



Longleaf pine seed source impacts on seedling performance in southern Georgia through age 10-years

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SUMMARY

Longleaf pine containerized seedlings from eleven different seed sources gathered throughout longleaf pine's native range were planted at five sites in central and southeastern Georgia. Trees at each site were regularly inventoried through stand age 10-years. Seed source effects were evident after 10-years as seedlings from the central Gulf Coast generally performed best in terms of survival and growth, but often had stem defect issues. More northern and western seed sources tended to grow more slowly and generally have fewer stem defects. Differences in growth rate were evident based on field site land use history (Surface soil (0-6 inches) P—cutover versus old-field sites) and management (use of mechanical/chemical site preparation and/or herbaceous weed control) at stand establishment. Of the seed sources still available for purchase as 1-0 stock containerized seedlings, Escambia County, Alabama and the Georgia/Florida improved bulk seed mix source may be the best options for landowners interested in planting longleaf pine in central and southeastern Georgia. More northern and western seed sources from longleaf pine's native range tend to grow at significantly slower rates than Gulf Coast seed sources.

INTRODUCTION

Longleaf pine (*Pinus palustris*) restoration throughout the southeastern United States is promoted by multiple federal (e.g., United States Department of Agriculture Natural Resources Conservation Service's Conservation Stewardship Program and Environmental Quality Incentives Program as well as Farm Service Agency's Conservation Reserve Program) and state (e.g., Georgia Forestry Commission Southern Pine Beetle Cost Share Program) cost-share programs. Cost-share programs provide funds for landowners to perform site preparation, purchase and plant seedlings, apply herbaceous weed control, thin, and implement prescribed burns while enrolled in these programs. Even if landowners or managers have the capacity to conduct many of these management activities themselves, they are still left with nursery and seedling selection decisions when purchasing longleaf pine seedlings if artificial regeneration is required. When choosing a nursery a landowner should consider seedling cost, stock type, seedling availability each year and seedling quality and consistency but also seed source location within longleaf pine's native range (Figure 1). Climate (especially annual precipitation and winter low temperatures) within the region and the site's past management history are important factors when considering a seed source. Vegetation communities, soil fertility and soil tilth can differ tremendously between old-field (usually former row crop field or pasture) versus cutover (previously one or more forested rotation) sites. Longleaf pine does not have the same levels of genetic improvement (e.g., faster growth, improved form, and less disease occurrence) as compared to other pine species such as loblolly (*Pinus taeda*) and slash pine (*Pinus elliottii*). Thus, longleaf pine geographic seed source is one important metric that landowners can use to discern if specific longleaf pine seedlings will perform well on their property. This information is important for ensuring landowners are aware of how individual trees and stands will develop for growth and yield estimates, carbon storage, and timber valuation. The objective of this paper was to report on 10-year survival and growth performance of 11 longleaf pine seedling sources planted on five sites with a variety of site and management histories throughout central and southern Georgia.

LONGLEAF PINE AND GEOGRAPHIC VARIATION

Longleaf pine has an extensive native range from eastern Texas to south-eastern Virginia. It is found in the Atlantic and Gulf Coastal Plains as well as the Piedmont, Ridge and Valley and Mountain physiographic regions of northeastern Alabama and northwestern Georgia (Boyer 1990). Tree species with large native ranges such as longleaf pine can have significant genetic differences among populations. This phenomenon is termed geographic variation (White and others 2007), and primary drivers of geographic variation include: annual precipitation, minimum winter temperatures, and latitude (sunlight and growing season length) differences across a species' native range. Geographic variation can affect important traits that impact longleaf pine seedling performance such as adaptability to climate in a given region, survival and growth rates, disease susceptibility, duration of the grass stage prior to active stem growth, and stem form characteristics (Henry and Wells 1967; Wells and Wakeley 1970; Kraus and Sluder 1990). As examples, past research has shown that survival and growth differences can occur as seed is moved from areas where average minimum winter temperatures differ by 6 °F or more (Schmidtling and Sluder 1995), and brown spot needle blight (*Scirrhia acicola*), a serious disease in grass stage longleaf pine seedlings, has been reported as being more prevalent in populations located west of the Mississippi River (Henry and Wells 1967).

Planting guidelines for southern pines that consider planting and seed source locations within a species' native range as well as temperature and precipitation gradients across individual species' ranges have been developed by U.S. Forest Service researchers to assist landowners and managers with seed source planting decisions (Schmidtling 2001). Longleaf pine has its own set of geographic variation guidelines that can assist with seed source seedling planting decisions (from Schmidtling 2001; Figure 2):

1. Seed will survive and grow well if they come from a region with a minimum average temperature within 5 °F of the planting site's minimum average temperature. For climate information visit <https://www.weather.gov/wrh/climate>.
2. Seedlings from a region with warmer winters will grow faster than seedlings from local sources, and seedlings from an area with cooler winters will grow slower.
3. Differences in winter lows can be as much as 10 °F, but with an increased risk of damage at the cold end of the range and growth losses at the warmer end of the range.
4. West-to-east seedling transfers are usually successful because of increasing precipitation moving from west to east across longleaf pine's native range, though long-distance movement from east to west may not be successful due to more droughty conditions in the western Gulf states.

Previous longleaf pine seed source studies (e.g., Wells and Wakeley 1970; Lantz and Kraus 1987) have investigated these well-accepted planting guidelines across large portions of the species' native range. This study investigated longleaf pine seed source survival, growth, and stem quality across a variety of sites with two different management histories using the most widely available containerized stock seed sources at the time of study establishment from 2010 through 2012.



Figure 1: *Healthy, containerized longleaf pine seedlings ready for planting.* Photo: David Clabo

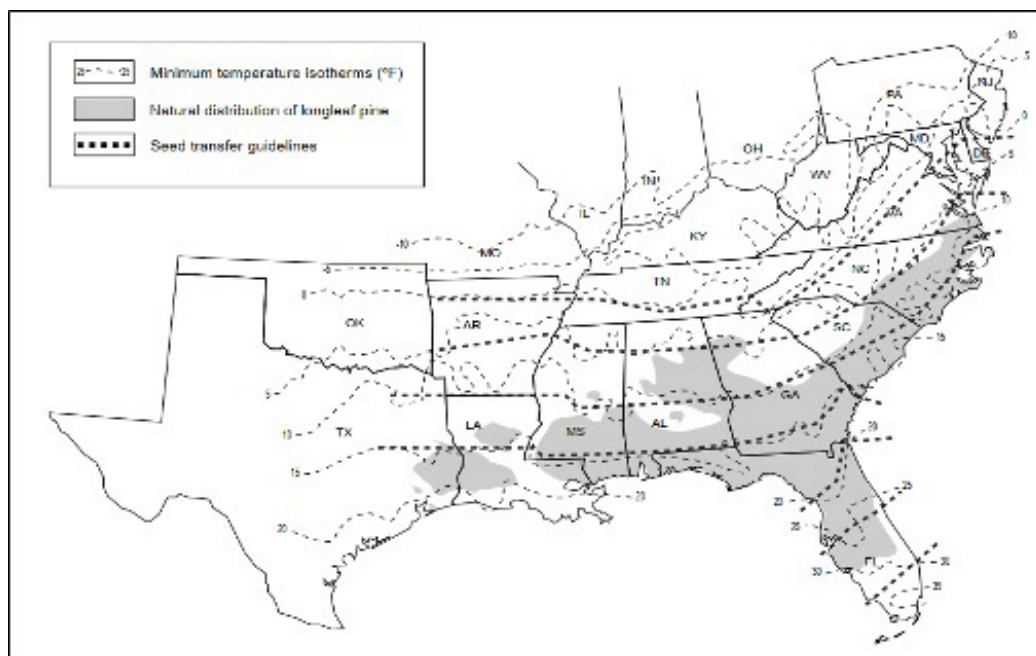


Figure 2: Map showing the natural range of longleaf pine and associated longleaf pine seed transfer boundaries. Seed source zone and selection rules are important when choosing a longleaf pine seed source. Source (Schmidting 2001).

METHODS

Study Sites

Five study areas located on former old-field and cutover sites were selected for installation of longleaf pine seed source trials. Study areas were located in south central and southeastern Georgia in the Lower and Upper Coastal Plain regions (Figure 3). The eleven seed sources available from International Forest Company (IFCO) from 2010 through 2012 are listed in Table 1. All seed sources came from a specific location (seed orchard) or county except for the Georgia/Florida improved source. This source consisted of seed collected from a seed orchard that was grafted with first generation selections. Improved denotes that seed collection was not from wild stands/seed production areas. Seed orchard trees were clones that were collected from superior phenotypes in natural stands from southern Georgia and northern Florida. Degree of improvement was expected to be minimal since seeds were collected from better phenotypes and placed in a bulk mix. Progeny testing by IFCO has not been completed for this source.

Starting from west to east, two of the study sites were located in Tift County, Georgia. The Prostko (seven-acre) and Peavy (11-acre) sites were located on privately owned, former old-field sites on moderately well drained to somewhat poorly drained upland soils. Information on site history, soils, site preparation, seed sources planted, plantation spacing, release operations, and follow-up measurements can be found in Table 2. The third study area was located at the University of Georgia Vidalia Onion and Vegetable Research Center (VOVRC) in Toombs County, Georgia. This site was an 11-acre former pine progeny test site and bermudagrass field on a moderately well-drained upland. The fourth study area was located on privately owned land (Dekle site) in Bulloch County, Georgia. This cutover site was four acres and consisted of a poorly drained soil (Table 2). The fifth and most eastern site was located on private property (TooHolly site) in Screven County, Georgia. This cutover, nine-acre site

was located on a well-drained upland soil (Table 2). Surface soil pH, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), zinc (Zn), and pH were assessed at each site (Table 3).

All seed sources were planted as 1-0 stock containerized seedlings grown at IFCO's nursery near Moultrie, Georgia. Internal measurement plots ranged from 0.08 to 0.17 acres in size and typically were comprised of two or three rows of trees. The first and last tree in each internal measurement row were aluminum tree tagged for future measurements. By stand age 10 years, a bark beetle infestation and excessive mortality in one replication of the Escambia, AL seed source at the VOVRC site resulted in that replication being dropped from the study.

Stand assessments were completed either three or four years after planting depending on location. A second assessment was completed at five, six or eight years after planting, and a third inventory was completed 10 years after planting at each site (Table 2). Survival (not reported here) and height were assessed during the first inventory, while survival, height and diameter at breast height (dbh) were assessed during the second and third inventories. Average total height by seed source from stand ages 3- or 4-years through stand age 10-years (three separate measurements per stand) are presented for each study area. Average diameter at breast height (dbh) (4.5 feet) was measured at stand ages 5-, 6-, or 8-years (first inventory age where dbh could be assessed) through age 10-years are also presented for each stand. Average survival rates, basal area per acre, and mean annual increment ($\text{tons ac}^{-1} \text{yr}^{-1}$) at stand age 10-years were assessed. The longleaf pine stemwood with bark green weight equation is from Harris and others (2022). In addition, presence of a defect and defect types were recorded including: forks, ramicorn branches, cankers, branch whorls (five or more branches originating from the same location on the trunk), broken top, sweep (greater than three-inch shift from vertical in a 16 feet trunk segment), and lean (greater than 5° from vertical). Defects are only presented for the age 10-year assessment.

