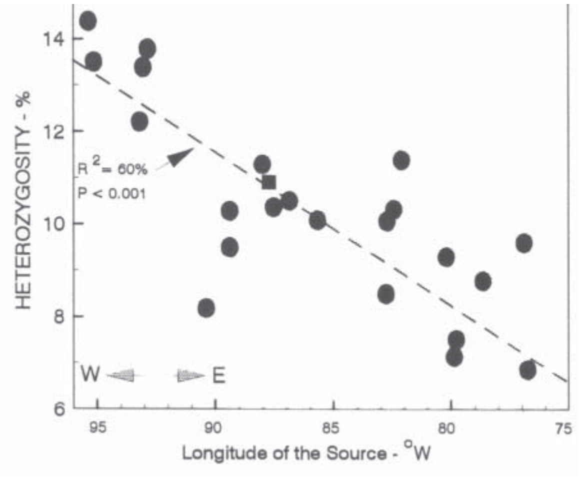

Figure 3.—Variation in expected heterozygosity by longitude in longleaf pine. Adapted from Schmidtling and Hipkins (1998).

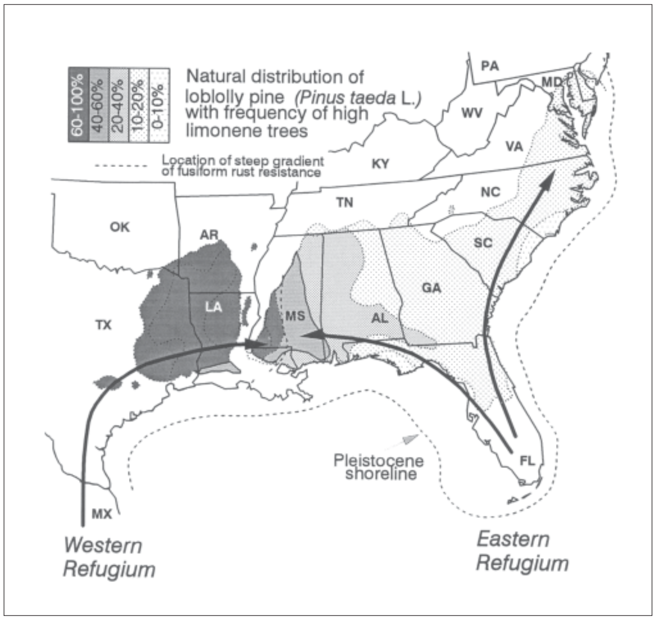

Figure 4.—Current natural distribution of loblolly pine showing the frequency of trees with high cortical limonene content. Also shown are the proposed Pleistocene refugia and migration routes.

Although east-west variation in adaptive traits such as growth, disease resistance and survival is minimal in longleaf pine, it is very important in loblolly pine (Wells and Wakeley 1966). In loblolly pine, western sources are slower growing, survive better, and have greater resistance to fusiform rust (*Cronartium quercuum* f.sp. *fusiforme*). The isolating effect of the Mississippi River Valley has often been cited to explain the east-west differences in loblolly pine. Pines do not exist in the Valley, because they cannot compete with broadleaved trees in the rich, moist alluvial soils where fire is infrequent. There is also an obvious difference in cortical monoterpenes between eastern and western populations (Fig. 4). Limonene is especially high in western populations (Squillace and Wells 1981). Although monoterpene composition is often considered a non-adaptive trait, it may function in insect resistance. The pattern of high limonene among populations on both sides of the Mississippi River appears to indicate there is gene exchange across the river, at least in the eastward direction. This possibility is supported by the existence of rust-resistant populations, common in the west, just east of the river (Fig. 4).

In loblolly pine, there was no east-west trend in allozyme variation (Schmidtling et al. 1999) and there appears to be a tendency for more variation in the central part of the natural range. There are some differences in the occurrence of rare alleles among populations. Twenty of the rare alleles were detected only in the eastern populations whereas only two were found exclusively in the western populations. Nearly all the alleles that are found in the western populations can be found in the eastern populations, but many of the alleles found in the eastern populations were not found in the western populations.

One of the alleles of enzyme 6PGD-1 is relatively common in many populations of loblolly pine east of the river, having a frequency as high as 0.29 in one population in Maryland, but is very rare west of the river. The distribution of allozyme alleles suggests that gene flow in a westerly direction across the Mississippi River is restricted. On the other hand, the continuous clinal variation in limonene content (Squillace and Wells 1981) and fusiform rust resistance (Wells et al. 1991) across the Mississippi River (Fig. 4) suggests that there is no barrier to gene flow in the eastern direction across the valley. Prevailing winds since the beginning of the Holocene 14,000 years ago are primarily in the eastern direction, and are certainly a factor in this predominantly one-way gene flow.

Some interesting similarities exist between all populations of longleaf pine and western populations of loblolly pine. Like western populations of loblolly pine, longleaf pine is resistant to fusiform rust and much less susceptible to tip moth and southern pine beetle (Snyder et al. 1977), although the mechanisms probably differ. These similarities suggests that western loblolly populations and all longleaf populations shared an environment at some time in the past where selection for resistance to these pests was important. The proposal that longleaf pine and western sources of loblolly pine both originated in a common refugium in south Texas/northeast Mexico fits the circumstantial evidence. The present climate in south Texas is too dry for *Australes* pines, but was probably much wetter during the Pleistocene (Watts 1983). Other pines occur just south of the border in Mexico, at high elevations (Critchfield and Little 1966).

The lack of a trend in allozymes in loblolly pine, coupled with the distinct east versus west variation in fusiform rust resistance and other adaptive traits suggests that loblolly pine was located in two refugia during the Pleistocene (Fig. 4), in Texas/Mexico and Florida/Caribbean as proposed by Wells et al. (1991). Using the genetic distances from the allozyme data of Schmidtling et al. (1999), I have calculated a divergence time of 97,000 years between the western and eastern sources, which is a good approximation of the time since the last interglacial period, the Eemian, in this region.

Shortleaf Pine

Shortleaf pine has the most temperate distribution of the major commercial southern pines, extending into Ohio and New Jersey to the north, and barely reaching into north Florida in the south (Fig. 1). Like longleaf and loblolly pines, shortleaf pines occur on both sides of the Mississippi River.

Like longleaf pine, provenance tests have shown that substantial variation in growth, survival, and disease incidence exists in shortleaf pine (Wells and Wakeley 1970). Growth is generally related to latitude or temperature at the seed source (Schmidtling 1995). As with longleaf pine, there is no east/west variation in adaptive traits in shortleaf pine.

Unlike longleaf pine, there is no east/west trend in allozyme variability (Raja et al. 1997, Edwards and Hamrick 1995). There is no trend consistent with a relatively fast migration from a restricted refugium. The relative cold-hardiness of shortleaf pine may have made such a migration unnecessary. It is here proposed that shortleaf pine had a more-or-less continuous distribution across the Gulf of Mexico, on the exposed continental shelf (Fig. 5).

Slash Pine

A number of the Australes pines occur only east of the Mississippi River Valley, including slash pine, pond pine (*Pinus serotina*), table mountain pine (*P. pungens*), pitch pine (*P. rigida*) and spruce pine (*P. glabra*). Slash pine is the most austral of the major southern pines and occurs mainly in Florida (Fig. 1). Slash pine has obvious affinities to *P. caribaea* of the Bahamas and Cuba, and before 1954 they were considered the same species (Little and Dorman 1954, Farjon and Styles 1997). There is clinal variation in many adaptive traits in slash pine in a north-south direction (Squillace 1966). It seems logical to assume that slash pine existed in a refugium in south Florida, the Bahamas, or Cuba, and migrated north after the retreat of the glaciers, approaching but not able to cross the Mississippi River against the prevailing winds. The expected decrease in variability in allozymes from south to north along the putative migration route has been documented (Schmidtling and Hipkins 2000).

The other southern pines with eastern distributions probably resided in refugia in north Florida to North Carolina (Fig. 5). Table mountain pine may be an exception. This pine exists at high elevations in the Appalachian Mountains and may simply have moved to a lower elevation.

THE FUTURE

Consensus is developing that global temperatures are on the rise, because of the human-induced increase in "greenhouse" gasses such as CO_2. During past climatic changes, forest trees, as well as other organisms, have been able to migrate to areas of favorable climate, or to change genetically through natural selection. Evolution is not static but is a constantly ongoing process.

Climate has been warmer in the past, such as during the Hypsithermal era, about 5,500 years BP. Climate has also been colder, e.g., "the Little Ice Age" in medieval times. The changes that have been projected by many climatic models, however, will be very fast, perhaps too fast for these natural processes to occur (Davis 1990).

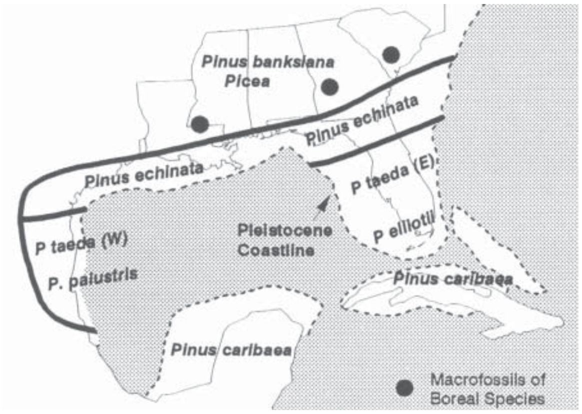

Figure 5.—Proposed location of the major southern pines during the Wisconsin Glaciation.

The southern pines have a great deal of genetic plasticity as is evident in the South Wide Southern Pine Seed Source Study (Schmidtling 2001). In this study, it is common for even very poorly adapted sources to live past 35 years (and reproductive maturity) albeit growing very slowly. Even this great plasticity may not be enough.

At some point foresters and other biologists may have to intervene in the process to mitigate the effects of this human-induced change. In this case, gene conservation would become very important.

CONCLUSIONS

In spite of the relative uniformity of the Coastal Plain of the southeastern United States, important genetic differences exist among the southern pine species in response to the last glaciation. Longleaf pine resided in a southwestern refugium and slash pine in a Florida refugium. Loblolly pine resided in both refugia, the two populations being isolated genetically. Shortleaf pine probably resided in a continuous population across the exposed continental shelf. The many advances and retreats of glaciation during the Pleistocene undoubtedly had profound effects on variation and speciation in the southern pines.

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FOREST STAND DYNAMICS OF SHORTLEAF PINE IN THE OZARKS

David R. Larsen[1]

EXTENDED ABSTRACT

Forest stand dynamics (Oliver and Larson 1996) examines the interactions among woody plants over time. Both the silvical requirements of the species present in the forest stand and the effects of these plants on each other must be understood. The components that are usually considered are regeneration, growth (in both diameter and height), mortality, and differences in species' tolerance of shade, fire, and drought. In addition, disturbance tends to shift the competitive advantage from one species to another.

Shortleaf pine has many interesting silvical characteristics (Burns and Honkala 1990) that distinguish it from the other southern pines. It is the most vigorous sprouter, it has the most northern range of the southern pines and it seems to occupy the marginal sites for southern pines (Record 1910, Liming 1946, Fletcher and McDermont 1957, Dingle and Burns 1954, Nash 1963). The reasons for these characteristics are many and but they tend to give shortleaf pine a reputation as a slow growing southern pine. Shortleaf pine actually has the potential to grow very well given a good site and proper levels of composition (Gingrich et al. 1965, Rogers and Brinkman 1965, Brinkman and Rogers 1967, Rogers 1982, Rogers and Sanders 1984).

Much has been written on the management of shortleaf pine in the Ozarks (Brinkman et al. 1965, Brinkman 1967, Brinkman and Smith 1968, Seidel and Rogers 1965, Seidel and Rogers 1966). In large portions of the Ozarks, shortleaf pine does not grow in pure stands but rather in mixes with various oak species. These mixes present unique challenges in finding the set of conditions that allow both species to survive and flourish. The author will comment on ideas of how these systems research and current work being done to quantify these ideas.

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THE IMPORTANCE OF SHORTLEAF PINE FOR WILDLIFE AND DIVERSITY IN MIXED OAK-PINE FORESTS AND IN PINE-GRASSLAND WOODLANDS

Ronald E. Masters[1]

ABSTRACT.—Shortleaf pine, by virtue of its wide distribution and occurrence in many forest types in eastern North America, is an important species that provides high habitat value for many wildlife species. Shortleaf pine functions as a structural habitat element in both mixed oak-pine forests and in pine-grassland woodlands. It also adds diversity throughout all stages of plant succession and stand development. Within the range of shortleaf pine, wildlife species are variously associated with shortleaf based on stand density, the proportion of hardwoods within a structural stage of development, and availability of habitat structure within the specific niche that each wildlife species occupies. Shortleaf also is a key species in ecosystems where it occurs naturally because its occurrence and relative dominance are defined to a large extent by the natural disturbance regime, particularly fire. Fire frequency and season, to some extent, define the understory plant community response and determine shortleaf pine's potential for regeneration, establishment of future codominant and dominant trees, and perpetuate a relative mix of pines with other associated tree species within a stand. This understory community response to fire or lack of fire defines much of the ground-dwelling or ground-foraging wildlife species populations. This paper discusses wildlife species associated with different structural characteristics and fire regime in mixed oak-shortleaf and shortleaf-dominated forests and woodlands.

INTRODUCTION

The oak-pine (*Quercus*-*Pinus*) forest type is the largest cover type in the eastern United States (Lotan and others 1978). In this area, shortleaf pine (*Pinus echinata* Mill.) is the most prevalent of the southern pines (Lawson and Kitchens 1983) and is associated with a wide array of other pines and hardwoods. It occurs in some 18 different cover types and is dominant in three of these (Eyre 1980). Its wide distribution and occurrence across many forest types make shortleaf pine of great value to associated wildlife species (Wigley 1986). Shortleaf also is a key species in ecosystems because its occurrence and relative dominance are defined by the natural disturbance regime, particularly fire (Masters and others 2003, 2005), which also influences the distribution and abundance of associated wildlife (Masters 1991a).

Shortleaf pine stands develop naturally as even- or uneven-aged stands, depending on the nature of the disturbance regime that initiated the stand and/or the periodic disturbance events that occurred throughout the life of the stand (Turner 1935, Bragg 2002, Masters and others 2005). Stands that initiate following catastrophic disturbance or as small old-field stands typically develop as even-aged stands (Turner 1935, Oosting 1942). If reoccurring fire is part of the disturbance regime, however, the stands will develop an uneven-aged structure (Masters and others 2005). As shortleaf pine ages, it becomes less tolerant of shade and neighboring crowns. By age 50 the crowns of trees develop an irregular shape and the canopy is often punctuated by numerous gaps (Mattoon 1915). Depending on the biophysical site conditions and fire frequency, oaks (*Quercus* spp.) and other hardwoods may vary in abundance based on their fire tolerance and site adaptability.

Stand structure in old-growth shortleaf has been reported as uneven-aged to even-aged and variable in density according to the frequency and nature of the disturbance pulse (Turner 1935, Bragg 2002) and also the scale of consideration. These forests typically had numerous canopy gaps and an open stand structure, depending on site conditions and fire regime (Little 1946, Fryar 1991, Murphy and Nowacki 1997, White and Lloyd 1998, Bragg 2002, Stambaugh and others 2002). However, in old-growth stands where anthropogenic disturbance are excluded, canopy-dominant old-growth pines eventually reach senescence and become prone to attack by various bark beetles, causing them to die and allowing midstory hardwoods to supplant pine in a relatively short period of time (Kreiter 1994, Masters and others 1995, Cain and Shelton 1996). In these senescing stands, shortleaf pine regeneration may occur as even-aged patches under large canopy gaps, or in several distinct size classes of different cohorts, or as individuals (Bragg 2002,

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[1] Director of Research (REM), Tall Timbers Research Station, 13093 Henry Beadel Drive, Tallahassee, FL 32312. REM is corresponding author: to contact call (850) 893-4153 or email at rmasters@ttrs.org

Stambaugh and others 2002, Cassidy 2004). Given enough time, mixed oak-pine stands will assume an uneven-aged structure with periodic canopy gaps whether initiated in an even-aged or uneven-aged fashion.

The range of structural conditions and successional states found in stands containing shortleaf pine provides a variety of niches for wildlife. A number of review papers have dealt with the influence of southern pine management and wildlife (e.g., Dickson 1982, Buckner 1982, Owen 1984) but only one specifically with shortleaf pine and wildlife (Wigley 1986). For brevity, this paper will focus primarily on habitat relations of small mammals, selected other mammals, and birds in mixed oak-pine and pine-grassland habitats.

FOREST SUCCESSION AND WILDLIFE HABITAT RELATIONSHIPS

Shortleaf pine either in pure stands or mixed oak-pine stands provides habitat for a large number of wildlife species from early seral stages through late seral stages. With progressive stand development and changes in stand structure comes a commensurate succession of wildlife species (Johnson and others 1974). Because some species are habitat specialists, some habitat generalists, and the remainder somewhere in between, structure (vertical and horizontal) and composition of a given stand will determine which species will be found there. Stand configuration, size, and the juxtaposition of stand ages and stand structures within a given landscape matrix also influence the occurrence of some wildlife species. Earlier literature refers to within-stand diversity, between-stand diversity, and landscape diversity (e.g., Wigley 1986). The presence of canopy gaps and the mix of oaks and other hardwoods in the canopy or in the midstory also provide suitable habitat for certain wildlife.

Early Succession

Following a disturbance event that takes a given stand back to an early seral stage, a fairly predictable chronosequence of vegetation replacement occurs (Johnston and Odum 1956, Meyers and Johnson 1978, Masters 1991a,b, Masters and others 2006). On old-field lands or following regeneration clear-cutting, the first stage is represented by herbaceous vegetation with an array of grasses and forbs. If the stand was clearcut and the site prepared for planting, the first stage may have considerable bare ground. Within 2 years of the clearcut, herbaceous vegetation will dominate the site and some woody component will have developed (Masters 1991a,b, Masters and others 2006). Soft mast production, important for many mammals and birds, typically has recovered by the third growing season and is more abundant than in mature mixed pine-hardwood stands (Perry and others 2004). Herbaceous and woody current annual growth will increase until canopy closure, generally within 6-8 years (Fenwood and others 1984, Masters and others 1993, 2006). The forage and browse production will be from 10 to 25 times greater than that in mature oak-pine stands over this short period of time (Masters and others 2006). Within 4 to 6 years woody vegetation begins to assert dominance as a distinct grass-shrub stage (Johnston and Odum 1956, Masters and others 2006). Then after 8 to 10 years a distinct sapling stage occurs. The replacement sequence and relative dominance of woody species can be redirected by subsequent disturbances such as fire (Masters 1991a, Masters and others 2005, 2006).

The chronosequence of mammals and birds that follow the stages of vegetation replacement are also somewhat predictable and fairly well documented except for meso-mammals and herpitofauna. From the first herbaceous-dominated stages, small mammals quickly colonize as cover develops (Atkeson and Johnson 1979, Thill and others 2004), and eastern cotton-tailed rabbit[2], white-tailed deer, and elk begin using the site (Masters 1991a,b, Masters and others 1997) (Fig. 1). Flying squirrel (Taulman and Smith 2004), gray squirrel, and fox squirrel, however, show dramatic declines compared to those in mature stands in these earliest sere stages (Flyger and Gates 1982). Nonetheless, squirrels of all three species have been noted to forage in early seral openings (Flyger and Gates 1982, Taulman and Smith 2004). Mammalian predators also are attracted to these sites (Wigley 1986). These groups of species continue to use these habitats through the shrub stage and into the sapling stage. By the fifth growing season, though, small mammal density (Thill and others 2004) and squirrel use declines dramatically (Flyger and Gates 1982).

Sapling stands provide beneficial escape and bedding cover and browse for white-tailed deer and elk in naturally- or artificially-regenerated stands, but cottontail use declines (Masters 1991a,b, Masters and others 1993, 1997). Deer and elk also preferentially use pine saplings over hardwood saplings as territorial marking sites or antler rubbing sites during the rut. When high stem densities develop, use by either species will decline rapidly with canopy closure where fire is excluded (Masters 1991a,b; Masters and others 1997). As crowns begin to close, herbaceous vegetation declines (Masters and others 1993), as do small mammal richness and density (Atkeson and Johnson 1979). By age 10 and at crown closure, rabbit, elk, and deer dramatically curtail use of either naturally-regenerated or clearcut stands (Masters and others 1997). Use of these stands is extended when prescribed fire is introduced early and at least on a 3-year late-dormant season cycle (Masters and others 1997) (Fig. 2). Prescribed fire reduces the density of small (< 6.5 ft) woody stems (Sparks and others 1999) and maintains herbaceous understory production at high levels (Masters and others 1993, 1996).

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[2] Animal species common names and scientific names with authority are found in the Appendix.

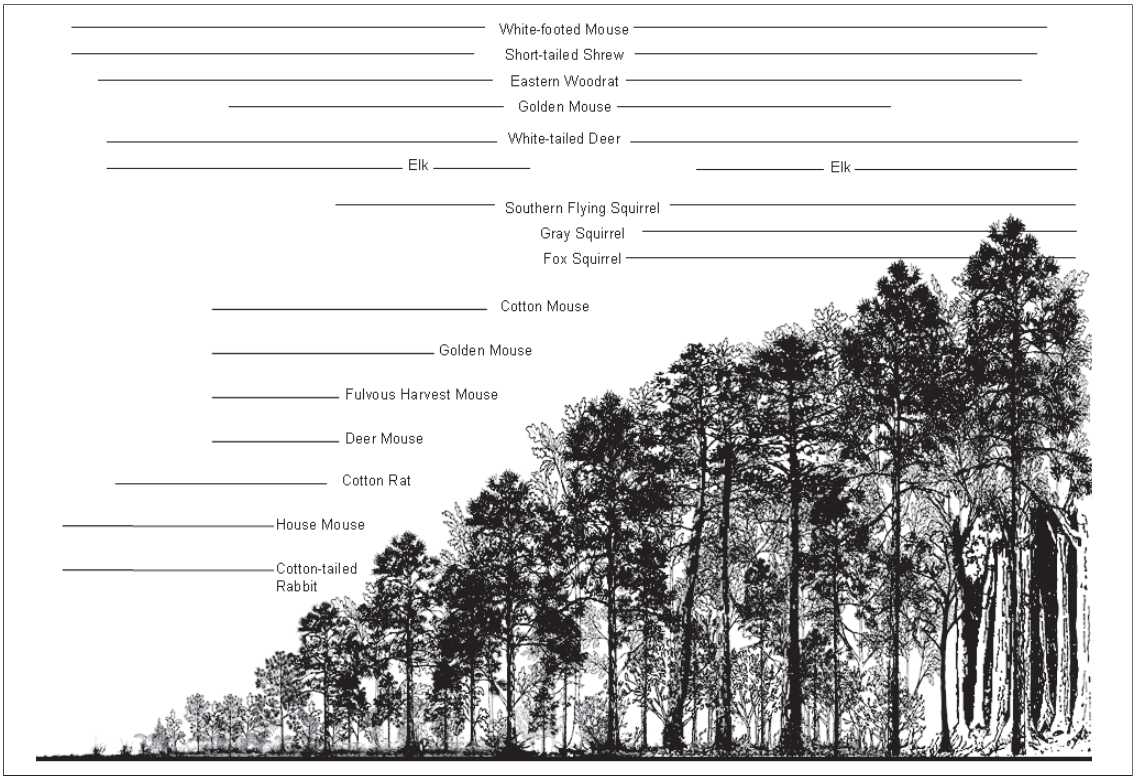

Figure 1.—Plant succession and mammal community succession model of selected common species occurrence associated with different stages of succession in the absence of fire. Horizontal lines indicate only the presence of the named species at a particular successional stage. Based on Atkeson and Johnson (1979), Tappe and others (1994, 2004), Masters and others (1998, 2002).

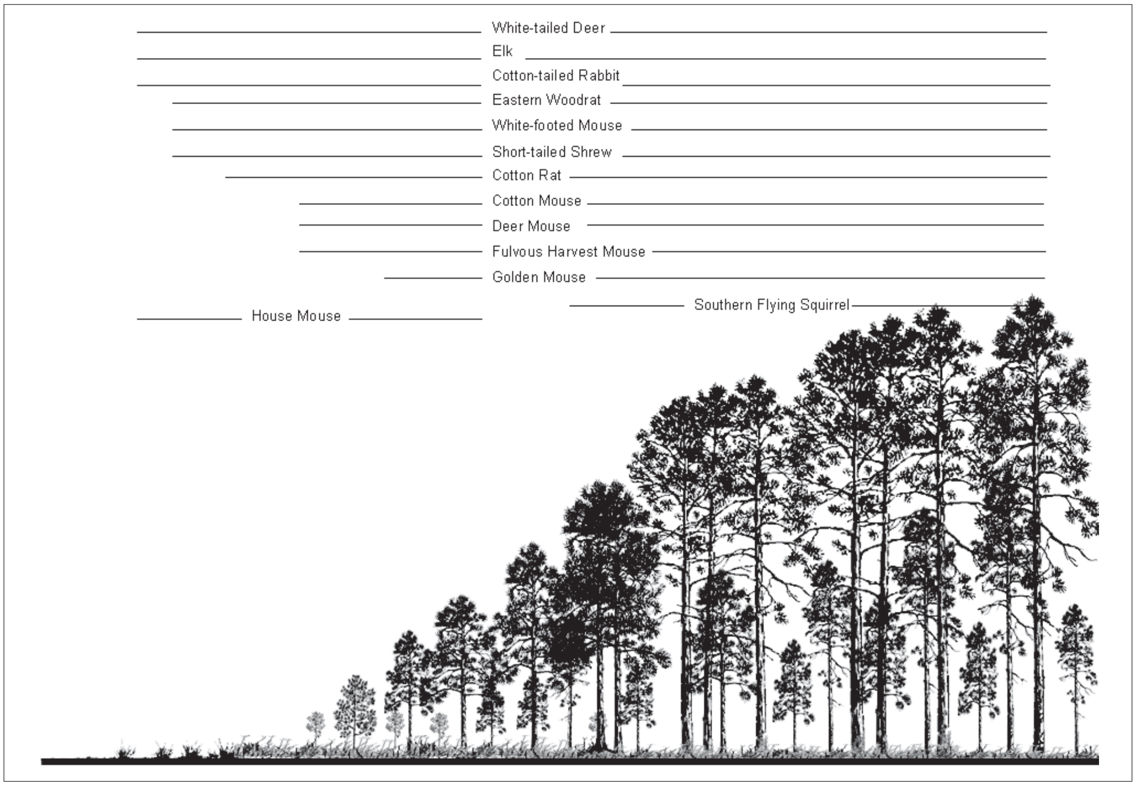

Figure 2.—Plant succession and mammal community succession model of selected common species occurrence associated with different stages of succession with frequent fire of at least 1- to 5-year intervals. Horizontal lines indicate only the presence of the named species at a particular successional stage. Based on Masters and others (1998, 2002).

From the earliest stages of secondary succession (bare ground), mourning dove begin using such sites. When the herbaceous stage is extended, such as in old field situations or in some clearcuts, eastern meadowlark, field sparrow, and grasshopper sparrow have been reported to use this stage (Johnston and Odum 1956, Meyers and Johnson 1978, Dickson and others 1993). Other early-succession bird species such as northern bobwhite, northern cardinal, indigo bunting, blue grosbeak, and, less frequently, Bachman's sparrow make some use of the grass-shrub stage found in regenerated stands as long as adequate ground cover and fairly dense brushy woody plants are present (Fig. 3). Eastern bluebird will use these sites where suitable snags are found. Where ground cover is predominantly needle litter in dense sapling- to post-sized stands, species such as prairie warbler and hooded warbler have been noted (Jennelle 2000). Periodic burning on at least a 3-year rotation in young sapling stands extends the period of use by early-sere wildlife species, such as numerous small mammals, bobwhite, wild turkey, and numerous songbirds, which will continue to use the stands as they develop (Masters 1991a, Stewart 1999, Jennelle 2000, Walsh 2004) (Fig. 4).

Mid-Succession

The mid-succession stage occurs from about 12 to 60 years of age. A common characteristic in stands where fires have been excluded are closed canopies with sparse patches of relatively few herbaceous plants in the understory (Oosting 1942, Meyers and Johnson 1978, Masters and others 2006). Stand density varies throughout this age span, but dense stands generally decline in density over time as competition-induced mortality takes place. Lower density stands will fill in during the early part of this stage, becoming more dense for a short period. But in either case, density will be similar by the later part of this successional stage (Oosting 1942). Once a mixed oak-shortleaf or shortleaf stand enters the post-size class (4-6 inches, diameter at breast height), use by many wildlife species will decline dramatically, as will density, especially in dense stands where fire is excluded. By age 15, stands support low numbers of small mammals (Atkeson and Johnson 1979). By age 18-20 flying squirrels begin using these developing mixed stands (Landers and Crawford 1995). Only during the latter part of this stage will significant numbers of fox or gray squirrels begin using the stand, at which time they may be more abundant than in late seral stages (Flyger and Gates 1982).

At age 12-15, depending on the site index, some songbird species more characteristic of later stages of succession will once again begin using the canopies of shortleaf stands as well as stands of other southern pine species (Engstrom and others 1984, Jennelle 2000). Species such as the red-eyed vireo, hooded warbler, and wood thrush become increasingly common, but ground-dwelling and -nesting species and some shrub-associated species decline (Engstrom and others 1984, Landers and Crawford 1995). The importance of fire in retaining early sere wildlife species was recently shown in a study on the Ouachita National Forest, AR, that examined northern bobwhite use of even-aged stands 12-15 years of age. Following only 3-4 seasons of fire exclusion, the northern bobwhite began avoiding stands that ranged from 600-700 stems/acre and that previously had showed extensive use (Walsh 2004).

In stands from about age 25 to 60, low densities of breeding birds characterize most dense southern pine forests (Johnston and Odum 1956). However, a host of songbirds uses the canopies of pole-sized stands and to a much greater extent the understory where frequent fire is used and lower stand density (<70 ft^2/ac) is maintained (Fig. 4). The songbird species complement in pole stands is similar to mature stands (Wilson and others 1995, Jennelle 2000, Masters and others 2002). In mid-succession stands excluded from fire, both species richness and density of small mammals and songbirds decline markedly as midstory hardwoods develop and as the herbaceous layer declines from litter buildup and shading by hardwoods (Engstrom and others 1984, Landers and Crawford 1995, Masters and others 2002).

Late Succession

Late seral stage mixed oak-pine stands may be characterized by an uneven-aged diameter distribution, sparse herbaceous understory, and considerable horizontal and vertical structure (Meyers and Johnson 1978, Kreiter 1994, Smith and others 1997). Often the canopy may have periodic gaps of different sizes. A snag component is evident.

Small mammal community density, species richness, and diversity are typically lower and composition somewhat different than in early seral stages (Tappe and others 1994, Masters and others 1998, 2002). Southern flying squirrel is considered to be a small mammal representative of mature mixed oak-pine forests (Taulman and Thill 1994), as are fox and gray squirrels, depending on the mix of oaks and other hardwoods (Flyger and Gates 1982).

Ovenbird, scarlet tanager, summer tanager, great-crested flycatcher, Acadian flycatcher, tufted titmouse, Carolina chickadee, Kentucky warbler, pine warbler, worm-eating warbler yellow-billed cuckoo, Northern cardinal, pileated woodpecker, hairy woodpecker, downy woodpecker, chuck-will's widow, whip-poor-will, wood thrush, tufted titmouse, Carolina wren, broad-winged hawk, red-eyed vireo, and possibly yellow-throated vireo are characteristic species of late succession mixed hardwood-pine hardwood stands (Johnston and Odum 1956, Meyers and Johnson 1978, Wilson and others 1995, Masters and others 2002). However, many of these are also characteristic of mature hardwood stands (Meyers and Johnson 1978). There is a paucity of conifer-specialized bird species in the southern forests compared with northern forests (Johnston and Odum 1956).

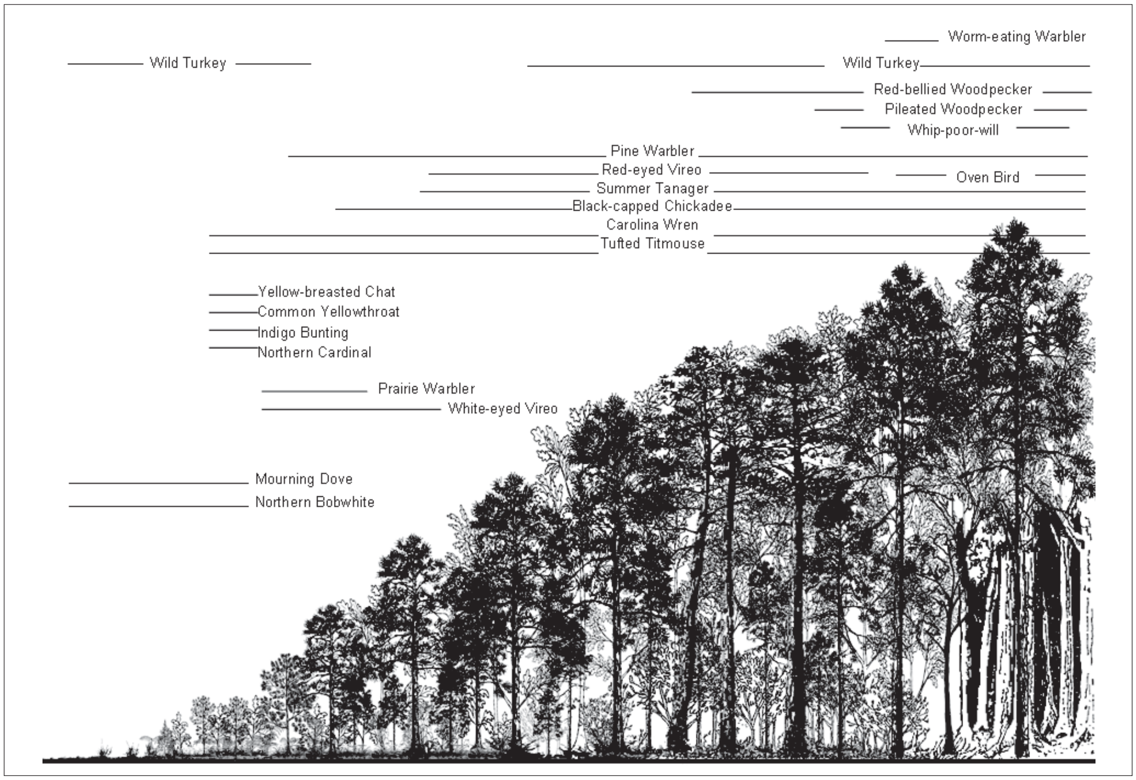

Figure 3.—Plant succession and breeding bird community succession model of selected common species occurrence associated with different stages of succession in the absence of fire. Horizontal lines indicate only the presence of the named species at a particular successional stage. Based on Johnston and Odum (1956), Meyers and Johnson (1978), Wilson and others (1995), Jennelle (2000), and Masters and others (2002).

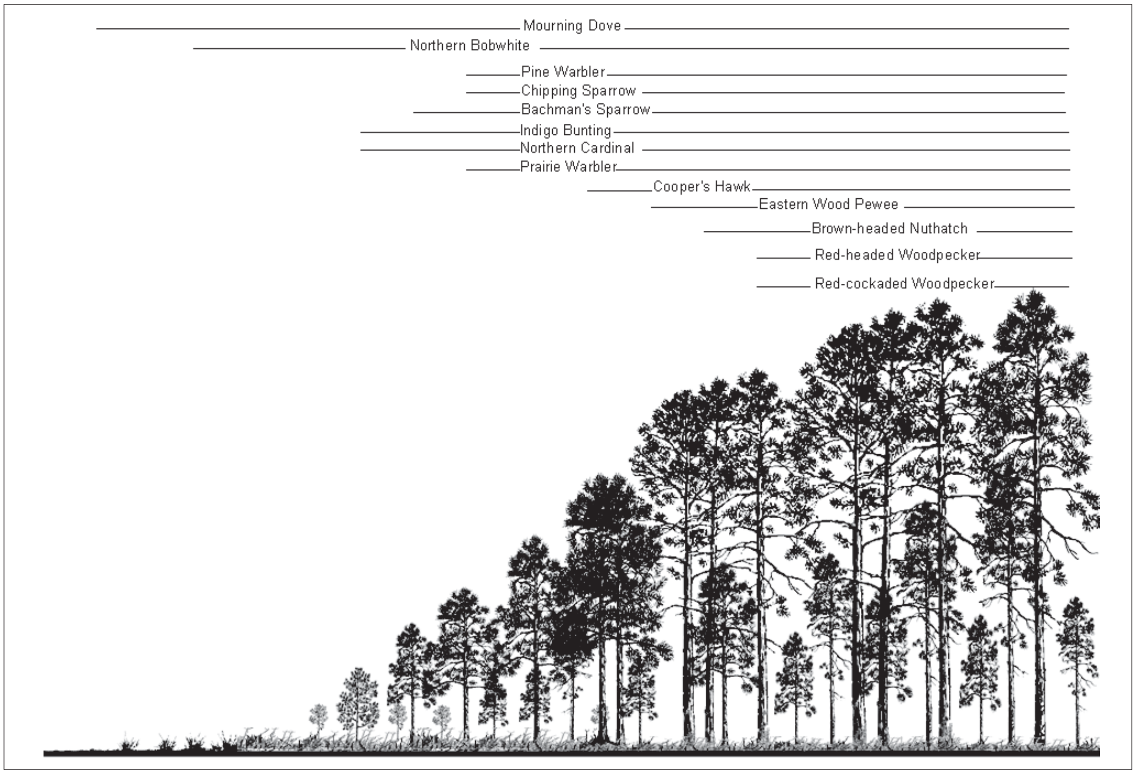

Figure 4.—Plant succession and breeding bird community succession model of selected common species occurrence associated with different stages of succession with frequent fire of at least 1- to 5-year intervals. Most of the bird species from Figure 3 will be found here as well if even 15 ft^2 of hardwood basal area per acre is present in the stand. Horizontal lines indicate only the presence of the named species at a particular successional stage. Based on Wilson and others (1995), Jennelle (2000), and Masters and others (2002).

Pine-bluestem

In ecosystems where natural disturbance processes, particularly frequent fire, are allowed to freely operate, old-growth stands may be characterized by open canopy (basal areas less than 70 ft^2/ac), pure or nearly pure pine stands with limited midstory, and a bluestem-dominated understory (See Vogl 1972, Komarek 1974, Fryar 1991, Masters and others 1995, Sparks and Masters 1996, Batek and others 1999). Oaks and other hardwoods may be present to varying degrees depending on site characteristics (Vogl 1972, Fryar 1991, Kreiter 1994, Masters and others 1995). The understory is rich in grass and forb species with grasses assuming a dominant aspect following repeated cycles of fire (Masters and others 1996, Sparks and others 1998). A distinct woody component will be present but suppressed, depending upon the time since last burned and the intensity of the fire (Sparks and others 1999, 2002). With increasing time since last burned, understory woody stems gradually grow into the lower midstory (Masters and others 2002).

Mature shortleaf pine-bluestem stands with abundant herbaceous ground cover and little to no hardwood midstory, managed with late-dormant season fire at 3-year intervals, show dramatic increases in both richness and density of small mammals and songbirds (Wilson and others 1995, Masters and others 1998, 2001, 2002). Low basal area pine-bluestem stands managed with frequent fire also provide more than adequate high-quality forage for white-tailed deer and elk (Masters 1991a, Masters and others 1993, 1996, 1997) and are used to a greater extent by both species than unburned closed-canopy sites (Masters 1991b, Masters and others 1997). Historically, bison and elk likely occurred throughout much of the range of the shortleaf pine-bluestem type (Smith and Neal 1991). Masters and others (1997) found that elk and white-tailed deer were able to persist together in areas endemic for the meningeal worm (*Parelaphostrongylus tenuis*) when over 21 percent of an area was in early successional openings. The meningeal worm can cause significant mortality in elk. In this system fire may have been particularly important for elk to persist because fire in woodlands causes mortality to woodland snails that may be the intermediate host to the meningeal worm. This hypothesis needs to be tested.

The entire small mammal community is benefited by this system of management. Both small mammal richness and total captures increase in response to thinning and fire, particularly following the first growing season (Masters and others 1998, 2001). In those studies, no part of the small mammal community was disadvantaged by restoration treatments to shortleaf pine-bluestems stands (Masters and others 1998, 2002). Exceptions might be the southern flying squirrel, gray squirrel, and fox squirrel, species which those studies did not examine. The most prevalent species in restored pine-bluestem stands included white-footed mouse and short-tailed shrew. Other species that increased in abundance as well but not significantly included the wood rat and cotton rat. The cotton mouse and deer mouse were found only in restoration treatments (Masters and others 2002). But perhaps the species that benefited the most were specialists such as the fulvous harvest mouse and the golden mouse (Masters and others 1998). In a pine-grassland community, the fire frequency also influences the structure of the understory and thus the small mammal community. If fires are very frequent, the cotton mouse and golden mouse are disadvantaged, but the cotton rat is distinctly benefited by frequent fire (Fig. 5). The golden mouse was more prevalent on 3- to 7-year fire intervals and the cotton mouse tolerated a wide range of frequencies from 2-12 years. The understory woody structure of each of the burn intervals is different, with more frequent fire causing lower height and less percent cover, while less frequent fire intervals allows greater height development and fuller canopies with greater percent cover. Small mammal and breeding bird response is strongly associated with this change (Masters 2002, Masters and others 2002).

At least 10 species of breeding birds are considered pine-grassland obligates and are benefited by pine-bluestem management (Wilson and others 1995, Conner and others 2002, Cram and others 2002, Masters and others 2002). This group of birds has declined more precipitously than any other group of songbirds in eastern North America (Jackson 1988). This group includes red-cockaded woodpecker, red-headed woodpecker, brown headed nuthatch, northern bobwhite, prairie warbler, pine warbler, Bachman's sparrow, chipping sparrow, eastern wood-pewee, and indigo bunting (see Wilson and others 1995, Cram and others 2002, Masters and others 2002). Other

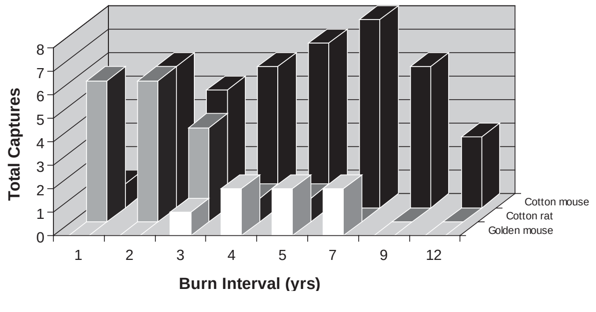

Figure 5.—Response of cotton mouse, cotton rat, and golden mouse to different fire frequencies on the Stoddard fire plots (three replications of 0.5-acre units), Tall Timbers Research Station, Tallahassee, FL. These pine-grassland stands were dominated by mature (>100 years) old-field derived shortleaf and loblolly and in the sub-canopy a mixture of oaks and other hardwoods of varying prevalence depending on fire frequency. From Masters (2002), L. Perkins, Jr., Tall Timbers Research Station (unpublished data).

species that have been noted to increase to some extent with pine-grassland management include the great-crested flycatcher, Acadian flycatcher, brown-headed cowbird, ruby-throated hummingbird, summer tanager, red-eyed vireo, yellow-throated vireo, white-breasted nuthatch, yellow-billed cuckoo, blue-gray gnatcatcher, hairy woodpecker and downy woodpecker (Masters and others 2002). Of note is the fact that these birds have in many cases been considered inhabitants of mixed oak-pine stands and hardwood stands. Their presence is likely related to retention of oaks and other hardwoods within pine-bluestem managed areas and associated hardwoods along ephemeral drainages within stands (Masters and others 2002). Size, composition, and juxtaposition of surrounding stands, as well as size of the stand that has been restored influence the species abundances found within restored stands. These characteristics are important for species that locally are sensitive to habitat condition, as has been found true of the Northern bobwhite quail (Cram and others 2002).

In pine-bluestem stands, there is a rapid successional progression of bird species not considered to be pine-grassland obligates that are associated with increasing height of lower-midstory hardwoods and pine depending on the duration since the last burn (Masters and others 2002). Following three or more growing seasons after burning, species such as the indigo bunting, yellow-breasted chat, common yellow throat, Northern cardinal, and blue grosbeak use the shrubs that develop in the lower midstory. However, other species like the chipping sparrow, Northern bobwhite, prairie warbler, and Eastern wood pewee will decline with increased woody cover in the lower midstory (Wilson and others 1995, Masters and others 2002). The importance of fire in maintaining suitable habitat structure was well illustrated in a recent study by Walsh (2004) in which Northern bobwhite avoided early seral stands and mature stands when they had not been burned for 3 to 5 years. These findings may also apply to the total small mammal community. A salient point is that the understory structure of pine woodlands and forests largely determines the composition of the bird community (Johnston and Odum 1956) and of the small mammal community. Desirable woodland and forest structure can be altered or maintained naturally by periodic fire (Masters and others 2002).

Snag retention has been named as a potential problem in frequently burned woodlands. Snags are essential for primary- and secondary-cavity nesting songbirds (e.g., red-headed woodpecker and eastern bluebird, respectively) (Masters and others 2002) and for southern flying squirrels (Taulman and Smith 2004). Periodic low-intensity fire can be of benefit in creating future snags, but fire under extended dry conditions will consume snags. Burning when snags have high moisture content (>25 percent) (Scott and Burgan 2005) or when the Keetch-Byram Drought Index (KBDI) is low will prevent consumption.

With fire exclusion and the resultant development of a hardwood mid- to upper midstory the pine-grassland obligate species will cease to use the stands (Wilson and others 1995, Masters and others 2002). Species related to a midstory hardwood presence such as the red-eyed vireo, black and white warbler, summer tanager, scarlet tanager, Acadian flycatcher, ovenbird, and worm-eating warbler become more prevalent. Midstory hardwood development has been directly associated with cavity tree abandonment by red-cockaded woodpeckers and subsequent population declines (Masters and others 1989, Jackson and others 1986).

As a food resource, shortleaf pine seed is an important and preferred food source for northern bobwhite (R.E. Masters, Tall Timbers Research Station, unpublished data) and for numerous small mammals (Stephenson and others 1963), including flying squirrels, fox squirrels, and gray squirrels as well as numerous ground-feeding song birds (Martin and others 1951). Shortleaf pine seed production in the southern Ozarks and in the Ouachita Mountains may be characterized as a “boom” or “bust” phenomenon with about one-third of the seed crops considered either good or bumper seed crops (Shelton and Wittwer 1996). Extensive consumption of shortleaf seed by many songbirds and small mammals has been reported as a hindrance to suitable seedling establishment from either natural seed fall or direct seeding of sites (Lawson 1990).

SUMMARY AND CONCLUSIONS

Although no wildlife species specifically requires shortleaf pine as a habitat element, a number of wildlife species do require a pine component to their habitats. Because of its distribution and abundance, shortleaf pine provides this structural and compositional element over a large area. As such, shortleaf pine satisfies habitat requirements for many breeding songbirds and is an important cover component and food resource for many songbird and mammal species. Only the pine warbler, brown-headed nuthatch and red-cockaded woodpecker require a pine species, but not specifically shortleaf. Within the range of shortleaf pine, wildlife species are variously associated with shortleaf pine based on the structural stage of stand development and the specific niche that a given wildlife species occupies. Specifically, stand density and thus understory conditions, and the proportion of hardwoods within a stand strongly influence the distribution and abundance of wildlife species associated with shortleaf at a given seral stage.

Fire frequency and season, to some extent, define the understory plant community response and determine shortleaf pine’s potential for regeneration, establishment, and perpetuation within a given stand and the relative mix with other associated tree species. This understory community response to fire or lack of fire defines the response of many of the ground-dwelling or ground-foraging wildlife species. However, a number of wildlife species are associated with the fire regime that corresponds to the occurrence of shortleaf pine, especially to the understory structure which varies with frequency of fire. This association is particularly true for pine-grassland obligate songbirds, and numerous small mammals.

ACKNOWLEDGMENTS

I wish to acknowledge the support, financial and otherwise, of many organizations that have funded much of the research cited in this paper, including Tall Timbers Research Station, Oklahoma State University, Oklahoma Department of Wildlife Conservation, Oklahoma Forestry Services, and the U.S. Forest Service. I am especially grateful to the team of graduate students, wildlife biologists, range scientists, and foresters who have been partners in the field on many of these projects and have enlivened my research experience and broadened my thinking. I am grateful to Kaye Gainey, who developed the graphics in Figures 1-4 and for helpful reviews by J. Cox, and K. Robertson and two anonymous reviewers.

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Appendix.—List of common and scientific names of bird and mammal species mentioned in the text and figures.

Common Name	Scientific Name (authority)
Birds	
Acadian Flycatcher	*Empidonax virescens* (Vieillot)
American Crow	*Corvus brachyrhynchos* (Brehm)
American Goldfinch	*Carduelis tristis* (Linnaeus)
American Kestrel	*Falco sparverius* (Linnaeus)
American Redstart	*Setophaga ruticilla* (Linnaeus)
Bachman's Sparrow	*Aimophila aestivalis* (Lichtenstein)
Black and White Warbler	*Mniotilta varia* (Linnaeus)
Blue Grosbeak	*Guiraca caerulea* (Linnaeus)
Blue Jay	*Cyanocitta cristata* (Linnaeus)
Blue-gray Gnatcatcher	*Polioptila caerulea* (Linnaeus)
Broad-winged Hawk	*Buteo platypterus* (Vieillot)
Brown Thrasher	*Toxostoma rufum* (Linnaeus)
Brown-headed Cowbird	*Molothrus ater* (Boddaert)
Brown-headed Nuthatch	*Sitta pusilla* (Latham)
Carolina Chickadee	*Poecile carolinensis* (Audubon)
Carolina Wren	*Thryothorus ludovicianus* (Latham)
Chipping Sparrow	*Spizella passerina* (Bechstein)
Common Flicker	*Colaptes auratus* (Linnaeus)
Common Yellowthroat	*Geothlypis trichas* (Linnaeus)
Cooper's Hawk	*Accipiter cooperii* (Bonaparte)
Downy Woodpecker	*Picoides pubescens* (Linnaeus)
Eastern Bluebird	*Sialia sialis* (Linnaeus)
Eastern Wood Pewee	*Contopus virens* (Linnaeus)
Field Sparrow	*Spizella pusilla* (Wilson)
Great-crested Flycatcher	*Myiarchus crinitus* (Linnaeus)
Great-horned Owl	*Bubo virginianus* (Gmelin)
Hairy Woodpecker	*Picoides villosus* (Linnaeus)
Hooded Warbler	*Wilsonia citrina* (Boddaert)
Indigo Bunting	*Passerina cyanea* (Linnaeus)
Kentucky Warbler	*Oporornis formosus* (Wilson)
Mourning Dove	*Zenaida macroura* (Linnaeus)
Northern Bobwhite	*Colinus virginianus* (Linnaeus)
Northern Cardinal	*Cardinalis cardinalis* (Linnaeus)
Northern Parula	*Parula americana* (Linnaeus)
Ovenbird	*Seiurus aurocapillus* (Linnaeus)
Pileated Woodpecker	*Dryocopus pileatus* (Linnaeus)
Pine Warbler	*Dendroica pinus* (Wilson)
Prairie Warbler	*Dendroica discolor* (Vieillot)
Birds (continued)	
Red-bellied Woodpecker	*Melanerpes carolinus* (Linnaeus)
Red-cockaded Woodpecker	*Picoides borealis* (Vieillot)
Red-eyed Vireo	*Vireo olivaceus* (Linnaeus)
Red-headed Woodpecker	*Melanerpes erythrocephalus* (Linnaeus)
Ruby-throated Hummingbird	*Archilochus colubris* (Linnaeus)
Scarlet Tanager	*Piranga olivacea* (Gmelin)
Summer Tanager	*Piranga rubra* (Linnaeus)
Tufted Titmouse	*Baeolophus bicolor* (Linnaeus)
Whip-poor-will	*Caprimulgus vociferous* (Wilson)
White-breasted Nuthatch	*Sitta carolinensis* (Latham)
White-eyed Vireo	*Vireo griseus* (Boddaert)
Wild Turkey	*Meleagris gallopavo* (Linnaeus)
Wood Thrush	*Hylocichla mustelina* (Gmelin)
Worm-eating Warbler	*Helmitheros vermivorus* (Gmelin)
Yellow-billed Cuckoo	*Coccyzus americanus* (Linnaeus)
Yellow-breasted Chat	*Icteria virens* (Linnaeus)
Yellow-throated Vireo	*Vireo flavifrons* (Vieillot)
Small Mammals	
Cotton Mouse	*Peromyscus gossypinus* (LeConte)
Deer Mouse	*Peromyscus maniculatus* (Wagner)
Eastern Woodrat	*Neotoma floridana* (Ord)
Fulvous Harvest Mouse	*Reithrodontomys fulvescens* (Allen)
Golden Mouse	*Ochrotomys nutalli* (Harlan)
Hispid Cotton Rat	*Sigmodon hispidus* (Say and Ord)
House Mouse	*Mus musculus* (Linnaeus)
Pine Vole	*Microtus pinetorum* (LeConte)
Southern Short-tailed Shrew	*Blarina carolinensis* (Bachman)
White-footed Mouse	*Peromyscus leucopus* (Rafinesque)
Other Mammals	
Bison	*Bison bison* (Linnaeus)
Eastern cotton-tailed rabbit	*Sylvilagus floridanus* (Allen)
Elk	*Cervus elaphus* (Linnaeus)
Fox squirrel	*Sciurus niger* (Linnaeus)
Gray squirrel	*Sciurus carolinensis* (Gmelin)
Southern flying squirrel	*Glaucomys volans* (Linnaeus)
White-Tailed deer	*Odocoileus virginianus* (Zimmermann)

RESTORATION AND MANAGEMENT OF SHORTLEAF PINE IN PURE AND MIXED STANDS—SCIENCE, EMPIRICAL OBSERVATION, AND THE WISHFUL APPLICATION OF GENERALITIES

James M. Guldin[1]

ABSTRACT.—Shortleaf pine (*Pinus echinata* Mill.) is the only naturally-occurring pine distributed throughout the Ozark-Ouachita Highlands. Once dominant on south-facing and ridgetop stands and important in mixed stands, it is now restricted to south- and southwest-facing slopes in the Ouachita and southern Ozark Mountains, and to isolated pure and mixed stands in the northern Ozarks. Its position as a minority component in mixed stands has declined to the status of relict. Restoration and management of shortleaf pine fall into three categories—science, empirical observation, and wishful application of generalities. In science, knowledge exists about regenerating pure stands of shortleaf pine through plantation forestry or natural regeneration, about managing second-growth stands to restore pine-bluestem communities, and about applying growth and yield models for pure stands of the species. Empirically, evidence suggests that relying on advance growth rather than seedfall will better regenerate shortleaf pine naturally over time, in conjunction with prescribed burning. Generalities become more wishful when considering the use of herbicides to supplement fire, and when thinking about effective ways to underplant a minor and varying shortleaf pine component in hardwood stands so as to recover the dramatically depleted area of oak-pine woodlands—the omitted step in restoring this species fully in the Ozark-Ouachita Highlands.

INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.) is the most widely distributed and least well understood of the four major southern pines. The natural range of shortleaf pine encompasses 22 states from New York to Texas, second only to eastern white pine in the eastern United States (Little 1971). It is a species of minor and varying occurrence in most of these States, and is usually found in association with other pines. But in the Ouachita Mountains of western Arkansas and eastern Oklahoma, and in the Boston Mountains and Springfield Plateau of the Ozark Mountains in northern Arkansas and southern Missouri, it is the only naturally-occurring pine. Here, shortleaf pine, pine-hardwood, and hardwood-pine stands once covered extensive areas.

Pine-dominated stands were and still are common in the Ouachitas. The folding and faulting of these heavily-eroded mountains date to late Paleozoic origin. The main axis of the Ouachitas runs east to west, which creates broad U-shaped valleys, long ridges, and hillside slopes dominated by northern and southern aspects. Site productivity is generally correlated with topographic position and colluvial pedogenesis, such that the ridgetops are the poorer sites and the lower slopes and valleys the better sites. The ridgetops and south-facing slopes in particular feature xeric conditions promoted by thin rocky soils and a high level of incident solar radiation, which favor microclimatic conditions under which the establishment and development of shortleaf pine is favored. Anthropogenic activity prior to European settlement kept fire on the landscape in a regular way. Periodic fire promoted shortleaf pine, perhaps at the expense of other pines, through shortleaf pine's adaptation of sprouting if the stem is killed or cut, a trait noted early on as an adaptation to surface fires (Mattoon 1915). Nowhere in the natural range of shortleaf pine does the species so dominate a landscape, and especially the stands on ridgetops and south-facing slopes within the landscape, as in the Ouachitas.

But shortleaf pine was also a dominant pine on the Ozark Plateau. Unlike the Ouachitas, the Ozarks are an uplifted calcareous plateau that has weathered over time into a landform that features benches underlain by resistant rocks at varying elevations. Due to vagaries of weathering and the distribution of underlying geology, slope aspect is distributed around all points of the compass. Site quality in the Ozarks is dependent on soil depth, which can vary considerably by slope position, depending on the presence or absence of these benches at differing elevations. As a result, site conditions are far more heterogeneous in the Ozarks than the Ouachitas. The Ozarks have many varied aspects rather than a few. Uniform site conditions are

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[1] Supervisory Ecologist and Project Leader, Southern Research Station, USDA Forest Service, 607 Reserve Street, Hot Springs AR 71902. To contact, call 501-623-1180 ext. 103 or email at jguldin@fs.fed.us

featured in a much smaller area, and where the best sites on a hillside might be on a bench toward the upper end of the slope. These conditions are suited to a pine that is very much a generalist, which is more the typical pattern of shortleaf pine throughout its natural range. Again, under the actions of drought and fire, shortleaf pine undoubtedly was and is found in pure stands in the Ozarks, but these stands are less contiguous than in the Ouachitas. Moreover, shortleaf probably existed as a varying majority or minority component in mixture with hardwoods across the Ozarks, depending on site conditions and disturbance history.

For those interested in the ecological restoration of shortleaf pine, a key question concerns restoring the mixed pine-hardwood and especially the hardwood-pine stands where shortleaf was found. The heyday of lumbering in the Interior Highlands was highlighted by high-grading shortleaf pine. The Missouri Mining and Lumber Company operated shortleaf pine mills at Grandin, MO, from 1888 to 1909 and cut about 75 million board feet (bf) annually (Flader 2004). Roughly speaking, that mill alone cut from 1.2 to1.5 billion bf from southern Missouri—a volume exceeding one-third of the standing sawlog volume in the shortleaf-loblolly pine species group in the Missouri Ozarks today (Miles 2006). That quantity speaks to a ruthless high-grading of shortleaf pine throughout the southern part of Missouri. Operationally speaking, this pine harvest could not have been taken simply from pure stands. Logging crews for the Grandin mill and others must have cut shortleaf pine trees wherever they were found, whether in pure stands on southerly aspects or even just a few trees in an oak-dominated stand.

If a stand was dominated by shortleaf pine before being high-graded, it had at least a chance of returning to shortleaf. Pines smaller than the accepted merchantable size would not have been cut; those small trees were probably mature, and would have dispersed seed on a recently harvested site that had sufficient exposure from logging and skidding so as to present a relatively favorable seedbed for shortleaf regeneration, especially if surface fires contributed to site preparation and competition control. Similar natural dynamics undoubtedly followed harvest of pure stands of shortleaf throughout the Interior Highlands, and must have been effective judging by the extent of second-growth shortleaf pine stands throughout the region.

But a different dynamic arguably ensued in hardwood-dominated stands. There, loggers looking for pines would not have cut the hardwoods, they would have cut only the few pines sought by their mill. A high-grading that took five or ten shortleaf pines per acre and left all the hardwoods would not have caused a sufficiently intensive disturbance to result in a new age cohort of shortleaf pine. These stands probably responded to pine logging as essentially a crown thinning, resulting in more growing space for the overstory hardwoods. Far fewer shortleaf pines were probably left as a seed source, and overstory hardwood shade would likely inhibit development of any shortleaf that persisted or were newly established in the understory. These speculations lead us to suspect that local extirpation of shortleaf pine was more likely in mixed stands than in pure stands, and especially in the oak-pine stands where pine was a minor component initially. Evidence of that extirpation exists today in stands that contain no shortleaf pine, but in which we can still find scattered shortleaf pine stumps. Such stands are not uncommon in the Missouri and Arkansas Ozarks.

The implications of this are interesting in light of the fact that restoration of shortleaf pine is moving forward. The silvicultural basis of ecological restoration includes re-initiation of suppressed ecological processes (e.g., fires), removal of encroaching native and exotic species, and the establishment of the native species that once dominated the landscape. This prescription is fairly straightforward when the native species is in relatively pure stands, as seen in the pine-bluestem restoration projects being undertaken by each of the three national forests in the Interior Highlands, and by the oak woodland restoration projects under way on the two national forests in the Ozarks. There are also opportunities in the restoration of mixed pine-oak and oak-pine stands in the region.

However, the research to support restoration of shortleaf pine is incomplete. Some elements are firmly established in the scientific literature and in practice, but other elements are based on empirical silvicultural tactics that we think we know but that are not yet firmly established in the literature. And some elements are unusually speculative, based on what could be considered the wishful application of generalities (WAGs) that can be derived from the silvics and silviculture of shortleaf pine. In this paper, elements important to consider in application of silvicultural concepts to shortleaf pine will be reviewed for each of these three elements—science, empiricism, and WAGs.

SCIENCE UNDERLYING SHORTLEAF PINE SILVICULTURE

A number of elements of shortleaf pine silviculture that can be applied in restoration prescriptions are drawn from good scientific findings firmly accepted in the literature. One set of findings can be taken from existing science that was originally intended to support productive management of shortleaf pine for timber products. The other set has been developed largely in direct support of pine-grassland habitat restoration, of direct benefit to the endangered red-cockaded woodpecker but also of great value in bringing back a suite of associated species originally found in pine-bluestem woodlands.

Planting Shortleaf Pine for Restoration

If a restoration decision is made to reforest or afforest a site with shortleaf pine where no natural seed source is available, the most direct approach is to use artificial regeneration. The science that supports artificial shortleaf pine regeneration is well established, largely through the actions of the shortleaf pine artificial regeneration task force of the late 1980s and reviewed elsewhere in these proceedings (Barnett and Brissette, this volume). In a nutshell, planting works well with shortleaf pine, especially when incorporating advances in seed and seedling quality (Barnett 1992). Among the important considerations for success was development of target seedlings in the nursery that were larger than had been produced previously (Brissette and Carlson 1992), which is consistent with commonly-accepted general trends that point to greater success with larger planting stock for any number of pine and hardwood species in the South over the past decade.

A second key factor in successful plantation establishment on the Ouachita NF was the site preparation treatment of ripping or subsoiling, in which a vertical steel bar is used to essentially plow a furrow from 12 to 18 inches deep in the rocky hillside soil during the late summer of the year prior to planting. Data suggest that ripping alone increased seedling survival by 10 to 30 percent (Walker 1992), from roughly 50 percent to 80 percent. Ripping is typically used to ameliorate planting conditions in soils with a prominent fragipan, but Ouachita soils do not have fragipans. Inspection of the rips suggests why they might be effective. During the 6 months between ripping and planting, rainfall dislodges soil particles l from the sides of the furrow toward the bottom, a microcolluvial effect that fills the cracks and fissures in the base of the furrow with several inches of soil fines (Fig. 1a). The seedlings are then planted in that thin layer of soil. Subsequently, when temperature and drought stresses reach their maximum late in the summer during the first growing season, that small amount of soil in the furrow provides a rooting medium for the seedling that moderates extremes of temperature and soil moisture deficit compared with a seedling planted directly in these rocky soils (Fig. 1b). These conditions contribute greatly to reduced seedling mortality.

Restoration Prescriptions

The prescription applied to immature and mature shortleaf pine stands for restoration or recovery of shortleaf pine woodlands is essentially a series of intermediate treatments (sensu Smith and others 1997). Those treatments are intended to promote habitat favorable to the endangered red-cockaded woodpecker, with attendant benefits to a number of associated woodland flora and fauna (Fig. 2). Hedrick and others (this volume) summarize that work with a synthesis of empirical treatments needed to execute the prescription, and a summary of numerous studies that have quantified fire occurrence and treatment effects on flora and fauna (Masters and others 1995, 1996, 1998; Sparks and others 1998, Wilson and others 1995, Cram and others 2002) and related ecological, economic, and silvicultural effects (Huebschmann 2003, Thill and others 2004, Guldin and others 2005, Liechty and others 2005).

Figure 1a.—Ripping promotes first-year survival of planted seedlings through microcolluvial deposition within the rip. Ripped furrow shortly after being created in the summer prior to planting (photo by James M. Guldin).

Figure 1b.—Shortleaf pine seedling planted in the ripped furrow, in August of its first growing season (photo by James M. Guldin).

Figure 2.—Restored stand in the pine-bluestem restoration area on the Ouachita NF, Scott County, Arkansas (photo by James M. Guldin).

The key elements in this prescription, in order of implementation, are using tree cutting to simulate natural disturbance patterns, removing the midstory hardwoods that have encroached upon the stand in the absence of fire for the past seven decades, and increasing the use of prescribed fire (Bukenhofer and Hedrick 1997, Guldin and others 2005). The studies cited have all explored the separate or combined effects of the thinning, midstory reduction, and burning, and it appears that in practice all three treatments are required to consistently give best results.

Restoration Applications of Growth and Yield Models

Finally, there are opportunities in restoration prescriptions to apply existing growth and yield models, especially individual-tree models that generate stand tables by diameter class. This is not the first time that timber-based models of stocking and growth have been of use to ecologists, because they can be used to quantify biomass, snags, woody debris, and other tree-based attributes that can be efficiently modeled with an understanding of tree size. In the Ouachitas and southern Ozarks, the Shortleaf Pine Stand Simulator model (Huebschmann and others 1987) provides a first-rate tool to model the development of naturally regenerated shortleaf pine stands, whether even-aged (Lynch and others 1999) or uneven-aged (Huebschmann and others 2000). The model requires input of stem density by diameter class and gives users a tool to predict growth over different time horizons of different intensities of treatment.

While growth and yield models have traditionally been interpreted from a timber-based perspective, it is equally appropriate to use a model such as this to evaluate stand development alternatives under different levels of commercial thinning in a restoration prescription. Individual tree models generate stand and stock tables that contain data on diameter distributions in terms of stem density by size class. To apply growth and yield models in the context of restoration, foresters should quantify desired future conditions using stem density by diameter class, and then apply the growth and yield models to analyze the degree to which different treatments might develop the target diameter distribution. These models might be especially meaningful in prescriptions that seek to accelerate mean stand diameter growth past a minimum threshold in a managed old growth context, to calculate changes in volume over time if leaving living relicts or snags of a given size and density, and so on.

EMPIRICAL EVIDENCE SUPPORTING SHORTLEAF PINE SILVICULTURE

The creative application or extension of known silvicultural practices and refinement of new practices for restoration of shortleaf pine fall less into the realm of known science and more into the realm of well-founded empirical experience. Some of these empirical advances relate to using old authorities in new ways and under new interpretations. Others relate to no less than the practical development of new techniques by personnel in the field rather than by scientists in a lab or academic setting.

Reinvestment of Harvest Proceeds in Restoration Treatments

The example of old authorities being interpreted and applied in new ways to new situations is nowhere more apparent than on National Forest System lands. Here, the old authority was the Knutsen-Vandenberg (KV) Act of 1933, which allowed Forest Service land managers to reinvest a portion of the harvest proceeds in reforestation of harvested areas. The reinterpretation of the authorities under the KV Act to allow for not only reforestation but also for general improvement of forest stand conditions within the sale area has opened the door for KV funds to be spent on reforestation not only by artificial regeneration, but also by natural regeneration. In addition, activities undertaken to improve forest conditions such as treatments to promote specific habitat conditions have also come to be interpreted as within the scope of the KV Act.

This is important because the KV Act provides funds beyond those appropriated funds authorized for annual agency activities. Because of competing agency priorities for increasingly limited appropriated funds on an annual basis, it is difficult to achieve restoration goals over ecologically significant areas through reliance on appropriated funds alone. The concept of the KV Act is also meaningful to private landowners, whose sole source of funding for treatments they choose is frequently a reinvestment of harvest proceeds.

Nowhere has a more creative blending of these authorities been practiced than in the shortleaf pine-bluestem restoration prescription in the National Forests of the Interior Highlands, especially the activities under

Management Area 22 on the Ouachita NF (Bukenhofer and Hedrick 1997, Guldin and others 2005, Hedrick and others, this volume). The commercial thinning of shortleaf pine in the restoration prescription provides appropriations-strapped National Forests with KV-based funds to support follow-up midstory and burning treatments. Those treatments can then occur for a longer time (as much as 10 years for follow-up prescribed burning) and over a much wider geographic area than could be afforded using appropriated dollars alone. In essence, part of the value of the standing volume of shortleaf pine sawlogs in excess of that needed for restoration is used to fund the restoration prescription.

This management tactic works as well as it does in western Arkansas because of the continued presence of a strong and viable local lumber manufacturing industry in the region. A model of timber sales for the region shows that bids are correlated to both the volume of pine sawtimber offered in the sale and to the ratio of the prevailing dimension lumber price index to the sawlog price index, a factor affecting mill conversion opportunities in a given market (Huebschmann and others 2000). The existence and proximity of lumber mills that manufacture pine dimension lumber from pine sawlogs are a key elements to the success of this tactic.

Use of Prescribed Burning

Prescribed burning has increased dramatically on National Forest lands in the region, but few others on forest industry or private lands apply the technique. A wider use of prescribed burning on other land ownerships in the region is not likely to occur because of legal issues that surround liability for prescribed fire, the perception that burning results in some minor growth loss, concerns about smoke management, and a still-strong attitude within the professional community that fires should be controlled rather than set. Even within Federal ownership, burning can vary by district because of differences in planning, application, and commitment of district personnel to the effort.

Prescribed burning requires considerable expertise to employ effectively. Probably no element of silvicultural practice is more difficult to translate from the classroom to the woods. Much of the education obtained when using prescribed fire occurs when things do not go quite as planned. The accumulated wisdom of the professional and technical personnel who conduct this burning program is an invaluable asset for meeting the commitments required for effectively using this tool on a landscape scale.

As with many agencies, however, U.S. Forest Service personnel represent a graying workforce and the districts that employ them are increasingly on limited budgets. District professionals also have responsibility for larger areas than a decade ago because of the prevailing trend for consolidation of ranger districts over that period of time. Ideally, the tenure of the old, outgoing professional would overlap with that of the young, incoming professional, to allow for translation of some of the experience-based knowledge from predecessor to new employee. But that situation is nearly impossible to achieve under the budgets with which the agency is working. Consequently, retirements and changes of duty station often diminish the district's capability to maintain a prescribed burning program. The technicians often become the bridge, and they are graying also.

Reproduction Cutting Methods other than Clearcutting

The use of reproduction cutting methods other than clearcutting is on the rise on National Forest land in the Interior Highlands, a trend mirrored by the use of natural regeneration rather than planting for reforestation after reproduction cutting (Guldin and Loewenstein 1999). The shift away from clearcutting and toward methods of cutting that rely on natural regeneration was triggered by the Walk in the Woods on the Ouachita NF (Robertson 1999). Recent forest planning activities on the Ouachita NF, Ozark-St.Francis NF, and Mark Twain NF suggest that this trend will continue.

Research on reproduction cutting methods that rely on natural regeneration has not kept pace with the application of the practice. Interim results 5 years after reproduction cutting in the Ouachita Mountains Ecosystem Management Research Project (EMRP) suggest that all reproduction cutting methods can be made to work, but that some work better than others (Guldin and others 2004a, 2004b). Regeneration in the shelterwood stands has not yet been subject to damage commonly associated with the partial removal cut of residual overstory trees, nor has the regeneration in the uneven-aged stands experienced the subsequent cutting cycle harvest; both of these activities are known to cause mortality that in the long term might affect sapling survival. Moreover, this study was installed without the use of prescribed fire as part of the site preparation, and different results are expected in the presence or absence of prescribed fire when conducting reproduction cutting. To be useful on both public and private forest lands in the region, robust silvicultural tactics associated with reproduction cutting must be developed in situations where fire can be used, and also where it cannot be used.

The lag between research and practice is evident in the preference of practicing silviculturists to employ the seed-tree and group selection methods, which interim research results suggest might be less effective than the shelterwood and single-tree selection methods (Guldin and others 2004a, 2004b). Practicing silviculturists point to the advantage of using prescribed fire as a site preparation tool in seed-tree stands to prepare a seedbed for pine seedfall. They also suggest that administrative advantages of group selection relative to single tree selection include greater efficiency in (1) contracting site preparation and release treatments; (2) logging (groups serve as logging decks); and (3) retention of hardwoods for wildlife and aesthetic reasons in the matrix between the group openings. These elements suggest that research scientists have more work to do to better quantify regeneration dynamics and development under these popular methods for application, especially if there are some yet-to-be-answered questions about stocking and distribution of regeneration resulting from their application.

Shortleaf Pine Seedfall

An understanding of seed production in natural stands of shortleaf pine is important in managing for natural regeneration of the species, and recent work had added to our understanding of this. Shelton and Wittwer (1995) analyzed 9 years of shortleaf pine seedfall data collected in the 1960s to 1970s. The study suggested that three to five adequate or better seed crops per decade, with an average of 100,000 seed annually. There was considerable geographic variation in seedfall, with higher amounts in the eastern Ouachitas and lower amounts in the western Ouachitas. Seedfall was also positively related to stand age and negatively related to pine and hardwood basal area, suggesting that overstocking and competition inhibit crown expansion and cone production in the pine component. Wittwer and others (2003) reported on a more recent seedfall study within the Ouachita EMRP; over a four-year period, seed crops were good, poor, poor, and bumper, with differences by reproduction cutting method in the first good crop but not the last. Their results suggest a crown response in shortleaf pine to cutting methods that reduce canopy competition, which was also noted by Wittwer and others (1997) when comparing seed tree versus single-tree selection stands. In summary, these studies suggest that in shortleaf pine stands, especially those that have been thinned prior to harvest (but not late in the rotation), adequate or better seed crops sufficient to regenerate shortleaf pine can probably be expected in two of three chances when using the seed-tree method (Shelton and Wittwer 1995). The odds are longer farther to the west of the Interior Highlands.

The commonly used subjective empirical tools for seed prediction—such as cone counts with binoculars, or inspection of the crowns of pines harvested in logging jobs, during the summer before seedfall—do not allow foresters to predict an average or better seed crop in a given season more than a few months in advance, or to make plans to take advantage of a forecast for a good seed crop. For example, logging activity is known to scarify the forest floor, and the exposed bare mineral soil that results is an excellent seedbed for natural seedfall of southern pines (Baker and others 1996). But a forester will have only a few months between prediction of a bumper seed crop and the seedfall itself. On private lands with limited acreage, landowners or the foresters who advise them can often arrange a small timber sale on short notice in a stand where reproduction cutting is desired, so as to catch a predicted seed crop on the freshly exposed soil of the forest floor.

But silvicultural operations take place more or less continually on larger holdings such as national forest lands or forest industry lands, and there is less opportunity to tailor a silvicultural treatment to take advantage of an ephemeral window for seedfall. Provisions in timber sale contracts on national forests often allow a multi-year window (3 years is typical in the South) for completion of the harvesting; loggers are free to operate at any time within that window provided that conditions are appropriate for forest operations. Timber sale contracts can and often do specify the months during which operations can and cannot occur, so as to avoid detrimental impacts of harvesting at specific times of the year (such as during the breeding season for wild turkey). But those contracts cannot specify the exact year within the multi-year window of the contract that harvesting is to occur, and this inability makes it risky for a forester to rely on the silvicultural tactic of having natural seedfall occur immediately after a logging operation. The remedy is to plan for supplemental site preparation independent of the logging job, where we can better control the timing of the operations through contracts for specific treatments within a given year.

WAGS ABOUT SHORTLEAF PINE SILVICULTURE

There is no shortage of topics for advances to be made by silviculturists either in research or active management positions. Some of these opportunities for advancement transcend the Interior Highlands—such as managing mixed stands, especially those having a minor and varying pine component. Others are unique to shortleaf pine, including answers to basic questions about the biology and silvics of this species. The topics that are proposed are interesting in that if shown to be true, they might find wide application in developing and using silvicultural practices in shortleaf pine management and restoration.

