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Composition, structure, and dynamics of a pine-hardwood old-growth remnant in southern Arkansas

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DON C. BRAGG (U.S. Department of Agriculture, Forest Service, Southern Research Station, P.O. Box 3516 UAM, Monticello, AR 71656). Composition, structure, and dynamics of a pine-hardwood old-growth remnant in southern Arkansas. J. Torrey Bot. Soc. 131: 320–336. 2004.—The Levi Wilcoxon Demonstration Forest (LWDF) was originally established by the Crossett Lumber Company in 1939 to promote forestry research and demonstration in the Upper West Gulf Coastal Plain of southern Arkansas. The reserve currently has at least 27 different overstory tree species, with loblolly pine (*Pinus taeda* L.), shortleaf pine (*Pinus echinata* Mill.), and white oak (*Quercus alba* L.) comprising the majority of stand basal area. Hardwoods are most numerous, dominated by shade-tolerant species such as red maple (*Acer rubrum* L.), flowering dogwood (*Cornus florida* L.), blackgum (*Nyssa sylvatica* L.), and winged elm (*Ulmus alata* Michx.), especially in the subcanopy and understory. Large pines, oaks, and sweetgum are scattered throughout the stand, with some individuals exceeding 100 cm DBH and 45 m tall. Overstory trees rarely proved sound enough to age, but some stumps, logs, and increment cores suggest that the dominant canopy pines are 100 to 150 years old, with the largest individuals exceeding 200 years. Pines contributed the greatest amount of coarse woody debris. The average volume of dead wood was noticeably less than other examples of old-growth upland forest in the eastern United States, attributable largely to salvage. Increased windthrow and the salvage of dead and dying pines have become the primary perturbations of the LWDF. Without large-scale disturbance like catastrophic fire or logging, shade-intolerant pines, oaks, and sweetgum (*Liquidambar styraciflua* L.) will decline in prominence, to be replaced by more shade-tolerant species.

Key words: coarse woody debris, fire, salvage logging, succession, Upper West Gulf Coastal Plain, windthrow.

For a variety of reasons, old-growth forests have virtually disappeared from the uplands in the states of Arkansas, Louisiana, Oklahoma, and Texas (Bragg 2003). Logging, large-scale agriculture, uncontrolled fires, and urbanization during the last 200 years of settlement have ensured that only a tiny fraction of developable land remains in some semblance of primary forest. Most of these old forests are preserved as small remnants imbedded within a matrix of managed forest, agricultural, and residential landscapes, and are typically protected by public agencies (e.g., the USDA Forest Service) and non-governmental organizations (e.g., the Nature Conservancy). However, a few are controlled by industrial landowners, including examples such as the Flomaton Natural Area, a 24 ha old-growth longleaf pine (*Pinus palustris* Mill.) stand in southern Alabama owned by International Paper Corporation (Meldahl et al. 1995), Louisiana-Pacific Corporation's pine-hardwood Lloyd P. Blackwell Demonstration Forest near Urania, Louisiana (Tompkins 2000), and Potlatch Corporation's ''Lost Forty'' bottomland hardwood-loblolly pine (*Pinus taeda* L.) tract near Warren, Arkansas (Grell 2003; Heitzman et al. 2004).

Regardless of ownership, there have been many questions about how representative and functional these small, isolated tracts are, given their management history. As early as the 1940s, scientists expressed concern that fire exclusion and the alteration of other forest conditions were adversely affecting the composition, structure, and dynamics of set-aside natural areas in the South (e.g., Chapman 1947, 1952, Walker 1963, Guldin and Baker 1985, Cain and Shelton 1996). Even though some remnant old-growth stands have been reintroduced to fire in recent years in an attempt to restore historical disturbance regimes (e.g., the Flomaton Natural Area, Varner et al. (2000)), most are still protected from catastrophes, natural or otherwise (although some landowners salvage dead or dying trees in an

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effort to minimize insect outbreaks and recover timber value).

Only limited information is available on the long-term impacts of altered disturbance regimes (including fire suppression and the salvage of dead trees) on old-growth preserve attributes such as stand composition, structure, and the function of elements like coarse woody debris. Unfortunately, too few old-growth pine-hardwood stands remain to compare different management strategies (complete protection versus salvage permitted versus reintroduced fire regimes) and their long-term impacts on stand dynamics. However, industrial old-growth has, in some instances, experienced extensive and long-term salvage logging, thereby allowing for closer examination of the impacts of this disturbance on stand development. Through careful consideration of structural and compositional features of these old-growth remnants, it may be possible to identify key trends that can aid in their restoration and management.

This paper describes the under- and overstory attributes of a small old-growth stand in the coastal plain of southern Arkansas that has largely escaped fire (but not salvage logging) since its establishment. Originally preserved in 1939 for research and demonstration by the Crossett Lumber Company (Anonymous 1948, 1950), the Levi Wilcoxon Demonstration Forest (LWDF) is now owned by Plum Creek Timber Company. The LWDF contains many large and old loblolly and shortleaf (*Pinus echinata* Mill.) pine, white oak (*Quercus alba* L.), sweetgum (*Liquidambar styraciflua* L.), post oak (*Quercus stellata* Wang.), and other hardwoods.

Materials and Methods. SITE DESCRIPTION. Regionally, parent materials of the Upper West Gulf Coastal Plain (UWGCP, west of the Mississippi Valley Alluvial Plain) primarily consist of marine sediments deposited during the late Cretaceous and early Tertiary periods. Many of these materials were reworked and new ones deposited during the Quaternary period. For instance, Pleistocene river terraces and Holocene alluvium associated with the numerous streams that drain the landscape dominate southern and eastern Arkansas (Saucier 1974, Haley et al. 1993). Large areas of southern Arkansas are also covered by Pleistocene-era loess, with some deposits over 4 m thick (Gill et al. 1979). The LWDF is located on the Prairie Terrace of the UWGCP in Ashley County, Arkansas approximately 6 km south of the city of Hamburg (Fig. 1).