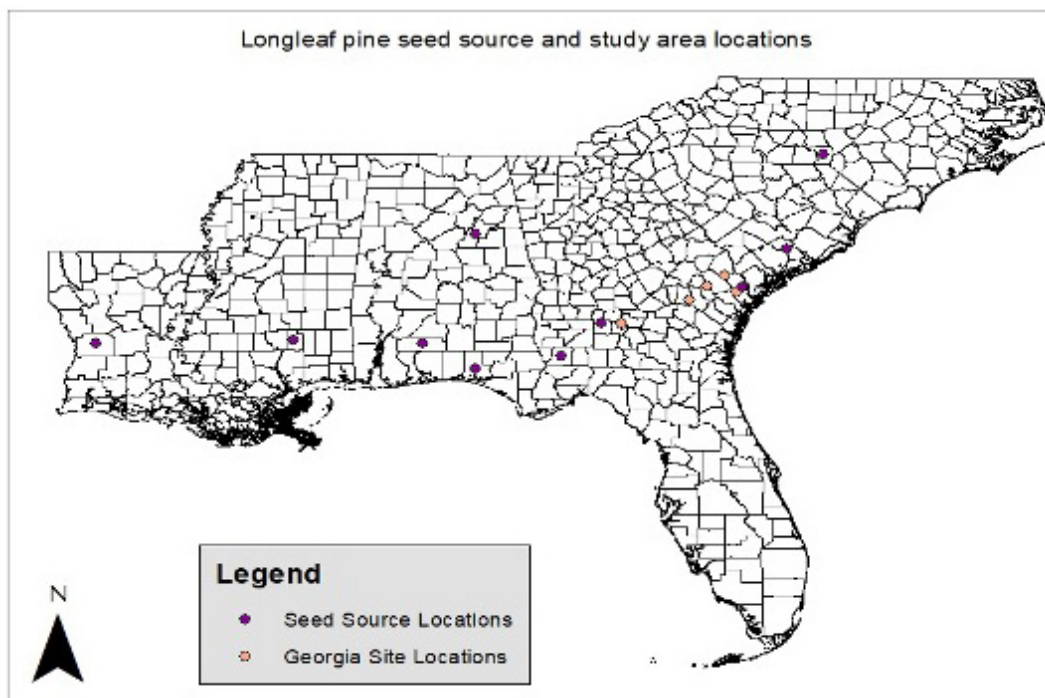


Figure 3: Map of eleven seed source locations from throughout longleaf pine's native range and five seed source trial locations in south central and southeastern Georgia.

Table 1. International Forest Company (IFCO) seed sources available during 2010–2012 and availability as of November 2020.

Seed Source	IFCO 2020 Availability
Decatur County, GA	Discontinued
Dorchester County, SC	Discontinued
Escambia County, AL	Available
Georgia/Florida Improved	Available
Lamar County, MS	Discontinued
Richmond County, NC	Available
Talladega County, AL	Available
Rincon, GA (Union Camp)	Discontinued
Vernon Parish, LA	Available
Walton County, FL	Discontinued
Worth County, GA	Discontinued

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Table 2. Site characteristics and management history for the five sites across south central and southeastern Georgia included in the longleaf pine seed source study. All study areas were hand planted using hoedads (Dekle and TooHolly) or tube dibbles (Prostko, Peavy, and VOVRC).

Site	Acres	Soil Series	CRIFF* Classifi- cation	Site History	Site Preparation			Seed Sources Planted	Date Plant- ed	Planting Spacing (ft)	Herbaceous Weed and/or Woody Plant Control	Prescribed Fire History	Measurement Date(s)
					Burn	Mechanical	Chemical						
Prostko Tift Co.	7	Leefield and minor Alapaha inclusions	B	Old- field	No	Disk	Glypho- sate (3.5 qts/ac) during Oct. 2012	Decatur; Dorchester; Escambia; GA/ FL Improved; Lamar; Rich- mond; Union (Rincon, GA); Vernon; Wal- ton; Worth	Dec. 2012	7 x 10	Yes (5 first and second- year herbaceous weed control applications)	None	April 2016 (stand age 3); March 2018 (stand age 5); early June 2023 (stand age 10)
Peavy Tift Co.	11	Clarendon and Ocilla	E and B	Old- field and former Christ- mas tree farm	Yes (fall 2012)	No	No	GA/FL Improved; Lamar; Talla- dega; Vernon; Walton	Dec. 2012	7 x 10	No	Three burns	April 2016 (stand age 3); March 2018 (stand age 5); early June 2023 (stand age 10)
Vidalia Onion Vegetable Research Center (VOVRC) Toombs Co.	11	Tifton and Irwinton	E	Old- field	Yes (Nov. 2012)	Yes-2 pass rip to 18- inch depth during summer 2012	Yes-Po- laris AC (imazap- yr) @24 oz/ac + 4 qt/ac Razor Pro (gly- phosate) during Sep. 2012	Dorchester; Decatur; Es- cambia; GA/ FL Improved; Lamar; Richmond; Union Camp (Rincon, GA); Vernon; Wal- ton; Worth	Dec. 2012	6 x 9 and 6 x 10	Yes-10 oz/ac Oustar during April of 1 st year and Envoy Plus (clethodim) in plots with Bermudagrass during second growing season	None	Feb. 2016 (stand age 3); March 2019 (stand age 6); Dec. 2022 (stand age 10)
Dekle Bulloch Co.	4	Pelham	B	Cutover	No	No	Yes-Po- laris SP (imazap- yr) + gly- phos-ate Oct. 2011	Decatur; Dorchester; Escambia; GA/ FL Improved; Lamar; Richmond; Talladega; Vernon; Wal- ton; Worth	Jan. 2012	7 x 10	No	None	Feb. 2016 (stand age 4); March 2018 (stand age 6); April 2022 (stand age 10)
TooHolly Screven Co.	9	Blanton	F	Cutover	Yes (fall 2011)	Yes-root rake and windrow summer 2011	No	Decatur; Dorchester; Escambia; GA/ FL Improved; Lamar; Richmond; Tal- ladega; Vernon; Walton; Worth	Jan. 2012	7 x 10	Yes- basal bark application of hardwoods in Feb 2012; foliar glyphosate spot sprays on hardwoods Oct. 2012, and understory and midstory hard- wood control with hack and squirt applica- tion summer 2019	Yes-burns at stand ages 4 and 6	Feb. 2017 (stand age 5); Feb. 2020 (stand age 8); April 2022 (stand age 10)

*CRIFF-Cooperative Research in Forest Fertilization-University of Florida soil classification system based on soil texture, drainage class, soil texture depths, and presence/depth of an argillic and/or spodic horizon for the Coastal Plain region of Florida and Georgia. For more information on the CRIFF soil classification system, refer to Jokela and Long (2018), <https://edis.ifas.ufl.edu/publication/FR053>

Table 3. Surface soil (0–6 inches) pH and nutrient levels (lbs ac⁻¹—Mehlich I extraction procedure) for each study area.

Site	pH range	Mehlich I lb ac ⁻¹ range					
		P	K	Ca	Mg	Mn	Zn
Prostko	5.4-5.9	47.0-68.0	15.0-35.0	307.0-751.0	31.0-61.0	8.0-12.0	2.0-3.0
Peavy	5.3-5.6	9.0-23.0	33.0-47.0	413.0-471.0	54.0-64.0	15.0-21.0	2.0
VOVRC	5.0-5.9	28.0-118.0	59.0-117.0	329.0-876.0	45.0-133.0	8.0-23.0	3.0-7.0
Dekle	4.6-4.8	3.7-4.6	15.3-29.9	101.8-261.0	20.6-46.6	3.3-13.1	0.6-1.5
TooHolly	5.1-5.5	29.9-33.7	24.8-46.4	284.0-534.0	55.4-96.4	21.3-34.3	0.7-4.7

RESULTS

Overall survival was greatest with the Lamar, MS seed source across all sites (82.9%), followed by Union Camp (Rincon, GA) at 76.5% and Vernon, LA at 75.4% (Table 4). Poorest survival by seed source across all sites was Walton County, FL (58.5%) followed by the GA/FL improved source (60.3%) and the Worth County, GA (62.4%) source (Table 4). The 11 longleaf pine seed sources differed in survival rate by site after 10-years (Table 5). The highest seed source survival rate at individual sites were Lamar, MS at Dekle (88.2 %), Prostko (85.9 %), and VOVRC (85.8%), Dorchester, SC (92.0%) at the Dekle site, Vernon, LA (90.9%) at the Dekle site, and Worth, GA (88.4%) at the TooHolly site (Table 5). Survival was generally greater than 55% across all site x seed source combinations (Table 5). The lowest survival rates were observed with the GA/FL Improved (33.6%) and Walton, FL (38.7%) sources at the Peavy site, 45.6% for the GA/FL improved source at the Prostko site and 54.5% for Worth, GA at the VOVRC site (Table 5). It should be noted that during October 2018 hurricane Michael caused sporadic individual tree mortality at the Peavy site.

Diameter growth tended to be greatest at the Peavy, Prostko and VOVRC sites, all sites that had a history of fertilization prior to being planted to longleaf pine. After 10-years, trees across all seed sources at the Dekle and TooHolly sites were at least one inch smaller in average dbh than the Peavy, Prostko, and VOVRC sites (Figure 5). The Dekle and TooHolly sites were the two cutover sites. At age ten years, seed source diameter growth was greatest across sites with the GA/FL Improved, Walton, FL, and Worth, GA sources averaging 5.5 in each (Figure 6). The Talladega, AL seed source had the smallest average dbh (4.7 in) followed by Lamar, MS and Vernon, LA (each 5.0 in). Diameter growth for each seed source through time is presented by site in Figures 7-11. For seed source x site combinations with survival greater than 60% at age 10-years, annual diameter increment was least on average for Vernon, LA at Dekle (0.39 in), Dorchester, SC at VOVRC (0.39 in), Richmond, NC at TooHolly (0.39 in), Lamar, MS at Dekle (0.40 in), and Walton, FL at Dekle (0.43 in). Average dbh annual increment was greatest for Lamar, MS (0.66 in) at Peavy, Vernon, LA (0.65 in) at TooHolly, Lamar, MS (0.63 in) at TooHolly, and Decatur, GA and Union Camp at the Prostko site with both averaging 0.62 in (Figure 12).

Similar to dbh, total height across all seed sources after ten years was greatest at the Prostko, VOVRC, and Peavy sites (Figure 13). On average across all sites, the Union Camp (Rincon, GA) seed source was the tallest (32.2 ft) followed by GA/FL improved (31.8 ft; Figure 14), Escambia, AL (31.5 ft), Worth, GA (31.1 ft), and Decatur, GA (31.0 ft). The shortest seed source on average was Talladega, AL (27.7 ft), followed by Richmond, NC (28.7 ft), Vernon, LA (29.5 ft), and Lamar, MS and Dorchester, SC both at 29.7 ft (Figure 15). Height growth through time by seed source starting at either age three or four through age ten years at each site is presented in Figures 16-20. Average annual height growth from ages three or four through five to eight years ranged from 1.9 ft year⁻¹

for the Richmond, NC source at the TooHolly site to 5.2 ft year⁻¹ for the GA/FL improved source at the VOVRC. The greatest annual height growth rates observed during the interval from the first to second inventory were all observed at the VOVRC. Other than GA/FL improved the next greatest were Walton, FL (5.2 ft year⁻¹), Decatur, GA (4.9 ft year⁻¹), and 4.8 ft year⁻¹ for both Escambia, AL and Union Camp (Rincon, GA). The smallest annual height growth rates by seed source for the same period were all observed at the TooHolly site. Other than Richmond, NC, the next shortest annual height growth rates were GA/FL improved (1.9 ft year⁻¹), Talladega, AL (2.0 ft year⁻¹), and Dorchester, SC and Walton, FL both at 2.2 ft year⁻¹. Most seed sources annual height growth ranged from 3 to 4.5 ft year⁻¹ across all sites from ages three or four through five to eight years after planting. Average annual growth rates increased at three (TooHolly, Peavy and Prostko) of the five sites during the period from the second through third inventory (stand ages five to eight through age ten years). The greatest annual height growth rates occurred at the Prostko site. The Union Camp (Rincon, GA) source averaged 4.8 ft year⁻¹ from stand age five to ten years, Lamar, MS 4.6 ft/year, Vernon, LA 4.6 ft year⁻¹, Escambia, AL 4.6 ft year⁻¹, and Decatur, GA 4.5 ft year⁻¹, respectively. The smallest annual height growth increment was the Walton, FL source at TooHolly (2.5 ft year⁻¹), Vernon, LA (2.7 ft year⁻¹) at Dekle, Worth, GA at TooHolly (2.8 ft year⁻¹), Richmond, NC (3.1 ft year⁻¹) at TooHolly, and Talladega, AL (3.1 ft year⁻¹) at the Dekle site. Most seed sources annual height growth ranged from 3.5 to 4.3 ft year⁻¹ across all sites ages five to eight through 10-years after planting.