The Natural Range of Loblolly Pine

There are curious elements about the natural range of loblolly and shortleaf pine that suggest ecologists and silviculturists have incompletely understood these species and the ecological circumstances and adaptations that govern their distribution. The northwesterly limit of the natural range of loblolly pine in the region coincides with the limit of the upper West Gulf Coastal Plain and the Athens Piedmont Plateau, where it is found as a dominant pine in stands having a minor and varying shortleaf pine component. There is some evidence to suggest that perhaps this mixture was dominated by shortleaf pine 70 years ago, mostly evident through the persistence of early forest scientists in the region referring to those Coastal Plain stands as “shortleaf-loblolly pine” stands (Reynolds and others 1944, Reynolds 1947).

Interestingly, the transition from mixed pine stands to pure shortleaf pine stands occurs within a range of about 20 miles, with a few scattered loblolly pine-dominated stands in transition. This is an unusually rapid ecological transition, which, while certainly influenced by the rise of the southern part of the Ouachita Mountains in that area, cannot be solely explained by the obvious actions of climate, weather, geology, flora, fauna, or humans. We might speculate that fire played a role, or ice storms, or anthropogenic burning prior to European colonization. While these factors might explain a gradual change across the Ouachitas generally, they do not explain the sharp transition that actually exists. If a causal ecological agent for this disappearance of loblolly from mixed pine stands could be elucidated and quantified, it might be of considerable ecological interest in the context of shortleaf pine restoration. It might also be possible to use that knowledge to develop silvicultural restoration tactics that favor shortleaf pine in stands that had been converted to loblolly pine by forest industry landowners, especially on that portion of the industry land base that has been reacquired by Federal land managers through purchase or exchange.

Advantages of the Sprouting Habit of Shortleaf Pine

The sprouting habit of shortleaf pine (Fig. 3) might be useful in silvicultural applications for natural regeneration in pure and mixed stands beyond that for which it is being used today. In an environment that features frequent surface fires, logic suggests that any given fire will result in topkilled seedlings that subsequently resprout, and might also create seedbed conditions favorable to germination of new seedlings. The sprouts and seedlings combine to create a new cohort that persists in the understory until a subsequent surface fire, which again promotes resprouts of the previous cohort as well as new germinants in the burned seedbed. Over time, this process of seedling establishment and resprouting after a series of fires should result in a bioaccumulation of pine seedlings and sprouts, constituting a stored seedling bank awaiting overstory disturbance to develop into the pine component of a new stand.

If properly applied, this stored seedling bank could make natural regeneration of shortleaf pine in managed pine stands more certain in any given year, even those in which an adequate or better seed crop is not expected. Applying late-rotation prescribed fire would be instrumental in development of the seedling bank. This prescription would be useful to circumvent the problems in seedfall timing promoted by the multi-year logging windows of modern timber sale contracts. It would be especially useful in the seed-tree method to circumvent problems of understocking due to limited seedfall.

In principle, this tactic might be applied to any of the even-aged or uneven-aged reproduction cutting methods used for natural regeneration. Several cycles of prescribed burning in properly-thinned stands prior to reproduction cutting would initiate the process. Executing the reproduction cutting would require suspension of the burning program for a cycle or two, so that the saplings could grow sufficiently so as not to be topkilled when prescribed fire is returned to the stand. This approach is being studied in the pine-bluestem management area on the Ouachita National Forest, and in a study of prescribed fire in seedling stands on the Ozark-St.Francis National Forest, as first steps in quantifying whether this bioaccumulation is silviculturally feasible.

Figure 3.—Shortleaf pine seedling sprouts emerging several weeks after the shoot was topkilled by a growing season prescribed fire, Ouachita NF, Scott County, Arkansas (photo by Richard Straight).

Mixed Pine-Oak and Oak-Pine Stands

Very little is known about the silvicultural practices needed to manage mixed stands of shortleaf pine and hardwoods in the region (Fig. 4). The fundamental premise in managing mixed stands is to use silvicultural practices that can be successfully applied for each of the species in the mixture, and to avoid those practices that discriminate against the species sought in mixture. Conceptually, the simplest approach to regenerating a mixed stand is to successfully

Figure 4.—A westerly view in the eastern Ouachita Mountains, Saline County, AR. The view illustrates the dominance of pines on south-facing slopes and the dominance of hardwoods on north-facing slopes in these east-west oriented ridges (photo by Rudy Thornton).

regenerate each of the species that are sought, and then to use individual-stem release treatments to adjust the proportions of species in the mixture to some desirable standard. This approach has been used in empirical practice on national forest lands, especially in pine-oak stands where pines are either planted or obtained through natural regeneration and where oaks are brought in through stump sprouts or advance-growth seedling sprouts.

Management of mixed oak-pine stands is more difficult because it is inherently difficult to regenerate just a few pines in a cohort dominated by oaks and other hardwoods. A stand being regenerated to hardwoods in the region is not likely to have a nearby pine seed source, either because pines may not be adapted to that particular site or because the pines that were adapted to that site may have been removed decades ago through partial cuttings. Nor has it been a traditional practice to plant just a few dozen pines per acre in a stand being regenerated to hardwoods. And even if a small number of pines were established naturally or by planting following a reproduction cut, they would be at a competitive disadvantage relative to sprout-origin hardwoods because sprouts grow more rapidly than seedlings.

If we accept the premise that mixed oak-pine stands were once common in the region and are no longer, and that efforts should be made to restore them, the silvicultural tactics for restoration of a minor pine component in an oak-hickory stand become of more than academic interest. To do so, we should separate establishment of pine seedlings and their development. Establishment will probably require direct silvicultural intervention, and development dictates using an advance growth strategy to promote the pines as well as the oaks.

To get pines established, we would rely on happenstance establishment of pine seedlings and on artificial regeneration. We might start by promoting the survival and growth of any pine seedlings or saplings that might exist in the stand understory. We would also plan to retain any existing natural seed sources in or adjacent to stands being regenerated in case seedlings appear through rare long-distance dispersal processes such as wind dissemination of seed over extraordinary distances, or through animal activity. And, we would probably work to successfully plant or underplant a few pines prior to or during harvest. But recommendations have yet to be established about planting density, pattern, or spacing. There might be some wisdom inherent in clustered planting of pines in a small multi-stem cohort such that pines in the center of the cohort would be subject only to intraspecific competition rather than the interspecific competition of hardwoods.

Further development of the mixed-species regeneration cohort through the sapling stage, especially in oak-pine mixtures, will certainly require individual-stem release treatment to obtain the desired proportion of oaks and pines in the mixed stand. Since we know so little about regenerating only a few pines in an oak-pine stand, we could always fall back on the most traditional silvicultural tactic based on practices intended to achieve pine dominance. Arguably, the most certain way of regenerating a small pine component in oak-pine stands is to aggressively work to establish a much larger number of pines than desired, and then aggressively kill most of them during a cleaning or release treatment. Admittedly, this is the costliest and least clever way to achieve this silvicultural objective, but it might serve as an interim measure until a better understanding of the natural oak-pine regeneration dynamic is obtained, which can then be emulated silviculturally.

The sprouting ability of shortleaf pine offers extraordinary potential along these lines also. This habit has much in common with the advance growth dynamic of oaks, and could possibly be developed as a legitimate pine-hardwood—or, more importantly, a hardwood-pine—regeneration prescription. The silviculture of oak requires planning for regeneration on the order of two decades in advance of harvest, with late-rotation thinning doubling as preparatory cutting and midstory removal of competing hardwoods required to promote advance regeneration of oaks (Johnson and others 2002, Loftis 1990). Adding prescribed burning to this prescription might be useful in promoting oak advance growth through topkilling and resprouting of seedling sprouts of oak. If a shortleaf pine seed source is available, some pines might be recruited and promoted in the mixed-species advance growth cohort. If no pines are present, and silviculturists seek a pine component in such a stand, they might be planted in conjunction with the prescribed fire program (such as immediately following or in the dormant season following a given fire, depending on when the burn is conducted) at whatever density the silviculturist seeks.

When this mixed-species regeneration cohort is ultimately released for recruitment into the overstory, the pines should respond much as do the hardwoods—which would give the pines a stronger competitive position with respect to the hardwoods than new seedlings would have, because they would have larger root systems built during their time as advance growth. Fine-tuning the mixture would also then be possible during precommercial release treatments 5 to 10 years after the initial overstory recruitment treatment (Fig. 5). Considerable research would be needed to precisely quantify the number, density, and timing of advance planting of shortleaf pine to attain given levels of shortleaf pine in mixture with hardwoods a decade or two after being released, especially for the oak-pine management objective. But using fire to deliberately trigger the topkill and resprouting would be consistent with the natural ecological dynamic for both pines and oaks, which seems not unlike the prevailing ecological influence in these forests in presettlement conditions.

Finally, there may be potential in retaining part of the pine overstory for an extended period of time. The straight-line and tornadic windstorms that periodically disturb pine stands in the Ouachitas occasionally leave a minor and varying overstory pine component on the site after the disturbance. Those escapees from the disturbance may have an important role in subsequent seeding of pines, and development of a mixed pine-hardwood regeneration component, over time. We might speculate that this new cohort might tend more to the pine component if fire had recently occurred in the understory prior to the wind event, to the hardwood component if fire had not recently preceded the windstorm, or again to the pine component if fire followed soon after the windstorm. The balance between use of fire to promote a mixed pine-hardwood regeneration cohort and the retention of pines and hardwoods as an older age cohort will be of interest to foresters in the 21st century, but much work remains to be done to better quantify these ideas.

CONCLUSION

Planting shortleaf pine will be required to restore the species on sites where it currently is not, such as abandoned agricultural or cutover land in the Interior Highlands. Ripping has been shown to be essential to improve survival of planted shortleaf pine. But the site-wide disturbance of the soil associated with ripping may be inconsistent with other restoration objectives, such as minimal disruption of the forest floor. Site preparation techniques must be developed that have the advantages of ripping for seedling survival but not the adverse effects on the forest floor throughout the stand. It seems that a localized soil disturbance of 3 feet or less in size might achieve the same advantages as ripping in microcolluvial soil deposition, and might better emulate a common natural soil disturbance event in nature—the uprooted root ball of a windthrown tree. Proper development of this site preparation treatment would also offer potential for localized collection of water, which might be useful for local populations of herpetofauna as well.

Figure 5.—A precommercially-thinned regeneration cohort beneath a shortleaf pine shelterwood in Scott County, Arkansas. The deliberate objective was to release both pines and oaks to promote a mixed pine-hardwood regeneration cohort (photo by Richard Straight).

The treatments associated with the shortleaf pine-bluestem restoration prescription to convert immature and mature second-growth shortleaf pine stands to pine-bluestem woodlands have to date relied upon the use of cutting and burning to remove the midstory hardwoods that built up in the stand through the period of fire exclusion over the past seven or so decades. But chainsaw felling and restoration of cyclic prescribed fires have not been sufficient to remove the rootstocks of those midstory hardwoods, and sprout clumps associated with those rootstocks persist in restored stands though multiple prescribed fires (Fig. 6). A more complete removal of these stems might be possible using herbicides

Figure 6.—A stand that meets the goals of pine-bluestem restoration in the western Ouachita Mountains growing seasons after prescribed burning, Scott County, Arkansas; hardwood resprouting is prominent (photo by Richard Straight).

that target mortality of the entire plant, not just the above-ground part. Herbicide use admittedly is unpopular on Federal ownerships, but there might be a place for limited stem-specific applications such as when the initial midstory removal treatment is implemented. More information is needed as to different qualities of understory condition in the presence or absence of these resprouting rootstocks to make better decisions about whether to remove them with unpopular herbicide prescriptions. That information could be especially useful in extending the restoration to private lands, where a carefully timed herbicide application might be less constrained than on public forest land.

Successful restoration over a broad area requires a thriving local timber industry. No doubt some might feel this is oxymoronic, but strong mill capacity and a regional market for pine sawtimber create opportunities for national forest land managers to provide commercial timber for sale; they can then use some of the profits from those sales to restore larger areas of a landscape than would be possible without those markets. Interestingly, many of these mills also purchase sawtimber from adjacent forest industry lands, which can in part provide alternative sources of supply for those mills when sales on national forest land become limiting. Thus, an intermingled ownership that allows local sawmills to buy timber from private lands when national forest timber sales are periodically limited may also be a positive element that promotes large-scale habitat restoration on the federal land base in the region.

Silviculture has been defined as both an art and a science, and there is probably no element of the body of silviculture more characteristic of the art than the application of prescribed burning as an intermediate treatment and in reproduction cutting. Efforts should be developed, perhaps through cooperation with state forestry or heritage agencies and conservation organizations, to develop regional prescribed fire training academies in the Forest Service that would provide some of the practical experience that seems to be more critical in application of burning than any other silvicultural practice. The staff of the academy could in part be composed of recent retirees from these agencies experienced in the use of the tool, and rehired to work in the incident command structure for wildfires and disaster response.

The broad set of reproduction cutting methods imposed in the Ouachita Mountains EMRP was constrained by their size and breadth of scope. The influence of prescribed fire on pine seedling recruitment and on the balance of regeneration through sprouting and new seedlings must be understood. Research should concentrate on the full spectrum of mixed-species stand dynamics as well, with efforts to quantify the effect of supplemental pine planting in advance of harvest under a burning program for goals of restoring both pine-hardwood and hardwood-pine stands on appropriate sites. An advance-growth seedling bank approach to shortleaf pine silviculture offers tremendous opportunity for silvicultural application in pure and mixed stands, and provides tactical advantages in simplifying regeneration establishment and development under the uncertainty of shortleaf pine seed crops and the timing of harvesting operations.

ACKNOWLEDGMENTS

Thanks to the many research foresters and resource managers in both the public and private sectors who have been willing to entertain abstract discussions about shortleaf pine ecology and silviculture over the years, including Jim Baker, Mike Shelton, Tom Foti, Louis Rainey, Gary Arpin, Ernest Lovett, Gerald Heath, John Strom, Ray Yelverton, Bill Walker, John Andre, and Larry Hedrick. Thanks also to Eric Zenner, whose review comments helped to markedly improve this paper.

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SUCCESSIONAL TRENDS OF SIX MATURE SHORTLEAF PINE FORESTS IN MISSOURI

Michael C. Stambaugh and Rose-Marie Muzika[1]

ABSTRACT.—Many of Missouri's mature oak-shortleaf pine (*Quercus-Pinus echinata*) forests are in a mid-transition stage characterized by partial pine overstory, limited pine recruitment, and minimal pine regeneration. Restoration of shortleaf pine communities at a large scale necessitates the understanding and management of natural regeneration. To understand late-successional conditions of shortleaf pine forests, we conducted a complete survey of woody vegetation and canopy openings at six uncut and old second-growth oak-pine stands in southeastern Missouri. A total of 121 canopy gaps were mapped and measured in terms of their size, age, and vegetation structure. Shortleaf pine was a common canopy replacement tree along with black oak (*Quercus velutina*), white oak (*Quercus alba*), and hickories (*Carya* spp.). The abundance of shortleaf pine appears to be diminishing, however, owing to the absence of shortleaf in understory and regeneration layers. The resulting forest probably will consist almost exclusively of hardwoods. Shortleaf pine regeneration in canopy openings was limited by aspect, seed source, and litter depth. In addition to their current conditions, information from these forests provides insight into the future development and management needs of younger oak-pine communities. In forests where regeneration and recruitment of shortleaf pine are lacking, restoration efforts require timely action because the overstory seed source is crucial to preserving the shortleaf pine component. These findings contribute to an understanding of shortleaf pine forests, and can ultimately determine restoration and management guidelines for shortleaf pine forests in the Missouri Ozarks.

INTRODUCTION

Although historic evidence suggests that oak-shortleaf pine (*Quercus-Pinus echinata* Mill.) forests of the Ozark region were strongly influenced, if not perpetuated, by recurring fires for at least 300 years prior to the 16th century (Masters and others 1995, Guyette and others 2002, Guyette and others 2006), contemporary policies and logistics often reduce the occurrence of burning. This situation is an important issue to the conservation of many fire adapted species, including shortleaf pine. In general, the disturbance regime of shortleaf pine forests has changed from one that included fire to one that primarily excludes fire and is represented by small-scale events (Stambaugh and others 2002) that result in canopy gap openings. In an attempt to understand the effects of these changes on species composition and forest succession, we examined canopy gap disturbances and forest stand dynamics of six representative uncut and old second-growth oak-shortleaf pine forests. Our objectives were to: 1) describe the current overstory composition, 2) characterize and quantify the frequency of canopy gap disturbances, and 3) identify trends in vegetation development within canopy gaps, specifically addressing the potential for shortleaf pine regeneration and recruitment to the overstory.

METHODS

Study Site Descriptions

Study sites were located throughout the Ozark Highlands region of southeastern Missouri in an area that occurs within the natural shortleaf pine range (Liming 1946). Investigations were conducted at the Eck Natural Area, Alley Spring, Indian Trails Conservation Area, Greer Spring, and two sites on the Mark Twain National Forest—one near the town of Bixby and another near Slabtown (Table 1). Detailed descriptions of study areas were presented in Stambaugh (2001). Study sites were selected non-randomly due to the limited availability of shortleaf pine forests exhibiting late-successional forest characteristics. Guidelines for selecting study sites were:

1. Average age of dominant overstory shortleaf pines > 100 years
2. Forested area greater than 10.1 hectares
3. A minimum of 25 percent overstory composition in shortleaf pine
4. No apparent anthropogenic disturbances, i.e., logging operations or prescribed burning
5. Some evidence of canopy gap disturbances, as reflected in a multi-structured canopy

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[1] Senior Research Specialist (MCS), Department of Forestry, University of Missouri-Columbia, Columbia, MO 65211; and Associate Professor (R-MM), Department of Forestry, University of Missouri-Columbia, Columbia, MO 65211. MCS is corresponding author: to contact, call (573)882-8841 or email at stambaughm@missouri.edu

Data collection

Canopy gap sampling was conducted during 1999 and 2000 in accordance with guidelines established by Runkle (1992), with modification. All gaps were located by systematically traversing the study sites. Canopy gaps were defined as the opening in the overstory forest canopy caused by the death of 1-10 trees. All observed canopy gaps 6 years old and less were sampled; therefore the data represent a complete "inventory" of gaps for each site. For each gap, measurements taken included gap size, gap maker(s) (i.e., trees that formed the gap), gap age, woody species, litter depth, and trees adjacent to the canopy opening. Expanded gap size was measured as the distance across the length and width of the gap to and from the boles of the trees surrounding the gap. Gap size was determined using the area of an ellipse. Using these data, we calculated rotation interval by summing the entire area in gaps, and dividing by six (the number of years in which gaps were considered) to create an annual gap area. Annual gap area was then divided into the total area of the site to determine the rotation interval. Rotation interval represents the number of years required for the entire area to be replaced by canopy gaps (i.e., disturbance frequency).

Basal increment cores were taken from at least one understory shortleaf pine > 1.37 m in height in each gap. Increment cores from various trees within the canopy gap provided an accurate determination of gap age and were used in analyzing recruitment years, growth rates, and the potential for shortleaf pine recruitment to the overstory.

Vegetation Sampling

At randomly determined distances (between 150 and 300 m) along transects, the overstory was sampled using the point centered quarter method (Cottam and Curtis 1956). The nearest live tree to plot center that was > 25 cm diameter at breast height (DBH) was measured in each quadrant. The tree species, DBH (to the nearest 0.1 cm), and horizontal distance from plot center to the center of the stem (to the nearest 0.1 m) were recorded. Importance values were calculated by summing the relative density, frequency, and dominance values (i.e., basal area) for each tree species.

In canopy gaps all woody stems > 1.37 m in height occurring within the expanded gap area were considered to be in the understory; stems were identified by species and recorded in 2 cm diameter classes. The tallest individuals were considered the most probable gap replacements if the individual tree had at least 20 percent live crown ratio and was well positioned within the canopy opening. Replacement tree species were noted, and DBH measurements (to the nearest 0.1 cm) and height measurements (to the nearest 1 m) were made. If the replacement tree was a shortleaf pine, a basal core was taken to determine age and growth rate.

All woody stems < 1.37 m in height occurring within the expanded gap area were considered to be in the regeneration layer, and four 1-m^2 circular regeneration subplots were located equidistant between gap center and the expanded gap edge in the four cardinal directions. Within subplots all woody species were tallied. Additionally, a one-minute timed count was used to determine the number of pine seedlings occurring in both the southern and northern half of the expanded gap area in order to quantify pine regeneration in gaps. The average litter depth of subplots was measured (four measurements per subplot) to the nearest cm from the top of the O horizon to the top of the litter. The percentage of the forest floor covered in leaves, needles, and exposed area was estimated for the ground surface of the expanded gap area.

RESULTS AND DISCUSSION

Gap Dynamics and Canopy Gap Characteristics

Across all six sites, we identified 121 gaps, and the Eck Natural Area had the greatest number of canopy gaps of any site (n = 48) as well as the greatest mean gap size (table 1). The Alley Spring site had the greatest area in gaps (522 m^2 ha^{-1}). Gap sizes were normally distributed at the Eck Natural Area and gaps constituted 4.0 percent of the total area. Mean gap size was 421 m^2 and sizes ranged from 104 - 1583 m^2. Unlike other sites, the Eck Natural Area had a relatively high number of gaps > 500 m^2. Canopy gap ages showed increasing frequency from recent gaps to gaps 6 years old. The majority of the identified canopy gaps at Eck Natural Area were created during 1993 and 1994. At the Alley Spring site, 28 canopy gaps were identified, accounting for 5.2 percent of the total area. Mean gap size was 322 m^2 and sizes ranged from 105 to 847 m^2.

Indian Trails, Greer Spring and Bixby each had nearly the same area in gaps, although we identified 13, 9, and 9 gaps respectively from these three sites. Canopy gaps constituted 1.6 percent of the total forested area at Indian Trails, Greer Spring, and Bixby. At Indian Trail, mean expanded gap size was 247 m^2 and sizes ranged from 87 to 394 m^2. Mean expanded gap size for Greer Spring was 323 m^2 and sizes ranged from 261 to 419 m^2, therefore generally larger than at Indian Trail. At Bixby, mean expanded gap size was 241 m^2 and gap sizes were more variable than at any other site, ranging from 15 to 404 m^2.

Fourteen canopy gaps were identified from the Slabtown site, constituting 1.8 percent of the total area or 186 m^2 ha^{-1}. Mean expanded gap size was 148 m^2 and sizes ranged from 30 to 280 m^2. Despite its proximity to the Eck Natural Area (~4 km) the relative abundance of gaps from year to year showed no similarities between the two sites. Patterns of gap formation may be strongly autogenically controlled and influenced by local weather patterns.

Gap rotation ranged from 115 years to 385 years. Alley Spring site had the lowest value and thus would completely regenerate via gaps in 115 years. Eck Natural Area would regenerate in 152 years. Our estimates indicate that Slabtown would regenerate in 323 years, Greer Springs and Bixby in 377. Indian Trails has the most protracted turnover rate. Although calculated, rotation interval represents a theoretical successional timeframe. Variation in disturbance or stochastic events can alter the rotation interval. Since canopy gaps are evident for less than about 10 years in these sites, a decadal rotation interval recalculation would provide greater predictability of stand dynamics.

Table 1.—Study site characteristics, overstory composition, canopy gap replacement trees, and percentage of trees species regenerating in gaps.

Site	**Eck NA**	**Alley Spring**	**IndianTrails**	**Greer Spring**	**Bixby**	**Slabtown**
Area (ha)	50.8	17.2	19	18.3	13.6	11.1
Forest Age (~years)	320	200	125	120	160	150
Canopy gaps (n)	48	28	13	9	9	14
Area in gaps (m^2 ha^{-1})	405	522	156	159	159	186
Mean gap size (m^2)	421	322	247	323	241	148
Rotation interval (yrs)	152	115	385	377	377	323
Overstory species importance values						
Pinus echinata	94.7	93.3	210.1	65.5	71.9	93.3
Quercus velutina	79.3	37.6	37.7	58.2	39.7	82.3
Q. alba	54.5	70.2	32.5	57.2	68.4	57.3
Q. stellata	26.1	40.5	11.9	0	0	28.4
Q. rubra	18.6	0	7.8	0	0	10.1
Q. coccinea	0	22.3	0	34.8	116.2	0
Carya tomentosa	0	0	0	28.5	0	0
C. texana	0	0	0	0	3.8	0
Gap replacement trees: sum of trees in all gaps (total number of gaps)						
Pinus echinata	43 (19)	15 (10)	11 (5)	0 (0)	5 (4)	5 (3)
Quercus velutina	34 (24)	9 (9)	11 (7)	1 (1)	2 (2)	2 (2)
Q. alba	44 (22)	5 (4)	16 (9)	6 (6)	10 (7)	5 (5)
Q. stellata	5 (4)	2 (2)	0 (0)	1 (1)	0 (0)	0 (0)
Q. rubra	5 (4)	3 (2)	2 (1)	1 (1)	0 (0)	0 (0)
Q. coccinea	0 (0)	6 (5)	1 (1)	0 (0)	4 (4)	0 (0)
Carya spp.	31 (20)	10 (7)	0 (0)	3 (3)	0 (0)	10 (8)
Acer rubrum	1 (1)	0 (0)	2 (1)	0 (0)	0 (0)	0 (0)
Ulmus spp.	4 (2)	1 (1)	0 (0)	1 (1)	0 (0)	0 (0)
Percentage of regeneration by tree species in all gaps						
Pinus echinata	12.9	0	0	0	0	11
Quercus velutina	16.4	13.6	16.1	10.1	17.4	14.7
Q. alba	13.3	8.1	10.8	0	0	16.6
Q. stellata	0	0	17.2	0	0	0
Q. coccinea	0	0	0	0	12.8	0
Carya spp.	0	13.3	0	8.3	9.3	0
Acer rubrum	0	0	0	17.4	22.1	14.7
Sassafras albidum	19	20.4	8.6	10.1	16.3	15.3
Cornus florida	12.3	13.6	20.4	14.7	0	0
Prunus serotina	0	0	0	8.3	0	0

Vegetation Structure – Existing Overstory

The five most important overstory species at the Eck Natural Area site, in order of importance, were shortleaf pine, black oak (*Q. velutina* Lam.), white oak (*Q. alba* L.), post oak (*Q. stellata* Wangenh.), and northern red oak (*Q. rubra* L.) (Table 1). Although shortleaf pine made up almost 1/3 of the total importance values (IV), as a group, the oaks comprised the majority (IV = 59.5). The average DBH of overstory trees was 38.2 cm and the largest individual was a black oak at 89.0 cm DBH. The majority of the trees were between 26 and 40 cm DBH. Shortleaf pine was the most abundant species at the site followed by black oak. Shortleaf pine was the most abundant species in the 25 to 40 cm DBH class, and the largest individual was represented in the 55 cm DBH class.

The five most important overstory species at the Alley Spring site, in decreasing order of importance, were shortleaf pine, white oak, post oak, black oak, and scarlet oak (*Q. coccinea* Muenchh.) (Table 1). As with the Eck Natural Area site, shortleaf pine comprised almost 1/3 of the total importance values, but the oak group made up the majority of total IV. Average DBH of the overstory trees was 41.4 cm and the largest individual was a 75.0 cm DBH white oak. Shortleaf pine was the most abundant species at the site, followed by white oak was. The bell-shaped diameter distribution of shortleaf pine (Fig. 1) suggests that recent recruitment to the overstory is less than historical.

At Indian Trails, the overstory consisted only of shortleaf pine, black oak, white oak, post oak and northern red oak. Shortleaf pine was clearly dominant at the site comprising over 2/3 of the total overstory importance values, and black oak was second in abundance. Average size of the overstory trees was 40.7 cm DBH and the largest individual was a 60.8 cm DBH black oak. The most abundant species across all size classes was shortleaf pine and its diameter distribution was somewhat bell-shaped (Fig. 1) with its greatest abundance occurring in the 40 cm DBH class.

The five most important overstory species at the Greer Spring site, from most to least important, were shortleaf pine, black oak, white oak, scarlet oak, and mockernut hickory (*Carya tomentosa* [Poir.] Nutt.) (Table 1). Similar to the Eck Natural Area and Alley spring sites, shortleaf pine was the most important species, but oaks constituted a majority (IV = 50.1 percent). Average size of the overstory trees was 38.3 cm DBH and the largest individual was a white oak at 74.7 cm DBH. The bell-shaped overstory distribution of shortleaf pine was best represented by the 35 cm DBH class (Fig. 1).

Scarlet oak dominated the Bixby site and comprised over 1/3 of the total importance values (Table 1). Shortleaf pine, white oak, black oak, and black hickory followed in importance. As a group, oaks accounted for nearly 75 percent of IV totals. Average size of the overstory trees was 34.3 cm DBH and the largest individual was a 55.6 cm DBH white oak. Shortleaf pine had the highest abundance in the smallest DBH class (Fig. 1), and its abundance decreased sharply until the 40 cm DBH class, above which it was absent.

The five most important overstory species at the Slabtown site, listed from most to least important, were shortleaf pine, black oak, white oak, post oak, and northern red oak (Table 1). Similar to the Eck Natural Area, Alley spring, and Greer spring sites, shortleaf pine made up almost 1/3 of all importance values, however oaks made up the majority of all importance values (59.4 percent). Average size of the overstory trees was 35.1 cm DBH and the largest individual was a white oak at 61.7 cm DBH. Shortleaf pine was the most abundant species in the smallest size class and its diameter distribution resembled a reverse J-shape (Fig. 1).

Vegetation Structure – Canopy Gap Understory and Regeneration

Eck Natural Area

Shortleaf pine was the most abundant gap replacement tree species at the Eck Natural Area followed by white oak and black oak; however, black oak occurred in more canopy gaps than did any other species (Table 1). Other overstory trees that occurred in gaps included hickories (*Carya* spp.), black tupelo (*Nyssa sylvatica* Marsh.), post oak, and elm (*Ulmus* spp). Post oak and shortleaf pine both showed somewhat bell-shaped diameter distributions (Fig. 1), suggesting that levels of current recruitment to the overstory are reduced compared to historical levels. Shortleaf pine exhibited the greatest number of stems in the 2- to 12-cm DBH classes. White oak had the second highest abundance in the smallest diameter class of all other tree species. Both white oak and black oak showed an approximately 75 percent reduction in stem density from the 0- to 2-cm DBH class with stem density from the 2- to 12-cm DBH class was relatively consistent.

Regenerating tree species at the Eck Natural Area included sassafras (*Sassafras albidum* Nees and Eberm.), black oak, white oak, shortleaf pine, and flowering dogwood (*Cornus florida* L.) (Table 1). Sixteen other species accounted for the remaining 26.1 percent of the regeneration.

Pith dates of shortleaf pines occurring in canopy gaps at the Eck Natural Area site were concentrated around the years 1935 to 1950, an era following the Dust Bowl and corresponding with a significant reduction in state-wide wildland fire occurrences. Shortleaf pine establishment in gaps decreased gradually both prior to and following this period. Other than one individual, no pines dated prior to 1920 or after 1965. The average diameter and height of understory shortleaf pines that were recruiting to canopy openings was 10.1 cm DBH and 13.6 m, respectively.

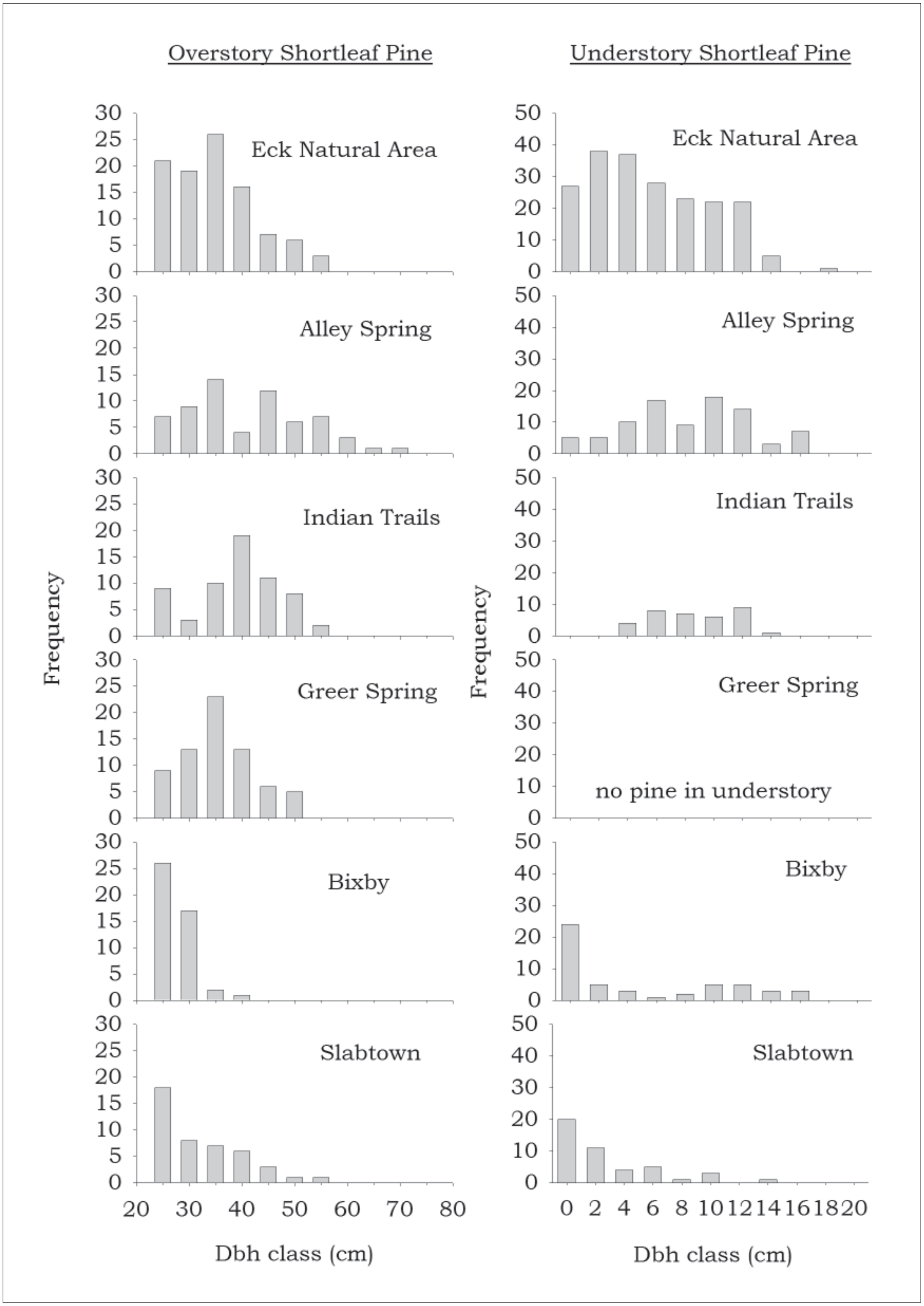

Figure 1.—Diameter distributions of shortleaf pine in the overstory (left column) and understory (right column) of the six study sites. DBH classes begin with the label value.

Average age of these trees was 59 years old and ranged from 38 to 80 years, with the exception of one individual at 147 years old. Twelve of 31 understory shortleaf pines cored showed a growth release due to canopy gap disturbances. Released trees occurred in canopy gap sizes that ranged from 200 to 700 m^2 in size.

Alley Spring

The most abundant species in the understory of canopy gaps of Alley Spring were hickories, black tupelo, shortleaf pine, white oak, scarlet oak, black oak, and elms. This is the same suite of species that was identified at the Eck Natural Area site but with the addition of scarlet oak. Similar to the Eck Natural Area site, shortleaf pine's abundance was characterized by a bell-shaped distribution. It was the most abundant gap replacement tree species, followed by hickories and black oak (Table 1). Shortleaf pine was also found in more gaps than any other species, though it was absent from the regeneration.

At Alley Spring, sassafras, flowering dogwood, black oak, hickories, and white oak (Table 1) were present as regeneration in gaps. Twenty-two other tree species accounted for the remaining 31 percent of regenerating tree species identified at Alley Spring.

Pith dates of shortleaf pines occurring in canopy gaps were most frequent during 1925 and 1935 and all understory pines sampled were established between 1915 and 1955. The bell-shaped diameter distribution (Fig. 1) and pith dates were similar to those from the Eck Natural Area, again suggesting a recent decrease in pine regeneration or successful recruitment to the understory. The average age of understory pines was 55 years and ranged from 31 to 84 years. Annual growth rates of understory pines ranged from 0.02 to 6.77 mm/yr and the average annual growth rate was 1.00 mm/yr, an extremely slow growth rate compared to its potential. Six of 24 understory shortleaf pines cored showed growth releases as result of the canopy opening and these trees occurred in gaps ranging from the 200 to 500 m^2.

Indian Trails

The most abundant tree species occurring in the understory of canopy gaps at the Indian Trails site were red maple (*Acer rubrum* L.), hickories, black tupelo, shortleaf pine, white oak, black oak, and post oak. Shortleaf pine and post oak diameter distributions were similar to those at the Eck Natural Area and Alley Spring sites. White oak and black oak showed bimodal distributions. Overall, black oak was the most common species found in canopy gaps at the Indian Trails site. Post oak, with a similar distribution to shortleaf pine, was represented by increasing abundance from the 0- to 10-cm DBH class with the majority of the stems occurred from the 6- to 10-cm DBH classes. White oak was the most abundant gap replacement tree species (n = 16) followed by shortleaf pine and black oak (n = 11) equally. White oak was found in more gaps than any other species followed by black oak and shortleaf pine (Table 1).

The most abundant regenerating tree species in canopy gaps at the Indian Trails site, listed from most to least abundant, were flowering dogwood, post oak, black oak, white oak, and sassafras (Table 1). Five other species comprised the remaining 26.9 percent of regenerating tree species identified. The diameter distribution of understory shortleaf pine was bell-shaped (Fig. 1) with no individuals recorded in the 0- to 6-cm DBH class.

Greer Spring

Shortleaf pine was absent as a gap replacement species in canopy gaps at Greer Spring. Red maple, sugar maple (*A. saccharum* Marsh.), hickories, black tupelo, white oak, northern red oak, and elm spp. were common. The dominance of mesic species such as red maple and sugar maple and the absence of shortleaf pine (Fig. 1) and post oak in canopy gaps distinguish this site from the others. Black tupelo showed the greatest abundance in the smallest diameter class; red maple and hickory had similar, yet smaller abundance. White oak was the most abundant gap replacement tree species followed by hickories.

The five most abundant regenerating tree species in canopy gaps at Greer Spring, listed from most to least abundant, were red maple, flowering dogwood, sassafras, black oak, and hickories and black cherry (Table 1). Twelve other species comprised the remaining 31.1 percent of the regenerating tree species.

Bixby

Red maple, hickories, black tupelo, shortleaf pine, white oak, scarlet oak, and black oak were the most commonly occurring species in canopy gaps at the Bixby site (Table 1). Shortleaf pine and white oak distributions were somewhat bimodal, both showed greatest abundance at the 0- and 6- to 10-cm DBH range. With the exception of species occurring only in the understory, red maple was the most abundant, followed by hickories and shortleaf pine. White oak and shortleaf pine were the only species represented in all DBH classes and they were the first and second most abundant species in diameter classes > 6 cm DBH. White oak was the most abundant gap replacement tree species, followed by shortleaf pine, scarlet oak, and black oak (Table 1).

The five most abundant regenerating tree species in canopy gaps at the Bixby site, listed from most to least abundant, were red maple, black oak, sassafras, scarlet oak, and hickories (Table 1). Five other species comprised the remaining 22.1 percent of regenerating tree species identified.

Pith dates of shortleaf pines occurring in canopy gaps of the Bixby site were most abundant in the 1940s, though only

10 trees were sampled from the understory layer because of the small number of gaps. Average age of shortleaf pines in the understory was 55 years. The abundance of pine regeneration was greatest between 1930 and 1940, as with the Eck Natural Area and Alley spring sites. No pith dates were represented prior to the 1930 class. Annual growth rates of understory shortleaf pines ranged from 0.03 to 3.66 mm/yr and the average annual growth rate was 0.96 mm/yr. Two of nine understory shortleaf pines cored showed growth releases as result of the canopy gap opening. Both trees were located in gaps with areas of 100 m^2.

Slabtown

The most abundant tree species occurring in the understory layer in canopy gaps at the Slabtown site were red maple, hickories, shortleaf pine, white oak, black jack oak, black oak, and elm species (Table 1). This site is the only one to include black jack oak among the seven most abundant overstory tree species occurring in the understory of gaps; its presence is indicative of a site with dry, sterile soils (Harlow and others 1991). Diameter distributions were somewhat similar for all species; and hickories, shortleaf pine, black jack oak, and elm species. were represented by a reverse J-shaped distribution. Hickories were the most abundant gap replacement species, followed equally by shortleaf pine and white oak (Table 1). Hickories were found in more gaps than were any other species (n = 8), followed by white oak (n = 5) and shortleaf pine (n = 3).

The five most abundant regenerating tree species in canopy gaps at the Slabtown site, from most to least abundant, were white oak, sassafras, black oak and red maple, and shortleaf pine. Thirteen other species comprised the remaining 27.7 percent of the regenerating tree species identified.

The greatest number of pith dates of shortleaf pines in canopy gaps at Slabtown occurred in the 1970 class. Average age of shortleaf pines in the understory of canopy gaps was 43 years. The oldest pith date was represented in the 1890 class and the youngest in the 1980 class. Pith dates occurring in the last 30 years were more common at the Slabtown site than at any other site. Pith dates of shortleaf pines at the Slabtown site were represented during the years of common regeneration at other sites (1930 to 1940); however, the greatest number was from 1960 to 1975. Annual growth rates of understory shortleaf pines ranged from 0.03 to 3.91 mm/yr and the average annual growth rate was 0.90 mm/yr. Two of 12 understory shortleaf pines cored showed growth releases as result of the canopy gap disturbance. Released understory shortleaf pines occurred in gaps with areas of 200 m^2.

Shortleaf Pine Regeneration

Shortleaf pine regeneration was absent from all canopy gaps at four of the six study sites. Despite the presence of shortleaf pine in the overstory, the two sites with shortleaf pine regeneration had a substantial component of black oak, white oak, and, in one case, red maple regeneration. Sassafras and flowering dogwood were abundant in the regeneration layer and likely imparted competitive effects (e.g., shading, resource competition) on shortleaf regeneration. Interestingly, several of these species (e.g., sassafras, flowering dogwood, red maple) are very fire intolerant and could be effectively reduced through prescribed burning.

Gap size is likely one of the most important variables controlling pine regeneration. We observed that the maximum number of shortleaf pine seedlings regenerating can increase by approximately eight times from smaller (e.g., 400 m^2) to larger (1700 m^2) canopy openings (Stambaugh and Muzika 2004). Larger gaps likely increase the potential for shortleaf pine regeneration because there is lowered leaf area, increased light, less leaf litter limiting seedling establishment, and increased temperatures at the forest floor that perhaps accelerate litter decomposition and minimize damping-off (Liming 1945). Certainly, an important consideration for regeneration is the presence of available seed trees. Seedling abundance in subplots increased with the number of overstory pines surrounding the canopy gap. The average number of pine seedlings increased by approximately three seedlings per 100 m^2 as the number of overstory shortleaf pine trees surrounding the gap increased from zero to one tree. Additionally, the average number of shortleaf pine seedlings per 100 m^2 increased by approximately nine seedlings as the number of overstory shortleaf pine trees surrounding the gap increased from two to three trees.

Shortleaf pine regeneration was highest near azimuth of 200 degrees (SSW) and decreased consistently as aspects deviated from 2000 (Fig. 2). The majority of shortleaf pine regeneration occurred on aspects between 150 to 2600 (e.g. south southwest to west), and no regeneration occurred between approximately 325 and 1100 (north northwest to northeast). Outlying regeneration data were fit to a third-order polynomial to show the potential bound of regeneration by aspect (Fig. 2).

Litter depth plays an important role in limiting shortleaf pine regeneration (Grano 1949). Shortleaf pine seedlings were found on litter depths of 0 to 6 cm and the greatest abundance of shortleaf pine regeneration was found on a litter depth of 2.5 cm (Fig. 3). The number of regenerating pine seedlings continually decreased as litter depth increased from 2.5 to 6 cm. No pine regeneration was found in subplots where litter depths exceeded 6 cm, and the type of litter was not found to be important.

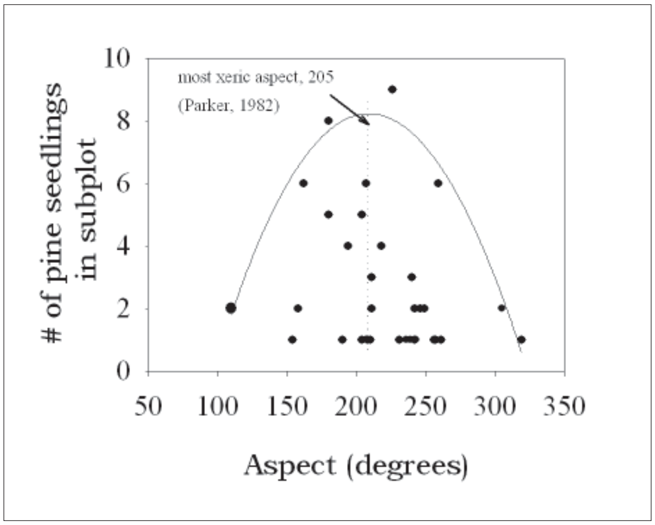

Figure 2.—Shortleaf pine seedling abundance and aspect of the subplots. Data are from all sites combined. The polynomial line was fit to outlying regeneration points to show the potential bound of regeneration across subplots.

Shortleaf Pine Recruitment

The relationship between diameter and height was analyzed for shortleaf pines occurring in the understory layer of canopy gaps. For trees from all sites that were probable gap replacements, a positive linear relationship existed ($r^2 = 0.72$; $p < 0.01$). The size of gap-replacing trees was variable, depending on the size of all other competitors. For this reason the variability in trees sizes was large ranging from 1.7 to 24.9 cm DBH and from 2 to 17 m in height. Nongap-replacing trees showed a diameter-height relationship similar to gap-replacing trees up to about 10 cm DBH or 10 m in height. Few nongap-replacing pines were represented above this size.

Shortleaf has the potential to persist in the understory for long periods of time (e.g., 80+ years) (Stambaugh 2001). Many of these trees have weak epinastic control as result of a prolonged suppression beneath high shade (Oliver and Larson 1996) resulting in “crooked” or flat tops. Much of the understory shortleaf pine observed in canopy gaps originated between 1930 and 1955. An informal survey of many more understory pines throughout the Ozarks found similar periods of origin and growth form (Stambaugh, unpublished data). Not only was this period relatively dry, but it also corresponded with extensive burning. Ring-widths of shortleaf pine trees growing in gaps were about 1 mm/year on average. This rate is extremely slow compared to the potential rates of open-grown pines (i.e., ring-widths of 5 mm/year). Shortleaf pine trees showed growth increases in response to small (e.g., 200 m^2) canopy openings, which result from mortality of a single-tree. However, the duration of increased growth was not tracked and is likely short-term, particularly in smaller gap sizes.

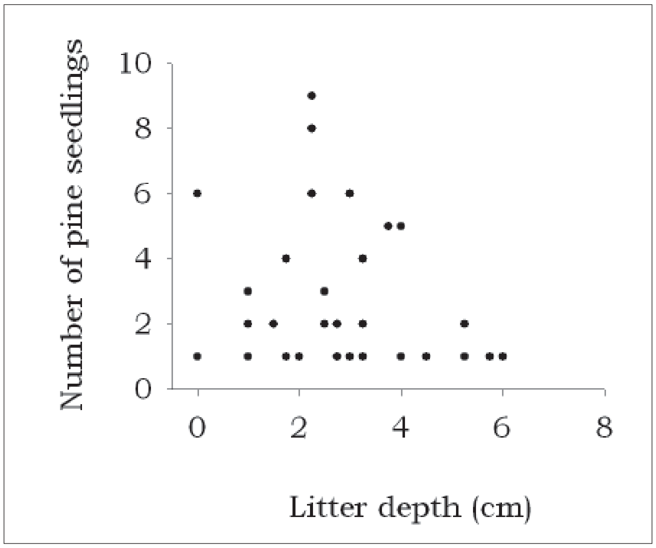

Figure 3.—Relationship between litter depth and shortleaf pine abundance in regeneration subplots. Data are from all sites; each point represents an individual subplot.

CONCLUSIONS

This study describes the vegetative status of six pine forests that are in mid-transition towards being replaced by hardwoods. Overall, this study suggests that natural, noncatastrophic canopy gap disturbances are not sufficient to maintain an overstory composition of shortleaf pine. In general, canopy gap disturbances do not have the effects on the understory or regeneration layer needed for sustaining the processes of regeneration and recruitment of shortleaf pine to the overstory. Small-scale disturbances such as canopy gaps appear to support the transition to forests dominated by hardwood species, particularly black oak, white oak, and hickories. The forest stand dynamics of these forests are similar to a mature pine stand studied by Shelton and Cain (1999), in which pines were described as being rapidly replaced by shade-tolerant hardwoods. This transition in forest composition is relatively common throughout the Ozark Highlands and likely represents an effect of lowered disturbance frequency, primarily fire.

ACKNOWLEDGMENTS

This study was partially funded by the Natural History Division of the Missouri Department of Conservation and the University of Missouri Conservation Biology Program. The authors thank Karen Kramer and the Missouri Natural Areas Committee for their commitment and support for this research; Richard Guyette, Dan Dey, and Gary Oakley for guidance and technical support; and Justin Wiles and Erin McMurry for field assistance.

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SHORTLEAF PINE: A SPECIES AT RISK?

Charles G. Tauer, Shiqin Xu, C. Dana Nelson, and James M. Guldin[1]

ABSTRACT.—Since the 1950s the existence of natural hybrids between shortleaf pine and loblolly pine has been recognized and reported in the literature. In a range-wide study of isoenzyme diversity in shortleaf pine, we found 16 percent of the trees from western populations were hybrids, based on the isocitrate dehydrogenase (IDH) locus. In stands thought to be pure shortleaf pine in west central Arkansas (Mt. Ida), we found 15 percent of the trees were hybrid. As a follow-up study to confirm or discount these results, we sampled native stands across Montgomery County, Arkansas, including the Mt. Ida area. These stands were mixed loblolly pine and shortleaf pine in the southeast part of the county and pure shortleaf pine in the northwest corner. In these stands we again found (1) a relatively high percentage of hybrid trees (14 percent); (2) hybrids in shortleaf pine stands beyond the natural range of loblolly pine; (3) introgression occurring in both directions; and (4) the IDH locus a reliable marker for species and hybrid determination. We are now engaged in a range-wide study of both loblolly pine and shortleaf pine to examine the cause and consequences of natural hybridization between these two species.

INTRODUCTION

Both loblolly pine (*Pinus taeda* L.) and shortleaf pine (*Pinus echinata* Mill.) have extensive ranges across the southeastern United States. A large portion of these ranges are sympatric, allowing for possible hybridization between the two species. The probable existence of natural hybrids between loblolly pine and shortleaf pine has been a topic of discussion and concern since at least the early 1950s (Zobel 1953). Prior to the 1950s, Schreiner (1937) reported that viable artificial hybrids of shortleaf pine X loblolly pine had been produced at the Institute of Forest Genetics in California. In a later report, Little and Righter (1965) documented that this cross was first made in 1933. These artificially produced crosses demonstrated the possibility that naturally occurring hybrids might exist. These two species are normally isolated from each other by time of strobili maturity (Mergen and others 1963), but early on Zobel (1953) noted the possibility of environmentally induced overlapping maturity. The questions then became, how high is the level of hybridization across the ranges of loblolly pine and shortleaf pine, and what effect, if any, will hybridization have on the long-term integrity of each species?

Early Morphological Studies

Artificial Hybrids

Early studies of shortleaf pine X loblolly pine hybrids necessarily relied on morphological traits. Characterization of artificial hybrids showed that the F_1 trees were generally intermediate formany of the traits examined. Little and Righter (1965) described the F_1 hybrids as looking something like a loblolly pine with small cones with stout, sharp prickles, intermediate needle anatomy, and two or three needles per fascicle. Snyder and Hamaker (1978) reported shortleaf pine X loblolly pine hybrids to be distinct and intermediate using a multivariate trait value based on needle characteristics. They reported that the traits most useful in identifying individuals as hybrids were needle length, fascicle sheath length, number of rows of stomata, needle diameter, and stomata/cm. In a summary paper, Schultz (1997) reported that the hybrids tend to be intermediate to their parents for growth and survival.

Perhaps the most extensive and thorough study of artificial hybrids was conducted by Mergen and others (1965). They examined nine needle traits, five twig traits, six bud traits, three male strobili traits, and three cone traits on 40 F_1 trees grown across three locations. They compared these F_1 hybrids to an approximately similar number of open pollinated parent tree offspring at each site. They reported several interesting results, including a large environmental effect, such that mean values for traits in one environment for either parent or F_1 could overlap values for the other groups in other environments. At the same time, they noted a general tendency for intermediate values for the hybrids for most traits. They also noted, as had Little and Righter

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[1] Professor (CGT), Department of Natural Resource Ecology and Management, Oklahoma State University, Stillwater, OK 74078; PhD student (SX), Department of Natural Resource Ecology and Management, Oklahoma State University, Stillwater, OK 74078; Research Geneticist and Project Leader (CDN), Southern Institute of Forest Genetics, USDA Forest Service, Saucier, MS 39574, Supervisory Ecologist and Project Leader (JMG), Southern Research Station, USDA Forest Service, P.O. Box 1270, Hot Springs, AR 71902. CGT is corresponding author: to contact, call (405) 744-5462 or email at chuck.tauer@okstate.edu

(1965), that for vegetative traits the hybrids tended to look more like loblolly pine than shortleaf pine. Mergen and others (1965) then examined all possible combinations of traits using pictorialized scatter diagrams (Anderson 1949) to determine which best distinguished the hybrids and the two parents. They found that by using needle length and fascicle sheath length as the two axes, and sheath type (smooth to rough), length to width ratio of the axillary scale, and twig color for the plotted points, the parents were clearly separated on the plots. They also reported that these scatter diagrams resulted in the hybrids being placed in a generally intermediate position. They concluded that in spite of large environmental influences on trait variability, the F_1 hybrids could be distinguished from the parent species using this combination of traits.

It is of interest to note that all the reported studies of artificial hybrids were of trees from the cross of shortleaf pine X loblolly pine, i.e., with shortleaf pine as the female parent. Various levels of difficulty in making the reciprocal cross have been reported, from no seed (our data, unpublished) to few (0.2 seed/flower) seed (Snyder and Squillace 1966), to not a serious problem (Richard Bryant, pers. commun. 2003). Little and Righter (1965) did report that the Institute of Forest Genetics in California produced the reciprocal cross in 1948, but apparently no information has been published concerning growing the offspring. Clearly, since loblolly pine male strobili shed pollen several weeks earlier than shortleaf pine, using shortleaf pine as the female is the easier cross, as pollen storage is not required. What is not clear is if the reciprocal cross is difficult because of logistics, or if some sort of incompatibility is involved.

Putative Hybrids

When putative hybrid individuals were found in the field, the use of morphological traits deemed useful for artificial hybrids was not as definitive. For example, when Mergen and others (1965) applied their set of traits to putative hybrids from two field populations, they were able to clearly separate the parents, but only 14 of the 62 individuals identified as putative hybrids fell in their hybrid category. They noted that the putative hybrids, although generally intermediate, tended to be similar to shortleaf pine in reproductive morphology, but resembled loblolly pine in vegetative traits. They speculated that some of the putative hybrids were backcrosses, as had Zobel (1953) in his report concerning the possible existence of natural shortleaf pine X loblolly pine hybrids.

Hicks (1973) took a statistical approach to the question of the most appropriate traits to use in identifying hybrid individuals. He measured six needle traits, three twig traits, and three cone traits, then calculated within-tree means and variances to allow estimation of sample sizes required to estimate within-tree means to within 5 percent of the original sample mean. He concluded that needle width, axillary scale width, and cone width required prohibitively large sample sizes, while terminal bud length and number of stomatal rows showed limited variability. Of the traits he measured, he found needle length, fascicle sheath length, number of needles per fascicle, terminal bud width, cone length, and seed weight to be most useful in distinguishing shortleaf pine, loblolly pine, and their hybrids.

One of the reasons the existence of these hybrids was of interest is illustrated by the work of Abbott (1974). Based on the presence of an “atypical” loblolly selection in the Oklahoma State University seed orchard, he examined 19 loblolly and 12 shortleaf orchard selections as possible hybrids. It is generally agreed that hybrids are undesirable in seed orchards. All the trees he examined were from extreme southeast Oklahoma (i.e., McCurtain County), or adjacent counties in Oklahoma, Texas, or Arkansas. This area represents the far northwestern edge of the range of loblolly pine. Based on the work of Hicks (1973), and conversations with him, Abbott chose to measure needle length, number of needles per fascicle, cone length, number of seeds per gram, and fascicle sheath length, and then constructed a hybrid index. He found that the atypical loblolly pine was intermediate for all traits, as were three of the shortleaf pine orchard selections. He concluded that hybridization must occur relatively frequently in the sample area.

Cotton and others (1975), looking for the existence of natural hybrids, conducted a study of trees from 16 stands within a 60-mile radius of Nacogdoches, TX. They used the same traits as Abbott (1974), except terminal bud width instead of number of seeds per gram. They concluded that hybrids may exist, but at a low frequency, and attributed the existence of intermediate types to the natural range in variation found in loblolly pine and shortleaf pine. This conclusion would agree with a report by Schoenike and others (1977), who found that on the Clemson Experimental Forest, SC, putative hybrids occur at a frequency of about one in 10,000 trees.

Early Chemical and Molecular Studies

Clearly, either the frequency of hybridization is highly variable, or the use of morphological traits is limiting our ability to distinguish hybrids from their parent species. Researchers thus turned to chemical and molecular methods to attempt to resolve these questions. One of the early works in this arena was that of Hare and Switzer (1969). They conducted an analysis of seed proteins using acrylamide gel electrophoresis to compare eastern and western sources of loblolly pine to shortleaf pine. With an analysis of banding patterns, they reported that eastern loblolly pine showed 34 percent similarity to shortleaf pine while western sources of loblolly pine showed 88 percent similarity to shortleaf pine. They concluded that introgression of loblolly pine with shortleaf pine is much more frequent in western sources, such as in Oklahoma and Texas. Hare and Switzer’s (1969) results would suggest that the frequency of hybridization is variable across the sympatric portion of these species' ranges, in particular, higher in the western part than in the eastern part.

Florence and Hicks (1980) used seed megagametophyte protein banding patterns to examine putative hybrids of these two species sampled in east Texas. Their intent was to relate hybridization to fusiform rust resistance, but in the process they also were able to use the banding patterns to support the hybrid nature of putative hybrids identified by a morphology-based hybrid index. They further suggested that introgression does occur, and probably in the direction of shortleaf pine.

Huneycutt and Askew (1989) screened both species with 20 isoenzyme systems in an attempt to identify a marker useful in distinguishing hybrids. They discovered that the isocitrate dehydrogenase (IDH) marker was monomorphic (a single allele) and monomeric (a single band) in both species, but differed between species by migration distance. They further tested the marker in the parent species and known hybrids and demonstrated that this was a simple and reliable marker to identify first-generation hybrids between loblolly pine and shortleaf pine. They also noted that the marker's utility in later generations and backcrosses would be limited by normal Mendelian segregation.

Edwards and Hamrick (1995) examined allozyme diversity in a wide-ranging sample of shortleaf pine. They screened 22 loci, including IDH, so they were able to estimate the level of hybridization in the 18 populations sampled. Of the populations they sampled, 11 were from east of the Mississippi River and seven from west of the river. They reported a generally high level of genetic similarity among all shortleaf pine populations, with one important distinction, that the eastern and western populations differed significantly in the level of hybridization to loblolly pine. The western populations had a higher percentage of hybrids (4.58 percent) than the eastern populations (1.09 percent). What is of considerable interest to us, but was not addressed, is that all but one of the western populations sampled were outside the accepted range of loblolly pine. These shortleaf pine populations are approximately 35 miles to well over 200 miles distant from the nearest natural loblolly pine populations. It is intriguing that these populations would show high levels of hybrids.

In an apparent follow-up study, Edwards and others (1997) used IDH to examine hybridization frequency in two naturally occurring, sympatric populations of loblolly pine and shortleaf pine in northern Georgia. They sampled all trees in both populations and reported 8 percent hybrids at one site and 0.4 percent hybrids at the second site. Using a chloroplast marker, they determined that shortleaf pine was the paternal parent (Wagner and others 1992) of all hybrids at both sites. They noted that all hybrid trees were juvenile, and spatially distant from mature shortleaf pines, supporting the paternal contribution of shortleaf pine. Interestingly, they also reported that morphologically, the hybrids were easily distinguished from loblolly, but not from shortleaf, which is contrary to morphological descriptions of artificial hybrids discussed above. They recognized this discrepancy, and suggested that tree morphology may change as the hybrid trees matured, or that the hybrids they described were backcrosses. Since no mature hybrids were found, however, they discounted the second possibility. Perhaps the IDH locus is not a reliable marker.

Recent Studies at OSU

At Oklahoma State University (OSU) in the early 1990s, we initiated studies (reported by Raja and others 1997, 1998) to examine the effect of various management strategies on genetic diversity in shortleaf pine. These studies were in cooperation with the USDA Forest Service's Ecosystem Management Research on the Ozark and Ouachita National Forests. Since this work was started before the Edwards and Hamrick (1995) work was reported, we needed to conduct an isoenzyme study to characterize the shortleaf pine species to support the management study. Our range-wide study of isoenzyme diversity in shortleaf pine turned out to be very similar to that of Edwards and Hamrick (1995). We sampled six western populations and nine eastern populations, and although these populations were entirely different from the Edwards and Hamrick (1995) samples, our results, in terms of the general genetic characterization of the species, were in close agreement with their results. However, we did note that, based on the IDH locus, more than 16 percent of the trees from western populations were hybrids (they reported 4.58 percent), while eastern populations showed 4.45 percent hybrids (they reported 1.09 percent). Although three of the western populations were outside the natural range of loblolly pine, we found evidence of hybridization, on average 10 percent, as did the Edwards and Hamrick (1995) study (although their percent of hybrids was lower). We cannot explain these differences in estimated level of hybridization between the two studies, except to point out that the populations sampled were different in number of trees sampled per stand, stand locations sampled, and time of sampling (we sampled trees from the South-wide Southern Pine Seed Source Study [SSPSSS] plantings, trees from seed collected in 1951-1952). Consequently, we speculated that IDH may not be a reliable marker for determining species or degree of hybridization. We then sampled stands of shortleaf pine in the Mt. Ida, AR area for the Ecosystem Management study, and again noted a high number (15 percent) of hybrid trees based on IDH. These were trees in what were thought to be pure shortleaf pine stands, several miles north of any native loblolly pine trees or stands.

As a follow-up study (Chen and others 2004) to confirm or discount these results, we sampled native pine stands across a southeast to northwest transect of Montgomery County, AR, which includes Mt. Ida. These stands were mixed loblolly pine/shortleaf pine in the southeast part of the county and pure shortleaf pine, up to 20 miles north of the closest known loblolly pine stands, in the northwest corner of the county. In this study we used a codominant nuclear marker and a chloroplast marker to identify hybrids and their paternity, respectively. Of the 80 trees sampled, ten (12.5 percent) were found to be heterozygous at the nuclear marker locus, i.e. hybrids. Seven of these were also confirmed to be hybrid using the IDH locus. Of the remaining three, one was not tested, and one each was homozygous for loblolly pine or shortleaf pine. We also found one tree heterozygous at the IDH locus, but not at the nuclear marker. Since we concluded that some of the hybrids were not F_1s, a few of these genotypes would be expected. The chloroplast marker showed some of the hybrids to be of loblolly pine paternity and some of shortleaf pine paternity. Morphological data agreed with the paternity analysis in that those of shortleaf pine paternity looked more like shortleaf pine, and those of loblolly pine paternity looked more like loblolly pine. In this confirmation study, we found (1) a relatively high percentage of hybrid trees (14 percent); (2) hybrids in shortleaf pine stands beyond the natural range of loblolly pine; (3) introgression occurring in both directions; and (4) the IDH locus apparently a reliable marker for species and F_1 hybrid determination.

Current Study at OSU

The obvious next questions are: Is this level of hybridization management induced, and what effect will such levels of hybridization have on the long-term integrity of these species? If the current intensive management of loblolly pine throughout the sympatric range of these two species is in part responsible for the relatively high level of hybridization found, there are serious implications regarding shortleaf pine management. Since the USDA Forest Service, by mandate, is one of only a few organizations in the South regenerating shortleaf pine stands, and most often relies on forms of natural regeneration to do so, will the potentially overwhelming loblolly pine background pollen cloud put the future of the shortleaf species at risk? The outcomes from this research project will begin to answer these questions, and may point to management strategies designed to maintain the integrity and diversity of the shortleaf pine species. Loblolly pine will probably not be at risk because of its varied and active tree improvement and artificial regeneration programs.

Based on the research and results described above, we initiated a study to examine the cause and consequences of introgression between shortleaf pine and loblolly pine. The objectives of the research are to:

1. Estimate the level of hybridization present in today's native populations of loblolly pine and shortleaf pine.
2. Estimate the level of hybridization present in 1950s range-wide samples of loblolly pine and shortleaf pine. Samples from the SSPSSS are being used.
3. Compare levels of hybridization from objectives 1 and 2.
4. Estimate the present day level and direction of introgression occurring between these two species.
5. Compare the level of hybridization present in native shortleaf pine stands from an area of intensive loblolly pine management to that in shortleaf pine from relatively undisturbed, continuous, native, mixed shortleaf pine/loblolly pine stands.

STUDY AREAS

Field tissue (needle) collections have been made from remaining SSPSSS plantings of both shortleaf pine and loblolly pine. These trees represent seed collected in 1951 and 1952, some 54 years ago, formed at a time when man's influence, at least in reference to vast plantings of loblolly pine, was minimal. We will match these collections with collections from loblolly pine and shortleaf pine trees found currently in the "wild" on sites as close as possible to the original collection sites of the SSPSSS, at least to within the same county. This current day collection will be made from the youngest trees found on the site to represent the most recent seed fall. These collections will allow us to estimate the level of hybridization in these species at present and approximately 50 years ago.

METHODS

To meet objective four, we will use the data from the present day shortleaf pine and loblolly pine collections and subject it to an appropriate analysis (e.g., Anderson and Thompson 2002).

To meet objective five, we intend to identify two stands meeting the following set of conditions. One stand will be native shortleaf pine which has been essentially undisturbed by humans, and is surrounded by a large area (thousands of acres) also fairly undisturbed, ideally consists of mixed shortleaf pine/loblolly pine. The second stand will also be an undisturbed native shortleaf pine stand, but this stand (100 acres or so) will be surrounded by mostly planted loblolly pine (thousands of acres). From these stands we will collect seed of about 100 trees each and this seed and the resultant offspring will be screened to determine the level of hybridization. These comparison stands will both be in relatively close vicinity (the same or adjoining counties) to avoid problems associated with natural variation in hybridization levels observed in stands from across the species' native ranges (Raja and others 1997, Edwards and Hamrick 1995). Such stands have tentatively been identified.

To date we have characterized the hybrid nature of individuals using the IHD isoenzyme locus (Huneycutt and Askew 1989), a codominant nuclear ribosomal DNA marker from the ITS-1 region and a chloroplast marker, both of which we developed (Chen and others 2004), and a number of simple sequence repeat (SSR) markers developed in Dr. Clare Williams's lab. We intend to utilize these markers in this study. We are also evaluating additional SSR markers screened at the Southern Institute of Forest Genetics in Mississippi, and we have developed a large set of amplified fragment length polymorphism (AFLP) markers to ensure a comprehensive characterization of every genotype.

RESULTS TO DATE

To develop our AFLP data set, we screened 48 primer pairs. Eighteen of these primer pairs were selected for producing multiple and clear bands. These primer pairs were then used to screen the SSPSSS shortleaf pine and loblolly pine collections. These primers produced polymorphic and monomorphic AFLP bands at 794 loci in the shortleaf pine samples and 647 loci in the loblolly pine samples. These AFLP makers were used to estimate the genetic diversity of natural shortleaf pine and loblolly pine populations sampled prior to extensive forest management.

The average heterozygosity of shortleaf pine throughout its range, west of the Mississippi River, and east of the river is 15 percent, 17 percent, and 15 percent, respectively. The heterozygosity value of the populations west of the river is a little higher than that of populations east of the river. This result agrees with the studies of Raja and others (1997) and Edwards and Hamrick (1995). The average heterozygosity of loblolly pine throughout its range, west of the Mississippi River, and east of the river is 12 percent, 12 percent, and 13 percent, respectively, based on the 647 loci. Both shortleaf pine and loblolly pine are outcrossing species, and it is not surprising to find high levels of heterozygosity in the natural populations especially given that hybridization between these two species may contribute to this high heterozygosity.

Of the numerous AFLPs produced by the 18 primer pairs, 96 were polymorphic among both the shortleaf pine and loblolly pine samples. These 96 AFLPs were produced by 17 primer pairs and should be useful in examining the hybridization level and the pedigree of hybrids, given the appropriate analysis. Preliminary analyses of these data do suggest that some of the sample trees are hybrids.

The IDH isoenzyme locus is being screened for all trees as a second indicator of trees which may be hybrids. With only some of the trees characterized to date, the IDH locus has also identified several trees as hybrids. The results from IDH and the AFLP markers will be compared to see whether these markers are reliable to distinguish shortleaf X loblolly hybrids.

By comparing the SSPSSS trees with contemporary trees from the same counties, we will be able to estimate with considerable reliability the preintensive forestry level of hybridization in loblolly pine and shortleaf pine (1950s), and the postintensive forestry level of hybridization (2000s) across the range of the two species. Sampling of current natural regeneration in the SSPSSS counties has just begun.

By comparing seed fall from shortleaf pine in a relatively undisturbed area with that of shortleaf pine in an area essentially surrounded by loblolly pine plantings, we will also be able to compare the level of hybridization which occurs under these scenarios. These data will allow some insight into the present and potential effect that intensive management of loblolly pine is having on the genetic integrity of shortleaf pine throughout their sympatric region. The pedigree of the hybrids will also be determined, at least to the F_2 and BC_1 level, or further if the available analytical methods and software allow. These samples have not yet been collected.

DISCUSSION AND CONCLUSIONS

Since Zobel's (1953) report of suspected hybrids, the collective evidence has proven that natural hybrids between loblolly pine and shortleaf pine exist, and that the frequency of occurrence of hybrids is greater in populations west of the Mississippi River (Edwards and Hamrick 1995, Raja et al. 1997, Chen et al. 2004, among others). If the IDH locus is a reliable indicator of hybrid trees, it would appear that in general all populations of shortleaf pine west of the Mississippi River contain some hybrids. Our study demonstrating bidirectional introgression would suggest that loblolly pine populations are also affected, but to what degree is not as well documented. In retrospect, Zobel was correct in his suspicion of the existence of natural hybrids between these two pine species. We suspect he did not know what the consequences of these hybrids might or will be, nor do we; however, there are some possibilities worth discussion and further study.

It is well known that the natural ranges of loblolly and shortleaf pine overlap throughout the South (Little 1971). For example, stands in the upper west Gulf Coastal Plain in northern Louisiana and south Arkansas, such as are found in the Reynolds Research Natural Area on the Crossett Experimental Forest in Ashley County, AR, contain both species, and loblolly pine dominates these stands while shortleaf pine is a minor component of varying occurrence (Cain and Shelton 1994). However, early publications based on studies at the Crossett Experimental Forest describe the stands as "shortleaf-loblolly pine stands" (Reynolds and others 1944, Reynolds 1947), which suggests that shortleaf pine dominated the mixture in the 1930s. Unwritten marking guides for lumber company crews working in these mixed forests encouraged retention of the loblolly pine and removal of the shortleaf pine, all other things being equal, because loblolly pine grows at a slightly faster rate than shortleaf pine. But trees one would identify clearly as shortleaf pine remain common in these mixed stands. An interesting question about these stand histories: What are the hybridization rates in shortleaf pine in the upper West Gulf Coastal Plain? Such a study might be included in the current OSU study or a follow-up study as a point of comparison with data from the pure shortleaf stands in the Ouachitas.

In this context, the ability of shortleaf pine to retain its independent identity in mixed stands on the upper west Gulf Coastal Plain suggests that it might also do so in the Ouachitas. In both situations, some attributes of shortleaf pine per se are ecologically advantageous, or were so prior to extensive forest management activity in this region. One unusual difference is shortleaf pine's ability to resprout if topkilled by fire (Mattoon 1915), which confers an advantage in establishment if fire burns through young stands containing both species. Shortleaf pine grows more slowly but endures competition longer than loblolly pine (Lawson 1990). It also is considered to be more tolerant of drought and of xeric sites than loblolly pine, which might lead to different survival probabilities for the respective species if a young mixed-species cohort experienced drought, or was established on a xeric site, or both.

It would also seem that the success of a hybrid might relate to the attributes that the hybrid inherits from its respective parents. A hybrid might grow more rapidly than a pure shortleaf pine, or might be slightly less tolerant of fire or drought than its shortleaf pine parent. One can imagine ecological circumstances that might discriminate in favor of or against the hybrid—such as a reduced ability (compared to shortleaf pine) to resprout if top-killed by fire, or a greater ability than a loblolly pine to tolerate drought. Since the most interesting silvical difference between shortleaf pine and loblolly pine is the aforementioned resprouting ability of shortleaf pine, it would be interesting to quantify this trait in hybrids. It might also be interesting to follow the percent survival of hybrids over time from seed fall, through seedling establishment to stand maturity, in stands on xeric and mesic sites, to determine if the percent of hybrids surviving increases or decreases during stand development.

The pattern of distribution of naturally-regenerated stands of shortleaf pine relative to loblolly pine plantations throughout the Ouachitas might also affect pollen distribution. Generally speaking, loblolly pine plantations in the region are on the lower slopes and valleys in the region: those lands were the acquired originally by timber companies for managing naturally regenerated shortleaf pine stands during the 1930s and 1940s because of their higher productivity than the stands on upper slopes and ridges, which remained (and still exist) in Federal ownership. Thus, on landscapes where the two species co-occur today, the loblolly pine plantations planted by those timber companies or their successors tend to be on lower slopes, whereas the shortleaf pine stands tend to be on upper slopes or ridges. Position may affect the degree to which natural introgression from the earlier shed loblolly pine pollen cloud to receptive shortleaf pine flowers can occur, since the introgressing loblolly pine pollen would generally have to float uphill. A recent study by Dyer and Sork (2001) showed limited pollen movement in a continuous forest due to both distance and vegetative structure, but they did not address pollen movement in actively managed forests with changing canopy structure.

Finally, the major seed orchard for shortleaf pine on federal lands in the western Gulf region is located at Mount Ida, AR, in terrain not unlike that from which we collected samples for the introgression results in the recent OSU study. If the prevailing pollen cloud from the hundreds of thousands of acres of loblolly pine plantations in the region is sufficient to be considered prevalent at a landscape scale, the protective buffers that surround this seed orchard might actually provide limited to no protection against the possibility of introgression in the dominant source of genetically improved shortleaf pine seed for the mid-South. Assays of IDH in seed from that orchard or the planting stock being raised in nurseries for outplanting might be interesting, especially if a test could be produced that might be used to cull hybrids from planting stock being distributed for outplanting.

ACKNOWLEDGMENTS

This study is supported by the USDA Forest Service, Southern Research Station, Cooperative Agreement SRS 05-CA-11330126-168 and by the Oklahoma State University Agricultural Experiment Station.