The study area averages 140 cm of precipitation and 200 to 225 frost-free days every year (Gill et al. 1979). The mean elevation of the LWDF is 45 m, varying only by ± 2 m, with predominantly gentle (0 to 2%) slopes. Most of the LWDF is upland, with Calloway and Grenada silt loams (Glossic Fragiudalfs) occupying the highest ground and soils along the minor bottomlands draining the LWDF are classified as Arkabutla silt loams (Aeric Fluvaquents), (Gill et al. 1979). A curious geologic feature common to the UWGCP and found in abundance in the LWDF are earthen mounds 1 to 2 m tall and 5 to 15 m in diameter. Called ''pimple,'' ''prairie,'' or ''gas'' mounds by locals, these concentric elevations are thought to have natural origins (Vanatta et al. 1916, Cain 1974, Saucier 1974, Johnson et al. 2002).

VEGETATION AND DISTURBANCE PATTERNS. The presettlement upland vegetation of southern Arkansas largely consisted of closed canopy pine, pine-oak, and oak-hickory-gum-pine forests, pine-oak-hickory woodlands, and scattered prairies (Vanatta et al. 1916, Turner 1937, Bragg 2002). Hardwoods and baldcypress (*Taxodium distichum* (L.) Rich.) dominated the bottomlands. Quaternary terraces were primarily pine or pine-hardwood admixtures, interspersed with small pockets of woodland, prairie, and perched hardwood swamps.

Dimensions of trees in the virgin forest of southern Arkansas were impressive. Bragg (2003) analyzed the General Land Office (GLO) notes for the Ashley County area and reported numerous pine, oak, and sweetgum > 150 cm in diameter, with some baldcypress exceeding 200 cm. Other Arkansas sources have reported white oaks, red oaks, and cottonwood (probably *Populus deltoides* Bartr.) that exceeded 180 cm in diameter (Langtree 1867, SLIMSR 1892, Anonymous 1909). Loblolly and shortleaf pine containing 30 m^3 (assuming 1 m^3 = 80 board feet (Doyle log rule), 30 m^3 = 2,400 board feet of lumber) were common in this part of the UWGCP, with the biggest individuals exceeding 100 m^3 (> 8,000 board feet) (Record 1910, Morbeck 1915, Chapman 1942, Bragg 2002, 2004a).

Fire and windthrow are thought to have been the primary presettlement disturbances of the region, with ice storms, insect outbreaks, lightning, and drought also affecting landscape dynamics (Turner 1937, Bragg 2002). Frequent

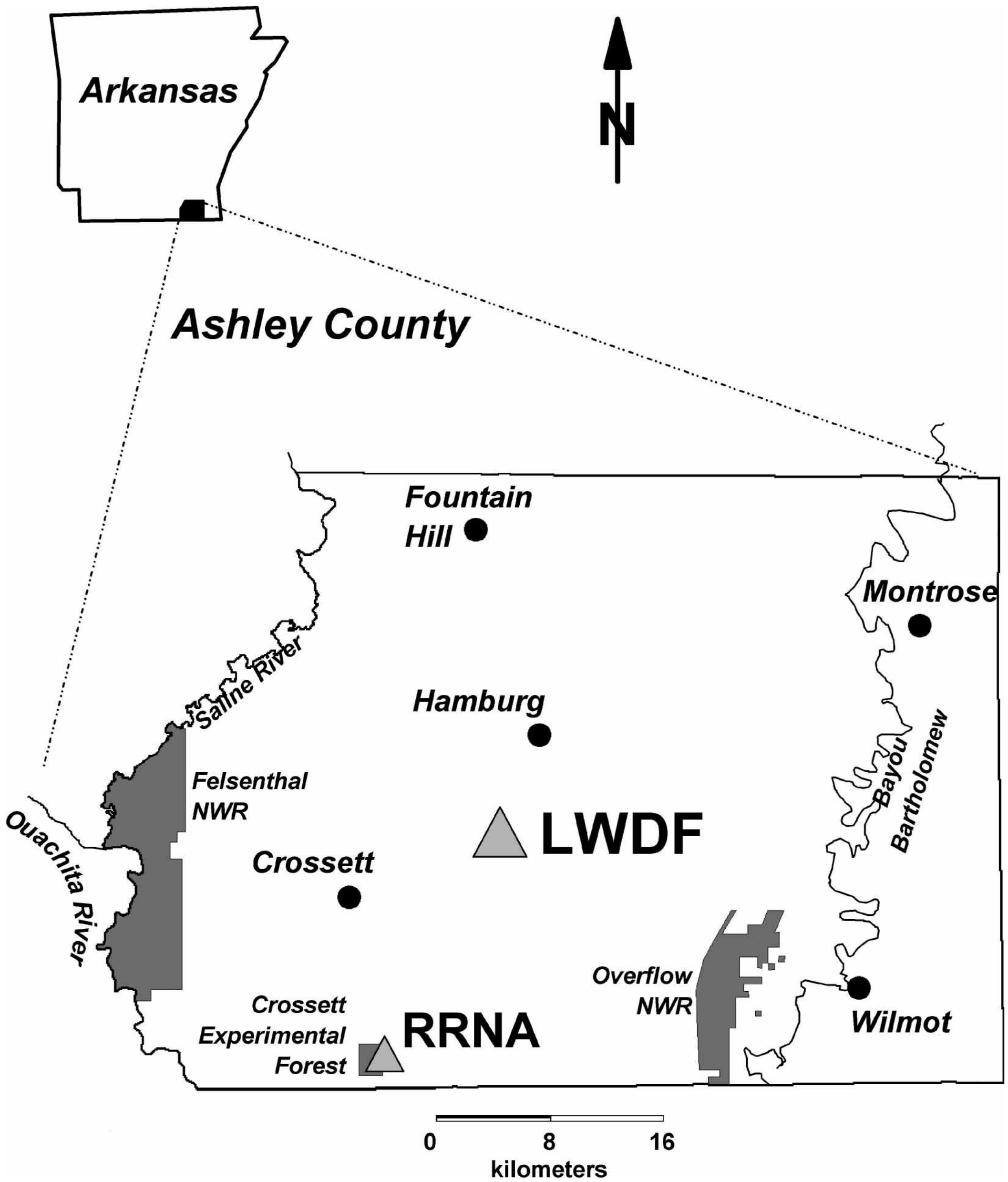

FIG. 1. Location of the Levi Wilcoxon Demonstration Forest in southeastern Arkansas.

burning helped maintain relatively open understories in upland forests and facilitated fire-adapted communities. In the UWGCP, shortleaf pine was considerably more common in presettlement times in part because young shortleaf can resprout following topkilling fires (Mattoon 1915, Bragg 2002).