Basal area per acre at age ten years did not differ by site but did differ significantly by seed source across all sites (Table 6). Escambia, AL (98.4 ft² ac⁻¹) and Dorchester, SC (91.3 ft² ac⁻¹) had the two largest basal areas per acre at age ten years, though it should be noted that one Escambia, AL replication at VOVRC was dropped from the study due to low survival caused by an Ips beetle outbreak. Worth, GA (68.6 ft² ac⁻¹) and Talladega, AL (70.4 ft² ac⁻¹) had the lowest basal area per acre values. It should be noted that Worth, GA had poor survival (54.5%) at VOVRC and Talladega, AL had poor survival (55.0%) at the Peavy site (Table 5). Similar to basal area per acre, mean annual increment growth expressed as tons per acre per year did not differ at age ten years across sites but did differ by longleaf seed source (Table 7). The Escambia, AL source had the largest mean annual increment 5.7 tons ac⁻¹ yr⁻¹, followed by Union Camp (Rincon, GA) at 5.2 tons ac⁻¹ yr⁻¹ and Dorchester, SC (5.1 tons ac⁻¹ yr⁻¹). Talladega, AL had the smallest mean annual increment at 3.4 tons ac⁻¹ yr⁻¹ followed by Walton, FL (3.9 tons ac⁻¹ yr⁻¹), and Worth, GA and Richmond, NC both with 4.0 tons ac⁻¹ yr⁻¹.

Stem defects were common across all seed sources with stems having no defects ranging from 48.5% for Dorchester, SC to 65.2% for the GA/FL improved source (Table 8). Ramicorn branches (a steep angled branch with a branch base diameter at least 33% of the stem diameter at the height of the ramicorn branch) were the most common defect type within pulpwood merchantable height (to a 3-inch top; outside bark) and the Dorchester, SC source had more frequently occurring ramicorn branches (24.1%) than all other seed sources. Forks were the next most common stem defect, followed by branch whorls and cankers (Table 8). Stems that had a second defect within merchantable pulpwood height were much less common. The second defect free rate ranged from 86.2% for Decatur, GA to 95.5% for Vernon, LA (Table 9). The most frequently observed second defect type was ramicorn branches (2.5 to 8.2% of stems with a second defect) followed by branch whorls (0 to 2.8%), and forks (0 to 2.8%) (Table 9).

Table 4. Longleaf pine average survival and standard error by seed source at stand age 10-years. Seed sources that do not share a letter differ statistically (p = 0.05).

Seed Source	Mean (%)	Standard Error (%)	Letter Group
Decatur, GA	72.3	3.8	BC
Dorchester, SC	73.3	3.7	AB
Escambia, AL	72.6	4.1	ABC
GA/FL Improved	60.3	3.4	D
Lamar, MS	82.9	3.4	A
Richmond, NC	66.0	3.8	BCD
Talladega, AL	69.9	5.0	BCD
Union Camp	76.5	4.8	AB
Vernon P, LA	75.4	3.4	AB
Walton, FL	58.5	3.4	D
Worth Co, GA	62.4	3.7	CD

Table 5. Longleaf pine average survival rate (± standard error) by seed source across five sites in south central and southeastern Georgia. Seed sources that do not share a letter within a column differ statistically (p = 0.05).

Average survival rate % (± SE) by seed source and site at age 10-years					
Seed Source	Peavy	Dekle	Prostko	TooHolly	VOVRC
Decatur, GA	-- ^a	74.6 ± 5.6 bc	73.3 ± 6.2 ab	56.6 ± 6.0 e	84.7 ± 3.9 a
Dorchester, SC	--	92.0 ± 5.6 a	67.2 ± 6.0 bc	82.8 ± 5.8 ab	72.6 ± 3.7 bcd
Escambia, AL	--	76.5 ± 5.6 bc	75.3 ± 6.0 ab	71.1 ± 5.5 bcd	82.0 ± 4.7 abc
GA/FL Improved	33.6 ± 5.4 c	81.5 ± 5.6 abc	45.6 ± 5.9 d	67.2 ± 6.0 cde	66.8 ± 3.8 def
Lamar, MS	74.0 ± 5.4 a	88.2 ± 5.6 ab	85.9 ± 6.0 a	77.6 ± 6.2 abcd	85.8 ± 3.9 a
Richmond, NC	--	81.7 ± 5.6 abc	65.6 ± 6.2 bc	84.0 ± 6.7 ab	61.6 ± 3.8 fg
Union Camp (Rincon, GA)	--	--	67.2 ± 6.0 bc	--	81.8 ± 3.7 ab
Talladega, AL	55.0 ± 5.2 b	84.3 ± 5.6 abc	--	70.4 ± 5.5 bcde	--
Vernon P, LA	60.5 ± 5.2 b	90.9 ± 5.6 a	83.0 ± 6.0 a	80.7 ± 6.3 abc	71.4 ± 3.8 cde
Walton, FL	38.7 ± 5.3 c	71.7 ± 5.6 c	55.7 ± 6.0 cd	63.4 ± 6.7 de	61.6 ± 3.9 efg
Worth Co, GA	--	73.2 ± 5.6 c	62.5 ± 6.0 bc	88.4 ± 4.9 a	54.5 ± 3.9 g

a ‘--’ indicates that a seed source was not planted at a given site.



Figure 4: *The Lamar County, Mississippi seed source had the highest survival rate (85.8%) of the 10 seed sources planted at the Vidalia Onion and Vegetable Research Center (VOVRC). This photo of a Lamar, MS plot is from July 2020 (stand age 7-years).*

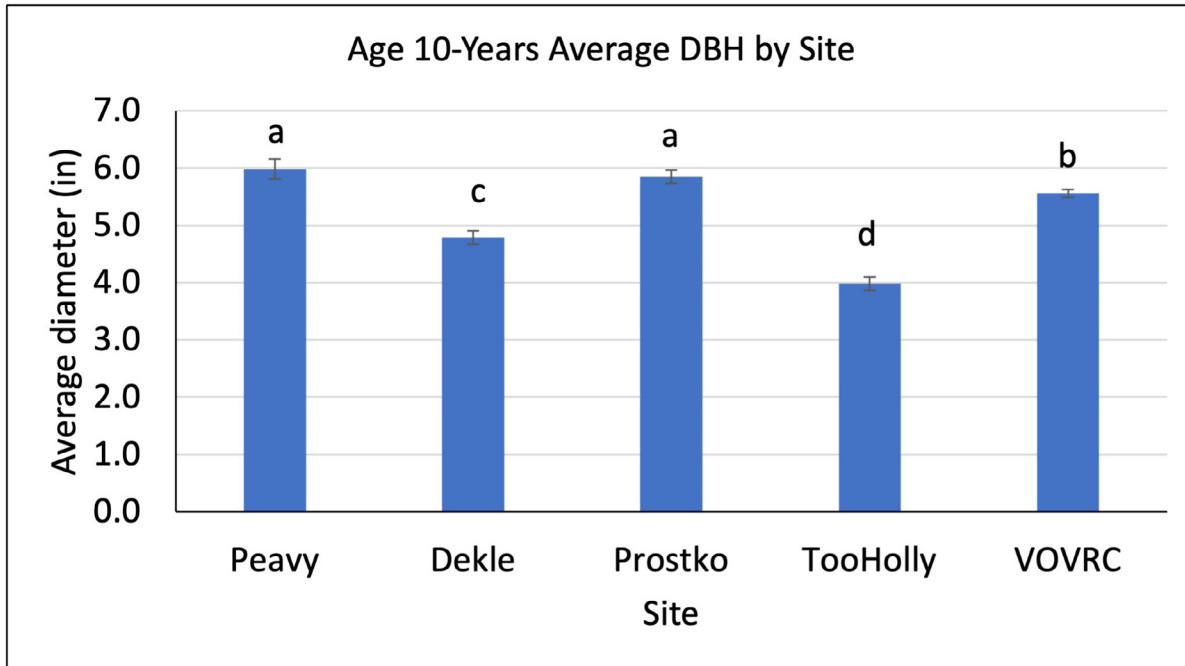


Figure 5: Longleaf pine average diameter at breast height (dbh) through ten years by study site in south central and southeastern Georgia. Bars within columns represent standard error. Sites that do not share the same letter differ statistically ($p = 0.05$).

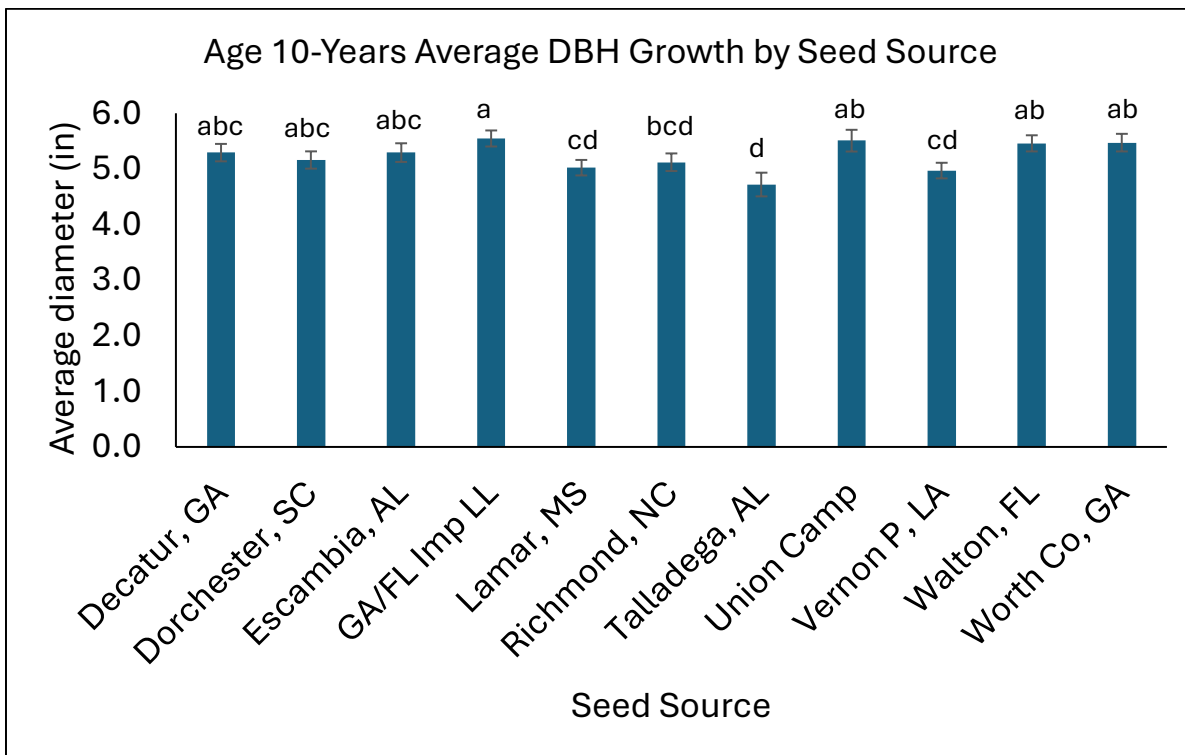


Figure 6: Longleaf pine average diameter at breast height (dbh) growth after ten years by seed source across five study sites in south central and southeastern Georgia. Bars within columns represent standard error. Seed sources that do not share the same letter differ statistically ($p = 0.05$).