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TREE SPECIES ASSOCIATIONS OF *PINUS ECHINATA* MILL. OVER A LARGE-SCALE SAMPLING REGIME ON THE INTERIOR HIGHLANDS OF ARKANSAS

James F. Rosson, Jr.[1]

ABSTRACT.—The Interior Highlands physiographic province of Arkansas is considered the ecological center of the geographic distribution of shortleaf pine (*Pinus echinata* Mill.). I used data from the U.S. Forest Service, Forest Inventory and Analysis (FIA) program to identify the major tree species associates of *P. echinata* across this 66,700-km^2 landscape. Across the region, 41,207 km^2 were covered by timberland. The study population was represented by 434 relatively undisturbed upland sample plots from the 1995 forest survey of Arkansas. *P. echinata* ≥12.7 cm in diameter at breast height (DBH) occurred on 211 of these sample plots. Additionally, it ranked first in basal area on 119 plots, second on 39 plots, and third on 19 plots. Where P. echinata was dominant, stand basal area averaged 23.1 m^2 ha^{-1} (± 0.57 SEM). I used chi-square to test for degree of association between the stand dominants and to test for positive and negative associations. There was a positive association between *P. echinata* and *Quercus alba* L. ($\chi^2 = 0.490$; 1df). In contrast, there was a negative association between *P. echinata* and *Q. velutina* Lam. ($\chi^2 = 15.571$; 1df). These results demonstrate that the chi-square test of association is effective even on the larger scales of sampling where lack of sample homogeneity may sometimes complicate analysis. Such quantitative tests for species associations offer meaningful insights into *P. echinata* communities at the landscape scale of sampling.

INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.) has an extensive range that covers an area from New Jersey to southeast Texas. In the northern part of its range, it stretches from New Jersey to southern Missouri and eastern Oklahoma. In the southern portion of its range, it is found from South Carolina all the way to east Texas. Much autecological work has been done on *P. echinata* and a summarization of its silvics can be found in Burns and Honkala (1990). Somewhat lacking, however, are detailed descriptions of species associates in specific *P. echinata* communities. Some of the few botanical and silvical descriptions of this species typically offer only brief general listings of community associates (Barrett 1995, Fralish and Franklin 2002, Harlow and others 1996, Burns and Honkala 1990, Eyre 1980, Braun 1950, Vankat 1979). Tree species associations are a theme central to much of ecological community analysis. These repeating patterns of species associations are the basis of the classification of vegetation communities. However, species with wide ecological amplitude, such as *P. echinata*, may often have different associates over different parts of their range. Usually, detailed descriptive work is done on small localized studies, often of stands that are unique in some respect such as stand history, species rareness, possibility of becoming endangered, etc. Lacking are studies that outline specific tree species associations over large geographic areas. Such studies will add to the full complement of information necessary to classify vegetation composed of species with wide ecological amplitude.

The center of highest ecological development of *P. echinata* is in the Interior Highlands physiographic province of Arkansas. This area contains the highest concentration of *P. echinata* volume in the U.S. As of the 1995 survey of Arkansas, there were 3.8 billion cubic feet of volume in *P. echinata* (Rosson 2002), far above any other state in the U.S. Most of the volume is concentrated in Montgomery, Scott, Yell, Perry, and Polk Counties, accounting for 43 percent of all *P. echinata* volume in Arkansas. Volume and relative ecological importance of *P. echinata* decreases north and south of this area. For instance, moving north onto the Salem-Plateaus province, the volume of *P. echinata* in Missouri is only 0.8 billion cubic feet (Miles 2006). The ecological importance of *P. echinata* in Arkansas on the Interior Highlands presented an opportunity to study its primary species associations across this large landscape. The objectives of the study were to determine the common tree associates of *P. echinata* across this region and determine whether these associations are positive or negative.

METHODS

The inclusive area of the study is the Interior Highlands Physigraphic Division in Arkansas (Fenneman 1938). This

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[1] Research Forester, Southern Research Station, USDA Forest Service, 4700 Old Kingston Pike, Knoxville, TN 37919. Author contact: call (865) 862-2067 or email at jrosson@fs.fed.us

area is divided into two provinces, the Ozark Plateaus Province and the Ouachita Province. These two provinces contain two Sections: the Springfield-Salem Plateaus and the Boston Mountains Sections in the Ozark Plateaus Province, and the Arkansas Valley and Ouachita Mountains Sections in the Ouachita Province (Fig. 1). The Interior Highlands covers approximately 66,700 km^2 of which 41,207 km^2 are forested. Using GIS software, I selected U.S. Forest Service Inventory and Analysis (FIA) plots that fell within each of these physiographic regions.

The data came from forest surveys conducted by FIA in 1968, 1978, 1988, and 1995. The sample plot study population was extracted from these four surveys by the following criteria. First, a plot had to fall within the Interior Highlands. Second, the plot had to be forested during all four surveys. Third and fourth, plots that showed evidence of disturbance (e.g. cutting) or were artificially regenerated were excluded. Fifth, the plot had to occur on an upland site. Evidence of cutting disturbance or planting was obtained by examination of the repeated-measures plots over time, where individual trees were tracked with descriptive tree histories. There were 1,179 plots that met the first two criteria, and 434 that met all five.

The total plot population, from which the 434 study plots were selected, came from a 4.8 km square sample grid. The same plots were visited and measured at each of the four surveys. Only trees ≥12.7 cm in diameter at breast height (DBH) were included in the study. These trees were tallied using an 8.6 m^2 per hectare basal area factor (BAF) prism on 10 points dispersed over an area of approximately 0.4 hectares (see Rosson 2002 for more details on sampling methods for these Arkansas surveys). Nomenclature follows Little (1979).

A 2 x 2 contingency table was used to define the tree species associations. The data entry for each cell was the presence or absence of two select species on each plot. In this study all species that occurred in the 434 sample plots across the Interior Highland were compared with *P. echinata* in the contingency table.

Species B

		P	A	
Species A	P	a	b	m
	A	c	d	n
		r	s	tot

Where

P = plots where species is present
A = plots where species is absent
a = number of plots species where A and B co-occur
b = number of plots where species A is present and species B is absent
c = number of plots where species A is absent and species B is present
d = number of plots where species A and species B are both absent
m = a + b
n = c + d
r = a + c
s = b + d
tot = total number of plots in sample (a + b + c + d)

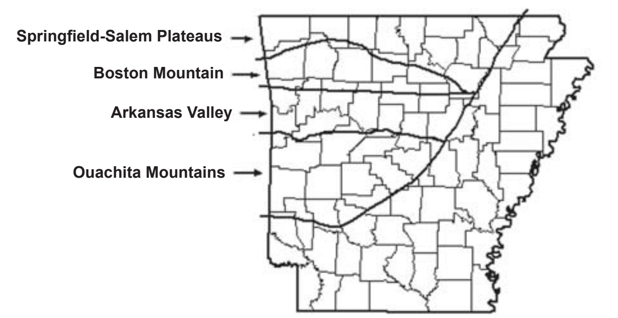

Figure 1.—The four physiographic sections on the Interior Highlands of Arkansas (after Fenneman 1938).

The chi-square test statistic was then applied to the data in the 2 x 2 contingency table. This formula includes the Yates correction that corrects for bias when any cell in the 2 x 2 contingency table has an expected frequency of <1 or if two or more of the table cells have expected frequencies of <5 (Zar 1984).

$$\chi^2 = \frac{N[|(ad) - (bc)| - (N/2)^2}{mnrs}$$

The null hypothesis is that the species are independent, i.e., there is no association between the two species being tested. If the chi-square value is >3.84, the null hypothesis is rejected and it is concluded that the species are associated. In addition, the chi-square value may be used as a measure of the degree of association, the higher the value the stronger the association (Causton 1988). There are two types of association possible (see Ludwig and Reynolds 1988):

Positive—the pair of species occurred more often than expected if independent. $a > E(a)$
Negative—the pair of species occurred less often than expected if independent. $a < E(a)$

Where

$$E(a) = \frac{(a+b)(a+c)}{N}$$

Goodall (1953) was the first to measure the association between species. The 2 x 2 contingency table with chi-square test of significance is the most commonly used approach. Testing for association between species has been called association analysis, species association analysis, interspecific association analysis, and species correlation analysis (Ludwig and Reynolds 1988, Causton 1988, Kershaw 1973, Greig-Smith 1983). Such species association constructions have been used in a variety of contexts beyond association analysis. One application is in multivariate analysis, where it is commonly applied in various ordination techniques. The association between two species is the degree and measure to which they occupy the same sample sites across the landscape and is an extremely important ecological indicator in multivariate techniques (Pielou 1984, Gauch 1982, Greig-Smith 1983).

RESULTS AND DISCUSSION

Overstory stand basal area averaged 19.3 m^2 ha^{-1} in the 434 post-stratified plots on the Interior Highlands. Fifty-two tree species ≥12.7 cm DBH were recorded. Often, these 10 species accounted for just over 90 percent of overstory basal area. *P. echinata* was the most dominant species, accounting for 22 percent of basal area, followed by *Quercus alba* L., *Q. rubra* L., *Carya* spp. Nutt., *Q. stellata* Wangenh., *Q. velutina* Lam., *Nyssa sylvatica* Marsh., *Liquidambar styraciflua* L., *Q. falcata* Michx., and *Juniperus virginiana* L. (Table 1).

There were some shifts in dominance by physiographic regions. *P. echinata* was strongly dominant in the Ouachita Mountains, accounting for 41 percent of basal area. *Q. alba* was second, accounting for 17 percent of basal area. Across the Arkansas Valley, *P. echinata* shared dominance with *Q. stellata*, each species accounting for 20 percent of stand basal area. Stand basal area in the Boston Mountains averaged 19.5 m^2 ha^{-1}. *Q. alba* was dominant there, followed by *Q. rubra*, accounting for 25 and 16 percent of basal area, respectively. *P. echinata* was fifth in dominance, accounting for 8 percent of stand basal area in this region. On the Salem-Plateaus, *Q. velutina* was dominant, with 22 percent of basal area, followed by *Q. alba* and *Q. stellata* with 16 and 14 percent, respectively. *P. echinata* ranked sixth there, accounting for 9 percent of basal area.

P. echinata's adaptation to a wide range of soils and sites contributes to its wide distribution. It favors and is most prevalent on acid soils, but is also very competitive on other soils with southern aspects, drier sites, and nutrient-deficient soils (Burns and Honkala 1990). *P. echinata* is most common on the Ouachita Province, where it is most competitive on the numerous southern exposure slopes and more acidic soils derived from sandstone bedrock. It declines in importance in the provinces to the north probably because of habitat limitations—fewer south-exposed slopes and more limestone-derived soils. In addition, the degree of past disturbance (fire and cutting) has played a large role in the trajectory of forest composition that currently occupies the Interior Highlands of Arkansas (Batek and others 1999, Chapman and others 2006, Stambaugh and others 2002).

Across the Interior Highlands, *P. echinata* occurred on 211 of the 434 upland plots and was the stand dominant on 119 plots (Table 2). *Q. alba* was the leading, second dominant tree, on these plots, occurring on 37 sample plots. Ranked third in dominance was *Q. stellata*, occurring on 25 plots. By physiographic region within the Interior Highlands, *P. echinata* occurred on 130 of the 152 Ouachita Mountain plots, on 26 of the 55 Arkansas Valley plots, on 41 of the 159 Boston Mountain plots, and on 14 of the 68 Salem-Plateaus plots.

Across the Interior Highlands the relative stand dominance of *P. echinata* varied. Thirty-eight percent of the plots had 50 to 75 percent of basal area in *P. echinata*, while 35 percent had basal area in the 25 to 50 percent range. Twenty-seven percent had basal area ranging from 75 to 100 percent. Less than 1 percent of the plots had *P. echinata* basal area in the 0 to 25 percent range. In the order of ranked dominance, 119 plots had *P. echinata* as the number 1 stand dominant, 39 plots had *P. echinata* ranked second in dominance, 19 plots had *P. echinata* ranked third, and the remaining 34 plots had a ranking of fourth or higher in *P. echinata* dominance. (Table 2).

One of the strongest patterns of group associations was in the *P. echinata*—*Q. alba*—*Carya* spp. type. Twelve percent of all plots were in this category. Stand composition of shade-intolerant pine in association with shade-tolerant species (oaks and hickories) is most likely a result of stand initiation from past disturbance. *P. echinata* probably became established after past logging or natural disturbance, but if succession proceeds without further disturbance, it will begin to drop out of these stands. *P. echinata* is moderately intolerant as a seedling but loses that tolerance after just a few years. Without major disturbance, hardwoods will take over the site. *P. echinata* may maintain some minor presence by taking advantage of canopy gaps and the ability to reach the canopy by high growth rates (Barrett 1995). *P. echinata* stands >100 years old begin to deteriorate rapidly and more tolerant hardwoods will take over the site without some kind of disturbance (Walker 1999). Table 2 illustrates other strong patterns described by the first three ranked species. These involve *P. echinata*, *Q. alba*, *Carya* spp., and *Q. stellata*. Involving first and second ranked species, there were 32 plots with *Q. alba*, 25 plots with *Q. stellata*, and 21 plots with *Carya* spp. (Table 2), together accounting for 66 percent of all plots dominated by *P. echinata*. Although Table 2 shows only the top three dominant species, it illustrates the high variability in dominance ranking, especially in the third dominant position, and beyond.

Table 1.—Basal area (m^2 ha^{-1}) by species, Interior Highland Physiographic Division, and four Interior Highland Sections; n=434 for the Interior Highlands, n=152 for the Ouachita Mountains, n=55 for the Arkansas Valley, n=159 for the Boston Mountains, and n=68 for the Salem-Plateaus. Data are from 1995.

FIA species code and name	**Ouachita**	**Arkansas Valley**	**Boston Mountains**	**Salem-Plateaus**	**Interior Highland**
	Average basal area (m^2 ha^{-1})				
68 *Juniperus virginiana* L.	0.153	1.126	0.249	0.847	0.420
110 *Pinus echinata* Mill.	8.515	3.503	1.585	1.050	4.171
131 *Pinus taeda*	0.215	0.000	0.027	0.000	0.085
311 *Acer barbatum* Michx.	0.000	0.000	0.005	0.000	0.002
313 *Acer negundo* L.	0.000	0.000	0.011	0.000	0.004
316 *Acer rubrum* L.	0.164	0.109	0.281	0.051	0.182
318 *Acer saccharum* L.	0.000	0.000	0.325	0.190	0.149
341 *Ailanthus altissima* (Mill.) Swingle	0.000	0.000	0.005	0.013	0.004
381 *Bumelia* sp.	0.000	0.000	0.000	0.013	0.002
400 *Carya* sp. Nutt.	1.256	2.220	2.585	1.669	1.930
404 *Carya illinoensis* (Wangenh)K.Koch	0.000	0.000	0.005	0.000	0.002
420 *Castanea* sp. Mill.	0.000	0.000	0.005	0.000	0.002
461 *Celtis laevigata* Willd.	0.017	0.000	0.000	0.000	0.006
462 *Celtis occidentalis* L.	0.000	0.000	0.022	0.013	0.010
471 *Cercis canadensis* L.	0.000	0.000	0.038	0.051	0.022
491 *Cornus florida* L.	0.011	0.000	0.022	0.063	0.022
521 *Diospyros virginінana* L.	0.017	0.016	0.016	0.000	0.014
531 *Fagus grandifolia* Ehrh.	0.011	0.000	0.335	0.000	0.127
541 *Fraxinus Americana* L.	0.057	0.078	0.227	0.266	0.155
544 *Fraxinus pennsylvanica* Marsh.	0.034	0.031	0.016	0.025	0.026
546 *Fraxinus quadrangulata* Michx.	0.000	0.000	0.000	0.025	0.004
552 *Gleditsia triacanthos* L.	0.011	0.031	0.005	0.000	0.010
602 *Juglans nigra* L.	0.006	0.031	0.076	0.139	0.055
611 *Liquidambar styraciflua* L.	0.656	0.891	0.633	0.038	0.581
621 *Liriodendron tulipifera* L.	0.000	0.000	0.000	0.025	0.004
651 *Magnolia acuminata* L.	0.000	0.000	0.049	0.025	0.022
682 *Morus rubra* L.	0.017	0.016	0.011	0.025	0.016
693 *Nyssa sylvatica* Marsh.	0.549	0.563	0.952	0.392	0.674
731 *Platanus occidentalis* L.	0.023	0.109	0.059	0.013	0.046
762 *Prunus serotina* Ehrh.	0.124	0.188	0.130	0.126	0.135
802 *Quercus alba* L.	3.491	1.673	4.911	2.795	3.672
812 *Quercus falcata* Michx.	0.436	0.579	0.254	0.683	0.426
813 *Quercus falcata* var. *pagodifolia* Ell.	0.023	0.360	0.005	0.000	0.055
823 *Quercus macrocarpa* Michx.	0.000	0.000	0.000	0.025	0.004
824 *Quercus marilandica* Muenchh.	0.232	0.266	0.114	0.468	0.230
825 *Quercus michauxii* Nutt.	0.000	0.000	0.000	0.013	0.002
826 *Quercus muehlenbergii* Engelm.	0.006	0.063	0.141	0.443	0.131
827 *Quercus nigra* L.	0.011	0.031	0.005	0.000	0.010
830 *Quercus palustris* Muenchh.	0.000	0.000	0.005	0.000	0.002
831 *Quercus phellos* L.	0.028	0.000	0.000	0.000	0.010
833 *Quercus rubra* L.	1.709	0.813	3.132	1.518	2.087
834 *Quercus shumardii* Buckl.	0.000	0.016	0.011	0.013	0.008
835 *Quercus stellata* Wangenh.	1.765	3.440	1.028	2.491	1.821
837 *Quercus velutina* Lam.	0.837	0.797	1.801	3.832	1.655
901 *Robinia pseudoacacia* L.	0.006	0.031	0.114	0.038	0.054
931 *Sassafras albidum* (Nutt.)Nees	0.000	0.000	0.005	0.051	0.010
951 *Tilia americana* L.	0.017	0.000	0.054	0.051	0.034
971 *Ulmus alata* Michx.	0.192	0.219	0.103	0.152	0.157
972 *Ulmus americana* L.	0.062	0.047	0.049	0.051	0.054
973 *Ulmus crassifolia* Nutt.	0.000	0.016	0.005	0.000	0.004
975 *Ulmus rubra* Muhl.	0.000	0.031	0.022	0.000	0.012
976 *Ulmus serotina* Sarg.	0.000	0.078	0.000	0.000	0.010
999 Unidentified trees	0.000	0.016	0.038	0.025	0.020
All species	20.651	17.388	19.472	17.706	19.344

Table 2.—The number of plots by dominant species. Listed are all plots where *P. echinata* was dominant. The species codes in the three dominant categories are identified in the species list, Table 1. Data are from 1995; n = 119.

Number of plots	Percent of all plots	No. 1 dominant	No. 2 dominant	No. 3 dominant
14	11.8	110	802	400
6	5.0	110	802	835
5	4.2	110	802	833
4	3.4	110	802	693
3	2.5	110	802	837
1	0.8	110	802	812
1	0.8	110	802	131
1	0.8	110	802	611
1	0.8	110	802	531
1	0.8	110	802	316
8	6.7	110	835	400
5	4.2	110	835	802
1	0.8	110	835	833
1	0.8	110	835	693
3	2.5	110	835	0
2	1.7	110	835	812
1	0.8	110	835	131
1	0.8	110	835	611
2	1.7	110	835	68
1	0.8	110	835	762
7	5.9	110	400	802
4	3.4	110	400	835
1	0.8	110	400	833
1	0.8	110	400	693
2	1.7	110	400	837
2	1.7	110	400	131
1	0.8	110	400	611
1	0.8	110	400	68
2	1.7	110	400	824
1	0.8	110	68	400
1	0.8	110	68	802
1	0.8	110	68	835
1	0.8	110	68	491
1	0.8	110	68	521
2	1.7	110	833	400
1	0.8	110	833	802
1	0.8	110	833	835
1	0.8	110	833	0
1	0.8	110	837	400
3	2.5	110	837	802
1	0.8	110	837	693
1	0.8	110	611	400
1	0.8	110	611	802
1	0.8	110	611	833
1	0.8	110	611	693
1	0.8	110	611	831
2	1.7	110	812	802
1	0.8	110	812	835
1	0.8	110	812	813
1	0.8	110	693	835
1	0.8	110	693	837
1	0.8	110	693	824
1	0.8	110	824	835
1	0.8	110	824	833
2	1.7	110	131	812
2	1.7	110	0	0
1	0.8	110	541	611
1	0.8	110	971	400
1	0.8	110	316	0

Table 3 shows the chi-square values and the type of association for each species in relation to its occurrence (or lack thereof) with *P. echinata*. This chi-square value is a measure of the degree of association, where the higher the value, the stronger the association (Causton 1988). It is also important to consider the number of plots that contain neither species. If this cell is 0, then a chi-square value cannot be calculated (Kershaw 1973). So, species with wide amplitude (typically those that occurred on every plot or a high number of plots) may demonstrate a weak chi-square value. Examples are *Carya* spp., where 352 of the 434 plots were occupied by this genus; and *Q. alba*, which occurred on 332 sample plots.

Of the 52 tree species tallied on various portions of the 434 sample plots, *P. echinata* had a positive association with 20 of them. The strongest positive associations were with *P. taeda*, *Liquidambar styraciflua*, and *Q. stellata*. In contrast, *P. echinata* had a negative association with 32 species. However, many of these are the result of much too small of a tally. For example, see *Acer negundo*, where it was tallied on only one sample plot. Some of the stronger negative associations were *A. saccharum*, *Cercis canadensis*, *Fraximus Americana*, *Q. muehlenbergii*, *Q. rubra*, *Q. velutina*, and *R. pseudoacacia*.

An interesting finding is that even though different species may have the same affinity for particular site and habitat conditions, the species associations between the two may be negative. The two species may be in direct competition for resource space or there may be something in the past history of the site that has given advantage to one species over the other. For example, both *P. echinata* and *Q. velutina*. prefer the same xeric sites and soils, but studies on the Interior Highland have shown that *P. echinata* dominance increased with increasing fire frequency while *Q. velutina* decreased with increasing fire frequency (Batek and others 1999, Chapman and others 2006, Stambaugh and others 2002). Selective cutting with preference for *P. echinata* arguably could produce an opposite effect, where *Q. velutina* dominance would then prevail on such sites.

When the chi-square coefficient is used to study species associations it is important to be aware of the scale of the sample domain from which the sample is drawn because sample plots without either species in the test are construed as similar (Causton 1988). Therefore, the larger the domain that contains plots outside the range of interest, the more artificially similar the chi-square values will be. While this situation will not directly impact the results of studies that stand alone, comparing studies from different size sample domains and varying degrees of species homogeneity across the landscape would result in a less rigorous comparison. The sample domains should be as close to the same size and homogeneity as possible for direct comparison of chi-square values. Unfortunately, sample homogeneity (or lack thereof) is a problem for all aspects of multivariate analyses,

Table 3.—Chi-square values and species association of 52 tree species with *P. echinata* on the Interior Highland of Arkansas. Data are from 1995; n = 434. A + indicates a positive association, a – indicates a negative association. Column labeled 'Plots both present' indicates the number of plots where the respective species occurred with *P. echinata*. 'Total plots present' indicates the total number of plots where each species occurred.

Species	Chi-sq. value	Association	Plots both present	Total plots present
Juniperus virginiana L.	0.071	–	40	86
Pinus echinata Mill.				211
Pinus taeda L.	11.014	+	12	12
Acer barbatum Michx.	2.081	–	0	3
Acer negundo L.	0.001	–	0	1
Acer rubrum L.	4.413	–	38	98
Acer saccharum L.	12.740	–	5	31
Ailanthus altissima (Mill.) Swingle	0.449	–	0	2
Bumelia sp.	0.449	+	1	2
Carya sp. Nutt.	0.161	+	169	352
Carya illinoensis (Wangenh)K.Koch	0.449	+	1	2
Castanea sp. Mill.	0.001	+	1	1
Celtis laevigata Willd.	0.005	+	4	7
Celtis occidentalis L.	5.856	–	0	8
Cercis canadensis L.	17.228	–	1	23
Cornus florida L.	9.162	–	46	125
Diospyros virgininana L.	0.142	+	8	14
Fagus grandifolia Ehrh.	3.474	–	4	17
Fraxinus americana L.	24.175	–	11	60
Fraxinus pennsylvanica Marsh.	0.009	–	6	11
Fraxinus quadrangulata Michx.	0.449	+	0	2
Gleditsia triacanthos L.	0.200	–	1	4
Juglans nigra L.	9.955	–	4	25
Liquidambar styraciflua L.	10.473	+	59	92
Liriodendron tulipifera L.	0.449	+	1	2
Magnolia acuminata L.	1.359	–	1	6
Morus rubra L.	0.214	–	5	13
Nyssa sylvatica Marsh.	1.263	–	88	194
Platanus occidentalis L.	0.763	–	6	17
Prunus serotina Ehrh.	1.557	+	30	52
Quercus alba L.	0.490	+	165	332
Quercus falcata Michx.	0.795	+	44	82
Quercus falcata var. *pagodifolia* Ell.	0.118	+	3	6
Quercus macrocarpa Michx.	0.449	–	0	2
Quercus marilandica Muenchh.	0.617	+	33	61
Quercus michauxii Nutt.	0.449	–	0	2
Quercus muehlenbergii Engelm.	12.131	–	7	36
Quercus nigra L.	0.004	+	3	5
Quercus palustris Muenchh.	0.001	–	0	1
Quercus phellos L.	0.312	+	3	4
Quercus rubra L.	23.669	–	90	238
Quercus shumardii Buckl.	0.117	–	2	6
Quercus stellata Wangenh.	5.453	+	122	226
Quercus velutina Lam.	15.571	–	83	214
Robinia pseudoacacia L.	14.189	–	1	20
Sassafras albidum (Nutt.) Nees	0.763	–	6	17
Tilia americana L.	3.028	–	2	11
Ulmus alata Michx.	0.001	+	59	121
Ulmus americana L.	4.716	–	6	24
Ulmus crassifolia Nutt.	0.449	+	1	2
Ulmus rubra Muhl.	5.856	–	0	8
Ulmus serotina Sarg.	0.449	–	0	2

especially where endpoint references are essential (Legendre and Legendre 1998).

Studies such as this are important in uncovering specific species associations, especially those species with wide ecological amplitude such as *P. echinata*. Further work is needed on species associations of *P. echinata* across the eastern and southern part of its range to compare patterns of association with those of the Interior Highlands of Arkansas.

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GENETIC IMPROVEMENT OF SHORTLEAF PINE ON THE MARK TWAIN, OUACHITA, AND OZARK NATIONAL FORESTS

Charly Studyvin and David Gwaze[1]

ABSTRACT.—A genetic conservation and breeding program for shortleaf pine (*Pinus echinata* Mill.) was initiated in the 1960s by the Mark Twain National Forest in Missouri. Superior trees were selected from natural stands throughout the Forest. Fifty of the top-ranked superior trees were grafted into a first generation seed orchard at the Ouachita National Forest in central Arkansas. Major seed collections from the clonal seed orchard were made in 1981, 1983, 1986 and 2003. Thirteen open pollinated progeny tests were established in the early to mid-1980s to evaluate orchard parents and obtain data to rogue the orchard. About half of these tests were lost or severely damaged by severe heat and drought in 1980 and 1983. A control pollinated progeny test was established in 2002 to further evaluate parents in the seed orchard, and to develop a second generation seed orchard. Progeny test results suggested that genetic variation exists in shortleaf pine, and genetic gain is predicted to be significant.

Improvement of shortleaf pine by the Ouachita and Ozark National Forests in Arkansas began in the early 1960s with the selection of superior shortleaf pine trees on the Ouachita and Ozark National Forests. Fifty superior trees were selected from each of the following geographic sources: East Ouachita, West Ouachita, and Ozark. Scions were collected from these superior trees and grafted to root stock at the orchard. Once established, these grafts were outplanted into their respective blocks of the Ouachita seed orchard. Eighty-four progeny tests were established from controlled pollinated crosses in breeding population one of the Region 8 shortleaf pine breeding program. Several of these progeny tests were lost for a variety of reasons, including fire, animal damage, and unfavorable weather conditions. However, data from over 60 valid full-sib progeny tests were used to choose selections to be established in the second-generation orchard. Challenges and opportunities of the shortleaf pine tree improvement programs on the three National Forests are discussed.

INTRODUCTION

Shortleaf (*Pinus echinata* Mill.) is one of the four major southern pines in the United States. Shortleaf pine has the most extensive natural range of any southern pine (Lawson 1990). The natural range of the species extends from New York to Oklahoma and Texas over a very wide range of sites. Because of its wide distribution, considerable genetic variation exists (Lawson 1990). Shortleaf pine's genetic diversity makes it amenable to genetic improvement.

Shortleaf pine is important for both wildlife habitat and timber products. For example, red-cockaded woodpeckers (*Picoides borealis*) prefer mature or over-mature shortleaf pine forests and are endangered because of the overexploitation of mature shortleaf pine trees (Cunningham 1940). Shortleaf pine has excellent stem form yielding high-valued posts and poles. It has dense, strong, and easy to work wood valued as sawn timber and pulpwood.

Its ecological and economic importance, coupled with its genetic diversity, makes shortleaf pine an excellent candidate for genetic improvement. It has been the object of genetic breeding since 1959, when the selection and grading plans for shortleaf pine for the U.S. Forest Service's southern region (Region 8) were finalized (Kitchens 1986). Selection of superior shortleaf pine trees by the Mark Twain National Forest in southern Missouri, the Ozark National Forest in northwestern Arkansas, and the Ouachita National Forest in west-central Arkansas and southeastern Oklahoma began in the early 1960s.

The objective of this paper is to give a historical account of the shortleaf pine tree improvement activities on the Mark Twain, Ouachita, and Ozark National Forests and to discuss future options for the genetic improvement of shortleaf pine.

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[1] Silviculturist (CS), Mark Twain National Forest, 401 Fairgrounds Road, Rolla, MO 65401, Resource Scientist (DG), Missouri Department of Conservation, 1110 S. College Avenue, Columbia, MO 65201. CS is corresponding author: to contact, call (573)364-4621 ext. 430 or email at cstudyvin@fs.fed.us

FIRST-GENERATION SELECTIONS AND SEED ORCHARD ESTABLISHMENT

Region 8 tree improvement work with shortleaf pine in Arkansas and Oklahoma began with the selection of superior shortleaf pine trees on the Ouachita and Ozark National Forests. Selections were made on the following criteria: growth and form, insect and disease resistance, flowering and cone production, specific gravity, and relative location (FSH 2409.26g TREE IMPROVEMENT HANDBOOK R8 AMENDMENT 94-1). Fifty superior trees were selected from each of the following geographic sources: East Ouachita, West Ouachita, and Ozark (the dividing line between East and West Ouachita was US Highway 71). Region 9 decided to cooperate with Region 8 and use the facilities in Arkansas, since the Mark Twain was the only forest in Region 9 to plant shortleaf pine. A few years later superior trees were also selected from the Mark Twain National Forest in Missouri. Scions were collected from the superior trees and grafted to root stock at the orchard. Once established, these grafts were outplanted into their respective blocks of the Ouachita Seed Orchard located on the Womble District of the Ouachita National Forest. The seed orchard for the Mark Twain National Forest was located in Arkansas, rather than Missouri, because it was thought that establishing the orchard in a more southerly location would increase cone production and reduce age of flowering. It was also less expensive to establish a seed orchard on the Ouachita National Forest, where an active tree improvement program with necessary personnel, facilities, and equipment already existed. Grafts were planted at a spacing of 15 x 30 feet. When establishment was complete, the orchard contained over 35,000 grafted trees.

Acreage of orchard located on the Womble Ranger District, Ouachita National Forest, Mount Ida, Arkansas, by species and geographic source were:

East Ouachita	138 acres
Ozark	101 acres
West Ouachita	74 acres
Missouri-Mark Twain	85 acres

The total acreage inside the fence, including the buffer strips, is approximately 696 acres.

MANAGEMENT AND MAINTENANCE OF THE OUACHITA SEED ORCHARDS

A 400-foot-wide buffer strip surrounds the exterior of the orchard and separating the geographic sources. This buffer is for pollen exclusion and fire protection, and it is burned each year in the late winter. After the buffer strip was burned each year, and the stumps and holes could be clearly seen, it was bushhogged to knock down the brush and hardwood sprouts. Additional acreage surrounding the exterior of the orchard is burned every other year for fuel reduction. The interior of the orchard was bushhogged at least once and preferably twice during the year. Herbicide was used along the rows where the trees were spaced too closely to allow bushhogging without damaging the trees. The orchard was fertilized once a year with 300 lbs per acre of Ammonium Nitrate (34-0-0). This fertilization increased cone production, but it also seemed to increase the incidence of pitch canker. Fertilizer applications were discontinued after 1986, and problems with pitch canker decreased noticeably.

Insecticide was used for protection from cone and seed insects. The main problems were the Nantucket pine tip moth, cone worms of the *Dioryctria* species, and the shieldback and leaffooted pine seed bugs. In the early years Furadan® and Guthion® were used. A granular formulation of Furadan® was applied with a modified power till seeder, and Guthion® was applied with a mist blower sprayer. However, due to the uneven terrain and large size of the orchard, timing the applications for maximum effectiveness with these methods was extremely difficult; it took more than a month to treat the entire orchard. A cone inventory system was implemented to monitor insect damage, evaluate treatments, and estimate cone crops. Starting in 1983, a helicopter was used for aerial application of the insecticides Guthion® and Pydrin®. With aerial application the orchard could be sprayed in 4 or 5 hours. A degree-day model was used to time the sprays to the life cycle of the target insects, and the effectiveness of the treatments increased dramatically. We normally sprayed the orchard 4 to 5 times each year. Pydrin® was originally used for the first spray of the season, when the timing was the most critical, because of its longer residual effects. However, after it was discovered that Pydrin® caused a huge buildup of scale insects, its use was discontinued. The ability to effectively control the insects increased production of seed tremendously.

During large cone harvests, most of the 25 to 30 Womble district employees were assigned to the orchard. This arrangement helped to get the cones picked and also financed the district out of the “Working Capital” fund for about a month. Some of the employees worked on rental bucket trucks as cone-pickers, some worked to clean and measure cones, and some worked to administer the cone-picking contract. In the cone harvest of 1986 approximately 100 people (cone-picking contractors plus district employees) worked at the orchard during the cone-picking season, which lasted about 30 days. A harvest of 4,973 bushels of the Ouachita/Ozark and 1,506 bushels of Mark Twain shortleaf pine cones was produced. To anyone who has ever picked a bushel of shortleaf pine cones, that total of 6,479 bushels is an almost unbelievable quantity. It amounts to approximately 7 million pine cones, picked off the trees one at a time, cleaned, measured, crated, loaded on trucks and shipped to the extractory. The seed yield was very good at nearly 1.8 pounds per bushel, and more than 11,000 lbs of pine seed was extracted and placed in storage. The Ouachita/Ozark source was stored at the Forest Service's Ashe Nursery in Brooklyn, MS, and the Mark Twain source was stored at the Missouri Department of Conservation's George O. White State Forest Nursery in Licking, MO. Twenty years later, this seed is still being used for reforestation on national forests in Arkansas, Oklahoma, and Missouri, on state and private lands in Missouri, and in other states with need for shortleaf pine seedlings. After the large 1986 crop, no cones were picked at the orchard until 2003. Shortleaf pine does not regularly produce large cone crops, and few cones were available for picking during that time, partly due to lack of fertilization and attacks from cone and seed insects.

BREEDING AND PROGENY TESTING

The Ouachita was the first orchard in Region 8 to complete its breeding program (Shortleaf Pine Breeding Population 1). The breeding program consisted of twenty-five 6 x 6 disconnected partial diallel crossing groups, each with 15 crosses, for a total of 375 crosses. Sausage casings were used to enclose the flowers prior to pollen shed. Pollen catkins from the desired families were collected and dried, and the pollen was extracted. The bagged flowers were then pollinated with the appropriate pollen. The controlled pollinated flowers were tagged and efforts were made to protect them until they were mature cones ready to be picked approximately 18 months later. At maturity the cones were picked and the seed was extracted by hand. The seed was shipped to the Ashe Nursery in Mississippi for storage. The seed was later planted in separate lots to grow seedlings for planting in progeny tests. It was quite a logistical effort to maintain the integrity of each cross throughout the process. Note that one of the major problems with successful breeding in shortleaf pine is timing the controlled pollinations to the maximum receptivity of the flowers. A large surplus freeze dryer was acquired from the National Tree Seed Lab to store pollen so it would be available when needed, and just a few years later the breeding program was completed.

Progeny tests were planted and evaluated on the Ouachita and Ozark National Forests. The families evaluated in these tests were replicated in space and time. Eighty-four progeny tests were established. Several of these progeny tests were lost from a variety of reasons, including fire, animal damage, and unfavorable weather conditions. However, data from over 60 valid full-sib progeny tests were used to choose selections to be established in the second-generation orchard. Measurements included FYS (first year survival), FIE (first interval evaluation at 5 years of age), and SIE (second interval evaluation at 10 years of age). Approximately 20 percent of the families were selected to be represented in the second-generation orchard. These families were selected on the basis of survival, insect and disease resistance, straightness and form, and height and volume growth. A portion of the original orchard was cleared and both a breeding orchard and a production orchard were established. Scions were taken from the appropriate families in selected progeny tests, grafted to root stock, and planted at the orchard. The production orchard consists of 16 acres with 65 families represented. The breeding orchard consists of 11 acres with 61 families represented.

The Mark Twain breeding program consisted of eight 6 x 6 disconnected partial diallel Crossing Groups, each with 15 crosses, plus a single-pair mating design, for a total of 305 crosses. An additional 200 crosses between Mark Twain and Ozark material were planned, but only a few were actually accomplished. Of the nine open pollinated progeny tests (of Mark Twain parents at the Ouachita Orchard) established by the Mark Twain National Forest at 8 ft x 10 ft spacing from 1980 -1983, only two had good survival (Boiling Springs, Houston Ranger District, 1982 and 1983). A third (Enough Plantation, Potosi Ranger District, 1982) had moderate survival and may help corroborate longer-term growth and form data. The original four evaluation plantations on the Mark Twain were established in the spring of 1980, and subsequently died in that summer's severe heat and drought. Five more plantations were established, two in 1982, and three in 1983. Due to unfavorable weather conditions and episodic insect damage from pine sawflies, only two of those tests had acceptable survival. Of four additional close spacing progeny tests of both containerized and bareroot seedlings established at the George O. White State Forest Nursery at Licking, MO, and on the Shawnee National Forest in Illinois in 1986, the Licking tests have provided some useful information. No full sib progeny test data are available for the Mark Twain material.

In 2002 a full-sib progeny test was planted at the George O. White State Forest Nursery at Licking, MO, with controlled crosses from the Mark Twain breeding program. Plans are to rogue and thin this progeny test to convert it to a seedling seed orchard.

U.S. Forest Service Eastern Region (Region 9) progeny tests indicate that all growth traits are strongly inherited, with age 17 family heritability estimates for height, diameter, and volume being 0.46, 0.31 and 0.46, respectively (Gwaze et al. 2005). Genetic correlations between growth traits were highly positive, suggesting that one can select and breed for one trait without affecting the others. Genetic gain estimates for volume are high (Gwaze et al. 2005). If the seed orchard is not rogued and all families are allowed to cross pollinate genetic gain in volume production is predicted to be 6.7 percent and 27.2 percent for 10-year and 17-year volume, respectively. Roguing the seed orchard by leaving the top 50 percent of the families results in a 17.8 percent and 37.6 percent gain in volume at 10 and 17 years, respectively. Genetic gains in 5-year volume of 10-15 percent from the first generation unrogued shortleaf pine seed orchard have been predicted in Arkansas (Kitchens 1986). Analyses of 30 full-sib progeny tests on the National Forests in Arkansas revealed that 5-year height and survival among the three seed sources—East Ouachita, West Ouachita and Ozark—were not significantly different (La Farge 1991). It was recommended not to keep these sources as separate breeding populations.

POLITICS AND ADMINISTRATION

In August 1990, Forest Service Chief Dale Robertson took the famous "walk in the woods" with Arkansas Senator David Pryor and decided that the major emphasis on clearcutting was a thing of the past. Almost overnight, the status of tree improvement went from favorite son to bastard child. Artificial regeneration and genetically improved seedlings became politically incorrect. Ecosystem management was the new buzzword, along with natural regeneration and uneven-aged management. The use of artificial regeneration was reduced dramatically, along with the need for shortleaf pine seed.

A few years later the Forest Service changed its budget process. Previously, funds identified for tree improvement were sent to the forests from the Regional Office. Now, each year the forests would prioritize funding requests to the Regional Office, and projects low on the priority list might not be funded. Tree improvement did not compete well in an era of shrinking budgets and immediate needs because of its lowered status and the long-term nature of the effort. In effect, tree improvement has nearly been unfunded out of existence. The Region 8 geneticist has stated that the tree improvement program's objective for quality timber became obsolete, and as a result some orchard components and all progeny testing were terminated (Crane 2005).

THE PENDULUM SWINGS BACK

A major epidemic of southern pine beetle occurred in the mid to late 1990s. Damage occurred on forests throughout Region 8, including the thousands of acres affected by southern pine beetle on the Ouachita National Forest. In December of 1999 a severe ice storm damaged or destroyed large acreages of timber in Arkansas. Serious problems with oak decline developed in both Arkansas and Missouri. Thousands of acres of black, red, and scarlet oaks growing on dry, rocky sites on the Mark Twain National Forest are at severe risk of oak decline. These sites were historically populated by shortleaf pine, and the new forest plans on the Mark Twain, Ouachita, and Ozark National Forests emphasize the restoration of historic vegetation. Once again, there was a need for reforestation using shortleaf pine seedlings. The value of the shortleaf pine tree improvement program became more evident with the realization that appreciable quantities of improved shortleaf pine seed of suitable geographic origin were not available anywhere—except at the Ouachita Seed Orchard.

During the ice storm in 1999, many trees at the orchard were damaged or destroyed. A large cleanup was required. The Missouri source had been in need of a thinning for several years. However, the Mark Twain did not want to thin until progeny test data for rouging were available. Missouri progeny test data became available about this time, and in the Missouri portion of the orchard a major rouging operation was accomplished along with the cleanup. Seventeen of the original 50 clones were removed. Partly as a result of the opening up of the orchard, a good cone crop was available for picking in 2003. The Ouachita and the Mark Twain National Forests were able to successfully collect a large number of these cones and now have a large supply of fresh shortleaf pine seed. The Ouachita picked a total of 1000 bushels from the Ozark, West Ouachita, and East Ouachita sources, with a seed yield of 1.34 lbs per bushel, for a total of 1343 lbs of seed. The Mark Twain picked 1100 bushels with a seed yield of 1.385 pounds/bushel for a total of 1523 lbs of seed. Soon after the Mark Twain seed was safely stored at the nursery in Watersmeet, MI, an agreement was initiated to transfer the remaining inventory of 1986 seed in storage at the Licking Nursery to the Missouri Department of Conservation. In return the Missouri Department of Conservation agreed to produce shortleaf pine seedlings for the Mark Twain National Forest.

What's Next for Shortleaf Pine Tree Improvement in Arkansas?

- Continue to maintain the Ouachita Seed Orchard for future seed collections.
- Use the wealth of data available from the Ouachita and Ozark progeny tests to study the genetics of shortleaf pine.
- Manage selected progeny tests for future seed collection areas.
- Use genetic resource management to focus on genetic diversity and to meet the seed needs for restoration of endangered ecosystems.
- Manage the Second Generation production and breeding orchards for future seed collections and breeding work.
- DNA testing? New selections?

What's Next for Shortleaf Pine Tree Improvement in Missouri?

- Convert the full-sib progeny test established in 2002 at Licking Nursery to a seedling seed orchard.
- Establish another progeny test/seedling seed orchard on the Mark Twain with some of the remaining seed from controlled crosses.
- Develop a strategy to obtain shortleaf pine seed for direct seeding, either from surplus seed orchard seed, or perhaps from seed production areas established in 1967 or subsequent progeny tests, if they can be managed effectively for seed production.

- Evaluate the genetic variation and population structure in shortleaf pine using micro-satellite genetic markers to help manage and maintain genetic diversity.

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PERFORMANCE OF SHORTLEAF PINE PROVENANCES IN MISSOURI

David Gwaze, Jennifer Myszewski, and John Kabrick[1]

ABSTRACT.—Two shortleaf pine (*Pinus echinata* Mill.) provenance tests established by the USDA Forest Service North Central Research Station as part of the South-wide Southern Pine Seed Source Study were examined to determine the most suitable seed sources for planting in Missouri. Each test comprised seven different provenances from six to seven states in the natural shortleaf pine distribution. Significant provenance differences in survival and height growth were found in both tests and a strong north-south trend was observed. More northernly sources (New Jersey and Tennessee provenances) had the best survival and greatest height growth while southern sources (Georgia and Louisiana) had the poorest survival and lowest height growth. Regression estimates of slope indicate that New Jersey and Tennessee provenances have the highest relative growth rates. Both survival and height were highly correlated with latitude at the seed source. Results from this study suggest that the best seed sources for planting in central Missouri are not those from Arkansas, as current practice suggests, but instead are in states in the northern portion of the natural shortleaf pine distribution.

INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.), whose natural range extends from New York and New Jersey south to Florida and west to Oklahoma and Texas, is the most widely distributed of the southern pines (Fig. 1, Lawson 1990). It is the only pine species native to Missouri and its restoration there is important for mitigating chronic oak decline (Law et al. 2004). Shortleaf pine is also an important source of food and habitat for many birds and mammals, and it produces high quality sawtimber on dry, nutrient-poor sites.

Efforts to restore shortleaf pine in Missouri are ongoing, but seed supply is sometimes limited. When seedling shortages occur, Arkansas seed sources are often used in place of locally-adapted stock. It is not known whether Arkansas sources are the most appropriate non-local seed sources for planting in Missouri. However, region-wide seed transfer guidelines for shortleaf pine suggest that Arkansas sources could suffer from cold injury when planted in central Missouri.

Studies such as the South-wide Southern Seed Source Study have shown that local sources are not always the best source of planting stock for afforestation (Wells and Wakeley 1966, Wells 1983). For example, loblolly pine seed originating in Livingston Parish, LA, tends to be fast growing and more resistant to fusiform rust than other sources (Wells 1985). As a result, Livingston Parish stock has been widely planted in Georgia, north Florida, and Alabama in lieu of stock from local sources. Likewise, seeds originating on the coastal plain of North Carolina and South Carolina are frequently planted in Arkansas, where they outgrow local sources (Lambert et al. 1984).

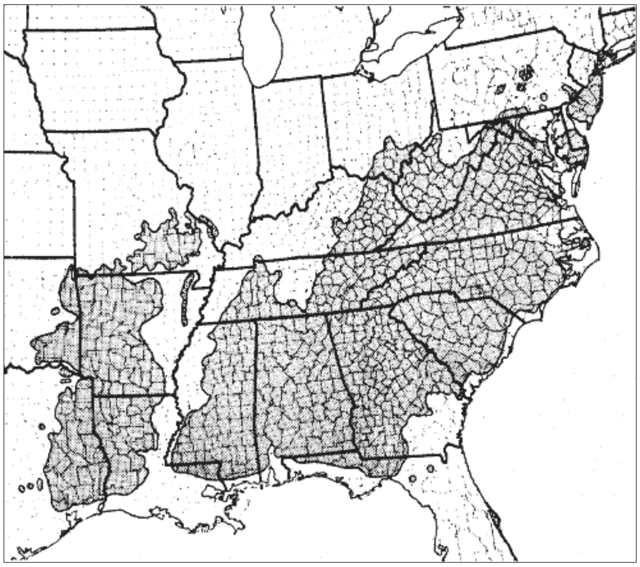

Figure 1.—Natural distribution of shortleaf pine (*Pinus echinata* Mill.) (Lawson 1990).

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[1] Resource Scientist (DG), Missouri Department of Conservation, 1110 S. College Avenue, Columbia, MO 65201; Geneticist (JM), Southern Institute of Forest Genetics, 23332 Hwy. 67, Saucier, MS 39574-9344; Research Forester (JK), U.S. Forest Service, North Central Research Station, 202 Natural Resources Building, Columbia, MO 65211. DG is corresponding author: to contact call (573)882-9909 ext. 3320 or email at David.Gwaze@mdc.mo.gov

In this study, the performance of seed sources from across the natural range of shortleaf pine are compared to determine which sources are best adapted to the environmental conditions in Missouri. The stability of provenance performance across ages is also examined.

MATERIALS AND METHODS

Materials

Two Dent County, Missouri provenance tests (441 and 444) were included in this study. Both were originally established by the USDA Forest Service's North Central Research Station in collaboration with the Committee on Southern Forest Tree Improvement as part of the South-wide Southern Pine Seed Source Study. In 1951 and 1955, seed was collected from multiple sources within the eastern part of the natural range of shortleaf pine (table 1). Source locations from as far north as New Jersey, south to Georgia and west to Louisiana were selected based primarily on their average annual temperatures (which ranged from 11.7 to 19.4 °C). At each source, seed were collected from 20 or more average-appearing trees to produce a representative sample of genotypes from each location. Each source collection was then mixed together and assigned a provenance number.

Seed for the two tests were sown and bedded at the George O. White Forest State Nursery near Licking, MO. After 1 year in the nursery, bare-root seedlings were lifted and graded. Then, seedlings were root pruned to about 20 cm and the best trees were outplanted on the Sinkin Experimental Forest located 5 miles northwest of Bunker in Dent County, Missouri (Lat. 91° 15'; Long. 37° 30', Alt. 380 m above sea level). In Spring 1953, Test 441 was planted using the seed collected in 1951 and in Spring 1957, Test 444 was planted using seed collected in 1955.

Test Design and Measurement

Test 441 and Test 444 were both established using a randomized complete block design (Snedecor and Cochran 1980). For each test, there were four blocks comprising seven provenances. Each provenance was planted in square plots of 11 x 11 tree planted at 1.8 x 1.8 m spacing. To minimize edge effects, only the center 49 trees in each square plot were measured. Tests 441 and 444 were assessed at ages 1, 3, 5, 10, 15, 20, 25, and 30. Because of large differences in survival and the sensitivity of diameter to competition, only survival and height were analyzed in this study.

Table 1.—Description of the shortleaf pine provenances planted in two tests in Dent County, Missouri.

Test	Year of collection	Provenance Number	State	County/Parish	Lat. (North)	Temp.* (°C)
441	1951	429	Arkansas	Ashley	33° 02'	-11.6
		427	Arkansas	Clark	34°	-11.8
		421	Louisiana	St. Helena	31°	-8.1
		419	Mississippi	Lafayette	34° 18'	-13.8
		433	Missouri	Dent	37° 31'	-20.2
		403	New Jersey	Burlington	39° 41'	-18.9
		435	Tennessee	Morgan	36°	-16.2
444	1955	465	Georgia	Webster	32°	-9.3
		473	Louisiana	St. Helena	31°	-8.1
		485	Missouri	Dent	37° 31'	-20.2
		453	New Jersey	Burlington	39° 41'	-18.9
		457	South Carolina	Union	35°	-12.0
		487	Tennessee	Anderson	36°	-16.2
		455	Virginia	Southampton	36°	-14.1

*Average annual minimum temperature

Statistical Analyses

Using the SAS PROC GLM procedure (SAS Institute 1985), analyses of variance (ANOVAs) were used to test for significant differences in height among provenances and blocks. To increase statistical power, we used P = 0.10 for all tests. Because the two provenance tests were established in different years, the data were analyzed separately by provenance test. Where significant differences were detected among provenances, Duncan's Multiple Range Test was used to compare means.

The stability of provenance growth rates was determined by regressing the provenance mean height against the overall test mean height at each age. The slope of the regression evaluates the provenance height growth trend in relation to the average trend and can be considered as a temporal stability parameter for the given provenance (Finlay and Wilkinson 1963). A value close to 1 indicates an average trend, values over 1 indicate a higher growth rate, and values below 1 indicate a lower growth trend.

Survival was analyzed using a chi-squared test. Only survival data for ages 1 through 15 were analyzed because the tests were thinned after collection of the 15-year data. We used the Kaplan-Meier method (Kaplan and Meier 1958) to compare the survival functions of the different provenances.

To determine the importance of climatic variables, simple linear regression analyses were performed with survival and height as dependent variables and latitude as the independent variable.

RESULTS AND DISCUSSION

Provenances had significantly different mean heights at age 30 (P < 0.1, Tables 2 and 3). Height ranged from 14.4 m for the Louisiana provenance to 16.2 m for the New Jersey provenance in Test 441 and from 13.0 m for the Louisiana provenance to 15.6 m for the New Jersey provenance in Test 444. In both tests, the New Jersey provenance was significantly taller than the local Missouri provenance and the Missouri provenance was significantly taller than the Arkansas provenances.

The north-south trend is supported by a high positive correlation between height and latitude in both tests (Table 4). The superior performance of northern sources observed in this study is not consistent with the results of provenance studies in other states. In Oklahoma, Tauer (1980) found that southern sources of shortleaf pine were more productive at age 20 than northern sources of shortleaf pine. Similarly, Schmidtling (1995) and Wells and Wakeley (1966) found that seeds moved a modest distance northward out-performed seeds from local sources. According to Schimdtling (2001) seedlings will survive and grow well if they come from any area having a minimum temperature within 2.8 °C of the planting site's minimum temperature. Seedlings from an area with cooler winters will grow slower than seedlings from local sources. In our study, the provenance from New Jersey was collected on sites with annual minimum temperatures within 2.8 °C of those in Dent County, Missouri. Provenances collected in Mississippi, Tennessee, South Carolina, and Virginia came from sites within 2.8 to 8.4 °C higher than those of Dent County in Missouri. However, provenances collected in Arkansas, Georgia, and Louisiana came from sites with annual minimum temperatures 8.4 to 14 °F higher than those of Dent County, Missouri. It appears that the north-south

Table 2.—Summary of the analyses of variance for age 30 height in two shortleaf pine provenance tests in Missouri⁺.

Test	Source	DF	Mean Square
441	Block	3	2.5*
	Provenance	6	1.9*
	Residual	18	0.7
444	Block	3	2.4^{ns}
	Provenance	6	3.3*
	Residual	18	1.2

⁺Significance level: *P < 0.1; ns = not significant

Table 3.—Provenance means for age 30 height growth in two shortleaf pine provenance tests in Missouri⁺.

Test	Provenance Number	Provenance (Country/Parish)	HT (m)
441	429	Ashley, AR	14.9^{cd}
	427	Clark, AR	14.9^{abc}
	421	St. Helena, LA	14.4^{d}
	419	Lafayette, MS	15.9^{abc}
	433	Dent, MO	15.2^{abc}
	403	Burlington, NJ	16.2^{a}
	435	Morgan, TN	16.1^{ab}
444	465	Webster, GA	13.6^{b}
	473	St. Helena, LA	12.2^{c}
	485	Dent, MO	13.5^{bc}
	453	Burlington, NJ	15.2^{a}
	457	Union, SC	13.7^{ab}
	487	Anderson, TN	14.3^{ab}
	455	Southampton, VA	14.8^{b}

⁺Means with the same letter are not significantly different at the 10% level on a Duncan's Multiple Range Test.

Table 4.—Estimated regression coefficients based on linear models for survival and latitude, and height and latitude of shortleaf pine in two provenance tests in Missouri.

Test	Dependent variable	Independent variable	Regression coefficient (slope)	Residual mean square	DF	R^2
441	Height	Latitude	0.18	0.10	5	0.62
	Survival	Latitude	4.19	63.88	5	0.76
444	Height	Latitude	0.26	0.44	5	0.56
	Survival	Latitude	3.63	47.40	5	0.77

trend observed in this study is the result of moving seed to a site with much colder annual minimum temperatures.

A similar north-south trend was found in percent survival (Figs. 2 and 3). The survival functions were significantly different in Test 441 (χ^2 = 388.3, P = <0.001) and in Test 444 (χ^2 = 297.9, P = <0.001). Similarly, the chi-square test at age 15 showed significant survival differences among provenances in Test 441 (χ^2 = 27.8, P = <0.001) and in Test 444 (χ^2 = 13.9, P = 0.031). In Test 441, survival at age 15 ranged from 23.5 percent for the Louisiana provenance to 62.2 percent for the New Jersey provenance and in Test 444, from 31.1 percent for the Georgia provenance to 69.4 percent for the Missouri provenance. Survival was positively correlated with latitude (r = 0.76 and 0.77 for Tests 441 and 444, respectively) (Table 4). In the past, Missouri has obtained seed from Arkansas for its restoration programs. Results from this study suggest that while northern Arkansas sources may survive well, the more southern sources break the seed transfer guidelines and could have poor survival.

Stability of Provenances Across Ages

When the mean heights of each provenance were regressed on the overall test means, the linear equations were highly significant (R^2 = 1.00). Differences in the relative growth rate of the provenances were evidenced by differences in the slopes of the regression lines for each provenance (Table 5). Growth rate is important as it can be a more efficient selection parameter than early total height because some provenances can be slow starters and outperform the early starters with time. In this study, provenances with high early height growth also had the highest relative growth rates.

Correlations

Correlations between height at the oldest assessed age in each test and height at earlier measurement ages are presented in Table 6. As expected, the correlations increased as the time between ages decreased. Correlations involving heights at a young age were very low, with a negative correlation between heights at age 1 and 30 in Test 444. In general, heights assessed prior to age 10 years were not reliable predictors of height at the oldest assessed age. These findings are in close agreement with those of Lambeth (1980), who reported poor age-age correlations in several *Pinaceae* species when heights at ages less than 4 years were used. Possible explanations for the low correlations in this study include post-planting stress and browsing.

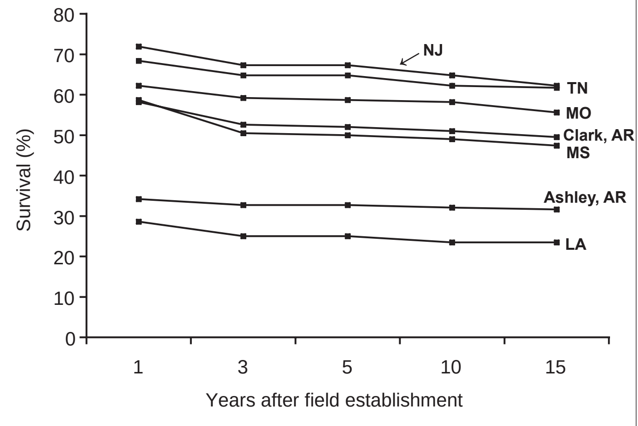

Figure 2.—Survival of shortleaf pine provenances established in Missouri in Test 441.

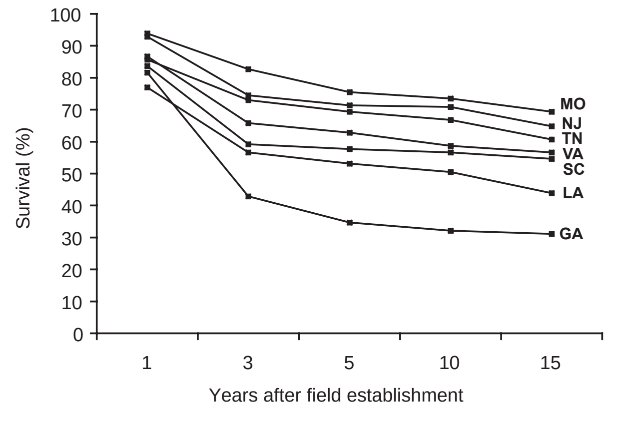

Figure 3.—Survival of shortleaf pine provenances established in Missouri in Test 444.

Table 5.—Estimated regression coefficients based on linear models for mean height of each provenance and test mean height for two shortleaf pine provenance tests in Missouri.

Test	Provenance number	Provenance	Regression coefficient (slope)	Residual mean square	DF	R^2
441	429	Ashley, AR	0.972	0.0045	6	1.00
	427	Clark, AR	0.968	0.0286	6	1.00
	421	St. Helena, LA	0.958	0.0003	6	1.00
	419	Lafayette, MS	1.019	0.0149	6	1.00
	433	Dent, MO	0.998	0.0088	6	1.00
	403	Burlington, NJ	1.050	0.0106	6	1.00
	435	Morgan, TN	1.037	0.0026	6	1.00
444	465	Webster, GA	0.929	0.0706	6	1.00
	473	St. Helena, LA	0.909	0.0201	6	1.00
	485	Dent, MO	0.985	0.0019	6	1.00
	453	Burlington, NJ	1.102	0.0045	6	1.00
	457	Union, SC	0.998	0.0381	6	1.00
	487	Anderson, TN	1.035	0.0136	6	1.00
	455	Southampton, VA	1.039	0.0076	6	1.00

Table 6.—Pearson product-moment correlation coefficients between heights at age 30 and heights at earlier measurement ages in two provenance tests in Missouri.

Test 441		Test 444	
Age	Correlation	Age	Correlation
1	0.16*	1	-0.13*
3	0.40*	3	0.10
5	0.54*	5	0.23*
10	0.69*	10	0.57*
15	0.83*	15	0.70*
20	0.88*	20	0.83*
25	0.94*	25	0.90*

*Significant at 0.05 or lower

CONCLUSION

Significant differences in the survival and height growth of trees with different seed origins were identified in two shortleaf pine provenance tests established in Dent County, Missouri. There was a north-south trend in survival and height growth with the northern sources tending to have better survival and height growth than the southern sources. In both tests, trees from New Jersey and Tennessee had the highest rate of survival and the greatest height growth while trees from Louisiana and Georgia performed the poorest. Results from this study suggest northern seed sources should be favored for planting in Missouri.

ACKNOWLEDGMENTS

The study was supported by the USDA Forest Service North Central Research Station and the Southern Forest Tree Improvement Committee. We thank Ken Davidson for providing information on the study and Jillian Lane for assistance with statistical analyses.

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LOBLOLLY PINE SSR MARKERS FOR SHORTLEAF PINE GENETICS

C. Dana Nelson, Sedley Josserand, Craig S. Echt, and Jeff Koppelman[1]

ABSTRACT.—Simple sequence repeats (SSR) are highly informative DNA-based markers widely used in population genetic and linkage mapping studies. We have been developing PCR primer pairs for amplifying SSR markers for loblolly pine (*Pinus taeda* L.) using loblolly pine DNA and EST sequence data as starting materials. Fifty primer pairs known to reliably amplify polymorphic markers in loblolly pine were screened for their use in shortleaf pine (*P. echinata* Mill.), longleaf pine (*P. palustris* Mill.), and slash pine (*P. elliottii* var. *elliottii* Engelm.). Thirty-four of these generated “high-quality” marker data for a small range-wide sample of shortleaf pines and 32 were polymorphic. Expected heterozygosities for the polymorphic markers averaged 0.71 and ranged from 0.40 to 0.88. A subset of the polymorphic markers should be very useful for determining identity or parentage of unknown trees while the whole set should provide excellent information on genetic diversity, gene flow, and population structure in shortleaf pine.

INTRODUCTION

Microsatellite, or simple sequence repeat (SSR), markers have been used to characterize factors affecting pollen flow in shortleaf pine stands in southern Missouri (Dyer and Sork 2001), and to study local and range-wide population histories in loblolly pine (Al-Rabab’ah and Williams 2002, 2004). Although isozyme markers have proven useful in studying shortleaf pine populations (Edwards and Hamrick 1995, Huneycutt and Askew 1989, Raja and others 1997), it is desirable to develop DNA-based markers for use in detailed studies of local and/or range-wide population dynamics. Most SSR marker development work in pines to date has centered on loblolly pine (*Pinus taeda* L.), a close relative of shortleaf pine (*P. echinata* Mill.). Given these facts, we have begun developing SSR markers for use in various other southern pine species. In the current study we tested a selected set of 50 loblolly pine SSR markers on a sample of 6 shortleaf pine trees. In addition, our test included a loblolly pine control sample and two samples each of longleaf pine (*P. palustris* Mill.) and slash pine (*P. elliottii* var. *elliottii* Engelm.).

MATERIALS AND METHODS

Fifty SSR primer pairs that were developed from loblolly pine DNA and characterized as high-quality genetic markers based on their reliable and repeatable amplification and detection in loblolly pine were tested in this study (Tables 1 and 2). Six shortleaf pine, two longleaf pine, two slash pine and two loblolly pine trees were used in testing the 50 primer pairs. The six shortleaf pine trees were all growing on the Harrison Experimental Forest in southeast Mississippi. Four trees were selected from four different provenances that were growing in a range-wide provenance test (Wells and Wakeley 1970). The sources included Southampton County, VA (source 455), Putnam County, GA (463), St. Helena Parish, LA (473), and Dent County, MO (485). The remaining two shortleaf pine trees were first-generation parent trees growing in a clone bank. Both of these trees originated in the Ozark National Forest in Arkansas.

Genomic DNA was isolated from fresh leaf samples from each tree using a DNeasy^{tm} 96 Plant Kit (Qiagen cat. no. 69181). The 50 primer pairs were screened with genomic DNA using the following PCR protocol for each 12 µl total volume reaction: 20 ng genomic DNA, 200 µM of each primer, 200 µM dNTPs, 1x *Taq* buffer (2.0 mM $MgCl_2$, 10 Mm Tris-HCl, 50 mM KCl), and 0.5 U *Taq* DNA polymerase (Promega). The PCRs were completed using the following touchdown protocol on PTC-200 thermal cyclers (MJ Research): 2 min at 94 °C; followed by 20 cycles of 30 s at 94 °C, 30 s at X, and 30 s at 72 °C, where X = 65 °C in the first cycle, decreasing by 0.5 °C every cycle thereafter; followed by 15 cycles of 30 s at 92 °C, 30 s at 55 °C, and 1 min at 72 °C; followed by a 15-min extension at 72 °C and an indefinite hold at 4 °C. The resulting PCR products were separated on an ABI PRISM 3100 Genetic Analyser (Applied Biosystems) as recommended by the manufacturer. ABI PRISM LIZ500 was used as an internal size standard. Allele sizes (in base pairs [bp]) were determined using the local southern algorithm implemented by ABI Prism

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[1] Research Geneticist and Project Leader (CDN), Biological Science Technician (SJ), and Research Geneticist (CSE), Southern Institute of Forest Genetics, USDA Forest Service, 23332 Mississippi 67, Saucier, MS 39574; Resource Scientist (JK), Missouri Department of Conservation, Columbia, MO 65201. CDN is corresponding author: to contact call (228) 832-2747 or email at dananelson@fs.fed.us

Table 1.—Allelic summary for 34 loblolly pine SSR markers screened for variability in shortleaf pine (n=6 trees), longleaf pine (n=2), and slash pine (n=2). Loci prefixes PtTX (Auckland and others 2002), ript (Echt and Nelson unpublished), and RPtest (Echt and Burns 1999). Min and max are range of allele sizes (base pairs), H_e is Nei's (1978) genetic diversity, and A_n is total number of alleles observed.

	Shortleaf				**Longleaf**			**Slash**		
Marker	**min**	**max**	**He**	**An**	**min**	**max**	**poly[1]**	**min**	**max**	**poly[1]**
PtTX2123	188	197	0.40	3	197	197	0	194	197	0
PtTX3011	160	212	0.70	5	160	185	1	160	.	0
PtTX3013	121	137	0.63	4	131	140	1	137	141	1
PtTX3029	258	261	0.49	2	267	271	1	262	.	0
PtTX3034	188	208	0.81	7	217	225	1	200	208	1
PtTX3052	239	259	0.70	4	239	259	1	240	259	1
PtTX4058	125	156	0.83	7	146	148	1	146	.	0
PtTX4093	170	323	0.84	8	474	.	0	319	.	0
PtTX4181	368	415	0.83	9	387	411	1	375	.	0
PtTX4205	134	153	0.78	5	134	146	1	.	.	.
PtTX4221	177	193	0.47	2	195	.	0	195	199	1
PtTX4228	141	166	0.76	5	156	160	1	158	162	1
ript0031	243	282	0.82	7	228	228	0	234	.	0
ript0065	130	145	0.51	4	142	142	0	142	144	1
ript0066	117	117	0	1	110	.	0	106	.	0
ript0079	136	171	0.74	4	142	159	1	146	152	1
ript0126	162	214	0.76	6	184	186	1	180	200	1
ript0165	196	209	0.61	3	192	200	1	194	198	1
ript0171	203	213	0.66	4	201	218	1	193	207	1
ript0211	144	160	0.74	5	148	157	1	138	154	1
ript0293	178	189	0.42	2	.	.	.	183	.	0
ript0367	191	213	0.74	4	189	209	1	191	.	0
ript0369	165	178	0.72	4	159	171	1	182	.	0
ript0376	185	200	0.81	7	196	200	1	181	196	1
ript0388	192	212	0.82	7	200	204	1	.	.	.
ript0467	158	185	0.88	9	153	169	1	186	.	0
ript0567	150	180	0.61	5	.	.	.	.	.	.
ript0619	184	206	0.80	6	200	208	1	208	212	1
ript0629	153	167	0.78	6	147	165	1	157	175	1
ript0852	199	205	0.74	5	191	.	0	203	209	1
ript0968	177	222	0.78	6	206	210	1	198	214	1
ript0984	212	237	0.75	6	217	.	0	217	.	0
RPtest9	273	295	0.79	5	278	.	0	257	.	0
RPtest11	218	218	0	1	218	.	0	218	.	0
Mean			0.67	4.9						
Total[2]							22			16

Note: SSR markers tested and not recommended for use in shortleaf pine: PtTX3047, PtTX3063, PtTX3087, PtTX3110, ript0032, ript0106, ript0123, ript0158, ript0255, ript0263, ript0287, ript0647, ript0649, ript0814, ript0990, and ript1077.

[1] poly = polymorphic score: 1 = more than 1 allele observed, 0 = 1 allele, . = 0 alleles.

[2] 32 of these 34 markers are polymorphic in shortleaf pine.

Table 2.—GenBank accession and dbSTS numbers for markers not previously described.

Marker	Acc#	dbSTS#
ript0031	BV683043	814084
ript0065	BV683047	814088
ript0066	BV683048	814089
ript0079	BV683053	814094
ript0126	BV683062	814103
ript0165	BV683070	814111
ript0171	BV683072	814113
ript0211	BV683076	814117
ript0293	BV683078	814119
ript0367	BV683081	814122
ript0369	BV683082	814123
ript0376	BV683083	814124
ript0388	BV683084	814125
ript0467	BV683150	814191
ript0567	BV683089	814130
ript0619	BV683091	814132
ript0629	BV683094	814135
ript0852	BV683115	814156
ript0968	BV683124	814165
ript0984	BV683125	814166

GeneMapper® software version 3.7. Due to mobility shift problems associated with the 250 bp and 340 bp bands, these sizes were excluded from all sizing calls. Allelic data were analyzed by standard genetic methods using SAS (SAS Institute).

RESULTS AND DISCUSSION

Of the 50 SSR primer pairs tested, 34 were characterized as "high quality" for use in population genetic analyses of shortleaf pine (Table 1; GenBank and dbSTS accession numbers for previously unreported loci are given in Table 2). These markers met criteria based on clean PCR amplification with low failure rates. Of the 32 markers that were polymorphic in shortleaf pine (Table 1), 30 and 29 cleanly amplified longleaf pine and slash pine DNA, respectively. Within this select group, 22 markers for longleaf pine and 16 markers for slash pine appeared to be polymorphic within these two species (Table 1). Although our diversity measure (i.e., expected heterozygosity, He) is based on only six shortleaf pine trees, it does suggest that these markers are at least as heterozygous as they are for loblolly pine. In fact, the average diversity of the 32 polymorphic markers is 0.71 for this sample of shortleaf pine compared to 0.68 for a similar range-wide sample of loblolly pine (Nelson unpublished). The correlation between shortleaf pine and loblolly pine diversity values is 0.42, suggesting that one cannot predict with any certainty diversity rates for individual SSR markers between these two species. Genetic drift since divergence from a common ancestor is a likely explanation for these results.

The transferability of loblolly pine SSR markers to shortleaf pine, longleaf pine, and slash pine was evaluated by comparing amplification and polymorphism results for two samples from each species. Four shortleaf pine trees were evaluated—two from Arkansas and one each from Louisiana and Georgia. As described in the Materials and Methods, two each of longleaf pine and slash pine trees of Mississippi origin were evaluated. Results of this comparison are provided in Table 3. Transfer rate of polymorphic markers was higher for shortleaf pine (70 percent and 72 percent) than for longleaf pine (54 percent) or slash pine (44 percent). The rate for longleaf pine is comparable to that reported by Shepherd and others (2002), who found 53 percent (19 of 36) of loblolly pine SSR markers polymorphic in slash pine and Caribbean pine (*P. caribea* Morelet). In contrast, Liewlaksaneeyanawin and others (2004) reported only 22 percemt (23 of 107) to be polymorphic in lodgepole pine (*P. contorta* Dougl. ex Loud.). The close phylogenetic relationship of loblolly pine to the other southern U.S. pines, particularly shortleaf pine, and the more distant relationship of loblolly pine to lodgepole pine (Little and Critchfield 1969) is a likely explanation for these results.

Polymorphism (i.e., two or more alleles detected) rates based on pairs of trees from the same area are also higher for shortleaf pine from the two sample areas (78 and 81 percent, calculated from Table 3) than for longleaf pine and slash pine (68 and 54 percemt, respectively). These rates are consistent with previous isozyme data that show longleaf pine to be less genetically diverse than shortleaf pine (Schmidtling and Hipkins 1998). The degree to which polymorphism can be predicted based on only two samples (four chromosomes in a diploid species) was evaluated by

Table 3.—Transfer of 50 loblolly pine SSR markers to shortleaf pine, longleaf pine, and slash pine.

Species	Origin of Sample Pair	Number (%) Amplified	Number (%) Polymorphic
Shortleaf	Arkansas	46 (92)	36 (72)
Shortleaf	Louisiana and Georgia	43 (86)	35 (70)
Longleaf	Mississippi	40 (80)	27 (54)
Slash	Mississippi	41 (82)	22 (44)

comparing the two-sample estimates from shortleaf pine with the six-sample (12 chromosomes) estimate. Based on six samples, 46 of the 50 markers were cleanly amplified and 41 were polymorphic (data not shown), indicating that the two-sample data underestimated the polymorphism rate by about 10 percent. Thus we might expect the actual polymorphism rates for these markers in longleaf pine and slash pine to be higher.

CONCLUSION

Loblolly pine SSR primer pairs proved to be a very good source of genetic markers for shortleaf pine, as well as for longleaf pine and slash pine. Thirty-two out of 50 PCR primer pairs successfully amplified high quality, polymorphic SSR markers in shortleaf pine. We are currently evaluating additional loblolly pine SSR markers. Based on the results of this study, we expect that a relatively high proportion of these markers will be transferable to shortleaf pine. With an average expected heterozygosity of about 0.70, these markers should provide a valuable tool in species restoration and conservation programs that require population genetic data and analysis.

ACKNOWLEDGMENTS

We thank Larry Lott and Dennis Deemer (Southern Institute of Forest Genetics), respectively, for making sample collections and assisting in scoring with GeneMapper, and Tom Kubisiak for helpful comments in review.

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CHROMOSOMAL LOCATIONS OF THE RIBOSOMAL DNA GENES IN SHORTLEAF PINE

Nurul Islam-Faridi, M. Abdul Majid, and C. Dana Nelson[1]

ABSTRACT.—A reference karyotype (i.e., chromosome-specific description of a species' chromosomal complement) is a pre-requisite for advanced genetic and genomic studies. The Southern Institute of Forest Genetics has initiated a project to develop reference karyotypes for each of the major southern U.S. pine species, including shortleaf pine, using AT-rich chromosomal banding and fluorescent *in situ* hybridization (FISH). About half of the project has been completed to date, including the development of karyotypes for loblolly pine and slash pine, with the remaining experiments being directed towards shortleaf pine and longleaf pine. Preliminary FISH results for rDNA genes in shortleaf pine show that there are seven major, and as many as eight medium-to-minor centromeric 18S-28S rDNA sites. In addition, one major and one minor 5S rDNA sites were observed and most of the chromosomes showed AT-rich bands. A complete shortleaf pine karyotype is being developed for comparison with other pine and conifer species.

INTRODUCTION

The genus *Pinus* ($2n = 2x = 24$), originally confined almost entirely to the northern hemisphere, includes many economically and ecologically important species. Loblolly pine (*Pinus taeda* L.), slash pine (*P. elliottii* var. *elliottii* Englm.), shortleaf pine (*P. echinata* Mill.), and longleaf pine (*P. palutris* Mill.) are the four *Pinus* species most commonly planted in the southern U.S. All *Pinus* species studied have 12 pairs of chromosomes with 10 or 11 pairs of long metacentric chromosomes and one pair of short sub-metacentric chromosomes (Sax and Sax 1933). Conventional cytogenetics has been used in studying the pines (Mergen 1958, Borzan and Papes 1978, MacPherson and Filion 1981, Hizume and others 1990). However, combining molecular cytology, *in situ* hybridization (ISH), and conventional cytological techniques provides more accurate information about genomes (Heslop-Harrison 1991, Leitch and Heslop-Harrison 1992, Leitch and others 1992, Hizume and others 2002, Doudrick and others 1995). We recently completed a reference karyotype and cytomolecular map for loblolly pine (Islam-Faridi and others 2007), as part of our institute's southern pine karyotyping project at the Southern Institute of Forest Genetics. In this paper, we present some preliminary data from our investigation of shortleaf pine.

