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

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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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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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