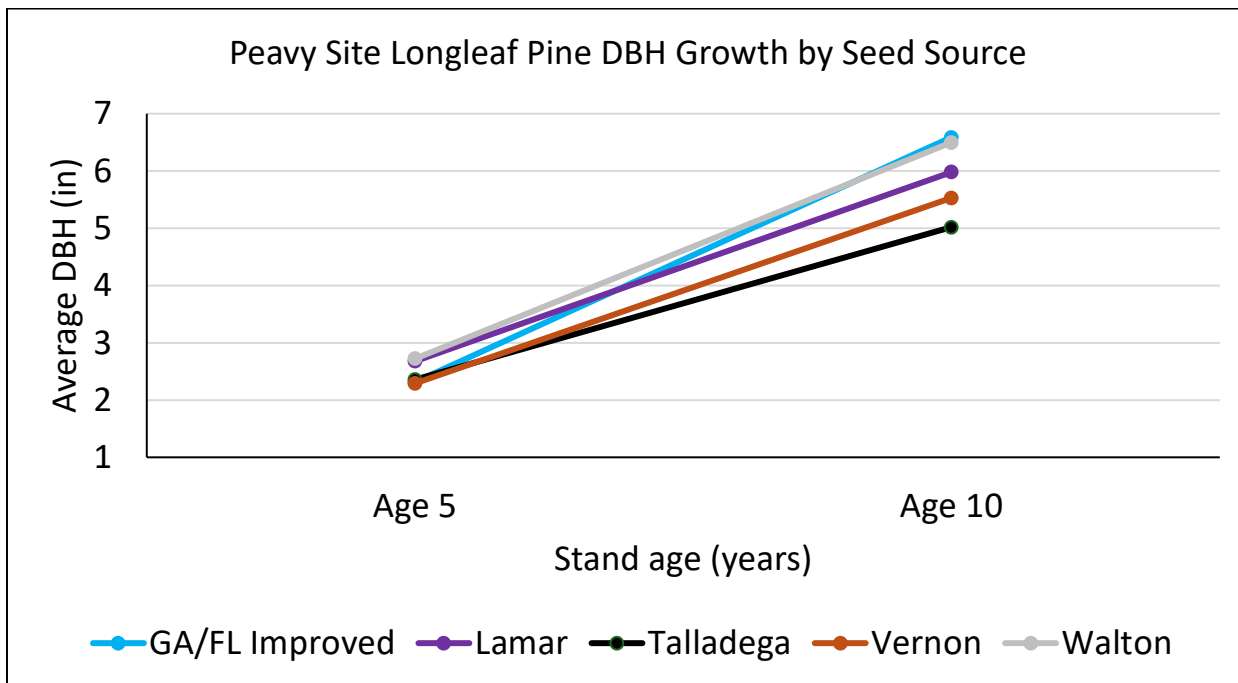


Figure 7: Average diameter growth through time for each seed source from age five through ten years at the old-field Peavy site in Tift County, GA.

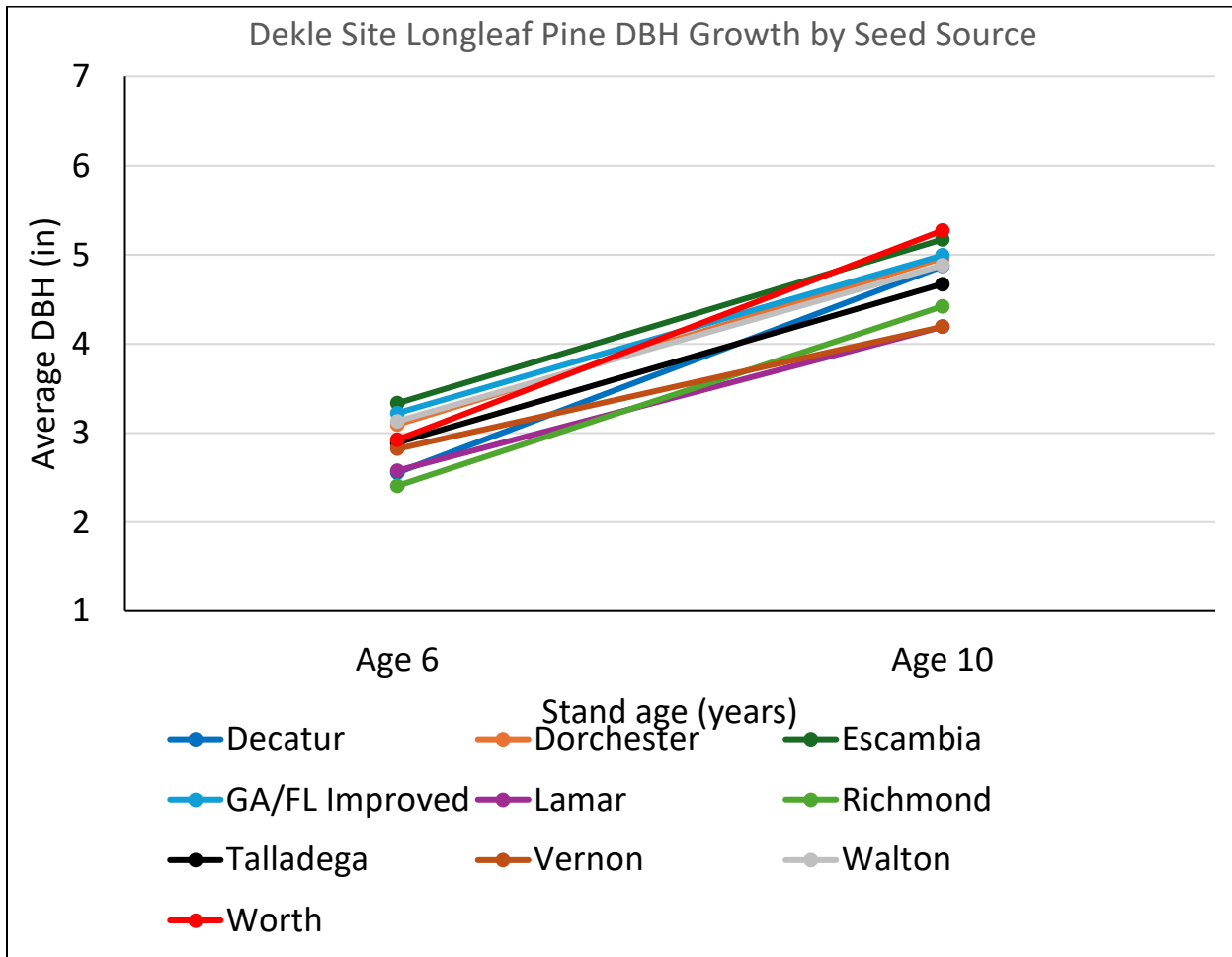


Figure 8: Average diameter growth through time for each seed source from age six through ten years at the cutover Dekle site in Bulloch County, GA.

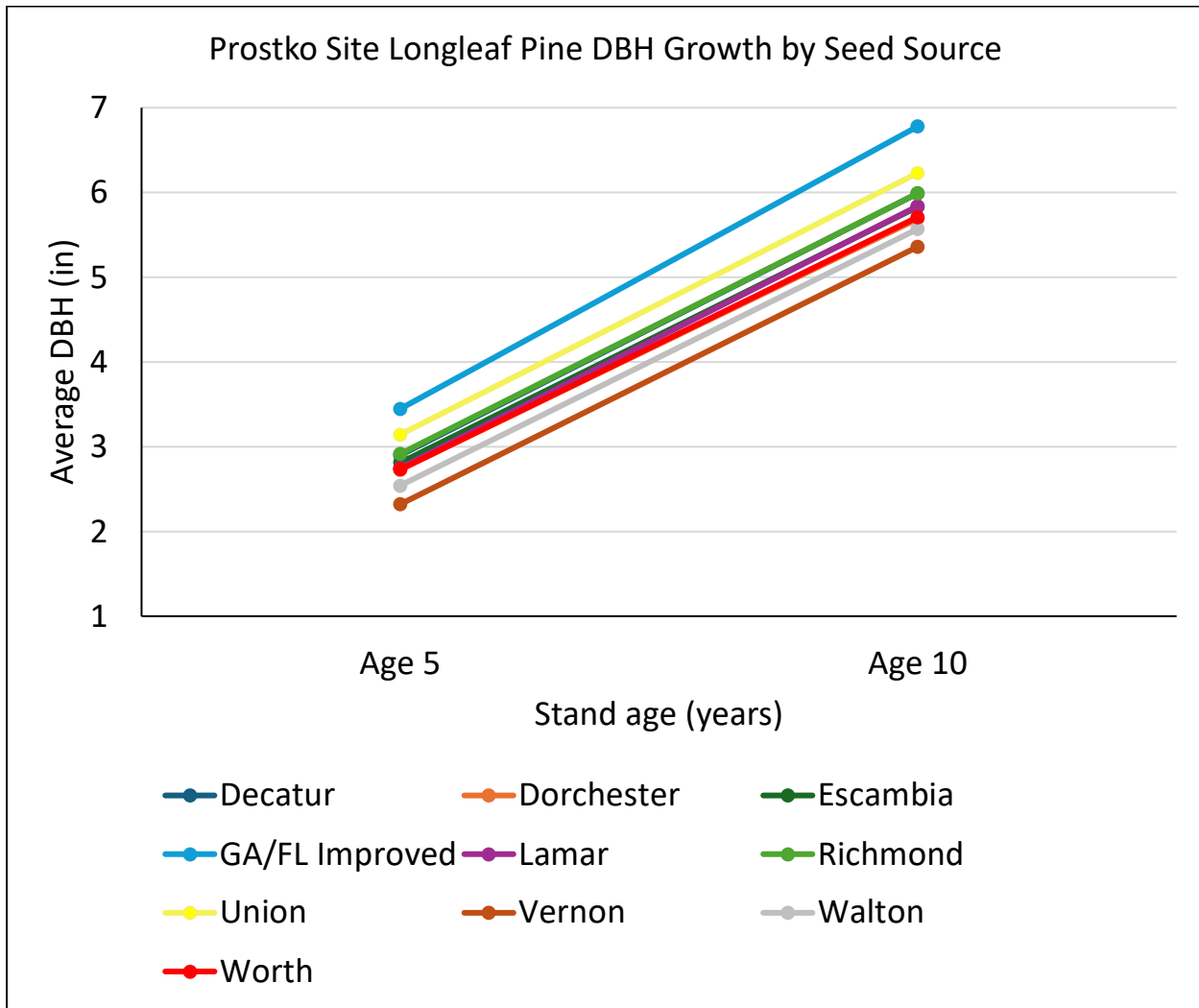


Figure 9: Average diameter growth through time for each seed source from age five through ten years at the old-field Prostko site in Tift County, GA.