MATERIALS AND METHODS

Plant Material

Seeds from an open-pollinated shortleaf pine clone, WO-5, were treated with 1 percent hydrogen peroxide to break dormancy and then germinated in the dark on moist filter paper in petri-dishes at 24 ˚C. Germinated seedlings were transferred to potting mix in pots and allowed to grow in a greenhouse prior to harvesting of root tips for cytogenetic analysis.

Slide Preparation

Actively growing roots tips, about 1.5 cm long, were excised and pretreated in 0.15 percemt colchicine (Sigma, P-9754) for 7 h at room temperature in the dark and then fixed in 2:1:1 ethanol (95 percent)-acetic acid-double distilled water. The fixed roots were treated enzymatically as described by Jewell and Islam-Faridi (1994). The digested root tips were macerated on a cleaned slide in 3:1 ethanol-acetic acid and squashed in 45 percent acetic acid with a cover glass (Islam-Faridi and others 2007). Finally, chromosome spreads were stored at -80 ˚C until used for fluorescence *in situ* hybridization (FISH).

Probe DNA and Nick Translation

Whole plasmids containing 18S-28S rDNA or 5S rDNA inserts were labeled by nick translation using biotin-16-dUTP (Biotin-Nick Translation Mix, Roche Diagnostics).

Fluorescent *In situ* Hybridization

A standard *in situ* hybridization technique was followed (Islam-Faridi and Mujeeb-Kazi 1995). Probe hybridization sites were detected with Cy3 fluorochrome conjugated

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[1] Research Geneticist (NI-F), US Forest Service, Southern Institute of Forest Genetics, Forest Tree Molecular Cytogenetics Laboratory, Texas A&M University, College Station, TX 77843; Research Associate (MAM), Department of Forest Science, Texas A&M University, College Station, TX 77843; Research Geneticist and Project Leader (CDN), US Forest Service, Southern Institute of Forest Genetics, Harrison Experimental Forest, 23332 Mississippi 67, Saucier, MS 39574. NI-F is corresponding author: to contact call (979) 862-3908 or email nfaridi@tamu.edu

streptavidin. The chromosome preparations were also counterstained with 4'-6-Diamidino-2-phenylindole (DAPI, 4 µg/ml) and mounted by Vectashield (Vector Laboratories) to prevent fluorochrome bleaching.

Microscopy

Digital images were recorded from an Olympus AX-70 epifluorescence microscope with suitable monochrome filter sets (Chroma Technology) using a 1.3 MP Sensys (Roper Scientific) camera and a MacProbe v4.2.3 digital image system (Applied Imaging). Images were processed with MacProbe v4.2.3 and Adobe Photoshop CS 8.

RESULTS AND DISCUSSION

We modified a technique for preparing pine chromosomes that consistently provides a high number of metaphase chromosome spreads in various pine species, including shortleaf pine. When our modified technique was employed, a single root tip yielded as many as 650 metaphase cells with as many as 40 of these containing well separated chromosomes that are ideal for DAPI and FISH analysis.

Various patterns of DAPI bands occurred near or around the centromere of most shortleaf pine chromosomes. Some of the centromeric DAPI bands appeared at both sides of the centromere, while others were clearly on one side or the other. Intercalary (the area between a centromere and a telomere) DAPI bands were also observed in some chromosomes. Similar results have been obtained for loblolly pine (Islam-Faridi and others 2007).

In shortleaf pine, we observed 13 major and 17 medium-to-minor 18S-28S rDNA signals (Fig. 1). All major and one medium (Fig. 1a and 1b, arrowheads) signals are located at intercalary positions, representing seven homologous loci, with one locus containing a major and a medium signal. A similar observation was also reported and has been observed for slash pine (Doudrick and others 1995, Islam-Faridi and others unpublished). In contrast, loblolly pine shows 14 major signals, two each for the seven homologous loci (Jacobs and others 2000, Islam-Faridi and others 2007). This observation suggests that the shortleaf pine and slash pine homologues with the medium signal lack several hundreds to thousands of copies of the highly repetitive 18S-28S rDNA gene. The remaining medium-to-minor intensity signals are located at or near centromeric positions. Taken together, these observations indicate that the shortleaf pine karyotype is more similar to slash pine than it is to loblolly pine.

The longest chromosome (i.e., chromosome 1) in shortleaf pine can easily be identified by its 5S rDNA signal (Figs. 1a and 1b, arrows), which appears to be the major 5S rDNA site. In addition, a minor 5S rDNA site was observed (Fig. 1a, insert). This second 5S rDNA site appeared toward the end of a different chromosome, which also showed a major intercalary 18S-28S rDNA site located on the opposite arm. Chromosome 2 of the loblolly pine reference karyotype has the same distinguishing characteristics (Islam-Faridi and others 2007).

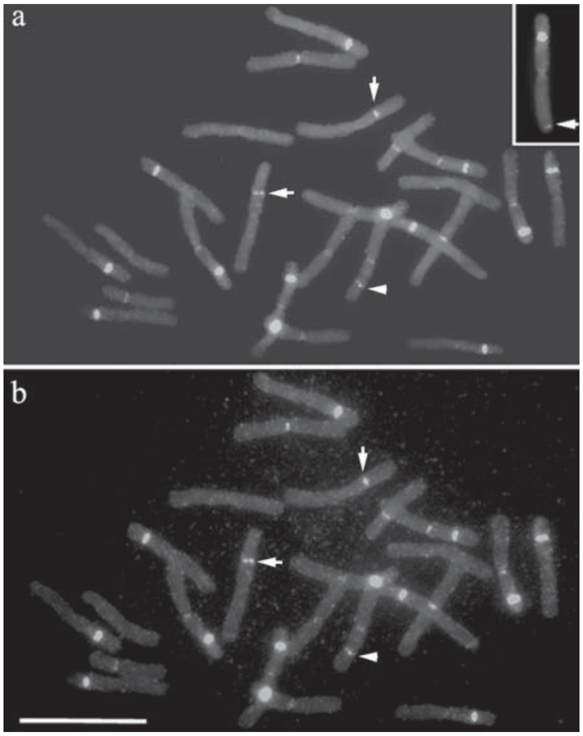

Figure 1.—FISH with 18S-28S rDNA and 5S rDNA probes on somatic metaphase chromosome spread of shortleaf pine, clone WO-5. The major 5S rDNA site is located on chromosome 1 (arrows, a and b). Also shown is a medium intercalary 18S-28S rDNA signal (arrowheads, a and b). The second 5S rDNA site is shown in the insert of a (arrow). Bar = 10 µm.

Further studies including use of an Arabidopsis–type telomere repeat sequence (A-type TRS) probe are being carried out to develop a comprehensive shortleaf pine karyotype for comparison with our loblolly pine reference karyotype (Islam-Faridi and others 2007) and two slash pine karyotypes (Doudrick and others 1995, Islam-Faridi and others unpublished). Cytogenetic analyses including karyotype comparisons are useful in identifying structural rearrangements (i.e., large translocations and/or inversions) within and between species which can be used to infer evolutionary relationships, to inform gene conservation efforts, and to guide interspecies breeding projects.

ACKNOWLEDGMENT

We thank Gay Flurry (Southern Institute of Forest Genetics, Saucier, MS) for processing the shortleaf pine seeds and for his assistance in growing the seedlings.

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SHORTLEAF PINE HYBRIDS: GROWTH AND TIP MOTH DAMAGE IN SOUTHEAST MISSISSIPPI

Larry H. Lott, Maxine T. Highsmith, and C. Dana Nelson[1]

EXTENDED ABSTRACT

It is well known that shortleaf pine (*Pinus echinata* Mill.), loblolly pine (*Pinus taeda* L.), and Virginia pine (*Pinus virginiana* Mill.) sustain significantly more Nantucket pine tip moth (*Rhyacionia frustrana* Comst.) damage than do slash pine (*Pinus elliotti* var. *elliotti* Engelm.) and longleaf pine (*Pinus palustris* Mill.) (Berisford and Ross 1990, Wakeley 1928). Understanding the cause of this difference in susceptibility is important since tip moth can be a serious pest, especially in commercial pine plantations. This study provides further information about the inheritance of susceptibility to tip moth damage in southern pine trees.

Three shortleaf pine x loblolly pine inter-specific F1 hybrid trees were control pollinated with shortleaf pine, loblolly pine, and slash pine trees and field tested at two sites in southeast Mississippi—Harrison Experimental Forest and Erambert Seed Orchard. In addition to the control-pollinated families, each parent was also tested as an open-pollinated (OP) family. Nineteen families were evaluated for height growth, number of branches, and percent of trees damaged by tip moth over 2 years (Table 1).

Overall, test trees were almost twice as tall at Erambert (129 cm vs. 70 cm). Both sites exhibited a relatively low amount of tip moth damage, although there was significantly more damage at Harrison (35.4 percent trees infested vs. 26.2 percent). F1 x OP families had the highest tip moth damage at both sites (46 percent and 38 percent), while the slash pine x OP families had the lowest (<10 percent). The average number of branches per tree was similar at each site, but slightly higher at Erambert (19.7 vs. 17.7). Inter-species crosses having lesser amounts of shortleaf pine per family were taller than those with larger amounts (Figure 1A), and, as expected, the opposite was true for loblolly pine. For tip moth, crosses with intermediate amounts (~50 percent) of shortleaf pine or loblolly pine were most damaged (Figure 1B).

These findings are in keeping with results of other coastal plain experimental plantings of susceptible and resistant pines and their inter-specific hybrids (Highsmith and others 2001, Highsmith and others 2003, Highsmith and Lott, unpublished), as well as earlier reports by Chapman (1922) and Grano and Grigsby (1968). Although this study is small and only 2 years old, it suggests that tip moth resistance in shortleaf pine might be advanced through hybridization and backcrossing with slash pine. The usefulness of this approach should be tested using many parents and crosses, preferably in BC1 intercrosses (BC1 x BC1) to allow for selection for tip moth resistance and adaptability to shortleaf pine environments.

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[1] Biological Science Technician (LHL), U.S. Forest Service, Southern Institute of Forest Genetics, Harrison Experimental Forest, Saucier, MS 39574; Associate Professor (MH), Department of Natural Science and Mathematics, Shaw University, Raleigh, NC, and Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC; Research Geneticist and Project Leader (CDN), U.S. Forest Service, Southern Institute of Forest Genetics, Harrison Experimental Forest, 23332 Mississippi 67, Saucier, MS 39574. CDN is corresponding author: to contact, call (228) 832-2747 or email dananelson@fs.fed.us

Table 1.—Means for height, number of branches, and tip moth damage over both planting sites.

Family Type	Families	Trees	Height[1]	Branches[1]	Tip Moth[1]
	number	*number*	*cm*	*number*	*% damage*
Slash x OP	4	254	97.4 b	13.2 c	5.1 b
Loblolly x OP	5	315	114.1 a	21.7 a	39.7 a
Shortleaf x OP	3	169	78.8 c	18.5 ab	34.9 a
(Shortleaf x Loblolly) x OP	3	170	92.2 b	19.2 ab	49.4 a
(Shortleaf x Loblolly) x Slash[2]	1	12	112.3 a	16.3 bc	.
(Shortleaf x Loblolly) x Loblolly	2	124	97.6 b	22.2 a	36.3 a
(Shortleaf x Loblolly) x Shortleaf[2]	1	18	78.1 c	16.9 b	.

[1] Means followed by the same letter are not significantly different at $p < .05$.

[2] '.' indicates that tip moth damage was not evaluated due to small sample size.

Figure 1.—Mean tree heights and mean tip moth damage by percent shortleaf pine in the cross after 2 years in the field at Erambert (EM) and at Harrison (HEF).

PHYLOGEOGRAPHIC ANALYSES AND EVALUATION OF SHORTLEAF PINE POPULATION STRUCTURE IN MISSOURI

Jeff Koppelman, Emily Parsons, Briedi Scott, Jennifer Collantes, Lori S. Eggert,
Sedley Josserand, Craig Echt, and C. Dana Nelson[1]

EXTENDED ABSTRACT

A great expanse of shortleaf pine in Missouri was logged before the mid-20th century, and since that time, seedlings of the species have been planted. Due to large-scale decline in oak trees occupying previous shortleaf pine range, restoration of the shortleaf pine is a priority in Missouri. Restoration can be enhanced through the use of locally adapted trees that have the genetic background to endure the nutrient- and water-limited environment of the Ozark hillsides of southern Missouri. This study's objective was to document the distribution of genetic diversity and population structure in natural, remnant shortleaf pine stands. Based on the geographic level of genetic structuring, the results will be used in combination with ecological and silvicultural results to formulate a conservation-oriented seed management strategy for effective restoration of the species.

Genetic diversity in the form of SSR (microsatellite) allelic variation was documented for shortleaf pine growing in four stands in east-central and southern Missouri. Those stands were selected because (1) they possessed a high abundance of large shortleaf pine trees, and hence were assumed to be natural rather than planted; and (2) they represented the extent of geographic distribution of the species in Missouri. Results from the first 10 polyallelic loci examined showed large amounts of diversity, although results for five of the loci were not sufficient (< 80 percent of individuals resolved) to be included in population diversity analyses. From the second five loci, sample size per site averaged 39 and results were obtained for an average of 36 trees per site. We observed a mean of 8.1 alleles per locus and direct-count heterozygosity of 0.56. At individual loci, stand genotype proportions ranged from 40 to 100, with an average of 58, meaning that more than half of the trees in the stand had unique genotypes.

Fixation index (FST) among the stands was low at all loci due to the great amount of among-tree (total) diversity. To improve our ability to diagnose relationships between the old native stands, the next stage of analyses will include adding five more loci that are not as polymorphic as those in the first stage. In addition, the stands will be resampled, expanding their geographic limits and focusing on larger trees (>18 in DBH) to help ensure native origins. Geographically intermediate stands will also be selected for sampling to refine geneflow limits, although the relationship between genetic diversity and geographic distance will likely prove to be on a scale that excludes all but the most distant remaining sites (Fig. 1).

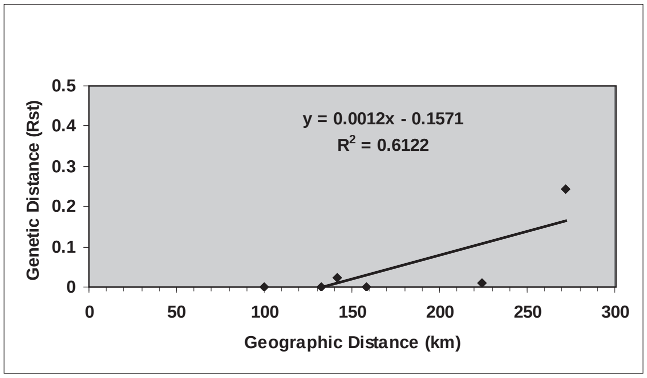

Figure 1.—The relationship between genetic distance and geographic distancefor four stands of native shortleaf pine representing range extremes for the species in Missouri.

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[1]Missouri Department of Conservation (JK, EP, BS, JC), Columbia, MO 65201; Biological Sciences Division (LSE), University of Missouri, Columbia, MO 65211; Southern Institute of Forest Genetics (SJ, CE, CDN), U.S. Forest Service, Saucier, MS 39574. JK is corresponding author. JK is corresponding author: to contact call (573) 882-9880 or email jeff.koppelman@mdc.mo.gov

REGENERATING SHORTLEAF PINE: RESULTS OF A 5-YEAR COOPERATIVE RESEARCH INITIATIVE

James P. Barnett and John C. Brissette[1]

ABSTRACT.—Shortleaf pine (*Pinus echinata* Mill.) is unique among the southern pines. It has the widest natural range and thrives on shallow rocky soils of the Interior Highlands, where most other pine species perform poorly. Although wood quality is excellent, it has been one of the most neglected species from both research and operational standpoints. It has a history of poor performance following outplanting with survival of less than 50 percent. The technology to change this situation was developed after formation of the Shortleaf Pine Artificial Regeneration Taskforce in 1984. Over a 6-year period, 15 studies were installed in Arkansas and Oklahoma to address seedling production and establishment. Information resulting from these studies resulted in increased seedling survival in both the Ozark and Ouachita National Forests. This paper summarizes research from these and other studies that led to the improved success in reforestation of the species.

INTRODUCTION

A limited number of studies have focused on the regeneration of shortleaf pine (*Pinus echinata* Mill.). Many sites that were originally forested with shortleaf pine have been regenerated with loblolly pine (*P. taeda* L.) because of loblolly's higher productivity on Coastal Plain soils. As a result, shortleaf pine has received little research and operational emphasis. During the 1970s and 1980s, the Ouachita National Forest in Arkansas and Oklahoma, and Ozark National Forest in Arkansas, developed major artificial regeneration efforts with shortleaf pine on their difficult highland sites. Traditionally, loblolly pine reforestation techniques were used as a model for shortleaf pine reforestation. Resulting regeneration success of this species was poor with survival typically averaging 50 percent or less (Walker 1992). The low success achieved with this loblolly pine-oriented approach became a major concern of U.S. National Forest System silviculturists, who concluded that there were research opportunities for developing the knowledge necessary to improve the field performance of planted shortleaf pine.

THE SHORTLEAF PINE ARTIFICIAL REGENERATION TASK FORCE

In late 1984, a group of 18 specialists representing USDA Forest Service management and research, the Weyerhaeuser Company, the Arkansas Forestry Commission, Oklahoma State University, and Louisiana State University met in Hot Springs, AR, to discuss the problems of shortleaf pine regeneration. The objectives of the session were (1) to identify causes of poor survival of planted shortleaf pine seedlings in the Ouachita and Ozark Mountains; (2) to determine research priorities for solving the problems of poor survival; and (3) to determine who could best work on each of the priority problems. The group agreed to form an ad hoc effort, the Shortleaf Pine Artificial Regeneration Task Force to be led by James Barnett and John Brissette of the USDA Forest Service's Southern Forest Experiment Station laboratory in Pineville, LA, to address these research needs.

The areas of research considered to be productive included: forest genetics, seed processing and handling, seedling production, seedling handling and storage, and stand establishment. Although all of these concerns had merit, the task force members felt that seed and seedling quality should have the highest research priority, and the initial research emphasized these topics. Determining optimum stratification or prechilling lengths was the highest-priority topic under seed quality. Identifying and evaluating seedlings that would perform well under stressful field conditions was considered important. So was determining differences in growth responses to nursery culture by families, so that families with similar growth patterns could be grouped together for improved seed efficiency and seedling uniformity. Another high-priority question concerned the best timing (as determined by budset and root growth potential) of lifting and storage to ensure good performance under stressful conditions.

During the 5+ years of the Task Force's effort, most of these topics were addressed to some extent. The purpose of this paper is to present a summary of these (Brissette and Barnett 1992) and other pertinent study results.

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[1] Emeritus Scientist (JPB), Southern Research Station, U.S. Forest Service, Pineville, LA 71360; and Project Leader (JCB), Northern Research Station, U.S. Forest Service, Durham, NH 03824. JPB is corresponding author: to contact call (318) 473-7214 or email jpbarnett@fs.fed.us

SEED PRODUCTION

An early consideration in any reforestation program is the selection of superior seed sources for the region. Wells and Wakeley (1970) published guidelines for moving shortleaf pine seed. Most sites in the Arkansas and Missouri highlands should be replanted from local sources, or seed from east and north of the planting sites (Lantz and Kraus 1987). Tauer and McNew (1985) found relatively small variability among provenances and large variability among families. Schmidtling (2001) recently updated the recommendations for moving shortleaf pine seed sources (Fig. 1). Seedlings will survive and grow well if they come from any area having a minimum temperature within 5 ºF of the planting site's minimum temperatures. East-west transfers within temperature isotherms are usually successful. Southern movement of sources across one 5 ºF isotherm will generally result in faster growing seedlings (Schmidtling 2001).

Sufficient seed orchards are present to provide genetically improved sources (Mexal 1992). Seed collecting, handling, and processing may affect seed quality. Seed maturation varies by half-sib family and there is variation in dormancy, which can be measured by speed of germination (Barnett and McLemore 1970, McLemore 1969). Few studies have evaluated the effects of cone maturity on seed extraction and viability, and guidelines (when cone specific gravity reaches 0.89 or less) by Wakeley (1954) are generally followed.

Seed storage for shortleaf pine is usually not a problem. Barnett and Vozzo (1985) reported the maintenance of viability for 50 years under less than ideal conditions. Proper seed treatment maximizes the proportion of seed resulting in seedlings optimal for the outplanting site—target seedlings. Treatments include: clonal collection, sizing seed to improve uniformity, and prechilling to speed emergence. Implementing these techniques improves not only nursery practices, but also improves long-term growth and yield (Mexal 1992).

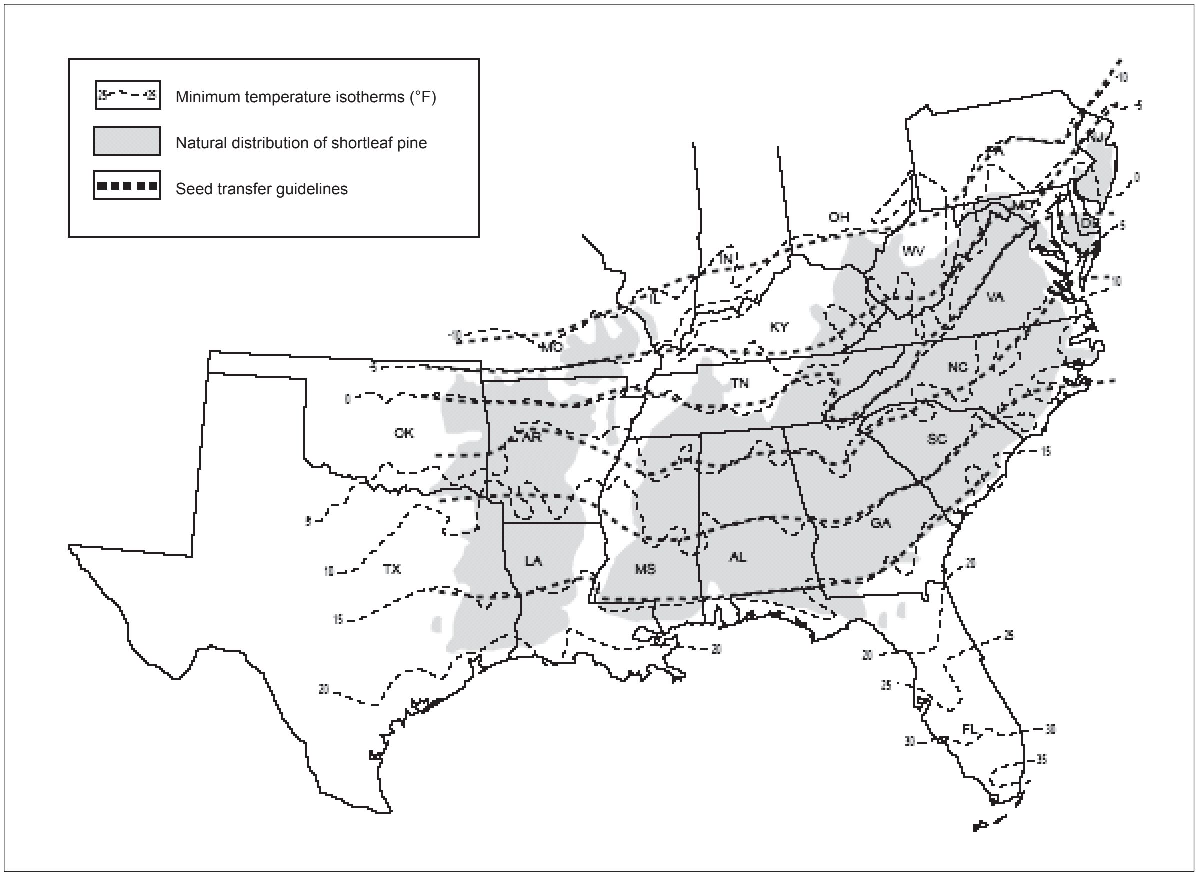

Figure 1.—Shortleaf pine distribution with seed transfer guidelines based on minimum temperature isotherms. Within isotherms movement east-west is usually successful (Schmidtling 2001).

NURSERY PRODUCTION

Significant advances in shortleaf pine seedling culture have been made over the last 40 years. As a result, target seedling specifications for bareroot stock have become more restrictive (Table 1). Standards for root/shoot (R/S) ratios and number of lateral roots have been developed (Mexal 1992). These data have been compiled from a number of studies over the years. Early studies were influenced by the small seeds of the species. Seedlings were grown at high seedbed densities ($>500/m^2$) (Wakeley 1954). As a result, seedlings were small when lifted, and survival after outplanting was often low.

Seed Treatment

Seed treatments should maximize the proportion of the seed that uniformly germinates and results in target seedlings (Barnett 1996). If collecting, processing, and storing activities result in good initial seed quality, seed treatments can enhance seed performance. Treatments may include: clonal collection and sowing, removal of empty and damaged seeds, sizing to improve uniformity, and stratification to speed emergence. Clonal collection, removal of empty and damaged seeds, and sizing are techniques commonly used to improve the uniformity of seedling germination and development of any southern pine species. Although seed sizing may improve germination of some portion of the seed lot, seed sizing improves uniformity of germination within the different sizing categories.

Stratification or prechilling recommendations are specifically developed for each species. However, this treatment is often inappropriately applied. Stratification treatments are usually based on laboratory tests that invariably indicate that 30 days of treatment result in the highest germination (Barnett 1992). However, the minimum length of stratification is longer, often 60 days, if the tests in the laboratory are conducted under lower temperatures that reflect actual nursery conditions.

The objective of stratification is to overcome dormancy and thus improve both amount and uniformity of germination, thereby increasing the number of target seedlings in the nursery. Stratification speeds germination, which permits earlier seedling establishment. Seedlings that emerge earlier in the season are more likely to survive and meet target seedling standards at harvest (Fig. 2). Seedlings emerging during the first 2 weeks after sowing were the largest at the end of the growing season, and accounted for 60 percent of the germinants meeting planting specifications (Barnett 1992).

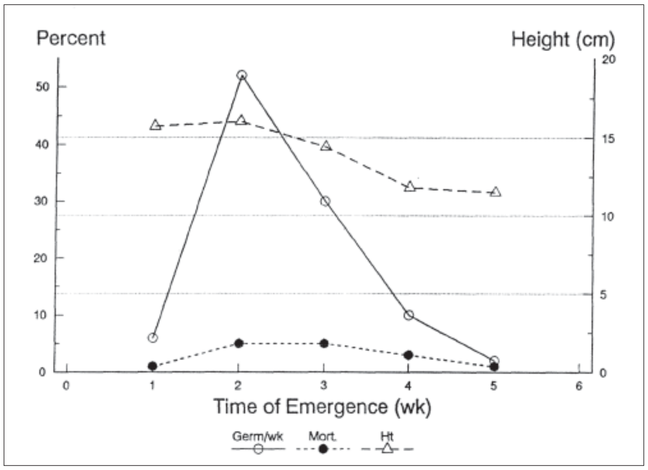

Figure 2.—Effect of time of emergence on mortality and height after one growing season of shortleaf pine seedlings (after Barnett 1992).

Table 1.—Changes in target shortleaf pine bareroot seedling specifications from 1954 to 1991 (Mexal 1992).

Parameter	Mexal and South 1991	Anon. 1989	Barnett et al. 1986	Wakeley 1954
Shoot height (cm)	15-25	20	15-25	10-30
Root collar dia. (mm)				
Cull	<4.0	--	<2.5	<3.0
Optimum	<5.0	<4.8	2.5-5.0	>3.0
Root/shoot ratio	>0.4	0.4	0.4	--
Lateral roots (no.)	>7	>5	7	--
Tap root length (cm)	--	15	10-20	--
Terminal bud	--	Present	Well developed	Present
Mycorrhizae	Many	Abundant	--	--

Seedling Quality

Seedling quality refers to seedlings that when planted will survive and show acceptable growth. The nursery system that produces quality stock incorporates the latest research information and applies it through the best technology available. Such technology for shortleaf pine includes: seed treatment as discussed in the previous section (Barnett 1992), sowing early and growing at low seedbed densities (about 200/m^2) (Brissette and Carlson 1987), and fertilizing at moderate rates of nitrogen (Brissette et al. 1989).

The aforementioned recommended nursery practices usually increase the size of shortleaf pine seedlings, and improve the balance between R/S biomass (Mexal 1992). The importance of the R/S in survival of loblolly pine seedlings was demonstrated by Mexal and Dougherty (1982). Research by Brissette and Barnett (1989) indicates it can also predict early growth of shortleaf pine (Fig. 3).

Shortleaf pine seeds collected from six half-sib families were grown as both bare-root and container stock and outplanted on two sites in the Ouachita Mountains of Arkansas. Survival and growth were measured at years 1, 3, 5, and 10 after planting. When outplanted, the bare-root seedlings had greater mean height and root-collar diameters than the container seedlings. However, the container seedlings had greater mean root volume and more favorable R/S ratios than the bareroot stock. Height growth of container and bareroot seedlings was correlated with R/S ratio following planting. Survival of both stock types was excellent, exceeding 90 percent after 10 years. The container stock performed consistently better than the bareroot at each interval measured, but there were no statistically significant interactions between stock type and half-sib family at 3, 5, or 10 years (Barnett and Brissette 2004).

Although visible presence of mycorrhizae on pine seedling roots has been known to improve survival for many decades (Jorgensen and Shoulders 1967), inoculation of seedlings in the nursery usually is not necessary (Mitchell and South 1992). Inoculation by airborne spores occurs in most nurseries within pine forest types. Harsh nursery lifting techniques can strip much of the visible mycorrhizae from seedlings and reduce survival.

SEEDLING CARE AND HANDLING

Care and handling activities include timing of lifting, sorting, length of storage, method of storage, and transportation. The handling practices for shortleaf pine might be expected to be similar to loblolly pine (Mexal 1992); however, Venator (1985) found shortleaf pine was sensitive to storage. Although unstored seedlings maintained fairly uniform survival when outplanted from early November through early April, seedlings stored 30 days at 36 ºF survived poorly when planted in November, March, and April (Hallgren 1992). Survival of seedlings stored 30 days averaged 10 percentage points lower than just-lifted seedlings during the optimum planting season (Fig. 4).

Ability to regenerate new roots is apparently correlated with survival of shortleaf seedlings. Brissette and others (1988) found root growth potential (RGP) of shortleaf pine sensitive to chilling hour accumulation (0 to 8 ºC at 200 mm above the ground). When lifting date was expressed in accumulated chilling hours, maximum RGP after lifting occurred after 610 hours, but no strong interaction occurred with cold storage. Hallgren (1992) did report maximum RGP following storage for seedlings lifted after 700 hours of chilling.

Improving storage life of shortleaf pine seedlings by treating the roots with a clay slurry-fungicide (Benomyl®) coating at packing significantly increased field survival. Barnett and others (1988) reported that treated seedlings could be stored for 6 weeks with no reduction in survival (Fig. 5). Survival

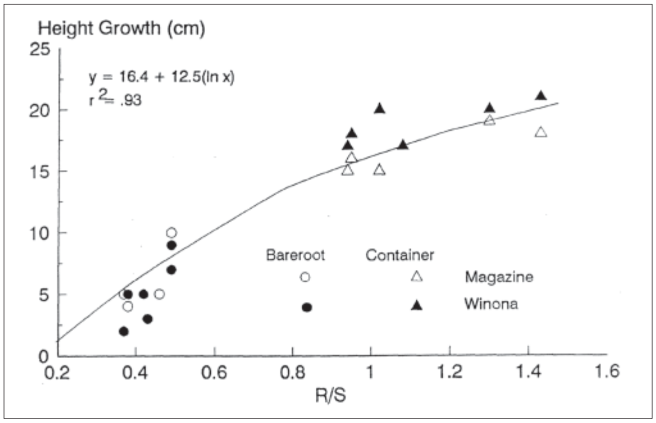

Figure 3.—Relationship between R/S and first-year height growth of bareroot and container shortleaf pine seedlings (after Brissette and Barnett 1989).

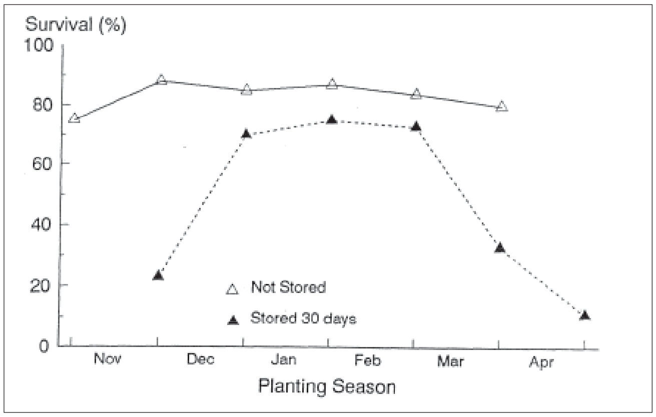

Figure 4.—Effect of lift date and 0-day or 30-day storage on the survival of shortleaf pine seedlings in Arkansas and Oklahoma (after Hallgren 1992).

of nontreated seedlings was reduced 15 percent after only 3 weeks, and 60 percent after 6 weeks of storage. These results with shortleaf pine were confirmed in a study by Hallgren (1992).

Although there was a strong effect of seedling storage on survival, growth following outplanting was not related to storage period or time (Hallgren 1992). Seedling heights after 2 years appeared more closely related to planting date. Maximum growth occurred for the December, January, and February plantings. Early planted seedlings provided greater opportunity for height growth the following spring and summer (South and Mexal 1984). In addition to reduced growth, planting late (mid-March and April) reduced growth 10 to 30 percent (Hallgren 1992).

SITE PREPARATION

Site preparation can be the most expensive activity in establishing a southern pine forest (Dougherty 1992). As with most expenditures, you usually get what you pay for. The key is to select those practices that are most appropriate for the site and species. Two practices that are commonly used for shortleaf pine regeneration on mountainous sites are ripping and chemical weed control (Mexal 1992). Ripping has been a common practice in the Ouachita Mountains for the last three decades (Sossaman and others 1980). The ripper blades tend to pull large rocks from the trench and increase the proportion of soil in the opening. Ripping usually improves plantability and soil moisture as the trench serves as a catchment basin for water flow (Mexal 1992). However, results of some long-term evaluations of ripping indicate that site preparation burning alone is equally effective in improving seedling survival and growth (Gwaze and others, in press).

Mountainous sites are typically droughty, and chemical weed control improves soil moisture by removing the vegetation that would otherwise increase stress due to competition. Yeiser and Barnett (1991) found that the growth response of shortleaf pine to weed control will last 2 years following either spot or total chemical application. The improved performance is likely due to improved water relations and light availability. In this study, total weed control was superior to spot control, but some weeds may actually protect shortleaf from severe infestations of tipmoth (*Rhyacionia frustrana* Cornstock) (Mexal 1992).

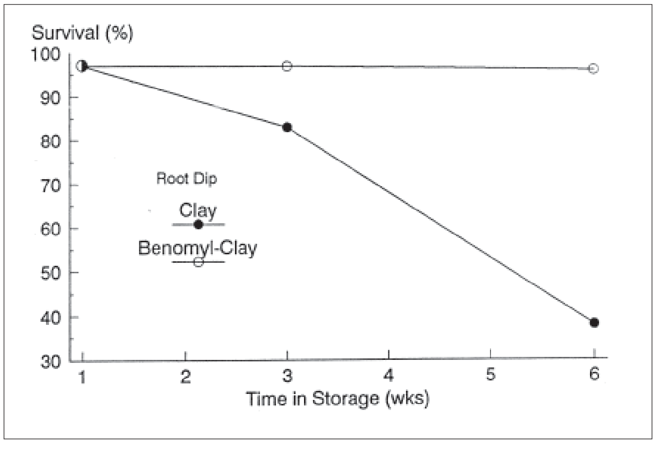

Figure 5.—Improvement in survival of stored shortleaf pine seedlings following treatment with Benomyl® (after Barnett and others 1998).

PLANTING

Successful reforestation requires a system of quality control through all phases of establishment. Poor planting can result in poor survival and reduced growth and yield, or both. Early evidence of poor planting is not always apparent (Mexal 1992). Harrington and others (1987) found that 30 percent of planted shortleaf pine seedlings lacked a taproot compared to 15 percent for seedlings seeded in place. Seedlings with a vertical taproot exhibited greater height growth than trees with root systems deformed by spiraling or shallow planting.

Harrington and others (1989) conducted additional studies on root orientation of surviving trees, but did not relate root deformation to survival. Brissette and Barnett (1989) found that deformation decreased survival of loblolly pine seedlings. Shallow planting was most detrimental, but J-rooting also decreased survival. Proper planting is key to improving survival and early seedling growth.

POST-PLANTING CARE

Regulating competition is probably the most important issue to address after planting to help achieve a successful plantation. Early weed control increases survival and growth (Yeiser 1992). Competition is commonly from grass, hardwood sprouts, and other planted pines. In a 12-year study reported by Cain and Barnett (2002), competition control from grasses and forbs increased survival by 68 percentage points for natural pines and 47 percent for planted pines. Volume gains of 150 to 200 percent were achieved after 12 years within the regeneration techniques as a result of release.

CONCLUSIONS

Successful artificial regeneration of shortleaf pine requires production of consistently uniform seedlings by either bareroot or container methods, adequate site preparation that improves the planting site, proper planting techniques, and control of competition for 1 or 2 years after outplanting. Successful establishment of shortleaf pine on its native sites is an accomplishment that is satisfying to many landowners in the highland areas of the South.

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UNDERPLANTING SHORTLEAF PINE IN THE MISSOURI OZARKS

Jason Jensen, Cliff Smith, Mark Johanson and David Gwaze[1]

ABSTRACT.—A study was established on Clearwater Conservation Area in the Missouri Ozarks in which shortleaf pine (*Pinus echinata* Mill.) seedlings were underplanted in mature mixed oak and oak/pine stands. Overstory trees were harvested a few months after planting, leaving different levels of residual overstory stocking. The different overstory treatments included 1) uneven-aged management with group openings; 2) clearcut; 3) shelterwood treatment with overstory reduction to B-level stocking; and 4) shelterwood treatment with overstory reduction to C-level stocking. Seven years after treatment application, clearcut stands had the best stocking and growth of planted shortleaf pine seedlings. The clearcut stands also had the highest number of free-to-grow seedlings. The higher the retained overstory stocking, the lower the number of free-to-grow shortleaf pine seedlings, and the lower the stocking and growth of underplanted shortleaf pine seedlings. Group openings established in uneven-aged management treatments appear to work, but the results suggest that they should be much larger to effectively regenerate pine. Growth of natural advance reproduction while in the understory, and released after clear cut harvesting was similar to growth of underplanted shortleaf pine seedlings and released after clearcut harvest, seven years after planting. This suggests that underplanting was effective in allowing planted pine seedlings time to become established and, therefore, capable of responding once released. Findings of this study suggest that clearcutting is the best method of regenerating pine, and that the higher the stocking rate of the residual overstory, the poorer the growth and stocking of the underplanted seedlings. The results also suggest that retaining the overstory for 7 years adversely affects stocking and growth of shortleaf pine seedlings and, thus, early release of underplanted seedlings is likely to result in a greater increase in stocking and growth.

INTRODUCTION

Shortleaf pine is an important source of food and habitat for many birds and mammals and it produces high quality sawtimber on dry, nutrient-poor sites (Lawson 1990). Shortleaf pine forests in Missouri have declined from 6.6 million acres to 397,100 acres since Euro-American settlement (Essex and Spencer 1976) The recent oak decline has underlined the importance of maintaining the shortleaf pine component in the pine-hardwood forests of Missouri because loss of oaks is greatest on sites that once had greater shortleaf pine stocking, and pine is well adapted to these sites for which they are considered a desirable species.

Currently, there is considerable interest in restoring shortleaf pine into areas where it has been lost due to past excessive logging, fire suppression, annual burning by farmers, highgrading, conversion to range and overgrazing. Underplanting is a potentially viable silvicultural option for restoring shortleaf pine. Underplanting is useful to establish advance reproduction where natural reproduction of shortleaf pine is lacking. Conceptually, underplanting will result in vigorous root systems that will provide the growth potential for seedlings when the mature trees are removed provided there is adequate light for net positive biomass production (Johnson 1993). Underplanting allows the control of the potential grow surge of competing hardwoods and allows removal of the overstory when the pine is established. Herbicide release may not be needed for underplanted seedlings. It is also easier, and hence cheaper, to hand plant before harvest because of lack of physical barriers at planting. Success of underplanting pine is not well known, and could be limited by the fact that shortleaf pine requires abundant light for rapid growth (Lawson 1990). However, Becton (1936) reported that shortleaf pine seedlings can become established under a dense canopy and persist for several years before dying, suggesting that newly established pine seedlings are moderately shade tolerant but become more shade intolerant with age.

The objectives of the study were to 1) compare seven-year stocking and growth of shortleaf pine seedlings planted underneath various overstory densities; and 2) evaluate influence of hardwood competition on growth and stocking of underplanted shortleaf pine seedlings.

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[1] Resource Forester (JJ), Missouri Department of Conservation, RR 4 Box 1002, Piedmont, MO 63957; Resource Forester (CS), Missouri Department of Conservation, Ellington, MO 63638; Private Lands Conservationist (MJ), Missouri Department of Conservation, PO Box 248, Sullivan, MO 63080; Resource Scientist (DG), Missouri Department of Conservation, 1110 S. College Avenue, Columbia, MO 65201.DG is corresponding author: to contact call (573)882-9909 ext. 3320 or email at David.Gwaze@mdc.mo.gov

MATERIALS AND METHODS

Site Description

The study was located in compartment 7 on the Clearwater Conservation Area of the Missouri Department of Conservation. The Clearwater Conservation Area (CCA) is located in the Reynolds and Shannon Counties located in southeast Missouri. The study site is located completely within the Current River and Black River oak-pine woodland/forest hills Land Type Association (Nigh and Schroeder 2002). These land types are characterized by hilly landscapes with narrow ridges, narrow valleys and steep slopes with 150 to 250 feet of local relief. The ridges and upper slopes are formed from the Roubidoux Formation whereas the lower hillslopes and valleys cut into the Gasconade Formation. Historically, this area was dominated by shortleaf pine and shortleaf pine-oak woodland complexes.

The compartment was managed to favor pine in the late 1990s. March 23 through March 29, 1998, 234.6 acres were planted with 97,741 shortleaf pine 1-0 bare-root seedlings. In May of 1998 the Conservation Commission approved the sale of 1,085,391 board feet of mixed hardwood saw timber from this compartment. The forester administering the sale used different management prescriptions to monitor pine seedling response to increasing overstory density and to determine the optimal overstory density for pine regeneration development. Overstory manipulations per stand were as follows: clearcut, unevenaged management with group openings, shelterwood treatment with overstory reduction to B-level stocking and shelterwood treatment with overstory reduction to C-level stocking.

Sampling Procedure

In November 2005, we assessed these stands to learn more about the successes and failures of the artificial regeneration techniques. We surveyed stands each with the following treatments:

1) Clearcut and planted with 1-0 shortleaf pine seedlings at 12 x 12 ft (CC).
2) Clearcut and not planted (CCN).
3) Thinned using uneven aged management guidelines (UAM) (see Missouri Department of Conservation Guidelines 1986) and planted with 1-0 shortleaf pine seedlings at 12 x 12 ft. UAM guidelines include group openings.
4) Thinned to B-level stocking (Gingrich 1967) and planted with 1-0 shortleaf pine seedlings at 12 x 12 ft (B-level).
5) Thinned to C-level stocking (Gingrich 1967) and planted with 1-0 shortleaf pine seedlings at 12 x 12 ft (C-level).

The goal was to retain a residual basal area of approximately 70 ft^2/acre for B-level and UAM treatments, and 55 ft^2/acre for C-level treatments. Group openings were one tree height (70 feet) in diameter. In the clearcut stands, all trees were cut except shortleaf pine trees.

In each stand we established six plots along one or more transects. Each transect followed the slope. Each plot was 60 ft x 40 ft and was meant to include 20 planted shortleaf pine seedlings. The stocking and height of each planted shortleaf pine seedling was assessed. Competition was assessed several ways. First, overstory basal area was measured by a prism count at the center of each plot. Second, number of hardwoods midstory species were counted within a 1/100th acre plot located within the center of each plot. Third, competition was assessed by measuring free-to-grow status of pine seedlings. Pine seedlings were assessed as being overtopped by hardwood competition or free-to-grow. Vegetation was considered competing with shortleaf pine seedlings if a leaf or branch of competing vegetation covered the pine's terminal leader or was close to the terminal leader; otherwise the shortleaf pine seedlings were judged as free-to-grow.

Statistical Analyses

Plot means were used for all analyses. Using the PROC GLM procedure in SAS Version 9.1 (SAS Institute Inc., Cary, NC), one-way analyses of variance (ANOVAs) were used to test for significant differences among treatments for growth and competition. All analyses were carried out at the $P \leq 0.05$ probability level. Where significant differences were detected among treatments, Duncan's Multiple Range Test was used to compare means.

RESULTS

Stocking of Shortleaf Pine Seedlings

After seven growing seasons, stocking of planted shortleaf pine was highest in the clearcut treatment and least in the unevenaged management treatment (Fig. 1). Stocking of shortleaf pine seedlings was estimated to be 12 percent in the UAM, 28 percent in the C-level, 52 percent in the B-level and 63 percent in the clearcut stand. The few trees observed in the UAM stand were in group openings, particularly in the center of the opening. The unplanted clearcut stand had a significantly higher stocking of shortleaf pine seedlings than planted stands with high residual overstory densities (UAM, B-level and C-level). Stocking of shortleaf pine seedlings did not differ significantly in unplanted (CCN) and planted clearcut (CC) treatments. The unplanted clearcut stand was not planted due to adequate advanced pine regeneration.

Growth of Shortleaf Pine Seedlings

Height of planted shortleaf pine seedlings was best in the clearcut treatment (Fig. 2). Height of planted shortleaf pine seedlings in clearcuts was more than twice the height

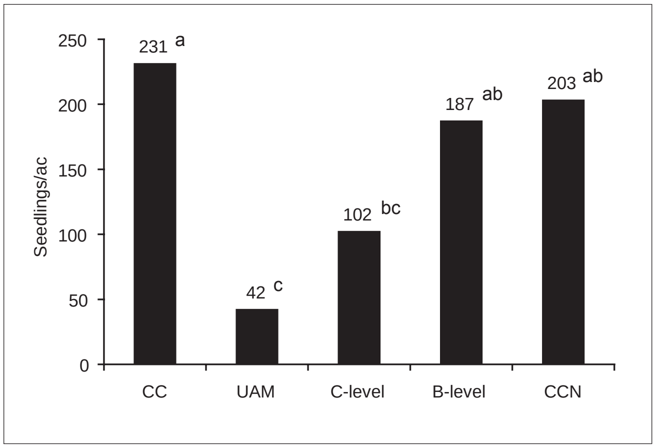

Figure 1.—Stocking of underplanted shortleaf pine seedlings 7 years after establishment. CC = clearcut and planting; UAM = uneven-aged management and plant; C-level = thin to C-level stocking and plant, B-level = thin to B-level stocking and plant; CCN = clearcut and no planting. Numbers on bars are treatment means. Different letters indicate significant differences among treatments based on the Duncan's Multiple Range Test. Same or shared letters indicate no significant difference at α = 0.05 level.

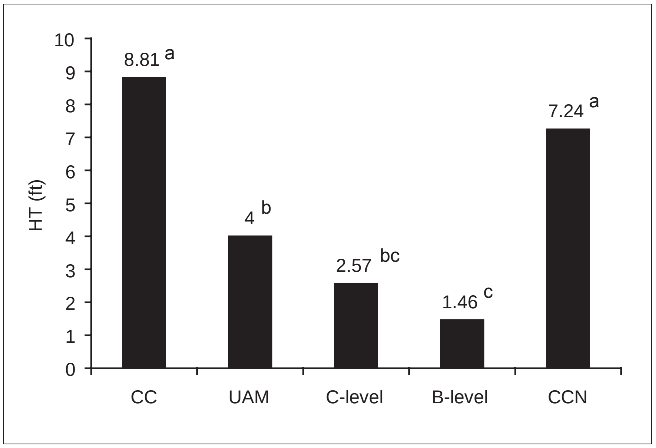

Figure 2.—Height growth of shortleaf pine trees 7 years after establishment. CC = clearcut and planting; UAM = uneven-aged management and plant; C-level = thin to C-level stocking and plant, B-level = thin to B-level stocking and plant; CCN = clearcut and no planting. Numbers on bars are treatment means. Different letters indicate significant differences among treatments based on the Duncan's Multiple Range Test. Same or shared letters indicate no significant difference at α = 0.05 level.

of those in the other treatments. Group openings made a difference in the UAM because the tallest seedlings were found in the center of the group openings. These seedlings were as tall as those in the clearcut stand. In clearcuts, planted and naturally regenerated shortleaf pine seedlings were not significantly different in height.

Competition

Overstory competition consisted of hardwoods and mature shortleaf pine trees retained as seed trees. As expected, the overstory competition was lowest in the clearcut stands (Fig. 3) and consisted of few scattered shortleaf pine seed trees. Midstory competition was inversely related to the amount of residual overstory trees, being highest in the clearcut treatments and least in the treatments with higher amount of residual overstory (Fig. 4). The high number of midstory trees in the UAM compared to the B and C-level stocking was due to high density of midstory trees in group openings.

Many of the shortleaf pine trees in clearcuts were judged as free-to-grow while the majority of the trees in the other treatments were suppressed (Fig. 5). While over 65 percent of the planted shortleaf pine seedlings were judged as free-to-grow in the clearcut stands, less than 25 percent were judged as free-to-grow in stands with a high residual overstory density. Shortleaf pine seedlings in the clearcuts were mainly overtopped by midstory hardwood sprouts, while those in the other treatments were overtopped by overstory hardwoods.

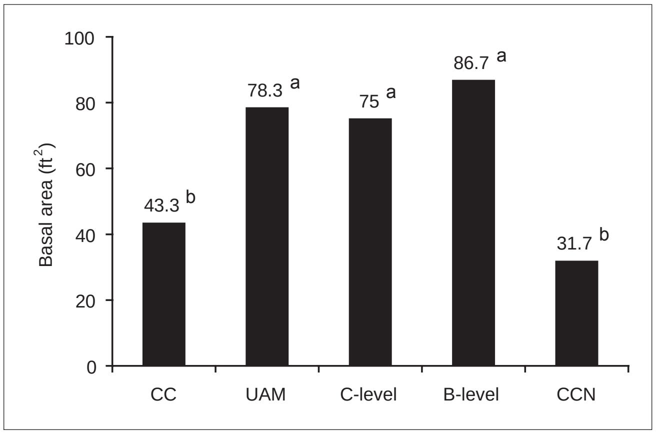

Figure 3.—Basal area of overstory trees 7 years after establishment. CC = clearcut and planting; UAM = uneven-aged management and plant; C-level = thin to C-level stocking and plant, B-level = thin to B-level stocking and plant; CCN = clearcut and no planting. Numbers on bars are treatment means. Different letters indicate significant differences among treatments based on the Duncan's Multiple Range Test. Same or shared letters indicate no significant difference at α = 0.05 level.

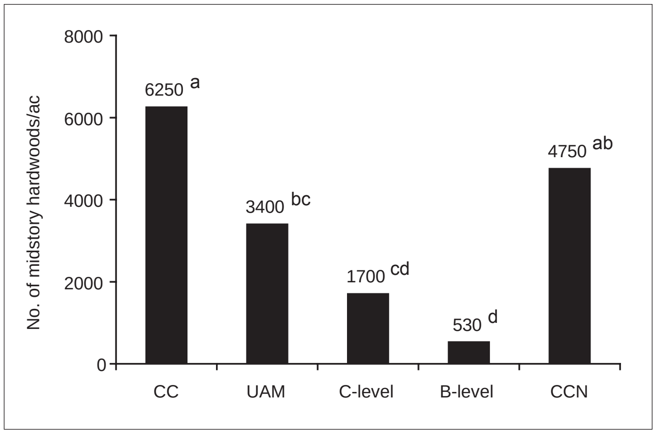

Figure 4.—Density of midstory hardwoods 7 years after establishment. CC = clearcut and planting; UAM = uneven-aged management and plant; C-level = thin to C-level stocking and plant, B-level = thin to B-level stocking and plant; CCN = clearcut and no planting. Numbers on bars are treatment means. Different letters indicate significant differences among treatments based on the Duncan's Multiple Range Test. Same or shared letters indicate no significant difference at α = 0.05 level.

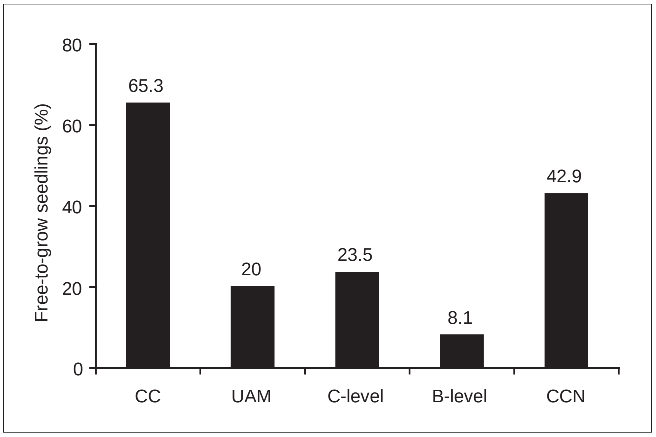

Figure 5.—Free-to-grow shortleaf pine seedlings 7 years after establishment. CC = clearcut and planting; UAM = uneven-aged management and plant; C-level = thin to C-level stocking and plant, B-level = thin to B-level stocking and plant; CCN = clearcut and no planting. Numbers on bars are treatment means.

DISCUSSION AND CONCLUSION

Results from our study indicate that shortleaf pine seedlings in the clearcuts had higher stocking than those in other treatments. Brinkman and Liming (1961) underplanted 1-0 shortleaf pine seedlings in 40-year-old oak-pine forest on the Mark Twain National Forest and removed the overstory leaving different residual densities (0, 27, 53 and 79 ft^2/acre). When they removed the overstory in the year of planting they found no significant differences in survival 11 years after planting. However, they found that survival of underplanted shortleaf pine was drastically reduced from 74 percent to 10 percent when the overstory release by clearcutting was delayed one year after planting. According to Liming (1946), complete release of overstory by clearcutting is an unsatisfactory method of releasing shortleaf pine one or more growing seasons after planting.

Results from our study further suggest that shortleaf pine seedlings in clearcuts developed more rapidly than those planted in other treatments. This is expected because there was less shading in clearcuts. Our results are consistent with reports by Brinkman and Liming (1961) and Guldin and Heath (2001) who reported that growth of underplanted shortleaf pine seedlings in clearcuts was superior to those where partial overstory was retained.

Because midstory competition was highest and growth was best in the clearcut treatments our study suggests that overstory competition is the main factor affecting stocking and growth of underplanted seedlings. Overstory vegetation has a substantial influence on underplanted seedlings by reducing light intensity, intercepting a significant proportion of precipitation and increasing competition for soil moisture and nutrients by roots (Anderson et al. 1969). Underplanted shortleaf pine seedling growth was found to be inversely related to increasing overstory retention after seven growing seasons (Guldin and Heath 2001).

Our study and previous studies indicate that clearcutting is the best for regenerating shortleaf pine. Brinkman and Liming (1961) further observed that delaying complete overstory removal by one year after planting reduced survival of planted shortleaf pine substantially. Liming (1946) recommended spring planting of pine and clearcutting the overstory the following dormant season. Certainly, early removal of the overstory appears to match the silvics of the species because shortleaf pine is generally considered a shade-intolerant species (Lawson 1990). Group openings (small clearcuts) established in uneven-aged management treatments appear to work, but our results suggest that they should be much larger to allow successful establishment and development of planted shortleaf pine seedlings for more than 7 years. Underplanted seedlings in the clearcut treatment had a similar growth response to advanced regeneration in unplanted clearcut treatment, 7 years after planting. This suggests that underplanting was effective in allowing planted pine seedlings time to become established and, therefore, capable of responding once released.

Possible future studies utilizing existing underplanted stands include determining the response of underplanted shortleaf pine seedlings to canopy removal and determining the more effective recruitment method for planted shortleaf pine seedlings in clearcuts. The first study should provide information about whether the underplanted seedlings in partial overstory retention treatments, particularly those in B-level and C-level treatments, will respond to release after seven or more years after planting. Some studies in Missouri carried out from the 1930s to 1960s indicated that underplanted shortleaf pine seedlings respond well to release even at a late stage such as 30 years (Brinkman and Smith 1968). The new studies will provide up-to-date information to supplement or confirm the historical studies. The second study may determine if there are any differences in stocking and growth of shortleaf pine trees in clearcuts released using different methods—mechanical, chemicals and fire—providing important information to resource managers on which method is best at recruiting shortleaf pine trees.

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UNDERPLANTING SHORTLEAF PINE
AT COLDWATER CONSERVATION AREA IN MISSOURI

Jason Jensen and David Gwaze[1]

EXTENDED ABSTRACT

Restoring shortleaf pine throughout its native range in the Ozark Highlands is a high priority in Missouri. Restoring shortleaf pine on former pine and oak-pine sites is a long-term strategy for mitigating chronic oak decline (Law et al. 2004). Underplanting or preharvest planting is one method that has potential for restoring shortleaf pine. Conceptually, underplanting will result in vigorous root systems that will provide the growth potential for seedlings when the mature trees are removed (Johnson 1993). Underplanting allows the control of the potential growth surge of competing hardwoods and allows removal of the overstory when the pine is established. It is also easier, and hence cheaper, to hand plant before harvest because of lack of physical barriers at planting. One of the potential advantages of underplanting is that release herbicide may not be needed. Success of underplanting is not well known, and could be limited by shortleaf pine's requirement for abundant light for rapid growth. The objectives of the study were (1) to compare survival and growth of shortleaf pine seedlings planted underneath various overstory densities; (2) to compare survival and growth of shortleaf pine seedlings planted before and after clearcutting; and (3) to evaluate the influence of hardwood competition on growth and survival of planted shortleaf pine.

The study was located on the Coldwater Conservation Area of the Missouri Department of Conservation and on the adjacent property owned by the Williams Family Limited Partnership. The three treatments applied after underplanting shortleaf pine seedlings underneath a mature overstory in March 2002 were clearcut, uneven-aged with group selection (UAM), and shelterwood. The fourth treatment consisted of planting shortleaf pine seedlings in March 2002 after clearcut. In April 2006, we assessed the study. In each treatment, we established six plots along one or more transects. Each plot was 60 ft x 40 ft and was meant to include 20 planted shortleaf pine seedlings. Survival and height of each planted shortleaf pine seedling was assessed.

Four years after treatments, shortleaf pine seedlings planted in clearcuts had moderate survival and the best growth (Figs. 1 and 2). Seedlings planted before and after clearcutting were not significantly different in both survival and growth. Seedlings underplanted in the shelterwood treatment had the poorest survival and growth. Seedlings planted in shelterwood treatment were 84 percent shorter than those planted in clearcuts. Seedlings underplanted in the UAM treatment had the best survival but had poor growth. Within the UAM treatment, group openings behaved like small clearcuts. Height of seedlings in group openings (4.43 ft) was as good as that in clearcuts, and height in single tree selection (2.27 ft) was as low as that in shelterwood treatment. The basal area was least in the clearcut treatments (3 to 8 ft^2/ac), and highest in the UAM (23 ft^2/ac) and the shelterwood treatment (28 ft^2/ac).

Results from this study suggest that clearcutting is the best method to regenerate shortleaf pine, and planting before or after clearcutting does not affect survival or growth of planted shortleaf pine seedlings. However, planting after harvest is more difficult than planting before harvest because of planting in and around logging debris. Thus, planting before harvest and clearcutting the overstory in the same year the shortleaf seedlings are planted appear to be a good regeneration strategy for shortleaf pine.

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[1] Resource Forester (JJ), Missouri Department of Conservation, RR 4 Box 1002, Piedmont, MO 63957; Resource Scientist (DG), Missouri Department of Conservation, 1110 S. College Avenue, Columbia, MO 65201; JJ is corresponding author: to contact call (573)223-4525 or email at Jason.Jensen@mdc.mo.gov

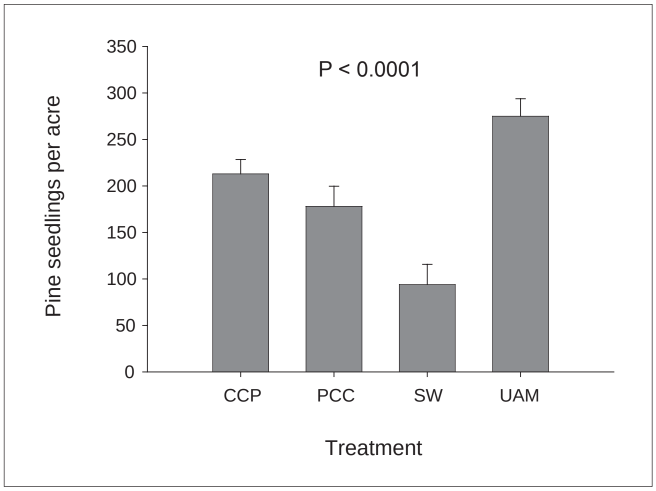

Figure 1.—Stocking of planted shortleaf pine seedlings 5 years after establishment. CCP = clearcut and plant; PCC = plant and clearcut; SW = shelterwood; UAM = uneven-aged management. Error bars are standard errors of the mean.

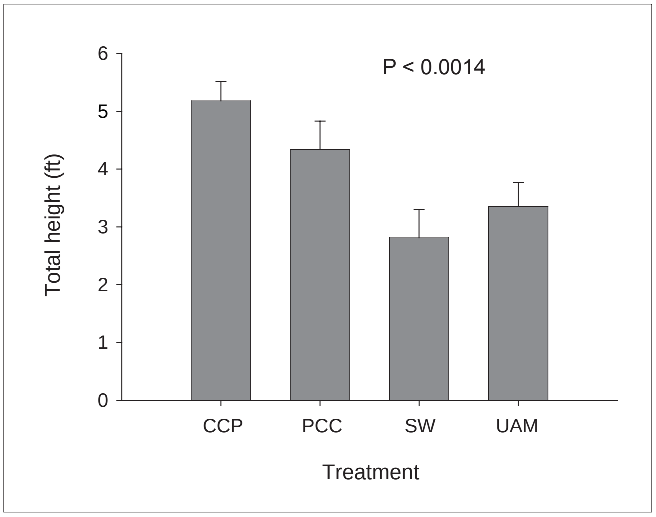

Figure 2.—Total height of shortleaf pine trees 5 years after establishment. CCP = clearcut and plant; PCC = plant and clearcut; SW = shelterwood; UAM = uneven-aged management. Error bars are standard errors of the mean.

DIRECT SEEDING OF SHORTLEAF PINE

Corinne S. Mann and David Gwaze[1]

EXTENDED ABSTRACT

Direct seeding is a potentially viable method for regenerating shortleaf pine, but it has not been used extensively. In Missouri, an estimated 10,000 acres have been direct-seeded with shortleaf pine; half of which are at Mark Twain National Forest. Direct seeding offers a flexible and efficient alternative to planting as a way to restore shortleaf pine in the Ozarks. The poster reviews the potential use of direct seeding for shortleaf pine restoration in Missouri.

Direct seeding affords many advantages, including: 1) initial costs are reduced; 2) natural root systems are developed on site; 3) transplant shock is avoided; 4) seeding is easier on sites with limited access, difficult terrain, or rocky, shallow soils; 5) it can be done during different times of the year (unstratified seed is sown in autumn; stratified seed is sown in late winter or early spring); and 6) it can be used to supplement natural regeneration in an area where few or no seed trees exist. Potential limitations of direct seeding include: 1) a large amount of seed is required; 2) low seedling survival rates; 3) reduced control over spacing of trees; 4) costly pre-commercial thinning; 5) potential for seed loss due to predation and rain washout; and 6) severe competition with other vegetation. Early growth of seeded seedlings is lower than that of planted seedlings (Fig. 1, Brunk 1977).

Proper seedbed conditions are critical for germination and survival of direct-seeded shortleaf pine. Shortleaf pine direct seeding is most successful on exposed mineral soils with sufficient light. Fire or mechanical disturbances are effective site-preparation methods. Seedlings were prohibited from establishing on litter depth exceeding 3 inches (Fig. 2, Grano 1949) and at least three times as many seedlings emerged on burned sites as on unburned sites (Fig. 3, Boggs and Wittwer 1993).

The following is recommended when sowing shortleaf pine seed: 1) treat seeds with repellents to prevent predation; 2) sow half a pound of shortleaf pine seed per acre; 3) mix pine seed with wheat seed (40 lbs per ac) to spread the pine seed evenly; 4) sow seed in spots or rows; or broadcast mechanically, by hand, or aerially.

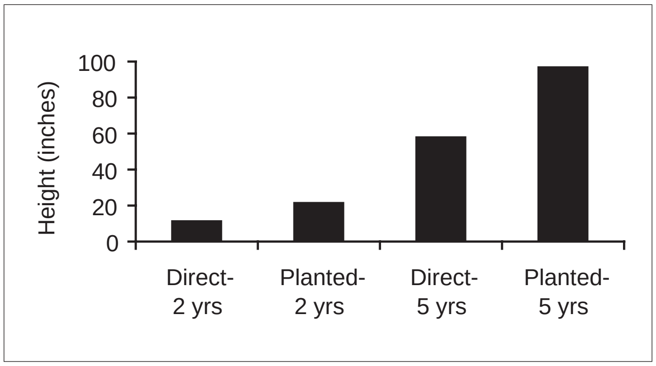

Figure 1.—Comparison of direct seeded and planted seedlings at Indian Trail Conservation Area, Dent County (Brunk 1977).

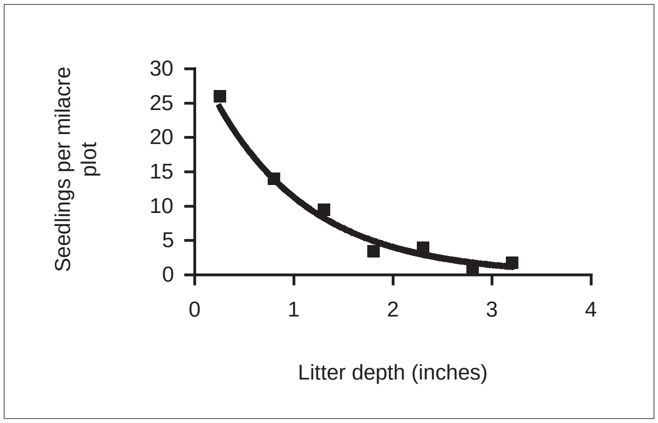

Figure 2.—Relationship between average litter depth and establishment of pine seedlings (adapted from Grano 1949).

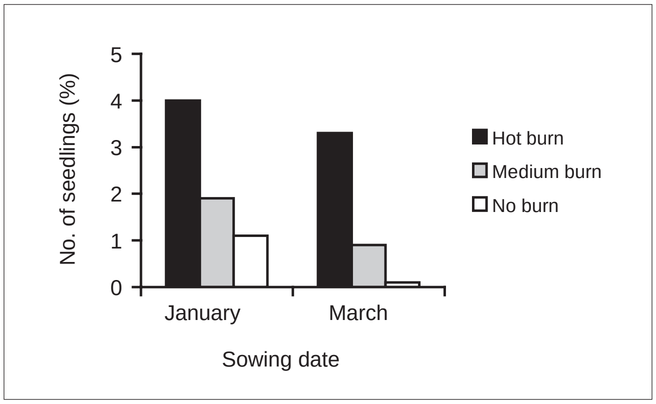

Figure 3.—Number of established seedlings as a percentage of seeds sown (Boggs and Wittwer 1993).

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[1] Resource Scientist-Intern (CSM) and Resource Scientist (DPG), Missouri Department of Conservation, 1110 S. College Avenue, Columbia, MO 65201. DPG is corresponding author: to contact call (573)882-9909 ext. 3320 or email at David.Gwaze@mdc.mo.gov

The first year is the most critical for establishment and survival; mortality after the first year is low. Establishment is best if a small amount of overstory shade is present to prevent desiccation. However, the species becomes less shade tolerant with age and benefits from a reduction of canopy cover and release of competition with understory vegetation once it is established. Inventories are recommended during summer and again at the end of the growing season in the first year: minimum acceptable is 1,400 seedlings per acre at the end of the first growing season.

Direct seeding is a simple, fast, economical, and flexible method that can supplement natural shortleaf pine reproduction or regeneration. It has the potential to make a significant contribution to shortleaf pine restoration efforts in the Missouri Ozarks.

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WHAT FIRE FREQUENCY IS APPROPRIATE FOR SHORTLEAF PINE REGENERATION AND SURVIVAL?

Michael C. Stambaugh, Richard P. Guyette, and Daniel C. Dey[1]

ABSTRACT.—Shortleaf pine community restoration requires an answer to the question, “What fire frequency is appropriate for shortleaf pine regeneration and survival?” The answer to this question is one of the most critical to successful restoration through fire management. We used three sources of information from Missouri to determine appropriate burning frequencies: a 400-yr historic shortleaf pine growth and fire-scar database, fire effects data from prescribed burning sites, and a vegetation dynamics prediction model that is widely used for characterizing fire regimes. The historic shortleaf pine and fire scar database provides actual past scenarios of regeneration dates, growth, survival, and associated fire events. Shortleaf pine regeneration established most commonly during the 4 years following fire events and generally decreased in abundance with years since fire. Surviving seedlings were those that were not fire scarred the year following establishment, and the mean number of years to a subsequent fire was about 7 years. Fire effects data from prescribed burn sites revealed that both hardwood and pine regeneration showed substantially increased mortality after four consecutive dormant season burns, but oak and hickory species were more likely to survive frequent fire. Mortality of advance regeneration was generally low in all hardwood species after one burn, while shortleaf pine seedlings had high mortality rates. The model showed 8 to 15 yr intervals are likely best for balancing both continual regeneration and recruitment. Model prediction runs for 500 years showed a significantly decreased pine component in the absence of burning. Conversely, long-term frequent burning (1- to 3-yr intervals) resulted in abundant regeneration, but poor survival and ultimately decreased abundance in mid- and late-successional forests. In summary, all three sources support the efficacy of frequent burning (1 to 4 yrs) in promoting pine regeneration, but survival and continued recruitment require longer fire intervals (8 to 15 yrs). Fire management prescriptions that incorporate both frequent burning and longer intervals will likely provide for the most long-term regeneration and recruitment success.

INTRODUCTION

It is widely recognized that fire is critical to shortleaf pine forest ecosystems (Cooper 1989, Bukenhofer and others 1994, Masters and others 1996, Stanturf and others 2002, Rimer 2003, USDA 2003). However, shortleaf pine restoration through fire management begs the answers to questions such as “What fire frequency is appropriate for shortleaf pine regeneration and survival?” Much of the information about shortleaf pine and fire comes from field trials and lies with experienced individuals while relatively little is published about experimental findings. Because of the dynamic conditions of fire events (due to fuels, weather and climate, vegetation, topography, burning technique, etc.), it is difficult to relate single experimental results to the management of large and different forested landscapes.

The historic role of fire within shortleaf pine communities of the Ozark Highlands has been well established and described (Guyette and others 2002, Guyette and others 2006) (Fig. 1). The pre-Euro-American dominance of shortleaf pine in the region was negatively related to historic mean fire intervals (Batek and others 1999). Wildfires likely maintained many of the presettlement shortleaf pine communities and, though at times severe, were predominantly non-stand-replacing surface fires resulting from anthropogenic ignitions. Mixed severity fires resulting in small stand-replacement events likely occurred within the region about every 20 years (Guyette and others 2006). Today, wildfires typically consist of small-scale, low severity surface fires (Westin 1992, Stambaugh and others in press) that are rarely stand-replacing events.

METHODS

In an attempt to provide regionally derived information on fire regime and shortleaf pine dynamics, we chose to summarize results of fire events and shortleaf pine regeneration and survival from many locations and time

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[1] Senior Research Specialist (MCS), Department of Forestry, University of Missouri-Columbia, Columbia, MO 65211; Research Associate Professor (RPG), Department of Forestry, University of Missouri-Columbia, Columbia, MO 65211; and Research Forester (DCD), U.S. Forest Service, Northern Research Station, Columbia, MO 65211. MCS is corresponding author: to contact, call (573)-882-8841 or email at stambaughm@missouri.edu

periods within the natural range of shortleaf pine in the Ozark Highlands of Missouri and Arkansas. We used three approaches to determine appropriate burning frequencies for promoting shortleaf pine regeneration and recruitment. The approaches were: analysis using a 400-yr historic shortleaf pine growth and fire scar database (Stambaugh and Guyette 2004), a summary of fire effects data from prescribed burning sites (Dey and Hartman 2005), and model simulations using the Vegetation Dynamics Development Tool (VDDT) (Essa Technologies Ltd. 2005).

Historic Shortleaf Pine Growth and Fire Scar Database

This database consists of approximately 600 cross sections cut from the base of shortleaf pine remnant trees, live trees, and existing stumps that were collected from throughout the Ozark Highlands region during the past 20 years (Guyette 1994, Guyette and others 2002, Guyette and Spetich 2003) (Fig. 1). This database represents trees that survived fire events and does not contain those that were killed and have since decomposed. Tree-ring data from cross sections span the past four centuries and the database was queried for those trees that had both pith dates (stem ages) and fire event dates. The query resulted in 96 trees with pith dates ranging from 1585 to 1896 (Fig. 2). Of these, 64 trees had information about the number of years since fire as derived from fire history studies at their respective sites. Ninety-one trees contained information about the number of years from the pith to the first fire scar on that tree and 95 had information about the number of years from the pith to the first fire event that occurred within the vicinity (less than 1 km^2). It is important to note that pith dates reflect the first year of growth of the stem and that it is not known whether stems initiated from a seedling or a sprout.

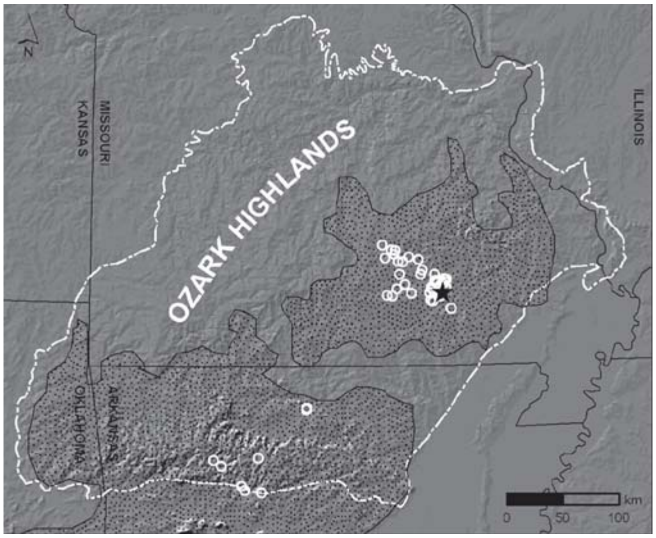

Figure 1.—Locations of shortleaf pine fire history sites (white circles), the Chilton Creek Preserve (black star), the boundary Ozark Highlands ecoregion (white line) (Bailey 1998), and the approximate range of shortleaf pine (stippled area). Fire history sites are where shortleaf pine specimens used in the growth and fire scar analysis were collected. The Chilton Creek Preserve is the location from which fire effects data were summarized.

