Composition and Structure of a Montane Longleaf Pine Stand on the Alabama Piedmont

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Abstract - Montane *Pinus palustris* (Longleaf Pine) forests of the southeastern United States are understudied compared to Longleaf Pine forests of the Coastal Plain. In this study, we quantified composition and structure of a montane Longleaf Pine stand in Weogufka State Forest in Coosa County, AL. We compared contemporary stand conditions to historical records to describe stand dynamics over time. Results indicated that the stand was dominated by Longleaf Pine, followed by Blackjack Oak, Chestnut Oak, and Mockernut Hickory. Longleaf Pine establishment began in the 1750s with continuous, minimal recruitment until a large establishment pulse, along with that of oak and hickory species, in the 1930s. Establishment trends over time corresponded to changes in land use and altered disturbance regimes, which included fire exclusion in the 1920s, intensive harvesting in the early 1930s, and Civilian Conservation Corps (CCC) occupation during 1933–1942. Compared to other published data on montane Longleaf Pine, the stand studied here had a higher density and basal area, as well as fewer Longleaf Pine stems in small size classes. It is important to understand how changes in land use and disturbance regimes alter montane Longleaf Pine successional and developmental pathways to inform restoration efforts in these understudied systems.

Introduction

Prior to widespread European settlement, the *Pinus palustris* (Longleaf Pine) ecosystem once occupied nearly 37 million ha in the southeastern United States (Frost 2006, Landers et al. 1995). Degradation of the Longleaf Pine ecosystem began in the late 1800s as turpentine production, agricultural land clearing, and timber harvesting contributed to the industrialization of the Southeast. Amplified by fire exclusion in the 1920s, the Longleaf Pine ecosystem is now absent from over 95% of its previous extent, and much of what remains exists in a degraded state (America's Longleaf 2009, Noss et al. 1995). Loss of the Longleaf Pine ecosystem is especially pronounced in the southeastern uplands, where Longleaf Pine is now largely absent in the Piedmont, Ridge and Valley, and Cumberland Plateau physiographic provinces (Peet 2006). To date, research on the Longleaf Pine ecosystem has focused primarily on Coastal Plain forests. However, montane Longleaf Pine forests in the Piedmont occupy a unique niche in the interior southeastern region, distinguishable by complex topography and distinct soil characteristics (Peet 2006).

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Successful restoration of the Longleaf Pine ecosystem requires a better understanding of this understudied forest type (Hammond et al. 2016, Stokes et al. 2010, Varner et al. 2003).

In 1933, the State of Alabama acquired 162 ha in Coosa County from the Kaul Lumber Company for the creation of Weogufka State Park. The park was to be situated atop Flagg Mountain, and was described as "one of the most scenic places in Alabama"(Pasquill 2008:121). The Civilian Conservation Corps (CCC) arrived at the site in October of 1933 to begin construction of the park. The CCC described the land to the south as "the largest yellow pine forest east of the Rockies" (Pasquill 2008:121). The CCC built a 16-m-tall observation tower atop Flagg Mountain, as well as cabins and trails on park property (Pasquill 2008). The CCC abandoned the park plan when the United States entered into World War II, but the land remained in state ownership. The majority of what was to be the state park is now managed by the Alabama Forestry Commission as Weogufka State Forest.

In our initial ground reconnaissance of Weogufka State Forest, we noted large-diameter (>65 cm), widely spaced Longleaf Pine trees with characteristic flat-topped canopies and tree ages up to 250 years. Based on our reconnaissance, we suspected this stand to be a mature, montane Longleaf Pine stand and thus set out to quantify the forest composition and structure by sampling using a systematic plot design. The objectives of our study were to (1) quantify the composition and structure of this montane Longleaf Pine stand in the context of land-use change and altered disturbance regimes, and (2) compare current forest conditions to past records (i.e., Reed 1905) at Weogufka State Forest. It is important to understand successional and developmental trajectories and stand conditions in these montane Longleaf Pine ecosystems to inform montane Longleaf Pine management and restoration.

