PROJECTING STAND DEVELOPMENT AND ECONOMICS OF LONGLEAF PINE PLANTED OUTSIDE ITS KNOWN HISTORICAL RANGE

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

ABSTRACT

As part of a regional study of new longleaf pine (*Pinus palustris* Mill.) genotypes, a trial was established at the Louisiana State University Agricultural Center Hill Farm Research Station in northwest Louisiana. The goal was to determine growth and development of genotypes planted north of the species' known historical range. This location is within the projected potential range of longleaf pine under moderate to severe climate change scenarios.

In January 2016, the site was hand-planted with 1-0 containerized longleaf pine seedlings in a 10-foot by 10-foot spacing using genotypes of diverse geographic origin (Alabama, North Carolina, east Texas); 17 genotypes were half-sibling and 2 were full-sibling crosses. Summary statistics and stand tables were calculated by genotype at age 5 and used to conduct projections using a variety of model systems. These projections were used to estimate future economic values, rotation ages, and to see how projections varied among model systems.

INTRODUCTION

Given advances in genetics, better quality seedlings, and an increase in the knowledge of how to transport, store, and plant longleaf pine seedlings (South 2006), and the fact that we now know it is essential to control non-crop tree vegetation early in the life of the stand (Haywood 2005, Nelson and others 1985), longleaf pine (*Pinus palustris* P. Mill.) plantations are a viable economic alternative compared to loblolly (*Pinus taeda* L.) or slash (*Pinus elliottii* Engelm. var *elliottii*) pine. This is especially true when accounting for the significantly greater number of poles found in longleaf pine stands (South 2006). Prices in east Texas during 2016 varied but sawtimber on the stump averaged $27/ton while pine poles averaged $50/ton (Stottlemyer and others 2017). Concerns about the lost ecosystem services associated with the reduction in longleaf pine ecosystems prompted restoration efforts; the improved seedling quality and yield potentials bolster those efforts.

Longleaf pine is relatively resilient to droughts, severe storms, fire, and pest outbreaks anticipated to occur with greater frequency with climate change in the Southeastern United States (Boyer 1990, Clark and others 2018). Prasad and others (2019) consequently predicted expansion potential of longleaf pine far north of its historical range, extending under high climate change scenarios into Arkansas and Missouri in the western portion of its range and Massachusetts in the eastern

Table 1—Description of genotypes established during this study

Genotype	Geographic origin	Code
1	East Texas	ETX
2	South Alabama	SAL1
3	South Alabama	SAL2
4	South Alabama	SAL3
5	North Alabama–Montane	NAL1
6 [a]	North Carolina [a]	NC1 [a]
7	South Alabama	SAL4
8	South Alabama	SAL5
9	South Alabama	SAL6
10	North Carolina	NC2
11	North Carolina	NC3
12	North Carolina	NC4
13	South Alabama	SAL7
14 [a]	North Carolina [a]	NC5 [a]
15	North Alabama–Montane	NAL2
16	North Alabama–Montane	NAL3
17	North Carolina	NC6
18	North Carolina	NC7
19	South Alabama	SAL8

[a] Full-sibling genotypes; all others are half-sibling.

Author Information: Curtis L. VanderSchaaf, Assistant Professor, Mississippi State University, Raymond, MS 39154; Michael A. Blazier, Professor, Louisiana State University Agricultural Center, Homer, LA 71040; and Joshua P. Adams, Associate Professor, Louisiana Tech University, Ruston, LA 71272.

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portion of its range. This projected climatic resilience as well as longleaf pine's sawtimber, pine straw, and wildlife habitat production potential has increased its attractiveness to landowners (Jose and others 2006). Hence, it is important to know if longleaf pine can be established effectively beyond its northern range as encountered by Europeans (Boyer 1990). Genotypes may vary in their adaptability to sites outside its range as well as in their productivity, so it is important to explore these genetic differences.

In this study, 19 genotypes of longleaf pine (table 1) drawn from diverse portions of its native range were established at a drought-prone site approximately 25 miles north of the northwestern most portion of the longleaf pine historical range. The objective of this study was to explore observed individual tree and stand development at age 5 years and long-term predicted stand development in terms of survival, basal area (BA), volume, and economic returns.

METHODS

Data Modeled

The study was conducted at the Louisiana State University Agricultural Center Hill Farm Research Station in northwest Louisiana (32°44'N, 93°03'W). Soils were classified as a gravelly fine sandy loam Darley-Sacul soil (an association of a fine, kaolinitic, thermic Hapludult and a fine, mixed, active, thermic Aquic Hapludult) common in upland forests of northwestern Louisiana, southwestern Arkansas, and eastern Texas (USDA SCS 1989). The Darley portion of the association occurs on upper slopes, and the Sacul portion is found within lower-slope positions. Droughts are common in the study area because late summer precipitation (USDA SCS 1989) is often below potential evapotranspiration during the same period; the moderately well- and well-drained soils of the site likely exacerbate impacts of drought.

