SILVICULTURAL STRATEGIES FOR CONVERTING LONGLEAF PINE PLANTATIONS TO MULTIAGED LONGLEAF PINE STANDS

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ABSTRACT

To meet objectives such as maintaining continuous forest cover and promoting multiple age classes within stands, there is interest among some landowners to convert longleaf pine (*Pinus palustris*) plantations to multiaged stands. However, silvicultural strategies for converting longleaf pine plantations to multiaged stands need to be developed for local site conditions. This was the aim of our study located at The Jones Center at Ichauway in southwestern Georgia. The study site included eight longleaf pine plantations that were commercially thinned in 2014 and impacted by Hurricane Michael in 2018. In 2015, half of the plantations were seeded with native groundcover species. Our strategies will be informed by inventories of longleaf pine seedlings that established from natural regeneration after partial disturbances. We will also determine the relative success of groundcover restoration efforts, which will be based on biomass of native grasses and forbs 8 years after seeding.

INTRODUCTION

In the late 1990s and early 2000s, incentives for planting longleaf pine (*Pinus palustris*) led to thousands of hectares of mostly marginal agricultural lands being converted to longleaf pine plantations (Oswalt and others 2012) (fig. 1). Many of these plantations were established with Conservation Reserve Program funds to limit the overproduction of certain agricultural crops and to reduce soil erosion and improve water quality. As some landowners consider new objectives, such as improved wildlife habitat and carbon sequestration, they may gradually convert plantations to a more natural condition with new cohorts of longleaf pine developing from natural regeneration (Puhlick and others 2022, 2023). This strategy aligns with objectives of maintaining continuous forest cover and promoting multiple age classes within stands (fig. 2).

However, silvicultural strategies for converting longleaf pine plantations to multiaged stands need to be developed for local site conditions. One approach for converting longleaf pine plantations to a more natural condition is to develop treatments that mimic natural disturbances. In naturally regenerated second-growth stands, Palik and Pederson (1996) found that 5-year mortality rates for longleaf and slash pine (*P. elliottii*) >10 cm diameter at breast height (d.b.h.,

Figure 1—Longleaf pine plantation in 2022 on former agricultural land subjected to row cropping. Photo taken 8 years after the first commercial thinning in 2014, during which every third row of trees was removed along with some poor-quality trees in leave rows, and 4 years after hurricane disturbance in 2018. (Photo courtesy of Joshua Puhlick)

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Figure 2—Multiaged longleaf pine stand in 2022 that originated from seedlings planted on marginal agricultural land in 1986. Commercial thinning occurred in 2004 and 2014, and salvage logging was conducted in 2017 after a tornado. (Photo courtesy of Joshua Puhlick)

Figure 3—Recruitment of longleaf pine in a longleaf pine plantation in 2022 that was commercially thinned in 2014 and salvage logged after Hurricane Michael impacted Ichauway in October 2018. (Photo courtesy of Joshua Puhlick)

1.37 m) averaged 2.3 trees/ha or 1.9 percent of original density, with the primary disturbance agents they identified as lightning, competition, and wind. Additional research is needed to determine if the rates of mortality observed in natural stands are the same for plantations with trees that have reached merchantable size and that have been recently impacted by the hurricane.

Studies that quantify the spatial patterns of mortality and associated density reductions within stands would be useful for developing silvicultural treatments that mimic partial disturbance regimes. For instance, within the historical range of longleaf pine, hurricanes can cause large-scale tree mortality across regions but may only result in partial mortality within plantations and natural stands (Zampieri and others 2020). Partial disturbance could favor the recruitment of new cohorts of longleaf pine by increasing the amount of light that reaches the forest floor and stimulating cone production in residual overstory trees (fig. 3).