Fire Effects

Fire effects data for shortleaf pine were summarized from the Chilton Creek Preserve, a 2289 ha site located along the Current River in Shannon and Carter Counties, Missouri. The preserve has been divided into five management units of approximately 200 ha each. All units were burned in the spring of 1998 and then burned during the dormant

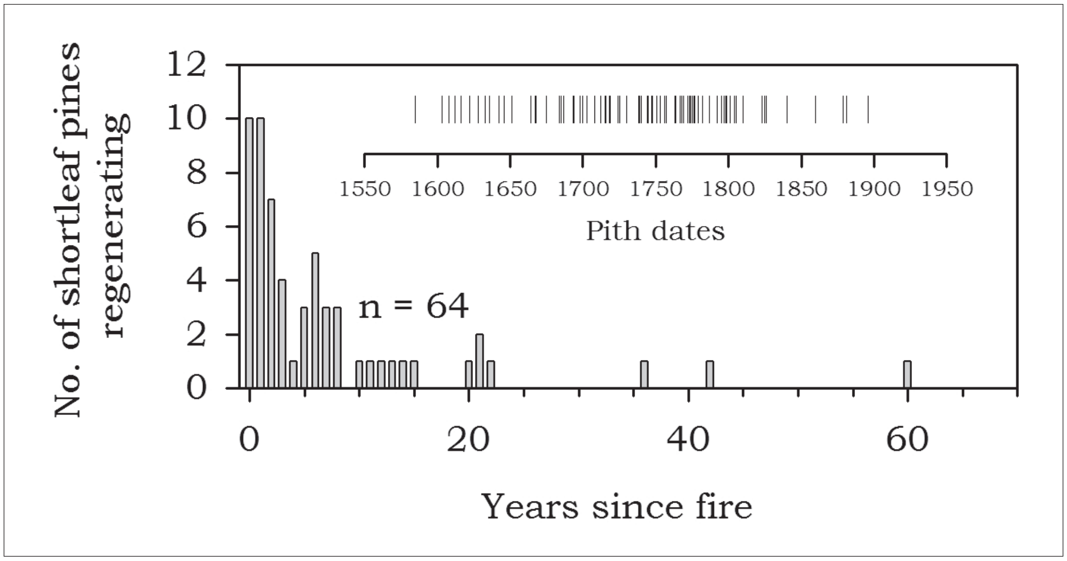

Figure 2.—Bar graph of the number of shortleaf pines regenerating during the years following fire events. Data were generated from a historic shortleaf pine specimen database (see methods). Years of regeneration of these trees are shown as pith dates (upper right of graph).

season on a randomly determined 1- to 4-yr return interval basis. One management unit (Kelly North) has been burned annually. Pre- and post-burn information is available for fuels and fire behavior, and fire effects information is available for herbaceous, seedling, and sapling vegetation layers (Sasseen 2003, Dey and Hartman 2005). Here, we summarize the fire effects findings of Dey and Hartman (2005) as they relate to the survival of shortleaf pine regeneration and compare their findings to those generated from the historic shortleaf pine database and VDDT modeling approaches.

VDDT Model

VDDT is a model developed for examining the influence of various disturbance and management actions on vegetation development (Essa Technologies Ltd. 2005). The model is a state and transition model that was developed for use in the Landfire project, a federally funded project producing consistent and comprehensive maps and data describing vegetation, wildland fuel, and fire regimes across the United States (Rollins and others 2003). VDDT has a suite of reference models that have been developed for many different vegetation types, including oak-hickory-pine forests, based on information from published literature, expert input, and peer review. We used a five-box model developed for oak-pine forests to explore the effects of different fire frequencies on the regeneration and survival of shortleaf pine communities, particularly over extended time periods (e.g., 500+ years). Details of this model can be found in Guyette and others (2004) and Shlisky and others (2005). In general, the model simulates the survivorship and transition of oak-hickory-pine forests as a result of fire disturbances (and other disturbances if chosen) which can be changed by the user. The model contains five forest seral states (Table 1). In subsequent model runs we decreased the fire frequency to understand the effects of fire on various forest states, particularly the maintenance of two states: an early seral mixed forest (i.e. regeneration) and late-seral forest with greater than 2 percent shortleaf pine (i.e., survivorship of shortleaf pine) (Table 1). Model simulations were generated using fire frequencies of annual burning, 2-yr, 4-yr, 8-yr, 15-yr, and 40-yr fire intervals, and no fire disturbance. For each scenario the model was run for 500 timesteps using 10 simulations. Initial model conditions began with equal area (20 percent of landscape) represented by each seral stage. VDDT calculates the percentage of area occupied by each seral state, and model results were produced for the 100 and 500 timesteps. No model modifications were made other than fire disturbance frequencies.

RESULTS

Historic Shortleaf Pine Growth and Fire Scar Database

The mean number of years from a pith date to a fire event was 6.8 years. The abundance of shortleaf pine regenerating fell sharply with time since fire; the majority occurred within the first 8 years from a fire event (Fig. 2). Much of the regeneration that survived underwent another fire within the first 12 years of regenerating (Fig. 3). The mean number of years from regeneration to the first fire scar was 45.5 years and the majority of trees survived at least one fire in the first 20 years of growth. No trees were represented as having survived a fire injury during the first year of growth.

Fire Effects

First year burning effects resulted in shortleaf pine having the highest seedling and sapling layer percent mortality (38 percent) of any species recorded (see Table 3 in Dey and Hartman 2005). Despite high initial mortality, shortleaf pine had only 1 percent additional mortality in subsequent fires, while all other species sustained higher mortality rates. Following 3+ burns (annual burning frequency), shortleaf pine showed the lowest percent total damage calculated as the sum of the percent mortality and percent shoot dieback. The probability of shortleaf pine seedlings and saplings (advance reproduction) in the understory of a mature oak-pine forest surviving a spring surface fire was significantly related to initial stem size (i.e., basal diameter and height). Small-diameter shortleaf pine advance reproduction had the

Table 1.—Forest developmental states of coarse (south central U.S.) and empirically-driven (Current River Hills, MO) oak-hickory-pine VDDT models developed by Guyette and others (2004) and validated by Shlisky and others (2005). The effects of different fire disturbance frequencies on the development and success of each seral state are shown in Figure 4.

Seral State	Age range (yrs)	Code
Early seral mixed forest	0-12	A
Mid-seral mixed forest; canopy cover >55%	13-70	B
Mid-seral mixed forest; canopy cover <55%	13-70	C
Late-seral forest; >55% canopy cover; <2% shortleaf pine	>70	D
Late-seral forest; >55% canopy cover; >2% shortleaf pine	>70	E

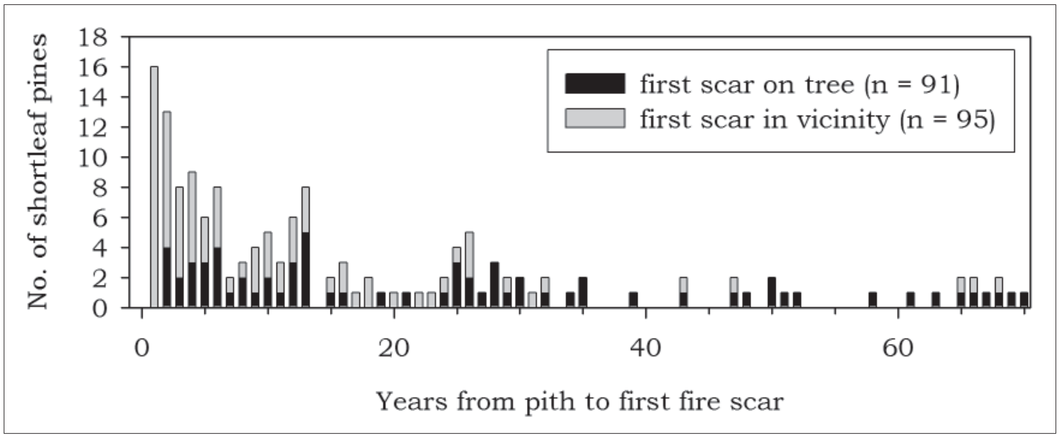

Figure 3.—Bar graph showing the historic shortleaf pine specimen trees and the number of years to the first fire they survived as documented by a scarring injury. Two types of fires are shown: fires that were recorded on that individual tree and fires that scarred other trees in the vicinity (within about 1 km) of where the tree grew.

lowest survival probabilities compared to similarly sized hardwood seedlings. Shortleaf pines that were less than 2 cm in basal diameter had less than 40 percent chance of surviving a single spring surface fire. In contrast, pines that were greater than or equal to 10 cm in basal diameter had a 90 percent or greater probability of surviving burning. Large diameter (greater than 5-cm basal diameter) pines that survived one fire had high probabilities of surviving repeated dormant-season surface fires. Overall, repeated burning in the dormant season reduced the height of understory trees and favored oak reproduction. Fire effects data from Chilton Creek demonstrated that the success of fire treatments may be better assessed after conducting multiple burns as high mortality may occur in the initial burn and not be representative of long-term repeated burning.

VDDT Model

Model simulations demonstrated that forest developmental states are highly sensitive to small changes in burning frequency. Simulations of annual burning allowed for the greatest proportion (nearly 60 percent) of the landscape to be in an early seral state (Fig. 4). The effect of decreasing the burning frequency from annual burning to 40-year fire intervals was a transition in the amount and types of seral states occupying the landscape. For example, the percent of area in early seral states decreased dramatically (60 to 4 percent) while mid-seral closed canopy developmental states slightly increased (Fig. 4). Forest developmental states that likely represent shortleaf pine success (i.e., classes C and E) showed different responses. Mid-seral open canopy states slightly decreased in percent area from 2-year to 40-year burning intervals. Percentage area of late-seral open canopy states with > 2 percent shortleaf pine (i.e., class E) increased from 2-yr to 8-yr burning intervals. The percent area of this late-seral state decreased as fire intervals increased beyond 15 years. The “no fire disturbance” scenario resulted in a dominance of the late-seral state with no shortleaf pine component on nearly 80 percent of the area at timestep 500 (Fig. 4).

DISCUSSION

Shortleaf Pine Regeneration and Survival

In this study the regeneration success of shortleaf pine appeared to be related to time since fire. Much of the regeneration summarized from the historic shortleaf pine database showed that regeneration following fire occurred within the first 10 to 15 years. This time period is likely related to many of the factors essential to regeneration establishment such as available light, nutrient release, and litter cover, as well as ability to resprout. In the Ozarks, litter and duff are important barriers to shortleaf regeneration (Grano 1949, Shelton and Wittwer 1992) and time since fire and shortleaf pine regeneration are inversely related (Ferguson 1958). Stambaugh and others (2006) estimated litter in Ozark forests accumulates to a maximum equilibrium within about 12 years post-fire. It is common for current Ozark oak-pine forests to have undergone decades of fire exclusion resulting in maximum litter accumulation levels, the development of a substantial duff layer, and ultimately large scale preclusion of shortleaf pine seedling establishment.

Although shortleaf pine regeneration showed a positive response to fire events, shortleaf pine’s survival following regeneration appeared to necessitate recurring fire (Fig. 3). The results suggest that following regeneration, immediate burning and repeated frequent burning (annual to 2-yr frequency) do not support shortleaf pine survivorship. Although shortleaf pine seedlings can resprout vigorously following topkill (Walker and Wiant 1966, Keeley and

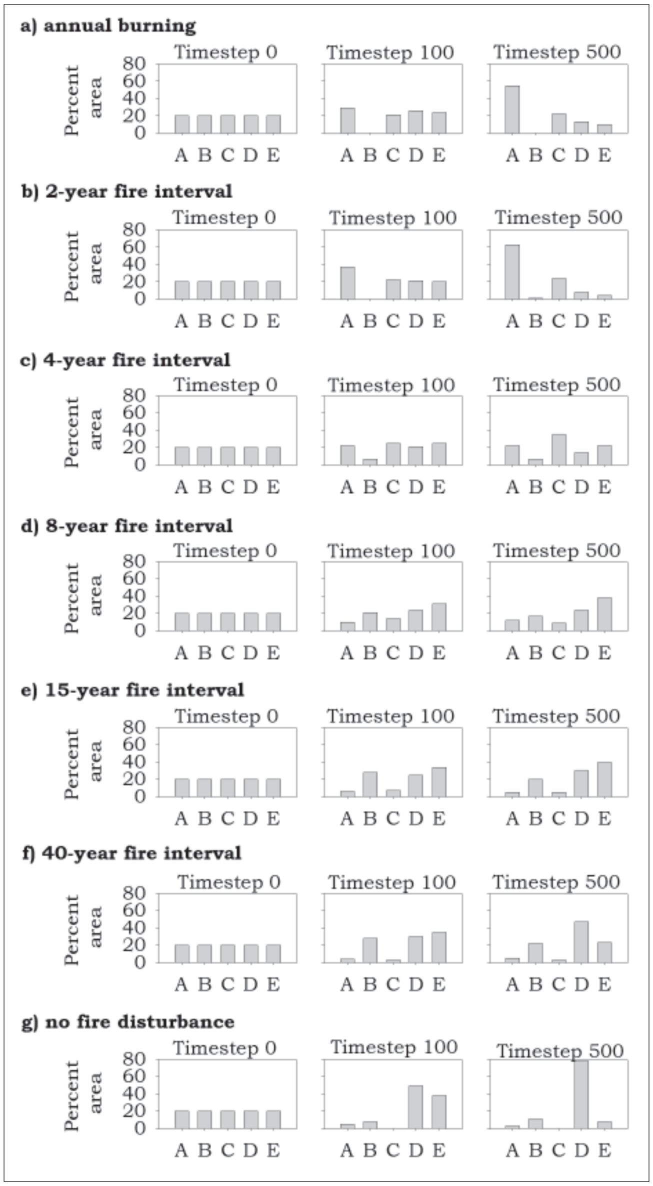

Figure 4.—Bar graphs of percent area of landscape (VDDT model simulated) that is comprised in five forest seral states (coded A through E, Table 1). The percent area in each seral state is shown for seven different fire frequency scenarios. Initial forest conditions (timestep 0) contain equal amounts of each seral state, and results are shown for 100 yr and 500 yr timesteps. Class codes are: A = Early seral mixed forest, B = Mid-seral mixed forest; canopy cover >55%, C = Mid-seral mixed forest; canopy cover <55%, D = Late-seral forest; >55% canopy cover; <2% shortleaf pine, E = Late-seral forest; >55% canopy cover; >2% shortleaf pine.

Zedler 1998), it is not known how many successive resprouting events can occur from the same root stock during a frequent burning regime; therefore, repeated frequent fire may prohibit survival of seedlings. In a study that compared a remnant stand of shortleaf pine with the existing stand at the same site, Guyette and Dey (1997) concluded that 100 years of burning with a mean fire return interval of 3.1 years contributed to the elimination and reduction of advanced pine regeneration.

A recurring question is “what amount time of does it take for a pine to gain some degree of fire resistance?” It appears from our analysis that this is within a range of 8 to 15 years, depending on stand and environmental conditions. Wade and others (2000) reported a range of 6 to 15 years for drier, nutrient poor sites and a 2- to 6-yr range on more fertile sites. Walker and Wiant (1966) showed comparable results based on tree size and Baker (1992) reported supporting results based on tree height. Respectively, they reported that shortleaf trees larger than about 2 to 10 cm diameter at breast height (DBH) and 4 to 5 m in height are somewhat resistant to surface fires. The range in tree height and size likely varies based on fire environment and behavior. Brinkman and Smith (1968) reported that “free growing” trees in Missouri within this fire-resistant size class were about 7 years old. Similarly, shortleaf growing in different regions (e.g., Arkansas and Oklahoma Ozarks and Ouachita Mountains) may reach resistance earlier than more northerly populations because of increased growth rates. Denser overstory stockings that cause decreased pine growth would also increase the age to resistance. Suppressed understory trees may be particularly problematic as they may be 30 years old or greater and still within a size range susceptible to fire kill (Brinkman and Smith 1968, Stambaugh 2001).

Along the lines of Dey and Hartman (2005), more information is needed to determine the different probabilities of survivorship by tree characteristics (e.g., tree size, growth, age) that exist between shortleaf pine and hardwood competitors. It is likely that shortleaf pine has a higher probability of surviving repeated fires compared to hardwood competitors, particularly over long periods of time and within a smaller diameter range (e.g., 4 to 20 cm basal diameter). Identifying the period of development in which shortleaf has a higher probability of surviving fires compared to hardwoods would help to develop prescribed fire management guidelines for shortleaf pine restoration. From the results of this and other studies mentioned above, it appears that shortleaf is tolerant of low-intensity surface fires within a specific diameter-height window (e.g., 4- to 20-cm basal diameter, 4 to 5 m in height) (Walker and Wiant 1966, Baker 1992) that corresponds to a specific range of tree ages and fire frequencies (8 to 15 yrs).

Long-term effects (e.g., 50+ years) of repeated burning on oak-pine forest dynamics are not well understood partly because few locations have been monitored for this length of time. However, much of this pine growth and fire information already exists in the historic record and can be gleaned from pine remnants that date to presettlement time periods (prior to 1820). Pieces of remnant wood are relatively common throughout the entire Ozark region and beyond and indicate locations of previous pine sites. The success and dominance of pine at time of settlement in the Ozarks (e.g., 2 to 6 million acres in Missouri) resulted from fire disturbances that favored shortleaf pine regeneration and survival. It is for these reasons that the historic information is relevant and perhaps critical to understanding present day shortleaf pine community restoration. It should be noted that results from the historic shortleaf pine database used in this study are based on wildfire events. More information is needed that compares fire effects resulting from prescribed fires versus wildfires (see Gnehm and Hadley, this proceedings).

Survivorship of shortleaf pine is not only reduced by short time lags to the next fire and repeated frequent burning, but also long-term suppression of fire. VDDT model simulations illustrated that long fire intervals (e.g., 40+ years) do not promote seral states containing shortleaf pine. VDDT estimates that long-term suppression of fire promotes the dominance (>80 percemt, Fig. 4) of hardwoods over shortleaf pine. In late-successional forests in the Ozarks little shortleaf pine regeneration is allowed by small-scale disturbances (Shelton and Cain 1999, Stambaugh 2001, Stambaugh and Muzika, this proceedings).

Fire Management

Fire management implications of these results pertain to burning frequencies and generalized effects on shortleaf pine. One important point is that burning frequencies represent mean fire intervals that are a result of variation in years between subsequent fires. Burning that incorporates variability in years between fires more closely mimics the historic fire regime and the results presented in this study. Initial burn effects from decades of litter accumulation may not represent those following repeated fires.

In young oak-pine forests in the Ozarks, conditions of fire suppression commonly result in pine being overtopped by hardwoods. This situation may be less common further south in the region, where the species attains greater height growth rates. In Missouri underplanting of pine prior to overstory removal has been used to enhance shortleaf's competitive ability. However, even under this condition, additional hardwood control may be required, further emphasizing the species' need for repeated disturbance.

Along with frequency, the timing of burning treatments is likely a critical consideration for promoting shortleaf pine. Regional fire scar histories show that fire events occurred almost exclusively during the dormant season (i.e., approximately October to March). Timing of burns should precede the timing of seed dissemination (late October, November) and seedling development (early spring season) to maximize regeneration survival. Information or monitoring of the timing of critical life stages and the fire environment would be of particular value towards understanding the appropriate season of fire for shortleaf pine restoration.

CONCLUSION

The three methods used to determine the appropriate burning frequencies for promoting shortleaf pine regeneration and survival all resulted in similar conclusions. Frequent burning (1- to 4-yr frequency) likely promotes regeneration, but a lowered frequency (8 to 15 yrs) promotes survival and recruitment into the overstory. We hypothesize that an 8- to 15-yr fire frequency may be a range where shortleaf has a higher probability of recruitment than many hardwood competitors, especially after longer periods of continuous burning. Additional information on fire effects (both prescribed fire and wildfire) specific to oak-pine forests and historic pine growth with corresponding fire information would aid in further defining appropriate fire frequencies.

ACKNOWLEDGMENTS

Data used in this study were generated from past studies that were funded by the Missouri Department of Conservation, Mark Twain National Forest, Ozark National Scenic Riverways-National Park Service, U.S. Forest Service Northern Research Station, and The Nature Conservancy. We are grateful for the many individuals involved in the data collection and analysis, particularly George Hartman, Adam Bale, and University of Missouri forestry students. In addition we thank Erin McMurry and two reviewers for their contributions to this manuscript.

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EFFECTS OF SITE PREPARATION SUBSOILING AND PRESCRIBED BURNING ON SURVIVAL AND GROWTH OF SHORTLEAF PINE IN THE MARK TWAIN NATIONAL FOREST: RESULTS AFTER 20 GROWING SEASONS

David Gwaze, Ross Melick, Lynn McClure, Charly Studyvin, and David Massengele[1]

ABSTRACT.—The objective of this study was to evaluate the effect of subsoiling (ripping) and prescribed burning on height, survival, diameter, volume, and competition of planted shortleaf pine (*Pinus echinata* Mill.). The study was established at the Salem Ranger District, Mark Twain National Forest. The treatments were subsoil/burn, burn, and control with no site preparation. Height was assessed at 5 and 20 years; survival, diameter, volume, and competition were assessed at 20 years. Survival rate was only 469 trees/ha in the control treatment, while the survival rate was 1680 trees/ha in the burn treatment and 1600 stems/ha in the subsoil/burn treatment. Subsoil/burn treatment improved height growth by 55.8 percent at 5 years, and 32.3 percent at 20 years over the control treatment. Although, subsoil/burn treatment improved volume by 46.5 percent over the control, and burn treatment improved volume by 30.6 percent at age 20 over the control, these improvements were not statistically significant. Twenty years after planting, these results suggest that site preparation is critical for regenerating shortleaf pine and that subsoiling after burning does not provide additional growth responses or increased survival to that attributed to burning.

INTRODUCTION

Shortleaf pine forests in Missouri have been severely altered by logging, grazing and fire suppression, prompting restoration efforts within the state. The future success of these restoration efforts requires a better understanding of site preparation methods. Many of the shortleaf pine sites being restored have a dense soil layer (fragipan) at soil depths near 18 inches, and hardwoods present serious competition problems for the planted shortleaf pine seedlings. Subsoiling (ripping) the soil may provide openings in the fragipan that allow root growth into and below this dense layer. In addition, subsoiling may reduce soil bulk density, improve overall root development, and increase nutrient uptake. Subsoiling reduces hardwood competition around the seedling during the first few years after planting, eliminating the need for follow-up release treatment from competing hardwoods (Wittwer et al. 1986). Subsoiling can be done alone, but is usually easier, safer, and more uniform if preceded by a slash-reduction treatment such as prescribed burning. Burning prior to subsoiling reduces slash, improves the visibility of stumps and other obstacles, reduces equipment wear and tear, and reduces the time spent freeing ripper teeth of accumulated slash, which hinders and reduces subsoiling depth (Fryar 1984). Burning reduces competition from grass, forbs and hardwoods. Few reports quantify benefits of subsoiling on shortleaf pine in the USA. In Georgia, subsoiling increased height growth by 17 percent, root-collar diameter by 15 percent and tree volume by 38 percent five years after planting compared to the control (Berry 1979). In Arkansas, subsoiling improved survival by 20-25 percent and competition from weeds and other vegetation was reduced (McClure 1984). In Missouri, subsoiling improved volume by 41.2 percent after two growing seasons, but reduced it by 10.2 percent at 16 years (Gwaze et al. 2006).

Prescribed burning is used for regenerating southern pines by direct seeding, planting, or natural regeneration (Pritchett 1979). It is probably the most economical site preparation tool (KcKee 1982). Fire alone can control competing vegetation until seedlings become established. Prescribed fire has an advantage over mechanical site preparation methods such as subsoiling in that less accessible sites (e.g., steep slopes) can easily be prepared using burning. Although site preparation burning is used in Missouri, there is no existing documentation of its effect on survival and growth of planted shortleaf pine. In Florida, burning improved neither survival nor growth of slash pine 10 years after planting (Outcalt 1982). Generally, prescribed burning is believed to be most effective when used in conjunction with chemical or mechanical site preparation methods (Frey 1984).

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[1] Resource Scientist (DG), Missouri Department of Conservation, 1110 S. College Avenue, Columbia, MO 65201; Former Silviculturist (RM) and Silviculturist (CS), Mark Twain National Forest, 401 Fairgrounds Road, Rolla, MO 65401, Former Silviculturist (LM) and Silviculturist (DM), Mark Twain National Forest, 1301 South Main, Salem, MO 65560. DG is corresponding author: to contact call (573)882-9909 ext. 3320 or email at David.Gwaze@mdc.mo.gov

The objective of the study is to quantify the long-term effects of subsoiling and prescribed burning on survival and growth of planted shortleaf pine seedlings at Mark Twain National Forest.

MATERIALS AND METHODS

Study Site

The study is located in stand 15, compartment 169, on the Salem Ranger District, Mark Twain National Forest. The compartment is located in SE of SW 1/4 Section 23, T32N, R3W in Reynolds County, southeast Missouri. The stand is 17 acres, has a SW aspect, and runs from a gentle ridgetop on the NE to a drainage on the SW. Slopes exceed 35 percent on spots, but the slope average is 20 to 25 percent. Soils on the ridge tops are Captina series, which characteristically have a fragipan at a depth around 18 inches. Clarksville soils are generally found on the side slopes, and these soils are excessively drained and lack fragipans. The original stand was a 60-year-old oak-pine stand, dominated by black oak (*Quercus velutina*), scarlet oak (*Q. coccinea*), post oak (*Q. stellata*), white oak (*Q. alba*), hickory (*Carya* spp.) and some scattered shortleaf pine (*Pinus echinata*). The overall site index for the stand is 60 based on black oak. The stand was clearcut in 1983.

Site Preparation, Planting, and Assessment

The southeast 6 acres of the stand (control) received no site preparation. In June 1984, the northwest 11 acres received a good, hot burn. Approximately half of the burned area was subsoiled to a depth of 20 inches in fall 1984. The other half of the burned area was not subsoiled. The subsoiling was done using a single-toothed 25-inch ripper with furrows spaced 8 feet apart. Unimproved 1-0 shortleaf pine seedlings were planted on a spacing of 8 x 8 feet in spring 1985.

In June 1989, "V"- shaped transects, with the point of the "V" down hill, were established in the burned plus subsoiled area and the control area. Transects in both areas ran from the ridge on the NE side at an azimuth of 2700 and returned at an azimuth of 300. The point of the "V" was located on about the same contour line in both treatments. Transects were designed to sample across possible variation in slope position. A total of 44 trees and 27 trees located along the transect were measured for height in subsoil/burn and control treatments, respectively. In July 2004 approximately the same trees were assessed for height. Because the "V" transects did not allow assessment of survival and competition, five random plots in each treatment (subsoil/burn, burn, and control) were established to assess survival and hardwood competition in July 2004. Each plot was 100 square meters (10 m x 10 m). The number, species, height, and diameter at breast height of all trees in a plot were measured. Height was measured using a height pole and diameter at breast height (DBH, cm) using a diameter tape.

Conical volume (V, dm^3 per tree) was calculated for all trees using the following equation:

$$V = \frac{1}{3}\pi\left(\frac{D}{2}\right)^2 H$$

where D = diameter at breast height (cm), and H = height (m).

Statistical Analysis

Analyses were carried out for survival, height, diameter, and volume for each age separately. Survival and stocking were analyzed using chi-squared tests. Growth data from the "V" transects were analyzed using pooled T-tests. The assumptions of equal variances and normality were tested prior to the pooled T-tests, and were accepted. Growth data from plots were analyzed using the PROC GLM procedure in SAS Version 9.1 (SAS Institute Inc., Cary, NC). The following linear model was used for analyzing the data from plots:

$$Y_{ij} = \mu + T_i + e_{ij}$$

where Y_{ij} is the jth observation on the ith treatment, μ is the population mean, T_i is the fixed effect of treatment, and e_{ij} is the error term. All analyses were carried out at the $P \leq 0.05$ probability level.

RESULTS

Survival

After 20 growing seasons, planted shortleaf pine had an average density of only 469 stems/ha in the control treatment, a significantly lower density ($P < 0.001$) than in the burn treatment (1680 stems/ha) and in the subsoil/burn treatment (1600 stems/ha) (Fig. 1). Survival in the areas that were prepared (burn and subsoil/burn treatments) was not significantly different, suggesting that subsoiling after burning does not provide additional increase in survival to that attributed to just burning. Pine stocking in the control treatment was 469 trees per ha (190 trees per acre), a

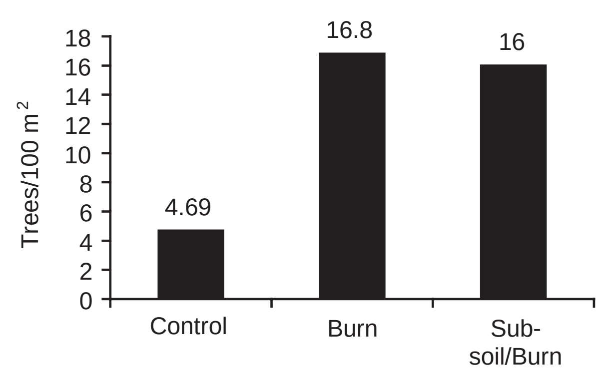

Figure 1.—Survival of shortleaf pine trees after 20 growing seasons.

stocking below the minimum required for a fully stocked shortleaf pine stand in Missouri.

Growth

Transects

Trees in the subsoil/burn treatment had significantly greater height growth (P < 0.001) than those in the control treatment at 5 and 20 years (Fig. 2). Subsoiling after burning increased height growth by 55.8 percent and 32.3 percent at age 5 and 20, respectively. The increased height advantage of subsoiling appears to decline with age.

Random Plots

Trees in the subsoil/burn and burn treatments had significantly greater height growth than those in the control treatment at 20 years (Table 1). However, no significant improvement in height growth was attributable to subsoiling over that obtained from burning alone. Burning alone increased height by 23.4 percent, while burning plus subsoiling increased height by 24.2 percent (Table 1). Although subsoiling after burning increased diameter and volume over the control treatment by 17.2 percent and 46.5 percent, respectively, these improvements were not statistically significant because of a large variation in diameter measurements in the control treatment.

Hardwood Competition

Twenty years after planting, naturally regenerated hardwood species had an average density of 1988 stems/ha in the control treatment, a much higher number than in the burn treatment (1422 stems/ha) and in the subsoil/burn treatment (1244 stems/ha) (Table 2). The differences between treatments were not statistically significant (P = 0.100).

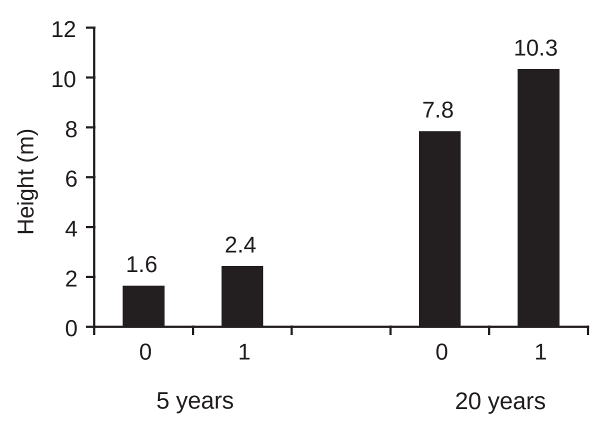

Figure 2.—Treatment effects (0 = control, 1 = subsoil/burn) on height growth at 5 and 20 years estimated from “V” transects.

Hardwoods were significantly taller in the burn treatment than in the control and subsoil/burn treatments (P = 0.03). Hardwoods in the subsoil/burn treatment were smaller in diameter compared to those in the burn and control treatments (P < 0.001).

DISCUSSION

Twenty years after field establishment, subsoiling improved survival compared to the control. Results from this study are consistent with other studies in Georgia (Berry 1979) and Missouri (Gwaze et al. 2006) which showed that subsoiling improved survival of shortleaf pine. The improvement in survival in this study was much higher than that reported by

Table 1.—Treatment effects on height, diameter, and volume at 20 years estimated from square plots. Standard errors of the means are in parentheses.

Trait	Subsoil/Burn	Increase (percent)	Burn	Increase (percent)	Control	P-value
Height (m)	9.76 (0.22)	24.2	9.69 (0.23)	23.4	7.86 (0.47)	< 0.001
Diameter (cm)	11.83 (0.47)	17.2	11.38 (0.39)	12.8	10.09 (0.92)	0.174
Volume (dm^3)	46.04 (3.48)	46.5	41.05 (2.83)	30.6	31.43 (5.51)	0.088

Table 2.—Status of naturally regenerated hardwood vegetation 20 years after planting.

	Subsoil/burn	Burn	Control	P-value
Stocking (trees/ha)	1244	1422	1988	0.100
Height (m)	6.32	7.09	6.45	0.03
Diameter (cm)	4.79	6.38	6.56	< 0.001

Gwaze et al. (2006) partly because the control was treated differently in the two studies. In Gwaze et al.'s study, the control treatment was bulldozed, while in this study the control treatment did not receive any site preparation. Because of the more intensive site preparation method in the control treatment in their study, the improvement in survival due to subsoiling was unimportant 16 years after planting. Despite the low survival in the control treatment in this study, the stocking of pine (190 stems per acre) may be acceptable given Mark Twain National Forest's current emphasis on pine-oak mixtures rather than pine plantations. Subsoiling did not provide benefits in survival beyond those provided by burning alone. Because the number of trees in the burn and subsoil/burn was more than 1500 trees per hectare (607 trees per acre), fewer seedlings need to be planted in both treatments to achieve a stocking of 400 seedlings at 5 years. In Missouri, a pine stand is considered fully stocked if it has 400 shortleaf pine seedlings per acre at 3-5 years (Gwaze et al. 2006).

When compared to the control, height growth was significantly improved by subsoiling at 5 and 20 years, a result consistent with other studies in the United States. Berry (1979) reported that height of shortleaf pine was improved by 17 percent by subsoiling at 5 years of age in a Piedmont site in Georgia. In Oklahoma, subsoiling increased height of loblolly pine by 10 percent after two growing seasons (Wittwer et al. 1986). In contrast, long-term results from studies in Missouri revealed that subsoiling at 16 years had no significant effect on height of shortleaf pine (Gwaze et al. 2006). Burning alone improved growth equally as well as subsoiling and burning. The increased growth in the burn/subsoil treatment in this study resulted from improved soil physical properties, improved short-term nutrient availability, improved soil-water extraction, and/or reduced hardwood competition. The increased growth in the burn treatment the result of improved short-term nutrient availability and reduced hardwood competition. Because productivity on the two prepared treatments was similar, the increased height growth on prepared treatments compared to the control treatment is likely to be the result of reduced hardwood competition.

Hardwood competitors reinvaded regardless of the site preparation treatment. However, competing hardwoods were fewer and smaller when the site was prepared by burning or burning and subsoiling. Burning is likely to have killed many hardwoods, and subsoiling damaged root systems, which probably reduced the vigor of subsequent hardwood sprouts. Survival of trees planted in the control treatment (unprepared site) could have been improved by follow-up release to control the hardwood competition a few years after planting. However, follow-up release may not be necessary when the site is prepared using burning or subsoiling after burning.

Our results are not consistent with other studies in Florida where burning did not improve survival or growth of slash pine 10 years after planting (Outcalt 1982). The relative effectiveness of prescribed burning depends on site characteristics and burn conditions. It is not clear why subsoiling after burning provided no benefit in survival, growth and hardwood competition beyond what was provided by burning in our study. It may be that the subsoiling depth was not sufficient to break the fragipan or that there are other limiting factors below the fragipan that restrict tree growth in the subsoiling treatment. It is difficult to relate the results to soil properties because information on soil properties is absent. Results from this study suggest that burning can be an effective site preparation method. Burning as a site preparation technique also can be unpredictable, however, due to varying amounts and types of fuel, variations in slope and aspect, and unstable weather conditions. Subsoiling might provide additional benefits on poorer sites which are either severely compacted or rocky.

CONCLUSION

This study demonstrated that site preparation is an important factor in regenerating shortleaf pine successfully. Without site preparation, high mortality and poor growth can be expected from the planted shortleaf pine. The study suggests that at 20 years after planting, subsoiling after burning does not provide additional growth responses or increased survival over that attributed to burning alone. Thus, burning might be the preferred site preparation method because the extra cost of subsoiling may not be justified.

ACKNOWLEDGMENTS

The work reported here was supported by the Mark Twain National Forest. We thank students Brandon Kell and John Muehlman for plot installation and measurements. We thank Jillian Lane for her assistance in the statistical analysis.

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THE EFFECTS OF A WILDFIRE ON PINE SEEDLING RECRUITMENT

Paula C. Gnehm and Brad Hadley[1]

ABSTRACT.—We investigated the effects of a single arson wildfire by comparing its impact on pine seedling recruitment with that of both prescribed fire and unburned compartments. Although a t-test detected no significant difference in pine seedling recruitment ($p = 0.38$), the "wildfire" treatment produced 127 more seedlings than the unburned treatment, and 96 more seedlings than the prescribed fire treatment. Managers should consider using burn conditions similar to a wildfire when the primary objective is a simple increase in the pine component of a particular stand.

INTRODUCTION

Wildfires are not an uncommon occurrence in the Missouri Ozarks. The differences between their effects and those of prescribed fire on shortleaf pine (*Pinus echinata* Mill.) seedling recruitment are unknown.

Shortleaf pine is one of the many pine trees that can be found in Missouri, but it is the only pine tree that is native to the state. It takes approximately 2 years for a shortleaf pine seed to germinate naturally. Shortleaf pine seedlings have a persistent J-shaped crook at the ground level (Lawson 2006). A shortleaf pine's above-ground growth during the first year is very minimal compared to the root system it is putting in the ground. A year-old seedling can easily be overlooked because even with its needles, it is only about 1 to 1.5 inch in diameter, and about the same in height. Shortleaf's intense need for full sunlight will allow it to grow only in open areas. Throughout the tree's life this need for sunlight continues; as the tree grows taller, the limbs at the top of the tree shade the older branches on the bottom. The older branches consequently wither and die, giving the tree its characteristic form of bare stems and leafy tops (Dorst and Crandall 2005).

Like other conifers, shortleaf pines are generally prolific seed producers. However, site preparation is usually necessary for natural regeneration. The small, winged seeds must come into direct contact with the soil on the forest floor to effectively germinate and grow. Usually a thick layer of litter deposits, such as leaves, grasses, branches, and weeds, will produce a barrier between the seeds and the soil. Prescribed burning is an excellent method to remove this barrier. This method is used to help promote the natural regeneration of many plants, including shortleaf pine. Fire will also eliminate most of the hardwood and vegetative competition and some of the standing dead trees, ultimately opening the canopy and allowing penetration of the direct sunlight the seedlings need to grow (Zimmerman 2006).

In April 2003, a very intense arson wildfire on Birch Creek Conservation Area burned approximately 160 acres. Four agencies were on site for approximately 8 hours, with an estimated total labor force of 25 people. The roughly 7,000 acres of the Birch Creek Conservation Area are under a 15-year management rotation. The particular area burned had received no management treatments in the recent past (since 1994), leaving it fully stocked with trees but little to no slash. In the 2 years since the fire, the area has had a salvage timber sale.

We investigated the effects of the wildfire by comparing its impact on pine seedling recruitment with that of both prescribed fire and unburned compartments.

STUDY AREA

Three study sites were located within the Current River Hills Subsection of the Ozark Highlands Ecological Section (Nelson 2005) on Birch Creek and Peck Ranch Conservation Areas. The primary study site was the site of the wildfire burn; it had been subject to wildfire 2 years prior to the study period, and was located within an existing pine stand. This site had a slightly north-facing slope. In our choice of comparison sites, we made every effort to match their attributes to those of the primary study site. Variation within a specific stand is always apparent, however, and it is therefore virtually impossible to perfectly "match" attributes among disjunct stands. Nevertheless, the two comparison sites were selected from those available with similar attributes, including aspect, slope, natural community types, seed source availability, and soil type. Beyond these

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[1] Resource Assistant (PCG), Peck Ranch Conservation Area, Missouri Department of Conservation, PO Box 180, Jefferson City, MO 65102; and Conservation Agent (BH), Shannon County, Missouri Department of Conservation, PO Box 181, Birch Tree, MO 65438; Biology Department Adjunct Faculty (BH), Drury University, 900 N. Benton Ave., Springfield MO 65802. PCG is corresponding author: to contact call (573) 300-9572 or email at tattat1@hotmail.com

attributes, the second site was within a prescribed burn compartment and had been subject to prescribed fire under conditions that were mild, compared to the wildfire site. The site was located on Peck Ranch Conservation Area. The third site was within an unburned compartment, which was also located on Peck Ranch Conservation Area.

METHODS

Randomly selected plots of approximately 1 acre were chosen within each treatment type. Twelve randomly selected (using random number key for bearing and distance from center) subplots 12 ft in diameter (≈ 113.25 square feet) within each treatment type plot were sampled. Subplots were sampled by driving a rebar stake with a 6-ft length of rope attached into the ground and pivoting around that stake to the true place of beginning, counting all seedlings (fitting subjective assessment as being ≤ 2 years old) observed.

Statistical analysis of sample means (t-test$_{[\alpha.05]}$) was performed using Minitab® 12.1 software (Minitab®, State College, PA) on a standard PC.

RESULTS

Twenty-six seedlings were counted for all three of the study sites. Their distribution in the sample is illustrated in Figure 1. The calculated average number of seedlings per subplot was extrapolated to estimate the number of seedlings per acre by treatment type (Fig. 2). Although the “wildfire” treatment produced 127 more seedlings than the unburned treatment, and 96 more seedlings than the prescribed fire treatment, the t-test detected no significant difference in pine seedling recruitment (*p = 0.38*).

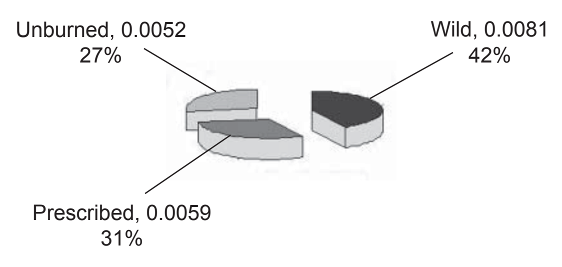

Figure 1.—Average pine seedling recruitment per square foot by fire treatment type, and percent of total number of seedlings in sample.

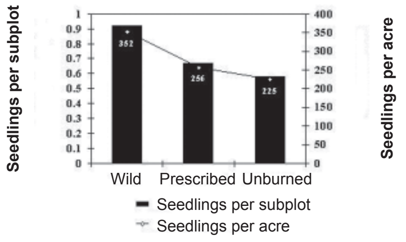

Figure 2.—Number of seedlings per acre as estimated from number per subplot by treatment type.

DISCUSSION

The t-test’s failure to detect a significant difference may be an artifact of sample size, in that only 3 percent of each of the study sites was sampled. It is possible that by chance alone the least intensely burned areas were sampled in the wildfire area, and the most productive pine seedling areas were sampled in the unburned area. The outcome of such chance events would tend to bias the sample towards no significant difference between treatments. Another factor that could have influenced this study is the fact that the wildfire-burned area had been subjected to a salvage sale. As stated earlier, removal of standing dead trees “opens” the ground to sunlight. This increase in sunlight could have contributed disproportionately to the greater seedling recruitment on the wildfire-burned area. However, the fact remains that this wildfire and its subsequent management resulted in the recruitment of an estimated 127 more pine seedlings per acre on the wildfire burned area than on the unburned area. Managers should consider using burn conditions similar to a wildfire if and when affecting a simple increase in the pine component of a particular stand is their primary objective.

Timing, intensity, and frequency of prescribed burns are critical to establish and develop successful shortleaf pine stands (Cain and others 1998). Our results suggest that to best achieve initial ecological release, prescribed fires should be performed under parameters that allow for intense heat, such as those in “wildfire” conditions.

ACKNOWLEDGMENTS

We thank the Peck Ranch Wildlife Division staff of Dan Drees, Kim Houf, Marshall Price, Patti Vessels, and Leta Hightower, and Eminence District Forestry staff of Johnny Tuttle and Gary Gognat for their time, effort, and support. We also thank reviewers of this manuscript for suggestions that resulted in its improvement.

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HARDWOOD REGENERATION RELATED TO OVERSTORY SHORTLEAF PINE BASAL AREA AND SITE INDEX IN ARKANSAS AND EASTERN OKLAHOMA

Douglas J. Stevenson, Thomas B. Lynch, and James M. Guldin[1]

EXTENDED ABSTRACT

Shortleaf pine (*Pinus echinata* Mill.) grows in association with many other woody species, particularly understory hardwoods, which compete with it, limiting its productivity. Along with other species, sweet-gum (*Liquidambar styraciflua* L.) is a major competitor on better-quality sites but decreases rapidly in importance as pine site index (SI) decreases and pine overstory increases.

Over 200 fixed-radius 0.2-acre plots were permanently established in naturally-occurring shortleaf pine stands located in the Ozark and Ouachita National Forests during the period 1985 to 1987 as part of a forest growth study. Five trees per plot were sampled using increment borers to determine age. Height measurements were made on two trees in each one-inch diameter class on each plot and diameter at breast height (DBH) was measured on all trees. SI was calculated using Graney and Burkhardt's (1973) equation for each SI sample tree and averaging the result for each plot.

Initially plots were thinned to assigned basal area levels and hardwoods were treated with chemical herbicide. During the 1995-1997 re-measurement of these plots, two 0.005-acre subplots were established within each of the shortleaf growth plots to assess shortleaf regeneration and abundance of understory hardwoods. During the 2000-2001 remeasurement, an additional two 0.005-acre subplots were added. At each re-measurement, saplings over 4.5 feet tall were tallied by plot and species.

Each plot was an observation. Shortleaf pine basal area (square feet per acre) and SI (50-year basis) were used as environmental (dependent) variables. Seedling counts by plot were used as species (independent) variables. Thinning treatment was used as a co-variable (dummy variable). There were 52 sapling species in the sample.

Analysis was carried out using partial Canonical Correspondence Analysis (pCCA) as described by Leps and Smilauer (2003). Analysis indicates that most associated hardwood species are sensitive to pine site quality as determined by SI and shade under shortleaf pine canopies using overstory basal area as a proxy for shade.

SI and basal area explained 12.9 percent of total variation in species composition. The first pCCA axis accounted for 4.5 percent of variation, the second for an additional 3.1 percent and the third for another 2.4 percent. Species vs. SI and basal area correlation was 0.551, 0.554 and 0.445 for the first, second and third axes, respectively.

Sweet-gum was the major hardwood species on the SI scale on sites above SI 85. Green ash (*Fraxinus pennsylvanica* Marsh.), red maple (*Acer rubrum* L.), dogwood (*Cornus* spp. L.), winged elm (*Ulmus alata* Michx.) and black oak (*Quercus velutina* Lam.) were common species on sites above 60 SI. Dogwood was the most common species on sites between 65 and 75 SI. Red maple was common throughout all sites but was the predominant hardwood species on sites below 65 SI.

All species responded along a decay curve related to pine basal area. Sweet-gum and black-gum (*Nyssa sylvatica* Marsh.) were the most-common species with almost identical curves. Both were strongly influenced by pine basal area. Mockernut hickory (*Carya tomentosa* Nutt.) was the species least affected by basal area, occurring at low levels on all sites.

ACKNOWLEDGMENTS

The cooperation of personnel on the USDA Forest Service Ozark and Ouachita National Forests greatly facilitated collection of data used for this project. The support and assistance of the USDA Forest Service Southern Research Station is also appreciated.

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[1] Senior Research Specialist (DJS), Natural Resource Ecology and Management, Oklahoma State University, Stillwater, OK 74078; Professor, Natural Resource Ecology and Management, Oklahoma State University, Stillwater, OK 74078; Supervisory Ecologist and Project Leader, Southern Research Station, USDA Forest Service, P.O. Box 1270, Hot Springs, AR 71902. DJS is corresponding author: to contact call (405) 744-5515 or email doug.stevenson@okstate.edu

SHORTLEAF PINE REPRODUCTION ABUNDANCE AND GROWTH IN PINE-OAK STANDS IN THE MISSOURI OZARKS

Elizabeth M. Blizzard, Doyle Henken, John M. Kabrick,
Daniel C. Dey, David R. Larsen and David Gwaze[1]

ABSTRACT.—We conducted an operational study to evaluate effect of site preparation treatments on pine reproduction density and the impact of overstory basal area and understory density on pine reproduction height and basal diameter in pine-oak stands in the Missouri Ozarks. Stands were harvested to or below B-level stocking, but patchiness of the oak decline lead to some plots having no overstory and some having over 200 ft^2/ac basal area at the end of the study. In all stands, the midstory and understory were chainsaw felled. If stands were inadequately stocked with pine reproduction, then mechanical scarifying or prescribed burning treatments were applied to increase the density of shortleaf pine reproduction. Pine reproduction basal diameter, height, and crown class within the understory were measured three to eight growing seasons later.

We found no long-term difference in pine reproduction density by treatment. Overstory density and reproduction competition both affected the growth of shortleaf pine seedlings. The basal diameter and height of pine reproduction were greatest when overstory basal area was low, reproduction density was low, and pine seedlings were dominant or codominant to competitors within the understory. Pines had an 80 percent chance of being dominant/codominant with 2,000 TPA of mixed-species reproduction with no overstory, but only a 50 percent probability with 6,000 TPA of reproduction and 70 ft^2/ac of overstory basal area.

INTRODUCTION

Foresters, conservationists and ecologists have expressed interest in restoring shortleaf pine (*Pinus echinata* Mill.) throughout its native range in the Ozark Highlands. Restoring shortleaf pine is a long-term strategy for mitigating chronic oak decline and bringing back natural mixed species forests and woodland communities that are important to wildlife (Nelson 2005, Dickson et al. 1995).

At varying times throughout the Missouri Ozarks, patches of oak decline have resulted in 30 to 70 percent mortality in the overstory. Scarlet oaks (*Quercus coccinea* Muenchh.) and black oaks (*Q. velutina* Lam.) , especially those that are older than 70 years, are particularly susceptible to oak decline (Starkey et al. 1989). Shortleaf pine and white oak (*Q. alba* L.) are longer-lived than scarlet and black oak, and where present they can lengthen the biological rotation age of mixed-species stands.

Shortleaf pine once was extensive in the Ozarks and was a major component of most forest types. Past forest uses have resulted in even- and mixed-aged scarlet, black, and white oak stands dominating former shortleaf pine sites. Mortality from oak decline is exacerbated in scarlet and black oaks grown on these poor sites (Starkey et al. 1989). Oaks on poor quality, droughty sites have slow growth due to nutrient and moisture deficiencies. Drought and insect defoliation and wood boring insects in turn weaken oaks, making them more susceptible to Armillaria root disease, which further weakens or damages black, scarlet, and some white oak trees. Shortleaf pine is not affected by most oak pests and pathogens, but it is susceptible to annosum root disease (*Heterobasidion annosum*) and southern pine beetle (*Dendroctonus frontalis* Zimmermann), among others (Woodward et al. 1988). However, shortleaf pine pathogens and pests tend to not be a problem in natural pine and pine-hardwood stands (Brinkman and Smith 1969).

There is growing interest in restoring pine and pine-oak mixes because of their ecological importance and their capacity to mitigate oak decline. Mixed species stands have several advantages. A mixed species stand may decrease

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[1] Graduate Research Assistant (EMB), Department of Forestry, 203 Natural Resources Building, University of Missouri, Columbia, MO 65211; Silviculturist (DH), USDA Forest Service, Houston/Rolla/Cedar Creek Ranger District, 108 S Sam Houston Blvd., Houston, MO 65483; Research Forester (JMK and DCD), USDA Forest Service, Northern Research Station, 202 Natural Resources Building, Columbia, MO 65211; Professor (DRL), Department of Forestry, 203 Natural Resources Building, University of Missouri, Columbia, MO 65211 and Resource Scientist (DPG), Missouri Department of Conservation Resource Science Center, 1110 South College Ave., Columbia, MO 65201. JMK is the corresponding author: to contact call (573) 875-5341 or email at jkabrick@fs.fed.us

the continuity of food sources for species-specific pests and decrease the occurrence of root grafts, thereby limiting the spread of pathogens. A mixed species stand may provide managers more options in the case of an insect or disease outbreak by allowing for partial thinnings. Although there is much research about growing pine monocultures, there is little information about restoring and managing pine and oak mixes. Pines and oaks have very different ecological strategies that makes regenerating them together a challenge, as upland oaks often readily regenerate on former pine sites in the Ozarks, whereas shortleaf pine may require some site preparation and release treatments.

Stands that were salvaged due to oak decline between 1997 and 2000 were selected for an operational management study as part of a collaboration between forest managers and researchers to evaluate success of site-preparation treatments and to begin evaluating the effects of retained overstory trees and same-age reproduction on pine reproduction growth. This paper has three objectives:
1) to evaluate pine reproduction densities several years after scarifying or burning compared with stands that had adequate pine reproduction densities after harvest;
2) to analyze the roles of overstory density and understory competition on growth of pine reproduction; and 3) to analyze the roles of overstory and understory densities on the density of oak and other hardwood species that were within 5.3 ft of the pine.

METHODS

Study Sites

Study sites were located in northern Texas County on the Houston Ranger District of the Mark Twain National Forest in Missouri. Sites fall within the Big Piney River Oak-Pine Woodland/Forest Hills within the Gasconade River Hills Subsection of the Ozark Highlands (Nigh and Schroeder 2002). Ecological land types included narrow to broad ridges, and slopes on all aspects. Soils are mostly mapped as Coulstone (loamy-skeletal, siliceous, semiactive, mesic Typic Paleudults), and include Clarksville (loamy-skeletal, siliceous, semiactive, mesic Typic Paleudults), Hobson (fine-loamy, siliceous, active, mesic Oxyaquic Fragiudalfs), and Lebanon (fine, mixed, active, mesic Typic Fragiudults). Slopes range from 6 to 32 percent with a mean of 15 percent. Growing seasons last 210-230 days with a mean annual temperature of 54-57 °F (Wendland et al. 1992). Shortleaf pine site indices range from 51 to 64 ft, with a mean of 58 ft (Table 1).

We classified stands with 25 to 48 percent pine as pine/oak and stands with more than 49 percent pine as pine (Table 2). Stands were fully stocked prior to salvaging, but had varying degrees of oak decline (Rogers 1982). Oak decline salvage operations left mature pine and pine/oak stands at or below B-level.

Table 1.—Acreage, ecological land types, site indices, and soil types of stands in the study.

Compartment-Stand	Size (ac)	Ecological Landtype	Site Index (ft at age 50 yr)	Soil Type
2-21	4	narrow ridge	Black Oak 55	Clarksville
2-25	9	narrow ridge	Shortleaf P 60	Clarksville
2-29	10	south or west slope	Shortleaf P 55	Coulstone
2-33	11	south or west slope	Shortleaf P 60	Coulstone
2-34	4	narrow ridge	Shortleaf P 59	Clarksville
2-45	7	south or west slope	Shortleaf P 56	Coulstone
2-46	7	north or east slope	White Oak 58	Coulstone
2-48	13	north or east slope	Shortleaf P 64	Coulstone
2-74	16	south or west slope	Shortleaf P 60	Lebanon
13-36	47	north or east slope	Shortleaf P 51	Clarksville
13-58	8	narrow ridge	Shortleaf P 64	Hobson
16-04	19	north or east slope	Shortleaf P 55	Coulstone
16-27	8	broad ridge	Shortleaf P 58	Coulstone

Table 2.—Overstory stocking and stand treatments.

Compartment Stand Type[1]	Post-Harvest Basal Area (ft²/ac)	Timeline (yr) Harvested Shelter-wood	Timeline (yr) Harvested Uneven	Timeline (yr) Site-Preparation Scarified	Timeline (yr) Site-Preparation Burned	Timeline (yr) Chainsaw Follow-up[2]
2-21 Pine/Oak[3]	50	1997			2000, 2002	2000
2-25 Pine	80	1997			2000, 2002	2000
2-29 Pine/Oak	80	1997			2000, 2002	2000
2-33 Pine/Oak	40	1997			2000, 2002	2000
2-34 Pine	80	1997			2000, 2002	2000
2-45 Pine	70		1997			2000
2-46 Black Oak	40		1997			2000
2-48 Pine/Oak	40	1997				2000
2-74 Pine/Oak	80		2000	2000		2000
13-36 Pine/Oak	92		1996	1998		1998
13-58 Pine	103		1996	1998		1998
16-04 Pine	70	1998		2000[3]		2000
16-27 Pine/Oak	100		1998			2000

[1] Pine/Oak = 25-48 percent pine; Pine = >49 percent; Black oak = >50 percent
[2] Cut undesired trees and sprouts
[3] Also filled in with pine seed

Site Preparation

We surveyed shortleaf pine reproduction after loggers completed the overstory salvage harvests. Even-aged stands with 435 shortleaf pine seedlings per acre and uneven-aged stands with a growing stock in 60 percent of the 0.2-ac openings were adequately stocked, received no further treatments, and are used as a benchmark in this study. Stands with inadequate stocking were either mechanically scarified or burned (Table 2).

The site was mechanically scarified to improve the seedbed in stands that had patches of pine reproduction already established. To scarify, we pulled an anchor chain assembly—two 25-lb anchor chains with round rods welded across the links—behind a bulldozer at about 5 ac/hr, focusing on areas within the stand that were inadequately stocked[2]. The anchor chain assembly appears to be less damaging to hardwoods than the heavy disk method recommended by Haney (1962). We then used chainsaws to fell residual unmerchantable mid- and understory trees according to even-aged or uneven-aged (removing the worst and leaving the best) guidelines after scarifying or before burning.

Burning was used in stands that required additional pine reproduction throughout. Logistic delays resulted in an ineffective initial burn, requiring a second prescribed fire (Table 2). We burned five stands 2 years after harvest to allow slash to decompose prior to burning. Unfortunately, the burn occurred after seed fall, so we did not expect much seedling establishment. The burn did not control hardwoods very well but did establish some pine reproduction. We conducted a second (and final) burn in November of 2002.

Data Collection

We inventoried the stands in the winter of 2005-2006. We ran transects with data collection nodes every 100 ft, used a 10 BAF prism to measure the overstory, and collected pine reproduction data using the point-centered quarter method (Fig. 1; Mitchell 2001). At each node, we recorded the distance to the closest pine in each of four quadrants. We measured the height and basal diameter of the tallest of the four pines and tallied understory competition within a 5.3-ft radius. Then, we recorded height and species of the tallest understory competitor within the circle.

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[2] Contact Doyle Henken for more information on building the anchor chain scarifier.

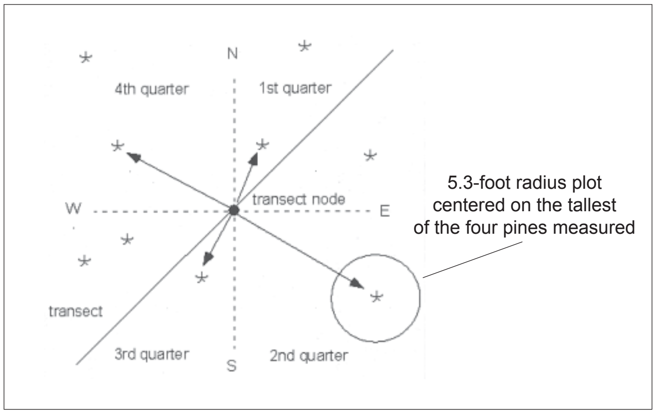

Figure 1.—Example of four-quarter sampling. Distance from the transect node to the closest pine seedling or sapling (*) in each quadrant was measured. The circled pine is the tallest of the four measured pines; all pine, oak, and other hardwood competition was tallied within a 5.3-ft radius of the tallest pine. Height of the tallest competitor was also recorded.

Data Analysis

We used linear and logistic regression to analyze the data (Proc Reg, Proc Logistic, SAS 2003). We used $Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_iX_i$ for all models, except the probability of a given pine being dominant/codominant for which we used $P = (e\text{^}(\beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_iX_i))/(1+ e\text{^}(\beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_iX_i))$. We tested combinations of indicator variables that we thought best modeled the stand dynamics that occur between a given pine seedling/sapling, the overstory and other reproduction. Some of the models tested are shown in Table 3. Most models tested had three components: overstory basal area, reproduction density, and age. Pine growth and density models included combinations of the following predictor variables: the pine's crown class within the understory, total basal area (or oak, other hardwood, and pine basal areas; ft^2/ac), density of total reproduction (TPA), density of non-pine reproduction (oak and other hardwoods; TPA), and age (yrs). Age was designated as the number of growing seasons since last treatment. Oak and other hardwood density models included the above predictor variables except pine crown class.

We differentiated the significant stand dynamics models using Akaike Information Criterion (AIC) scores (Table 3; Burnham and Anderson 2003, Proc Mixed, Proc Logistic, SAS 2003). Models with the lowest AIC scores best describe the stand dynamics with the fewest indicator variables. We considered models $\geq$ 2 AIC units apart to be different (Burnham and Anderson 2003).

RESULTS

Indicator Variables

We selected stands to include a wide range of overstory densities at the plot level. Overstory basal area at the plot level ranged from 0 to 200 ft^2/ac, with a mean of 63 ft^2/ac 3 to 8 years after regeneration (Table 4). Because of the wide range in basal area, the density of understory competitors with pine ranged considerably from 0 to 20,732 TPA, with a mean of 4,615 TPA. Understory competitor heights ranged from 0 to 19 ft, with heights relative to the sample pine of -10 ft to 15 ft.

Pine Density

Prescribed burning and mechanical scarification both maintained stocking levels comparable to stands that were adequately stocked after harvest (Benchmark, Fig. 2). Benchmark stands had a mean of 201 ±98 TPA, prescribed burned stands had a mean of 345 ±98 TPA, and mechanically scarified stands had a mean of 257 ±126 TPA. Thus, both prescribed burning and mechanical scarification operation treatments were successful.

Pine Basal Diameter

The basal diameter of pine reproduction increased as its crown class in the understory improved, and as the overstory basal area decreased (Fig. 3). Canopy class (within the understory), overstory basal area, and height of the tallest competitor were the strongest predictors of pine basal diameter (Table 5). The total reproduction density was not found to be a significant factor affecting the basal diameter of pine reproduction. Models with overstory basal area and/or other reproduction specified by species group did not improve the prediction of pine basal diameter based upon AIC scores. These results suggest that the basal diameter of pine is primarily affected by its crown class within the understory but also by the basal area of the overstory.

Pine Height

Pine height increased with increasing crown class and decreased with increasing overstory basal area (Fig. 4). A combination of crown class, overstory basal area, age, density of reproduction, and height of the tallest competitor best predicted pine height (i.e., lowest AIC value) and had an R^2 of 0.47 (Table 5). The species of neither the overstory nor the understory added sufficient information to warrant their inclusion in the model based upon AIC. The results also show that relatively large changes in overstory basal area are required to have the same impact on pine reproduction height compared to the effect of crown position.

Probability of a Given Pine Being Dominant/Codominant

Because of the importance of crown class for predicting height and diameter growth, we examined factors related to the crown position of the pine reproduction. Crown class is determined in part by the density of reproduction in the understory and by density of the overstory. Factors included in modeling crown class were density of non-pine

Table 3.—Linear and logistic models with diagnostic statistics for measures of pine growth and density of competition around the pine. Models are ordered by inclusion of components. Models with the lowest Akaike Information Criterion (AIC) scores best describe the stand dynamics with the fewest indicator variables. Models with < 2 AIC units apart were similar (∆AIC).

			Statistics	
MODELS[1,2]	**AIC**	**∆AIC**	**F-value**	**R²**
PINE BASAL DIAMETER[3]				
OverBA Age TotalRepro. Compht’	464	146	10	0.12
Dom Codom Inter OverBA Age TotalRepro.’	354	36	32	0.38
Dom Codom Inter OverBA Age TotalRepro.’ Compht	318	0	39	0.46
Dom Codom Inter OverBA Age Nonpinecomp’ Pine’ Compht	325	7	34	0.46
Dom Codom Inter OakBA PineBA HwdBA Age PineRepro.’ Non-PineRepro.’ Compht	345	27	27	0.47
PINE HEIGHT[3]				
OverBA Age TotalRepro. Compht’	1377	159	11	0.12
Dom Codom Inter OverBA Age TotalRepro.’ Compht	1218	0	40	0.47
Dom Codom Inter OverBA Age Non-PineRepro.’ PineRepro.’ Compht’	1223	5	35	0.47
Dom Codom Inter OakBA PineBA HwdBA’ Age NonPineRepro.’ PineRepro.’ Compht	1237	19	28	0.48
DENSITY OF NON-PINE[3]				
OverBA’ Age’ PineRepro.’	1859	0	2’	0.01
OakBA HwdBA’ PineBA’ Age’	1861	2	3	0.04
OakBA HwdBA’ PineBA’ Age’ PineRepro.	1860	1	3	0.05
DENSITY OF OAK[3]				
OverBA’ Age’	1567	23	1’	0.01
OverBA’ Age’ Non-OakRepro.’	1552	9	8	0.07
OakBA Age’	1561	18	3	0.02
OakBA Age’ Non-OakRepro.’	1544	0	10	0.09
OakBA PineBA’ HwdBA’ Age’ PineRepro. HwdRepro.	1555	12	6	0.11
DENSITY OF HWD[3]				
OverBA’ Age’ Non-HwdRepro.	1817	4	67	0.06
OakBA PineBA’ HwdBA’ Age	1835	22	2’	0.03
OakBA Age	1825	12	3	0.02
OakBA Age Non-HwdRepro	1813	0	8	0.07
OakBA PineBA’ HwdBA’ Age Non-HwdRepro	1824	11	5	0.07
PROBABILITY OF A GIVEN PINE BEING DOM./CODOM.[4]			**Chi-Square**	
OverBA Age’ TotalRepro.’ Compht	298	0	73	
OverBA Age’ Non-PineRepro Pine Compht	298	0	105	
OakBA PineBA HwdBA’ Age’ TotalRepro.’ Compht	330	32	75	
OakBA PineBA HwdBA’ Age’ Non-PineRepro. Pine Compht	300	2	107	

[1] Abbreviations: Age = number of growing seasons since regeneration treatment; BA = Basal area (ft^2/ac); CompHt = height (ft) of the tallest competitor within the understory; Dom., Codom., Inter. = dominant, codominant, or intermediate pine within the understory, use 1 if true, 0 otherwise; Int. = y-intercept; Over. = overstory; Oth. Hwd. = other hardwood tree species; and Repro = density of reproduction (TPA).

[2] All parameters and statistics are significant except those followed by an “ ’ ”.

[3] Model: $Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_iX_i$.

[4] Model: $P = (e\hat{}(\beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_iX_i))/(1 + e\hat{}(\beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_iX_i))$.

Table 4.—Winter 2006 overstory basal area (ft²/ac), understory density (TPA), height (ft) of the tallest competitors, and height (ft) of the tallest competitor relative to the pine reproduction.

	Overstory	Understory Competitors		
	Basal Area Mean (Range) (ft²/ac)	Density Mean (Range) (TPA)	Height Range (ft)	Relative Height of Tallest Competitor Range (ft)
All Species	63 (0 – 200)	4,615 (0 – 20,732)	0.0 – 18.5	-10.4 to 14.5
Pine	38 (0 – 190)	1,020 (0 – 19,251)	0.8 – 18.5	-3.0 to 11.9
Oak	23 (0 – 130)	1,228 (0 – 8,391)	2.1 – 16.6	-10.4 to 14.5
Other Hardwoods	1 (0 – 40)	2,368 (0 – 7,404)	1.4 – 15.9	-9.2 to 13.9

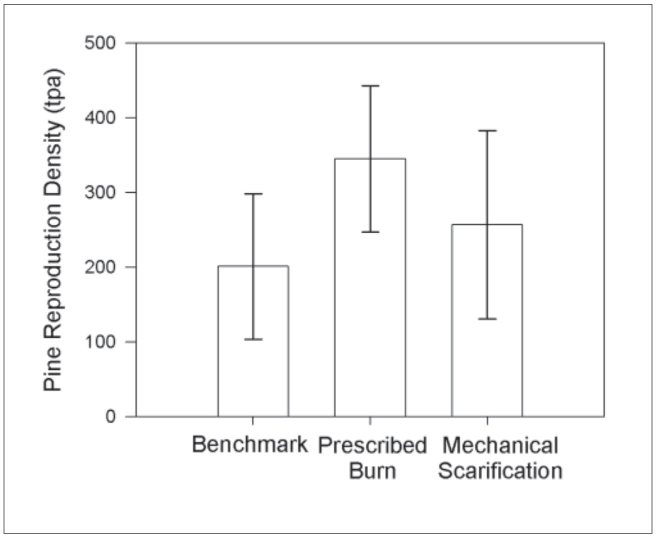

Figure 2.—Density of pine reproduction by site preparation treatment. Error bars represent 1 standard deviation. Mechanical scarification treatments were applied as needed, rather than uniformly, across the stand. There was no significant difference in pine density at the stand level by treatment.

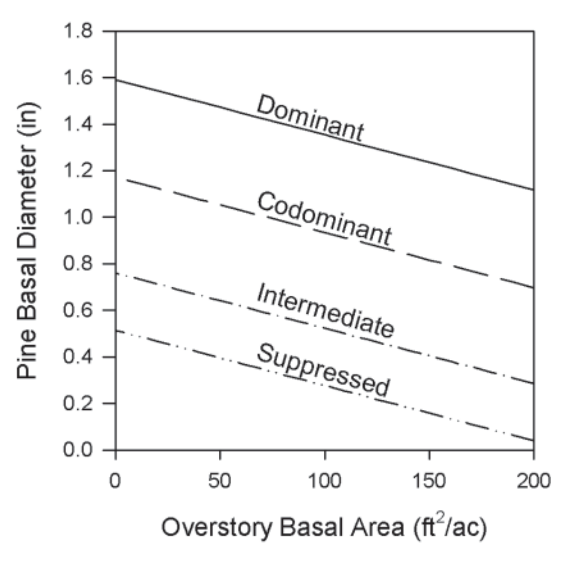

Figure 3.—Basal diameter of pine reproduction at age 10 yr based upon the pine's crown class, height (ft) of its tallest competitor and 5,000 TPA competitors (all species) by overstory basal area (ft²/ac). Dominant pine reproduction had twice the basal diameter of intermediate pine reproduction.

reproduction, density of pine reproduction, overstory basal area, and age and height of the tallest competitor; the model had a Chi-square of 105.2 (Table 5).

The probability of a given pine being dominant or codominant increased with decreasing overstory density and with decreasing reproduction density (Fig. 5). To have a greater than 50/50 chance of a given pine being dominant or codominant the overstory basal area must be less than 70 ft²/ac with 2,000 TPA or less in the understory, or less than 10 ft²/ac overstory basal area with 6,000 TPA or less in the understory.

Density of Non-Pine Competitors

We also examined factors potentially affecting the density of non-pine competition around sampled pines. Density of non-pine competitors was related to overstory oak basal area and density of non-pine understory competition (other hardwoods for oak or oaks for other hardwoods) (Table 5). However, the models failed to account for much of the variance in the data, as indicated by the low R^2 values of 0.05 and 0.10.

Table 5.—Linear models with growth of pine reproduction dependent upon crown class within the understory, overstory density, understory density, height of the tallest competitor and age; crown class within the understory dependent upon density of non-pine reproduction, pine reproduction, overstory basal area, age and height of the tallest competitor, and age; and density of understory competitors dependent upon overstory basal area and density of understory by species. There were 320 observations of each dependent variable.

	Parameter Estimates (X)[1,2]								Statistics	
Dependant variable	Int.	Dom.	Codom.	Inter.	Over. BA	Age	Total Repro.	Comp. Ht	F-value	R^2
	β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7		
Pine Basal Diameter[3]	-0.055’	1.078†	0.658†	0.246†	-0.002*	0.019*	-0.000’	0.052†	39†	0.46
Pine Height[3]	-0.006’	4.505†	2.957†	1.067†	-0.012†	0.091†	0.000’	0.233†	40†	0.47

	Parameter Estimates (X)[1,2]						Statistics
Dependant variable	Int.	Non-Pine Repro.	Pine Repro.	Over. BA	Age	Comp. Ht	Chi-Square
	β_0	β_1	β_2	β_3	β_4	β_5	
Probability of a Given Pine Being Dom./Codom.[4]	2.8228†	-0.0005†	0.0002¤	-0.0236†	0.0980’	-0.2378†	105†

	Parameter Estimates (X)[1,2]								Statistics	
Dependant Variable	Int.	Oak BA	Age	Oth. Hwd. BA	Pine BA	Pine Repro.	Oak Repro.	Oth. Hwd. Repro.	F-value	R^2
	β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7		
Density of Oak and Oth. Hwd.	3750.5†	-19.75‡	67.25’	0.623’	-0.575’	-0.136¤			3*	0.05
Density of Oak	2004.3†	-10.12†	-5.333’			-0.074’		-0.182†	9†	0.10
Density of Oth. Hwd.	2793.1†	-14.88¤	77.86¤			-0.101’	-0.419†		9†	0.10

[1] Abbreviations: Age = number of growing seasons since regeneration treatment; BA = Basal area (ft^2/ac); CompHt = height (ft) of the tallest competitor within the understory; Dom., Codom., Inter. = dominant, codominant, or intermediate pine within the understory, use 1 if true, 0 otherwise; Int. = y-intercept; Over. = overstory; Oth. Hwd. = other hardwood tree species; and Repro = density of reproduction (TPA).

[2] Parameter estimates differ from zero at the following alphas: † = <0.0001, ‡ = ≤0.001, * = ≤0.01, ¤ = ≤0.05, ’ = not significant (>0.05).

[3] Model: $Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_iX_i$.

[4] Model: $P = (e\^(\beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_iX_i))/(1+ e\^(\beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_iX_i))$.

DISCUSSION

Shortleaf pine-upland oak mixtures occur naturally in Missouri, but foresters would like to better understand the stand dynamics in order to more predictably achieve these mixtures. While stand-wide regeneration events are natural—the tornado near Poplar Bluff being an excellent example—widespread and chronic oak decline has provided an opportunity to study regeneration and growth of shortleaf pine under a thinned canopy. Our results show that given these stand structures, overstory retention results in slowed shortleaf pine growth.

Both mechanical scarification and prescribed burning increased pine reproduction densities to levels similar to stands that had adequately reproduction stocking without treatment. Scarification is more practical than burning in small stands or when there are smoke management issues. Scarification treatments by skilled operators may cause less damage to crop oak trees than prescribed fire, particularly in stands that have not been burned for decades. Prescribed fires can cover large areas in a day or two, and proper timing and fire techniques aid in reducing or increasing oak reproduction (Dey and Hartman 2005, Van Lear et al. 2000).

Overstory densities must be kept low to recruit seedlings, especially shortleaf pine (Larsen et al. 1997, Baker 1992, Liming 1945). Shortleaf pine seedlings are moderately shade tolerant, but become shade intolerant with age (Baker 1992). Thus, if shortleaf pine is being recruited, then the

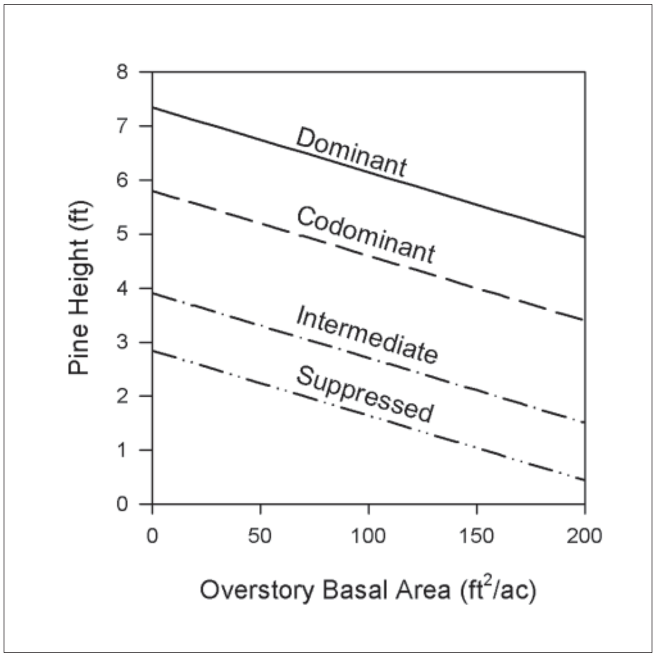

Figure 4.—Height (ft) of pine reproduction at age 10 yr based upon the pine's crown class, height (ft) of its tallest competitor, and 5,000 TPA competitors (all species) by overstory basal area (ft^2/ac).