Following Euroamerican settlement, logging and agriculture spread rapidly across the UWGCP. However, most farming operations failed, and much of the land in Ashley County reverted back to forest (Vanatta et al. 1916). The implementation of effective fire control in the 1930s, coupled with the onset of intensive forest management, further altered the dynamics of the region. For instance, loblolly pine's prominence has increased greatly in the UWGCP since 1900. Naturally seeded forests are considerably denser, younger, and more even-aged than their virgin counterparts, frequently with a thick under-growth of briars, vines, shrubs, and shade-tolerant tree species (Bragg 2002). Most of the prairies and open woodlands have been converted to farmland and loblolly pine plantations, or have reverted to closed canopy forests of natural origin.

LWDF TRANSECT AND PLOT CONFIGURATION. When established in 1939, the LWDF covered 40.5 ha (Anonymous 1948). In the decades since, two major highways have divided the stand into unequal thirds (Fig. 2), and some portions have been removed from the demonstration forest. Currently, only 6 ha of old timber are officially part of the demonstration forest, although the remaining area has received the same salvage-only management.

Plot sampling has been limited to the northwest corner (Fig. 2) because this section presents the best opportunity for long-term monitoring. However, most of the area originally set aside as the LWDF is outside of this reserved section, and still contains many large pines and hardwoods. To better use these external locations, incidental data were collected as they presented themselves. For example, if a salvaged but sound stump was located anywhere in the LWDF, it was aged. Similarly, very large individuals found outside the sample plots were measured for their dimensional information.

OVERSTORY AND UNDERSTORY SAMPLING. In the reserved section of the LWDF, 24 circular 0.1 ha (17.84 m radius) overstory plots were established in the summer of 2000. Because of the long, narrow configuration of the sample area (Fig. 3), eight plots were placed on each of three transects. Each transect was placed 40 m from the next transect to avoid overlap between overstory plots, and plot centers were spaced 100 m apart along the transect. Every merchantable-sized ($>$ 9 cm DBH) live tree within the overstory plot was tallied for species and DBH (measured to the nearest 0.25 cm). From this information, stand density information (number of trees and basal area per hectare) were derived. Very few of the large trees of any species in this stand are sound to the pith—overstory pines tend to have extensive red heart (*Phellinus pini* Ames), and most of the largest hardwoods are hollow. Therefore, age information was collected opportunistically by sampling the sound pines with an increment borer and counting the rings on freshly cut pine logs or stumps (no hardwoods were dated).

Understory woody vegetation (including woody vines, shrubs, and tree species) were identified using four 0.0004 ha (1.14 m radius) subplots per overstory plot. Live woody plants were separated into one of six size classes: 15 to 74 cm tall; 75 to 136 cm tall; 0 to 1.5 cm DBH; 1.5 to 3.8 cm DBH; 3.9 to 6.3 cm DBH; and 6.4 to 9.0 cm DBH. Individuals were identified to species when possible, but because of their small stature and poor leaf condition, some understory woody plants were only keyed to genus. Understory species abundances are reported in aggregate and by size class on a per hectare basis, and importance values (average of relative frequency, relative dominance, and relative abundance) were also calculated.

COARSE WOODY DEBRIS SAMPLING. Coarse woody debris (CWD) was sampled using the overstory plots as the delimiter. To be measured, the dead wood needed to be a snag (standing dead tree $>$ 2 m tall and at least 10 cm in diameter), stump (standing dead tree $<$ 2 m tall and at least 10 cm in small-end diameter, with a solid volume of at least 0.01 m^3), or downed log (solid woody debris at least 1 m long and at least 10 cm in diameter). Large- and small-end diameter was measured to the nearest 0.25 cm using a set of calipers or diameter tape. For snags that could not be directly measured, an estimate of small-end diameter (to the nearest 2.5 cm) was made. When accessible, piece length was determined to the nearest 0.03 m using a measuring tape. Otherwise, piece length was estimated to the nearest 0.3 m in height with a clinometer. Logs that crossed the boundary of the plot were truncated at that intersection. However, overhanging or leaning snags entirely rooted in the plot but extending past the edge were considered within the sampling area.

Volume (V) of each piece of CWD was determined using Smalian's formula:

$$V = \frac{\pi(D^2 + d^2)L}{8}$$

where D is piece large-end diameter, d is piece small-end diameter, and L is piece length (all dimensions in m). CWD frequency and volume per hectare were determined by summing and averaging over total plot area. Pieces of CWD were also checked for evidence of being cut with a saw, indicating their link to timber salvage.

Results. OVERSTORY SPECIES COMPOSITION, STOCKING, AND DENSITY. Hardwoods comprise over 81% of the merchantable-sized stems in