Methods

Study area

Weogufka State Forest is located in the Piedmont physiographic province, a transition region of foothills from the mountainous Appalachians to the Coastal Plain (Fenneman 1938). The forest is 97 ha with steep sloped north- and south-facing ridges and a maximum elevation of 351 m. The underlying geology of the site is muscovite-schist, with local masses of roscoelite-graphite-quartz schist, and thin layers of biotite-gneiss varying from coarse- to fine-grained (Szabo et al. 1988). Soils are in the Louisa–Mountain Park complex. Louisa series soils consist of a loamy surface horizon up to 25 cm deep situated above a sandy clay loam that can reach 43 cm in depth to bedrock, whereas Mountain Park series soils contain a gravelly sandy loam surface horizon as deep as 25 cm, a gravelly sandy clay loam layer up to 58 cm thick, and a sandy loam horizon reaching 80 cm to bedrock (USDA 2008).

The Southern Inner Piedmont ecoregion (level III) is within the broader Oak–Pine forest region (Braun 1950, Griffith et al. 2001). In the General Land Office (GLO) survey conducted in 1832, surveyors described the land as hilly, third rate, with growth of *Pinus* spp. (pine), chestnut (presumably *Castanea dentata* (Marsh.) Borkh. [American Chestnut]), *Quercus velutina* (Black Oak), *Carya* spp.(hickory), *Nyssa sylvatica* (Blackgum), and red oak (particular species unknown). Surveyors recorded chestnut, pine, Blackjack Oak (*Quercus marilandica*), Blackgum, *Cornus florida* (Flowering Dogwood), *Oxydendrum arboreum* (Sourwood), hickory, and *Liquidambar styraciflua* (Sweet Gum) witness trees. Of the 24 witness trees in the Weogufka area, 14 were pine. Mohr (1901) classified vegetation of this region as Xerophile Forest of Metamorphic Hills where Longleaf Pine was dominant on the slopes with Blackjack Oak of limited growth present transitioning to hickory species, *Quercus montana* (Chestnut Oak), and the now functionally extinct American Chestnut near and at the top of ridges. Reed (1905) observed similar forest types, specifically at Flagg Mountain, with the tops of ridges dominated by stunted oaks and hickories with pines dispersed sparingly, while the slopes, especially southern-facing, were predominantly dominated by Longleaf Pine. Other species present included Black Oak, *Quercus stellata* (Post Oak), *Prunus serotina* (Black Cherry), Flowering Dogwood, Blackgum, Sourwood, and small populations of *Pinus echinata* (Shortleaf Pine), with a distinct absence of *Liriodendron tulipifera* L. (Tulip-poplar) and *Magnolia acuminata* (L.) L. (Cucumber Tree), which are abundant in other forest types in the Coosa Hills region (Mohr 1901, Reed 1905). Fire was excluded from this site in the 1920s, and public-range grazing was forbidden in 1902 (Reed 1905).

Field and laboratory methods

We subjectively established a 500-m sampling transect positioned on a southeast-facing upper slope with elevation spanning 250–270 m to capture conditions of the Longleaf Pine stand that exhibited mature composition and structure. The transect was situated in a southwest-to-northeast direction parallel to slope contours (Fig. 1). Slope of the study site varied from 19° to 32°. We established twenty 0.04-ha fixed-radius plots (0.8 ha total area sampled) along the sampling transect at even spacings. For all living trees (≥5 cm diameter at breast height [1.37 m above root collar; dbh]), we identified to species, measured for dbh, and assigned a crown class (sensu Oliver and Larson 1996). We extracted 2 cores from all trees ≥15 cm dbh, as low to the ground as possible and perpendicular to the slope to avoid reaction-wood influence. Cores were dried for >48 hours, glued onto wooden mounts with the cells vertically aligned, and sanded using progressively finer grits (Orvis and Grissino-Mayer 2002, Stokes and Smiley 1996). Once processed, we dated tree rings to the calendar year of formation with aid of a stereo microscope to calculate year of establishment. We used pith estimators to determine establishment dates on samples that did not contain pith but had substantial ring curvature (Villalba and Veblen 1997).

We tallied seedlings (<1 m height) and saplings (≥1 m height, <5 cm dbh) within a nested 0.004-ha circular plot established 5 m north of each overstory plot center. We tallied coarse woody debris (CWD, ≥5 cm diameter); classified pieces as either snag (standing dead trees with crown mostly intact), snapped stem, or downed log;

and assigned each piece to a decay class from I to V, with I indicating least decayed and V indicating most decayed (FIA 2005).