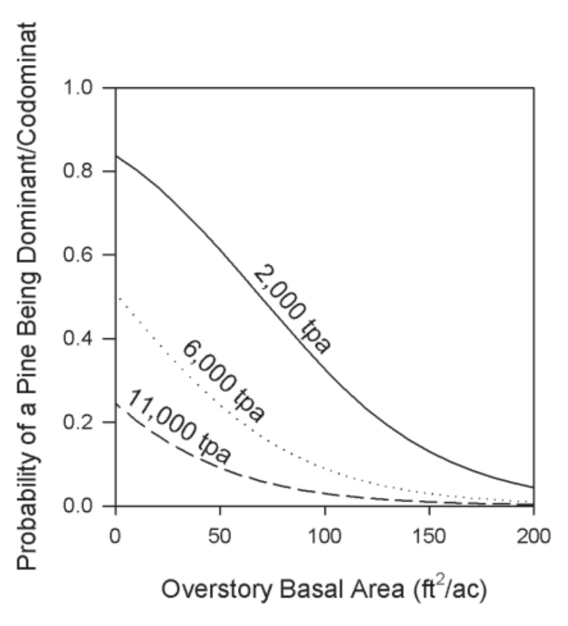

Figure 5.—Probability of a given pine being dominant/codominant for a given understory density (TPA) by overstory basal area (ft^2/ac). There is a 50 percent probability of a given pine being dominant/codominant with 2,000 TPA mixed-species reproduction at 70 ft^2/ac basal area and with 6,000 TPA mixed-species reproduction at 10 ft^2/ac basal area.

mature overstory basal area should be kept low during seedling establishment and even lower after establishment to promote maximum reproduction height growth (Fig. 5).

In addition to reductions to overstory density, periodic releases have long been recognized as key to reliably recruiting shortleaf pine among oak reproduction (Brickman and Smith 1969, Baker 1992, Liming and Seizert 1943). Our data suggest that recruiting pine under a thinned canopy requires a commitment to periodic release from oak and other hardwood reproduction, particularly where there is a high density of hardwood competition (Fig. 5). While oaks also grow best in the open, they are more shade tolerant than shortleaf pine. Even under low overstory stocking levels, a high density of oaks in the reproduction cohort can greatly reduce the likelihood that pine reproduction will successfully compete for growing space and grow into the overstory.

ACKNOWLEDGMENTS

The USDA Forest Service's Mark Twain National Forest and North Central Research Station, and Missouri Department of Conservation Resource Science Division funded this project. Thank you to Eli Engelken and Mark Peeper for data collection.

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SHORTLEAF PINE SEEDLING PRODUCTION AND SEEDING TRENDS IN MISSOURI

David Gwaze, Greg Hoss, and Dena Biram[1]

ABSTRACT.—The Missouri Department of Conservation operates the only nursery that supplies bare-root shortleaf pine seedlings in Missouri. Seedlings and seed have been sold to landowners since 1935. Prior to 1981 most seed was locally collected wild seed, some was purchased from neighboring states. After 1981, most of the seed for artificial regeneration was improved orchard seed. The highest production of shortleaf pine seedlings occurred prior to 1987 with at least 2 million seedlings being produced annually. Today less than half a million seedlings are produced at the nursery. Before 1990 most of the seedlings were delivered to the Mark Twain National Forest, but now it is a minor player in artificial regeneration of shortleaf pine. Trends in seed distributed for direct seeding followed those of seedling production. This paper discusses factors that influenced the trends in shortleaf pine seed distribution and seedling production, and makes suggestions for future direction.

INTRODUCTION

George O. White Nursery, which is operated by the Missouri Department of Conservation (MDC), is the only nursery that produces bareroot shortleaf pine for use by private landowners and state and federal agencies. This nursery was owned and operated by the U.S. Forest Service from 1935 to 1946 with assistance from the Civilian Conservation Corps (CCC) employees. The goal of the nursery in its inception was to grow shortleaf pine seedlings for reforestation efforts at the Clark and Mark Twain National Forests, to ensure continuous supply of timber production. In 1947 the nursery was leased to MDC by the U.S. Forest Service; in 1976, MDC obtained ownership of the site (Mugford 1984). The nursery currently occupies about 748 acres of which 50 acres are a seedbed production area.

Shortleaf pine seedlings and seed have been sold to landowners to improve habitat, increase biodiversity and produce timber since 1935. From 1935 to 1981 most shortleaf pine seed was locally collected wild seed or purchased from neighboring states, particularly Arkansas. After 1981, most of the seed for artificial regeneration came from a grafted seed orchard established in Mt. Ida, AR, using Missouri superior trees. Today all planting and seeding needs in Missouri are being met from genetically improved seed collected from this grafted seed orchard.

All shortleaf pine seedlings produced at the George O. White nursery are 1-year-old bareroot seedlings. Shortleaf pine is stratified and sown in nursery beds in spring. Seed for direct seeding is stratified, repellent-coated, and sown in late March or early April. Seed germination will begin about 4 weeks after sowing as temperature and moisture conditions become favorable.

The objective of this study is to summarize trends in shortleaf pine seedling production and seeding in Missouri.

SEEDLING PRODUCTION

At least 2 million shortleaf pine seedlings were produced each year at the George O. White Nursery from 1960 to 1987, except in 1977 and 1984 (Figure 1). The highest seed production was between 1963 and 1966, when at least 6 million seedlings were produced each year, reaching a peak of nearly 9 million seedlings in 1965. After 1987, seedling production decreased exponentially to about 400,000 seedlings in 2005. Since 1990 annual seedling production levels have stayed below 1 million, where they remain to this day. This more recent production figure is well below the 45-year long-term average annual seedling production of 2.7 million.

Seedling Distribution by Land Owner Group

Federal

Although the Mark Twain National Forest (MTNF) owns only 9.9 percent of Missouri's forest land, most of the shortleaf pine seedlings produced by the George O. White Nursery were delivered to MTNF from 1960 to 1989 (Figure 2). The biggest orders from MTNF were in the 1960s, particularly from 1963 to 1968, when between 2.5 million and 5 million seedlings were delivered annually. The second biggest orders were in the early 1980s, when 4.4 million were delivered in 1980 and 2.5 million in 1985.

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[1] Resource Scientist (DG), Missouri Department of Conservation, 1110 S. College Avenue, Columbia, MO 65201; Nursery Supervisor (GH) and Computer Operator (DB), Missouri Department of Conservation, 14027 Shafer Road, Licking, MO 65542. DG is corresponding author: to contact call (573) 882-9909 ext. 3320 or email at David.Gwaze@mdc.mo.gov

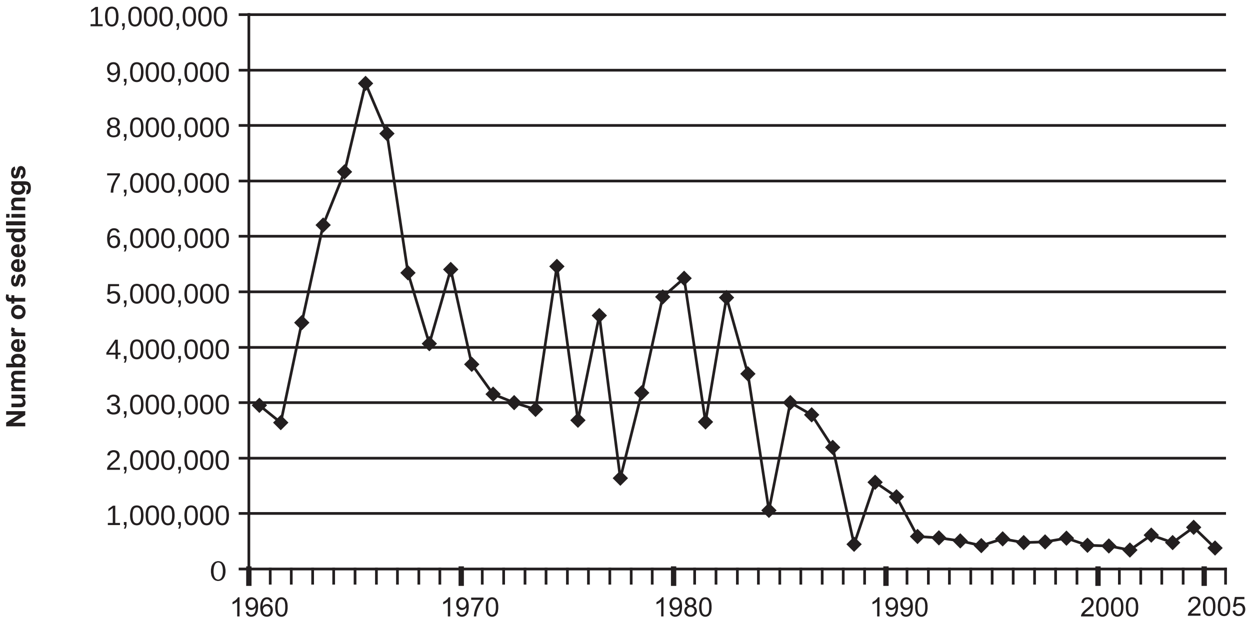

Figure 1.—Number of shortleaf pine seedlings produced at the George O. White Nursery 1960-2005.

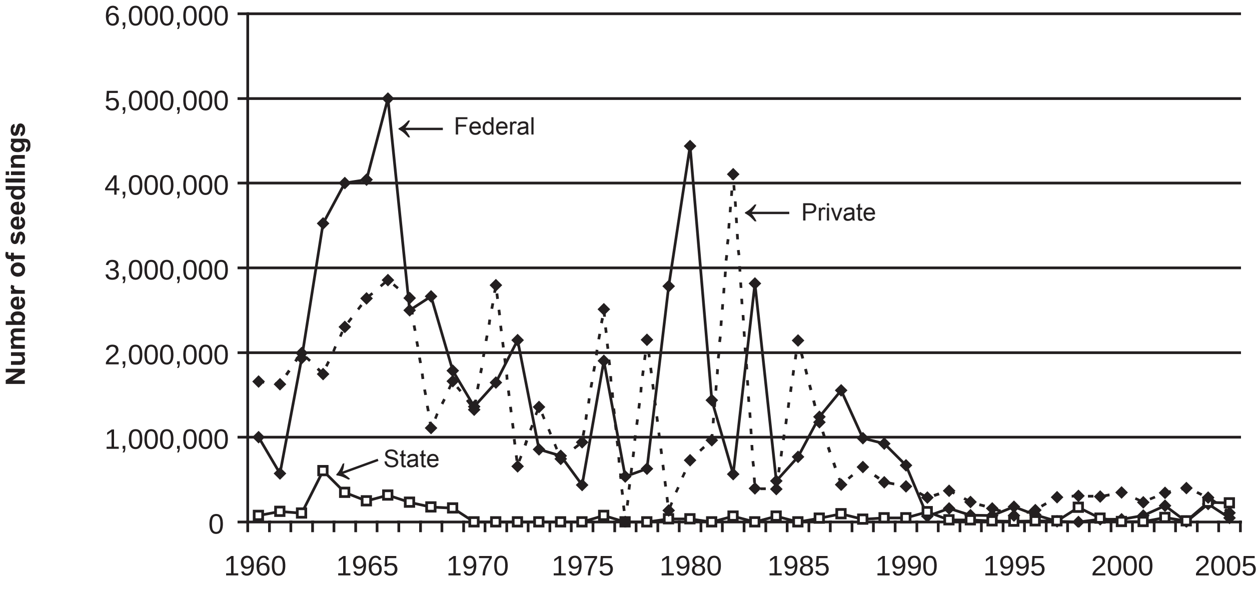

Figure 2.—Number of shortleaf pine seedlings distributed by the George O. White Nursery by ownership group 1960-2005.

After 1985, the seedlings ordered by MTNF never exceeded 1 million, and since 1990 the orders have remained below 0.2 million. Since 1990, MTNF has been a minor player in artificial regeneration of shortleaf pine. In 2005, it ordered only 46,000 seedlings, representing a dramatic drop in shortleaf pine planting from the 1 to 2 million seedlings planted annually during the 1980s.

Several factors profoundly influenced the trend in shortleaf pine seedling demand by MTNF. Changes in policies by the Federal government caused less demand for seedlings from MTNF. In the early 1990s, the U.S. Forest Service adopted the concept of ecosystem management, which called for a reduction in the practice of clearcutting. As a result, timber harvesting practices on the National Forests shifted to favor methods using natural regeneration, such as seed tree, shelterwood, and uneven-aged management. This policy shift led to less timber harvesting and dramatically reduced artificial regeneration. In general, fewer old fields were purchased after the 1980s, which also meant fewer plantings. The new initiatives such as the Healthy Forest Initiative are unlikely to greatly accelerate seedling and seed demand on MTNF. The 2005 Forest Plan, however, emphasizes restoration and enhancement of natural communities, and an increase in pine planting will be required to restore shortleaf pine in parts of its former range.

Private Landowners

Generally, private landowners ordered the second largest quantity of seedlings, particularly prior to 1990 (Fig. 2), but there were a number of years in this period when their orders surpassed those from MTNF. Since 1990, private landowners have taken the lead, but the amount ordered has dropped sharply. The biggest order from private landowners was in 1983 when 4 million were ordered, and between 1960 and 1970, they consistently ordered more than 1 million seedlings per year. Since 1987, the private landowners never ordered more than 1 million seedlings in any year, and more recently they have ordered less than 0.5 million have been ordered annually.

Shortleaf pine seedling distribution to private landowners has been a response to major federal planting programs. The major federal program that assisted with tree planning from the 1970s to the present were the Forestry Incentive Program (FIP) and Forestland Enhancement Program (FLEP). FIP was originally authorized in 1978 to share up to 65 percent of the costs of tree planting, timber stand improvements, and related practices on nonindustrial private forest lands, and was terminated in 2002. FLEP replaced FIP in 2002 and its objective is to provide educational, technical, and financial assistance to help private forest landowners implement their sustainable forestry management objectives. The maximum FLEP cost-share payment for any practice may be up to 75 percent. Despite the existence of these federal programs, demand for shortleaf pine seedlings by the private landowners continues to decrease perhaps because of the limited markets for shortleaf pine products in Missouri. With 85 percent of the forest lands in Missouri in private landowners' hands, efforts should be made to identify solutions for increasing shortleaf pine seedling demand by the private landowners.

State

Finally, the smallest number of seedlings was distributed to MDC (Fig. 2). The seedlings delivered to MDC never exceeded 1 million in any year, and only exceed 0.5 million in 1963. The small amount of seedlings distributed to MDC could be due to the fact that the state only owns 3 percemt of the forested lands in Missouri.

In 2005, 59 percent of the seedlings were delivered to the MDC, 29 percent to private landowners and 12 percent to federal government (Fig. 3). That year was the first time MDC had ordered more seedlings than the federal government and the private landowners.

DIRECT SEEDING

Direct seeding received a lot of attention during the 1960s and 1970s, and peaked between 1960 and 1964 when 4,500 pounds of seed was distributed for direct seeding by the George O. White Nursery (Fig. 4). The largest amount of seed for direct seeding in a single year was 1200 pounds, which was delivered to MTNF in 1963. Seed distributed for direct seeding decreased during the 1980s and 1990s. The relatively large amount of seed distributed between 1995 and 1999 was due to aerial seed requirements for the Eminence District of MDC in 1997.

The reduction in demand of seeds for direct seeding at the MTNF could be attributed partly to reduction in the practice of clearcutting and the difficulty in using herbicides. The reduction in demand for seeds for direct seeding by the private landowners may be attributed to shrinking markets for shortleaf pine timber products.

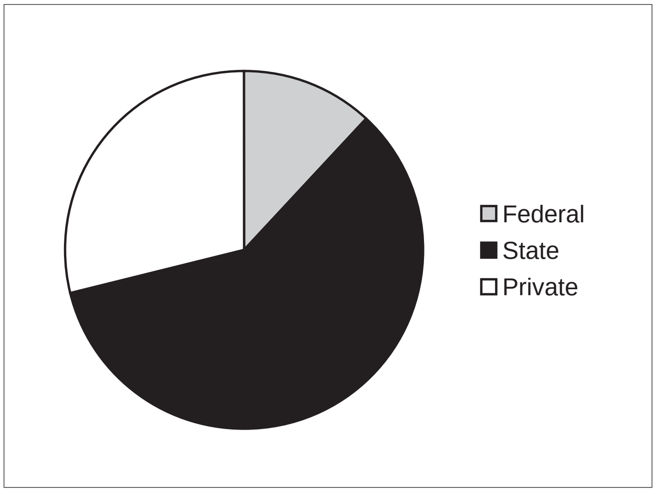

Figure 3.—-Seedling purchase by land owner group in 2005.

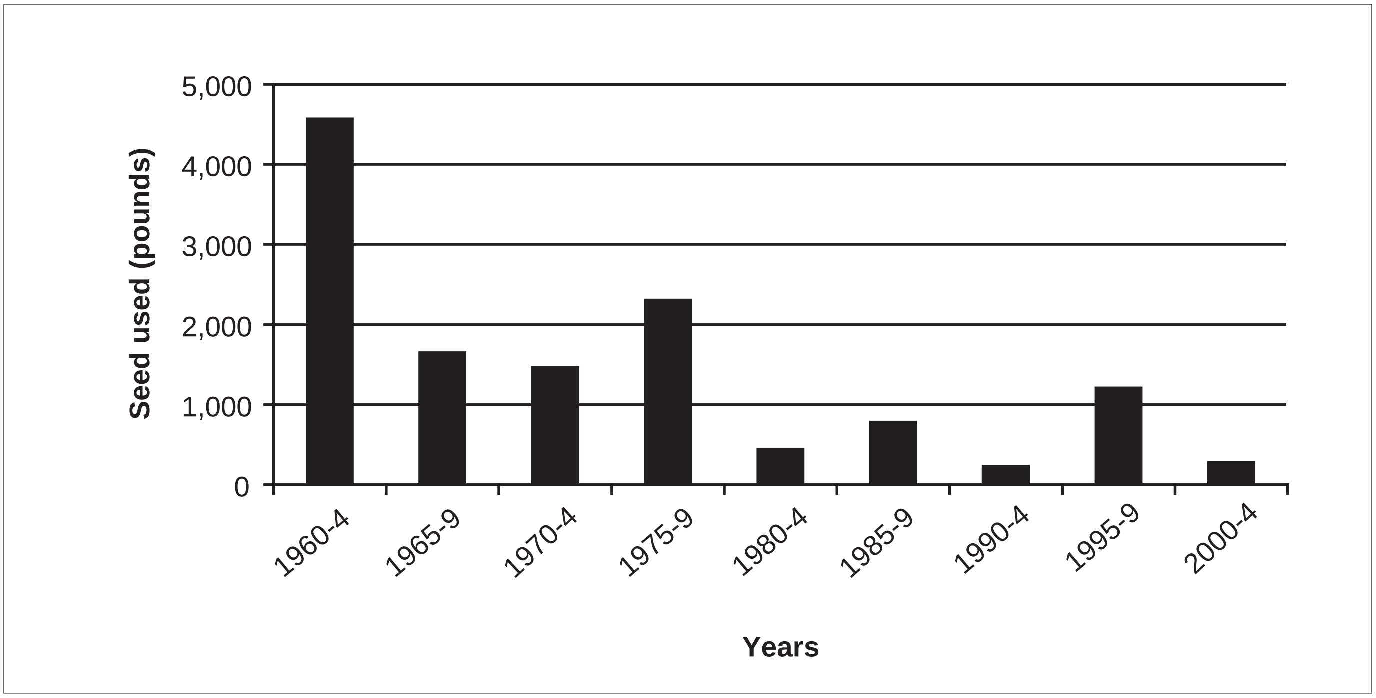

Figure 4.—Shortleaf pine seed distributed by the George O. White Nursery for direct seeding, 1960-2005.

SEED SUPPLY AND REQUIREMENTS

Most of the seed collected between the 1960s and early 1980s was collected in Missouri by local contract pickers. Some seed was obtained from other states such as Arkansas (e. g. Arkansas Forestry Commission, Ouachita National Forest, and Ozark National Forest), Oklahoma and Louisiana. Seed collections by the U.S. Forest Service for operational planting in Missouri date back to 1967 when unimproved seed was collected from Ozark National Forest, AR and given to MDC for storage (Table 1).

Beginning in 1981, improved seed was used mostly for artificial regeneration of shortleaf pine. The improved seed came from an 85-acre clonal seed orchard, located on the Womble Ranger District of the Ouachita National Forest, Mount Ida, AR. This seed orchard was established using 50 superior trees selected from the MTNF. These trees were grafted into a clonal seed orchard between 1969 and 1971. Seed was first collected from the Mt. Ida orchard in 1981, when 215 pounds were collected. A total of 1,578 pounds were harvested in 1983. After this second collection, there was an ample supply of seed in storage and a decision was made to collect only when there was a good seed crop. The third collection was made in 1986, when a massive 2,554 pounds were collected. The bumper harvest in 1986 is attributed partly to the use of pesticides and fertilizers. After this large harvest, no cones were picked from the orchard until 2003. In 2003, 1,500 pounds of seed were collected. This harvest was attributed partly to favorable weather conditions and partly to the thinning and rouging carried out in 2000. The only improved seed not collected from the seed orchard in Mt. Ida was supplied by the Arkansas Forestry Commission in 1986 and 1987.

Currently, all planting and seeding needs in Missouri are being met from genetically improved seed collected from the grafted seed orchard in Mt. Ida. The State of Missouri has used 34 to 80 pounds of seed for planting and 0-109 pounds for seeding per year over the past 8 years (Fig. 5). Seed requirements for direct seeding fluctuate greatly while seedling production needs are more stable. Thus, average annual seed requirements are approximately 100 pounds for both direct seeding and seedling production. Based on this seed requirement figure, MTNF and Missouri Department of Conservation in combination have about a 30-year supply of shortleaf seed available for future afforestation needs. Storing shortleaf pine for 30 years should not present any problems as shortleaf pine is known to store well for up to 35 years (Wakeley and Barnett 1968). However, recent tests in Arkansas have shown that viability decreases rapidly after 10 years of storage (Barbara Crane, USDA Regional Geneticist, pers. comm.).

OUTLOOK

Restoring shortleaf pine throughout its native range in the Ozark Highlands is a top priority in Missouri. Restoring shortleaf pine on former pine and oak-pine sites is a long-term strategy for mitigating chronic oak decline (Law et al. 2004). To restore the ecological and economic importance of shortleaf pine, several restoration efforts were established, including the U.S. Forest Service Pine Knot

Table 1.—Details of seed collections for shortleaf pine restoration in Missouri. All seed was stored at George O. White State Nursery except for the 2003 collection, which is stored in Watersmeet, MI.

Seed source	Year of collection	Lot Number	Amount (pounds)
Ozark National Forest, AR	1967	MT617	842
Northwest Arkansas, AR	1972	MT618	400
Mark Twain National Forest, MO	1975	MT613	49
Ouachita National Forest, AR	1975	-	941
Mark Twain National Forest, MO	1979	MT614	1793
Seed Orchard, Mt Ida, AR*	1981	MT619	215
Seed Orchard, Mt Ida, AR*	1983	MT621	1578
Arkansas Forestry Commission, AR	1984	-	110
Seed Orchard, Mt Ida, AR*	1986	MT625	2554
Arkansas Forestry Commission, AR*	1986	-	350
Arkansas Forestry Commission, AR*	1987	-	510
Missouri Department of Conservation, MO	1995	-	43
Unknown supplier, MO	1997	-	31
Louisiana Forest Seed Company, LA	1997	-	48
Seed Orchard, Mt Ida, AR*	2003	-	1500

*Genetically improved seed

restoration project, and MDC's Peck Ranch Conservation Area (CA), Birch CA, Rocky Creek CA and Sunklands CA, restoration projects. More restoration projects are expected to be developed. These projects will increase the demand for shortleaf pine seedlings and seed for direct seeding. The demand is likely to increase because natural regeneration in most cases is inadequate. Moreover, the increased concern about global warming could prompt a major federally funded restoration program, thereby increasing demand for seeds and seedlings. The seedling production and seed demand for direct seeding are expected not come anywhere near the pre-1990s however, because 1) current policies have shifted from timber production to ecosystem restoration; 2) clearcutting and use of herbicides have been significantly reduced on MTNF; and 3) markets for shortleaf pine are weak.

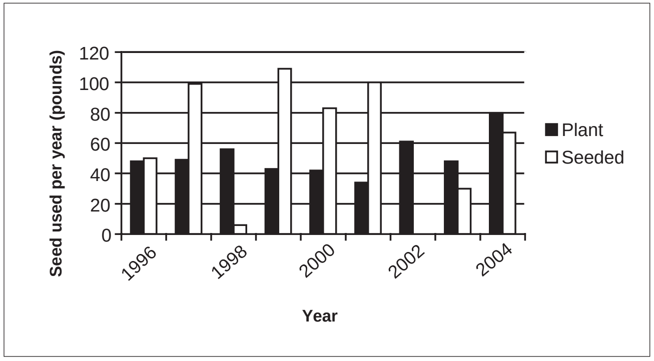

Figure 5.—-Trend in the amount of seed used for seeding and planting, 1996 to 2004.

We propose the following options to ensure seedling and seed demand for shortleaf pine are maintained or increased in the future:

- Develop markets for shortleaf pine and small diameter hardwoods. As markets are developed, demand for shortleaf seedlings by the private landowners is likely to greatly increase. Small increases in demand for seedlings will be expected from public agencies given their increased emphasis on forest values other than timber production.
- Educate the private landowners who own the bulk of the forested lands in Missouri about the benefits of shortleaf pine restoration. The public should be provided with 1) a simple definition of what shortleaf pine restoration is; and 2) a demonstration of the economic and ecological viability of shortleaf pine restoration, including aesthetics.

- Every effort should be made to make seed available to those who want to regenerate shortleaf pine by direct seeding. Direct seeding is desirable for landowners and resource managers who prefer low-cost artificial regeneration methods.
- We highly recommend that two shortleaf pine seed orchards be established, one close to the George O. White State Nursery in Licking and the other on the MTNF using existing surplus seed from controlled crosses. This will ensure that all seed needs are met from seed orchards in Missouri. In addition, if the current second–generation seed orchard established the George O. White State Nursery in Licking in 2002 is destroyed by fire or drought, an alternative seed supply of improved seed will be available.

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THE STATE OF MIXED SHORTLEAF PINE-UPLAND OAK MANAGEMENT IN MISSOURI

Elizabeth M. Blizzard, David R. Larsen, Daniel C. Dey, John M. Kabrick, and David Gwaze[1]

ABSTRACT.—Mixed shortleaf pine-upland oak stands allow flexibility in type and timing of regeneration, release, and harvesting treatments for managers; provide unique wildlife and herbaceous community niches; and increase visual diversity. Most of the research to date focused on growing pure pine or oak stands, with little research on today's need to grow pine-oak mixtures. Despite this lack of information, resourceful foresters are using various regeneration treatments in even- and uneven-aged stands to increase the density of shortleaf pine among oaks. In this paper, we discuss past and current regeneration treatments applied by Missouri Department of Conversation and USDA Forest Service foresters.

INTRODUCTION

Mixed species forests are common in the Missouri Ozarks and there is increasing interest in regenerating mixed stands of shortleaf pine (*Pinus echinata* P. Mill.) and upland oak (white oak, *Quercus alba* L.; black oak, *Q. velutina* Lam. and scarlet oak, *Q. coccinea* Muenchh.). Mixed pine-oak stands are used by neotropical migratory birds, game animals and other fauna and may be managed to promote a rich herbaceous layer (Dickson et al. 1995, Nelson 2005). Restoring pine-oak mixes may be an alternative to maintaining oak-dominated stands suffering from chronic oak decline (Law et al. 2004). In declining oak stands, merchantable scarlet and black oaks, which are at high risk of dying, can be harvested, leaving white oak, shortleaf pine and some younger scarlet and black oaks. Much of the land area affected by chronic oak decline is within shortleaf pine's native range (Nigh and Schroeder 2002). These salvage operations can be combined with treatments to regenerate shortleaf pine and restore pine-oak mixes to their historic importance in Missouri's Ozarks.

Little research has been conducted in Missouri on regenerating shortleaf pine under varying levels of understory competition and overstory density/composition that result from salvage cuts in oak decline stands. Hardwood competition reduces pine growth, and the shade-intolerant pine reproduction does poorly in heavy shade from the overstory (Brinkman and Smith 1969). Overstory composition may also affect light quantity and quality, as well as the presence of shortleaf pine seed sources. The existence of mature pine-oak stands, however, indicates that the two species are not incompatible.

Foresters have begun exploring regeneration methods in pine-oak and oak-pine combinations by modifying regeneration techniques traditionally used for pine or oak. Some foresters have had success, but no one has developed reliably consistent management practices for regenerating pine with hardwoods in natural stands. We surveyed Missouri Department of Conservation (MDC) and U.S. Forest Service (USFS) foresters to get an overview of how they were trying to regenerate shortleaf pine in hardwood dominated stands. The purpose of this paper is: 1) to present variations we observed in how foresters are regenerating a mixture of pine and oak forests; 2) to discuss the need to control hardwood competition in the regeneration layer; and 3) to discuss the need to release shortleaf pine reproduction from the overstory. Results are presented based upon the order of activities in a typical stand.

METHODS

MDC and USFS foresters who had shortleaf pine on their areas or who worked with private landowners to regenerate shortleaf pine were asked to provide examples of mixed pine and oak stands to assess current pine-oak regeneration practices in Missouri. Stand history data were collected to document the management activities. Examples of recent reproduction (0- to 25-years-old) were easy to come by in some areas and non-existent in others. Where examples of recent regeneration were available, the regeneration techniques and release treatments were recorded. Then the foresters were asked what they would prescribe next. Mature stands provided an opportunity to discuss regeneration cuts and options for seedling establishment.

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[1] Graduate Research Assistant (EMB) and Professor (DRL), Department of Forestry, 203 Natural Resources Building, University of Missouri, Columbia, MO 65211; Research Forester (DCD and JMK), USDA Forest Service, Northern Research Station, 202 Natural Resources Building, Columbia, MO 65211; and Resource Scientist (DPG), Missouri Department of Conservation Resource Science Center, 1110 South College Avenue Columbia, MO 65201. EMB is the corresponding author: to contact call (573) 882-7242 or email at embvf2@mizzou.edu

RESULTS

Pine and Oak Mixtures

Pine-oak mixtures generally occur as even-aged stands or as two-aged stands where oaks grew into a pine stand. In some stands, pines grew into large gaps within oak stands. The ridges and sideslopes near Buzzards' Roost Cave on the Big Piney River in northern Texas County are examples of variation in spatial distribution. Pines and oaks occur as small groups of single species and as more even mixtures (Fig. 1).

Regeneration Cuts

Regeneration cuts applied to regenerate shortleaf pine-oak combinations include both even- and uneven-aged methods. The cuts include clearcut, typically with reserves; seedtree; shelterwood; and group selection. The range of regeneration cuts reflects the variation in owner objectives and the impact of oak decline. The interest in maintaining continuous canopy cover in tourism corridors and centers and the extensiveness of oak decline are causing some foresters to use uneven-aged methods in pine-oak stands. Some research on uneven-aged management has taken place in the Ouachita Mountains of Arkansas. However, the sites differ greatly in geology and climate, and the stands are generally fire-maintained woodlands with few oaks. Oaks are important economically and ecologically; therefore, research should be done to help foresters meet their goals of managing pine-oak combinations in uneven-aged cycles.

Site Preparation

Site preparation for pine-oak stands is not much different from that for pine stands as practiced in Missouri. Chainsaw felling is the most common site preparation practice. All stems above a given height, such as 4.5 ft, are removed to help prevent shading of the next generation. Burning and scarifying are used to allow pine seeds access to mineral soil. Burning removes most or all of the duff layer prior to seedfall. Scarifying disturbs the leaf and duff layers sufficiently to incorporate fallen seed with bare mineral soil; thus, it is applied in the fall or winter after seedfall. Foliar herbicide is sometimes applied to retard hardwoods and other plants.

Shortleaf Pine Seedling Sources

Shortleaf pine seedlings come from three basic sources: on-site seedtrees, direct seeding, and planting. Ideally seedtrees are the best phenotype and genotype that grew in the previous generation on that site. Short of hand-pollinating the cones, there is little room for introduction of more disease-resistant trees. Seed for both direct seeding and planting came from superior trees located throughout what is now the Mark Twain National Forest (Fig. 2; Gwaze et al. 2005, Studyvin and Gwaze this volume). Some foresters prefer direct seeding, especially in very rocky soils. It can be expensive at over $100 per pound and often results in dense stands. Mixing the pine seed with native grass seed helps avoid overstocking the stands and provides additional habitat for early successional wildlife. Pine planting in mixed stands is commonly practiced at wider spacings than in a pure pine plantation, and like direct seeding, it is a way to restore genetic diversity to a stand. Both direct seeding and planting may be used to augment natural regeneration and speed up the process.

Release from Understory

Foresters regenerating pine-oak stands face the challenge caused by the rapid early growth of oak sprouts and the slower early growth of shortleaf pine. Competition from non-pine reproduction can dramatically slow growth of pine reproduction, thereby shifting the species mixture (Fig. 3). Most foresters follow regeneration cuts with chainsaw felling of residual trees, including understory stems. Some foresters also release clearcuts 3 to 5 years after

Figure 1.—Variations in spatial distribution of pines and oaks on a ridge near Buzzards' Roost Cave on the Big Piney River in northern Texas County. Pines and oaks occur both as single-species groups and as mixtures. Fall foliage helps to distinguish the hardwoods (light-colored foliage) and pines (dark-colored foliage).

Figure 2.—Superior trees once used for genetic improvement of Missouri's shortleaf pine. Stands of planted and tagged superior trees like this one in the Willow Springs Ranger District can still be found on the Mark Twain National Forest.

regeneration, even in their pine-oak stands. Unfortunately, most foresters interviewed did not plan a second release treatment in canopy gaps. During this investigation we found that understory competition had unexpectedly overshadowed the pine seedlings in canopy gaps. An operational study by Doyle Henken (silviculturist, Mark Twain National Forest) confirms that understory competition plays an important role in slowing pine growth (Blizzard et al. this volume). Canopy openings allow hardwood sprouts and other understory vegetation to take advantage of the direct sunlight and compete for growing space with pine reproduction. Foresters should consider releasing pines from competitors in the reproduction cohort at 3-5 years after regeneration, just as they do in clearcuts.

Release from Retained Overstory

Shortleaf pine has been known to remain in the midstory/understory for over 50 years. For instance, Stambaugh (2001) found a live, 55-year-old stem that was approximately 3 inches DBH. While this discovery shows that shortleaf pine can be somewhat persistent in the understory, this slow diameter growth may not be commercially sustainable. Studies are needed to determine how long pine reproduction can remain in the understory and still grow well after release from the overstory.

A study under way on MDC's Piedmont District by Jason Jensen examines underplanting (Jensen this volume). Figure 4a shows a stand underplanted in 1998 and then clearcut less than a year later; and Fig. 4b shows a stand also planted in 1998, but under C-level stocking. The reproduction in the clearcut stand appears to have grown roughly twice as tall as the reproduction in the stand thinned to C-level stocking. This difference shows the dynamic impact of a partial canopy on shortleaf pine seedling growth.

Figure 3.—Shade slows height growth of shortleaf pine.

Timber Stand Improvement

Release from competition continues in even-aged stands through the first 20-25 years after regeneration. Chainsaw fellers are given decision rules to rank stems by species, form and spacing for target stand conditions. This thinning may shift the balance toward pine or retain more of a mixture of pine and oak. A typical species ranking is: shortleaf pine, white oaks and then red oaks. This ranking is used particularly in declining red oak stands that have a component of shortleaf pine, and shifts the mix towards the longer-lived shortleaf pine and white oak group.

CONCLUSION

All studies on shortleaf pine-upland oak must be evaluated based upon the starting condition of the stand as well as the moisture regimes, desired fire regimes, and soils to determine how the stands and treatments fit the conditions in a local area. Not all potential pine-oak sites are the same. Some pine-oak sites are currently fire-maintained as early successional open woodlands, while others have not been burned recently, receive more rain, or have a higher proportion of non-oak hardwood sprouts. Both even- and uneven-aged regeneration cuts are being applied due to oak

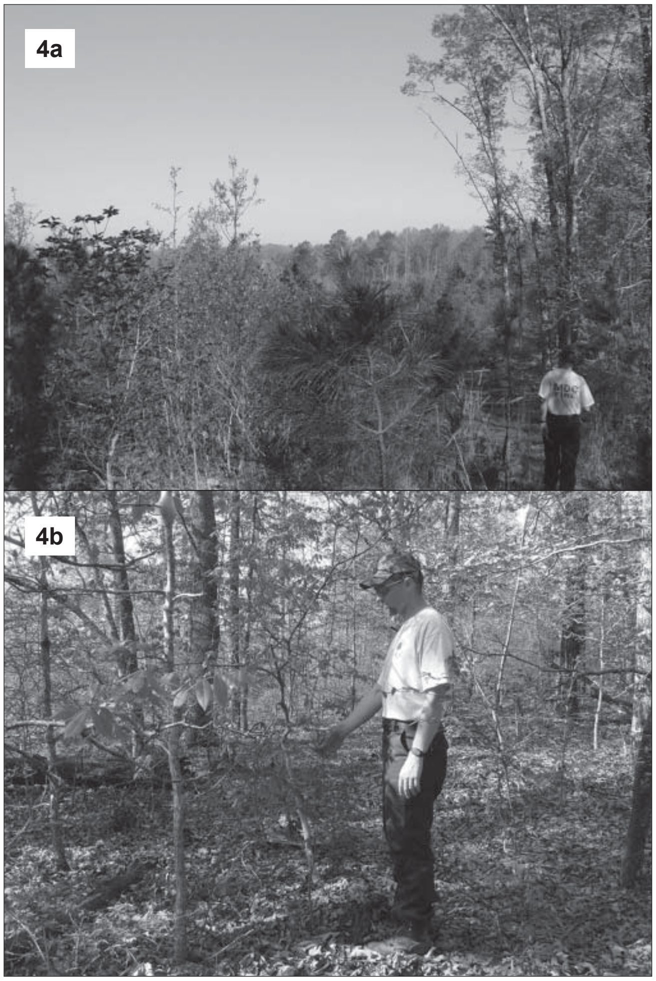

Figure 4.—Positive impact of overstory release on shortleaf pine growth underplanted in 1998 and clearcut within 1 year (a). Shortleaf pines appear to be over twice as tall as those planted under a C-level stocking (b). Both pictures were taken in late spring 2006.

decline and increased tourism. There are examples of 20- to 25-year-old even-aged pine-oak stands in the Missouri Ozarks. Examples of 20-25 year-old uneven-aged pine-oak stands are less common, owing to past management trends and lack of information about the timing of applicable regeneration and release treatments.

While shortleaf pine can remain alive in shade, the species is generally considered intolerant of shade and grows more vigorously in full sunlight. Release from both the overstory and the understory may be required to provide sufficient sunlight. Studies are being developed and are underway to further understand the role that overstory and understory shade combinations play in shortleaf pine growth in mixed pine-oak stands.

ACKNOWLEDGMENTS

Funding was provided by the Missouri Department of Conservation Resource Science Division in collaboration with the U.S. Forest Service North Central Research Station and the University of Missouri – Columbia Forestry Department. To all of the Missouri Department of Conservation and U.S. Forest Service foresters who participated in this management review: Thank you!

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PRODUCTIVITY OF PLANTED SHORTLEAF PINE IN ARTIFICIALLY COMPACTED CLARKSVILLE SOIL

Felix Ponder, Jr.[1]

ABSTRACT.—After 9 years, tree survival was 72, 65, and 70 percent for not compacted, medium compacted, and severely compacted treatments, respectively, for shortleaf pine (*Pinus echinata* Mill.) planted in a forest clearcut on the Carr Creek State Forest in Shannon County, Missouri. The study is in one of the USDA Forest Service's Long-term Soil Productivity Sites to assess the effects of soil disturbance on site productivity across a range of forest sites.

Both total height growth and diameter growth of shortleaf pine at breast height were markedly higher for compacted treatments than for treatments not compacted. Controlling understory vegetation also increased both tree height and diameter at breast height growth. Soil bulk density differences were significant only for the 10-20 cm depth, which were 1.40 and 1.84 g•cm^3 for not compacted and compacted plots at the beginning of the study, were 1.32 and 1.80 g/cm^3 for the same depth and treatments after 8 years. Results suggest that soil compaction associated with tree harvesting on this soil persisted at some depths for more than 5 years. Soil compaction benefited both survival and growth of shortleaf pine. Further discussion is warranted as to how soil physical properties associated with compaction are advantageous to shortleaf pine growth.

INTRODUCTION

Compaction is perceived as one of the leading causes of soil degradation resulting from forest operations (Brais 2001, Froehlich 1988, Powers and others 1990). Soil compaction commonly reduces the growth of young trees that regenerate on sites following harvesting with ground-based machines (Greacen and Sands 1980). Tree susceptibility to compaction, however, has been shown to be species-specific (Wästerlund 1985, Mohering and Rawls 1970, Froehlich and others 1986, Corns 1988) and different soils compacted to the same degree may induce different growth responses (Wästerlund 1985, Powers 1999). For example, shoot and root weight of Douglas-fir (*Pseudotsuga menziesii* var. gluca [Beissn.] Franco) and western white pine (*Pinus monticola* Dougl. Ex D. Don) seedlings were not affected by compaction after one growing season, but root volume was 41 percent less for the Douglas-fir seedlings and seedling height was 6 percent greater for western white pine (Page-Dumerose and others 1998). Corns (1988) reported that lodgepole pine (*P. contorta* Dougl. var.) root weight, shoot weight, stem diameter, and stem height declined due to compaction on all four soils tested, yet white spruce [*Picea glauca* (Moench) Voss] growth on two of the soils did not decline but increased twofold. Wästerlund (1985) also reported species differences with Norway spruce [*Picea abies* (L.) Karst] growth being more impeded by compaction than Scotch pine (*P. sylvestris* L.) growth.

Once compacted, forest soils can remain compacted for decades (Froehlich and others 1985). Even in cold climates where freezing and thawing are assumed to loosen soil to considerable depths, the bulk density of compacted soil decreases slowly (Voorhees 1983, Corns 1988). The persistence of soil compaction over several decades has been shown to reduce the growth of Douglas-fir for similar periods of time (Wert and Thomas 1981, Heninger and others 2002).

The effects of compaction in forest soils are not always associated with reduce tree growth. On several California sites, Gomez and others (2002) reported that compaction effects on 4-year-old ponderosa pines (*Pinus ponderosa*) varied with soil texture and soil water regime. Stem volume on compacted soils was less, the same, and higher on clayey, loamy, and sandy loam soils, respectively. Powers and others (2005) reported that soil compaction significantly improved tree performance in 10-year-old Long-term Soil Productivity Study (LTSP) installations. Compaction was also found to be beneficial to black spruce (*Picea mariana* Mill.) and jack pine (*Pinus banksiana* Lamb.) growing on coarse-textured soils classified as humo-feric podzols in northwestern Quebec (Brais 2001). Growth increases on these soils were linked to harvest traffic compaction causing a more favorable pore-size distribution, which improved the balance between aeration porosity and available water holding, similar to the findings by Gomez and others (2002). The effect of harvest traffic on soils was described earlier by Hyder and Sneva (1956) and Rashid and Sheikh (1977).

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[1] U.S. Forest Service, Northern Research Station, 208 Foster Hall, Lincoln University, Jefferson City, MO 65102; contact at: fponder@fs.fed.us

They concluded that compaction generally reduces the available water-holding capacity of fine-textured soils, but in coarse-textured soils, compaction can reduce the size of very large pores and increase water retention.

The LTSP, composed of large-scale field experiments located at sites across the United States, was developed to assess the effects of soil compaction and surface organic matter removal on site productivity across a range of forest sites (Powers and others 1990). Similar projects on industry lands have also been developed. This paper examines (1) the effect of three levels of soil compaction on the 9-year growth of young planted shortleaf pine (*Pinus echinata* Mill.); and (2) soil bulk density 1 and 8 years after harvesting and site preparation in the Missouri LTSP.

MATERIALS AND METHODS

Site Description

The study was implemented in 1994 in the Ozark Region of southeastern Missouri on the Carr Creek State Forest in Shannon County, on northeastern aspects on sideslopes of two ridges. Before harvesting, the study site was occupied by a mature, second-growth oak-hickory forest with a site index ranging from 22.6 to 24.4 m based on black oak (*Quercus velutina* Lam.) at 50 years (Hahn 1991). Slopes of 20-28 percent are characteristic of the site. Soils are silt loams that developed from cherty residuum, primarily of the Clarksville series (loamy skeletal mixed mesic Typic Paleudults) (Gott 1975).

Experimental Design

Main soil treatments (3 x 3 factorial design) were three levels of organic matter removal (boles-only removal, whole tree removal, and whole-tree plus forest floor removal) and three levels of compaction (none, moderate, and severe) applied to the soil surface. Main treatments were split in half to provide a weed versus no weed (herbicide) comparison. All treatments were replicated three times. The desired compaction level was achieved by driving over plots multiple times with a 14-ton vibrating sheep-foot roller. Logging debris and forest-floor material were removed before compaction so that mineral and organic components would not be mixed. Severe compaction was intended to approach 80 percent of the approximate growth-limiting bulk densities in the surface 10 cm of soil (Daddow and Warrington 1983). Moderate compaction levels were designed to come close to the midpoint between no and severe compaction. Soil bulk density measurements were taken after one, three, five, and eight passes (Blake and Hartge 1986). Bulk density samples were collected from the 0-10, 10-20, and 20-30 cm depths. After mineral soil compaction was complete, forest floor and logging debris were returned, as needed, to achieve each plot treatment combination. Following treatment installation, 1-0 seedlings of red oak (*Q. rubra* L.), white oak (*Q. alba* L.), and shortleaf pine were planted in rows at a spacing of 3.66 m apart in and between rows at a ratio of three oaks of each oak species to one shortleaf pine. The oak to shortleaf pine ratio approximated the preharvest oak to shortleaf ratio. Complete description of the site and the LTSP installation are provided elsewhere (Ponder and Mikkelson 1995).

For this report, only shortleaf pine and the three levels of soil compaction with and without weed control were used. For the first 2 years after planting, a 0.5-m-radius area around all seedlings was sprayed annually in the spring with a mixture of glyphosate and simazine to control weeds. Thereafter, weeds were controlled in only half of all plots.

Post-harvest (after 8 years) bulk density measurements were collected from no and severe compaction treatments only, using the method described by Page-Dumroese and others (1999). Generally, Page-Dumroese and others (2006) reported that differences between the moderate and severe compaction levels have been small, if detectable at all, after 5 years for LTSP installations. An irregularly shaped hole was carefully excavated to the desired soil depth. Soil from the hole was placed in zip-locked plastic freezer bags. Once excavated, the hole was filled with expanding polyurethane foam, and a plywood plate weighted with a rock was placed on the surface. The plate ensured that continued expansion of the foam would fill any irregularities in the hole. The foam was left to cure for at least 8 hours. The foam cast was then removed from the hole and returned to the laboratory where excess soil, small rocks, and roots were removed from the outside of the foam. Foam cast volume was determined by water displacement.

Seedling survival, height, and diameter were measured after planting and annually thereafter. Diameter at 2.54 cm above the soil surface, which is not presented here, and diameter at breast height (DBH), when trees reached at least 1.4 m tall, were measured.

Statistical Analyses

The experiment was analyzed as a randomized complete block design. Survival was analyzed using the PROC LIFETEST procedure (Allison 1995). Growth and bulk density data were analyzed using analysis of variance with the PROC GLM procedures in SAS Version 8.2 (SAS Institute 1999). All statistical tests were performed at the $\alpha = 0.05$ level of significance. Because organic matter was removed prior to compaction, then returned to each plot, 1- and 8-year bulk density results were assumed to be unaffected by organic matter removal treatments. Therefore, results from the different organic matter removal treatment plots were combined for each level of compaction.

RESULTS

Bulk Density

Eight years after applying compaction treatments, soil bulk densities for the 0- to 10- and the 20- to 30-cm depths did not differ (*p* = 0.0991 and *p* = 0.6202) between no and severe compaction. Compaction was only 5 and 14 percent higher than no compaction for the two depths (Table 1). But at 10 to 20 cm depth, average bulk densities for severe compaction were 24 percent higher (*p* = 0.0041) than for no compaction. Average bulk densities were not affected by weed control.

Survival and Growth

After the first 9 years following planting, survival of shortleaf pine averaged 70 percent (Table 2) and has not been affected by compaction or weed control treatments (*p* = 0.2781 and 0.1102). Most of the 30-percent mortality occurred during the first growing season.

Table 1 .—Average bulk density of a Clarksville cherty silt loam soil 9 years after soil compaction and weed control treatments. Standard deviations are in parentheses.

Treatment	**Depth** cm	**Bulk density**[1] Mg/m³
Compaction		
None	0-10	1.37(0.33)a[2]
Severe	0-10	1.60(0.28)a
p value		0.0991
Weed control		
With	0-10	1.47(0.39)a
Without	0-10	1.49(0.25)a
p value		0.9967
Compaction		
None	10-20	1.40(0.24)a
Severe	10-20	1.84(0.41)b
p value		0.0041
Weed control		
With	10-20	1.71(0.48)a
Without	10-20	1.53(0.30)a
p value		0.1931
Compaction		
None	20-30	1.70(0.44)a
Severe	20-30	1.79(0.40)a
p value		0.6202
Weed control		
With	20-30	1.79(0.27)a
Without	20-30	1.70(0.53)a
p value		0.6085

[1]Mean of 12 samples.
[2]Within the column, for each treatment and depth combination, values with the same letter are not significantly different.

Although bulk density for the moderate compaction level was not measured, total height and DBH were. Shortleaf pine in moderate and severe compaction plots averaged 41 cm taller and 12 mm larger in diameter than trees in the no compaction treatment plots (Table 2). Total height growth and DBH differences between moderate and severe compaction were not significant. Vegetation control increased both height and DBH (*p* = 0.0202 and *p* = 0.0001) compared to no vegetation control (Table 2). Interactions between vegetation control and compaction for total height growth and DBH were not significant (*p* = 0.1009 and *p* = 0.5434).

DISCUSSION

Coarse fragments (rocks, stones, chert, etc.) and large roots make it extremely difficult to accurately determine bulk density on these soils. Bulk density measurements taken immediately after treatment application were accomplished using soil cores (30 cm in length x 9 cm in diameter) extracted from plots using a newly developed soil-coring device (Ponder and Alley 1997). A subset of the bulk density data showed that the compaction increased bulk density for the 0-10 cm depth approximately 8 percent (to 1.65 Mg/m^3) for moderate treatments and approximately 15 percent (to 1.78 Mg/m^3) for severe treatments. However, upon examination of the complete data set, it was discovered that the sampler introduced error during the coring process, causing an overestimation of bulk density (Lichter and Costello 1994). The magnitude of error cannot be determined because the sampler error was not discovered until several years later, by which time plots may have begun to recover from compaction. Although the error is now apparent, there is no reason to believe that levels of

Table 2. --Average survival, total height, and diameter at breast height (DBH) of shortleaf pine as affected by three levels of soil compaction and weed control, 9 years after planting.

Treatment	**Survival** Percent	**Total height** cm	**DBH** mm
Compaction			
None	72a	586.3a[1]	96.5a
Medium	65a	613.7b	103.3b
Severe	70a	641.0b	112.9b
p value	0.2781	<0.0001	0.0019
Weed control			
With	69a	632.9a	131.3a
Without	70a	603.5b	82.1b
p value	0.1102	<0.0202	0.0001

[1]In each column, within compaction and weed control levels, values followed by the same letters are not significantly different according to Duncan Multiple Range test.

soil compaction based on earlier bulk density measurements were not achieved. Large-scale field plots similar in size to those in the current study have been successfully compacted to different levels using ground-based equipment (Page-Dumroese and others 2006) with several years of vegetation development and measurements (Fleming and others 2006). The polyurethane foam method was used for remeasuring bulk density in year 8.

Once compacted, forest soils usually require several decades to recover to undisturbed levels of bulk density (Sands and others 1979, Tiarks and Haywood 1996). Recovery rates depend on many factors, including the frequency of harvest cycles, soil moisture conditions during harvest, soil texture, and rock-fragment content (Miller and others 1996, Williamson and Neilsen 2000, Liechty and others 2002). Natural soil processes such as swelling and shrinking due to moisture changes, movement of soil particles by freezing and thawing (including frost heave), and biological activity tend to restore soil physical properties to predisturbance conditions (NCASI 2004). Froehlich and McNabb (1984) described three criteria necessary for these processes to be effective: 1) the soil must be sensitive to the process; 2) the climate must produce the temperature and moisture regimes necessary for the process to occur; and 3) the cycles or processes must occur with sufficient frequency and duration. The extent of compaction, initial bulk density, depth of impact, and subsequent soil recovery are all factors that determine the consequences of timber harvesting or site preparation on productivity (Page-Dumroese and others 2006). In the case of the present study, although some amelioration of initial treatment bulk density has probably occurred over time, the amount cannot be adequately measured because of errors in the initial measurements. Any future recovery should be detected in the next round of bulk density measurements.

Snow and ice damaged some trees during the winter of 2000-2001. Thirty-four trees (14, 9, and 12 trees respectively, in no, moderate, and severe compaction treatments) with crooked main stems, broken and deformed branches, and broken tops were removed in the summer of 2002. The number of trees damaged did not vary with compaction, but all except one of the trees removed were in the weed control plots. Apparently, the damage occurred when the build-up of snow and ice in tree crowns became greater than what trees could bear without bending. The duration of the snow and ice weight was sufficient to cause breakage and permanent bending. Subsequently, when trees resumed springtime growth, new growth added to the already crooked stems, deforming them more. Trees receiving weed control were 29 cm taller and had more diameter growth (table 2) and their crowns were larger and could collect more snow and ice than smaller crowned trees in no weed control subplots. Hence, trees in no weed control subplots had very little damage.

The better shortleaf pine growth in the compacted treatments as compared to trees in the no compacted treatment is not completely understood. Compaction can alter the water-holding capacity of soils and has different effects depending on the texture of the soil. Compaction generally reduces the available water holding capacity of fine-textured soils; in coarse-textured soils, compaction can reduce the size of very large pores and increase water retention (Hyder and Sneva 1956, Rashid and Sheikh 1977). Shortleaf pine is a species that is found across a broad range of sites due to its tolerance of a wide range in soil conditions; however, it does best on soils with silt loam and fine sandy loam textures (Lawson 1992). The soil in this study was a silt loam (Clarksville cherty silt loam with ~ 40-70 percent angular fragments by volume < 15 cm in diameter). The impact of coarse fragments on properties of the Clarksville due to compaction is questionable. Once compacted, does it behave as a fine-textured or somewhat coarse-textured soil? Rock fragments alter the physical properties of soils in ways that can increase water availability. Surface and subsurface rock fragments can act as mulch, reducing evaporation from soils primarily in the upper 25 cm of the profile (van Wesemael and others 1995). Soils containing significant rock fragments have lower fine-earth water content in their top layer due to the small water retention capacity of stony soils (Childs and Flint 1990, van Wesemael and others 1995). Therefore, evaporation rates are lower in soils containing rock fragments compared with stone-free soils. The soil compaction process for the Missouri study pressed the rock fragments on the soil surface, which ranged from 30 to 50 percent, into the upper soil layer, which already contains 15 to 25 percent by volume chert fragments, greatly increasing rock fragment content in that soil layer. A 15-cm thick layer of rock fragment mulch reduced evaporation compared with a non-stony soil (van Wesemael and others 1995).

In a greenhouse experiment using sieved Clarksville silt loam soil, shortleaf pine root growth was limited by compaction due to reduced aeration (Siegel-Issem and others 2005). Although the study demonstrated how shortleaf root growth is inhibited in the compacted sieved or the fine-earth fraction of the soil, it does not contribute to the understanding of how compaction of unsieved Clarksville soil, as in the present study, affects tree growth. Brais (2001) reported that the 5-year mean height of planted white spruce [*Picea glauca* (Moench) Voss] on fine textured soils free of coarse fragments in response to soil compaction due to skidding during timber harvesting was only 28 percent higher in the between track areas and 25 percemt higher in the track areas than in undisturbed areas. But the relative productive rate of trees growing in between track areas (0.44 per year) was higher than that for trees growing in undisturbed areas (0.26 per year), while no significant differences were found between undisturbed and wheel track areas. Moreover, vegetation competition rather than skid trail traffic explained over 40 percent of the differences in total tree height and root collar diameter (Brais 2001).

Compaction has been shown to reduce vegetative competition and increase moisture availability at several LTSP locations and improve survival or growth (Powers and Fiddler 1997, Gomez and others 2002, Li and others 2003, Page-Dumroese and others 2006). Compaction has also been found to increase growing-season soil temperature at many of the LTSP locations (Fleming and others 1999, Kranabetter and Chapman 1999, Page-Dumroese and others 2006). At the Missouri site, both average fifth-year soil water and temperature were higher (14 and 16 percent, respectively), for the severe compacted treatment than for the no compaction treatment (Ponder 2004). Further differences in soil water and temperature were manifested by controlling weeds, which also affected growth. The greater height of trees in the absence of weeds compared to the presence of weeds can likely be attributed to better soil water because the no weed treatment had higher soil water. Five-year seasonal soil water content was 64 percent higher for no weed subplots than for subplots with weeds (Ponder 2004). The difference in mean 5-year seasonal soil water content for no weed subplots was 6 percent higher for severely compacted plots compared to plots not compacted and 34 percent higher for plots with weeds for plots severely compacted, compared to plots not compacted. Also, during the dry, hot season, soil temperatures at the Missouri site were higher in no weed subplots than in subplots with weeds (20.2 ˚C versus 13.4 ˚C, respectively).

CONCLUSIONS

After 8 years, differences in bulk density were present for no compaction and severe compaction treatments for the 10-20 cm depth only. Weed control did not affect bulk density. After 9 years, neither soil compaction nor weed control affected shortleaf pine survival but both benefited growth. Growth differences attributed to compaction and weed control can generally be explained by the increase in soil water. Factors not measured may also be at work such as rooting depth, rooting pattern, and impact of compaction on the soil matrix to influence soil moisture availability. Nine years is a short time in the development of a Missouri shortleaf pine plantation and current rate of growth can change, especially as canopy expansion continues placing greater demand on soil water and nutrients.

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AMOUNTS AND SPATIAL DISTRIBUTION OF DOWNED WOODY DEBRIS, SNAGS, WINDTHROW, AND FOREST FLOOR MASS WITHIN STREAMSIDE MANAGEMENT ZONES OCCURRING IN SHORTLEAF PINE STANDS FIVE YEARS AFTER HARVESTING

Hal Liechty[1]

EXTENDED ABSTRACT

Shortleaf pine (*Pinus echinata* Mill.) is a dominant tree species in pine and pine-hardwood forest communities located on ridges and upper- to mid-slope positions in the Ouachita Mountains. The stream reaches located in these stands flow infrequently and are classified as ephemeral or intermittent, have low stream orders, and have relatively narrow channels and floodplains. Land management agencies, such as the Ouachita National Forest, typically establish buffers or streamside management zones (SMZs) along these streams to protect water quality and other riparian functions within as well as downstream of these reaches. Since channels and floodplains are narrow, SMZ width is also narrow along these headwater streams. Given the high edge-to-interior ratios of these riparian zones, I was interested in 1) how forest characteristics such as stand density, forest floor mass, and coarse wood debris (CWD) volumes differ between SMZs and adjacent upland locations in these stands; and 2) how forest harvesting outside SMZs affect tree density, forest floor mass, CWD volume, snag density, and windthrow density.

Eleven shortleaf pine stands in the Ouachita National Forest in Arkansas were included in this study. They were between 14 and 16 ha in size, mature with dominant tree ages >70 years, and located on south- to west–facing slopes. In 1993 three of the stands were clearcut and planted to loblolly pine, four of the stands were cut using a shelterwood reproductive harvest with the intent to retain 6.8 m^2/ha of pine and 2.3 m^2/ha of hardwoods, and the other four stands were uncut and used for controls. Streams in these stands generally extended from the upper slopes of the stand to the bottom of the slope. Prior to the 1993 harvest, SMZs were established along each stream channel in each stand. Five years after harvesting, two to four plots were established within the SMZs of each stand. The plots spanned the entire width of a SMZ. In addition a plot was established adjacent to each of the SMZ plots in the upland portion of the uncut stands. Tree density, forest floor mass, and coarse woody debris (CWD) volumes were measured in the plots. Transects were located every 30 to 50 m along all SMZs in the stands. Each transect extended across the entire width of a given SMZ. Location and characteristics of each snag and windthrow within 10 m of each transect was recorded.

Total basal area was significantly greater in the SMZs than in the upland portions of the uncut control stands (Table 1). Differences were due to the higher numbers of hardwoods in the SMZs plots than the upland plots. Although tree basal area was higher in the SMZs, forest floor mass in the uncut control stands was 23 percent greater in the upland portion of stands than in the riparian zones. These differences appear to reflect a higher rate of decomposition in the SMZs due to the greater levels of hardwood litter or soil moisture within the riparian zones. CWD volumes were very similar in the upland and riparian areas of the stands.

Reproductive cutting methods had little influence on tree basal area or CWD volumes within the SMZs (Table 2). Differences in living overstory and midstory basal area among cutting methods were generally less than 10 percent. Mean CWD volume was nearly twice as high in the clearcuts compared to the uncut or shelterwood stands. Because of the high variability in CWD volumes and the potentially low power of these tests, however, differences among volumes were not significant.

A total of 160 snags were located in the 5.6 ha of SMZs that were inventoried. Snags were equally distributed as pine and hardwoods. The average diameter at breast height (DBH) of the snags was 17.5 cm. Snag densities were significantly lower in the SMZs that were located in the clearcut and shelterwood stands than in the uncut stands (Table 2). Harvesting forests can increase the wind speed, solar radiation, air temperature, and soil temperature in riparian zones (Moore and others 2005). This alteration in microclimate is likely responsible for an accelerated deterioration of snags and thus a reduction in snag density in the clearcut and shelterwood stands. The reduction in snag density was greatest in narrower SMZs. In the uncut stands, snag densities rapidly decreased with increasing SMZ widths up to 40 to 50 m. In the clearcut and shelterwood stands, however, snag density was not significantly correlated with SMZ width. Although other studies have found increased mortality and snag recruitment along edges of harvested stands, this study indicated no increase but rather a decrease in snags during the first 5 years following harvesting.

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[1] Associate Professor (HOL), School of Forest Resources, University of Arkansas at Monticello, P.O. Box 3468, Monticello, AR 71656. To contact call (870) 460-1452 or email liechty@uamont.edu

Table 1.—Mean (standard deviation) living tree basal area, forest floor mass, CWD volume, and P-values associated with SMZs and upland plot comparisons in four uncut shortleaf pine stands in the Ouachita Mountains.

Stand Characteristic	SMZ	Upland	P-Value
Tree basal area (m^3/ha)			
Pine	22.4 (9.4)	22.2 6.2)	0.955
Hardwood	11.8 (4.5)	7.6 (2.7)	0.006
Total	34.2 (7.2)	29.8 (5.6)	0.092
Forest floor (kg/m^3)	2.2 (0.4)	2.7 (0.5)	0.049
CWD Volume (m^3/ha)	8.9 (13.1)	9.3 (10.3)	0.922

Table 2.—Mean (stand deviation) living tree basal area, CWD volume, and snag density; median forest floor mass, median windthrow density, and P-values associated with the comparisons of SMZ 5 years following application of three reproductive shortleaf pine regeneration cutting methods in the Ouachita Mountains.

Stand Characteristic	Uncut	Shelterwood	Clearcut	P-Value
Tree basal area (m^3/ha)				
Pine	20.8 (2.2)	19.5 (6.4)	18.8 (4.2)	0.661
Hardwood	9.7 (1.6)	9.9 (2.6)	10.2 (1.6)	0.501
Total	34.2 (2.1)	29.4 (5.7)	29.0 (3.3)	0.403
Forest floor (kg/m^3)	2.2	2.4	2.7	0.422
CWD Volume (m^3/ha)	8.9 (7.9)	7.6 (2.0)	16.1 (8.1)	0.331
Snags (#/ha)	38.9 (9.7)	22.7 (11.3)	25.7 (10.2)	0.014
Windthrow (#/ha)	0.3	0.0	11.8	0.020

Twelve windthrows were located in the SMZs. All but two of the windthrows occurred in the clearcut stands and only one of the windthrown trees was a hardwood. The average DBH of the windthrows was 25.8 cm, which was much larger than the average DBH of the snags. Windthrow densities were significantly greater in the SMZs within the clearcut stands than in either of the other stand types (Table 2). Alteration of the microclimate, especially windspeed, in the SMZs with clearcutting appears to have increased the windthrow susceptibility of large pine trees. In the clearcut stands, nine of the 10 windthrows were located in SMZs that had widths less than 29 m. The high edge-to-interior ratio of these narrow SMZs also appears to have an impact on windthrow occurrence with clearcutting.

These results suggest that land managers who wish to retain snags in SMZs located in upper- to mid-slope shortleaf pine stands, should minimize tree removal outside these riparian zones. To reduce windthrow of large pine trees, land managers should also refrain from clearcutting stands. Some evidence indicates that widening SMZs may also reduce snag deterioration and windthrow susceptibility in these SMZs following harvesting operations.

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WILDLIFE DIVERSITY OF RESTORED SHORTLEAF PINE–OAK WOODLANDS IN THE NORTHERN OZARKS

Corinne S. Mann and Andrew R. Forbes[1]

EXTENDED ABSTRACT

Historic changes in land use have altered the plant composition and structure of shortleaf pine-oak woodlands in the northern Ozarks. As a result, the composition of wildlife communities in these landscapes has shifted to species that are more associated with closed canopy oak forests. For example, the red-cockaded woodpecker (*Picoides borealis*) has been extirpated from much of its former range in the Ozarks, and the pine buck moth (*Hemileuca maia*) has declined in numbers, while other species associated with closed canopy forests have become more abundant.

Managing tree density with silvicultural practices and recovering characteristic ground flora with prescribed fires will restore habitat and result in a shift in the composition of wildlife species in pine-oak woodland communities. Landscape-scale habitat restoration is a major emphasis of Missouri's Comprehensive Wildlife Conservation Strategy (CWS), which also focuses on preserving healthy landscapes. The goal of the CWS is to conserve all wildlife, which includes plants, animals, and natural communities. Central to the CWS are a statewide network of Conservation Opportunity Areas (COA), which have been identified as the best landscapes in Missouri to focus on conservation of all wildlife. Shortleaf pine woodland restoration is an objective in several of the COAs in the Missouri Ozarks. The Current River Hills COA includes the forests, woodlands, glades, fens, and caves surrounding the Current and Jacks Fork Rivers. Once the site of Missouri's most extensive shortleaf pine woodlands, the Eleven Point Hills COA lies in some of the most rugged and least developed portions of the Missouri Ozarks. Historically, pine-oak woodlands occupied high elevations in the North Fork COA, which today is dominated by dense second-growth forest with only scattered pine plantations. The success of our efforts to conserve all wildlife in these COAs can be assessed by monitoring for the suite of animal and plant species that require a healthy pine-woodland community for survival.

The restoration of shortleaf pine woodlands will benefit many species of birds, including Partners in Flight Watchlist Species, such as red-headed woodpecker (*Melanerpes erythrocephalus*), Bachman's sparrow (*Aimophila aestivalis*), and brown-headed Nuthatch (*Sitta pussilla*). However, red-cockaded woodpeckers will only return in the Missouri Ozarks with intentional reintroductions. While many species such as these probably will benefit from shortleaf pine restoration, it is likely that many others that thrive in closed canopy forests, such as wood thrush (*Hylocichla mustelina*) and ovenbird (*Seirus aurocapilla*), will decline, at least locally in the restored pine woodlands. Fortunately, birds will not be the only beneficiaries of habitat restoration. Other animal species that are expected to benefit include ringed salamander (*Ambystoma annulatum*), northern fence lizard (*Sceloporus undulatus*), wood frog (*Rana sylvatica*), and plains spotted skunk (*Spilogale putorius interrupta*) (Nigh 2005).

Plants that are expected to benefit include lowbush blueberry (*Vaccinium pallidum*), big-flowered gerardia (*Aureolaria grandiflora*), farkleberry (*V. arboreum*), lead plant (*Amorpha canescens*) and goat's rue (*Tephrosia virginiana*) (Nelson 1985). The Missouri CWS outlines research and inventory needs, current and potential conservation partners, and overall conservation strategies that will work toward restoration of shortleaf pine woodland communities in the Missouri Ozarks.

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[1] Ornithologist (ARF), Missouri Department of Conservation and Audubon Missouri, 2620 Forum Blvd., Suite C-1, Columbia, MO 65203; and Wildlife Intern (CSM), Missouri Department of Conservation, P.O. Box 180, Jefferson City, MO 65102. ARF is corresponding author: to contact call (573) 447-2249 or email at Andrew.Forbes@mdc.mo.gov

BIRDS OF SHORTLEAF PINE FORESTS IN MISSOURI: AN HISTORICAL AND CONTEMPORARY PERSPECTIVE

William R. Eddleman, Richard L. Clawson, and Jody Eberly[1]

ABSTRACT.—Knowledge of the original bird communities in Missouri's shortleaf pine (*Pinus echinata*) is limited to accounts of early travelers, and infrequent observations between 1907 and 1946. Prior to logging and fire protection, red-cockaded woodpecker (*Picoides borealis*), pine warbler (*Dendroica pinus*), and Bachman's sparrow (*Aimophila aestivalis*) were common in shortleaf pine forests; while the sycamore warbler (yellow-throated warbler) (*D. dominica*) was uncommon. Two brown-headed nuthatches (*Sitta pusilla*) collected in 1907 represent the only records for the region. Recent information on the composition of breeding bird communities in Missouri shortleaf pine forests is available from a point count data set collected in 1984 from a search for red-cockaded woodpeckers in a 15-county area, and from Breeding Bird Survey-type routes through the 4,400-ha Pineknot Shortleaf Pine Restoration Project in the Mark Twain National Forest in Carter County. Contemporary second-growth pine forests are invaded by hardwoods and lack the open nature of the original forests. Consequently, pine warbler, yellow-throated warbler, and chipping sparrow are the only species unique to pine habitats that remain in Missouri pine forests; other birds breeding in pine forests are also found in deciduous forests. The Pineknot site has greater species richness than other Missouri pine forests, had higher detection rates of pine warblers and chipping sparrows, and is beginning to attract small numbers of bird species characteristic of open habitats. As this habitat improves over the next couple of decades, reintroduction of red-cockaded woodpecker and brown-headed nuthatch might be feasible using methods developed in other areas, but there are currently no reintroduction methods for the migratory Bachman's sparrow.

INTRODUCTION

Missouri's shortleaf pine avifauna has undergone profound but poorly documented changes during the time since presettlement. Little information is available because few trained observers visited the area in the settlement era of 1790-1880 because this ecosystem was lost fairly early (1880-1909); remnant stands were logged up to 1946 (Cunningham 1946, Hill 1949). As one example of how poorly the birds of Missouri's shortleaf pine forests were known historically, Widmann (1907) listed the pine warbler (see Appendix Table 1 for list of common and scientific names of birds) as a rare summer resident when in fact, it was likely a very common breeder in the pine forests of the Missouri Ozarks.

Robbins and Easterla (1992) list red-cockaded woodpecker, brown-headed nuthatch, yellow-throated warbler, pine warbler, Bachman's sparrow, and chipping sparrow as species of shortleaf pine forest that have declined in Missouri since 1900 due to human's alteration of their primary breeding habitat. Since local information on these species is lacking, there are few benchmarks against which any efforts at restoration of the ecosystem could be measured. Thus, synthesis of available information is crucial to the restoration of Missouri's shortleaf pine avifauna.

In this paper, we seek to: review historical information on birds in shortleaf pine forests in Missouri; describe historic and contemporary bird communities in Missouri shortleaf pine forests; compare bird communities of second-growth shortleaf pine and oak-pine stands with those of the Pineknot Shortleaf Pine Restoration Project; and make recommendations for future restoration actions for selected bird species in Missouri shortleaf pine forests.

STUDY AREAS

Birds were counted in pine and oak-pine forests in a 15-county area throughout the range of shortleaf pine in Missouri in June 1984 (Eddleman and Clawson 1987), and at the Pineknot Shortleaf Pine Restoration Project site in Carter County, Missouri, in 2004-2006. Shortleaf pine forests in Missouri occur in the Salem Plateau and St. Francis Mountains sections of the Ozark Plateau (Liming 1946, Eddleman and Clawson 1987, Nelson 2005). Old-

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[1] Professor of Biology (WRE), Southeast Missouri State University, Department of Biology, MS 6200, Cape Girardeau, MO 63701; Wildlife Research Biologist (RLC), Missouri Department of Conservation, 1110 S. College Ave., Columbia, MO 65201; and Wildlife Biologist (JE), Mark Twain National Forest, U.S. Forest Service, 401 Fairgrounds Road, Rolla, MO 65401. WRE is corresponding author: to contact call (573) 651-2170 or email weddleman@semo.edu

growth pine forests were cleared in the region from 1880-1950. Subsequently, annual burning and open range livestock grazing through the 1950s, followed by complete protection from fire were the primary land management activities in the region. Modern timber management began in much of the area with the establishment of Clark and Mark Twain National Forests (now Mark Twain National Forest). As a result, the area of pine has been reduced, many pine stands have been replaced with oak or oak-pine forest, and many open-pine forest areas have been converted to closed-canopy forests. Other characteristics of the region have been previously described (Eddleman and Clawson 1987).

The Pineknot Shortleaf Pine Restoration Project site is a 4,400-ha area in the Current River drainage south of Fremont, MO, and southwest of Van Buren, MO, in T26N, R1W, sections 18-20 and 29-32; and T26N, R2W, sections 13-16 and 21-36, Fifth Principal Meridian (Eberly 2001). It was established in 2001 to restore a landscape-level area to the open pine woodland described by early European visitors to the area. Management activities to restore the open nature of the forest began in the 1990s and have included reduction of canopy cover of overstory trees and reintroduction of prescribed fire. The area is characterized by relatively extensive coverage by pine and oak-pine forest (almost 50 percent), good accessibility, presence of natural fire control lanes, and a high percentage of public land. Vegetation of the area is similar to that of the entire range of shortleaf pine in Missouri, but generally there is greater coverage by grass and more open understory than in other portions of the pine range. The project is a partnership among the U.S. Forest Service, Mark Twain National Forest; The Nature Conservancy; National Wild Turkey Federation; Bat Conservation International; Missouri Department of Conservation; National Park Service, Ozark National Scenic Riverways; private landowners; and others.

METHODS

Information on the original avifauna of Missouri's shortleaf pine forests was gleaned from published information. In addition, literature from other portions of the shortleaf pine range was consulted to determine the primary species in the habitat, and to provide comparative information.

Point Counts

Birds were counted in mature pine stands in 1983-1984 as part of a project to assess the population status and potential habitat of red-cockaded woodpeckers in Missouri (Eddleman and Clawson 1987). Pine and oak-pine stands were selected for visits by obtaining information from the USDA Forest Service, Mark Twain National Forest; National Park Service; Missouri Conservation Department, and Missouri Department of Natural Resources, Division of State Parks. Of particular assistance in the Mark Twain National Forest were the Timber Management Information System and Wildlife Management Information System, which were used to select all pine stands (≥ 50 percent pine stems) in the heart of the shortleaf pine range in the central Ozarks of Missouri (Liming 1946). Compartments where point counts were conducted had at least 20 ha of 70-year-old pine, and had trees averaging > 25.4 cm diameter at breast height. Sites were located using USGS topographic maps or compartment maps, or from discussions with resource agency personnel.

Point count sites were selected using randomly-generated Universal Transverse Mercator coordinates within each compartment. One point was generated per 5 ha (12 a) of potential habitat. Point counts followed Reynolds and others (1980). Each observer used an optical rangefinder to determine distance between himself or herself and the bird. He then used a clinometer to determine the vertical angle to the bird. Point counts lasted 8 minutes, and all birds seen and heard were included. Counts were conducted from 0.5 hr before local sunrise until 5 hr after local sunrise. Vegetation data were also collected at each point, and results have been reported elsewhere (Eddleman and Clawson 1987). To make data from this part of the study more comparable to that collected at Pineknot, only June 1984 point data are included.

Two roadside routes were used to determine bird species at Pineknot in 2000-2006, but only data from 2004-2006 are presented. The two routes, Ridgetop and Big Barren, had 25 and 10 stops, respectively. The Breeding Bird Survey methodology was used to assess species present (Sauer and others 1997). Running of routes began at 0.5 hr before local sunrise, and ended within 4.5 hr. All birds heard, and all birds seen within 0.25 mi, were tallied at each point for 5 min. These data were treated as point counts to make them comparable to data from the 1984 part of the study. Counts are summarized by species as mean number detected (averaged across 2004-2006) ± standard error of the 3 years for that species.

