REVISITING SHORTLEAF OUTPLANTINGS OF THE SOUTHWIDE PINE SEED SOURCE STUDY ON THE CROSSETT EXPERIMENTAL FOREST

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Abstract—In early 1953, eight blocks of the Southwide Pine Seed Source Study (SPSSS) featuring two geographically based series of shortleaf pine (*Pinus echinata*) were planted in Compartment 46 of the Crossett Experimental Forest (CEF). These shortleaf pines originated from Arkansas, Louisiana, Mississippi, Missouri, New Jersey, Oklahoma, Pennsylvania, Tennessee, and Texas seed sources. Their survival, fusiform rust (*Cronartium quercuum* f. sp. *fusiforme*) resistance, and height growth performance were tracked closely until the late 1960s, when the original effort to monitor these blocks for the SPSSS was discontinued. Remeasured into the 1980s, these outplantings were largely forgotten until recently, when interest in shortleaf pine reemerged. Although some unplanned harvests and other losses have occurred, enough surviving SPSSS shortleaf pines remained in the latter half of 2018 to reassess their diameters, heights, and derived merchantable volumes. After 65 years in the ground, some significant differences in height, diameter at breast height, and volume by seed source have persisted. In addition to assessing these shortleaf pines for long-term, seed source-based success, the remaining outplantings also present opportunities to further investigate species-based DNA markers useful for describing the genetic variation of this declining yet still important southern pine species. Better documentation of the growth performance and genetic attributes should also help silviculturists hone their strategies for the restoration of shortleaf pine.

INTRODUCTION

Initiated in 1951 by the Committee on Southern Forest Tree Improvement, the program that became known as the Southwide Pine Seed Source Study (SPSSS) represented the first regionally coordinated effort to test the capacity to move seedlings across the distributions of the various southern pines (Subcommittee on Geographic Source of Seed 1956). The four major southern pines (loblolly, *Pinus taeda*; longleaf, *Pinus palustris*; slash, *Pinus elliottii*; and shortleaf, *Pinus echinata*) have long dominated the southern timber industry, and their large-scale propagation and restoration via planting were critical for the development of tree improvement programs. However, prior to the SPSSS, very little research had been done to support the planting efforts of foresters and landowners.

Specifically, the SPSSS sought to better understand the performance (in terms of survival, vigor, productivity, etc.) of a given species when seeds from a given geographic location were germinated and planted in other parts of the South (Subcommittee on Geographic Source of Seed 1956). This study was the first cooperative study of this topic by the Committee on Southern Forest Tree Improvement and was administered by the Southern Forest Experiment Station (SOFES) of the Forest Service, U.S. Department of Agriculture. While SPSSS standardized this research, there were some variations in how the study was implemented based in part on species (for example, seed source areas or outplanting locations) and environmental circumstances (for example, differential mortality of plantations due to regional drought in the early 1950s).

Variation in shortleaf pine for the SPSSS was based on latitude and longitude. In the selection of different “series” for the SPSSS, shortleaf pine seed sources and outplantings were originally placed into “Eastern Temperature” and “Western Temperature” series (Series I and Series II, respectively) (Subcommittee on Geographic Source of Seed 1956). Wells and Wakeley (1970) described the shortleaf pine series and some limited early results. In their paper, Series I represented the “Latitude series” because it encompassed a greater range of latitude than Series II, which they labeled the “Intermediate series.” Some of the SPSSS outplantings of all species, including many of the shortleaf pines, were badly impacted by severe drought of 1953–54 and were addressed (in part) by a replanting of the most affected sites with seed collected in the fall of 1955 and planted in 1956–57 (Subcommittee on Geographic Source of Seed 1956, Wells and Wakeley 1970). A

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third shortleaf pine series (Series III) was later added to consider botanical origin and migration (Wells and Wakeley 1970) associated with longitude, as it spanned the east-west distribution of shortleaf pine, but Series III was not installed at all SPSSS locations.