Prior to establishment, the site was a loblolly pine plantation for 46 years. The native forest ecosystem of the region is loblolly pine, shortleaf pine (*Pinus echinata* Mill.), and southern red oak (*Quercus falcata* Michx.) mixtures (USDA NRCS 2000, 2015). After the plantation was clearcut-harvested in 2007, the site was replanted with loblolly pine in 2009 and 2010. Both replanting attempts were unsuccessful due to drought-related mortality of 50 to 70 percent. After 2010, the site naturally regenerated with loblolly pine and a mixture of hardwoods primarily of coppice origin. To foster replanting of the site, an aerial broadcast application of saflufenacil (Detail), imazapyr (Chopper Gen2), and glyphosate (Accord XRT) herbicides at 0.7, 10.1, and 57.1 fluid ounces active ingredient (a.i.) per acre, respectively, was conducted in June 2015. In July 2015, the study site was operationally mulched to comminute the vegetation killed by the herbicide application. In September 2015, the site was subsoiled to a 2.62-feet depth. In the same month, 250 pounds per acre of diammonium phosphate was broadcast-applied by a tractor-mounted spreader to supply, respectively, 50 and 45 pounds per acre of P and N.

In January 2016, the site was hand-planted with container-grown seedlings in a 10-foot by 10-foot spacing. Treatments consisted of 19 genotypes of diverse geographic origin; 17 genotypes were half-sibling and 2 were full-sibling crosses (table 1). Each experimental unit was a row of six trees all of the same genotype; each genotype was replicated six times. Treatments were applied in a randomized complete block design with gradual changes in slope (which was associated with soil type change within the Darley-Sacul association) as the blocking factor; each genotype was represented one time per block. For this analysis, the six replicates of six trees were combined (n = 36 trees), and the survival, and diameter and height characteristics, across the 36 trees of a genotype were considered to be representative of stand behavior for a particular genotype.

After planting, non-crop vegetation was suppressed to better isolate genotype effects. Rotary mowing was carried out two times per year (late spring and mid-summer) in 2016 and 2017. In 2018, the site was mowed one time, in mid-summer. In March 2016, 11.3 ounces per acre of Oustar herbicide was applied to supply 7.2 and 1.3 ounces a.i. per acre of hexazinone and sulfometuron methyl for competing vegetation suppression. The Oustar was applied via tractor-mounted sprayer within a 6.0-feet wide band along the tree rows. In July 2017, Velpar L herbicide was spot-applied via backpack sprayer at 16.4 fluid ounces a.i. per acre of hexazinone; a circular spot 2.95 feet in diameter was sprayed around each seedling. Table 2 contains individual tree summary data and table 3 contains estimated per acre summary data by genotype.

Modeling

Approach One–forest vegetation simulator (FVS)

The Southern variant (SN, version 1860) of FVS covers forest areas in the Southern United States including Louisiana, east Texas, and Mississippi (Keyser 2008). This is a distance-independent individual tree model. Individual tree data (n = 36) at age 5 by genotype were entered into FVS and projections were conducted annually until age 40. The "MANAGED" keyword was selected within FVS to inform the modeling system that projections are for plantations. This keyword is used within FVS since in general plantations have greater diameter growth rates relative to natural, or "unmanaged" stands.

Approach Two

The second approach used a stand-level volume equation presented in VanderSchaaf (2022c). Data used in model development were obtained from the Forest Service, U.S. Department of Agriculture Forest Inventory and Analysis (FIA) annual surveys of Alabama, Florida, Louisiana, Mississippi, and Texas.

Per-acre volume at a particular age (A_2) was predicted using equation 1:

$$Vol_2 = Vol_1[(1-exp^{[-0.104124A_2]})/(1-exp^{[-0.104124A_1]})]^{[1 - 0.746766]^{-1}} \quad (1)$$

where Vol is volume of trees of d.b.h. 5.0 inches and greater from a 1-foot stump to a 4-inch top diameter outside-bark (essentially trees merchantable for pulpwood, sawtimber, veneer, etc.).

For Approach Two, merchantable volume was estimated by taking the ratios of pulpwood, chip-n-saw, and sawtimber to total merchantable volume as predicted by FVS for each genotype by age. The predicted total merchantable volumes from equation (1) were then multiplied by the ratio associated with a particular product class.