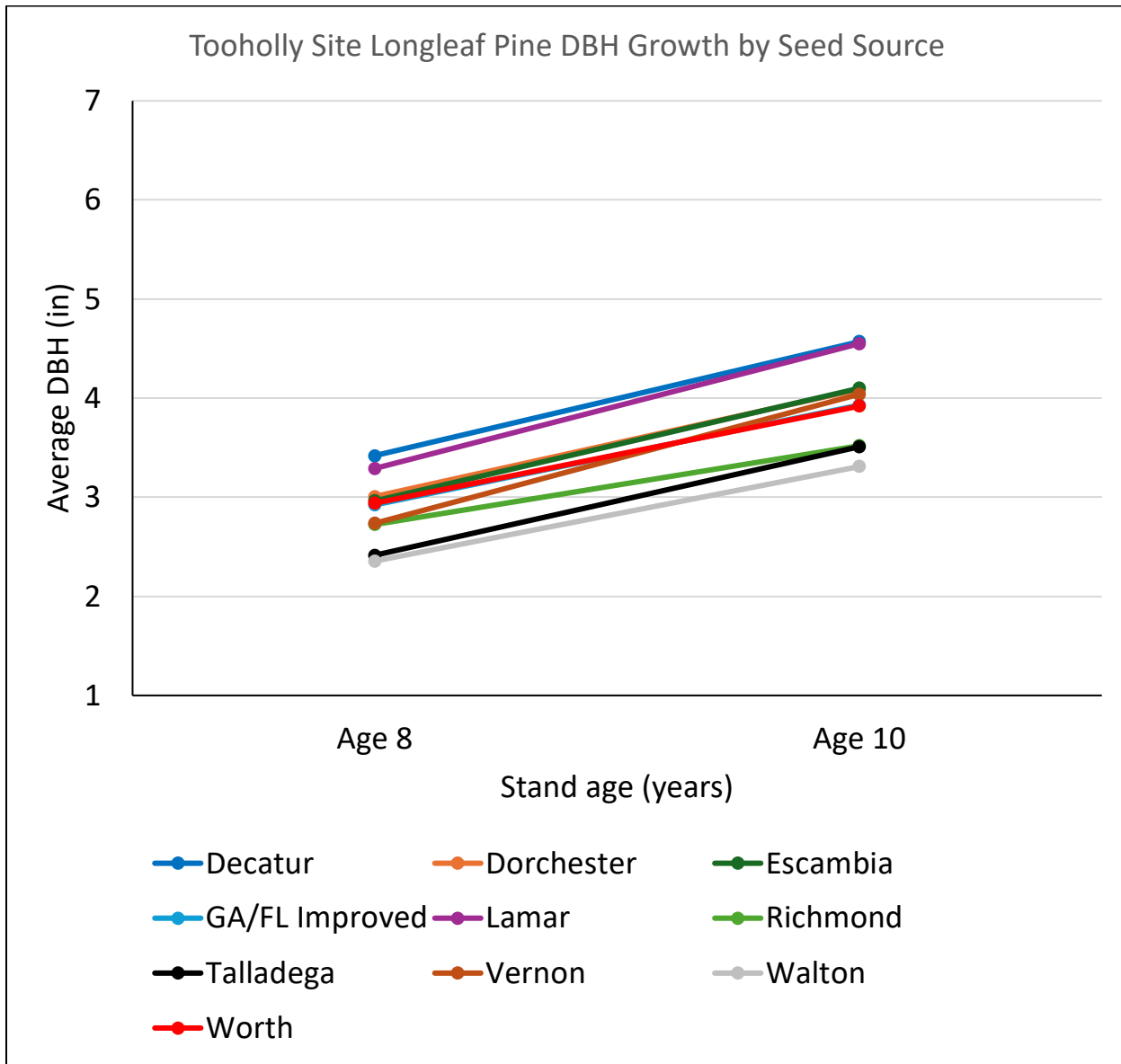


Figure 10: Average diameter growth through time for each longleaf pine seed source from age eight through ten years at the cutover TooHolly site in Screven County, GA.

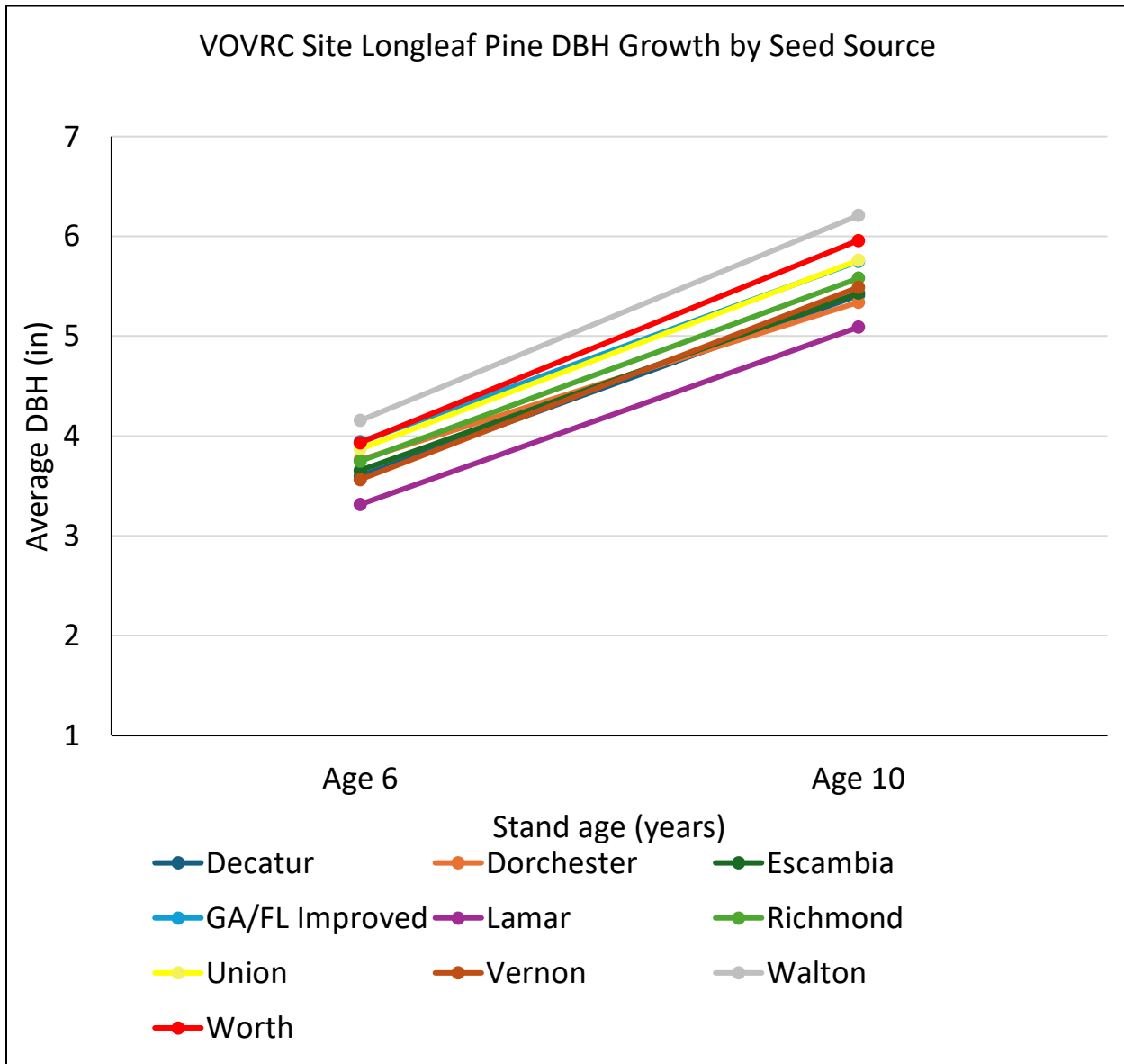


Figure 11: Average diameter growth through time for each longleaf pine seed source from age six through ten years at the old-field Vidalia Onion and Vegetable Research Center (VOVRC) site in Toombs County, GA.



Figure 12: The Union Camp (Rincon, Georgia seed orchard) seed source grew 0.62 inches year⁻¹ in diameter from stand ages five to ten years. The photo on the left from July 2020 shows the Union Camp source at the Prostko site during its eighth growing season, while the photo on the right shows the same stand (Tift County, GA) during 2023 during its 11th growing season.

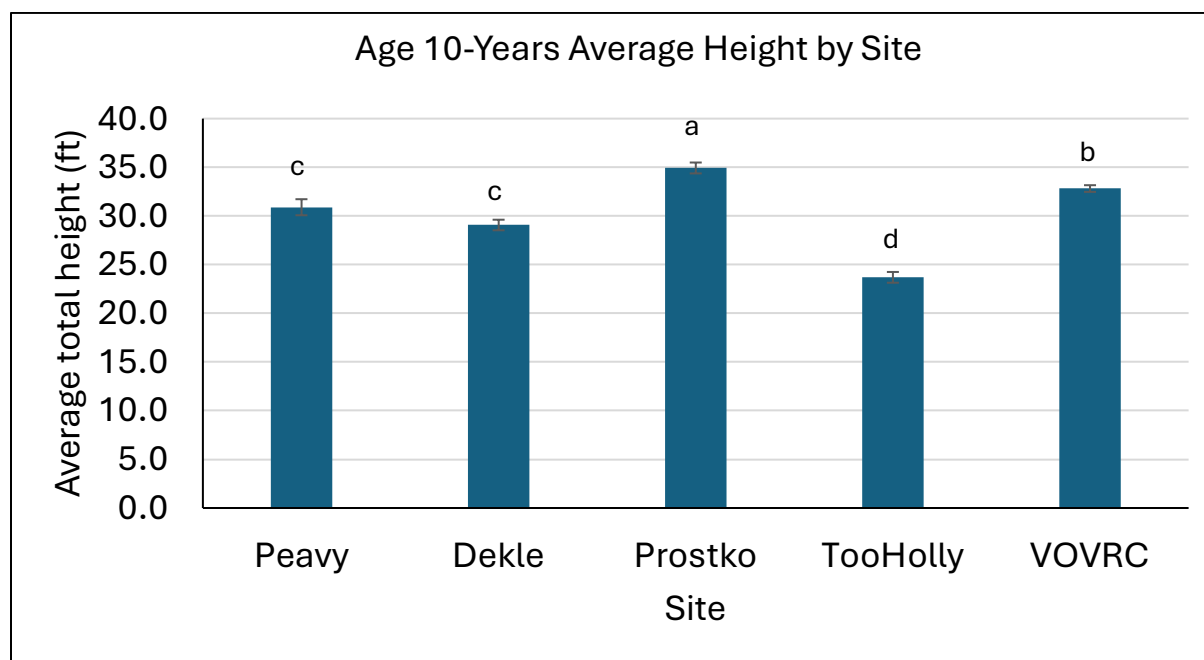


Figure 13: Longleaf pine average total height at age ten years by study site in south central and southeastern Georgia. Bars within columns represent standard error. Sites that do not share the same letter differ statistically ($p = 0.05$).