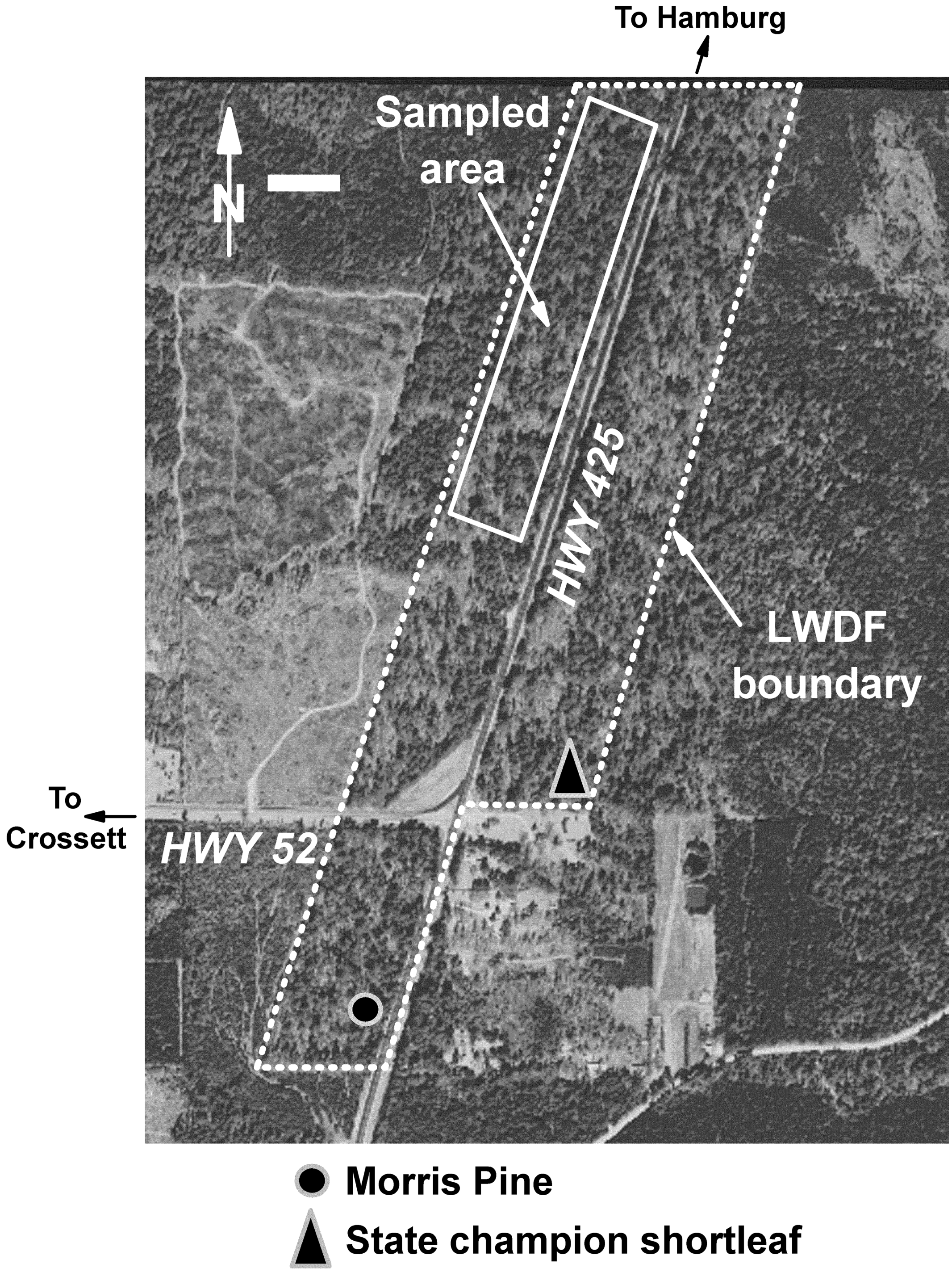

FIG. 2. Contemporary configuration of the LWDF, including the reserve area (northwest corner), the Morris Pine (southwest corner), and the new state champion shortleaf pine (southeast corner). Scale bar near north arrow represents approximately 100 m.

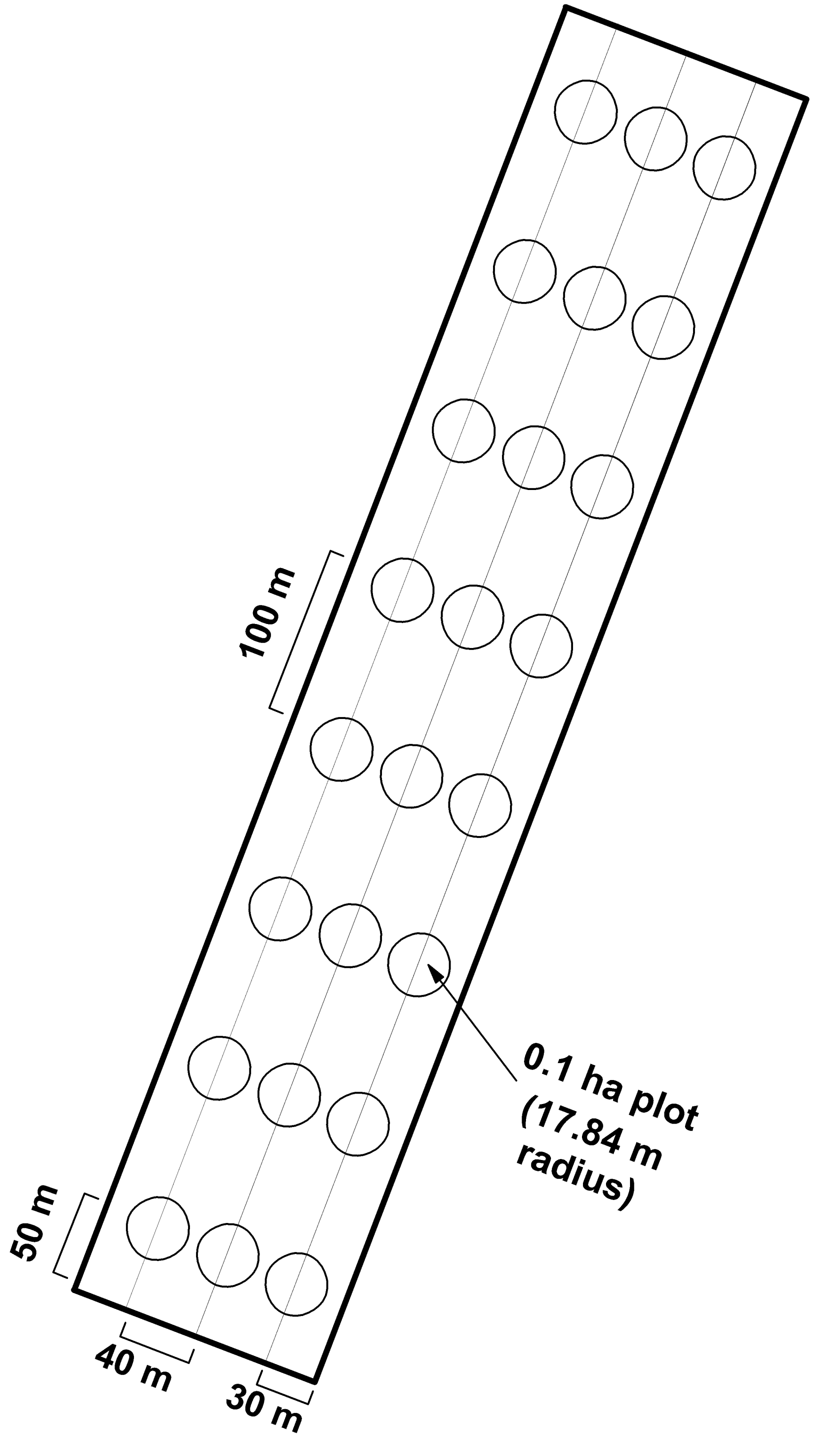

FIG. 3. Transect and overstory plot layout in the reserved section of the LWDF.