While some may be surprised that shortleaf pine was included in the SPSSS, historically its abundance across the South was much higher than the present day (Bragg 2008). Since the installation of the SPSSS, dramatic declines in shortleaf pine abundance over the last half-century across the region have made this species of particular conservation concern (Anderson and others 2016, Moser and others 2007, Oswalt 2012). Although there are multiple reasons behind this decline, recent conservation and research efforts [for example, the Shortleaf Pine Initiative (http://www.shortleafpine.net/); Anderson and others 2016] offer some promise that this trend can be halted if not reversed in many parts of its range. To this end, we believe that additional lessons can still be learned from the surviving SPSSS-origin shortleaf pine outplantings on the Crossett Experimental Forest (CEF), and this paper represents the first reassessment of these in 30 years.

MATERIALS AND METHODS

SPSSS Series I and II Implementations at the CEF

Even though the CEF is best known for its many decades of naturally regenerated southern pine silviculture research (especially uneven-aged management), it also housed a forest genetics/tree improvement program from the early 1950s until the location was temporarily closed in the early 1970s (Bragg and others 2016). Some of the earliest work of this CEF program, the SPSSS outplantings were from Series I and Series II (Series III was not installed at CEF, and no replantings in 1956–57 were done, either). The shortleaf pine seed sources by series are described in table 1 and figures 1 and 2. Series I consisted of four seed sources from the western portion of shortleaf pine's range, a Burlington County, NJ source, a local Ashley County, AR source, and one from Morgan County, TN. Series II had three different shortleaf pine seed sources from the western portion of its range, plus a Franklin County, PA source and the same Ashley County and Morgan County sources. Each series was replicated four times in a randomized block design, with plots being 0.1 acre in size and containing 121 trees (11 rows of 11 trees) at 6-foot by 6-foot spacing, with only the innermost 49 trees measured in the original analyses (Grigsby 1964).

Shortleaf were the only southern pines planted on the CEF for the SPSSS; relatively limited space, staffing, and other resource constraints kept the CEF from installing loblolly outplantings, and neither longleaf nor slash pine were native to Arkansas. The CEF shortleaf were planted in Compartment 46 in late January and early February of 1953 under the direction of SOFES Forest Geneticist Roland E. Schoenike (Schoenike 1953b). After establishment, a limited set of measurements were taken, including survivorship (percent of live trees), diameter at breast height (d.b.h.) to the nearest 0.1 inch, total tree height (to the nearest 0.1 foot), and rate of fusiform rust (*Cronartium quercuum* f. sp. *fusiforme*) infection (as a percent). Measurements were taken at a number of intervals over the first few decades: first annually, then every few years, and finally every 5 years to age 35. The CEF SPSSS results have been summarized elsewhere (for example, Grigsby 1964, 1979; Schoenike 1953a, 1956; Wells and Wakeley 1970) and will only be briefly mentioned in this paper.

Table 1—Description of the Southwide Pine Seed Source Study (SPSSS) shortleaf pine seed sources planted in 1953 on the Crossett Experimental Forest (CEF)

Original study label	Series	Source origin location (# of sources)	Average annual temperature (°F)	Location key (fig. 1)	CEF block numbers (fig. 2)
----SPSSS seed source----				----*This paper*----	
C-401	II	Franklin Co., PA (1)	53	10	5, 6, 7, 8
C-403	I	Burlington Co., NJ (1)	53	11	1, 2, 3, 4
C-419	I	Lafayette Co., MS (1)	63	8	1, 2, 3, 4
C-421	I	St. Helena Parish, LA (1)	67	7	1, 2, 3, 4
C-423	II	Angelina Co., TX (1)	67	6	5, 6, 7, 8
C-425	II	Pushmataha Co., OK (1)	63	5	5, 6, 7, 8
C-427	I	Clark Co., AR (1)	63	2	1, 2, 3, 4
C-429	I, II	Ashley Co., AR (2)	63	1	1, 2, 3, 4, 5, 6, 7, 8
C-431	II	Stone Co., AR (1)	58	3	5, 6, 7, 8
C-433	I	Dent Co., MO (1)	58	4	1, 2, 3, 4
C-435	I, II	Morgan Co., TN (2)	58	9	1, 2, 3, 4, 5, 6, 7, 8