Figure 14: *The GA/FL improved longleaf seed source was the second tallest on average across all sites. This photo shows the GA/FL improved plot at the Prostko site (Tift County, GA) during its 11th growing season during early June 2023.*

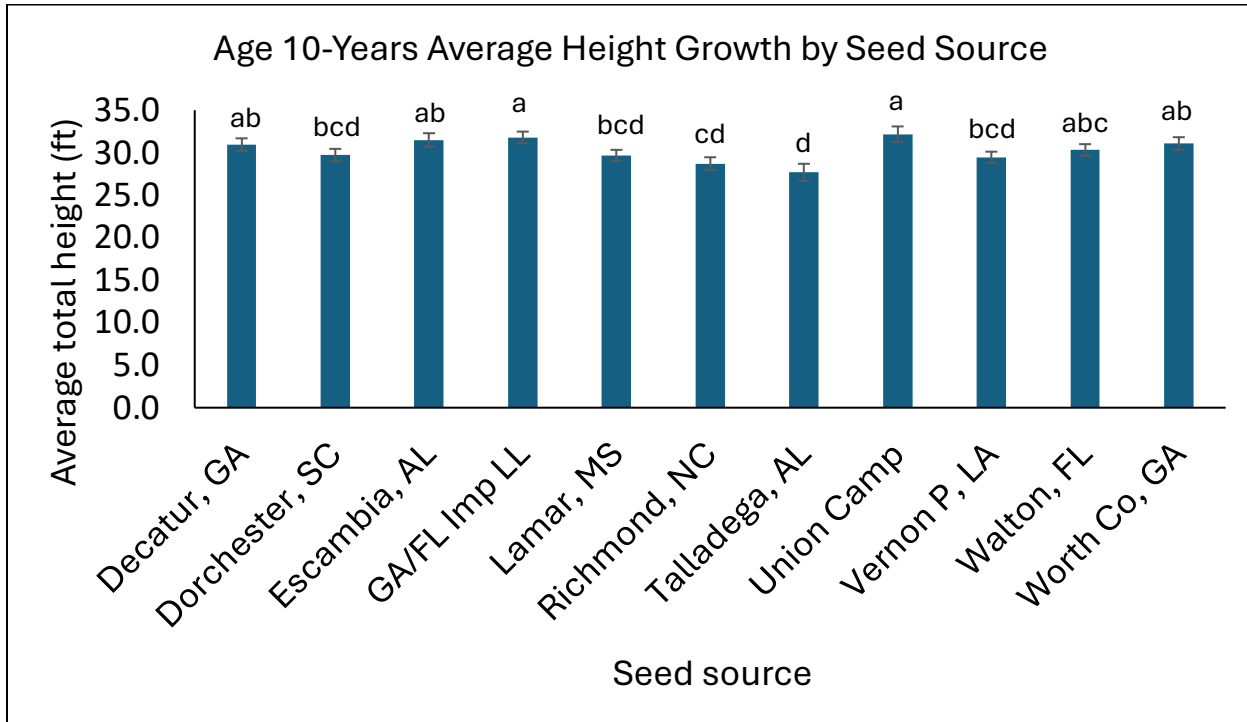


Figure 15: Age ten longleaf pine average total height by seed source across five study sites in south central and southeastern Georgia. Bars within columns represent standard error. Seed sources that do not share the same letter differ statistically ($p = 0.05$).

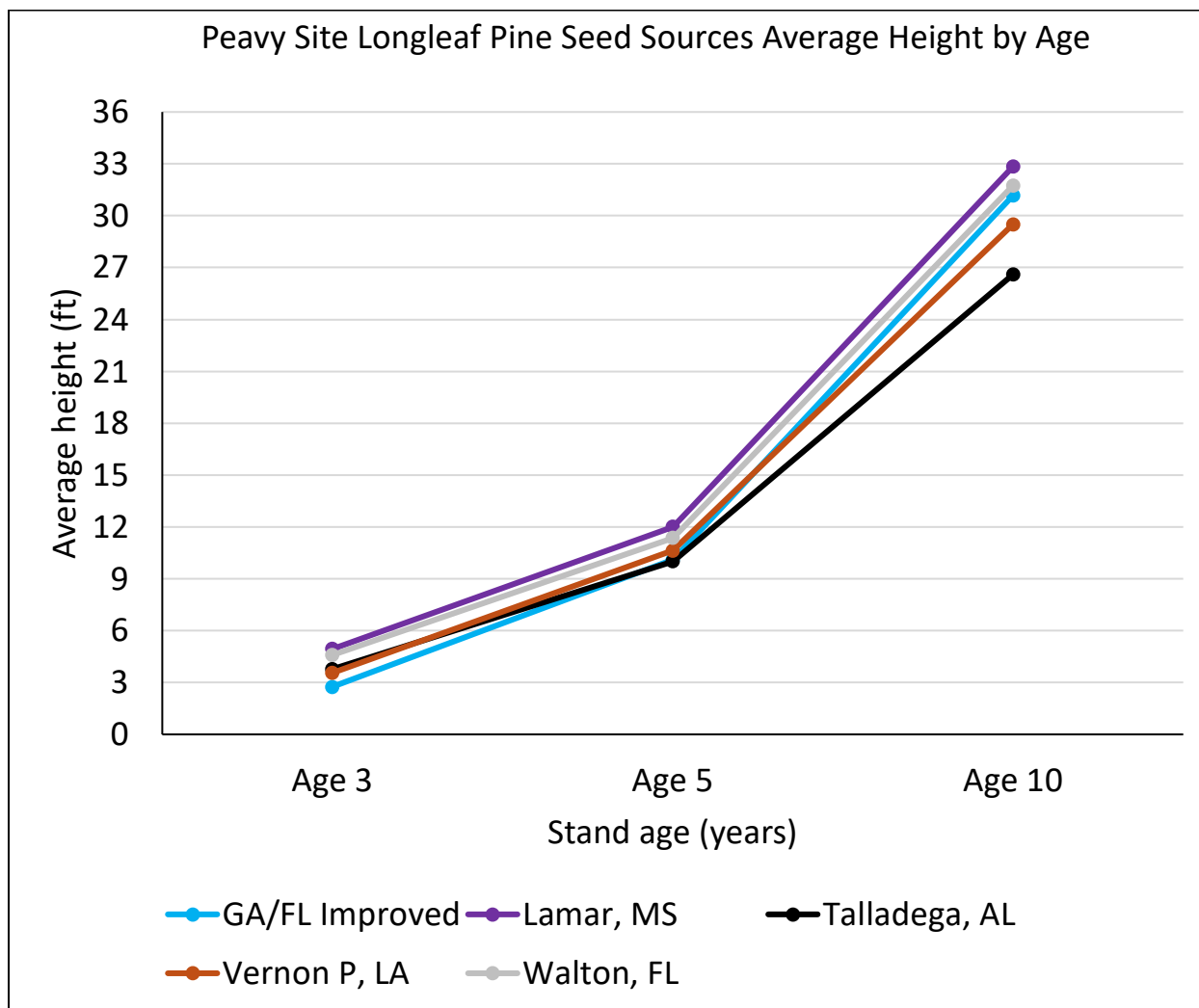


Figure 16: Average height growth through time for each seed source from age three through ten years at the old-field Peavy site in Tift County, GA.

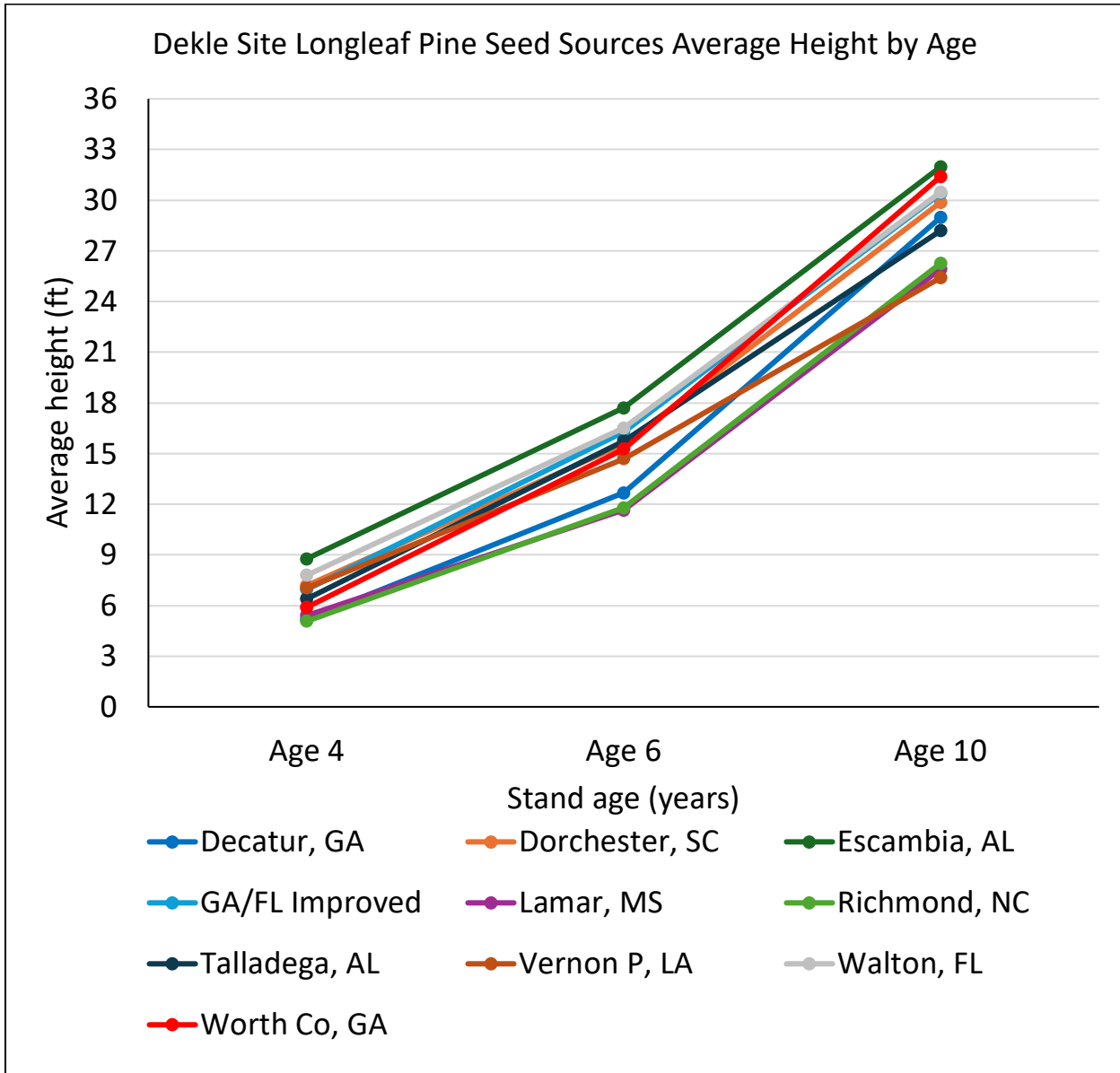


Figure 17: Average height growth through time for each seed source from age four through ten years at the cutover Dekle site in Bulloch County, GA.