Data were summarized for each species detected using Microsoft Excel, and are presented as mean number detected ± standard error.

RESULTS AND DISCUSSION

Historical Accounts of Birds in Missouri Shortleaf Pine Forests

No systematic surveys of birds in Missouri's shortleaf pine ecosystem were undertaken prior to the beginning of logging in the 1880s. Most early travelers who wrote of their experiences tended to stay near rivers or larger settlements. This also appears to be the case in neighboring Arkansas (Smith and Petit 1988, Smith and Neal 1991). Henry Rowe Schoolcraft documented open pine forests in the region, but he mentions only game species, and does not make specific reference to the habitats in which these species occurred (Schoolcraft 1821, Rafferty 1996). For example, Schoolcraft commonly mentions wild turkeys, but not in relation to the habitats in which they were most abundant. Other birds mentioned included ducks (species not identified), wild geese (probably Canada goose), pigeon (probably the extinct passenger pigeon), swan (probably trumpeter swan), and prairie-hen (greater prairie chicken).

George W. Featherstonhaugh, a U. S. government geologist, traveled through the eastern edge of the region in November 1834 while he was examining the area for mineral and metallic resources (Featherstonhaugh 1844). He noted not only "pine barrens" in the area between Fredericktown, Madison County, and Greenville, Wayne County, but also passed through one burned-over area near Fredericktown and an active fire in southern Butler County. He often mentions park-like forests, but not the dominant tree species in these forests.

The first and sole thorough description of the original avifauna of Missouri's shortleaf pine was made when most of the habitat had been lost, in 1907. E. Seymour Woodruff, a forester from New York who was also interested in birds, visited Shannon and Carter counties from March 7 to June 8, 1907 (Woodruff 1907, 1908). At that time, virgin pine forest still remained in the most rugged portions of Shannon County along the upper Current River, in Townships 29 and 30, Ranges 5 and 6 West. There, Woodruff observed the avifauna from March 10 to May 15, and gave us the best "snapshot" of what the original bird community must have been in Missouri's shortleaf pine forests. Pines were restricted to the tops of ridges and the plateau of this area. He also commented that the understory was open, perhaps because local settlers annually burned the ground to improve grazing. He states that the "characteristic birds were turkeys, red-cockaded woodpeckers, Bachman's sparrows, and pine warblers." Woodruff moved to the Grandin area in Carter County after May 16, and commented that all of the pine and oak had been cut-over, leaving only young second-growth woodland.

Woodruff (1908) also recorded small flocks of red crossbills until May 1, and found one female white-winged crossbill feeding with two red crossbills on April 18. He also found a number of pine siskins, including one late one on June 4 in Carter County. He found no evidence of breeding, and it is possible the year 1907 might have been an irruption year for northern finches.

James W. Cunningham was the next observer to report birds from pine forests in Missouri (Cunningham 1940). Although there was a 33-year gap between Woodruff's (1908) observations and Cunningham's, red-cockaded woodpeckers still persisted in the one known virgin pine forest west of Highway 19 near Round Spring, Shannon County. Pine warblers and yellow-throated warblers were also in the same area, but pine warblers were also recorded in small pine stands in Carter, Wayne, and Reynolds counties (Cunningham 1940).

The species composition of birds present in Missouri's historic shortleaf pine forest is known from the few studies reviewed, but we will probably never know the relative abundance of bird species in this habitat. Of the pine-dependent birds in Missouri, two are extirpated, one no longer occurs in contemporary pine habitat, and three are common because they are not dependent on open pine forest. The history and habitat of the pine-dependent species is probably best reviewed on an individual species basis.

Red-cockaded Woodpecker

This endangered woodpecker was apparently "fairly common" in Missouri pine forests prior to logging (Woodruff 1907, 1908). They were seen "constantly" after April 10 in Shannon County pine woodlands, and Woodruff collected 5 birds (Robbins and Easterla 1992), two of which were in breeding condition. The species was found again near the northern border of Carter County (Township 27, Range 2 E), but Woodruff commented that they would, "be driven out of this region as fast as these woods are cut off." It disappeared in 1946 after all large virgin pine forests were logged (Cunningham 1946). Subsequent searches in the area in the 1950s (Robbins and Easterla 1992) and a search throughout the range of shortleaf pine in the state (Eddleman and Clawson 1987) failed to locate this species, and it is presumed to be extirpated in the state. The loss of this species reflects what occurred in the neighboring states of Arkansas and Oklahoma, where the woodpecker persisted only because there were areas that escaped logging and the effects of fire suppression (Smith and Neal 1991). The habitat needs of red-cockaded woodpeckers are well-documented after nearly 40 years of intensive study throughout its range (Jackson 1994). These requirements include mature pine trees infected with heart rot, open pine habitat with little hardwood encroachment, regular fires to prevent hardwood encroachment, and a high degree of connectivity with other suitable habitat areas.

Brown-headed Nuthatch

This species was never proven to breed in Missouri, but Woodruff (1907, 1908) collected a pair in some "yellow" pines on the edge of a small clearing in Black Valley, Shannon County on March 19, 1907. Robbins and Easterla (1992) consider its past status "perplexing" because (1) there are only two records; (2) none were found during the 1940s, when red-cockaded woodpeckers were still present in the Missouri Ozarks (Cunningham 1940); and (3) they are thought to have less exacting habitat requirements than red-cockaded woodpeckers. Seemingly suitable habitat is found across the Missouri Ozarks today, but the nearest populations are in central Arkansas, there is a hiatus in pine habitat between Missouri and central Arkansas, and the species is a poor colonist (Robbins and Easterla 1992, Withgott and Smith 1998). It does prefer open, older pine stands, however (O'Halloran and Conner 1987), and is more abundant in burned stands than unburned stands (Wilson and others 1995). Suggested limiting factors in other parts of its range may include loss of mature pine habitat, fire suppression, habitat fragmentation, lack of suitable nesting snags, cone crop fluctuations, and nest predation (Jackson 1988, Withgott and Smith 1998).

Yellow-throated Warbler

This warbler was most common in pristine shortleaf pine, "invariably found high up in pines on top of the ridges," and not in sycamores (*Platanus occidentalis*) in valley bottoms (Woodruff 1908). Today this species is locally common in three separate habitats in Missouri: rivers with sycamores, baldcypress (*Taxodium distichum*) stands, and shortleaf pine (Robbins and Easterla 1992). Little study has focused on the species in shortleaf pine. It is possible it may have been more abundant in open pine forests, but this needs more study (Jackson 1988). It seems to have survived the loss of the original pine forests rather well, although density could be lower than in the past.

Pine Warbler

Widmann (1907) considered this species a rare summer resident and common transient in Missouri. Widmann probably made this mistake because he did not visit the Ozark area where it nests. Woodruff (1908) considered pine warbler common and they are still fairly common where there is shortleaf pine (Robbins and Easterla 1992). A few overwinter. While it is possibly less common and widely distributed than before the pine was harvested at the turn of the century (Robbins and Easterla 1992), it seems to occur wherever pines are a component of the overstory. Thus, it is one of the few pine-dependent species in Missouri to have persisted through the loss of open pine forests. Rangewide, pine warblers have increased (Rodewald and Smith 1995). They are most abundant in pure pine, but use pine plantations ≥ 40 years old. They become less abundant with increasing deciduous overstory and understory.

Bachman's Sparrow

Most indications are that this sparrow was common in Missouri's pristine open shortleaf pine forest, but clearing of pine and fire protection has resulted in succession and loss of its habitat (Woodruff 1907, 1908, Cunningham, 1941, 1945, Robbins and Easterla 1992). Today, the only known breeding Bachman's sparrows in Missouri are on limestone glades, although isolated glades are unlikely to support them (Hardin and others 1982, W. R. Eddleman and B. Stratton, unpublished data). Range-wide, the species occurs in a variety of habitats that have grassy ground cover or understory, including glades, old fields, pine plantations, clearcuts, and open pine forests, although it is likely to avoid isolated habitat parcels (Dunning 1993, Hammerson 1997). Open pine forests apparently supported the highest density, and percent coverage by grass has the strongest influence on habitat occupancy (Tucker and others 2004). Bachman's sparrow underwent a substantial range expansion in 1890-1920, but the range then contracted to its present limits prior to 1960 (Dunning and Watts 1990, Dunning 1993). Reduction of litter, low tree and shrub density, and good growth of forbs and grasses such as *Andropogon* and *Aristida* are recommended management in pine plantations in Arkansas (Haggerty 1998).

Chipping Sparrow

In 1907, chipping sparrows were found, "everywhere—in the depths of the pine woods on top of the plateaus, and in the open stretches in the valley bottoms" (Woodruff 1908). This sparrow remains most common in open stands of conifers, but also is common in residential areas (Robbins and Easterla 1992). It seems to prefer open areas in pine forests, or roadsides in heavily forested areas. It is unknown how much the species has declined in natural habitats, but any decline has been more than offset by its tolerance for suburban habitats.

Contemporary Bird Communities in Missouri Shortleaf Pine Forests

Forty species were detected during point counts across the range of shortleaf pine in Missouri in 1984 (Table 1). The principal species detected (≥ 0.2 per point) included red-eyed vireo, blue jay, tufted titmouse, pine warbler, and ovenbird. In contrast, 60 species were detected on the Pineknot routes in 2004-2006 (Table 1). Those species averaging ≥ 1.0 detected per stop included red-eyed vireo, American crow, blue-gray gnatcatcher, pine warbler, and indigo bunting. Only 2 species—red-headed woodpecker and brown thrasher—were found at points in 1984 but not on the Pineknot routes. In contrast, 22 species occurred on the Pineknot routes, but not on the point counts done in 1984 (Table 1). Most species detected at Pineknot but not on the 1984 point counts were species found in open habitats. Of particular note is that three of the species of pine-dependent bird were not detected in either set of counts: red-cockaded woodpecker, brown-headed nuthatch, and Bachman's sparrow. No chipping sparrows were detected during the 1984 study, but they were present on the routes at Pineknot; possibly the location of most points in the interior of forest stands may have avoided them. Yellow-throated warblers were present in low frequencies in both studies, with slightly more detected per point in 1984. Pine warblers, however, were detected at Pineknot at nearly three times the level of the 1984 study (Table 1).

Bird species richness and number of birds detected were lower at the pine and oak pine forests visited in the 1984 study than at Pineknot in 2004-2006 (Table 1). Most sites visited during the 1984 study were too densely stocked

Table 1.—Summer birds detected on point counts in pine and oak pine forests in Missouri in June 1984, and on Breeding Bird Survey (BBS) mini-routes in the Pineknot Shortleaf Pine Restoration Project in June 2004-2006.

	1984 point counts (n=130)			Pine Knot BBS routes, 2004-2006 (n=35)		
Species	**n**	**No. per point + SE[a]**	**% freq.**	**Mean detected**	**No. per point + SE[b]**	**% freq. + SE[b]**
Wild Turkey	2	0.015 ± 0.009	1.5	0.7	0.019 ± 0.019	1.9 ± 1.9
Northern Bobwhite	0	0	0	2.3	0.067 ± 0.067	4.8 ± 48
Turkey Vulture	0	0	0	0.3	0.010 ± 0.010	1.0 ± 1.0
Red-shouldered Hawk	1	0.008 ± 0.006	0.8	1.0	0.029 ± 0.016	2.9 ± 2.9
Broad-winged Hawk	1	0.008 ± 0.006	0.8	0.7	0.019 ± 0.019	1.9 ± 1.9
Red-tailed Hawk	2	0.015 ± 0.009	1.5	0.3	0.010 ± 0.010	1.0 ± 1.0
Mourning Dove	1	0.008 ± 0.006	0.8	4.3	0.124 ± 0.124	9.5 ± 9.5
Yellow-billed Cuckoo	23	0.177 ± 0.028	16.9	21.0	0.600 ± 0.214	47.6 ± 17.5
Great Horned Owl	0	0	0	0.7	0.019 ± 0.010	1.9 ± 1.0
Barred Owl	0	0	0	9.7	0.276 ± 0.158	21.0 ± 10.6
Whip-poor-will	1	0.008 ± 0.006	0.8	1.3	0.038 ± 0.019	2.9 ± 1.6
Ruby-throatedHummingbird	3	0.023 ± 0.010	2.3	2.7	0.076 ± 0.025	4.8 ± 1.0
Red-headed Woodpecker	2	0.015 ± 0.006	0.8	0	0	0
Red-bellied Woodpecker	7	0.054 ± 0.016	5.4	2.0	0.057 ± 0.028	5.7 ± 2.8
Downy Woodpecker	8	0.062 ± 0.019	5.4	3.7	0.105 ± 0.062	9.5 ± 5.3
Hairy Woodpecker	2	0.015 ± 0.009	1.5	2.3	0.067 ± 0.038	5.7 ± 2.8
Northern Flicker	1	0.008 ± 0.006	0.8	0.3	0.010 ± 0.010	1.0 ± 1.0
Pileated Woodpecker	5	0.038 ± 0.016	3.1	6.7	0.190 ± 0.148	18.1 ± 13.8
Eastern Wood-pewee	11	0.085 ± 0.019	8.5	11.7	0.333 ± 0.010	32.4 ± 1.0
Acadian Flycatcher	19	0.146 ± 0.029	10.8	10.0	0.286 ± 0.129	21.0 ± 9.4
Eastern Phoebe	1	0.008 ± 0.006	0.8	2.3	0.060 ± 0.067	5.7 ± 5.7
Great Crested Flycatcher	13	0.100 ± 0.023	9.2	1.7	0.048 ± 0.025	3.8 ± 2.5
Eastern Kingbird	0	0	0	4.7	0.133 ± 0.069	11.4 ± 5.9
White-eyed Vireo	0	0		8.0	0.229 ± 0.033	14.3 ± 2.8
Yellow-throated Vireo	0	0	0	1.7	0.048 ± 0.034	2.9 ± 1.6
Red-eyed Vireo	35	0.269 ± 0.033	25.4	69.7	1.990 ± 0.149	91.4 ± 3.3
Blue Jay	82	0.631 ± 0.069	36.2	10.7	0.305 ± 0.119	24.8 ± 10.5
American Crow	13	0.100 ± 0.031	6.9	69.3	1.981 ± 0.050	90.5 ± 3.4
Barn Swallow	0	0	0	6.0	0.171 ± 0.033	4.8 ± 1.0
Carolina Chickadee	6	0.046 ± 0.021	2.3	18.0	0.514 ± 0.141	33.3 ± 6.9
Tufted Titmouse	44	0.338 ± 0.042	27.7	22.7	0.648 ± 0.069	49.5 ± 8.3
White-breasted Nuthatch	13	0.100 ± 0.023	9.2	17.0	0.486 ± 0.119	40.0 ± 10.3
Carolina Wren	0	0	0	6.0	0.171 ± 0.044	15.2 ± 5.0
Blue-gray Gnatcatcher	13	0.100 ± 0.023	9.2	40.0	1.143 ± 0.119	57.1 ± 3.3
Eastern Bluebird	0	0	0	3.0	0.086 ± 0.033	5.7 ± 1.6
Wood Thrush	7	0.054 ± 0.016	5.4	1.0	0.029 ± 0.028	1.9 ± 1.9
Brown Thrasher	1	0.008 ± 0.006	0.8	0	0	0
Cedar Waxwing	0	0	0	0.3	0.010 ± 0.010	1.0 ± 1.0
Blue-winged Warbler	0	0	0	5.3	0.152 ± 0.025	10.5 ± 1.0
Northern Parula	3	0.023 ± 0.010	2.3	3.0	0.086 ± 0.049	7.6 ± 5.0
Yellow-throated Warbler	9	0.069 ± 0.018	6.9	1.7	0.048 ± 0.034	4.8 ± 3.4
Pine Warbler	73	0.562 ± 0.047	46.9	44.0	1.257 ± 0.129	61.9 ± 2.5
Prairie Warbler	0	0	0	5.0	0.143 ± 0.016	13.3 ± 1.9
Black-and-white Warbler	11	0.085 ± 0.019	8.5	10.3	0.295 ± 0.025	21.9 ± 2.5
Worm-eating Warbler	13	0.100 ± 0.021	10.0	6.7	0.190 ± 0.069	16.2 ± 6.7
Ovenbird	109	0.838 ± 0.058	61.5	8.7	0.248 ± 0.053	21.0 ± 4.8
Kentucky Warbler	3	0.023 ± 0.010	2.3	2.7	0.076 ± 0.019	7.6 ± 1.9
Common Yellowthroat	0	0	0	4.0	0.114 ± 0.028	9.5 ± 1.0
Yellow-breasted Chat	0	0	0	15.0	0.429 ± 0.119	30.5 ± 5.8
Summer Tanager	25	0.192 ± 0.030	17.7	22.7	0.648 ± 0.053	56.2 ± 4.2
Scarlet Tanager	19	0.146 ± 0.025	14.6	24.0	0.686 ± 0.072	48.6 ± 3.3
Eastern Towhee	12	0.092 ± 0.025	6.9	2.3	0.067 ± 0.034	4.8 ± 2.5
Chipping Sparrow	0	0	0	9.0	0.257 ± 0.072	18.1 ± 3.4
Field Sparrow	0	0	0	3.0	0.086 ± 0.016	5.7 ± 0.0
Northern Cardinal	13	0.100 ± 0.023	8.5	7.7	0.219 ± 0.042	19.0 ± 2.5
Blue Grosbeak	0	0	0	0.3	0.010 ± 0.010	1.0 ± 1.0
Indigo Bunting	16	0.123 ± 0.026	10.8	39.7	1.133 ± 0.182	68.6 ± 5.7
Red-winged Blackbird	0	0	0	2.7	0.076 ± 0.010	3.8 ± 1.0
Eastern Meadowlark	0	0	0	4.3	0.124 ± 0.034	5.7 ± 1.6
Brown-headed Cowbird	16	0.123 ± 0.024	11.5	0.7	0.019 ± 0.010	1.9 ± 1.0
Orchard Oriole	0	0	0	0.7	0.019 ± 0.010	1.9 ± 1.0
American Goldfinch	0	0	0	3.0	0.086 ± 0.044	6.7 ± 2.5

[a] Standard error calculated from all points

[b] Standard error calculated from means among all 3 years

in terms of number of stems, especially hardwoods, and basal area in comparison to ideal red-cockaded woodpecker habitat (Eddleman and Clawson 1987). Pines of the correct age for red-cockaded woodpeckers are present, but thinning of hardwood understory trees would be necessary to make the habitat suitable. A particular problem in these sites was a dense understory of tall hardwood saplings and shrubs. As a result, birds more often found in hardwood forests, such as Acadian flycatcher, red-eyed vireo, and ovenbird, were among the most common on the 1984 point counts (Pagen and others 2000).

Smith and Petit (1988) state that coniferous habitats in the Ozarks have a depauperate avifauna. It is possible, however, that this situation is a combination of degraded forests due to hardwood invasion, low productivity with fire exclusion, and the relatively young age of many coniferous habitats (e.g., pine plantations). Most stands included in the 1984 portion of the study were heavily invaded by hardwoods and were not burned (Eddleman and Clawson 1987).

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Three pine-dependent bird species have been extirpated or nearly extirpated from Missouri. All were common at one time except possibly the brown-headed nuthatch. Today, yellow-throated warbler, pine warbler, and chipping sparrow remain common, but available information indicates these species might become more common in open pine stands (Wilson and others 1995).

Many of the species present on the routes at Pineknot, but absent from the 1984 study, were those that increase after pine forests are thinned and burned, such as northern bobwhite and prairie warbler (Dram and others 2002). Suggested mechanisms by which bird species increase or decrease depend on the species: removal of hardwoods, increase in grassy vegetation and arthropod abundance, increased low shrubs (the latter two associated with increased light) (Conner and others 2002). Thinning and prescribed fire should continue to improve the habitat. Summer fires are thought to be the primary type of fires that occurred in pristine Southeast pine forests (Jackson 1988), so restoration should incorporate a variety of fire regimes.

The extirpated bird species of pine forests would have to be restored to Missouri. It will probably be many years before habitat is suitable on a large enough scale to maintain populations of these species, however. Any such restoration should include intensive habitat assessment prior to the attempt, and assurance that management for producing high quality habitat would continue (Jackson 1994). Methods for moving red-cockaded woodpecker colonies have been developed and have enjoyed some degree of success. These methods include cavity restrictors to exclude competitors, movement of young females from natal sites to clans lacking a female, and artificial cavity construction methods (Jackson 1994). Brown-headed nuthatch reintroduction may be feasible, but only one large-scale project has been undertaken with this species (Slater 2004). In 1997-2001, 53 were released in Everglades National Park, and the project was judged to be a success because the population increased and demographic measures were similar to those in a high-quality reference population. Prior to the attempt, the forest in the area had matured, snags were present due to Hurricane Andrew in 1992, and the area could support an estimated 200 territories. Burning had also been implemented (Slater 2004).

Bachman's sparrow management includes prescribed fire and maintenance of core areas of mature pine forest to provide for colonization of ephemeral habitats such as abandoned fields and certain clearcuts (Hammerson 1997). Reintroduction should not be undertaken, however, until dispersal in this species is better understood. The species is also migratory in Missouri, and methods for reintroduction of migratory songbirds do not exist at present. A more likely scenario is that Bachman's sparrows will disperse into suitable habitat when a large enough block is created through appropriate management (Dunning and Watts 1990).

ACKNOWLEDGMENTS

We thank K. Kelley and C. Price, U.S. Forest Service, Doniphan Ranger District, for conducting point counts at Pineknot.

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Appendix Table 1.—Scientific names of birds mentioned in the text.

Acadian Flycatcher (*Empidonax virescens*)
American Crow (*Corvus brachyrhynchos*)
American Goldfinch (*Carduelis tristis*)
Bachman's sparrow (*Aimophila aestivalis*)
Barn Swallow (*Hirundo rustica*)
Barred Owl (*Strix varia*)
Black-and-white Warbler (*Mniotilta varia*)
Blue Grosbeak (*Passerina caerulea*)
Blue Jay (*Cyanocitta cristata*)
Blue-gray Gnatcatcher (*Polioptila caerulea*)
Blue-winged Warbler (*Vermivora pinus*)
Broad-winged Hawk (*Buteo platypterus*)
Brown Thrasher (*Toxostoma rufum*)
Brown-headed Cowbird (*Molothrus ater*)
Brown-headed Nuthatch (*Sitta pusilla*)
Canada Goose (*Branta canadensis*)
Carolina Chickadee (*Poecile carolinensis*)
Carolina Wren (*Thryothorus ludovicianus*)
Cedar Waxwing (*Bombycilla cedrorum*)
Chipping Sparrow (*Spizella passerina*)
Common Yellowthroat (*Geothlypis trichas*)
Downy Woodpecker (*Picoides pubescens*)
Eastern Bluebird (*Sialia sialis*)
Eastern Kingbird (*Tyrannus tyrannus*)
Eastern Meadowlark (*Sturnella magna*)
Eastern Phoebe (*Sayornis phoebe*)
Eastern Towhee (*Pipilo erythrophthalmus*)
Eastern Wood-pewee (*Contopus virens*)
Field Sparrow (*Spizella pusilla*)
Great Crested Flycatcher (*Myiarchus crinitus*)
Great Horned Owl (*Bubo virginianus*)
Greater prairie chicken (*Tympanuchus cupido*)
Hairy Woodpecker (*Picoides villosus*)
Indigo Bunting (*Passerina cyanea*)
Kentucky Warbler (*Oporornis formosus*)
Mourning Dove (*Zenaida macroura*)
Northern Bobwhite (*Colinus virginianus*)
Northern Cardinal (*Cardinalis cardinalis*)
Northern Flicker (*Colaptes auratus*)
Northern Parula (*Parula americana*)
Orchard Oriole (*Icterus spurius*)
Ovenbird (*Seiurus aurocapilla*)
Passenger Pigeon (*Ectopistes migratorius*)
Pileated Woodpecker (*Dryocopus pileatus*)
Pine Siskin (*Carduelis pinus*)
Pine Warbler (*Dendroica pinus*)
Prairie Warbler (*Dendroica discolor*)
Red Crossbill (*Loxia curvirostra*)
Red-bellied Woodpecker (*Melanerpes carolinus*)
Red-cockaded Woodpecker (*Picoides borealis*)
Red-eyed Vireo (*Vireo olivaceus*)
Red-headed Woodpecker (*Melanerpes erythrocephalus*)
Red-shouldered Hawk (*Buteo lineatus*)
Red-tailed Hawk (*Buteo jamaicensis*)
Red-winged Blackbird (*Agelaius phoeniceus*)
Ruby-throated Hummingbird (*Archilochus colubris*)
Scarlet Tanager (*Piranga olivacea*)
Summer Tanager (*Piranga rubra*)
Trumpeter Swan (*Cygnus buccinator*)
Tufted Titmouse (*Baeolophus bicolor*)
Turkey Vulture (*Cathartes aura*)
Whip-poor-will (*Caprimulgus vociferus*)
White-breasted Nuthatch (*Sitta carolinensis*)
White-eyed Vireo (*Vireo griseus*)
White-winged Crossbill (*Loxia leucoptera*)
Wild Turkey (*Meleagris gallopavo*)
Wood Thrush (*Hylocichla mustelina*)
Worm-eating Warbler (*Helmitheros vermivorum*)
Yellow-billed Cuckoo (*Coccyzus americanus*)
Yellow-breasted Chat (*Icteria virens*)
Yellow-throated Vireo (*Vireo flavifrons*)
Yellow-throated Warbler (*Dendroica dominica*)

AVIAN RESPONSE TO PINE RESTORATION AT PECK RANCH CONSERVATION AREA

Richard Clawson, Carrie Steen, Kim Houf, and Terry Thompson[1]

EXTENDED ABSTRACT

Midco Pine Flats is a 2,223-acre region of Peck Ranch Conservation Area (CA) that is classified as a pine-oak plains land type association. Extensive logging in the early 1900s removed most overstory shortleaf pine allowing oak to become the primary overstory component. In 2000, Missouri Department of Conservation staff initiated a pine-oak woodland restoration project with the primary goal of determining whether management practices (selective black oak harvest, fire, leave pine) in the pine-oak-vaccinium natural community at Peck Ranch are restoring the natural community. The study used prescribed fire, harvest, or both as primary restoration tools.

In 2004, a concurrent study was initiated to focus more directly on pine regeneration. The Midco Pine Flats area was divided into 10 treatment units to examine the effects of different competition control methods used to advance pine regeneration. Three units were assigned to each of three treatments (chemical, mechanical, and prescribed fire), and the remaining unit was left untreated as the control. Within these units, restoration is focused on areas characterized by pine-oak/vaccinium Dry Ultic and mixed oak-pine/Desmodium, vaccinium chert natural communities. Some of the area was planted in pine, while the rest was deemed adequate in natural regeneration. These sites also were slashed and site preparation prescribed burning was applied.

Methods

To monitor the effects of pine restoration on migrant and resident birds, a modified breeding bird survey (BBS) (Anonymous 1970) is conducted annually at Peck Ranch CA. The BBS route consists of 25 points, approximately 0.5 mi apart, on gravel roads and woods trails that are accessible by vehicle. At each point, observers exit the vehicle, stand for 5 minutes, and record all birds heard and seen. This route is run twice from May 15 to June 30. Data have been collected via this BBS since 2000. From these data, indexes to bird distribution and abundance have been generated.

Vegetation has also been sampled within the shortleaf pine restoration project area. Twenty-four permanent vegetation sampling plots (0.2 ac) were established randomly in 2000, stratified by four ecological land types (ELT) (Rimer 2003.) Thirty additional plots were established in 2005 within designated pine restoration sites. Vegetation sampling includes percent class of ground flora/ground cover; sapling species, height and diameter at breast height (DBH); and overstory species and DBH. Initial plots were sampled in 2000, 2002 and 2006; sampling for ground flora and saplings began in 2006 for additional plots.

Results and Discussion

Fifty-two species of birds have been detected on the Peck Ranch CA BBS between 2000 and 2006 (Table 1). The number of species detected each year has trended upward, primarily because canopy-dwelling birds have remained on the site and early-successional species have responded positively to the treatment. Only one species has apparently disappeared from the survey. The rates and frequency of detection for these birds are varied (Table 1.)

Pine warbler was common prior to the pine restoration project (Table 1) but retention of pine in the overstory, along with opening the canopy, probably enhanced its habitat. This is consistent with increases in overstory pine throughout this period. Northern parula prefers large tree crowns that stick out from their surroundings; opening the canopy enhanced habitat for this species. One canopy dweller, red-eyed vireo, decreased, probably because of the reduction of deciduous trees in the canopy as evidenced by the overall decrease in stem density of overstory trees.

Mixed forest/open habitat-dweller Mourning Dove and early successional habitat-dwellers yellow-breasted chat, white-eyed vireo, and prairie warbler all increased (Table 1). At the same time, overstory density decreased, allowing an increase in sapling stem density. These species probably benefited from the more open canopy and the increased herbaceous and shrub vegetation at ground level. Early-sucessional habitat-dweller indigo bunting has remained essentially unchanged. This species already was abundant in the area when the pine restoration project began.

Finally, subcanopy-dweller yellow-billed cuckoo has disappeared from the survey (Table 1), probably as a result of a more open canopy and a reduction in midstory saplings. This change can be seen in the frequency of saplings occurring by foot class: Vegetation sampling from 2006 shows that the greatest number of saplings range from only 5 to 8 feet tall, creating more "brushy" habitat rather than a developed midstory at this time.

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[1] Missouri Department of Conservation (RC), Columbia, MO; Missouri Department of Conservation (CS), West Plains, MO; Missouri Department of Conservation (KH), Winona, MO; Missouri Department of Conservation (TT), Eminence, MO. RC is corresponding author: to contact call (573) 882-9880 or email rick.clawson@mdc.mo.gov

Although vegetation sampling is still in the preliminary stage, we are finding that structural changes due to management activities may account for changes in avifauna in the pine restoration area of Peck Ranch CA.

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Table 1.—Mean number of birds and detection frequency per stop, 2000-2006.

	Mean number of birds per stop							**Mean number of stops at which birds were detected**						
Species	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Turkey vulture	0	0	0.04	0.02	0	0	0	0	0	0.5	0.5	0	0	0
Red-tailed hawk	0	0	0.04	0.02	0.04	0	0.04	0	0	1	0.5	1	0	1
Red-shouldered hawk	0	0.04	0	0	0	0.1	0.02	0	1	0	0	0	2.5	0.5
Broad-winged hawk	0	0	0	0	0.04	0	0	0	0	0	0	0.5	0	0
Wild turkey	0.08	0.04	0.08	0.14	0.02	0.12	0	1.5	0.5	2	2.5	0.5	2.5	0
Mourning dove	0.08	0.04	0.12	0.1	0.22	0.22	0.32	1.5	1	2.5	2.5	4.5	5	7
Yellow-billed cuckoo	0.4	0.68	0.64	0.5	0.2	0.06	0	9	12	12.5	9	4.5	1.5	0
Chimney swift	0	0	0	0.04	0	0	0	0	0	0	0.5	0	0	0
Ruby-throat. hummingbird	0.04	0.06	0.04	0.1	0.06	0.02	0.08	1	1.5	1	2	1.5	0.5	1.5
Pileated woodpecker	0.46	0.7	0.94	0.84	0.5	0.76	0.52	8	14	15.5	14	10	13.5	8.5
Red-bellied woodpecker	0.16	0.14	0.16	0.2	0.12	0.24	0.16	3.5	3.5	4	5	2.5	5.5	4
Red-headed woodpecker	0	0.02	0	0	0	0.06	0.06	0	0.5	0	0	0	1.5	1.5
Hairy woodpecker	0	0	0.02	0.02	0.08	0.02	0	0	0	0.5	0.5	1.5	0.5	0
Downy woodpecker	0.02	0.2	0.06	0.04	0.02	0.06	0.1	0.5	4	1.5	1	0.5	1.5	2.5
Great-crested flycatcher	0.26	0.2	0.24	0.34	0.12	0.08	0.14	6	4	5.5	7	3	1.5	3.5
Acadian flycatcher	0.08	0	0.02	0.04	0.04	0.04	0.08	2	0	0.5	1	1	1	2
Eastern wood pewee	0.54	0.68	0.54	0.64	0.66	0.74	0.5	12.5	16	11.5	11.5	13	16	11.5
Purple martin	0	0	0	0.02	0	0	0	0	0	0	0.5	0	0	0
Blue jay	0.02	0.1	0.12	0.12	0.06	0.26	0.04	0.5	2.5	1	2	1.5	6	1
Common crow	0.94	1.12	0.88	1.2	0.74	0.94	0.98	12.5	18	14	18	10.5	16.5	16
Carolina chickadee	0.08	0.14	0.14	0.14	0.12	0.2	0.04	1	2.5	2.5	2.5	2.5	3.5	0.5
E. tufted titmouse	0.36	0.32	0.7	0.38	0.42	0.24	0.34	8	5.5	11.5	7.5	8.5	6	7
White-breasted nuthatch	0.42	0.12	0.3	0.2	0.4	0.36	0.32	8	3	7	5	8	6.5	6.5
Carolina wren	0.12	0	0.06	0.08	0.24	0.2	0.28	3	0	1.5	2	5	4	6
Wood thrush	0.02	0	0.04	0	0.02	0.02	0.04	0.5	0	1	0	0.5	0.5	1

(Table 1 continued on next page)

Table 1.—Mean number of birds and detection frequency per stop, 2000-2006. *(continued)*

Species	Mean number of birds per stop							Mean number of stops at which birds were detected						
	2000	2001	2002	2003	2004	2005	2006	2000	2001	2002	2003	2004	2005	2006
Eastern bluebird	0	0	0	0.04	0	0.12	0	0	0	0	0.5	0	1.5	0
Blue-gray gnatcatcher	0.44	0.56	0.62	0.64	0.44	0.3	0.54	10.5	11	13.5	10.5	9.5	6	11
White-eyed vireo	0	0	0.08	0.08	0.38	0.32	0.48	0	0	2	2	8	6.5	8.5
Yellow-throated vireo	0.08	0.04	0.1	0.02	0.1	0	0.08	2	1	2	0.5	2.5	0	2
Red-eyed vireo	1.38	1.32	1.66	1.34	1.34	1.04	0.92	21	21.5	20.5	24	18.5	18.5	15.5
Black and white warbler	0.08	0.06	0.06	0.24	0.2	0.14	0.1	2	1.5	1.5	6	5	3.5	2.5
Worm-eating warbler	0.04	0	0	0	0.04	0	0	1	0	0	0	1	0	0
Blue-winged warbler	0	0.02	0	0.04	0.04	0.12	0.06	0	0.5	0	1	1	3	1.5
Northern Parula	0.18	0.12	0.3	0.4	0.62	0.48	0.6	4.5	3	6.5	4	11	9.5	12
Cerulean warbler	0	0	0.02	0	0.02	0	0	0	0	0.5	0	0.5	0	0
Yellow-throated warbler	0.5	0.42	0.56	0.38	0.58	0.36	0.34	11	9	11	9	11.5	8	7
Pine warbler	0.78	0.56	1.12	0.82	1.24	1.12	1.08	16	11	17.5	15.5	20	17	18
Prairie warbler	0.16	0.12	0.36	0.48	0.46	0.4	0.22	4	3	8	10.5	10.5	8.5	5.5
Ovenbird	0	0.04	0	0.02	0	0.04	0.02	0	1	0	0.5	0	1	0.5
Common Yellowthroat	0	0	0	0	0.06	0.04	0.06	0	0	0	0	1.5	1	1.5
Yellow-breasted Chat	0.22	0.62	0.82	0.96	1.32	1.22	1.24	5	12.5	13.5	17	19	20	19
Kentucky Warbler	0	0	0	0.02	0.02	0.1	0.08	0	0	0	0.5	0.5	2	2
Orchard Oriole	0	0	0	0	0.02	0.02	0	0	0	0	0	0.5	0.5	0
Brown-headed Cowbird	0.26	0.08	0.4	0.16	0.12	0.16	0.12	6	2	8.5	3.5	3	3.5	3
Scarlet Tanager	0.22	0.46	0.26	0.36	0.26	0.34	0.16	4	9.5	5.5	8.5	6	8	3.5
Summer Tanager	0.56	0.64	0.74	0.3	0.22	0.44	0.34	11.5	13.5	14.5	7.5	5	10.5	7
Northern Cardinal	0.2	0.12	0.28	0.14	0.26	0.28	0.18	5	2.5	7	3.5	5.5	7	3.5
Indigo Bunting	1.24	1.52	1.88	1.7	1.54	1.36	1.44	20.5	22.5	22.5	22	20	21	19
American Goldfinch	0	0	0	0.04	0.06	0.04	0	0	0	0	0.5	1.5	0.5	0
Eastern Towhee	0.04	0.06	0.12	0.12	0.16	0.14	0.18	1	1.5	3	3	3.5	3.5	4
Chipping Sparrow	0	0.06	0	0	0.02	0.1	0.06	0	0.5	0	0	0.5	2	1
Field Sparrow	0	0.02	0.04	0.1	0.06	0.04	0.2	0	0.5	1	2	1.5	1	5
Total No. Species Observed	33	35	38	43	45	44	40							

TIMBER HARVEST LEVELS AND PRESSURE ON SHORTLEAF PINE IN MISSOURI

Thomas B. Treiman, Ron J. Piva, and W. Keith Moser[1]

ABSTRACT.—Data from two sources are used to estimate the harvest pressure on Missouri's shortleaf pine (*Pinus echinata* Mill.) resource. By overlapping Timber Product Output (TPO) and Forest Inventory and Analysis (FIA) inventory data, we examine utilization pressure on shortleaf pine and the residual inventory. Conducted every three years in Missouri, the TPO survey consists of a complete census of all primary mills and is a snapshot in time of timber use. TPO data from 1969 to 2003 show that annual shortleaf pine harvest has varied between 4.0 and 8.9 million cubic feet. Most of the shortleaf pine harvested in the State was processed in Missouri. FIA field plots offer another method of estimating both shortleaf pine growth and removals on an annual basis using plot and tree measurements over time. In 1989, FIA data estimated annual removals of shortleaf pine growing stock at 6.8 million cubic feet (including both harvest and land use changes); in 2004, annual removals of shortleaf pine growing stock were 5.0 million cubic feet. In both 1989 and 1999-2003, most of the removals came from the medium- and small-size classes. FIA data also show overall sustainable utilization pressure, with annual net growth of shortleaf pine growing stock that has increased from 18.5 million cubic feet in 1989 to 25.1 million cubic feet in 2003. Questions of long-term ecological and economic sustainability and impacts are also addressed using these data sets.

INTRODUCTION

When early European settlers first reached Missouri, there were an estimated 6.6 million acres of shortleaf pine (Pinus echinata Mill.), concentrated particularly in the Ozarks. By 2003, shortleaf pines occupied only about 163,500 acres, a net loss of approximately 6.4 million acres (Moser et al. 2005). This decrease has substantially changed the appearance and ecology of the forests once dominated by the species (Stambaugh and Muzika 2001). Shortleaf pine was a primary source of timber in Missouri from the late 1800s until the early 1920s, when millions of board feet were harvested for large sawmills in the southern Missouri Ozarks. Railroad networks reached from the woods to the sawmills. Where railroads were lacking, oxen pulled wagons loaded with large pine logs to the mills. Missouri's timber production peaked in 1899. By 1910, nearly all the pine had been cut (Palmer 2000). Over the last century, the economic importance of shortleaf pine to Missouri has declined along with the area of the state dominated by pine forest.

Gwaze (2005) notes that the current population structure of shortleaf pine has been heavily influenced by past human activities. Shortleaf pine forests in Missouri have been reduced by the combined effects of 1) uncontrolled logging and high-grading between 1880 and 1920; 2) excessive surface fires in the first half of the 20th century that were used to encourage the growth of pasture but which also discouraged pine regeneration; 3) open-range grazing; and 4) effective fire suppression by state and federal agencies since 1950, preventing the periodic fires necessary for regeneration of shortleaf pine, a fire-dependent species. These disturbance patterns resulted in establishment of millions of acres of oak-dominated forest on areas that previously were dominated by shortleaf pine.

Shortleaf pine used to be a major component of Missouri's economy, and remains important to the state's biodiversity and natural heritage. The economic, ecological, and scientific importance of shortleaf pine has spurred the active promotion of both natural and artificial regeneration of the species to restore former pineries, increase forest diversity, and mitigate oak decline on sites better adapted to shortleaf pine. Over the last decades, natural resource management agencies have developed strategies and projects to restore shortleaf pine in areas of its previous range (Missouri Department of Conservation 2005). Indeed, shortleaf pine restoration on oak sites that are better suited to pine and have a high potential for future oak decline may be one way to deal with forest health issues. But such efforts may not be successful or sustainable, especially on private land, if the economic incentives of restoring shortleaf pine, and the harvest pressure it faces, are not well understood.

DATA AND METHODS

Forest Inventory and Analysis Methods

The national Forest Inventory and Analysis (FIA) program provides estimates of forest area, volume, change, and forest

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[1] Natural Resource Economist (TBT), Missouri Department of Conservation, Columbia 1110 S. College Ave., MO 65201; Research Forester (RJP and WKM), Northern Research Station - USDA Forest Service, St. Paul, MN 55108. TBT is corresponding author: to contact call (573) 882-9909 or email at tom.treiman@mdc.mo.gov

health throughout the United States (McRoberts 1999). The FIA sampling design consists of a random, equal probability sample with a base intensity of one plot per approximately 6,000 acres. Beginning with the 1999 inventory, Missouri was one of the first states in the nation to be inventoried with the new annualized FIA system (Moser et al. 2005). The FIA annual inventory system measures approximately one-fifth of all field plots each year. After 5 years, an entire inventory cycle will be completed. After the first 5 years, FIA will report and analyze results as a moving 5-year average. We used data from the 1999-2003 and the 2000-2004 inventories of Missouri to analyze the shortleaf pine resource. For estimates of both growth and removals these inventories demonstrate wide variation because of the long time gap between the last periodic inventory (1989) and the first full 5-year annualized inventory as well as changes in definitions and methods over that time period. In addition, the 2000-2004 inventory, although using consistent definitions and methods relies on the remeasurement of only one year's worth of data (the plots taken in 1999 and again in 2004) for growth and removals estimates.

Timber Product Output Data

Periodic Timber Product Output (TPO) survey is an on-going cooperative effort between the Missouri Department of Conservation (MDC) and the USDA Forest Service's Northern Research Station (NRS) (Treiman and Piva 2005). Consulting foresters from Missouri and MDC personnel visit all primary wood-using mills within the State every 3 years. They use questionnaires designed and supplied by MDC to determine the size and composition of the resources that are utilized by the State's primary wood-using industry, its use of roundwood, and its generation and disposition of wood residues. Survey questions and reports refer to wood-use during the previous calendar year. Follow-up visits are made as needed in an effort to achieve a 100-percent response. Completed questionnaires are sent to MDC for data entry and then electronically forwarded to NRS for editing and processing. As part of data editing and processing, roundwood volumes are converted to standard units of measure using regional conversion factors. Timber removals by source of material and harvest residues generated during logging are estimated using factors developed from logging utilization studies previously conducted by NRS. Finalized data on Missouri's industrial roundwood receipts are loaded into a national timber removals database along with data from TPO studies from other States to provide a complete assessment of Missouri's timber product output.

Missouri Timber Price Data

MDC surveys Missouri foresters, loggers, and members of the forest industry on a quarterly basis to determine current price trends in the state. Survey response is voluntary and confidential; MDC has no statutory or regulatory power to compel sale reporting. For this reason, most reported sales tend to be reported by professional foresters and the results must be interpreted with that caveat in mind. We surmise that forester-assisted sales, which tend to be inventoried, marked, and bid out, represent the upper range of prices paid for stumpage. MDC publishes the survey results quarterly as Missouri Timber Price Trends and makes the publication available to landowners and the forest industry in paper and on the web: http://mdc.mo.gov/forest/products/prices/index.htm (Treiman and Tuttle 2006). Foresters turning in reports are free to lump species together in sale reports, and often do. Consequently, detailed price data for shortleaf pine is not available for all reporting periods.

RESULTS

Forest Inventory and Analysis Data

The 1972 Forest Inventory and Analysis plots in Missouri showed total annual removals of 167.7 million cubic feet (Spencer et al. 1976). Shortleaf pine accounted for 6.9 million feet per year (4 percent of the total). About 30 percent of the removals were from the Eastern Ozarks Forest Survey Unit (Table 1 and Figure 1).

The results from the 1989 forest inventory in Missouri show 6.8 million cubic feet of annual removals of shortleaf pine, representing about 6 percent of the 116.6 million cubic feet of total annual removals of all species in the State. The inventory found that over half (53 percent) of the removals came from the Eastern Ozarks unit with the rest coming from the Southwest Ozark unit. About two-thirds of the removals were from National Forest land with most of the remainder coming from private lands. Between 1972 and 1989, there was an average net annual growth of 19.6 million cubic feet of shortleaf pine. Sixty-two percent of

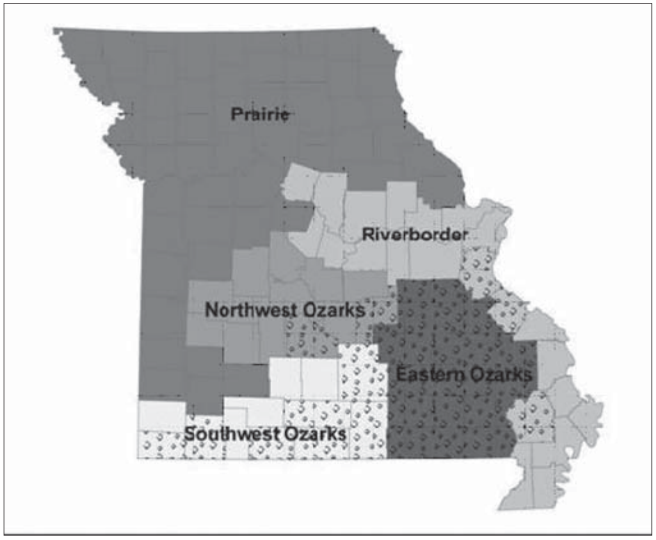

Figure 1.—A map of the FIA analysis units for Missouri. Counties with tree symbols had shortleaf pine or shortleaf pine/oak forest types in the 2000-2004 FIA inventory.

Table 1.—Average net annual growth and average annual removals of shortleaf pine on timberland by survey year and Forest Survey Unit, Missouri (in thousand cubic feet).

	Total			Forest Inventory Unit							
				Eastern Ozarks		Southwestern Ozarks		Northwestern Ozarks		Riverborder	
Survey Year	Growth	Removals	Pct. of Growth	Growth	Removals	Growth	Removals	Growth	Removals	Growth	Removals
1959[1]	15,642	5,000	32%	na	na	na	na	na	na	na	na
1972[1]	10,718	6,854	64%	8,241	2,060	2,256	4,704	141	3	79	88
1989	19,618	6,788	35%	12,138	3,613	5,761	3,175	1,432	--	287	--
1999-2003[2]	18,480	8,560	46%	11,028	4,513	5,500	4,047	1,798	--	155	--
2000-2004[2]	25,094	5,059	20%	17,842	3,864	6,925	1,195	--	--	327	--

na = Not available

[1] Converted from cords at 79 cubic feet per cord.

[2] From Forest Inventory Mapmaker version 2.1 at: http://www.ncrs2.fs.fed.us/4801/FIADB/index.htm

the growth occurred in the Eastern Ozarks unit with most of the rest coming from the Southwest Ozark unit. Some net growth also occurred in the Northwest Ozarks and Riverborder units (Spencer et al. 1992).

Results from the 1999-2003 annual inventory show an increase of annual removals of shortleaf pine to 8.6 million cubic feet, but shortleaf pine still makes up around 7 percent of the total 118.6 million cubic feet of annual removals in the state. Almost 40 percent of the removals were in the Eastern Ozarks unit. Average net annual growth was 18.5 million cubic feet for shortleaf pine. About 60 percent of the growth occurred in the Eastern Ozarks unit (Moser et al. 2007). Table 1 also shows results labeled “2004”, based on the continuing annual FIA plots. For removals, the figures vary widely from the “2003” figures (based on 5 years of plots, 1999-2003) and those labeled “2004” because they represent only a 20 percent sample—those plots measured in 1999 and remeasured in 2004.

In addition, FIA plot data can be analyzed to show growth and removals by public and private ownerships, and acreage in each ownership category (see Table 2). Note that although 83 percent of timberland in Missouri was privately owned (1999-2003) and 85 percent of all growth of growing stock volume occurred on that private land, only 45 percent of shortleaf pine growth occurred on private land. Similarly, although 69 percent of all removals came from private land only 55 percent of shortleaf pine removals were from private land. These findings accord with overall volume on private land: 8 percent of all growing stock volume was on private land while only 42 percent of shortleaf pine growing

Table 2.—Removals, growth, and growth removed by ownership type (percent of cubic foot volume).

		Inventory Year and Species			
		1999-2003		2000-2004	
		All Species	Shortleaf Pine	All Species	Shortleaf Pine
Removals	Private Land	69%	55%	83%	90%
	Public Land	31%	45%	17%	10%
Growth	Private Land	85%	45%	82%	48%
	Public Land	15%	55%	18%	52%
Removals/Growth	Private Land	15%	56%	31%	38%
	Public Land	39%	38%	28%	4%
	Overall	19%	46%	30%	20%

stock volume was on private land. Given these volume percentages growth and removals figures for shortleaf pine by ownership are not surprising. In addition, FIA plots show that in both 1989 and 1999-2003 most of the removals came from the medium- and small-size classes.

Timber Product Output Data

In TPO surveys conducted between 1969 and 2003, total production of industrial roundwood in Missouri ranged from a low of 87.6 million cubic feet (1980) to 139.6 million cubic feet (1997). During this period, shortleaf pine remained in the top five species harvested, peaking at number three from 1987 to 1997. In 2000, shortleaf pine fell to the fourth most harvested species. Red and white oaks have always had much higher harvest levels. The total harvest of shortleaf pine varied from a low of 4.0 million cubic feet in 1969 to a high of 8.9 million cubic feet in 1991 (Table 3).

The Eastern Ozark Unit has historically contained most of the harvest volume of shortleaf pine in the State. The highest harvest in the region was 6.5 million cubic feet in 1994, about 80 percent of all shortleaf pine harvested that year. The low came in 2003, 3.4 million cubic feet or 75 percent of the total shortleaf pine harvest for that year. Since 1980, the Southwestern Ozark Unit has had the second highest shortleaf pine volume harvested, with an average of just over 20 percent of the State's harvest.

Historically, more than 95 percent of the shortleaf pine harvested in Missouri was processed in Missouri and the majority has been used for sawlogs. The percentage used for other purposes (mostly posts) has varied from a low of 9 percent in 1987 to a high of 34 percent in 1969. Since 1969, posts have remained as the second most processed product in the State using shortleaf pine. The production of poles from shortleaf pine reached its peak in the 1969 survey, and has since disappeared from TPO reports. This situation may change with the opening in 2006 of a pole mill near Licking, MO (John Tuttle, MDC Forest Products Supervisor, pers. commun. with the author).

In 1987, a logging utilization study was conducted which lets us estimate of the volume of industrial roundwood that is removed during harvest and the volume that is left on the ground as harvest residue. The volume of shortleaf pine harvest residues since 1987 has ranged from a high of 5.3 million cubic feet in 1997 to a low of 3.1 million cubic feet in 2000. About two-thirds of the volume of the trees that are cut is utilized for products. Ninety percent of the volume that is utilized comes from growing stock sources (Blyth and Massengale 1972, Blyth et al. 1983, Smith and Jones 1990, Hackett et al. 1993, Piva and Jones 1997, Piva and Treiman 2003, Treiman and Piva 2005).

The most recent TPO data from 2003 were also used to compile a directory of Missouri's primary wood processing mills which showed that 92 out of 444 processed some shortleaf pine (Jones et al. 2004).

Missouri Timber Price Data

Stumpage prices for shortleaf pine sawlogs have ranged between $90 and $155 per International ¼" MBF, according to sales reports collected for *Missouri Timber Price Trends*. Fence post prices have ranged between $0.20 and $0.65 per post over the same period (see Figure 2).

Combining the TPO results with these price data allows the calculation of the total value of all shortleaf pine sales, assuming that all landowners receive the forester-assisted

Table 3.—Total industrial roundwood production and shortleaf pine industrial roundwood production by year and Forest Survey Unit, Missouri (in thousand cubic feet).

		Shortleaf Pine Production						
				Forest Inventory Unit				
Survey Year	Total Roundwood	Total Shortleaf Pine	Pct. of Total Roundwood	Eastern Ozarks	Southwestern Ozarks	Northwestern Ozarks	Prairie	Riverborder
1969	123,546	4,023	3.2%	na	na	na	na	na
1980	87,558	5,450	6.2%	3,642	1,633	88	0	87
1987	99,932	7,114	7.1%	5,860	1,153	55	0	46
1991	121,392	8,865	7.3%	5,520	2,790	54	0	501
1994	132,593	8,127	6.1%	6,472	1,489	132	12	23
1997	139,643	8,723	6.2%	6,022	2,380	209	0	112
2000	128,974	5,239	4.1%	4,496	652	64	0	27
2003	128,106	4,560	3.6%	3,442	869	84	17	147

na = Not available

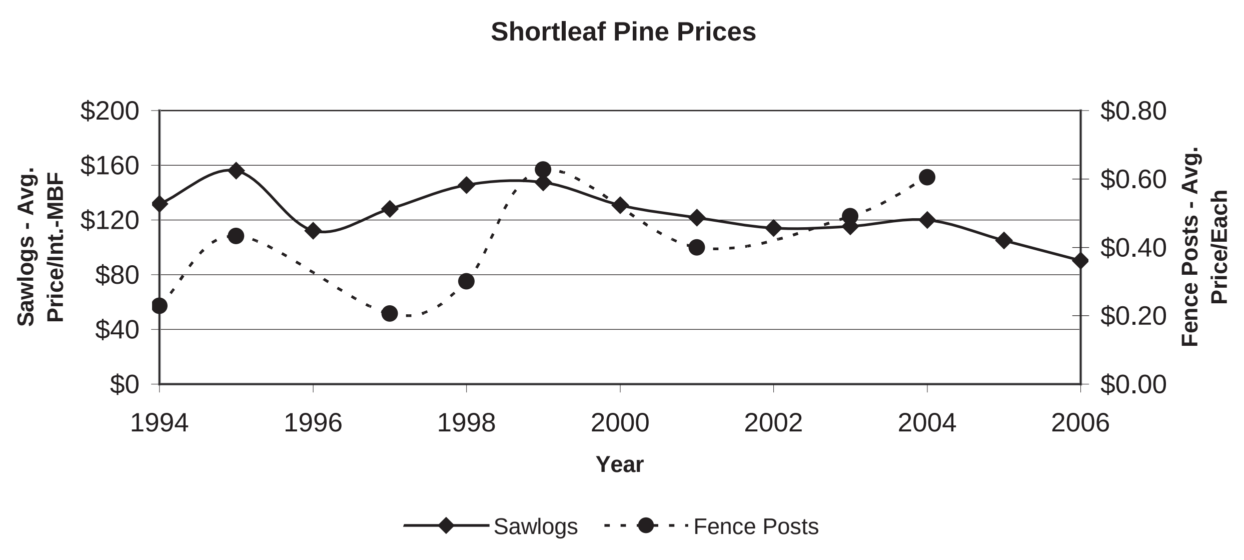

Figure 2.—Shortleaf pine prices for sawlogs (Int-MBF) and fence posts (each) in Missouri. Prices are based on reports received for the Missouri Timber Price Trends publication. These reports are voluntary and come from sales assisted by a professional forester. As such, the price trends shown tend towards the price for a well planned sale that is bid out to multiple loggers. (Prices were not available for posts from 2004-2006.)

prices represented by the *Missouri Timber Price Trends* data. The *Missouri Timber Price Trends* reports prices for sawlogs, posts, and pulpwood. Volumes for these species and products are also reported in the TPO surveys. The value of shortleaf pine products peaked in the 1990s at $7.5 million. After 1997, the value of the shortleaf pine harvest has continued to fall to the 2003 level of $3.5 million. These values are in Figure 3 as the line labeled "production". All annual totals have been converted into 2006 dollars.

Using FIA data, the potential value for the shortleaf pine resource in Missouri can be calculated. Assuming the maximum sustainable cut would be no more than total annual growth, and the highest value (price) is for the highest value product, which proves to be sawlogs, a theoretical upper bound to the sustainable total value of shortleaf pine can be calculated (Fig. 3).

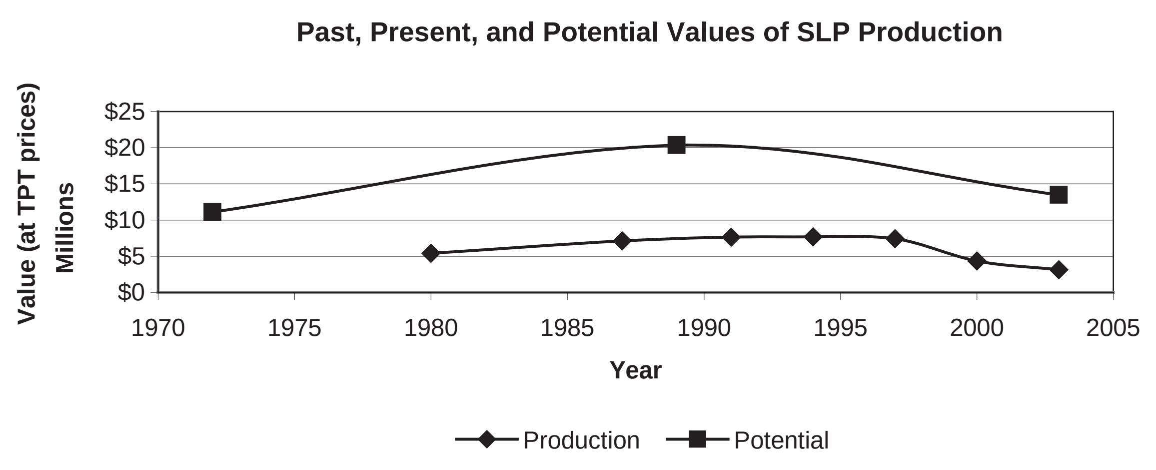

Figure 3.—Calculated present values of shortleaf pine industrial roundwood production[1] and potential production[2] in Missouri by year.

[1] Production is the value of product based on products and volumes harvested from TPO studies and *Missouri Timber Price Trends* reports in 2006 dollars.

[2] Potential is based on the maximum sustainable cut, which would be no more than total annual growth, and the highest value (price) for the highest value product.

DISCUSSION

From a low point in the early 20th century, shortleaf pine has been making a slow return to Missouri's forests. To date, more of this return (growth) has occurred on public land than on private land (Table 3). If shortleaf pine is to return to its historical prominence as a component of both the state's biodiversity and its economy, the role of private landowners will take on ever greater importance. Financial incentives are of paramount importance to many private forest landowners, so profitable markets for shortleaf pine will also be essential to the species' return.

Shortleaf pine is growing faster than it is being harvested in Missouri, a clear indicator of sustained yield. Shortleaf pine's rate of growth increased dramatically between 1972 and the 1999-2003 and the 2000-2004 FIA inventories. In 1972, 64 percent of shortleaf pine growth was removed, while for the 1989, the 1999-2003 and the 2000-2004 FIA inventories this percentage varied between 20 percent and 46 percent. For all species combined 30 percent of growth is being removed. Utilization of shortleaf pine is relatively high compared to all other species.

The 1999-2003 inventory estimates removals of shortleaf pine occur disproportionately on private land; 56 percent of private land shortleaf pine growth is being removed compared with 38 percent on public land. The 2000-2004 inventory estimates removals of shortleaf pine of only 4 percent of public land shortleaf pine growth compared with 38 percent on private land. (Note the high variation between the two, in part because of the earlier mentioned issues with switching inventory systems.) Many factors contribute to forest utilization, including markets, availability, and operability. The lower rate of utilization (as a percentage of growth) on public lands may indicate that public lands managers may have a valuable role to play in helping develop and improve markets for shortleaf pine. The higher rate of utilization of shortleaf pine on private lands may indicate that private forest landowners will be willing to take advantage of such markets for the product. Our rough calculation of the upper bound, "potential", also shows that the full economic benefits that might be reaped from this softwood are not yet being realized by landowners and as such, shortleaf pine may not be a fully thought-out part of many land management plans.

These results suggest a potentially fruitful area for further research: How does shortleaf pine potential (as defined in this paper) compare to that of other commercial species in the state? What is the relative economic position of shortleaf pine? Answers to these questions may help professional foresters working with private landowners to better understand why shortleaf pine is not in many management plans, and how to get it there. Some of this work may best be accomplished after another full 5-year annualized inventory is complete, allowing for more precise estimates of growth and removals.

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FINANCIAL RATES OF RETURN ON SHORTLEAF PINE STANDS IN ARKANSAS BETWEEN 1978 AND 1995

Andrew J. Hartsell[1]

ABSTRACT.—The objectives of this study are to estimate the annual rate of change in value of Arkansas' shortleaf pine forests using financial maturity concepts and to compare it to the change in other forest types and alternative investment options. Timber Mart-South stumpage price data were combined with inventory data spanning 17 years from the USDA Forest Service, Southern Research Station, Forest Inventory and Analysis (FIA) unit. Two distinct FIA survey periods were utilized, resulting in a study period ranging from 1978 to 1995. The average annual real rate of return on all Arkansas timberland investments during this time frame was 5.8 percent using simple financial maturity and 3.3 percent using adjusted financial maturity. Stands comprising primarily of shortleaf pine outperformed these state averages during this period, averaging 6.5 percent and 3.9 percent annually using simple and adjusted financial maturity models, respectively. Average annual rates of change in value were computed and compared for shortleaf pine and four other forest-type groups. Additionally, comparisons were made between forest type and ecoregion to determine which scenario produced the maximum rate of return. The highest earning shortleaf stands were found in the Arkansas Valley section of the State, with value changes of 8.2 percent per year for the simple financial maturity model and 6.9 percent per year for the adjusted model.

INTRODUCTION

Historically, shortleaf pine (*Pinus echinata* Mill.) ecosystems have played an important role in Arkansas forest lands, supporting hundreds of plant and animal species. Because of its many timber, nontimber, and ecosystem benefits, there is strong interest in maintaining and restoring shortleaf pine ecosystems. For this to happen, shortleaf pine must be viewed as a viable financial investment by forest managers and landowners, particularly the private landowners who control 58 percent of the state's timberlands (Rosson 2002).

This study investigates biological and financial growth rates of undisturbed stands in Arkansas by applying Timber Mart-South (TMS) stumpage prices to Forest Inventory and Analysis (FIA) sample trees. Each FIA sample tree was assigned a dollar value based on species, size, and condition. Saw-log trees were divided into multiple products (saw log and topwood) and rough cull trees were treated as pulpwood. The tree values were summed for each plot to derive the total plot stumpage value in dollars per acre.

STUDY AREA

The study area consists of the 75 counties of Arkansas, with the emphasis on timberlands. Timberland is defined as land that is at least 10 percent stocked by trees of any size, or formerly having such tree cover, and not currently developed for nonforest uses (Fig. 1). Minimum area considered for FIA classification and measurement is 1 acre.

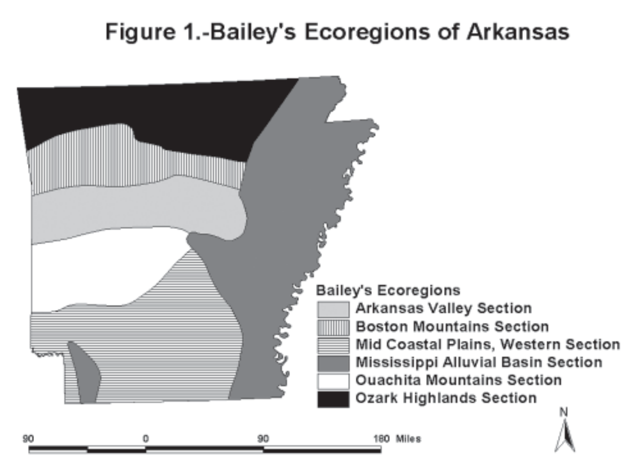

Figure 1.—Ecoregions (by section) of Arkansas (Bailey 1996).

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[1] Research Forester, Forest Inventory and Analysis, Southern Research Station, USDA Forest Service, 4700 Old Kingston Pike, Knoxvillle, TN 37919. To contact call (865) 862-2032 or email at ahartsell@fs.fed.us

METHODS

Two time periods coinciding with FIA surveys of Arkansas were investigated: 1978-1988 and 1989-1995. Plots had to meet the selection for both time periods in order to be included in the study.

Plot Selection

Value change computations require input from two points in time. Therefore, when the 1978-1995 period is discussed, 1978-1988 is time 1 and 1989-1995 is time 2.

All plots must be classified as forested for all survey periods in question. All time 2 plots must be classified as saw log-size stands, while time 1 plots may be either poletimber-size or sawtimber-size stands. Stands classified as seedling/sapling in either survey are omitted. All time 2 stands must have at least 5,000 board feet per acre. Several plots classified with forest types of elm-ash-cottonwood were excluded because of insufficient sample size (less than 10 plots for each survey period). All stands with evidence of management, disturbance, or harvesting for the survey periods in question, as well as the previous survey period, were excluded. This exclusion was necessary, as total plot values and volumes depend on the inventory of the stand when visited by cruisers. In almost every case, stands had less volume and value after undergoing management practices such as thinnings. Therefore, these stands are dropped from the study and only those stands that remained relatively undisturbed were included. A total of 330 plots met the selection criteria (Table 1).

Tree Selection

All live trees greater than or equal to 5.0 inches diameter at breast height (DBH) were included in the sample set, except rotten cull trees. Rough cull tree volumes were given pulpwood value. No cull trees were used in sawtimber computations. Tree selection was performed by variable radius sampling (37.5 basal area factor). Since tree selection was performed by variable radius sampling, new trees appear over time. These new trees were included in all computations and therefore affect growth and value changes. Trees that died between survey periods were included only in the survey year(s) in which they were alive. This approach could create negative biological and economic value growth between surveys.

Timber Mart-South Data

This study uses TMS price data to calculate individual tree values. TMS has been collecting delivered prices and stumpage prices for 11 southern states since December 1976. All TMS price data are nominal. Real prices were calculated using the U.S. Bureau of Labor Statistics all commodities producer price index. As 1987 was the midpoint of the study period, all TMS prices were inflated/deflated to 1987 levels.

Tree Products and Values

The algorithm used for determining tree products was: 1) all poletimber-size trees are used for pulpwood; 2) the entire volume of rough cull trees, even sawtimber-size trees, is

Table 1.—Average annual biological growth percent (BGP)[1], real timber value growth percent (TVG)[2], and real forest value growth percent (FVG)[3] by forest type, Arkansas 1978-1995.

				Land Value Dollars per Acre					
Forest Type	**N**	**BGP**	**TVG**	**250**	**500**	**750**	**1000**	**1250**	**1500**
		percent							
Loblolly pine	11	4.92	8.47	6.99	6.06	5.39	4.88	4.47	4.13
Shortleaf pine	54	3.22	6.50	5.26	4.49	3.94	3.53	3.19	2.92
Shortleaf pine-oak	35	2.38	5.04	4.11	3.50	3.05	2.71	2.44	2.22
Loblolly-hardwood	18	3.40	7.70	5.95	4.96	4.29	3.79	3.41	3.10
Oak-hickory	122	2.50	5.72	4.31	3.53	3.01	2.63	2.34	2.12
Oak-gum-cypress	90	2.28	5.07	4.13	3.52	3.09	2.76	2.49	2.28
Statewide	330	2.67	5.80	4.57	3.84	3.34	2.96	2.66	2.42

[1] The average annual change in volume expressed as a percentage.
[2] The unadjusted annual real rate of return.
[3] The adjusted annual real rate of return uses land value to account for opportunity costs.

used for pulpwood; 3) the saw-log section of sawtimber-size trees is used for sawtimber; and 4) the section between the saw-log top and 4-inch DOB pole top is used for pulp and often referred to as topwood. Poletimber-size trees are softwoods 5.0 to 8.9 inches DBH and hardwoods 5.0 to 10.9 inches DBH. Sawtimber-size trees are all softwoods that are at least 9.0 inched DBH and hardwoods that are at least 11.0 inches. Cull trees are trees that are less than one-third sound.

In 1981, TMS began to report southern pine chip-n-saw prices. Therefore, the two survey periods after this time included a third product, southern pine chip-n-saw. Chip-n-saw trees are southern pines 9.0 to 12.9 inches DBH. All trees less than 9.0 inches are still treated as pulpwood, and trees greater than or equal to 13.0 inches DBH are treated as sawtimber trees. This modification was made for the 1988 and 1995 survey periods.

FIA traditionally computes all board foot volumes in International 1/4-inch log rule. Most of the TMS price data is in Doyle log rule. To accommodate the price data, all FIA tree volumes were recalculated using the Doyle formula. In a few instances, prices are reported in Scribner log rule. To accommodate this, the Doyle prices for these few instances were converted to Scribner prices by multiplying the Doyle price by 0.75 (Timber Mart-South 1996).

The TMS reports include a low, high, and average price for standing timber for various products. This report does not consider peeler logs or poles and piling as possible products because determining these products from FIA data is questionable. Omitting these classes allows for a slightly conservative approach to estimating tree and stand value. FIA data contain information on species, product size (poletimber or sawtimber), and quality (tree class and tree grade). Prices for each section of the tree were assigned based on these factors. These prices were then applied to the different sections of a tree.

Growth Models

Timber volumes and values are summed for each plot. These totals are then used as inputs for the growth models. Three growth models were used in this study. Each is based on the formula used in determining average annual change.

Timber value growth (TVG) is a simple financial maturity model that considers only the actual change in value for a plot for the survey period in question. Incomes derived from future stands are ignored (Hartsell 1999). The basic formula for TVG is:

$$TVG = [(TVF/TVP)^{1/t} - 1] * 100$$

where

TVG = timber value growth percent
TVF = ending sum of tree value on the plot at time 2
TVP = beginning sum of tree value on the plot at time 1
t = number of years between surveys

Forest value growth (FVG) includes the value of land in the computation of economic value change (Hartsell). The formula for FVG is:

$$FVG = [((TVF + LVF) / (TVP + LVP))^{1/t} - 1] * 100$$

where

FVG = forest value growth percent
TVF = ending sum of tree value on the plot at time 2
LVF = ending land value
TVP = beginning sum of tree value on the plot at time 1
LVP = beginning land value
t = number of years between surveys

FVG is an adjusted financial maturity model. Adjusted financial maturity concepts account for all implicit costs associated with holding timber. These are sometimes referred to as opportunity costs. In doing so, revenues from future stands are accounted for. One method of adjusting the model is to include bare land value (LV) in the equation, because bare LV accounts for future incomes and the inclusion of LV adjusts the simple financial maturity model. This study computes multiple FVGs using LVs ranging from \$250 per acre to \$1500 per acre in \$250 increments.

Biological growth percent (BGP) is similar to TVG, except it uses timber volumes instead of timber values. The BGP model accounts for the actual annual change in tree volume for a plot over a survey period. The BGP model is the same as the TVG model, except it uses the sum of tree volumes on the plot instead of the sum of tree values (Hartsell 1999).

RESULTS AND DISCUSSION

Initial investigations analyzed value growth based on various plot strata such as county, ownership, and forest type. Table 1 details the sample size, BGP, TVG, and FVG of Arkansas timberlands by forest type. FVG is computed in \$250 increments ranging from \$250 to \$1,500. This sample set is more likely to represent true trend for the extended period as it contains only plots that met the selection criteria for all three surveys. All financial rates of return are real, meaning that inflation has been removed, and all returns are over and above inflation. Table 1 reveals that loblolly pine (*Pinus taeda* L.) stands outperformed all other stands in terms of biological and economic growth. Average loblolly stand volume increased 4.9 percent per year, while these stands earned nearly 8 percent per year using the simple model. The adjusted rates of return for mature loblolly stands ranged from 4.1 percent to almost 7 percent per year, depending on land value.

While stands comprising primarily shortleaf pine generally failed to outperform loblolly pine, it is not to the degree that many would expect. Additionally, shortleaf pine stands grew at a faster rate (3.2 percent) than the statewide average (2.7 percent). Shortleaf pine stands outperformed the statewide averages in terms of economic rates of return as well.

Shortleaf pine stands earned 6.5 percent per year using the simple financial maturity model, while the statewide average for all stands was 5.8 percent. The same pattern holds true for the adjusted model at all land values.

Landowners may use Table 1 as a guideline for the rates they might expect to earn on their timberlands if they know the value of their land or nearby parcels. They should use an estimate representing the average land value of their tract for the time period. Table 1 illustrates the effect that land value has upon rates of return and management decisions. The interaction of land value and timber value is an interesting dynamic. As land value increases, the rate of return decreases. There may come a point where land value will play a greater role than timber values in determining land use.

Another avenue of investigation involves stratifying value change not on a plot or condition level variable such as ownership or forest type, but on ecoregion. Bailey (1966) classified six different ecoregions for the State (Fig. 1). The Arkansas Valley section proved to have the highest rates of return, both biologically and economically. Stands in this section grew on average 3.3 percent per year and earned almost 7 percent per year using the simple model and 4 percent per year using the adjusted model with a $750 per acre land value (Table 2). The Ozark Highlands section was the second fastest growing region, growing 2.9 percent per year. However, this section's economic performance did not reflect its growth rates. This section was ranked third in terms of TVG and last in FVG for a number of reasons, including species, quality, tree size, and possible products.

Stratifying the data by both forest type and ownership reveals that shortleaf pine is generally the best performing forest type in those ecoregions where loblolly pine is absent. In fact, the Mid Coastal Plains section is the only ecoregion where there is more than one pure loblolly stand in the data set (Table 3). Shortleaf pine stands are the top ranked species in the Arkansas Valley section in both biological and financial growth. And while shortleaf pine stands are only ranked third in both BGP and FVG in the Ouachita Mountains section, the top two types, loblolly-hardwood and oak-gum-cypress, have only two and three plots, respectively, in the data set. The 4.6 percent FVG for shortleaf pine stands in the Arkansas Valley section is the second highest annual rate of return of any forest type that has at least five plots in any ecoregion.

Comparing the rates of return from timberlands to other investment options yields interesting results (Table 4). Using the simple financial maturity model (TVG), shortleaf pine stands outperforms all other investment options except the Dow Jones Industrial Average and the S&P 500 Stock Index. The results differ, however, when using the adjusted model. Arkansas' shortleaf pine timberlands continue to rank higher than certificates of deposits and U.S. Treasury Bills, but fail to match the returns found in stocks and bonds. However, the 3.9 percent real annual rate of return on shortleaf stands for this period occurred on unmanaged stands. It is important to note that forest management has the potential to increase the earnings on these lands.

This study did not consider the effects of taxes. The impacts of taxes paid or tax exemptions for the various investment options were not taken into account. These have the potential to affect the final rates of return. The stands must be completely liquidated to meet the specified rate of return. The landowner maintains possession of the land. Income from selling the land is not included. Bare LV change over time is not considered. The purpose for holding LV constant is to help determine the rate of return from the timber on the

Table 2.—Average annual biological growth percent (BGP)[1], real timber value growth percent (TVG)[2], and real forest value growth percent (FVG)[3] by ecoregion, Arkansas 1988-1995.

Bailey's ecological section	N	BGP	TVG	FVG
Arkansas Valley	41	3.35	6.96	3.95
Boston Mountains	56	2.42	5.62	3.02
Mid Coastal Plains	72	2.82	6.43	3.83
Mississippi Alluvial Basin	68	2.33	4.94	2.98
Ouachita Mountains	65	2.57	5.36	3.26
Ozark Highlands	28	2.89	5.89	2.85

[1] The average annual change in volume expressed as a percentage.

[2] The unadjusted annual real rate of return.

[3] The adjusted annual real rate of return with land value = $750 per acre.

Table 3.—Average annual growth percent (BGP)[1], real timber value growth percent (TVG)[2], and real forest value growth percent (FVG)[3] by forest type and ecoregion, Arkansas 1988-1995.