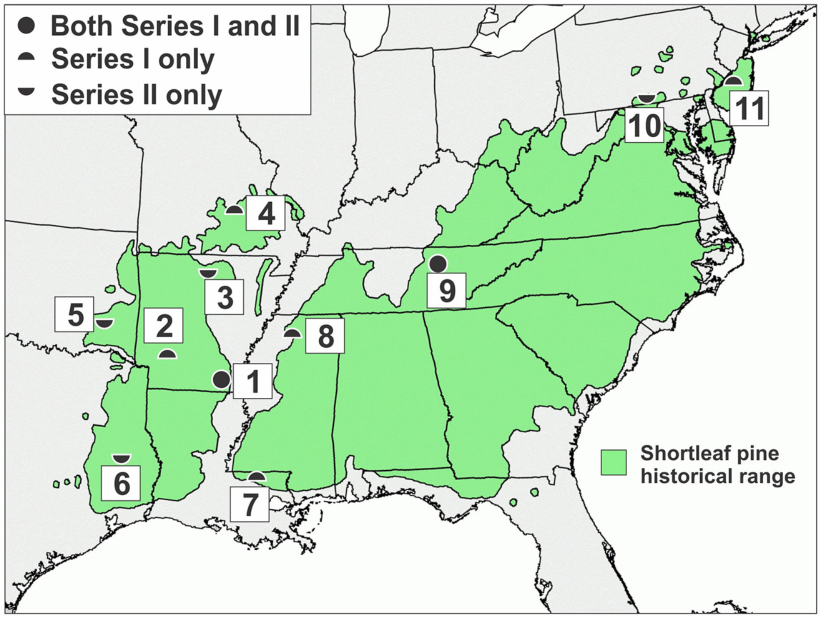

Figure 1—Distribution of Southwide Pine Seed Source Study Series I and Series II outplantings of shortleaf pine. Numeric code locations include: 1: Crossett Experimental Forest, Ashley County, AR; 2: Clark County, AR; 3: Stone County, AR; 4: Dent County, MO; 5: Pushmataha County, OK; 6: Angelina County, TX; 7: St. Helena Parish, LA; 8: Lafayette County, MS; 9: Morgan County, TN; 10: Franklin County, PA; and 11: Burlington County, NJ. Shortleaf pine distribution based on E.L. Little's map (Little 1971).

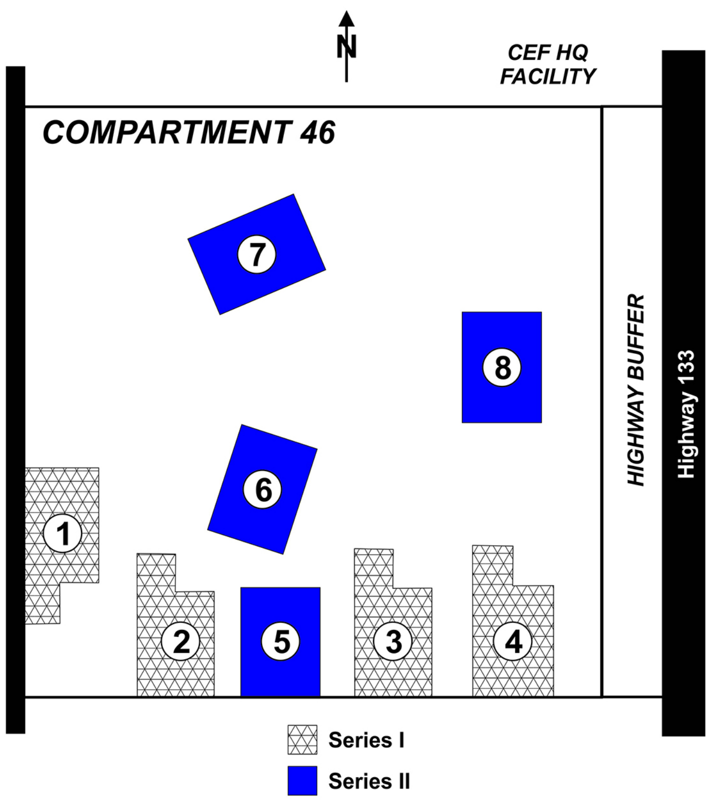

Figure 2—Shortleaf pine planting blocks from the 1953 Southwide Pine Seed Source Study in Compartment 46 on the Crossett Experimental Forest. Blocks 1–4 are from Series I; blocks 5–8 are from Series II.