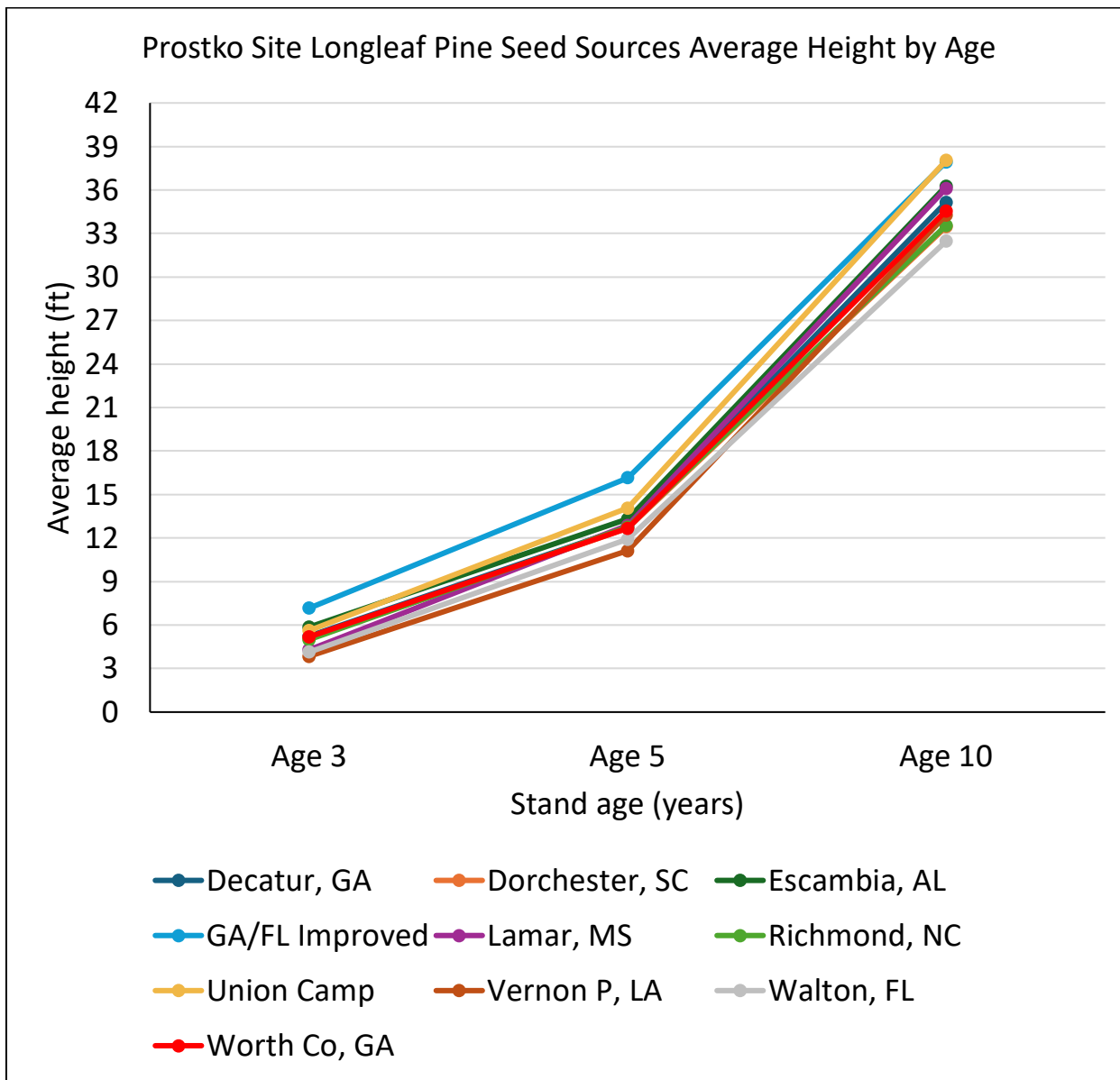


Figure 18.: Average height growth through time for each seed source from age three through ten years at the old-field Prostko site in Tift County, GA.

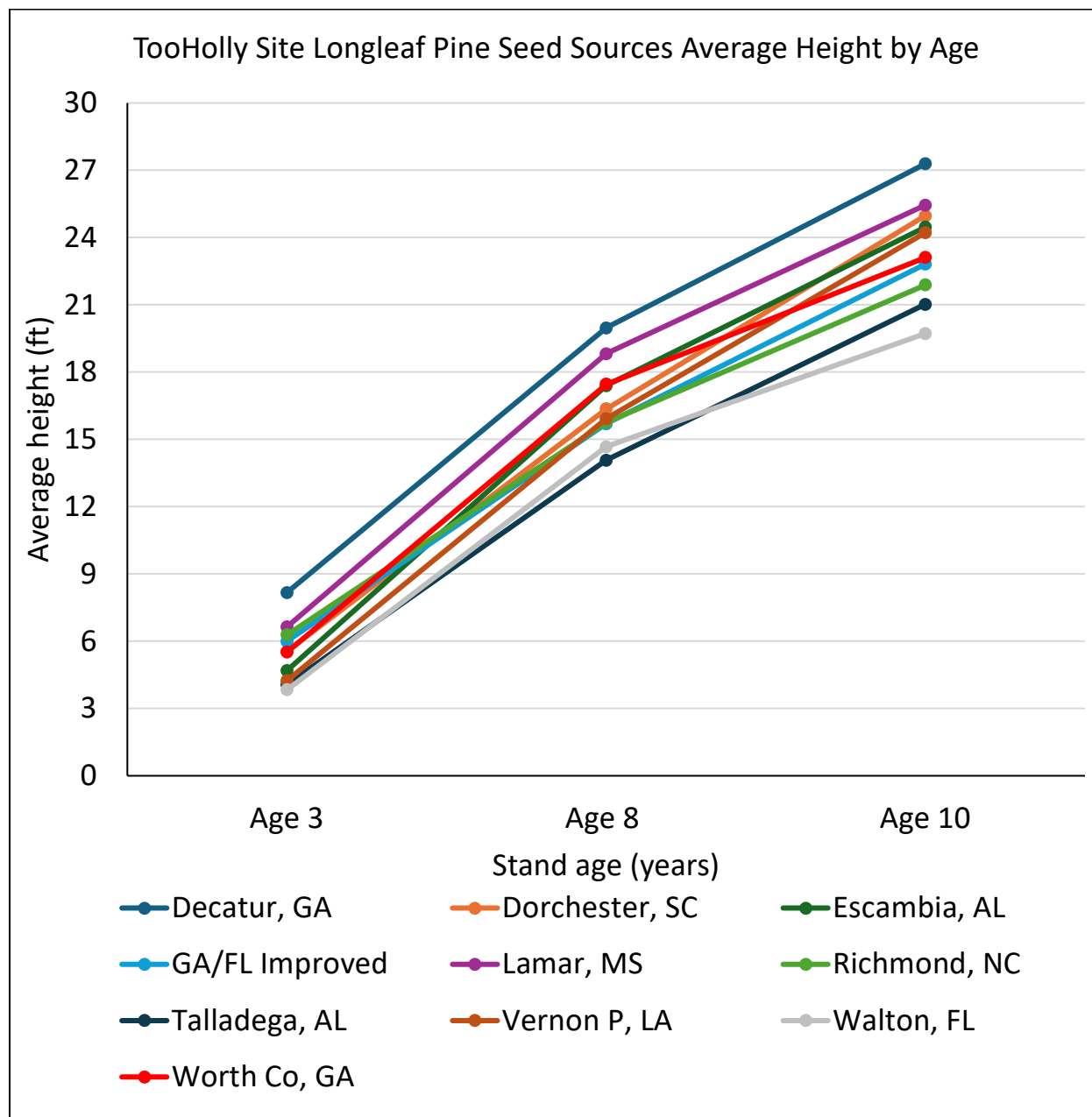


Figure 19: Average height growth through time for each longleaf pine seed source from age three through ten years at the cutover TooHolly site in Screven County, GA.

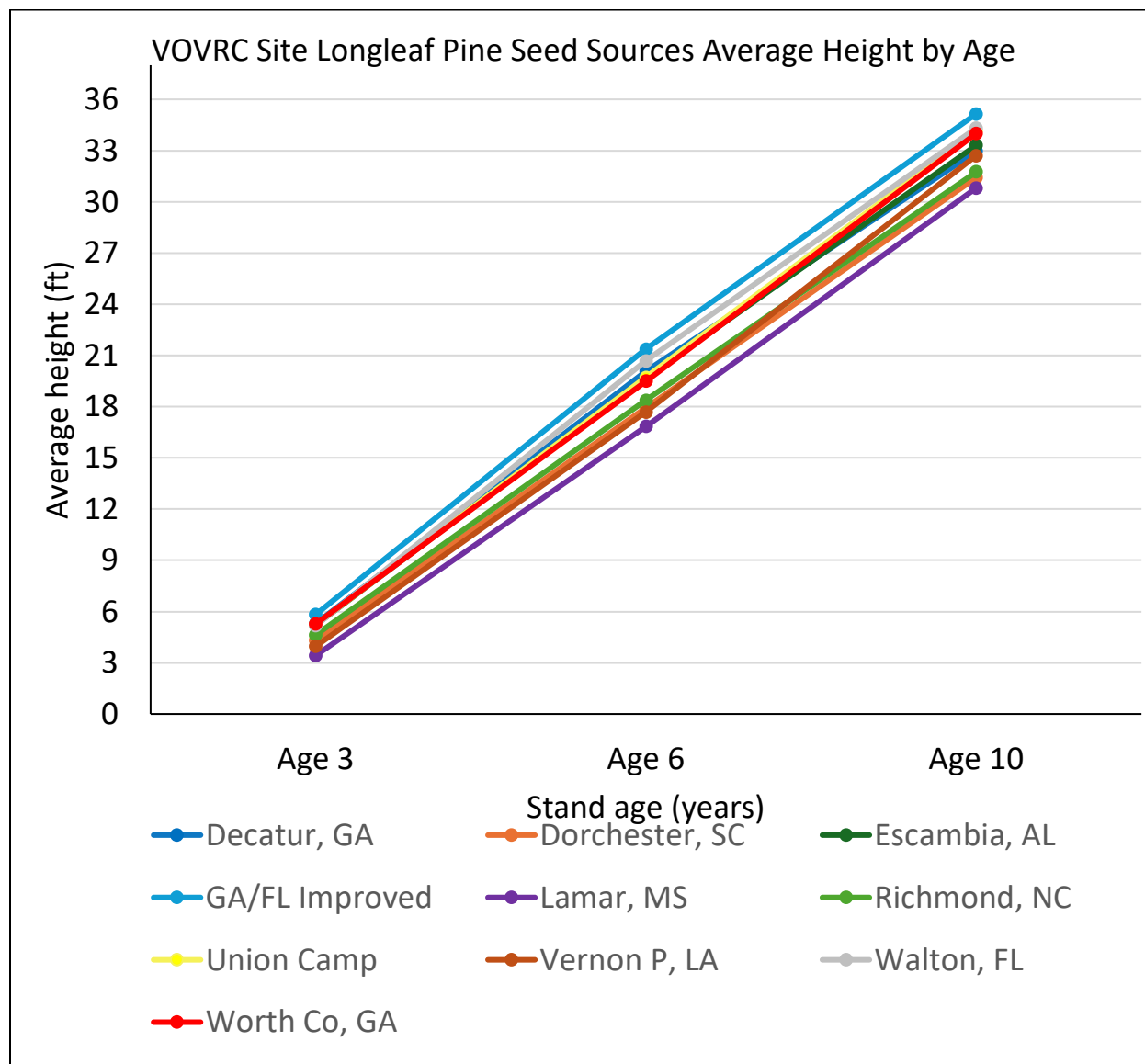


Figure 20: Average height growth through time for each longleaf pine seed source from age three through ten years at the old-field Vidalia Onion and Vegetable Research Center (VOVRC) site in Toombs County, GA.

Table 6. Age ten average basal area per acre by seed source across all study areas. Seed sources that do not share the same letter differ significantly ($p = 0.05$).

Source	Estimate (ft ² ac ⁻¹)	Standard Error (ft ² ac ⁻¹)	Letter Group
Decatur, GA	82.9	12.9	ABCD
Dorchester, SC	91.3	9.6	AB
Escambia, AL	98.4	21.5	A
GA/FL Improved	76.7	7.3	BCD
Lamar, MS	89.6	16.1	AB
Richmond, NC	73.4	10.3	CD
Talladega, AL	70.4	9.2	CD
Union Camp	88.4	17.5	ABC
Vernon P, LA	85.1	5.7	ABC
Walton, FL	71.6	11.5	CD
Worth Co, GA	68.6	3.5	D

Table 7. Age ten average mean annual increment (tons ac⁻¹ yr⁻¹) by seed source. Seed sources that do not share the same letter differ statistically ($p = 0.05$).

Source	Estimate (tons ac ⁻¹ yr ⁻¹)	Standard Error (tons ac ⁻¹ yr ⁻¹)	Letter Group
Decatur, GA	4.9	0.8	ABC
Dorchester, SC	5.1	0.5	AB
Escambia, AL	5.7	0.9	A
GA/FL Improved	4.5	0.4	BCD
Lamar, MS	5.0	0.8	AB
Richmond, NC	4.0	0.5	CD
Talladega, AL	3.4	0.6	D
Union Camp	5.2	0.8	AB
Vernon P, LA	4.6	0.2	BCD
Walton, FL	3.9	0.6	D
Worth Co, GA	4.0	0.3	CD

Table 8. Age ten defect rates by defect type and seed source across five longleaf pine seed source study sites in south central and southeastern Georgia. Percentages are for trees that have at least one stem defect below pulpwood (3-inch top; outside bark) merchantable height. Values highlighted in bold indicate a significant relationship between defect type and seed source ($p = 0.05$).