Table 1. Basal area and size distribution of trees >9.0 cm DBH from the sample plots in the reserved area of the LWDF.

Species[a]	Trees per hectare	Basal area per hectare	Min. DBH (cm)	Max. DBH (cm)	Avg. DBH (cm)	DBH std. dev. (cm)
Shortleaf pine (*Pinus echinata* Mill.)	21.7	5.0	20.8	85.1	52.4	14.54
Loblolly pine (*Pinus taeda* L.)	49.6	13.2	15.5	92.5	55.9	16.57
Red maple (*Acer rubrum* L.)	13.8	0.2	9.4	24.1	12.6	3.13
American hornbeam (*Carpinus caroliniana* Walt.)	1.2	<0.1	9.7	20.8	14.4	5.74
Bitternut hickory (*Carya cordiformis* (Wang.) K. Koch)	1.7	0.1	10.7	49.5	23.8	18.06
Mockenut hickory (*Carya tomentosa* Nutt.)	4.6	0.2	11.4	39.4	21.6	10.26
Sugarberry (*Celtis laevigata* Willd.)	0.4	0.1	12.4	12.4	12.4	0.00
Flowering dogwood (*Cornus florida* L.)	10.8	0.1	9.4	18.0	12.4	2.28
Persimmon (*Diospyros virginiana* L.)	0.4	<0.1	9.4	9.4	9.4	0.00
Green ash (*Fraxinus pennsylvanica* Mill.)	0.4	<0.1	9.9	9.9	9.9	0.00
American holly (*Ilex opaca* Ait.)	0.8	<0.1	11.9	14.7	13.3	1.98
Sweetgum (*Liquidambar styraciflua* L.)	85.8	3.8	9.4	62.7	21.5	10.26
Red mulberry (*Morus rubra* L.)	2.1	<0.1	12.7	22.9	16.7	4.10
Blackgum (*Nyssa sylvatica* L.)	25.0	0.6	9.4	43.2	15.5	6.32
Eastern hophornbeam (*Ostrya virginiana* (Mill.) Koch)	0.4	<0.1	9.9	9.9	9.9	0.00
Black cherry (*Prunus serotina* Ehrh.)	7.5	0.2	10.2	27.7	17.3	4.99
White oak (*Quercus alba* L.)	5.50	3.6	9.4	79.5	24.6	14.79
Southern red oak (*Quercus falcata* Michx.)	23.3	1.6	9.7	69.6	26.5	12.06
Cherrybark oak (*Quercus pagoda* Raf.)	17.9	0.7	10.7	34.0	21.0	6.21
Water oak (*Quercus nigra* L.)	8.8	0.8	10.7	69.9	28.8	16.39
Willow oak (*Quercus phellos* L.)	1.7	<0.1	11.7	35.1	20.1	10.59
Post oak (*Quercus stellata* Wang.)	2.5	0.6	13.5	77.7	49.9	24.85
Black oak (*Quercus velutina* Lam.)	6.2	0.2	11.2	33.8	19.0	7.19
Sassafras (*Sassafras albidum* (Nutt.) Nees.)	5.8	0.1	9.7	25.7	15.9	4.57
Winged elm (*Ulmus alata* Michx.)	33.8	0.6	9.4	31.0	14.7	5.04
American elm (*Ulmus americana* L.)	0.4	<0.1	10.9	10.9	10.9	0.00
Slippery elm (*Ulmus rubra* Muhl.)	5.8	<0.1	9.9	29.9	12.7	5.03
TOTAL PER HECTARE:	387.5	31.8				

[a] Species nomenclature from Harlow et al. (1979), Smith (1988), and Moore (1999).

this survey, with sweetgum and white oak alone accounting for over 1/3 of the stems (Table 1). Loblolly pine (12.8%), winged elm (8.7%), blackgum (6.5%), southern red oak (6.0%), and shortleaf pine (5.6%) individually contributed more than 5% of the total stems. The remaining 20 species constituted less than a quarter of the number of stems, including five species that each tallied less than a single live individual per hectare (sugarberry (*Celtis laevigata* Willd.), persimmon (*Diospyros virginiana* L.), green ash (*Fraxinus pennsylvanica* Mill.), eastern hophornbeam (*Ostrya virginiana* (Mill.) Koch), and American elm (*Ulmus americana* L.)).

Even though they constitute less than 20% of the total number of overstory stems in the LWDF, loblolly (13.2 $m^2 \cdot ha^{-1}$) and shortleaf (5.0 $m^2 \cdot ha^{-1}$) pine account for 57.2% of the live overstory basal area (Table 1). Among the hardwoods, only sweetgum (3.8 $m^2 \cdot ha$), white oak (3.6 $m^2 \cdot ha^{-1}$), and southern red oak (1.6 $m^2 \cdot ha^{-1}$) individually contributed more than 5% of the stand's basal area, with the rest more or less evenly distributed between the other species. Figure 4a highlights the dominance of large loblolly and shortleaf pine in the LWDF's basal area as distributed by diameter class.

MAXIMUM TREE DIMENSIONS. While some large individuals were inventoried in the overstory plots on the reserve area (Table 1), the biggest trees in the LWDF fell outside of the plot boundaries. Many of the largest pines in Arkansas are found in the LWDF (Table 2). The Morris Pine (see Fig. 2), a local landmark, currently has a DBH of 142 cm, a height of almost 40 m, and an average crown spread of 14 m. A new Arkansas state champion shortleaf pine (91 cm DBH, 43 m tall, 17.4 m average crown spread) was also discovered in the LWDF. The largest white oak observed in this stand was over 111 cm in DBH, 40.5 m tall, and had an average crown spread of 20.4 m. Other white oaks, post oaks, and sweetgums range from 80 to 100 cm DBH (Table 2).