Approach Three

This approach uses equations developed by Gonzalez-Benecke and others (2012). Stand-level equations predicting dominant height, trees per acre, BA per acre, and total and merchantable volumes were fit using data from across the Gulf region of the Southeastern United States. This system of equations was incorporated into an Excel spreadsheet-based Timber Decision Support System (TDSS) entitled *LongGulf* (available from Curtis VanderSchaaf). To be consistent with the definition of dominant height by Gonzalez-Benecke and others (2012), at age 5 the average height of all trees taller than the upper 25th percentile tree height were used for each genotype (table 3).

Approach Four

The fourth approach used a stand-level, nonlinear, mixed-effects Chapman-Richards (Zeide 1993) BA equation to predict BA per acre.

$$BAj = (199.14+u_{0i})*(1-exp[-0.1854*Age_j])^{2.8210+u_{2i}} \quad (2)$$

where BA is basal area (square feet per acre); the variances of u_{0i} and u_{2i}, are 222.08, and 0.3984, respectively, there is also a covariance of -5.2133, and the constant random error variance is 6.0568; *i* indexes a specific plot or stand and *j*

Table 2—Individual tree d.b.h. and total tree height (Ht) summary statistics by genotype at age 5[a]

Genotype	Code	D.b.h.	Stdev.	Min.	Max.	*n*D	Ht	Stdev.	Min.	Max.	*n*H
		inches					*feet*				
1	ETX	2.44	0.68	1.00	3.71	26	10.4	3.3	2.3	16.2	26
2	SAL1	2.62	0.52	1.30	3.50	30	10.5	2.4	5.8	15.0	31
3	SAL2	2.36	0.51	1.00	3.20	27	9.8	2.1	5.0	13.9	28
4	SAL3	2.54	0.42	1.40	3.20	31	10.6	1.6	7.8	14.0	31
5	NAL1	2.57	0.64	1.30	3.71	27	10.4	2.5	6.0	15.6	27
6	NC1	2.90	0.52	2.00	4.00	25	11.7	1.8	8.8	14.0	25
7	SAL4	2.71	0.56	1.00	3.60	32	11.4	2.0	8.0	15.7	32
8	SAL5	2.57	0.46	1.80	3.50	30	10.9	1.8	7.1	14.5	30
9	SAL6	2.77	0.38	2.00	3.30	33	12.2	2.4	2.9	15.6	34
10	NC2	2.18	0.53	1.00	3.00	31	9.3	2.6	3.0	13.5	32
11	NC3	2.54	0.58	1.30	4.00	27	10.6	2.2	6.0	15.0	27
12	NC4	2.41	0.62	1.00	3.60	31	9.9	2.9	4.0	15.8	31
13	SAL7	2.66	0.50	1.90	4.00	28	11.2	2.3	3.1	15.1	29
14	NC5	2.74	0.64	1.40	4.00	29	11.1	2.2	7.0	15.0	29
15	NAL2	2.35	0.72	1.00	3.30	31	10.2	2.5	4.0	14.7	32
16	NAL3	2.77	0.43	1.90	3.40	26	10.4	2.6	3.8	13.7	29
17	NC6	2.72	0.55	1.50	3.70	26	10.7	2.3	4.4	15.0	27
18	NC7	2.62	0.50	1.30	3.50	34	11.0	2.1	5.6	15.5	34
19	SAL8	2.86	0.61	1.21	4.00	32	11.2	2.0	5.2	14.1	32

D.b.h. = diameter at breast height; nD = d.b.h. tree number; Ht = total tree height; nH = Ht tree number.

[a]Number of trees planted per genotype was n = 36. If Ht tree number (nH) exceeds d.b.h. tree number (nD) by genotype, then not all trees had yet reached d.b.h.

Table 3—Stand-level summary statistics by genotype at age 5

Genotype	Code	DomG	DomHt	D_q	Percent survival	TPA	TPA_d	BAA	VAA
		feet	*feet*					*square feet*	*cubic feet*
1	ETX	14.8	15	2.53	72	315	315	11.0	82
2	SAL1	13.5	13	2.67	86	375	363	14.1	99
3	SAL2	12.6	11	2.41	78	339	327	10.4	68
4	SAL3	12.7	12	2.57	86	375	375	13.5	92
5	NAL1	13.0	13	2.65	75	327	327	12.5	87
6	NC1	13.9	13	2.95	70	303	303	14.3	108
7	SAL4	14.1	12	2.76	89	387	387	16.1	117
8	SAL5	13.3	13	2.61	83	363	363	13.4	94
9	SAL6	14.6	13	2.79	94	411	399	17.0	137
10	NC2	12.1	12	2.24	89	387	375	10.3	68
11	NC3	13.2	13	2.60	75	327	327	12.0	86
12	NC4	13.1	13	2.49	86	375	375	12.7	86
13	SAL7	13.5	12	2.70	81	351	339	13.5	103
14	NC5	14.2	12	2.82	81	351	351	15.2	111
15	NAL2	13.3	12	2.45	89	387	375	12.3	87
16	NAL3	12.8	12	2.80	81	351	315	13.5	94
17	NC6	13.3	12	2.77	75	327	315	13.1	96
18	NC7	13.7	14	2.67	94	411	411	16.0	113
19	SAL8	13.4	12	2.93	89	387	387	18.1	131