We analyzed tree, sapling, and seedling categories with standard descriptors. We calculated density (stems ha^{-1}), relative density (proportion of total trees ha^{-1}), basal area (dominance, m^2 ha^{-1}), relative dominance (proportion of total basal area ha^{-1}) and relative importance (average of relative density and relative dominance) for all tree species. We calculated density and relative density for seedlings and saplings to characterize understory composition. For all layers of woody plant categories, we quantified species richness, Shannon diversity (H'), and species evenness. We assigned all trees to 5-cm–diameter intervals to examine diameter distributions. We calculated the q-factor to quantitatively describe the diameter distribution of the stand. The q-factor is the mean ratio of the density of trees in one diameter class to density of trees in the next larger diameter class for a stand. To compare contemporary forest conditions to past records, we used data collected by Reed (1905). In one of the earliest surveys of the forests of central Alabama, Reed (1905) quantified forest composition and structure to aid in the creation of a forest management plan. Weogufka State Forest is within Block VI (236 ha) of the Coosa Country tract. In Block VI, he divided parcels into Longleaf Pine land, creek land, and unwooded land. According to Reed (1905), block VI was the least valuable block in the Coosa County tract because of its steep, rocky hills and ridges. On Longleaf Pine land,

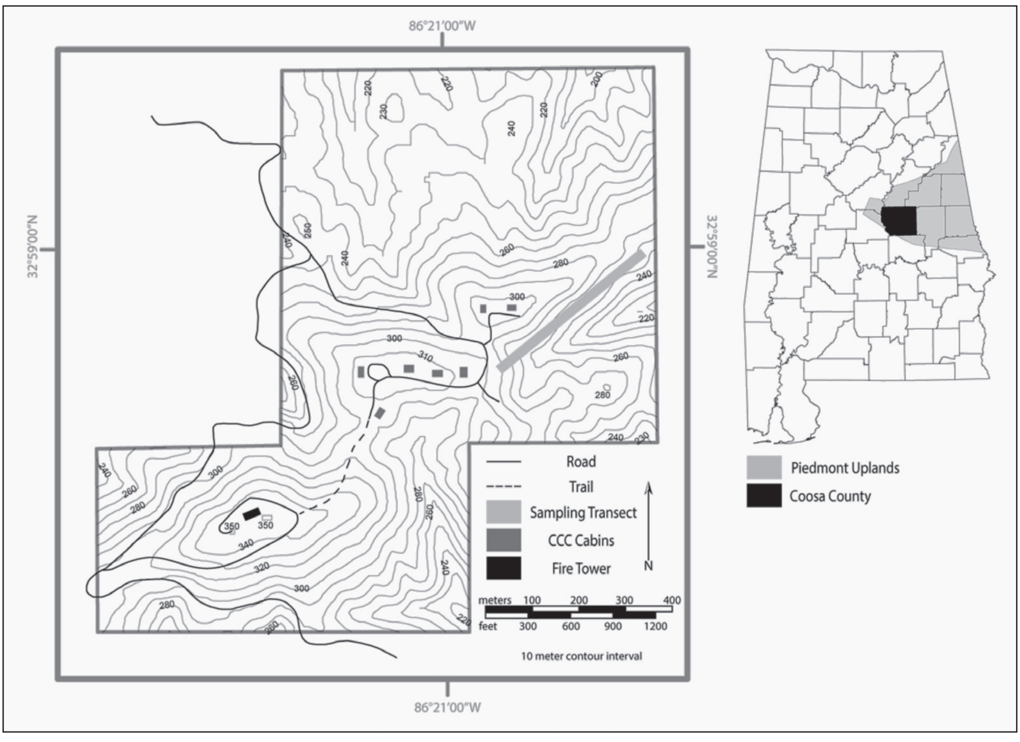

Figure 1. Map of Weogufka State Forest, Coosa County, AL, within the Piedmont physiographic province. Sampling plots were evenly spaced along the sampling transect parallel to slope contours.

Reed (1905) inventoried all Longleaf, Loblolly, and Shortleaf Pine >3 cm dbh. To quantify compositional shifts over the 113-year period, we calculated percent change in density of the 3 pine species from the Reed (1905) survey on Longleaf Pine land. Because of the methods utilized by Reed (1905), we were unable to statistically compare our data with his records.