STAND AGE. The LWDF is an uneven-aged stand. Most of the oldest pine cohort has long since succumbed to insects, disease, wind, or

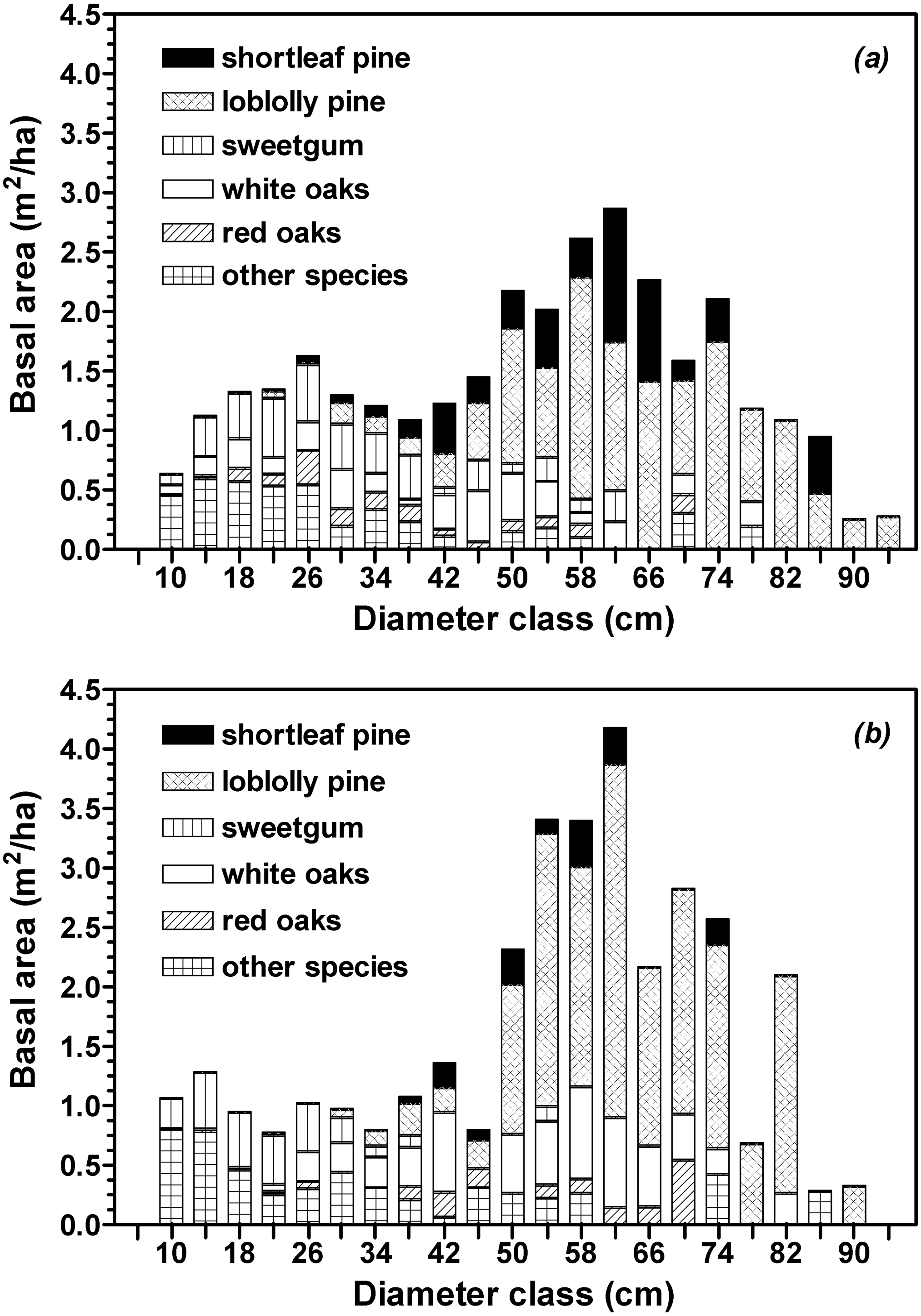

FIG. 4. Basal area distribution by major species group for the LWDF (*a*) and the RRNA (fall of 2000 remeasurement) (*b*).

Table 2. Dimensions of select large trees found in the entire area of the LWDF.

Species	DBH (cm)	Height (m)	Average crown width (m)	Bigness Index[a]	Comments
Loblolly pine	142.0	39.6	13.9	317	Morris Pine
Loblolly pine	120.7	45.6	18.2	314	felled by May 2003 storm
Loblolly pine	103.6	45.9	12.8	289	
White oak	111.5	40.5	20.4	288	
Loblolly pine	106.2	41.4	15.6	280	
Loblolly pine	106.0	40.2	14.3	276	
Shortleaf pine	90.7	43.3	17.4	268	new AR state champion
Loblolly pine	105.9	36.6	16.3	264	
White oak	91.2	38.4	20.4	255	
Southern red oak	92.7	36.9	23.8	255	
Shortleaf pine	85.1	42.6	10.4	254	
White oak	91.9	36.6	20.6	251	
Sweetgum	72.6	40.5	15.4	235	
Sweetgum	79.5	37.5	15.1	234	
Shortleaf pine	80.3	37.8	12.4	233	
Post oak	76.5	36.0	19.6	229	
Shortleaf pine	86.1	33.9	13.1	228	
Post oak	80.3	33.9	16.3	224	
Post oak	75.2	33.0	20.7	218	
Sweetgum	71.9	34.8	16.4	217	
White oak	83.8	28.2	20.2	213	

[a] Bigness Index = tree circumference (in inches) + tree height (in feet) + 1/4 (average crown width (in feet)), as calculated for the National Register of Big Trees (American Forests 2000).

lightning. The Morris Pine was estimated to be 250 years old in 1950 (Anonymous 1950), and appears to be the last surviving loblolly in the LWDF that established well before Euroamerican settlement. The largest individuals (those > 90 cm DBH) probably exceed 200 years, with most dominant pines between 100 and 150 years old (Table 3). The youngest pines cored for this study were between 50 and 60 years old, and the only pines noticeably less than 50 years old in the LWDF are saplings along the edge of the highways and recent skid trails. The oldest hardwoods in the LWDF likely surpass 100 years, and some have widely spreading crowns with large branches, suggestive of considerably more open conditions during early stand development (Marks and Gardescu 2001).

Evidence suggests that many upland pine-dominated forests of the UWGCP in the presettlement period were uneven-aged, with multiple age cohorts intermingled within a particular tract (Chapman 1912, 1913, Forbes and Stuart 1930, Bragg 2002). The LWDF shares this attribute (Table 3). The oldest cohort appears to be solely represented by the 300 year old Morris Pine. A somewhat larger group of pines is approximately 200 years old, with another age cluster appearing to be 140 to 160 years old. In general, the smallest diameter pines are between 50 and 75 years old. However, as with most uneven-aged stands, diameter is not a good indicator of tree age, as many of the younger (80 to 120 years old) canopy pines are as big in diameter as those in the oldest cohorts.