DomG = average height of the upper 25th percentile of heights (feet); DomHt = the dominant height calculated using FVS (feet); Dq = quadratic mean diameter (inches); Percent Survival = percent survival of all trees (TPA); TPA = trees per acre; TPA_d = trees per acre with a d.b.h.; BAA = basal area per acre (square feet, 4.5 feet); VAA = volume per acre (cubic feet) from FVS.

indexes the current age. Calibration of the mixed-effects model was accomplished using each genotype's age 5 BA per acre (table 3). Data used in model fitting were obtained from loblolly pine, slash pine, and longleaf pine container-stock plantations established in central Louisiana.

Modeling systems presented for cutover and old-field sites in southwestern Georgia were also examined (Brooks and Jack 2016). However, they greatly over-predicted BA per acre (e.g., 450 to 750 square feet per acre at age 25) or volume per acre (7,100 to 31,000 cubic feet per acre at age 25). Large overpredictions occurred because our observed values at age 5 exceed the data used in model fitting at this age and the plots used in model fitting had very little observed mortality (self-thinning) through time.

Volume Modeling Assumptions

For the three approaches that estimated merchantable cubic foot volume (Approaches One, Two, and Three), minimum merchantability limits were essentially consistent with standard FVS SN protocol and stump height was set to 0.5 feet. Minimum merchantable pulpwood diameter at breast height (DBH, 4.5 feet above ground level) was 4.0 inches, and upper-stem diameter outside bark (DOB) was 4.0 inches. Chip-n-saw specifications were minimum DBH of 8.0 inches to 11.0 inches, and an upper-stem DOB of 4.0 inches. Sawtimber specifications were minimum DBH of 11.0 inches and an upper-stem DOB of 7.0 inches. For FVS projections, volumes were calculated using the "SpMcDBH" keyword within FVS. Topwood, or upper-stem pulpwood on chip-n-saw and sawtimber merchandized trees, was included in the pulpwood class. The default FVS max stand density index of 332 was changed to 400 (Reineke 1933, Shaw and Long 2007, VanderSchaaf and others 2007).

Cubic feet volumes were converted to green tons assuming 62 pounds per cubic feet (Baldwin and Saucier 1983). Stumpage values per green ton for pine pulpwood, chip-n-saw, and sawtimber were $9, $19, and $25, respectively, and were obtained from the 2nd quarter, 2019 Louisiana Timber Market Report (Tanger 2019). An interest rate of 6 percent was used.

RESULTS AND DISCUSSION

Despite being established north of the species historical range in Louisiana, the genotypes on this site are relatively productive, and some are extremely productive for this species. Our study consisted of early herbaceous weed control, which has been known for some time now to be essential for longleaf pine growth and survival (Dickens and others 2010, Haywood 2005, Nelson and others 1985). There is some separation in DBH among the genotypes, but there are more meaningful differences in height among the genotypes (table 2). At comparative ages, these observed DBHs were within the range of, or exceeded, many other container-grown studies within its historical range (Cram 2019, Creighton and Bitoki 2011, Dickens and others 2010, South and others 2012) and the heights as well (Cram 2019, Creighton and Bitoki 2011, Dickens and others 2010, Haywood and others 2015, South and others 2012). Our average DBHs and total heights at age 5 are comparable to those in southwestern Virginia at age 7 (Creighton and Bitoki 2013). Of surviving trees, all genotypes had >90 percent with a DBH (TPA_d and TPA) at age 5 (table 3).

Our percent survivals (table 3) were within the range, and often exceeded, many other container-grown studies within the species historical range (Cram 2019, Creighton and Bitoki 2011, Dickens and others 2010, South and others 2012). The lowest genotype survival rate in this study was 70 percent. These percent survivals exceed countless bare-root studies.