Restoring native grasses and forbs in plantations is another way to transition plantations to a more natural condition, especially when previous land use was row cropping. One restoration approach has been to seed native grasses and forbs after the first commercial thinning of longleaf pine plantations (Baniya and others 2022). Seeding could also be done during stand establishment, but a potential drawback to this approach is that the tree canopy quickly (within approximately 7 years) begins to close and shade out the understory (Kirkman and Giencke 2017). Studies on the relative success of groundcover restoration efforts are often based on cover estimates of the seeded species. However, biomass may be a better way to evaluate groundcover restoration efforts in longleaf pine ecosystems. This is because there is a high degree of horizontal overlap among plants that complicates estimating cover by species or species group within a given area. New approaches for evaluating the success of groundcover restoration efforts are needed to guide management recommendations for increasing plant diversity and wildlife habitat in longleaf pine plantations.

The overall goal of this project is to develop silvicultural strategies for converting longleaf pine plantations to multiaged longleaf pine stands. Our first objective is to determine the influence of disturbance (commercial thinning and hurricane) on recruitment of new cohorts of longleaf pine in longleaf pine plantations. Our second objective is to determine the success of groundcover restoration efforts that were initiated after the first commercial thinning of longleaf pine plantations. This is an ongoing project with field measurements and sampling being conducted during the summer of 2023. In this paper, we present descriptive statistics on overstory conditions in 2013 (before thinning in 2014) and in May 2023. At the stand scale, we also present extractable phosphorus (P) concentration results from mineral soils. On completion of the project, our findings will be used to inform strategies for converting longleaf pine plantations to multiaged longleaf pine stands with enhanced groundcover diversity of native species.

MATERIALS AND METHODS

Study Area

The study was located at The Jones Center at Ichauway, which is in the Gulf Coastal Plain of southwestern Georgia. Soils are predominately well-drained loamy sands over sandy loams. The climate features long, hot summers and cool, short winters. Our study was conducted in eight longleaf pine plantations ranging in size from 2.7 to 8.0 ha. The plantations were established on marginal agricultural land from 1991 through 1996. Prior to stand establishment, peanut (*Arachis hypogaea*) was grown as the primary crop and fertilizers with P and potassium (K) were repeatedly applied to soils (Baniya and others 2022). The planting density of longleaf pine was 988 trees/ha at a spacing of 2.74 m by 3.66 m (Baniya and others 2022).

From March to May 2014, all eight plantations were commercially thinned for the first time. The method of thinning was a geometric thinning in which every third row of trees was removed, including some poor quality trees in leave rows. Though shade from the overstory canopy had reduced the presence of understory plants prior to thinning, all of the plantations were sprayed with 1,121 g ha^{-1} isopropylamine salt of imazapyr (Arsenal®, BASF, Florham Park, NJ) and 112 g ha^{-1} metsulfuron-methyl (MetcelTM, Agsurf Corporation, Wilmington, DE) because of the occurrence of pasture grasses such as Bahia grass (*Paspalum notatum* var. *notatum*) and Bermuda grass (*Cynodon dactylon*) (Baniya and others 2022). Based on photo time stamps, this spraying treatment occurred in September 2014 (fig. 4).

Figure 4—The first herbicide treatment that occurred after commercial thinning, 2014. (Photo courtesy of The Jones Center at Ichauway)

In 2015, logging slash was removed from all plantations using a grapple rake so that native groundcover could be sown and hunters could more easily navigate through stands while hunting northern bobwhite quail (*Colinus virginianus*) (fig. 5). During April and May 2015, half of the plantations were seeded with five warm-season C4 grasses and the legume goat's rue (*Tephrosia virginiana*) using a no-till seed drill (Truax Company, New Hope, MN) (fig. 6). Seed would have been sown earlier in the year, but for logistical reasons the seeding was delayed. The seed drills had coulters and openers to create furrows in the soil, into which seed was sown and covered with soil by press wheels. The seeded grasses were wiregrass (*Aristida stricta*), little bluestem (*Schizachyrium scoparium*), yellow Indian grass (*Sorghastrum nutans*), lopsided Indian grass (*Sorghastrum secundum*), and switchgrass (*Panicum virgatum*). For these grasses, the pure live seeding rates were 0.54, 1.93, 1.77, 0.50, and 0.03 kg ha^{-1}. For goat's rue, the seedling rate was 0.27 kg ha^{-1}. The seeded species were sown adjacent to rows of trees that were removed ("take-out rows") during thinning (fig. 6). A treatment of 2,242 g ha^{-1} glyphosate