Results and Discussion

Stand composition

Overstory species richness of the sampled area was 20, Shannon diversity was 2.01, and evenness was 0.67. Overstory basal area was 17.96 m^2 ha^{-1} and density was 878 trees ha^{-1}. Longleaf Pine was the most important tree species with 31% relative importance, followed by Blackjack Oak (24.3%), *Vaccinium* spp. (12.5%), Chestnut Oak (10.1%), and *Carya tomentosa* (Mockernut Hickory; 6.9%). The remaining species had relative importance values under 5% (Table 1). The most important genera were oak (38.4% relative importance), and pine (33.8% relative importance).

The most dominant overstory species was Longleaf Pine with a basal area of 6.74 m^2 ha^{-1} and a relative dominance of 37.5%. Blackjack Oak, Chestnut Oak, and Mockernut Hickory were the next 3 most dominant species, with basal area varying

Table 1. Density (stems ha^{-1}) and dominance (m^2 ha^{-1}) of all live stems ≥5 cm dbh, and relative importance (average of relative density + relative dominance, both given in %) in a Longleaf Pine stand in Weogufka State Forest, Coosa County, AL. Dom. = dominance; Rel. = relative; and imp. = importance.

Species	Common name	Density	Rel. density	Dom.	Rel. dom.	Rel. imp.
Pinus palustris Mill.	Longleaf Pine	214	24.4	6.74	37.5	31.0
Quercus marilandica Münchh.	Blackjack Oak	234	26.6	3.95	22.0	24.3
Vaccinium spp.		178	20.2	0.87	4.8	12.5
Quercus montana Willd.	Chestnut Oak	45	5.1	2.70	15.0	10.1
Carya tomentosa (Lam.) Nutt.	Mockernut Hickory	64	7.3	1.17	6.5	6.9
Prunus serotina Ehrh.	Black Cherry	33	3.7	0.32	1.8	2.7
Pinus echinata Mill.	Shortleaf Pine	26	3.0	0.40	2.2	2.6
Acer rubrum L.	Red Maple	29	3.3	0.28	1.5	2.4
Quercus stellata Wangenh.	Post Oak	10	1.1	0.56	3.1	2.1
Quercus rubra L.	Northern Red Oak	9	1.0	0.26	1.4	1.2
Oxydendrum arboreum (L.) DC.	Sourwood	9	1.0	0.24	1.3	1.2
Nyssa sylvatica Marshall	Blackgum	13	1.4	0.16	0.9	1.1
Quercus falcata Michx.	Southern Red Oak	4	0.4	0.10	0.6	0.5
Liquidambar styraciflua L.	Sweetgum	1	0.1	0.10	0.5	0.3
Pinus taeda L.	Loblolly Pine	4	0.4	0.02	0.1	0.3
Fagus grandifolia Ehrh.	American Beech	1	0.1	0.05	0.3	0.2
Cornus florida L.	Flowering Dogwood	3	0.3	0.02	0.1	0.2
Quercus velutina Lam.	Black Oak	1	0.1	0.02	0.1	0.1
Carya glabra (Mill.) Sweet	Pignut Hickory	1	0.1	0.01	0.0	0.1
Cercis canadensis L.	Eastern Redbud	1	0.1	0.00	0.0	0.1
Totals		878	100.0	17.96	100.0	100.0

from 1.61 m^2 ha^{-1} to 3.95 m^2 ha^{-1}. The 4 most dominant trees represented 81% of basal area ha^{-1}. Although *Vaccinium* spp. had the second highest importance value, species in this genus, composed primarily of *Vaccinium arboreum* Marshall (Tree Sparkleberry), had a basal area of 0.86 m^2 ha^{-1} and represented 4.8% of basal area ha^{-1}. All remaining species represented <5% of the basal area ha^{-1}. Because the Piedmont is a transition between the Coastal Plain and the Appalachian Mountains, species composition was representative of this transition. Longleaf Pine typically occurs as a Coastal Plain species, and Chestnut Oak primarily inhabits the Appalachian Highlands (Weakley 2015), but both species coexisted in the canopy of this stand. Blackjack Oak had the highest tree density with 234 stems ha^{-1}, followed by Longleaf Pine with 214 trees ha^{-1}. *Vaccinium* spp. had a density of 178 trees ha^{-1}. The high density of *Vaccinium* spp. has been documented in previous studies of fire-excluded Longleaf Pine forests (Kleinman et al. 2017) and could likely be reduced with re-introduction of prescribed fire (Wade and Lunsford 1989). At the genus level, oaks had 303 stems ha^{-1} and pines had 244 stems ha^{-1}.