Genotypes 9 (SAL6) and 19 (SAL8) exhibited the greatest BA and volume per acre measurements while genotypes 10 (NC2) and 3 (SAL2) exhibited the lowest BA and volumes per acre (table 3). Based on Goelz and Leduc (2001) for plantations established within its native range in the Western Gulf, observed volumes per acre for genotypes 9 (SAL6) and 19 (SAL8) would be considered High, while all other genotypes would be considered Medium at a minimum. The 435 per acre planting density is relatively low, and yet all genotypes can be considered of Medium productivity using Goelz and Leduc (2001), hence, it can be said that all genotypes at age 5 are exhibiting good rates of growth for this species. Their Medium- and High-BAs and total volumes per acre at age 5 were 5 and 14 square feet per acre and 43 and 156 cubic feet per acre, respectively. However, most of their data are from older generation longleaf pine plantations (established prior to 1980) that likely were established using bare-root stock and used less intensive regeneration practices. Nonetheless, our plantations, planted outside longleaf pine's historical range, are productive and it currently appears that longleaf pine can be successfully grown in this region of Louisiana, although their tolerance to extreme weather events such as ice storms must be evaluated as well.

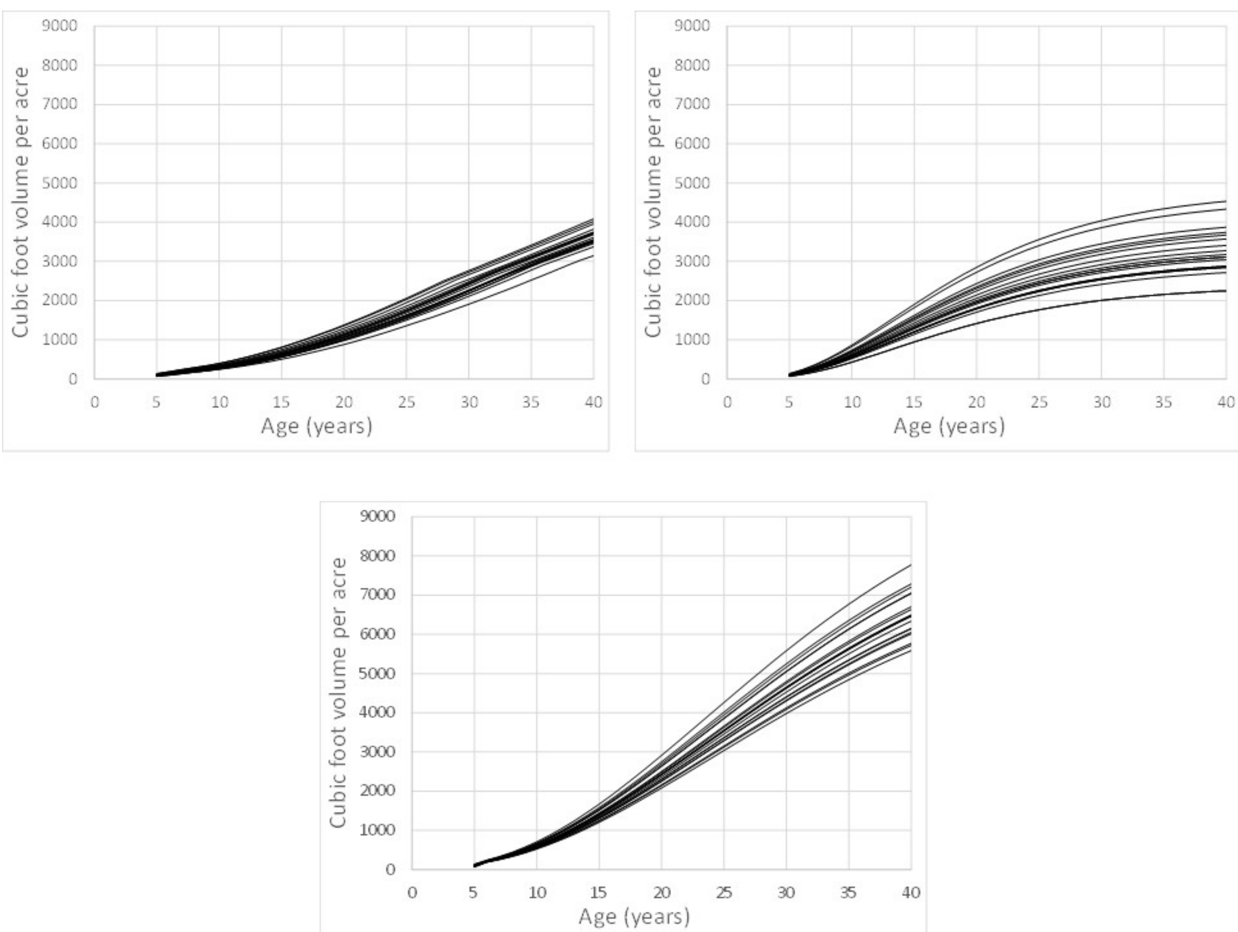

Figure 1—Approach One–Forest Vegetation Simulator (FVS) (upper left), Approach Two (equation 1) (upper right), and Approach Three [*LongGulf*—Gonzalez-Benecke and others (2012)] (lower) projected unthinned standing cubic foot volume per acre trajectories by genotype.