UNDERSTORY SPECIES COMPOSITION. The composition of woody vines, shrubs, and trees < 9 cm DBH can be found in Table 4. Grapevines (*Vitis* spp., especially muscadine (*Vitis rotundifolia* Michx.)) were the most abundant lianas (almost 800 stems/ha combined). *Vitis* spp. grows in the canopies of smaller trees and shrubs and often reaches the crowns of the dominant overstory trees. Rattan (*Berchemia scandens* (Hill) K. Koch) vines were less common, followed by greenbriars (*Smilax* spp.) and Virginia creeper (*Parthenocissus quinquefolia* (L.) Planchon). *Smilax* tended to be smaller in stature than *Vitis* or *Berchemia* and heavily browsed by white-tailed deer (*Odocoileus virginianus* Zimm.). Locally, *Smilax* rivals *Vitis* for abundance. Shrubs also constitute a large portion of the understory of the LWDF. American beauty berry (*Callicarpa americana* L.) is particularly abundant, averaging over 2,000 stems per hectare, with other shrubs like *Vaccinium* spp., *Rubus* spp., and serviceberry (*Amelanchier arborea* (Michx. f.) Fern.) much less common. With the exception of American beauty berry, shrubs and woody vines were patchily distributed throughout the

Table 3. Pine age estimates taken from increment cores, culled butt logs, or stump ring counts in the LWDF.

Pine species	Tree log (length), or stump	Diameter (cm)[a]	Ring count[b] (years)	Estimated age[c] (years)	Comments
Loblolly	tree	142.0	—	>300	Morris Pine (Anonymous 1950)
Loblolly	tree/log (6 m)	120.7	82	>200[d]	Cored age of outer 24 cm radius
Loblolly	stump	109.2	134		felled by May 2003 windstorm
Shortleaf	stump	101.6	123		felled by May 2003 windstorm
Loblolly	stump	92.5	157		felled by May 2003 windstorm
Loblolly	tree	91.7	115	>200	Cored age of outer 21 cm
Loblolly	stump	91.4	119		felled by May 2003 windstorm
Shortleaf	stump	88.4	146		felled by May 2003 windstorm
Shortleaf	stump	86.9	124		felled by May 2003 windstorm
Loblolly	stump	86.1	150		felled by May 2003 windstorm
Loblolly	stump	83.1	115		felled by May 2003 windstorm
Loblolly	stump	82.8	103		felled by May 2003 windstorm
Loblolly	tree	82.6	128	>150	Cored age to rotten heartwood
Shortleaf	stump	82.6	142		felled by May 2003 windstorm
Loblolly	stump	81.3	98		felled by May 2003 windstorm
Loblolly	stump	79.0	140		felled by May 2003 windstorm
Shortleaf	log (2 m)	78.7	133	>150	felled by May 2003 windstorm
Loblolly	stump	77.5	114		felled by May 2003 windstorm
Shortleaf	log (1.5 m)	76.5	147	>150	felled by May 2003 windstorm
Loblolly	stump	74.7	118		felled by May 2003 windstorm
Loblolly	stump	73.7	80		felled by May 2003 windstorm
Shortleaf	stump	73.2	122		felled by May 2003 windstorm
Shortleaf	log (3 m)	71.9	160	>200	felled by May 2003 windstorm
Shortleaf	log (3 m)	71.4	161	>200	felled by May 2003 windstorm
Loblolly	stump	69.6	121		
Shortleaf	stump	66.5	147		felled by May 2003 windstorm
Loblolly	stump	66.3	84		
Shortleaf	stump	62.5	103		felled by May 2003 windstorm
Shortleaf	stump	60.7	90		
Shortleaf	stump	59.9	86		
Shortleaf	stump	59.2	100		felled by May 2003 windstorm
Loblolly	tree	58.4	90		
Shortleaf	log (9 m)	57.2	136	>200	felled by May 2003 windstorm
Shortleaf	tree	56.1	75		
Shortleaf	stump	55.6	85		
Shortleaf	log (6 m)	54.1	142	>200	felled by May 2003 windstorm
Shortleaf	tree	48.5	144		
Loblolly	stump	46.2	74		felled by May 2003 windstorm
Shortleaf	tree	46.2	66		
Shortleaf	stump	42.2	76		
Shortleaf	tree	40.4	129		
Loblolly	tree	38.6	52		
Loblolly	tree	36.8	104		
Shortleaf	tree	33.0	71		
Shortleaf	tree	32.3	66		
Loblolly	tree	31.0	62		
Loblolly	tree	29.0	53		
Loblolly	tree	25.4	56		
Loblolly	tree	20.1	51		
Shortleaf	tree	17.8	54		
Loblolly	tree	16.0	52		

[a] DBH for individuals that were increment cored, small-end log diameter, or stump diameter for trees, logs, and stumps, respectively.

[b] From stump age or increment core of standing tree.

[c] Estimated ages were developed for individuals with extensive heart rot or if rings were counted further from the base of tree (e.g., at the small end of a cull butt log).

[d] After being cored for age at DBH in 2001, this loblolly pine was toppled in the May 2003 windstorm. A count at the small end of its 6 m long cull but log found 144 annual rings.

Table 4. Woody understory composition of the Levi Wilcoxon Demonstration Forest reserved sample area.