Forest type	**N**	**BGP**	**TVG**	**FVG**
			percent	
Arkansas Valley Section				
Shortleaf pine	20	4.10	8.18	4.60
Shortleaf pine-oak	7	1.86	4.45	2.75
Oak-hickory	8	3.27	6.63	3.79
Oak-gum-cypress	6	2.65	6.23	3.36
Boston Mountains Section				
Shortleaf pine	2	3.43	7.51	4.32
Shortleaf pine-oak	4	4.14	7.99	4.26
Oak-hickory	50	2.25	5.35	2.87
Mid Coastal Plains Section				
Loblolly pine	9	4.97	8.51	5.50
Shortleaf pine	1	4.21	5.99	4.49
Shortleaf pine-oak	2	1.48	5.66	3.27
Loblolly-hardwood	15	3.36	7.56	4.25
Oak-hickory	17	2.44	5.93	3.45
Oak-gum-cypress	28	2.12	5.54	3.33
Mississippi Alluvial Basin Section				
Loblolly pine	1	4.65	7.35	3.23
Shortleaf pine-oak	1	0.73	4.05	2.66
Loblolly-hardwood	1	2.51	7.96	3.86
Oak-hickory	14	2.54	6.35	3.47
Oak-gum-cypress	51	2.25	4.46	2.84
Ouachita Mountains Section				
Shortleaf pine	30	2.62	5.37	3.48
Shortleaf pine-oak	18	2.14	4.47	2.82
Loblolly-hardwood	2	4.10	8.63	4.77
Oak-hickory	12	2.82	5.91	3.00
Oak-gum-cypress	3	2.56	6.33	3.85
Ozark Highlands Section				
Loblolly pine	1	4.72	9.21	6.60
Shortleaf pine	1	2.10	5.33	3.26
Shortleaf pine-oak	3	3.82	5.83	3.54
Oak-hickory	21	2.66	5.53	2.42
Oak-gum-cypress	2	3.44	8.41	4.26

[1] The average annual change in volume expressed as a percentage.
[2] The unadjusted annual real rate of return.
[3] The adjusted annual real rate of return with land value = $750 per acre.

Table 4.—Average annual real rates of return, expressed as a percentage, for Arkansas timberlands and alternative investment option, 1978-1995.

Investment options	Average annual rate of return
Timber value growth percent (TVG)[1] – all stands	5.80
Forest value growth percent (FVG)[2] – all stands	3.34
Timber value growth percent (TVG)[1] – shortleaf stands	6.50
Forest value growth percent (FVG)[2] – shortleaf stands	3.94
1-month certificate of deposit	2.68
6-month certificate of deposit	2.89
1-month treasury bill	2.10
6-month treasury bill	2.09
AAA corporate bonds	4.40
Dow Jones industrial average	5.61
S&P 500 stock index	5.92

[1] The unadjusted annual real rate of return.

[2] The adjusted annual real rate of return with land value = $750 per acre.

tract. Including changing land values is a study in real estate or land plus timber. Landowners and resource mangers need to know if managing for timber is a wise investment option for their holdings.

Regeneration costs, and other silvicultural practices, are excluded from the analysis as well. Returns from intermediate harvests, thinning, and costs of land improvements are not included. Therefore, foresters and land managers have the potential to improve upon these rates through species selection, intermediate practices, and final products the stands produce.

The results of this study indicate that shortleaf pine stands can be profiTable. In certain areas of the State, the Arkansas Valley section in particular, shortleaf appears to be the species of choice. This observation is particularly true when one considers that the rates discussed were from unmanaged stands and do not include changes in land value. Both of these factors have the potential to greatly improve upon the financial gain and make Arkansas' shortleaf pine stands competitive with other investment options.

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BRANCH AND FOLIAGE BIOMASS RELATIONS FOR SHORTLEAF PINE IN SOUTHEAST OKLAHOMA

Charles O. Sabatia, Thomas B. Lynch, and Rodney E. Will[1]

EXTENDED ABSTRACT

Data from 36 shortleaf pine trees, sampled from thinning study plots in even-aged naturally regenerated shortleaf pine forests in Southeast Oklahoma, were used to fit tree branch and foliage biomass equations. In 1989 sample plots were thinned to 50 percent stocking or 70 percent stocking, with the remainder as unthinned controls; basal areas ranged from about 16 m^2/ha to 44 m^2/ha. Three hundred seventy branches sampled on the basis of one branch per whorl, and the terminal branch, on the 36 trees, were used to fit regression equations to predict branch wood and branch foliage biomass. The best equations are shown in Table 1, with parameters fitted by weighted nonlinear regression using SAS PROC NLIN (SAS Institute). The variables in these equations were selected from the log-transformed form of the model

$$w = b_0 d^{b1} R^{b2}\, S^{b3}$$

using stepwise selection procedure of SAS PROC REG (SAS Institute). In this model, w is the branch or branch foliage dry weight in grams; d is the diameter at the base of the branch in centimeters; R is the relative branch height, in meters, obtained as (H – h) where h is height to the branch and H is the total height of the tree; S is the ratio (H/D) where D is the DBH of the tree in centimeters, and H is the total height of the tree, in meters; b_0, b_1, b_2, and b_3 are parameters. The model is that proposed by Ek (1979) for estimating branch weight and branch foliage weight in biomass studies.

Tree level estimates of branch and foliage biomass, obtained by summing up individual estimates obtained using the equations in Table 1, were regressed on tree dendrometric variables to obtain tree level branch and foliage biomass equations. Using stepwise selection procedure of SAS PROC REG (SAS Institute), to select variables from the log-transformed form of tree biomass models of the form $w = b_0 X_1^{b1} X_2^{b2} \ldots X_n^{bn}$, DBH alone was found to be the best predictor of tree foliage biomass. Stand density was found to have an effect on the b_1 parameter. DBH and crown width were found to be the best predictors for tree branch biomass; stand density appeared not to have an effect on the parameters. DBH and crown width together were also observed to be good predictors of foliage biomass. The tree level biomass equation forms are shown in Table 2.

In the equation forms in Table 2, w is the tree level biomass in kilograms, D the DBH in centimeters, CW the crown width in meters, and X1 a dummy variable—1 if the tree is from an unthinned stand and 0 otherwise. The parameters b_0, b_1, and b_2 are fitted by weighted nonlinear regression using SAS PROC NLIN (SAS Institute).

The model:

$$w = \xi \mathit{dob}^{\beta} C_h^{\tau}[2(1-e^{-\gamma l})-\gamma l(\gamma l+2)e^{-\gamma l}],$$

developed by Zhang et al. (2004) for predicting tree foliage biomass, was found to provide the best fit to the foliage biomass data, with a Fit Index of 0.940. The model was slightly modified by replacing *dob* (diameter at crown base) with D (DBH):

$$w = \xi D^{(\beta+\delta X1)} C_h^{\tau}[2(1-e^{-\gamma l})-\gamma l(\gamma l+2)e^{-\gamma l}]$$

The model was fitted to the pine data by weighted nonlinear regression using SAS PROC NLIN (SAS Institute). In the modified form, w, D, and X1 are as in Table 2 above; C_h is the height of the crown while *l* is the length of the crown, both of them in meters; ξ, β,δ,τ, and γ are parameters; e is the base of the natural logarithm. These models will be used to predict individual tree biomass components on the thinning study plots to obtain per-unit area biomass values.

ACKNOWLEDGMENT

The invaluable assistance of R. Heinemann, R. Holeman, D. Wilson, G. Campbell and K. Anderson of OSU Kiamichi Forest Research Station in the data collection for this project is acknowledged.

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[1] Graduate Research Assistant (COS), Department of Natural Resource Ecology and Management, Oklahoma State University, 008C Agricultural Hall, Stillwater, OK 74078; Professor (TBL), Department of Natural Resource Ecology and Management, Oklahoma State University, 008C Agricultural Hall, Stillwater, OK 74078; and Associate Professor (REW), Department of Natural Resource Ecology and Management, Oklahoma State University, 008C Agricultural Hall, Stillwater, OK 74078. TBL is the corresponding author: to contact call (405) 744-5447 or email at tom.lynch@okstate.edu

Table 1.—Equations for predicting branch and branch foliage biomass in shortleaf pine.

Stand Type	Branch		Foliage	
	Equation form	Fit Index	Equation form	Fit Index
Thinned to 50 percent stocking	$w = b_0 d^{b1}$	0.8876	$w = b_{01} d^{b11} R^{b21}$	0.6354
Thinned to 70 percent stocking	$w = b_0 d^{b1} S^{b3}$	0.9687	$w = b_{02} d^{b12} R^{b22}$	0.6220
Unthinned	$w = b_0 d^{b1}$	0.9670	$w = b_{03} d^{b13} S^{b3}$	0.3746

Table 2.—Equations for predicting tree level branch and foliage biomass in shortleaf pine.

Tree part	Equation	Fit Index
Branch	$w = e^{b01} D^{b11} CW^{b21}$	0.956
Foliage	$w = e^{b02} D^{b12} CW^{b22}$	0.894
Foliage	$w = e^{b03} D^{(b13+b22X1)}$	0.919

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AN INDIVIDUAL-TREE DBH-TOTAL HEIGHT MODEL WITH RANDOM PLOT EFFECTS FOR SHORTLEAF PINE

Chakra B. Budhathoki, Thomas B. Lynch, and James M. Guldin[1]

EXTENDED ABSTRACT

Individual tree measurements were available from over 200 permanent plots established during 1985-1987 and later remeasured in naturally regenerated stands of shortleaf pine (*Pinus echinata* Mill.) in western Arkansas and eastern Oklahoma. The objective of this study was to model shortleaf pine growth in natural stands for the region. As a major component of the shortleaf modeling effort, an individual-tree diameter at breast height (DBH)-total height model was developed in which random parameters were estimated for plots. The model predicts total tree height based on DBH and dominant stand height (which could be obtained from a site index model). The mixed-effects model approach was found to predict the total height better than similar models developed previously for this species. Moreover, such a model has the appeal of generalization of the results over a region from which the plots were sampled; and also of calibration of parameters for stands with minimal measurements.

The following DBH-total height model was developed by Lynch and Murphy (1995) and provides a starting point for development of a random effects model:

$$(H_i - 4.5) = b_0(H_D - 4.5)^{b_1} \exp(-b_2 D_i^{-b_3}) \qquad (1)$$

where H_i is the total height of tree i in feet; H_D is the dominant height of the stand in feet; D_i is the DBH of tree i in inches; and b_0, b_1, and b_3 are parameter estimates which Lynch and Murphy (1995) obtained using generalized least squares. For predictive applications, H_D can be obtained using site index relationships for shortleaf pine developed by Graney and Burkhart (1973). This equation is used to obtain individual tree total heights in the Shortleaf Pine Stand Simulator, an individual-tree growth simulator for even-aged shortleaf pine stands (Lynch et al. 1999).

The parameters in equation 1 were estimated using the first two measurements on shortleaf pine trees in the shortleaf pine growth study discussed above. The availability of a third measurement of the permanently established plots in this study provided the opportunity to apply mixed-model or random parameter methods of estimation to develop an improved DBH-total height model. A random parameter model is able to represent the situation in which the parameters in Equation 1 may change in different forest stands. When a stand is selected at random from the total population of stands, the parameters representing this change can be termed random parameters. Lappi (1997) provided an early application of mixed-model estimation with random parameters for tree height models. Budhathoki's (2006) analysis of these shortleaf pine data indicated that there was a significant random component associated with the b_2 parameter estimate in equation 1. This finding leads to the following equation:

$$(H_i - 4.5) = b_0(H_D - 4.5)^{b_1} \exp(-(a_{2j} + b_2) D_i^{-b_3}) \qquad (2)$$

where a_{2j} is a plot-level random effect associated with plot j and fixed-effects parameter estimates are b_0, b_1, and b_2. Conceptually, fixed-effects parameters remain the same for all forest stands while random-effects parameters vary by stand; in our data, stands are represented by plots. Mixed-effects estimation techniques can be used to estimate fixed and random effects simultaneously. SAS PROC NLMIXED (SAS 2000-2006) was used to estimate parameters in equation 2 for our data. Statistics of fit including the Akaike Information Criterion (AIC), the Bayesian Information Criterion (BIC), and the log-likelihood indicated that inclusion of a random parameter associated with b_2 improves the fit of the model to our DBH-total height data for shortleaf pine natural stands. Additionally, a variety of residual plots from the model indicated that the model performs well for these data since no pronounced biases or trends were evident.

Mixed-effects modeling improved the performance of a DBH-total height model for naturally-occurring shortleaf pine forests by including a random parameter that reflects changes in the equation for different forest stands (represented by plots). This approach also provides the opportunity to calibrate the model for a particular stand by collecting a small amount of data used to estimate the random parameter associated with that forest stand. Lappi (1991) indicated how random parameter models can be used to calibrate height and volume equations. Recently Lynch et al. (2005) fitted a random parameter DBH-height model for cherrybark oak (*Quercus pagoda* Raf.) and demonstrated the procedure used to calibrate the model for particular forest stands of interest.

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[1] Formerly Graduate Research Assistant, Dept. NREM Oklahoma State University (CBB), now Division of Cardiology/School of Medicine, University of Colorado at Denver and Health Sciences Center, 4200 East 9th Ave, B-139, Denver, CO 80262, Professor (TBL), Department of Natural Resources Ecology and Management, Oklahoma State University, Ag Hall Room 008C, Stillwater, OK 74078, Supervisory Ecologist and Project Leader (JMG), Southern Research Station, USDA Forest Service, P.O. Box 1270, Hot Springs, AR 71902. TBL is corresponding author: to contact call (405) 744-5447 or email at tom.lynch@okstate.edu

ACKNOWLEDGMENTS

The cooperation of personnel on the U.S. Forest Service's Ozark and Ouachita National Forests greatly facilitated collection of data used for this project. The support and assistance of the USDA Forest Service Southern Research Station are also appreciated.

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SHORTLEAF PINE NATURAL COMMUNITY RESTORATION ON PECK RANCH CONSERVATION AREA IN THE MISSOURI OZARKS

John G. Tuttle and Kim J. Houf[1]

ABSTRACT.—Oak decline has become a significantly increasing problem on Peck Ranch Conservation Area over the last several years. Most of the oak decline problems exist on past shortleaf pine sites. To address this issue, the area managers wrote a natural community restoration plan for 2,233 acres located on the Current-Eleven Point Oak-Pine Woodland Dissected Plain land type association. The goal of this plan is to restore the shortleaf pine-oak/vaccinium natural community on appropriate sites. Timber harvesting activities occurred between 1999 and 2003 on most of the restoration area. The silvicutural prescriptions used were a combination of pine seed tree and irregular shelterwood seed cuts. Three different treatments are being used to achieve the desired results. These treatments will be replicated on three different areas. A combination of artificial and natural tree regeneration along with mechanical thinning, herbicide release, and prescribed fire is being used to achieve the desired natural community. One additional area is a control that received the same type of harvests but will not be planted or receive any post harvest pine seedling releases. Most of the artificial tree regeneration occurred on the pine sites between 2004 and 2006. The entire project area is being monitored by the Resource Science Division to see which technique works best for restoring the appropriate natural community.

INTRODUCTION

This article explores the forest management activities taking place on Peck Ranch Conservation Area (CA). Through careful planning, Natural Community management is starting to enhance the forest community that was once dominant on the area. The shortleaf pine-oak/vaccinium dry ultic woodland natural community encompasses approximately 4,000 acres on the southern portion of Peck Ranch. The main objective for the area managers is to create the desired natural community and to determine the most efficient way of carrying out the management by taking into account time, money, and all the resources on site. The desired future condition 40 years from present is a sparsely stocked stand of mostly shortleaf pine (60 percent or greater), with scattered white and post oak trees and a diverse component of herbaceous/forbs in the understory. This project is being monitored for overstory, ground vegetation, and wildlife responses.

The current Peck Ranch CA forest is a result of actions that began around 1900, when most of the virgin pine forest was cut to provide lumber for a growing nation. This activity left few shortleaf pine trees on the southern portion of the Ranch, where the land is mostly flat with rolling hills.

Around 1917, the Mid-Continent Iron Company began operation near Fremont, MO. The small town that sprang up was called Midco. To fuel the smelting furnaces each day, 180 cords of wood were required to produce 100 tons of pig iron. Most of the southern half of Peck Ranch was clearcut to provide wood for the iron company.

The Griffith Stave Company bought the remaining timber rights sometime after the end of Prohibition from George Peck, the previous owner. Most of the white oak trees that were big enough to make whiskey barrels were cut at this time.

In this era wildfires were frequent; many were to enhance grass for livestock grazing on open range. This burning often occurred during the driest time of the year, when trees were most susceptible to damage from fire. This burning caused oaks to re-sprout many times and the small pine seedlings simply did not have the resources to keep sprouting. These types of activities led to the present scarlet oak, black oak, and hickory forest located on past shortleaf pine growing sites.

The current condition of the forest is such that many acres of scarlet and black oak trees are declining in health, exhibiting symptoms caused mostly by age. Most of the problems occur in the southern portion of Peck Ranch primarily because of soil conditions. Where the former shortleaf pine forest existed, fragipan soils are typically found, leading to very dry conditions during droughts and

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[1] Forestry Field Program Supervisor (JGT), Missouri Department of Conservation, P.O. Box 180, Jefferson City, MO 65102; and Wildlife Biologist (KJH), Missouri Department of Conservation, RR1, P.O. Box 1395, Winona, MO 65588. JGT is corresponding author: to contact call (573) 522-4115 Ext. 3304 or email at john.tuttle@mdc.mo.gov

very wet conditions during periods of heavy rain. The recent drought years and soil conditions have proved to be very hard on the aging scarlet and black oak trees.

In 1999, the Peck Ranch Planning Team wrote an area plan that included Natural Community management. The Ecological Classification System was used to identify land type associations (LTA), ecological land types (ELTs), and each natural community represented on the area. In the plan, the team described natural community management groups, objectives, and strategies to achieve the structure and composition of the natural communities located on the area. In addition to the area plan, managers also wrote a restoration plan for 2,223 acres focused on restoring the shortleaf pine-oak/vaccinium natural community on appropriate sites.

The restoration plan focused on three management approaches. The first management emphasis identified was artificial/natural shortleaf pine regeneration accompanied by mechanical release on three management units. Mexel (1991) stated that mechanical control is not feasible from an economic standpoint. However, mechanical release is to be monitored to determine whether shortleaf pine seedlings can be released without damaging the herbaceous/forb component of the area.

The second management emphasis identified was artificial/natural shortleaf pine regeneration accompanied by prescribed fire on three management units. This combination of treatments will demonstrate whether prescribed fire can be used in conjunction with regenerating shortleaf pine trees while enhancing herbaceous diversity. In this treatment, two of the units will have fire withheld until the pine trees reach approximately 6 feet tall. Waiting for the trees to reach this height will prevent the terminal bud from being killed, which typically causes the trees to die. Shortleaf pine is unique in its ability to sprout prolifically when the crown is killed or badly damaged (Lawson 1990). The one remaining unit will be burned as needed to retard the oak sprouts and to enhance the herbaceous/forb component of the area.

Artificial/natural shortleaf pine regeneration accompanied with herbicide release was the third management emphasis involving three management units. The objective is to see whether herbicide can be used without damaging the herbaceous/forb component and the residual oak trees that were left scattered throughout the stands. Miller et al. (1999) found that after herbicide was used in site preparation in Georgia, the herbicide had little influence on total (herbaceous) species numbers or diversity 11 years after treatments. We hope to have the same results in species diversity and richness on our study site.

STUDY AREA

Peck Ranch Conservation Area is located in the northwest corner of Carter County, Missouri. The largest portion of Peck Ranch CA was purchased in 1945 by the Missouri Department of Conservation from George Peck. The area encompasses 23,048 acres and is about 95 percent forested.

This Conservation Area has four LTAs. The Current River Oak-Pine Woodland/Forest Hills is the largest LTA, comprising 47 percent of the area. The second largest is the Eminence Igneous Glade/Oak Forest Knobs (20 percent). Another 17 percent of the area is in the Current-Eleven Point Oak-Pine Woodland Dissected Plains, where the pine-oak/vaccinium community restoration work is taking place. The smallest LTA is the Current River Oak Forest Breaks, which makes up 14 percent of the area.

The study area is located on the southern portion of the Ranch. In 2004, area managers wrote a restoration plan for a portion of this area. This plan addressed different management ideas and concerns such as the lack of shortleaf pine on historical pine sites, the lack of good quality wildlife habitat, and the need to restore degraded natural communities. The Midco Pine Flats Restoration Area encompasses 2,223 acres of mostly high quality pine-oak/vaccinium restoration sites.

METHODS

The project is being conducted on Peck Ranch Management Compartments 10, 13, and 17. These three compartments have been further divided into 10 management units for planning and implementing monitoring activities. All 10 management units have had a salvage timber harvest carried out on them, leaving shortleaf pine for seed trees and about 20 feet2 of basal area per acre of white and post oak trees, when possible. The logging occurred between 1999 and 2003. Following logging, all stands were slashed to kill remaining suppressed oak and hickory trees. Since 2005, 568 acres (171,537 seedlings) have been planted to shortleaf pine on the study area. The next step is to control hardwood and herbaceous competition on the seedlings. Hardwood competition that is effectively managed can result in 40 percent volume increases on pine crop trees (Lowery 1986). Cain (1991) stated that even when an area has adequate numbers of pine seedlings, a rank ground cover of herbaceous species can reduce pine growth and may dictate the application of release treatments. The other nine management units were logged and artificial regeneration was used to supplement natural shortleaf pine regeneration. These latter nine units were subdivided into groups of three; one group received an additional treatment with prescribed fire, one group received herbicide release, and one group received mechanical release. One management unit was logged and follow-up slashing was conducted; the only shortleaf pine regeneration in this unit is that which occurs naturally. Missouri Ozark Forest Ecosystem Project site number 8 is adjacent to the study area and is being used as a control; this area had previously been set aside as an unmanaged site.

In the herbicide release area a spot treatment method using Arsenal® AC and Escort® XP was used on 181 acres to release the shortleaf pine and preserve the herbaceous component. The application rate was 4 oz/100 gallons water for Escort® XP, and 1 oz /100 gallons of water for Arsenal® AC. All vegetation within a 6 foot radius of a shortleaf pine equal to or less than 4 inches diameter at breast height (DBH), was chemically treated. No chemical application was directly applied to any shortleaf pine trees or within the drip line of any residual tree equal to or greater than 10 inches DBH.

MONITORING AND EVALUATION

Vegetation

All 10 management units will be monitored to learn which technique works best and is the most cost effective. Our goal is to produce a pine stand with a diverse understory that will enhance wildlife habitats.

During the year following shortleaf pine seedling planting, a seedling survival inventory was implemented to determine how many planted seedlings survived after the initial planting. This inventory was conducted by establishing fixed 100th-acre plots throughout the area and counting the number of seedlings that survived within each plot.

To evaluate vegetative response, a fixed plot design is used for long-term data collection. In each of the 10 management units, three random points were placed within areas that were designated for restoration work. These points were used to establish 0.2-acre circular plots. Within each plot, all overstory trees are tagged and species and DBH are recorded.

Tenth-acre subplots consisting of the northeast and southwest plot quadrants are used for sampling pine seedlings and all saplings. For all non-pine species, we record species, height, and DBH. All pine saplings are tagged and the height and DBH are measured. For pine seedlings (< 4.5 ft height) we record height and basal diameter. Up to 60 seedlings are also tagged to track survival. Of the tagged seedlings, a sub-sample is selected to collect data on competition.

To track competition, a circular subplot of 3.5-foot radius is centered on a pine seedling. We then identify each woody plant to species and record the height. For dense shrub or vine species (*Rubus*, *Vaccinium*, *Vitis*, etc.) a stem count is recorded.

Twelve 1-m^2 quadrats are placed within the plot (three in each cardinal direction) to sample ground flora and ground cover. For ground cover, percent classes are used to measure the percent cover of bare ground, dead wood, litter, lichen, rock, and vegetation. Ground flora are identified to species and recorded in percent classes. For seedlings of any woody species, a stem count is also recorded.

Pretreatment data collection is under way and post-treatment data collection is scheduled to occur at 3-year intervals. In addition, we will continue to collect the same overstory, sapling, and ground flora data on 20 plots previously placed randomly according to the initial harvest areas.

Wildlife

The Peck Ranch Pine Management Zone Breeding Bird Survey (BBS) was patterned after the national BBS, but was modified to meet management objectives. The roadside survey has been conducted annually since 2000. The Pine Management BBS is conducted two to three times a year during the peak of nesting season, primarily in May and June. The route is 12 miles and encompasses all 10 management units. Twenty-five stops are located at 0.35- to 0.5-mile intervals along the route. Starting half an hour before sunrise, a five minute point count is conducted at each stop, during which the observer records all birds heard or seen. The objective of the Pine Management BBS is to monitor the composition and relative abundance of the songbird community within the management zone.

A northern bobwhite quail (*Colinus virginianus*) survey is also conducted within the management units. The roadside quail survey has been conducted since 2005 and is performed two to three times a year from June 15 to July 15. The quail survey consists of three routes, each of which is 7 miles long. Route 1 is located along the North Boundary Road and has 15 stopping points. Route 2 is located along Road 1 and has 14 stopping points. Route 3 is located along the South Boundary Road and has 13 stopping points. All stopping points are located at 0.35- to 0.5-mile intervals along each route. Starting half an hour before sunrise, a 5-minute point count is conducted at each stop, during which the observer records all quail heard or seen. The objective of the quail survey is to assess the relative abundance and spatial distribution of bobwhite quail.

RESULTS

Vegetation

During the summer of 2005, a pine survival survey was done on all areas that were planted on units 7-9. The pine seedlings that were planted on 12 x 12 foot spacing at a rate of 302 trees per acre averaged 40 percent survival overall (mean = 40, standard error ± 4.9). The lowest survival was on stand 27 on unit 8, which was only 23 percent. The highest survival was on stand 14 on unit 7, which was 60 percent survival. The expected survival rate before planting was 50 percent.

We are just now finishing data collection and data entry for the first season pre-treatment data on the treatment areas. So far it is too early to make any comparisons to show which treatment is working best.

Wildlife

The efforts to restore a unique natural community type have affected a suite of bird species. Over the past 6 years, the mean number of species detected on the route has increased from 30 birds to more than 40 birds, perhaps due to the influx of early-successional habitat species. Several early successional habitat species, such as the indigo bunting (*Passerina cyanea*), yellow-breasted chat (*Icteria virens*) and prairie warbler (*Dendroica discolor*), have shown evident increases (Fig. 1). The mean number of individuals per stop for the indigo bunting has increased from 1.24 in 2000 to 1.44 in 2006, while the yellow-breasted chat increased from 0.22 to 1.24 and the prairie warbler increased from 0.16 to 0.22. Mature-forest species, such as the eastern wood pewee (*Contopus virens*), which lives on ridge tops and has a moderate density, seem to have shown little population change, whereas the red-eyed vireo (*Vireo olivaceus*) has decreased in the mean number of individuals per stop from 1.38 to 0.92, perhaps due to the reduction in deciduous forest canopy. Target pine savanna species, such as the pine warbler (*Dendroica pinus*) and chipping sparrow (*Spizella passerine*), have also responded well to the management practices. The increase in the mean number of individuals per stop for each species from 2000 to 2006 is: pine warbler 0.78 to 1.08 and chipping sparrow 0.0 to 0.06. Other target species such as the yellow-throated warbler (*Dendroica dominica*) have kept a steady level with no significant increase or decrease.

We have only 2 years of data collection from the quail census. Although no quail have been recorded, it is too early to make any conclusions on abundance, spatial distribution, or to compare treatments.

DISCUSSION

The purpose of the study is to evaluate methods for restoring the shortleaf pine/oak/vaccinium natural community. In addition managers want to restore the forest communities that once existed on the site in order to enhance wildlife benefits and forest health. If oak is allowed to grow on historical pine sites, a manager can expect to have oak decline problems as the trees become older, particularly following droughts, and attacks by insects and pathogens.

Herbicide in combination with planting and natural tree regeneration is probably the best and most efficient way of regenerating trees. Success depends on the size of the area treated and type of application.

Prescribed fire accompanied with planting and natural tree regeneration is a technique that appears to work well for shortleaf pine as long as the trees reach a sufficient height before burning. Burning, however, may encourage a single-species stand of trees, which could create problems with insect infestation or disease outbreaks. Fire can enhance forbs and herbaceous vegetation, which in turn can lead to severe competition to the shortleaf pine seedlings.

Mechanical control in combination with planting and natural tree regeneration appears to be labor intensive. We located each tree and released a circle around it by cutting all the oak sprouts. Without herbicide, the oaks immediately sprouted back and within one growing season were again competing with the pine seedling. Managers have observed that in stands with many suppressed oak trees, delaying the slashing or cutting of these trees allows the pine seedlings time to get established. When pine seedlings were already established in the understory and the suppressed hardwood trees were cut, pine trees competed much better. In stands where very few pine seedlings were present and where the suppressed oak trees were immediately cut after logging, pine trees appeared to respond more slowly.

In the 10th unit the main factor affecting pine establishment is how much advance pine regeneration was present on the forest floor before logging took place. We have observed that where advance regeneration was located, pine trees are doing well. We have also observed that the herbaceous component is starting to diminish as the canopies start to close.

Many stands received a salvage harvest in which all shortleaf pine and 20 basal area of white and post oak trees were retained. We have observed an increase in many early successional species as a result of the sunlight reaching the forest floor. Quail, turkey, and many migratory birds use early successional grasses as nesting habitat, while forbs and legumes offer abundant food throughout the year. The variety of mature oaks provides mast crops to serve as high energy food for wild turkey, white-tailed deer, and squirrels. As some of these stands begin to have a more closed overstory, we are beginning to see a different suite of species favored, such as sedges, grasses, low shrubs, and wildflowers.

It is too early in the process to know which combinations of management techniques are going to work the best. Resource Science Division has only completed the initial layout of the plots and collected the baseline data. A literature review of published research suggests that, depending on the goal, each technique has its benefits and disadvantages. The role of the research is to determine the best technique to achieve our goal of restoring and managing the shortleaf pine-oak/vaccinium dry ultic woodland natural community.

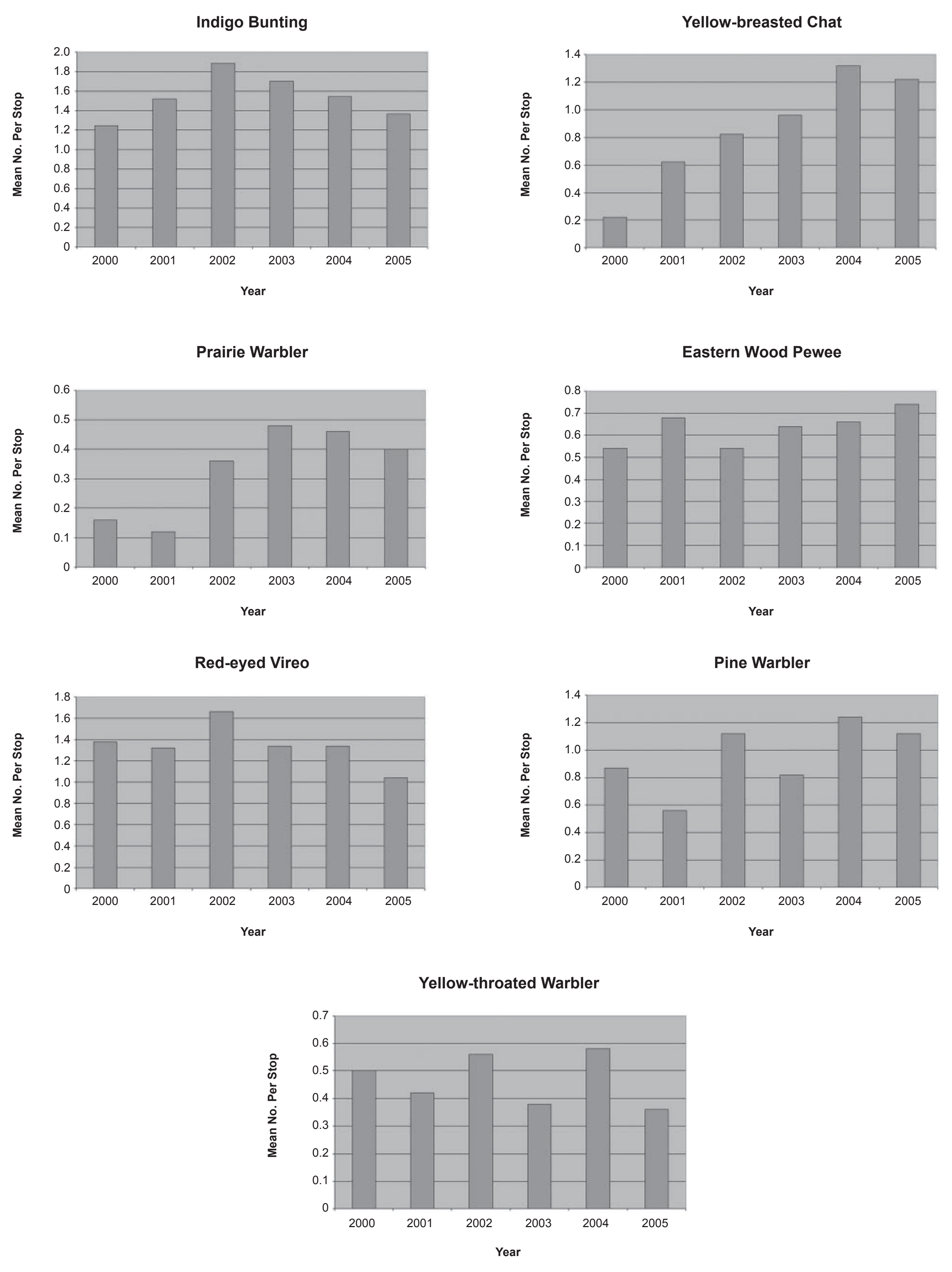

Figure 1.—Mean number of birds per stop from annual breeding bird surveys conducted in the restoration area.

ACKNOWLEDGMENTS

We thank Carrie Steen from Missouri Department of Conservation's Resource Science Division for writing the paragraphs describing data collection methods and design. We thank Rick Clawson from Missouri Department of Conservation's Resource Science Division for sharing his information on the Breeding Bird Survey.

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GLADE/WOODLAND RESTORATION IN THE ST. FRANCIS MOUNTAIN BIRD CONSERVATION AREA

David A. Hasenbeck[1]

EXTENDED ABSTRACT

The Missouri Department of Conservation (MDC), the Missouri Department of Natural Resources, the U.S. Forest Service, and American Bird Conservancy, share goals to restore and manage high quality glade, savanna, and woodland habitats within the Saint Francis Bird Conservation Area. The partnership endeavors to maintain and enhance an ecosystem with native glade and pine woodland components across a large landscape in which private and public land management work together to contribute to the overall habitat goals.

The primary purpose of this project is to increase habitat available to grass-shrub bird species. Species targeted have declined significantly since the inception (1966) of the annual North American Breeding Bird Survey. A secondary goal of the project is to develop contractors capable of delivering prescribed fire management in the Ozark Mountains of southeastern Missouri by utilizing grant dollars. The project also will increase landowner awareness and foster cooperation through outreach and technical assistance with the public and through interagency partner planning and coordination.

The St. Francis Mountains Bird Conservation Area (SFBCA), established in 2003, lies in the eastern Ozarks of southeastern Missouri and located within an ecological subsection known as the St. Francois Knobs and Basins (Fig. 1). It comprises portions of St. Francois, Madison, and Iron Counties and minor portions of Washington, Reynolds, Wayne, Bollinger. and Ste. Genevieve counties. The SFBCA supports a diverse array of habitat types, including igneous glades, oak savannas, and oak and oak-pine woodlands.

This project seeks to secure and expand declining bird species within the St. Francois mountain region through the restoration of glade, woodland, and grass habitats on public and private lands. Partner agency staff and resources, coupled with grant dollars, were used to implement the management plan.

Key private land parcels were identified and prioritized. Highest priority was placed on cooperative public-private land restoration. The second priority was private land restoration adjacent to or nearby publicly-owned glade complexes. Private lands were selected by MDC cooperators or by partner agency referrals and by landowner interest. Three contracts of 800 to 1200 acres with an average of 10 units per package were developed and implemented with grant dollars with mixed success.

In an attempt to ensure long-term success of the restoration units, federal costshare will be utilized to implement follow-up burns.

Facilitation of public burn units was accomplished through contracted snag felling and line construction to best complement limited labor.

Partners met formally on an annual basis to better coordinate restoration work. Several cooperative projects have been identified.

During the granting period, more than 5000 acres of habitat were treated using prescribed fire within the SFBCA (>2200 acres on private land). Approximately 350 acres (>110 acres on private land) of eastern red cedar were removed from habitats within the SFBCA. Twelve miles of fireline was contracted. Eight workshops were conducted by MDC and other project partners within the SFBCA. Increased opportunity for cooperation was created via interagency planning.

Figure 1.—Project Area

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[1] Private Land Conservationist (DAH), Missouri Department of Conservation, RT 4 Box 1002, Piedmont, MO 63957. To contact call (573) 223-4525 or email at David.Hasenbeck@mdc.mo.gov

We have achieved success in habitat improvements, but maybe equally important is the continued development of fire contractors and administrative mechanisms to have contractors conduct prescribed burns on large private parcels. It will be necessary to coordinate several burn units each spring (1000 acres or more) to ensure adequate acreage to continue to attract contractors capable of conducting large woodland burns. Coordination of multiple-ownership restoration involves communication between private landowners, natural resource agencies, and contactors. This is especially evident in situations where large tracts of public land encompass small private parcels. At times, private inheld parcels preclude conducting landscape-level burn units. It is necessary to target these key inholdings and actively assist with facilitation of the burn between landowner, agency, and contractor to ensure successful restoration efforts. We found that contracting woodland fire units cost at least $1000 to $1200 per day. For this reason, we selected units over 30 acres in size. More contractors are needed. Timber stand improvement allows fire contractors crews to stay busy while in the area and minimize down time when weather is not conducive to burning or line construction. Private land-burn costs averaged $45/acre for a burn plan, line installed, and a burn conducted. Costs averaged $30/acre for woodland burns when the lines were installed and a plan provided to the contractor. Follow-up burns are ongoing and typically occur 2 to 3 years after the initial prescribed fire and periodically thereafter.

ACKNOWLEGMENTS

I would like to thank the National Fish and Wildlife Foundation, Missouri Bird Conservation Initiative, and Missouri Conservation Heritage Fund for funding much of this management.

THE PINEKNOT PROJECT: RESTORATION OF A MISSOURI OZARK PINERY

Douglas Ladd, Blane Heumann, and Paul Nelson[1]

EXTENDED ABSTRACT

Pine dominated more than 4 million acres of the Missouri Ozarks prior to European settlement. These pineries supported a diverse array of plants and animals, including several taxa no longer present in the state (e.g., *Desmodium ochroleucum*, *Picoides borealis*, *Sitta pusilla*). Intensive logging activity and subsequent land management practices at the close of the 19th century resulted in a complete loss of functional pinery systems, although shortleaf pines continue to be a common component of mixed woodlands in the region.

Prior to European settlement, these pineries consisted of relatively uniform pine or pine-oak dominated canopies over large expanses of well-drained rolling to dissected uplands, with minimal subcanopy and shrub development. As is the case with structurally similar hardwood systems in the Ozarks, and many pine woodlands elsewhere in the New World, we postulate that most of the vegetational diversity in these systems existed in the ground layer. This ground layer consisted of a diverse assemblage characterized by perennial herbaceous forbs and a smaller number of graminoid species that were disproportionately prevalent and shaped the fuel characteristics of the system. These pineries require frequent, low-intensity, prevailingly dormant-season fire events to maintain the open structure and facilitate canopy replacement dynamics.

In 1998, the U.S. Forest Service and The Nature Conservancy initiated a partnership to restore a functional pinery system within a landscape producing both ecological and economic outputs, and capable of eventually sustaining viable populations of the full array of indigenous pineland biodiversity. Initial phases of the work have consisted of: (1) identification of historically appropriate sites of suitable scale and continuity; (2) rapid ecological assessment of candidate sites and the resulting area delineation of the Pineknot Pine Restoration Project; (3) presettlement vegetation analysis and detailed baseline assessment of current vegetation; (4) derivation of an ecological model for Ozark pinery vegetation; (5) development and implementation of silvicultural and fire management treatments; and (6) initial post-treatment vegetation assessment and data analysis.

The Pineknot site consists of 12,419 acres in southwestern Carter County, on a rolling upland plain with moderate topographic relief. Soils are derived from clay and chert residuum, and are xeric, acidic, and nutrient limited. Vegetation monitoring was established using 100 permanent points randomized within area-proportional representation for each of the four landform classes at the site. These selections were stratified to ensure area-proportional representation of even-aged stands <15 years old, and buffered to exclude roads, ponds, and other anthropogenic attributes. Canopy vegetation was sampled for the first 50 points using 0.1-acre square macroplots. Each of the 100 points was sampled for ground cover vegetation using fifty 0.25-m^2 square quadrats randomized within intervals along radial line transects.

Presettlement vegetation analysis indicates a heavily pine-dominated woodland in the region, with an open canopy of moderately large trees. At the Pineknot site, most of the landscape in 1821 had a canopy cover of 40-80 percent, with a mean stocking rate of 45 trees per acre and an average distance of 27 feet from a survey point to a witness tree. Shortleaf pine comprised 76 percent of the witness trees, with a mean DBH of 17 inches. Virtually all the other witness trees in the site were various upland oak species, with slightly smaller mean DBH.

This situation contrasts dramatically with the pretreatment condition of abundant, smaller, more closely spaced trees, increased canopy cover, and a dominant hardwood component. In contrast to 1821, when the site composition was entirely pine types, less than half the site is currently classified as pine, with the remainder consisting of oak-dominated hardwoods. Although current canopy patterns suggest a relationship between topographic position and hardwood composition and abundance, none of these stand trends, such as greater hardwood component on northeast-facing or bottom stands, was evident in 1821. As contrasted with the open woodland structure in 1821, pre-treatment site vegetation consisted of more abundant, closed canopy with more trees and a much higher proportion of hardwoods.

Floristic models indicate that Missouri Ozark pineries were composed of a diverse but relatively consistent assemblage of about 300 predominantly perennial upland herbaceous vascular taxa, including several conservative species with high local fidelities to pineland systems. Mean per-unit area ground cover diversity in intact Ozark pineries probably exceeded 10 (perhaps approaching 15) native taxa per 0.25 m^2; pretreatment baseline data reveal 2.2 taxa per 0.25 m^2.

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[1] Director of Conservation Science (DL), The Nature Conservancy, St. Louis, MO, 63144; Director of Stewardship (BH), The Nature Conservancy, Van Buren, MO, 63965; and Ecologist (PN) Mark Twain National Forest, U.S. Forest Service, Rolla, MO 65401. DL is corresponding author: to contact call (314) 968-1105 or email dladd@tnc.org

Most of the conservative floristic cohort of these pineries (C values ≥6) are associated with relatively high light intensities and are currently absent or sparse over the Pineknot site. Analysis of vegetation monitoring data reveals that initial, largely fire-based site treatments have increased native ground cover diversity (2.2 to 3.1), floristic quality (6.0 to 7.4), and abundance (11,245 to 15,503).

These increases have been attenuated by remaining high hardwood cover and consequent shading levels through most of the site. A compelling need is indicated for increased intensity of silvicultural treatments and hardwood sprout reduction to advance restoration goals from current condition towards a compositional and structural state more evocative of the vegetation model. Restoration of a diverse, sustainable pinery community will require: (1) adoption of intensive treatments to secure canopy cover and composition within the range of natural variation resembling General Land Office data; (2) restoration of a fire regime encompassing both the mean and extremes within the prevailing presettlement fire dynamics; and (3) recruitment or reintroduction of an abundant, diverse ground layer dominated by herbaceous perennials, including a prominent graminoid component and a high diversity and presence of a suite of conservative taxa.

Pinelands once occupied a substantial portion of the Missouri Ozarks. From the perspective of both global and local conservation value and irreplaceability, it is imperative that we actively restore functional examples of this legacy of our natural heritage, while sustaining the full array of biota characteristic of these systems.

SHORTLEAF PINE-BLUESTEM RESTORATION IN THE OUACHITA NATIONAL FOREST

Larry D. Hedrick, George A. Bukenhofer, Warren G. Montague, William F. Pell, and James M. Guldin[1]

ABSTRACT.—The fire-dependent shortleaf pine-bluestem ecological community, once common in the Ouachita Mountains, had all but disappeared by 1970. This absence was due to the cutting of the original forests in the early part of the 20th century followed by effective fire suppression since the late 1930s. With the adoption of Forest Plan amendments in 1994, 1996, and 2002, and a Forest Plan revision in 2005, the Ouachita National Forest committed to restore the shortleaf pine-bluestem ecosystem on some 250,000 acres. Restoration treatments include thinning pine stands to a residual basal area of about 60 ft^2 per acre, felling most of the woody midstory stems, and prescribed burning at 3- to 4-year intervals. Achieving conditions similar to those depicted in historic photographs normally requires a thinning, a midstory reduction treatment, and three prescribed fires over about 10 years. Since 1994 some 52,992 acres have been thinned, 42,948 acres have received midstory reduction, and 143,233 acres have received one or more prescribed burns. Managers estimate that 18,653 acres are presently in a substantially restored condition. During this time the endangered red-cockaded woodpecker (*Picoides borealis* Vieillot) population has more than doubled, and populations of several other previously declining species of conservation concern have increased markedly.

PRE-EUROPEAN SETTLEMENT AND CURRENT ECOLOGICAL CONDITIONS

The Ouachita Mountains of west-central Arkansas and southeastern Oklahoma encompass 6.6 million acres, and together with the Boston Mountains and Ozark Plateaus to the north and east, form the Interior Highlands physiographic region (USDA Forest Service 1999). The Ouachitas are an eroded mountain system that originated in the late Paleozoic period some 280 million years ago through tectonic activity that folded and faulted the ocean sediments of the area from south to north, resulting in an unusual east-west orientation with broad long aspects facing south and north. Elevations range from 500 to 2,700 feet.

Travelers, settlers and scientists in this region during the 1800s and early 1900s described open pine (*Pinus echinata* Mill.) and hardwood forests with floristically rich understory vegetation of grasses and forbs (Nuttall 1999, Jansma and Jansma 1991, Palmer 1924, Little and Olmstead 1931, Cogburn 1976, McBride 1978) (Fig. 1). Elk (*Cervus elaphus* L.) and bison (*Bison bison* L.) once found suitable habitat in these open woodland communities (Smith and Neal 1991), and are enshrined in local names such as Buffalo Creek. Fires were common (Nuttall 1999, Featherstonhaugh 1844, Little and Olmstead 1931) and maintained the open condition (Foti and Glenn 1991). In a typical Ouachita Mountain area in Oklahoma, fires occurred at an average return interval of less than 10 years for most sites (Masters and others 1995). Tree densities then averaged 170 trees per acre and the average diameter was 11.4 inches (Kreiter 1995).

While the Ouachita Mountain landscapes of today are still dominated by forests, the composition and structure of these forests are much different. Many hundreds of thousands of acres of shortleaf pine-hardwood forests have been

Figure 1.—Historic conditions in the Ouachita National Forest circa 1920 (US Forest Service file photo).

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[1] Team Leader, Integrated Resource Management (LDH), Ouachita National Forest, P.O. Box 1270, Hot Springs, AR 71902; Endangered Species Coordinator (GAB), Southern Region, USDA Forest Service, 1720 Peachtree Rd. NW, Atlanta, GA 30309; District Wildlife Biologist (WGM), Ouachita National Forest, P.O. Box 2255, Waldron, AR 72958; Team Leader, Planning and Recreation (WFP), Ouachita National Forest, P.O. Box 1270, Hot Springs, AR 71902; and Supervisory Ecologist and Project Leader (JMG), Southern Research Station, USDA Forest Service, P.O. Box 1270, Hot Springs, AR 71902. LDH is corresponding author: to contact call (501) 321-5270 or email at lhedrick@fs.fed.us

converted to loblolly pine (*Pinus taeda* L.) plantations on industry lands. The remaining second-growth stands of shortleaf pine and hardwood today on average have more trees and smaller trees than pre-European settlement stands. Today in the Oklahoma study area, for example, the average number of trees per acre ranges from 200 to 250, and their diameters average 9 inches (Kreiter 1995). Average fire return intervals now range from 40 to more than 1200 years (Masters and others 1995). Throughout the region understory vegetation is now dominated by woody species, and once-common grasses and forbs are scarce (Fenwood and others 1984, Masters 1991, Sparks 1996). Bison and elk have been extirpated. Other species such as Bachman's sparrow (*Aimophila aestivalis* Lichtenstein), brown-headed nuthatch (*Sitta pusilla* Latham), and northern bobwhite (*Colinus virginiana* L.) have been negatively affected by the loss of habitat (Jackson 1988), and the red-cockaded woodpecker (*Picoides borealis* Vieillot) has become endangered (Neal and Montague 1991).

Historic and present-day forests of the 1.78 million acre Ouachita National Forest (ONF) very much fit the descriptions above. The typical shortleaf pine-hardwood stand today ranges from 70-90 years old and comprises 90 to 100 ft^2 basal area of pine, and 30 ft^2 basal area of hardwoods per acre (Fig. 2). Of the hardwood basal area, two-thirds is in trees 3 to 9 inches in diameter (Guldin and others 1994). The condition of today's stands derives largely from two factors: the cutting of the original trees and more than 60 years of fire suppression. Large-scale exploitation of the original forests began in the early 1910s and was largely finished by 1940 (Smith 1986). Under U.S. Forest Service stewardship, the period of regeneration that followed the cutting was marked by a strict policy of fire suppression that continued well into the 1980s. The ecological upshot is that by about 1970, the shortleaf pine-bluestem woodland community had all but disappeared from the Ouachita Mountain landscapes (Foti and Glenn 1991).

PLANNING FOR RESTORATION

The ONF initiated large-scale restoration efforts for the shortleaf pine-bluestem ecosystem with the adoption in 1994 of a forest plan amendment to restore old-growth shortleaf pine stands on some 54,000 acres (USDA Forest Service 1994). In 1996 a forest plan amendment was adopted to restore another 120,000 acres of this ecosystem in west-central Arkansas to aid recovery of the endangered red-cockaded woodpecker (USDA Forest Service 1996). In 2002 still another forest plan amendment allocated 30,000 acres in McCurtain County, OK, for recovery of the red-cockaded woodpecker (USDA Forest Service 2002). Finally, a recently adopted revised forest plan (USDA Forest Service 2005) designated an additional 50,000 acres, unrelated to either old-growth forests or red-cockaded woodpecker recovery, to receive restoration treatments. Thus the total acreage allocated to shortleaf pine-bluestem ecosystem restoration is 254,000 acres, about 25 percent of the total pine-dominated acreage on the ONF and about 14 percent of the entire forest.

Figure 2.—Typical unrestored mature second-growth shortleaf pine-hardwood stand on the Ouachita NF today (photo by Joe Neal).

RESTORATION PRESCRIPTIONS

Restoration treatments vary somewhat between stands of native second-growth shortleaf pine and artificial plantations of loblolly pine. In the Ouachita Mountains the latter species was originally naturally distributed in narrow bands along larger stream corridors, mostly along the southern edge of the mountains. Since the late 1960s, however, the trend on private industrial forest lands has been to replace the shortleaf pine forests on upland sites with loblolly pine plantations, thus increasing loblolly pine's acreage far in excess of its original extent. Some of these formerly private lands have been acquired for the National Forest system by purchase or exchange. Each of the areas now dedicated to restoration of the shortleaf pine-bluestem ecosystem contains some loblolly pine plantation acreage.

Native Second-Growth Shortleaf Pine

For typical second-growth shortleaf pine stands, the restoration prescription requires thinning to a residual basal area of about 60 ft^2 per acre, felling most of the woody midstory stems in a treatment known within the agency as wildlife stand improvement (WSI), followed by prescribed burning at 3- to 4-year intervals. Overstory hardwoods, mainly oaks (*Quercus* spp.) and hickories (*Carya* spp.), are retained as individuals or clumps within pine stands, and as entire stands throughout the landscape. Flowering trees and fruiting shrubs such as dogwood (*Cornus florida* L.), serviceberry (*Amelanchier arborea* (Michx. f.) Fern.), and wild plum (*Prunus* spp.) are retained during midstory reduction treatments. Implementation of these treatments will result in substantially restored conditions in about a decade (Fig. 3).

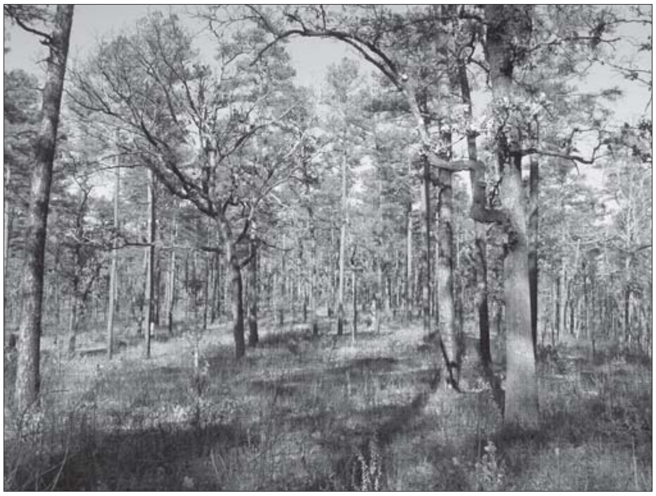

Figure 3.—Restored shortleaf pine-bluestem community on the Ouachita NF (photo by James M. Guldin).

When stand regeneration is desired, advantage can be taken of shortleaf pine's ability to resprout following fire, a habit noted early on by Mattoon (1915). The repeated prescribed burning should serve to provide advanced regeneration of shortleaf pine through resprouting of existing seedlings as well as recruitment of new seedlings over time. Thus, when a decision is made to regenerate these stands, foresters should be able to rely on release of adequate numbers of seedlings from the advance-growth seedling bank, rather than simply upon seedfall and germination of new seedlings, which can be uncertain in shortleaf pine. Reproduction cutting methods utilizing either irregular seedtree (seedtree with reserves) or irregular shelterwood (shelterwood with reserves) methods will be employed to naturally regenerate these stands. Nominal rotation lengths are 160 years for old-growth restoration units, 120 years in areas managed for red-cockaded woodpecker recovery, and 70 years for the remainder.

Loblolly Pine Plantations

Restoration treatments for loblolly pine plantations include thinning to a residual basal area of about 60 ft^2 of basal area to encourage development of the desired understory grasses and forbs, and prescribed burning at 3- to 4-year intervals to maintain the understory vegetation and discourage loblolly pine reproduction. The loblolly pines will be carried to ages and sizes that are economically efficient. The stands will then be clearcut and replanted with native shortleaf pines, which will then be managed as described above.

The Role for Timber Sales

The ability to sell valuable wood products is at the very heart of restoration efforts regardless of whether the stand currently consists of native second-growth shortleaf pines or planted loblolly pines. All commercial thinning or regeneration cutting is accomplished through the use of timber sales that are advertised and sold to the highest bidder. Further, under authority of the Knutson-Vandenberg Act of 1933 and the National Forest Management Act of 1976, portions of the proceeds from these timber sales are retained to pay for most of the follow-up midstory reduction and prescribed burning needed to restore the stands. The upshot is this: timber purchasers are willing to pay a substantial price for the privilege of cutting and removing trees under the Forest Service restoration prescription, helping us achieve desired conditions across many landscapes. The use of sale proceeds to pay for midstory reduction and prescribed burning reduces the need to rely upon scarce federal appropriated dollars for these treatments, and results in the ability to restore much larger areas than would be possible through expenditure of appropriated dollars alone. In this ecological context, timber sales are a means to an end rather than an end unto themselves.

ENVIRONMENTAL EFFECTS OF RESTORATION

While understanding the essential need for restoration in order to recover the endangered red-cockaded woodpecker (Fig.4), and sensing the ecological correctness of restoring an ecosystem that was once widespread but had practically vanished, Forest Service planners and land managers acknowledged that there were unanswered questions about the environmental effects of restoration activities. Studies designed to answer many of these questions were undertaken in cooperation with Oklahoma State University, the University of Arkansas, and the Southern Research Station of the Forest Service. These studies were based on a completely randomized experimental design with three to four replications depending on the study. All studies included treatments of 1) thinning, WSI and burning with measurements taken 1, 2, and 3 years after the burn; and 2) an untreated control. Some of the studies also included a thinning, WSI, and no burn treatment. The experimental units were all typical mature second-growth stands of mostly shortleaf pines ranging in age from 70 to 90 years, and averaging about 40 acres in size.

Biological and Physical Environmental Effects

Birds

Wilson and others (1995) studied the effects of restoration on populations of breeding birds. They found populations of 10 species significantly greater in the treatments than the untreated controls, indicating beneficial treatment effects. Among these species are the eastern wood-peewee (*Contopus virens* L.), a declining neotropical migrant, and the brown-headed nuthatch, a non-migratory species of conservation concern. Two neotropical migrant species of concern, the ovenbird (*Seiurus aurocapillus* L.) and black-and-white warbler (*Mniotilta varia* L.) had significantly lower numbers in the treatments than the controls, indicating adverse effects. Some 27 species showed higher but non-

Figure 4.—The red-cockaded woodpecker on a shortleaf pine, Ouachita NF (photo by Joe Neal).

significant population numbers in the treatments than in the controls, suggesting the possibility of beneficial treatment effects. Among this group are the neotropical migrants Kentucky warbler (*Oporornis formosus* Wilson), ruby-throated hummingbird (*Archilocus colubris* L.), great-crested flycatcher (*Myiarchus crinitus* L.), yellow-breasted chat (*Icteria virens* L.), common yellowthroat (*Geothlypis trichas* L.), white-eyed vireo (*Vireo griseus* Boddaert), yellow-throated vireo (*V. flavifrons* Vieillot), blue-gray gnatcatcher (*Polioptila caerulea* L.), and prairie warbler (*Dendroica discolor* Vieillot). Other species of conservation concern in this group were the red-cockaded woodpecker, Bachman's sparrow, northern bobwhite, wild turkey (*Meleagris gallopavo* L.), and red-headed woodpecker (*Melanerpes erythrocephalus* L.). Some 10 species had non-significantly lower population numbers in treated stands, suggesting the possibility of adverse effects. Species of conservation concern in this group include the neotropical migrants scarlet tanager (*Piranga olivacea* Gmelin), Acadian flycatcher (*Empidonax virescen* Vieillot), and whip-poor-will (*Caprimulgus vociferous* Wilson). However, in a follow-up songbird study Masters and others (2002) found that the rate of occurrence of the Acadian flycatcher increased in the second and third year post-burn treatments as compared to the untreated control. In a subsequent study of northern bobwhites in the restoration area, Cram and others (2002) detected population increases ranging from 5-fold to 19-fold in treated stands as compared to untreated controls, confirming the beneficial effects of treatments on this important game bird.

In yet another study focused on habitat quality for early successional songbirds, Jennelle (2000) concluded that pre-commercial thinning and burning in stands of young trees, and commercial thinning and burning in stands of mature trees, provided suitable foraging and nesting habitat for several such species of conservation concern, including the prairie warbler, yellow-breasted chat, and common yellowthroat. Of special importance was the presence of hardwoods in the shrub layers of both treatments.

In response to restoration efforts and an aggressive translocation program, the red-cockaded woodpecker population has increased from about 32 adult birds and 13 active territories in 1990, to some 88 adults and 37 active territories in 2006 (Figs. 5 and 6). Further, 40 or more young have been fledged in five of the last six breeding seasons (Fig. 6).

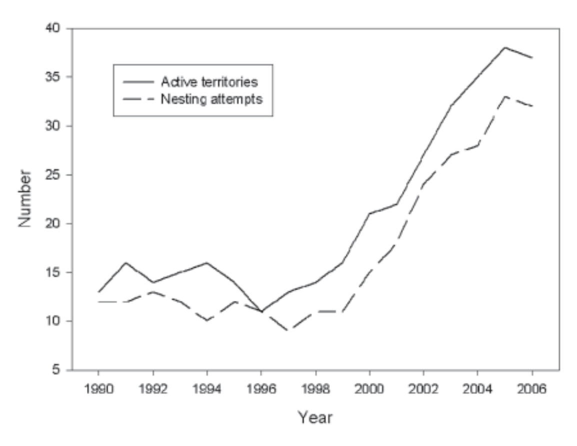

Figure 5.—Changes in number of red-cockaded woodpecker territories and nesting attempts, 1990-2006, Ouachita NF.

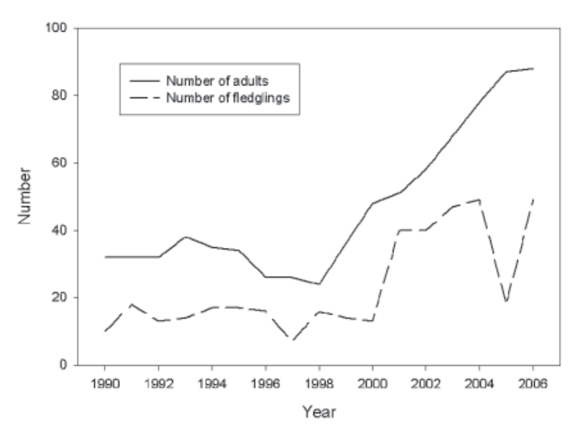

Figure 6.—Changes in number of red-cockaded woodpecker adults and fledglings, 1990-2006, Ouachita NF.

Mammals

Masters and others (1998) found that populations of small mammals in treated stands increased in abundance and diversity; no species was adversely affected. Total community abundance, richness, and diversity were lowest in untreated controls. The authors concluded that restoration efforts may be particularly beneficial to the white-footed mouse (*Peromyscus leucopus* Rafinesque), golden mouse (*Ochrotomys nuttalli* Harlan), and fulvous harvest mouse (*Reithrodontomys fulvescens* Allen), species that may have historically depended on pine-grassland habitats. In a study to determine the effects of restoration on the production of forage for white-tailed deer (*Odocoileus virginianus* Zimmermann), Masters and others (1996) found that preferred deer forage in treated stands was 6 to 7 times greater than untreated controls. Another mammal study currently underway is investigating habitat quality for the eastern spotted skunk (*Spilogale putorius* L.) in shortleaf pine-bluestem landscapes (Leismeister, unpublished data). Restored areas apparently are among the few places in Arkansas where this species of conservation concern can be regularly found.

Other Taxa

Thill and others (2004) studied the effects of restoration on populations of amphibians and reptiles, butterfly fauna and nectar sources, and moth fauna. In most years amphibian relative abundance, richness and diversity were comparable to or higher in restoration treatments than in untreated controls. Overall, values for reptile relative abundance, richness, and diversity were greater in the restoration treatments than in the controls, though the differences were generally not statistically significant. Numbers of adult butterflies were lowest in the untreated controls, highest in the treated stands the first year after burning, and intermediate in the second and third years after burningpresumably due to available nectar sources, which exhibited treatment effects nearly identical to numbers of adult butterflies. A butterfly species of conservation concern, the Diana fritillary (*Speyeria diana* Cramer), was significantly more abundant in treated stands. The moth fauna study yielded different results. For late summer and autumn, moth numbers showed a response similar to butterflies with higher relative numbers in the treatments than in the controls. However, the pattern in spring was reversed, with higher relative numbers of moths in the controls. Additional work is necessary to explain these differing seasonal responses.

Vegetation

Sparks and others (1998) identified more than 150 herbaceous species in their prescribed-burn study stands that were generally absent from untreated controls. Among these were some 40 species of native legumes whose nitrogen-fixing activities augment soil fertility, and whose foliage and seeds provide an important source of food for wildlife. Species richness increased in restored stands after both late growing-season and late dormant-season prescribed fires, and was lowest in unburned stands. Overall, herbaceous species richness, diversity, and total forb and legume abundance increased in treated stands as opposed to untreated controls. A key finding in the study is that season of burn influenced the numbers of fewer than 10 percent of the herbaceous species, and none were excluded by season of burning (Sparks and others 1998). It appears that none of the herbaceous species in the Ouachitas depend exclusively on summer burning to maintain their presence in these restored stands.

Soil and Foliar Nutrients

Liechty and others (2005) compared soil chemistry and foliar nutrients of treated stands with untreated controls. Mineralizable N, total N, C, Ca, and pH of surface soils were higher in treated stands than in the untreated controls. Foliar concentrations of N, P, and K were significantly higher in treated stands for at least a year after burning, though only K concentrations remained higher for the entire 3-year post-burn period. The authors concluded that surface soil fertility and productivity had improved in treated stands.

Tree Growth

Over 4 years of a study comparing tree growth in restored and untreated controls, Guldin and others (2005) found no significant differences in tree growth between treatments and controls. However, growth in both treated and untreated stands was substantially less than that predicted by a regional shortleaf pine growth model (Lynch and others 1999); observed growth was 70 percent less than predicted by the model in treated stands, and 50 percent less than predicted in the controls (Guldin and others 2005). This unexpected outcome is possibly due to generally drier-than-normal weather conditions during the tree growth study. At any rate, the lower than expected tree growth rates were not due to treatment effects.

ECONOMIC EFFECTS

Before considering the economic effects of restoration treatments, it should be understood that there is no law requiring that National Forest lands be managed for profit. In fact, there is specific language in the National Forest Management Act of 1976 directing that managers should not select treatments based on a “greatest return” criterion. Nevertheless, it is useful to describe economic effects in terms of opportunities foregone so as to private landowners an idea of costs and returns should they be interested in applying these restoration prescriptions.

Huebschmann (2000) used an input-output model to estimate the economic effects of shortleaf pine-bluestem restoration for red-cockaded woodpecker recovery over a 100-year simulation period for a 155,000-acre study area in

Scott County, AR. He compared present net value (PNV) for the area if managed under the restoration prescription with a 120-year rotation and low tree density, to what its PNV might be under a more traditional management prescription with a 70-year rotation and heavier stocking. He estimated that after 100 years the PNV for the restored area would be $111 million less than the PNV for the area had it been managed in a more traditional manner. This value translates into an opportunity cost of about $9.25 per year for each acre of pine in the study area. Most of this opportunity cost is attributable to the fact that old pine trees, of which there are many more on the landscape under a long-rotation restoration prescription, do not grow as fast as younger trees. The economic model was based on present average stumpage value for pines, and thus overestimates the economic costs if the future value of large old trees is significantly greater, which is a distinct possibility. At this point, there is no reason to believe that an area managed under a restoration prescription would produce any dramatically different economic value than an area under traditional management provided that the rotation lengths are the same.

RESTORATION PROGRESS AND FUTURE CHALLENGES

From the work that began in the late 1970s as a treatment applied to a few acres surrounding red-cockaded woodpecker cavity tree clusters, the restoration efforts today have burgeoned to encompass landscapes at a scale of hundreds of thousands of acres. Since the adoption of the first formal shortleaf pine-bluestem restoration decision document in 1994, the Ouachita National Forest has thinned 52,992 acres, conducted mid-story reduction treatments on 42,948 acres, and applied prescribed burning at least once on some 143,233 acres within restoration areas. Managers estimate that 18,653 acres are currently in a substantially restored condition.

Because of the scale of the undertaking, however, there are significant challenges to achieving restoration objectives. Ultimately, almost 85,000 acres will likely have to be burned annually in order to maintain desired conditions in the restoration areas. State smoke management plans currently being implemented in Arkansas and under development in Oklahoma may limit the acreage that can be ignited in a single burn, and/or limit the total acreage that can be burned in a single day. Furthermore, the forest's work force is aging, with fewer individuals able to meet the physical fitness requirements each year for prescribed burning. These changes could make it more difficult to burn sufficient acreage each year. Though herbicides have been used only sparingly to date, their use might have to be increased substantially if prescribed burning capability erodes. Further, prescribed burning which has historically been done only by Forest Service employees might have to be done by outside contractors.

SUMMARY

This conservation effort, which had its first stirrings as a concern for an endangered species on a few scattered parcels of land, has grown with public support to encompass a commitment to restore a quarter million acres—a pace and a scale scarcely imaginable 15 years ago. It proceeds by utilizing elements of landscape ecology and restoration ecology supported by local research results published, for the most part, in peer-refereed scientific journals. It promises to substantially restore an ecosystem that was once widespread but is now rare. It offers the opportunity to develop self-sustaining populations of an endangered species and several other species of conservation concern that are presently underrepresented on the landscape. At the same time, the work maintains all of the traditional human uses of the land from logging and firewood gathering to hunting, hiking, and camping. This work enjoys the support of the conservation and lumber manufacturing communities, in addition to the general public. It integrates all of the conservation laws that govern management of National Forest lands. Finally, we and others think it restores an aesthetic beauty to the land not seen in many decades. As a result, we believe this work serves as an example of ecosystem renewal and as a showcase for appropriate management of National Forest lands.

ACKNOWLEDGMENTS

We wish to acknowledge the efforts of the district rangers, foresters, wildlife biologists, and many technicians on the Ouachita National Forest who are primarily responsible for the day-to-day activities in implementing this extraordinary conservation work. We also acknowledge the assistance and support of our partners: Oklahoma State University, the University of Arkansas, the University of Missouri, the Southern Research Station of the USDA Forest Service, the Arkansas Game and Fish Commission, the Arkansas Natural Heritage Commission, the Oklahoma Department of Wildlife Conservation, the Oklahoma Biological Survey, The Nature Conservancy, Arkansas Audubon Society, National Wild Turkey Federation, and Quail Unlimited. Finally, we salute the contribution of the Ouachita Timber Purchasers Group who cheerfully compete among themselves to buy our timber and thereby make the entire restoration enterprise economically feasible and implementable on a large scale.

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THE OZARK HIGHLANDS PINE-OAK WOODLAND RESTORATION PARTNERSHIP

Tim A. Nigh[1]

ABSTRACT.—A partnership of more than 20 state, federal, and nongovernmental organizations has been formed to pursue and promote restoration of Shortleaf Pine-Oak Woodland ecosystems throughout the Ozark Highlands. This paper provides a brief overview of the partnership, its goals and strategies, partner organizations, and current activities.

INTRODUCTION

Shortleaf pine and shortleaf pine-oak woodlands once covered millions of acres in the Ozark Highlands and Boston Mountains of southern Missouri and northern Arkansas. Wholesale logging around the turn of the century and subsequent fire suppression has significantly reduced the acreage and quality of this ecosystem throughout the region. The Comprehensive Wildlife Conservation Strategies in both Missouri and Arkansas recognize this ecosystem and the numerous species it supports as a target for restoration efforts. Significant interest and activity surrounds shortleaf pine-oak woodland restoration throughout the region on state, federal and private lands.

Obstacles to successful region-wide restoration of this system are many. Principle among these obstacles is a lack of manpower and dollars to adequately carry out the management, including thinning, commercial harvest and prescribed fire. In addition, creating markets and management techniques that allow harvest and utilization of small or sub-standard trees in the restoration process is also a challenge. Other challenges include inventory and monitoring, and the development of educational materials.

PARTNERSHIP GOALS AND STRATEGIES

The Ozark Highlands Shortleaf Pine-Oak Woodland Restoration Partnership is a consortium of state, federal, and nongovernmental organizations dedicated to the region-wide restoration of shortleaf pine-oak woodlands.

The goal of this partnership is to promote the development of a network of restored shortleaf pine-oak woodlands throughout the Ozarks at scales suitable to support populations of the numerous species it supports.

Principle strategies include:

1. Identify and map potential restoration sites throughout the region
2. Seek grants to support restoration activities
3. Develop sustainable harvest techniques that allow economically viable thinning and commercial harvest
4. Promote markets for small-diameter and substandard materials resulting from restoration activities
5. Promote markets for commercial pine sawlogs
6. Develop standard monitoring protocols, especially for target wildlife species
7. Develop and disseminate educational materials
8. Share information among partners

INITIAL PROJECT PARTNERS

The partnership is currently composed of 24 state, federal, and nongovernmental organizations. The cumulative knowledge and experience of the partners has established a foundation upon which the restoration of these valuable ecosystems can proceed.

Missouri

Missouri Chapter – The Nature Conservancy
Missouri Audubon
Pioneer Forest
Mark Twain National Forest
U.S. Fish and Wildlife Service
Ozark National Scenic Riverways
Missouri Department of Natural Resources
Missouri Department of Conservation
Eastern Ozark Forest Consortium
Missouri Chapter National Wild Turkey Federation
American Bird Conservancy

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[1] Resource Scientist, Missouri Department of Conservation,
1110 South College Ave., Columbia, Mo 65201. To contact or call:
(573) 882-9909 Ext. 3244; Timothy.Nigh@mdc.mo.gov

Arkansas

- Arkansas Chapter – The Nature Conservancy
- Arkansas Audubon
- Ozark National Forest
- USDA Southern Research Station
- U.S. Fish and Wildlife Service
- Natural Resource Conservation Service
- U.S. Army Corps of Engineers
- Buffalo National Scenic Riverways
- Arkansas State Parks
- Arkansas Game and Fish Commission
- Arkansas Natural Heritage Commission
- Arkansas Chapter Quail Unlimited
- Arkansas Chapter National Wild Turkey Federation

In addition to providing the land base, these partners will provide individual commitment to restoring pine oak woodlands and associated habitats through ongoing annual programs tied to comprehensive long range management plans. These partners will also provide the tools and technical experience essential for success. In summary, partners and plans are in place to make this project a success while making the most efficient use of funding.

CURRENT AND FUTURE ACTIVITIES

Thirty-four pine-oak woodland restoration sites, encompassing more than 230,000 acres, were identified by the partnership at its first meeting (Fig. 1). A dozen sites were included in a grant request to the National Fish and Wildlife Foundation for 2006 restoration activities on more than 6500 acres. The partnership was awarded a $100,000 grant in August 2006. In addition to initiating management, the funds will be used to create an informational brochure and to host field tours.

The partnership is having its second annual meeting in conjunction with this symposium. We plan to pursue additional grants to continue restoration activities. We also hope to fund an economic analysis of restoration benefits and a field demonstration of various alternative harvest techniques.

If you are interested in participating in the Ozark Highlands Pine-Oak Restoration Partnership, please contact the author (TN).

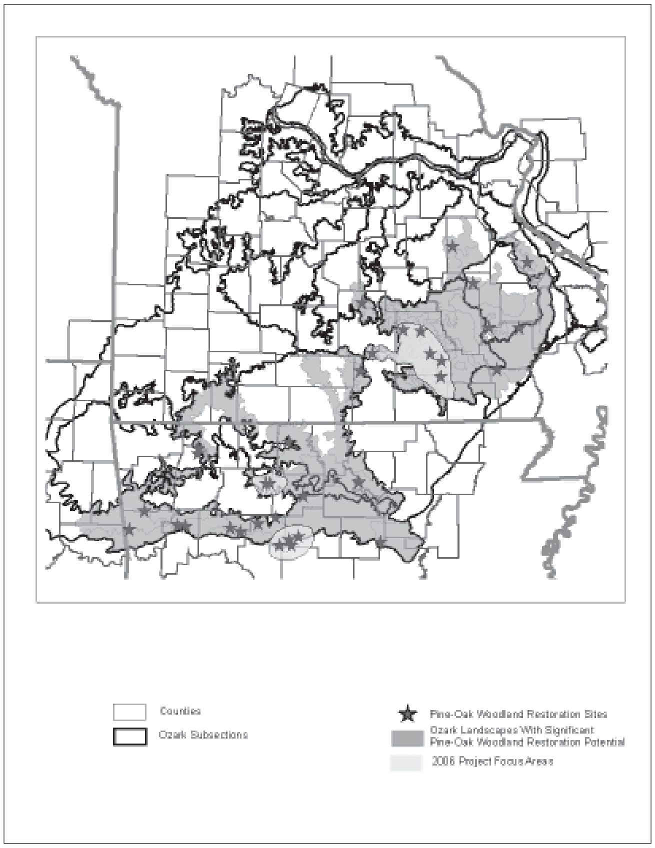

Figure 1.—Ozark highlands pine-oak woodland restoration sites.

Kabrick, John M.; Dey, Daniel C.; Gwaze, David, eds. 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.

Contains 27 papers and 14 extended abstracts from the symposium “Shortleaf Pine Restoration and Ecology in the Ozarks” held November 7-9, 2006, at the University Plaza Hotel and Convention Center in Springfield, MO.

Keywords: woodland restoration, southern pines, pine regeneration and management, tree improvement, wildlife diversity

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Capitalizing on the strengths of existing science capacity in the Northeast and Midwest to attain a more integrated cohesive landscape scale research program