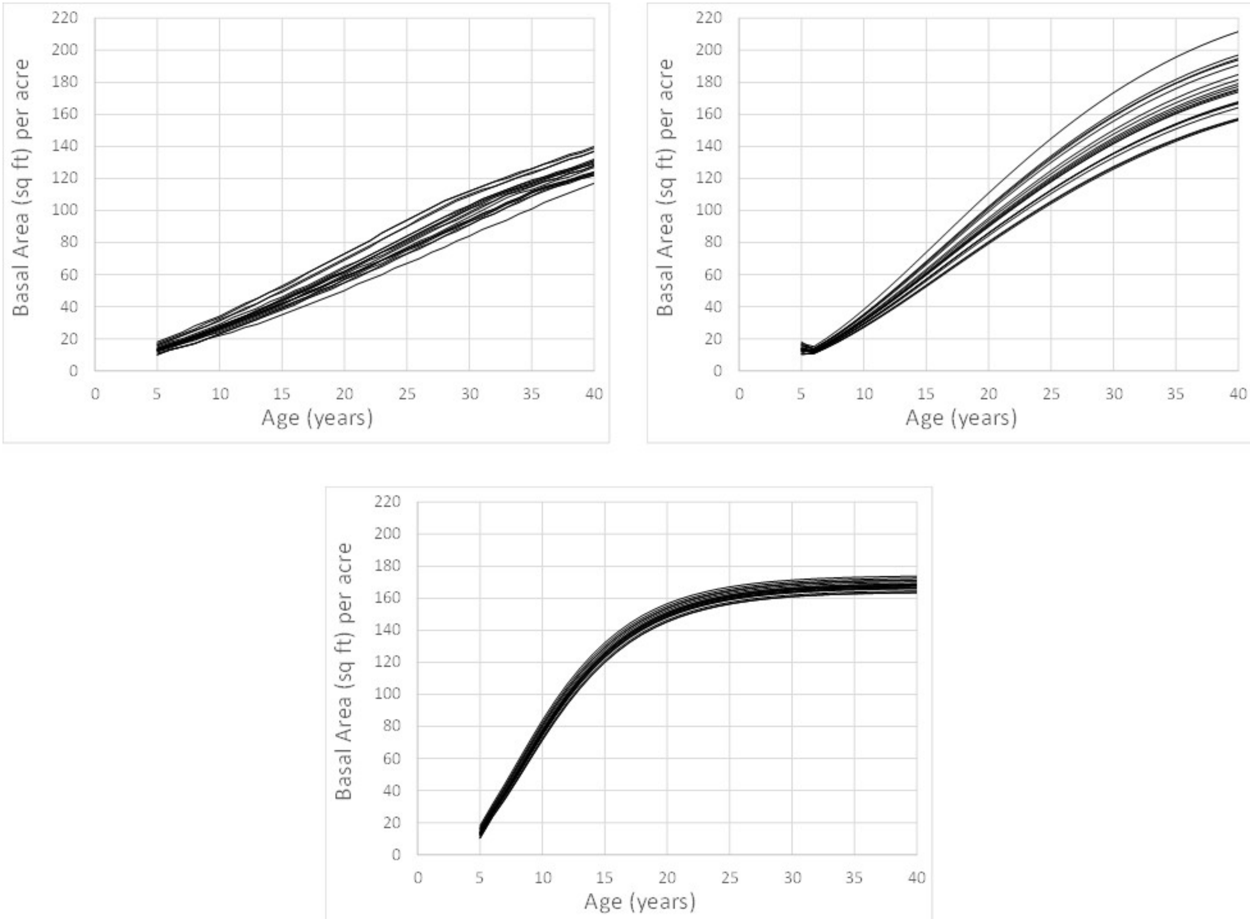

Figure 2—Approach One–Forest Vegetation Simulator (FVS) (upper left), Approach Three [*LongGulf*—Gonzalez-Benecke and others (2012)] (upper right), and Approach Four [mixed effects—equation (2)] (lower) projected unthinned standing basal area per acre trajectories by genotype.