Figure 5—Removal of logging slash from plantations using a grapple rack. Photo taken in May 2015 after commercial thinning. (Photo courtesy of The Jones Center at Ichauway)

Figure 6—Sowing of native groundcover species with a no-till seed drill while simultaneously applying herbicides to reduce competition of undesired species. Photo taken in May 2015 after commercial thinning and slash removal. (Photo courtesy of The Jones Center at Ichauway)

Figure 7—Frequent, low-intensity prescribed burning in plantations minimizes hardwood recruitment to midstory canopy positions. Grasses and forbs will dominate the understory of this plantation within weeks after dormant season burning. (Photo courtesy of Joshua Puhlick)

(Roundup®, Monsanto, St. Louis, MO), and 280 g ha^{-1} ammonium salt of imazapic (Panoramic, Alligare, Opelika, AL) was applied while simultaneously seeding native groundcover species (Jack 2015) (fig. 6).

For the plantations in this study, the warm season grasses that were sown were chosen because they were found in naturally regenerated, second-growth longleaf pine woodlands at Ichauway, they provided critical fine fuels for use of prescribed fire, and they offered cover for ground-nesting birds (Kirkman and Giencke 2017). Goat's rue is an important nitrogen fixer and a valuable resource for insect pollinators. The plantations were burned biennially between February and May since 1999 (Baniya and others 2022) (fig. 7). They were also impacted by Hurricane Michael in October 2018, and damaged and downed trees were removed from the plantations during salvage logging operations from January through February 2019.

Overstory Trees

In May 2023, we measured overstory tree attributes on a total of sixty-eight 0.04-ha plots (radius = 11.3 m), which had been established in 2013. In each plantation, there were 7–11 plots. For each plot, we recorded species and d.b.h. for trees at least 12.7 cm d.b.h. We also located previous records of trees on these same plots that were inventoried from May through September 2013 before commercial thinning. After this initial inventory, fixed-radius plot sampling was abandoned until our 2023 measurements.

Grasses and Forbs

In the summer of 2023, understory plants were clipped at ground level and collected from 1-m^2 quadrats. The five seeded grasses and goat's rue were bagged separately, oven dried to constant mass at 70 °C, and weighed. Quadrats were systematically located adjacent to take-out rows (i.e., offset 1.37 m from and perpendicular to stumps in the take-out rows) and between rows of overstory trees that were retained. In seeded stands, the location of clip plots adjacent to take-out rows ensured that plants were sampled from locations where seed was sown into the soil (fig. 6). We clipped plants from approximately four quadrats per hectare.

Tree Regeneration

In the summer of 2023, longleaf pine regeneration was measured within a 0.001-ha area at each clip plot location. For trees <1.37 m tall, height from the groundline to the base of current year's growth along the apical meristem was measured and recorded. Diameter at breast height was measured and recorded for trees ≥1.37 m tall and <12.7 cm d.b.h.

Data Analysis

Once the 2023 field measurements are complete and groundcover samples have been collected, we will compare the mean biomass of each seeded species between treatments (i.e., plantations with versus without seeding). Hemispherical photos will be taken at each clip plot location, so that metrics such as canopy openness can be used as explanatory variables in models of seeded species biomass. Plantation and row classification (take-out or leave row) will be included in models as random effects. Hurdle or two-stage models will be considered for modeling longleaf pine regeneration density due to the expected high frequency of zero counts. For this paper, descriptive statistics on overstory attributes in 2013 and 2023 are presented. We also present extractable P concentrations for the mineral soils of each plantation.

RESULTS AND DISCUSSION

For the eight plantations in this study, mean tree densities were 667 trees/ha before thinning and 191 trees/ha after thinning and salvage logging (table 1). During this same time period, quadratic mean diameter increased from 20.9 to 29.9 cm. Before thinning, mean stand density index (SDI) was 197; in 2023, mean SDI was 96. An SDI of 140 represents the lower limit of full site occupancy for longleaf pine, which is 35 percent of the maximum size density (Shaw and Long 2007). In 2023, there was a wide range of tree densities among and within plantations. We observed and are currently measuring longleaf pine seedlings in the eight plantations. These seedlings likely became established after commercial thinning in 2014 and salvage logging following Hurricane Michael. Many of the seedlings have persisted through multiple prescribed fires and will likely be recruited into midstory canopy positions. Hence, partial disturbances of commercial thinning followed by hurricane damage contributed to the development of a two-aged structure in most of the plantations.