Other potentially influential factors were documented as they arose. For example, Schoenike (1956) observed substantial impacts of tip moth (*Rhyacionia frustrana*) in all seed sources and also remarked that three of the Morgan County shortleaf actually proved to be Virginia pine (*Pinus virginiana*) seedlings that had somehow contaminated the original seedling pool. Silvicultural treatments were also built into the original design. The CEF SPSSS plots were thinned to "about half" of the original number of trees planted at 15 years, followed by some additional thinning at age 20 (Grigsby 1979). Further thinnings were done after the year 35 measurements, but these were more operational in nature and not well documented. Compartment 46 has been affected by a number of natural disturbances over the years, with unknown impacts on the SPSSS outplantings.

2018 Remeasurement

As a part of a broader study of shortleaf pine genetics, we revisited the SPSSS outplantings in the latter months of 2018 (fig. 2). Because most of the original plot monuments had long been lost, the first step was to relocate the study blocks using available plot maps. Whenever available, old tags attached to planted pines within each block were used to help confirm block identity. After each block was relocated, all of the living, now 65-year-old shortleaf pines remaining in these blocks (not just the interior trees) were measured for their d.b.h. and total tree height. These diameters and heights were then used to estimate total merchantable volume (*V*) (to a 4-inch top) using the following regional loblolly pine equation (Van Deusen and others 1981):

$$V = 0.00296 + 0.00193881 d.b.h.^2\, HT \times R \qquad (1)$$

where

HT is total tree height and *R* is a top-diameter conversion ratio:

$$R = e^{-2.9637X^{4.7564}} \qquad (2)$$

where

X is top diameter (4 inches) divided by d.b.h.

While Van Deusen and others' (1981) volume model was not developed for shortleaf pine, previous experience on the CEF has shown that equation (1) works well for this allometrically similar species. Given that equation (1) incorporated height, which was expected to vary by seed source, the use of this variable allowed for better precision than the local CEF-based (Farrar and others 1984) equation for loblolly and shortleaf pines that only uses d.b.h. to predict volume.

Numbers of live shortleaf pines per replicate within blocks were also recorded, but no attempt was made to look for any evidence of fusiform rust. We also did not look for differences in seed production capacity, as had been done in some of the earlier analyses. Given that most sources were not shared between series, direct comparisons using traditional approaches were problematic. However, because a present-day comparison between seed sources regardless of series was desired, we tested the two seed sources common to both series. There were no blocking effects indicating that there were no series-based differences. Hence, this suggests that combining all seed sources for this direct comparison would be valid. Differences in seed source performance by d.b.h., height, and merchantable volume were compared in Statistica (version 12) using analysis of variance and then mean separation with Tukey's honestly significant difference test for unequal sample sizes at an $\alpha = 0.05$ (for d.b.h. and height) and $\alpha = 0.10$ for merchantable volume. The higher alpha level for merchantable volume was applied because its substantial variation (culminating from the highly varying d.b.h. and height measurements) may have otherwise masked meaningful differences, thereby resulting in an unnecessarily high Type II error with an $\alpha = 0.05$ (Zar 2010).

RESULTS

After 65 years, an average of 2.5 percent of planted shortleaf pine in the SPSSS plots on the CEF remained alive, including survivors from all seed sources (table 2). In general, there were greater numbers of surviving shortleaf pine from the local (Arkansas region) and western (Texas, Missouri, and Oklahoma) seed sources (2.1 to 4.1 percent) and slightly less from Pennsylvania, New Jersey, Louisiana, and Tennessee (1.8 percent), with the lowest overall survivorship from the Mississippi seed source (1.2 percent). For circumstances that will be discussed later, no further analysis of survivorship was done.

Not surprisingly, shortleaf pine seed sources from the western and southern portions of the sampling distribution produced the largest diameters at age 65, with most of these seed sources averaging between 16 and 18 inches d.b.h. However, only the Tennessee seed sources (average of 14.1 inches d.b.h.) proved to be significantly smaller ($p < 0.05$) than those from Arkansas, Missouri, Texas, and Oklahoma. The Pennsylvania (14.8 inches) and New Jersey (14.6 inches) shortleaf pines were both on the smaller end, but they were not statistically smaller in d.b.h. than the better performing seed sources (table 2). This lack of significance arose from the considerable variability in tree d.b.h. (standard deviation ranged between 1.5 and 3.2 inches) in the diameters measured in 2018.