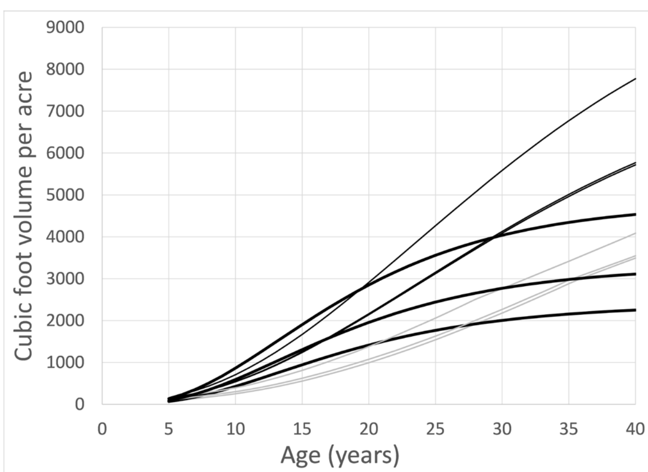

Figure 3—Approach One–Forest Vegetation Simulator (FVS) (gray lines), Approach Two [equation (1)–bold black lines], and Approach Three [LongGulf—Gonzalez and others (2012)] (light black lines) projected standing cubic foot volume per acre trajectories for the lowest (genotype 3–SAL2), median (genotype 16–NAL3), and greatest volume (genotype 9–SAL6) genotypes, observed at age 5. For Approach Three, the lowest and median trajectories are nearly identical.

Volume and BA per acre projections differed substantially by model system both in terms of carrying capacity and trajectory shape through time (figs. 1 through 3). For volume (figs. 1 and 3), Approach Two [equation (1)] produced the most sigmodal trajectories while Approach One (FVS) had little sigmodal shape. The variability among the projection approaches demonstrates uncertainty regarding projections from young ages to rotation ages. The intent of this study is merely to have some idea of the likely behavior in the future and to obtain relative values among the genotypes.

Figure 3 provides the clearest indication of projected volume behavior among the approaches. For all three genotypes, respectively, Approach Three (*LongGulf*) predicts substantially more volume. The Approach One-FVS projected trajectories show very little sigmodal shape and generally the relatively lowest productivity levels across time, respectively by genotype.

Projected volumes are comparable and, in some cases, exceed those from published studies, particularly Approach Three (*LongGulf*). Our projected yields at age 25 generally exceed those observed on a cutover site in southern Mississippi of relatively the same planting density and receiving various cultivation and NPK fertilization treatments

(Schmidtling 1987, VanderSchaaf 2022a). Our projected yields are comparable to those presented in yield tables from plantations in Louisiana and Texas (Lohrey and Bailey 1977), and South (2006) as predicted using the SiMS03 growth and yield model (ForesTech 2005). Based on site class productivities in Goelz and Leduc (2001), at age 25 most genotypes for all three volume approaches are projected to be of Medium-site quality (3,057 cubic feet per acre), with just a few being of Low- (956 cubic feet per acre) and High- (4,331 cubic feet per acre) site qualities.

Projected BAs at age 20 using Approach Four are comparable to those from Haywood and others (2015) and as reported in VanderSchaaf (2022b), a container-stock study located in central Louisiana. The data from that study was in part used to fit the mixed-effects equation [equation (2)] that was calibrated to produce the BA projections presented in figure 2. However, basal area projections using Approaches One and Three are vastly less than those presented in Haywood and others (2015), which averaged 169 square feet of BA per acre at age 20. However, their (Haywood and others 2015) site was found to be relatively productive for longleaf pine.

For Approaches One and Two, given current regeneration costs and the assumed stumpage values, growth rates will not be enough to offset those costs such that a financial profit will be produced (fig. 4). However, economics of Approach Three (*LongGulf*) projections show that establishing many genotypes at this site will produce a financial profit. Our analysis fails to include any stumpage being sold as poles. For southern yellow pines, pole stumpage is often twice that of sawtimber stumpage (LDAF 2019, South 2006, Stottlemyer and others 2017, Tanger 2019). Mills and Stiff (2013) for east Texas showed that having as little as 25 percent of sawtimber stumpage sold as poles can substantially enhance economic returns, and these greater revenues make longleaf pine much more competitive with loblolly pine and in some cases actually producing greater returns than loblolly pine.