On land classified as Longleaf Pine land by Reed (1905) in Block VI of the Coosa County tract, he recorded 131 Longleaf Pine ha^{-1}, 16 Shortleaf Pine ha^{-1}, and 6 Loblolly Pine ha^{-1}. Compared to results from this study, density of Longleaf Pine and Shortleaf Pine increased within Block VI by 83 stems ha^{-1} (63% increase) and 10 stems ha^{-1} (63% increase), respectively. Loblolly Pine stem density decreased slightly by 2 stems ha^{-1}. Overall change in density could not be determined because the inventory of other species was not conducted as part of the Reed (1905) survey of the slopes of Flagg Mountain, though it is likely that there was an increase in hardwood species because fire and grazing have been excluded from the system since the early 1900s. Compared to contemporary inventories of montane Longleaf Pine, we documented a greater number of stems ha^{-1}, a greater basal area ha^{-1}, and fewer Longleaf Pine in smaller size classes (Stokes et al 2010, Varner et al. 2003). We speculate that the primary driver of these differences was the re-introduction of prescribed fire in these aforementioned studies that led to increased Longleaf Pine regeneration and reduced hardwood basal area.

Sapling species richness of the sampled area was 11, Shannon diversity was 1.15, and evenness was 1.48. All 3 compositional metrics for the sapling stratum were lower than the overstory. The overstory had nearly twice the species richness as the sapling stratum. Sapling density was 641 stems ha^{-1}. It is uncommon for conifer-dominated forests to have higher overstory species richness than the sapling layer, especially in Longleaf Pine forests (Kleinman et al. 2017). However, previous studies have observed a decline in understory richness with the exclusion of prescribed fire (Kirkman et al. 2016, Peterson and Reich 2008). Furthermore, lower sapling richness may be attributed to the relatively harsh abiotic conditions (i.e., increased solar radiation) on the southern slopes of Flagg Mountain, and suppression from high density patches of *Vaccinium* spp. *Vaccinium* was the most abundant sapling taxon with 436 sapling ha^{-1}, followed by Longleaf Pine with 93 saplings ha^{-1} (Table 2). *Vaccinium* spp. and Longleaf Pine represented 83% of sapling density. We recorded 86 Longleaf Pine seedlings ha^{-1}. We documented 18 different seedling species, with seedling Shannon diversity of 1.46 and seedling evenness of 0.51. Seedling density was 4695 stems ha^{-1}. *Vaccinium* spp. had the highest seedling relative density (39%), followed by *Acer rubrum* (Red Maple; 36%) and Chestnut Oak (12%). All remaining seedling species had a relative density of <4%.

The majority of canopy individuals (dominant or codominant canopy positions) were pines (50%) and oak–hickory (46%). Other species documented in canopy positions included Red Maple, Black Cherry and *Fagus grandifolia* (American Beech). Longleaf Pine was the most abundant canopy individual with 71 stems ha^{-1} in the canopy, followed by Blackjack Oak with 28 stems ha^{-1} in the canopy. Blackjack Oak was also the most abundant subcanopy individual (intermediate or overtopped crown positions), with 206 trees ha^{-1}. In total, we documented 170 trees ha^{-1} in canopy positions and 708 trees ha^{-1} in subcanopy positions. Of the 708 trees ha^{-1} in subcanopy positions, 313 trees ha^{-1} were in intermediate positions and 395 trees ha^{-1} were overtopped. *Vaccinium* spp. were the most abundant overtopped genera, with 153 stems ha^{-1}.

Stand structure

The diameter distribution for all trees combined exhibited a reverse J-shape from the 5–10-cm size class to the ≥65-cm size class, with the greatest density of trees in the smallest size class. We documented 433 trees ha^{-1} in the smallest size class, with decreasing tree density in each subsequent size class. The q-factor for all trees was 1.72. *Vaccinium* spp. were the most abundant in the 5–10-cm size

Table 2. Density measures for live stems ≥1 m height and <5 cm dbh (saplings) and live stems <1 m height (seedlings) in a Longleaf Pine stand in Weogufka State Forest, Coosa County, AL.