Table 2—Results from 2018 remeasurement of the shortleaf pines in the Crossett Experimental Forest's Southwide Pine Seed Source Study (SPSSS) planting blocks

Original study label	Alive in 2018		d.b.h.		Total height		Merchantable volume	
			Mean	SD	Mean	SD	Mean	SD
	number	*percent*	-------*inches*-------		----------*feet*----------		------*cubic feet*--------	
C-401	9	1.8	14.8 ab	1.48	73.9 ab	4.68	31.3 ab	6.58
C-403	9	1.8	14.6 ab	2.10	67.4 b	12.74	28.9 ab	11.88
C-419	6	1.2	16.6 ab	1.61	71.7 ab	15.58	39.6 ab	14.03
C-421	9	1.8	17.3 ab	2.64	80.0 ab	13.23	48.2 ab	19.04
C-423	20	4.1	17.8 a	2.70	82.3 ab	7.26	52.4 a	18.14
C-425	10	2.1	17.8 a	2.41	82.8 a	8.27	51.9 ab	16.18
C-427	11	2.3	17.5 a	2.03	79.1 ab	17.75	48.3 ab	18.25
C-429	28	2.9	17.3 a	2.08	84.8 a	5.65	50.1 a	13.65
C-431	18	3.7	16.3 ab	3.17	75.9 ab	7.31	41.4 ab	21.30
C-433	18	3.7	17.5 a	2.31	78.6 ab	11.03	47.9 a	16.79
C-435	18	1.8	14.1 b	2.50	75.2 ab	8.60	29.9 b	12.70
Total	156							
Average		2.5						

d.b.h. = diameter at breast height, SD = standard deviation.

Means in a column with the same letter are not significantly different [$p < 0.05$, Tukey's honestly significant difference (HSD) for unequal sample sizes].

Merchantable volume to a 4-inch top following Van Deusen and others (1981); significance for this column is $p < 0.10$, Tukey's HSD for unequal sample sizes.

When measured in 2018, the New Jersey (67.4 feet) seed source was significantly ($p < 0.05$) shorter than Oklahoma (82.8 feet) and Ashley County, Arkansas (C-429) (84.8 feet) seed sources, while the rest were not significantly different (even though their mean heights ranged from almost 72 feet to almost 83 feet tall). This lack of significance again was due to high variability, as height standard deviations for many of these trees ranged from 11 to nearly 18 feet (table 2).

Because the merchantable volume equation (1) is particularly responsive to differences in d.b.h., the low diameters of the Tennessee shortleaf pine seed sources translated into their having significantly ($p < 0.10$) lower volumes at 65 years compared to the most voluminous trees from Texas and Oklahoma (under 30 cubic feet, compared to about 52 cubic feet). Otherwise, the other seed sources proved to be statistically similar in volume, again attributable to high variation in volume estimates (table 2). This was true even for the New Jersey and Pennsylvania sources, both of which averaged only about 30 cubic feet per tree (comparable to the Tennessee seed sources).

DISCUSSION

Survivorship and Fusiform Rust Occurrence Observations

While differential response to disturbances and stressors is probably at least partially a heritable trait, because this was not controlled for it would be inappropriate to attribute survivorship in 2018 (table 2) as directly related to seed source. Too many unknown (and uncontrolled) circumstances occurred between the last year (1988) that survivorship was measured and the present day. For example, this compartment on the CEF has been inconsistently thinned over the last 3 decades and variably impacted by windthrow, insect attacks, and other environmental factors. Shortleaf pines that had survived fusiform rust infection early in their life may have been preferentially thinned in recent years, when such decisions were made operationally.