	Broken top*	Branch whorl	Crook	Fork	Canker	Lean $\geq 5^\circ$	Ramicorn branch	Sweep	Defect free
Longleaf pine seed source% Defect rate.....								
Decatur, GA	0.3	4.9	0.9	10.3	4.9	0.3	18.7	2.9	56.8
Dorchester, SC	1.3	13.5	0.2	7.4	4.5	0.3	24.1	0.0	48.5
Escambia, AL	0.0	4.9	0.6	10.8	9.2	0.0	21.2	1.5	51.8
GA/FL Improved	0.5	3.6	0.7	9.1	4.3	1.1	14.6	0.9	65.2
Lamar, MS	2.1	11.6	0.2	7.3	4.1	0.0	22.1	0.7	51.9
Richmond, NC	0.6	3.8	0.0	8.5	5.0	0.3	18.6	2.1	61.1
Talladega, AL	1.2	6.8	0.0	11.7	2.4	1.6	15.8	0.0	60.3
Union Camp	0.0	12.9	0.9	10.2	7.4	0.0	16.2	0.5	51.9
Vernon P, LA	0.4	16.4	0.7	7.6	1.4	0.9	15.9	0.2	56.5
Walton, FL	0.5	6.7	0.0	8.5	4.3	0.7	16.9	2.4	60.0
Worth Co, GA	1.7	5.5	0.5	10.0	3.2	0.8	16.3	1.8	60.2

* broken top—broken stem below a 3-inch top; branch whorl—five or more branches originating from the same location on the trunk; crook—a 90° turn in the stem; fork—point where one stem divides into two stems of roughly equal diameter; canker—a growth on the stem caused by a fungal infection; lean—greater than 5° from vertical; ramicorn branch—a steep angled branch whose base diameter is at least 1/3 the diameter of the stem at the branch attachment point; sweep—greater than three-inch shift from vertical in a 16 feet trunk segment.

Table 9. Age ten-year defect rates by defect type and seed source across five longleaf pine seed source study sites in south central and southeastern Georgia. Percentages are for trees that have a second visible stem defect below pulpwood (3-inch top; outside bark) merchantable height. Values highlighted in bold indicate a significant relationship between defect type and seed source (p = 0.05).

	Broken top*	Branch whorl	Crook	Fork	Canker	Ramicorn branch	Sweep	Defect free
Longleaf pine seed source% Defect rate.....							
Decatur, GA	0.3	0.6	0.3	2.0	2.6	6.9	1.1	86.2
Dorchester, SC	0.0	1.8	0.0	2.1	0.0	7.2	0.3	88.6
Escambia, AL	0.6	0.6	0.3	2.8	3.1	4.9	0.6	87.1
Imp LL	0.0	1.1	0.5	1.1	0.9	4.6	0.2	91.6
Lamar, MS	0.0	2.0	0.0	2.1	0.5	4.1	0.2	91.1
Richmond, NC	0.3	0.3	0.0	0.6	0.6	8.2	0.6	89.4
Talladega, AL	0.4	0.0	0.0	1.2	0.0	4.9	0.0	93.5
Union Camp	1.4	2.8	0.0	0.0	0.9	5.6	0.0	89.3
Vernon P, LA	0.0	0.2	0.2	0.5	0.9	2.5	0.2	95.5
Walton, FL	0.2	1.7	0.2	1.2	1.2	6.0	1.2	88.3
Worth Co, GA	0.5	0.8	0.0	1.0	0.5	5.0	0.5	91.7

* broken top—broken stem below a 3-inch top; branch whorl—five or more branches originating from the same location on the trunk; crook—a 90° turn in the stem; fork—point where one stem divides into two stems of roughly equal diameter; canker—a growth on the stem caused by a fungal infection; lean—greater than 5° from vertical; ramicorn branch—a steep angled branch whose base diameter is at least 1/3 the diameter of the stem at the branch attachment point; sweep—greater than three-inch shift from vertical in a 16 feet trunk segment.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Similar to larger, former longleaf pine seed source studies and trials from throughout the species' native range (e.g., Bey and Snyder 1978; Lantz and Kraus 1987; Wells and Wakeley 1970), Central Gulf Coast (southern Alabama and southern Mississippi) seed sources such as the Escambia, AL and Lamar, MS sources had the greatest adaptability and performed best (combined survival and growth) in the central and southern regions of Georgia. The Union Camp source (Rincon, GA), though not from the Central Gulf Coast region, also performed well in most categories except for stem defects. It should be noted that the Union Camp seed source was planted at only two of the five study sites (VOVRC and Prostko).

Longleaf pine seedlings originating from the Central Gulf Coast region have been reported to perform well as far west as central Louisiana and eastward to central Georgia. In addition, seed sources from this region perform well up to 150 miles north of where they originated (Wells and Wakeley 1970). Seed sources from more western regions of longleaf pine's range (e.g., Lamar, MS and Vernon, LA) had excellent survival rates, but growth rates tended to trail central Gulf Coast seed sources. It should be noted that overall wood production of these sources was sometimes similar to more central Gulf Coast sources due to their improved survival making up for slower diameter and height growth. These more western seed sources performed nearly identically in terms of dbh and height growth after 10-years. Northern seed sources including Talladega, AL, Richmond, NC, and Dorchester, SC, had moderate to good survival and poor to moderate growth rates compared to Central Gulf Coast seed sources located closer to the field trial sites. Defect-free percentages tended to be greater in slower growing sources (e.g., Richmond, NC and Talladega, AL) other than the GA/FL improved seed source which had the greatest defect-free percentage (65.2%) of any seed source. Conversely, faster growing sources usually had the lowest defect-free percentages (e.g., Escambia, AL and Dorchester, SC). Fast growth rates have been associated with high defect rates in longleaf pine (Dickens and others 2018) and other pine species such as loblolly pine (Xiong and others 2010). If high value timber products (e.g., sawtimber and poles) are a management objective, slower growing seed sources that tend to have fewer defects may be an important consideration for landowners and managers. Tighter planting spacings can also help achieve this objective.

Average annual diameter growth increment through time was lowest at the VOVRC site (0.46 in year⁻¹ stand ages six to ten years old), and greatest at the Peavy site (0.69 in year⁻¹ stand ages five to ten years-old). Two factors likely can explain this finding. Basal area per acre on average was greatest at the VOVRC site (124 ft² ac⁻¹) at age ten years indicating that plots at this site were already in need of thinning as biologically longleaf stands should be thinned prior to reaching 120 ft² ac⁻¹. Bark beetle infestations in or near this site in the past two years also confirm the overstocked status of this site. The Peavy site had the lowest survival rate across all seed sources of any site. Hurricane Michael during October 2018 (end of the 6th growing season) and recent high severity prescribed fires have resulted in some mortality causing less intraspecific (among the same species) competition and improved diameter growth. The remaining three sites have had good to excellent annual diameter growth increments of 0.47 in year⁻¹ (Dekle) to 0.61 in year⁻¹ (Prostko) for cutover and old-field sites from stand ages five, six or eight through age 10-years. Average periodic height growth increment increased during the second measurement interval (ages five or six through age ten years) compared to the first measurement interval (ages three or four through ages five or six years) at three of the five study areas. Average annual growth rates increased by 0.4-0.5 ft year⁻¹ over this period at these three sites. This period from five or six years after planting to age ten is when most planted longleaf pine stands reach canopy closure. Once canopy closure is reached, height growth rates are likely to slow. The VOVRC and TooHolly sites did not have accelerated height growth during the second measurement interval. At the VOVRC site, this is likely due to greater stand stocking levels (i.e., more trees ac⁻¹ and basal area ac⁻¹) than other sites and canopy closure being reached at a younger age resulting in greater intraspecific competition. At the TooHolly site, hardwood (primarily oaks) tree competition has been an issue causing greater interspecific (among different species) competition to occur in most plots despite pine release efforts.



If not completely controlled this hardwood competition is likely to continue to negatively impact longleaf pine growth through the life of the stand (e.g., Glover and Zutter 1993).

More intensive early stand management and land use history at the various study sites impacted growth. Excluding the Peavy site due to lower average survival caused by hurricane Michael and high severity prescribed fire resulting in more open-grown trees (large diameters and low survival at age 10-years), the Prostko and VOVRC sites had the largest average diameters and total heights after 10 years. These sites also had the highest average basal areas per acre. Neither site has a history of prescribed fire since planting and both sites received chemical site preparation and first year (Prostko site first and second year herbaceous weed control) herbaceous weed control. Surface soil P availability also impacted growth. The Prostko (47.0-68.0 lb ac⁻¹) and VOVRC sites (28.0-118.0 lb ac⁻¹) had the greatest surface soil P levels observed. In contrast, the cutover Dekle site had the smallest tons per acre mean annual increment (2.8 tons ac⁻¹ yr⁻¹), yet it had the highest overall survival rate (82.1%) of any site. Soil P levels at the Dekle site were below sufficiency levels (6-10 lb ac⁻¹) using the Mehlich I procedure as recommended by Dickens et al. (2003), and woody competition was prevalent at this site. These results illustrate how strongly site history and management prior to and just after stand establishment can impact pine growth for many years.

Only five of the eleven seed sources tested in this study were available from IFCO as of November 2020. Of these five available seed sources, Escambia, AL may be the best option if a combination of excellent survival and fast growth are critical while stem form (stem percent defect) is not as important to a landowner or manager. Comparatively, if fast growth and good stem form are important but good to excellent survival is not as critical then the GA/FL seed source could be a good option. At age 10-years compared to the GA/FL improved source, the Escambia, AL seed source survival rate was 12.3 percentage points better on average across all sites. When the Escambia, AL replication at VOVRC that had beetle kill issues is removed from the dataset, Escambia, AL had 70+% survival at all four sites where it was planted, while the GA/FL improved source had less than 50% survival at two of the five sites where it was planted. At age 10-years, height (31.8 vs 31.5 ft) and dbh (5.5 vs 5.3 in) were only slightly less than the GA/FL improved source for Escambia, AL. Stem defects at age 10-years were significantly more common with the Escambia, AL seed source and its defect-free rate was only 51.8% compared to the GA/FL improved source's 65.2% defect-free rate. Ramicorn branches and fusiform rust cankers occurred more regularly with the Escambia, AL source compared to the GA/FL improved source. The percentage of trees with a second defect did not differ significantly between the Escambia, AL (87.1% defect-free) and GA/FL improved (91.6% defect-free) seed sources. These two seed sources offer managers and landowners different qualities that should be carefully weighed when considering long-term objectives.

Shopping for longleaf pine seedlings, like other tree seedlings, should begin well over a year in advance of an expected planting date. This will ensure that the best seed sources are available or can be requested from a nursery (if this option is available). When choosing longleaf pine seedlings, select containerized stock if available, and sites in the coastal plain region of Georgia should be planted with longleaf pine seed sources from the Central Gulf Coastal Plain region of longleaf pine's range if the nursery you shop with has seed source options for customers, making sure not to move seed source parent material more than 100 miles or 5° north of its origin. Work with your nursery representative to select the best seed source possible for your new longleaf pine stand.

ACKNOWLEDGEMENTS

The authors would like to thank the landowners who have graciously allowed access to their property for the past 10+ years. In addition, thanks go to Cassandra Waldrop, Pamela York, and Haley Vaglianti for their assistance with field data collection and data entry. The original funding for this project was provided by the USDA Forest Service and portions of this work were funded by USDA Institute of Food and Agriculture project number SC-2022-10900, 'Promoting Climate-Smart and Resilient Forestry in the Southeastern United States'.



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