	Seedling		Sapling	
Species	density (ha^{-1})	Relative density (%)	density (ha^{-1})	Relative density (%)
Vaccinium spp. (blueberry)	1852	39.4	436	68.1
Acer rubrum (Red Maple)	1698	36.2	2	0.4
Quercus marilandica (Blackjack Oak)	564	12.0	25	3.9
Carya tomentosa (Mockernut Hickory)	186	3.9	16	2.5
Quercus montana (Chestnut Oak)	180	3.8	7	1.1
Pinus palustris. (Longleaf Pine)	86	1.8	93	14.5
Carya glabra (Pignut Hickory)	43	0.9	2	0.4
Prunus serotina (Black Cherry)	43	0.9	39	6.0
Oxydendrum arboreum (Sourwood)	7	0.2	5	0.7
Pinus echinata (Shortleaf Pine)	7	0.2	14	2.1
Quercus stellate (Post Oak)	7	0.2	-	-
Diospyros virginiana L. (Eastern Persimmon)	5	0.1	-	-
Pinus taeda (Loblolly Pine)	5	0.1	-	-
Quercus rubra (Red Oak)	5	0.1	2	0.4
Asimina triloba (L.) Dunal (Paw Paw)	2	0.05	-	-
Fagus grandifolia (American Beech)	2	0.05	-	-
Nyssa sylvatica (Blackgum)	2	0.05	-	-
Quercus falcata (Southern Red Oak)	2	0.05	-	-
Total	4695	100.00	641	100.0

class, followed by Blackjack Oak and Longleaf Pine. The 5–10-cm size class contained 2.3 times the number of trees as the 10–15-cm size class. When diameter distributions were analyzed by taxonomic group (pine, oak–hickory, and others), each group had a similar reverse J-shaped distribution. Quadratic mean diameter for all trees was 13.3 cm. Of the trees in canopy dominant or codominant positions, Chestnut Oak had the highest mean diameter (31.2 cm), followed by Post Oak (29.0 cm), *Quercus rubra* (Northern Red Oak; 27.9 cm), and Longleaf Pine (27.1 cm). *Vaccinium* spp. had a mean diameter of 7.4 cm.

We documented 149 occurrences of CWD ha^{-1} (≥5 cm diameter), which were classified as snags, snapped stems, and logs. Of all recorded CWD, snags were the most abundant, with 63 stems ha^{-1}, followed by snapped stems with 50 stems ha^{-1}, and logs with 34 pieces ha^{-1}. Thus, the majority of CWD was standing (76%). Longleaf Pine and Blackjack Oak were the most abundant CWD species, together representing 67% of recorded CWD. Basal area of standing CWD (i.e., snags and snapped stems) was 0.11 m^2 ha^{-1}. Of the standing CWD, 51% were Blackjack Oak and 28% were Longleaf Pine. The majority of CWD pieces (81%) were in decay class I or II, with 25 pieces ha^{-1} in more advanced stages of decay.

Age structure

The oldest tree documented was a Longleaf Pine that established in 1757 and had a dbh of 66.4 cm. The 10 oldest trees recorded were Longleaf Pine, of which 4 established prior to 1800. The oldest non-Longleaf Pine was a Post Oak that established in 1866. Of the 182 stems analyzed for age structure, 48 trees ha^{-1} established prior to 1930. The largest establishment pulse occurred in the 1930s, in which 45 trees ha^{-1} established. Of the 45 trees that established in the 1930s, 36 were in the oak–hickory taxonomic group, and 9 were in the pine taxonomic group. Another distinct establishment pulse occurred in the 1960s, in which 43 trees established. Of the 43 trees, 23 were in the oak–hickory taxonomic group, and 20 were in the pine taxonomic group. In that 30-year span (1930–1960), 56% of the canopy individuals established. Of the canopy trees analyzed for age structure, average age of canopy Longleaf Pine was 101.5 years, and average age of Mockernut Hickory was 102.7 years. Average age of all canopy stems was 86.8 years. Longleaf Pine had at least 1 stem ha^{-1} establish in each decade from 1750–1930. The first distinct establishment pulse for Longleaf Pine occurred in the 1930s and again in the 1960s. For oaks and hickories, the first distinct establishment pulse was in the 1930s with continuous establishment into the 1960s with another pulse. The age–diameter relationship for Longleaf Pine revealed that size was an adequate predictor of age (r^2 = 0.73, P < 0.01), with the larger diameter individuals having older establishment dates (Fig. 2). Size was a poor predictor of age in oak individuals (r^2 = 0.12, P < 0.01), which is likely attributed to the high density of small-diameter Blackjack Oak that have persisted in subcanopy positions for many decades. We acknowledge species-specific trends may have been masked by analyzing these relationships by genera (Pond and Froese 2015).