Differences in survival as a function of seed source were noted early in the SPSSS study (when this degree of control was possible), especially during the first 5 years after planting (Grigsby 1964; Schoenike 1954, 1955, 1956). Some of the earliest mortality arose from different quality seedlings and planting issues, compounded by an early flooding rain and then a multi-year drought (Schoenike 1954). After the first few observation periods, mortality in all seed sources stabilized, became fairly constant over the years, and eventually became statistically insignificant between sources (Grigsby 1964). During these intervening years, various factors killed shortleaf pine in these blocks, including windthrow, lightning, insects/disease, and thinning (Grigsby 1964, 1979; Schoenike 1955). These early assessments did find that fusiform rust resistance was greatest in the shortleaf pine seed sources from the more westerly portion of the species distribution. Indeed, the only seed source Grigsby (1979) reported with significantly greater amounts of fusiform rust (almost 16 percent) at 20 years was the one from New Jersey (all others he reported had between 1 and 3 percent fusiform rust occurrence).

Size and Volume Trends

This limited set of data supports some of the original conclusions of the SPSSS. With these genetically unimproved shortleaf pine seed sources, local sources generally fared the best—or close to the best—under most circumstances regardless of observed productivity variable (Wells and Wakeley 1970). After 65 years, the local Ashley County, AR (C-429) seed source was consistently amongst the largest sources (whether measured in d.b.h., height, or merchantable volume) in the CEF outplantings. Other western sources (especially Texas and Oklahoma) of shortleaf pine also performed at the highest levels observed, followed by Missouri and Louisiana sources. The Tennessee shortleaf pine source produced significantly less volume than the best performing seed source areas, and the Pennsylvania and New Jersey sources also performed poorly after 65 years. Grigsby (1979) reported similar d.b.h., height, and volume trends at age 20 in the CEF outplantings, with the Ashley County, AR (C-429) seed source performing the best in all three measures and the New Jersey and Tennessee sources faring the worst.

These results in Ashley County, AR, are generally comparable to analyses of the SPSSS outplantings in Dent County, MO, and Pushmataha County, OK, if considered from the perspective of the supremacy of local (or near-local) sourcing. In the Missouri study, Gwaze and others (2007) evaluated provenances from the two tests (Series I and III) and found that the seed sources from the more northerly collections (New Jersey and Tennessee, in the case of Series I) did the best, followed closely by those from more mid-latitudes and with the southerly collections performing worst. The trend of better survival and greater height growth of more northerly seed sources in the northerly Dent County outplanting is consistent with earlier findings from Oklahoma (Tauer 1980) and, not surprisingly, helped support the seed zone recommendations for shortleaf pine (for example, Wells 1973; Wells and Wakeley 1970) derived from the SPSSS.

CONCLUSIONS

Sixty-five years after establishment, we believe the SPSSS shortleaf pine outplantings on the CEF still offer promise for new discoveries, even though following the original study design has little potential given the unplanned thinnings and substantial mortality that have occurred over the decades. The shortleaf pine remaining at CEF today could be combined with any remaining outplantings at the other SPSSS locations to determine if sufficient numbers remain from enough of the seed sources for performance-based meta-analysis across the region. While the results of such a synthesis are not likely to change drastically from their original assessments, the further comparison of growth performance over long periods of time over the region would be a useful means to evaluate seed zone determinations from decades past (especially in the light of a changing climate).

Perhaps the best opportunity for new research from the surviving SPSSS outplantings may lie in the DNA of these surviving trees. Although never intended to be a component of the original study—the structure of DNA itself was not described scientifically (Watson and Crick 1953) until after the early SPSSS plantings—the genetic constituents of these seed sources have already been used to better understand potential changes to hybridization frequency in shortleaf pine (for example, Stewart and others 2010). Locally, we plan to use the CEF outplantings of the SPSSS to supplement other sources of shortleaf and loblolly pine from the Arkansas region in a series of different DNA marker tests to better document genetic diversity of these species. This information could prove useful regionally and nationally, as much of the focus on shortleaf pine is now conservation based, rather than production driven (as when the SPSSS progeny tests were installed).

Such opportunities further demonstrate the value of maintaining carefully controlling progeny tests from establishment through intended completion and beyond. So long as their limited footprint does not interfere with later studies in space-constrained experimental forests, these long-term progeny tests should be retained until mortality ends their usefulness.

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ADDENDUM

An EF-2 tornado struck parts of the CEF on April 25, 2019. While most of Compartment 46 was not affected, winds from this supercell storm toppled five of the SPSSS shortleaf pines (two each in blocks 2 and 5, and one in block 6). These trees came from different States and were 16 to 18 inches in diameter.

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