Plus, we did not include potential returns for pine straw production. Several studies, South (2006), Mills and Stiff (2013), and Dickens and others (2014), have demonstrated that the sale of pine straw can substantially increase financial returns and/or make longleaf pine financial returns much more comparable to loblolly and slash pine. Future work can examine how varying stumpage values and interest rates will

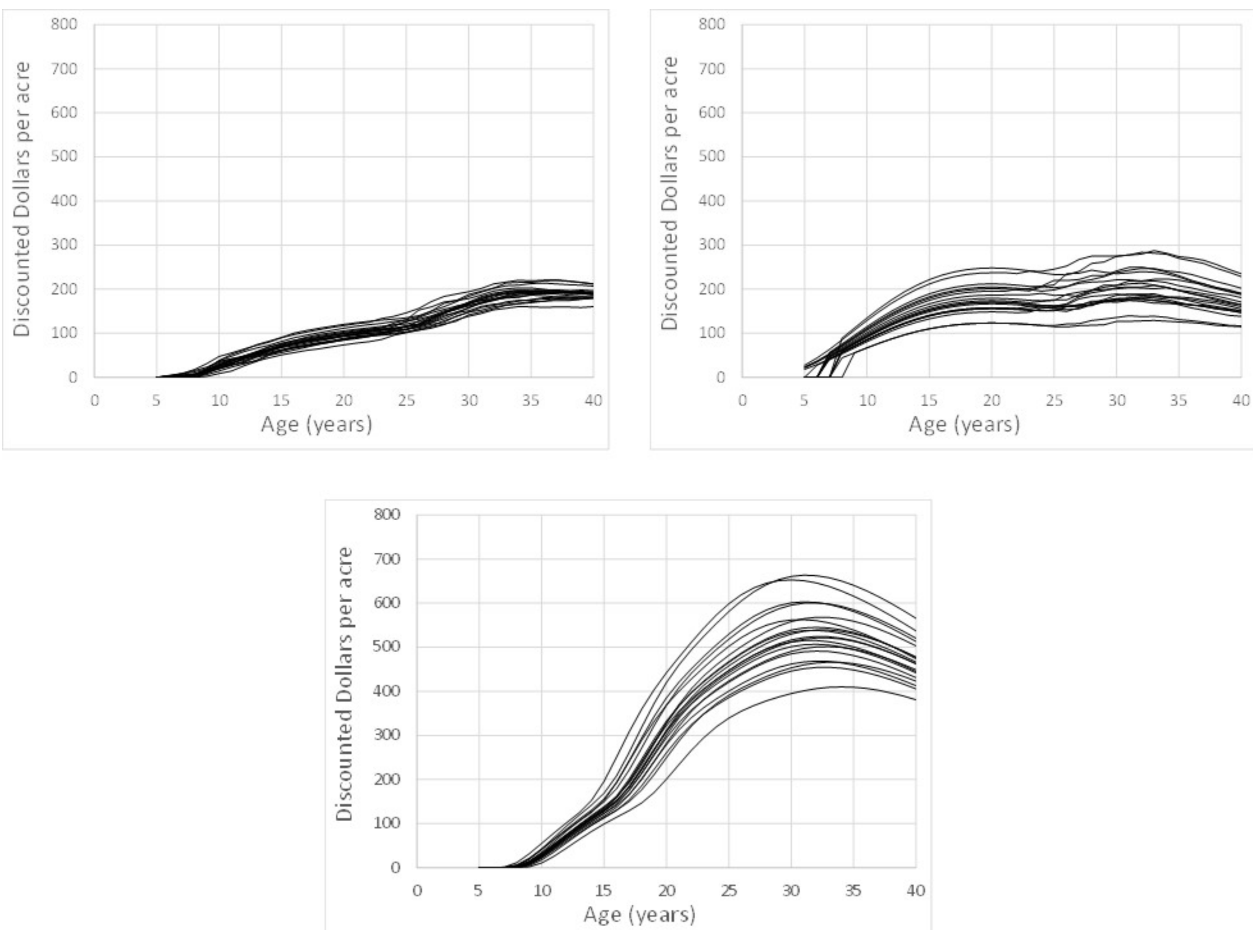

Figure 4—Approach One–Forest Vegetation Simulator [FVS]) (upper left), Approach Two (equation 1) (upper right), and Approach Three [*LongGulf*—Gonzalez-Benecke and others (2012)] (lower) projected discounted revenue per acre trajectories by genotype. Stumpage values were $9, $19, and $25/ton for pulpwood, chip-n-saw, and sawtimber, respectively (Tanger 2019). An interest rate of 6 percent was used.

impact projected financial returns. Additionally, as future measurements are made, a clearer depiction of even further future stand development should be observed such that we can obtain a more meaningful projection of when an initial thinning should be conducted, if desired. Timely thinning treatments might improve financial returns.

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