Summary

The oldest trees in this stand were Longleaf Pine that established in the 1750s with continuous, but limited canopy recruitment until large establishment pulses occurred in the 1930s and 1960s. Changes in land use and disturbance regimes influenced contemporary stand composition and structure. Specifically, we speculate that fire exclusion in the early 1920s resulted in reduced Longleaf Pine regeneration, and intensive harvesting in the 1930s resulted in the large pulse of hardwood establishment. It appears likely that Kaul Lumber Company intensively harvested the majority of the forest on Flagg Mountain prior to federal acquisition and CCC occupation (Cox and Hart 2015, Pasquill 2008). We know that the CCC utilized forest resources to build park structures, but those resources were utilized from clearings of road right-of-ways (Pasquill 2008). One of the goals of the CCC at the site was reforestation of previously degraded forest, but artificial regeneration by the CCC was unlikely. The large, old Longleaf Pine trees that were not harvested proved to be important structural legacies in this stand. Retention of these stems increased stand structural complexity and provided potential habitat for species that would otherwise be absent. The unintended consequences of retaining poor-form, perhaps inaccessible Longleaf Pine trees may expedite future restoration efforts in these systems. Although the largest establishment pulse that occurred in the 1930s was primarily oak and hickory individuals, the Longleaf Pines that established prior to 1900 aided in maintaining Longleaf Pine dominance in the stand. Residual Longleaf Pines provide a seed source for regeneration and a fuel source as pine needles for the potential reintroduction of prescribed fire. Results from this study

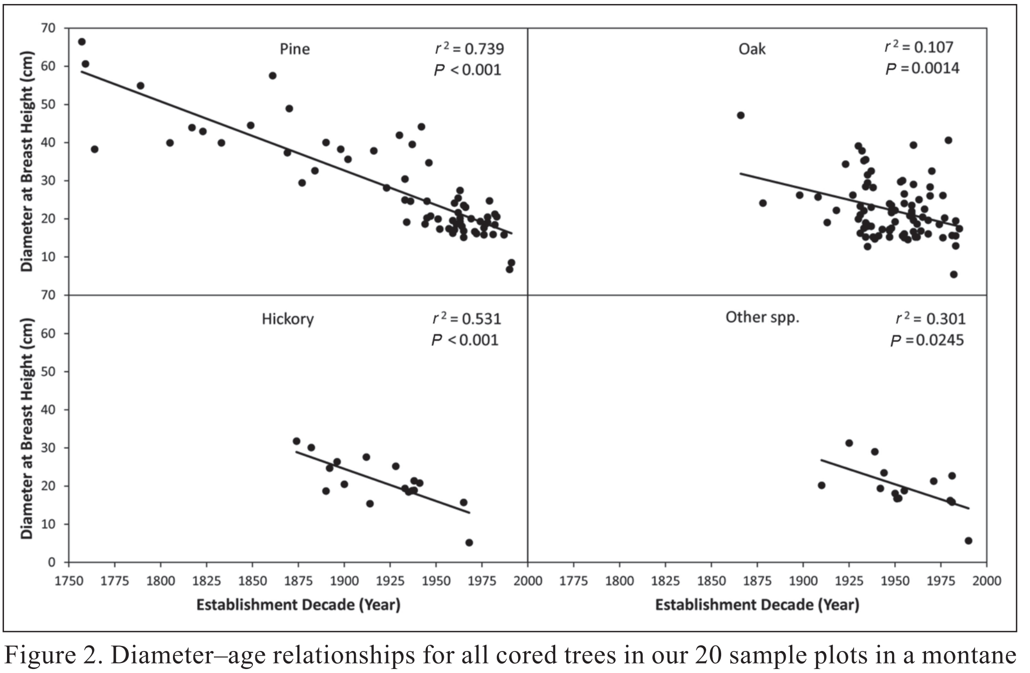

Figure 2. Diameter–age relationships for all cored trees in our 20 sample plots in a montane Longleaf Pine stand in Weogufka State Forest, Coosa County, AL.

add to a relatively small, but growing body of literature on montane Longleaf Pine ecosystems. In particular, these results supplement our understanding of development and successional trajectories in this forest type with altered disturbance regimes and land-use change.

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