Table 1—Grand mean and range of plantation attributes by time period

	2013		2023	
Plantation attribute	Mean (SD)	Range	Mean (SD)	Range
Basal area (m^2/ha)	22.3 (4.0)	13.2–26.2	12.6 (2.3)	8.6–15.0
Density (trees/ha)	667 (153)	341–828	191 (69)	111–331
QMD (cm)	20.9 (1.2)	18.9–22.7	29.9 (2.6)	24.3–32.0
SDI	197 (27)	139–224	96 (18)	70–122

The 2013 values include trees at least 2.5 cm diameter at breast height (d.b.h.) and the 2023 values include trees at least 12.7 cm d.b.h.

Mean values for the eight plantations of this study were used to compute these statistics.

2013 = before the first commercial thinning which occurred in 2014; 2023 = approximately 5 years after Hurricane Michael which impacted Ichauway in October 2018; SD = standard deviation; QMD = quadratic mean diameter; SDI = stand density index.

In 2020, extractable P concentration was determined for the mineral soils of each plantation (Baniya and others 2022). Those authors suggested that elevated stocks of available soil P had allowed old field plants to persist and perhaps inhibit establishment of the seeded groundcover species. We revisited the 2020 extractable P concentration dataset and determined that one plantation (stand 3) had a greater mean P concentration than that of other plantations (fig. 8). For plantations other than stand 3, soil available P may not have been the dominant factor influencing the relative success of groundcover restoration efforts. However, determining the impact of extractable P stocks on aboveground biomass of the seeded species would involve having estimates of soil bulk density or soil mass by depth increment, neither of which were reported by Baniya and others (2022). We propose that location within plantations, specifically in take-out rows versus leave rows, and differences in the light environment within and across plantations may be a better explanation for variation in presence of the seeded species.

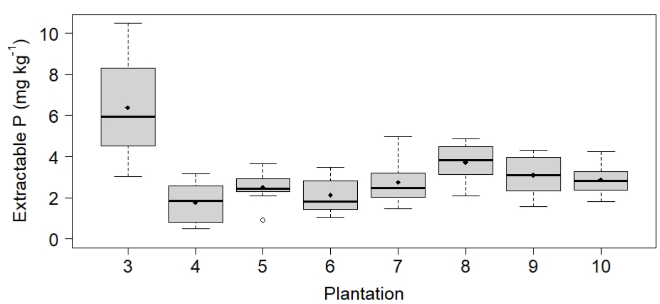

Figure 8—Extractable phosphorus concentration for the 0- to 10-cm depth increment of the mineral soil in 2020 by plantation, which were assigned numbers 3–10. The boxes define the hinge (25–75 percent quartile, and the line is 1.5 times the hinge) and the horizontal line in each box is the median. Solid black dots are means.

CONCLUSIONS

Quantifying stand attributes, including longleaf pine regeneration densities and spatial patterns, after commercial thinning and salvage logging in longleaf pine plantations can inform silvicultural prescriptions for promoting multiaged stand conditions. For the mid-rotation longleaf pine plantations of this study, we will examine how silvicultural treatments and natural disturbance influenced regeneration outcomes. Restoring longleaf pine stands to a more natural condition can also include native groundcover restoration, especially when previous land use was row cropping. In this study, seeding of native groundcover species was done after commercial thinning, which may be a better alternative than seeding grasses and forbs at the time of tree planting when financial resources are limited. The ability of seeded grasses and forbs to spread throughout stands could influence decisions about skid trail layout during future timber harvesting. For groundcover species with limited dispersal, some portions of stands where they occur may require reduced trafficking of machinery. Determining seeded groundcover species and longleaf pine regeneration presence and biomass in take-out and leave rows is crucial for making such decisions.

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