Taxonomic group Species or genus[a]	Total stems per ha	Number of stems per hectare by size class code[b]						RF[c] (%)	RD[c] (%)	RA[c] (%)	IV[c] score
		A	B	C	1	2	3				
Woody vines											
Virginia creeper (*Parthenocissus quinquefolia* (L.) Planchon)	25.7	0	0	25.7	0	0	0	0.18	0.07	1.04	0.43
Grapevine (*Vitis* spp.)	103.0	0	0	25.7	77.2	0	0	0.73	2.42	3.12	2.09
Muscadine (*Vitis rotundifolia* Michx.)	695.0	0	0	617.7	77.2	0	0	4.93	4.03	16.67	8.54
Greenbriar (*Smilax* spp.)	154.4	0	0	154.4	0	0	0	1.09	0.42	3.12	1.55
Rattan (*Berchemia scandens* (Hill) K. Koch)	205.9	0	0	180.2	25.7	0	0	1.46	1.27	6.25	2.99
Shrubs											
Rubus spp.	180.2	0	0	180.2	0	0	0	1.28	0.49	5.21	2.33
Serviceberry (*Amelanchier arborea* (Michx. f.) Fern.)	360.3	180.2	25.7	103.0	51.5	0	0	2.55	1.87	7.29	3.90
Vaccinium spp.	51.5	0	0	25.7	25.7	0	0	0.36	0.85	2.08	1.10
Tree huckleberry (*Vaccinium arboreum* Marsh.)	489.0	0	0	489.0	0	0	0	3.47	1.34	1.04	1.95
American beauty berry (*Callicarpa american* L.)	2084.9	0	0	2007.7	77.2	0	0	14.78	7.83	22.92	15.18
Trees											
Pine (loblolly + shortleaf)	103.0	103.0	0	0	0	0	0	0.73	0.01	2.08	0.94
Red maple	2419.5	1698.8	283.1	283.1	103.0	25.7	25.7	17.15	14.28	35.42	22.28
Pawpaw (*Asimina triloba* (L.) Danul.)	231.7	0	0	77.2	154.4	0	0	1.64	4.90	2.08	2.88
Unidentified hickory (*Carya* spp.)	51.5	51.5	0	0	0	0	0	0.36	0	2.08	0.82
Flowering dogwood	592.0	257.4	128.7	77.2	77.2	25.7	25.7	4.20	12.78	12.50	9.82
Persimmon	51.5	0	0	25.7	25.7	0	0	0.36	0.85	2.08	1.10
Green ash	25.7	25.7	0	0	0	0	0	0.18	0	1.04	0.41
American holly	25.7	0	0	0	25.7	0	0	0.18	0.78	1.04	0.67
Sweetgum	205.9	103.0	25.7	0	51.5	0	25.7	1.46	8.61	6.25	5.44
Red mulberry	103.0	77.2	0	0	25.7	0	0	0.73	0.79	4.17	1.89
Blackgum	463.3	308.9	51.5	0	51.5	51.5	0	3.28	7.86	9.38	6.84
Eastern Hophornbeam	77.2	51.5	25.7	0	0	0	0	0.55	0.01	2.08	0.88
Black cherry	103.0	77.2	0	0	0	0	25.7	0.73	7.04	4.17	3.98
Unidentified[d] white oaks (*Quercus* spp.)	25.7	25.7	0	0	0	0	0	0.18	0	1.04	0.41
White oak	3449.1	2728.4	308.9	360.3	51.5	0	0	24.45	2.86	48.96	25.42
Unidentified[d] red oaks (*Quercus* spp.)	360.3	334.6	25.7	0	0	0	0	2.55	0.03	10.42	4.34
Southern red oak	51.5	25.7	25.7	0	0	0	0	0.36	0.01	2.08	0.82
Water oak	77.2	77.2	0	0	0	0	0	0.55	0.01	3.12	1.23
Willow oak	77.2	77.2	0	0	0	0	0	0.55	0.01	3.12	1.23
Sassafras	669.2	360.3	51.5	154.4	77.2	25.7	0	4.74	5.94	15.62	8.77
Unidentified elm (*Ulmus* spp.)	25.7	25.7	0	0	0	0	0	0.18	0	1.04	0.41
Winged elm	540.5	308.9	77.2	25.7	77.2	25.7	25.7	3.83	12.62	17.71	11.39

[a] Species nomenclature from Harlow et al. (1979), Smith (1988), and Moore (1999).

[b] Size class codes: A = 15 to 74 cm tall; B = 75 to 136 cm tall; C = ≥137 cm tall, <1.5 cm DBH; 1 = ≥137 cm tall, 1.5 to 3.8 cm DBH; 2 = ≥137 cm tall, 3.9 to 6.3 cm DBH; 3 = ≥137 cm tall, 6.4 to 9.0 cm DBH.

[c] RF (relative frequency) = 100 × (total number of stem of species/total number of stems); RD (relative density) = 100 × (total basal area of species/total understory basal area); RA (relative abundance) = 100 × (number of subplots species found/total number of subplots); IV (importance value) score = (RF + RD + RA)/3.

[d] Unidentified white and red oak groups were used when individuals could not be distinguished based on their limited sample of browsed shade leaves, but they could be placed into one of these groups.

Table 5. Comparison of estimated presettlement forest conditions with the LWDF and two other contemporary old-growth pine-hardwood remnants in the UWGCP of southern Arkansas.

Stand[a]	Overstory tree richness	Max. pine age (years)	Total trees per ha	Total tree BA ($m^2 \cdot ha^{-1}$)	Loblolly pine BA ($m^2 \cdot ha^{-1}$)	Shortleaf pine BA ($m^2 \cdot ha^{-1}$)	CWD volume ($m^3 ha^{-1}$)	Source(s)[b]
Historical	10–20	300–400	50–200	10–16	5–10	5–10	variable	1
LWDF	27	300	387.5	31.8	13.2	5.0	33	2
RRNA	27	150	414.0	34.4	17.2	1.6	120	3
Lost Forty	23	150	433.3	31.3	7.1	0.0	unknown	4

[a] The ''historical'' stand description is consistent with presettlement forest conditions found in a ''typical'' and similarly-sized parcel on a terrace (or similar) site in the UWGCP of southern Arkansas. Other abbreviations: LWDF = Levi Wilcoxon Demonstration Forest, Ashley County, AR; RRNA = Russ Reynolds Research Natural Area, Ashley County, AR; Lost Forty, Calhoun County, AR.

[b] Sources of information: 1—Bragg (2002); 2—this study; 3—Bragg (2002, unpublished data on file) Cain and Shelton (1996); Zhang (2000); 4—Grell (2003), Heitzman et al. (2004).

study area. Most lianas are associated with large trees, while the shrubs are most common near areas of soil disturbance and/or canopy gaps.

Tree species constitute the largest portion of the woody understory in the LWDF. White oak and red maple (*Acer rubrum* L.) both exceeded 2,400 stems per hectare, and sassafras (*Sassafras albidum* (Nutt.) Nees.), flowering dogwood (*Cornus florida* L.), winged elm (*Ulmus alata* Michx.), and blackgum (*Nyssa sylvatica* L.) ranged from 400 to 700 stems per hectare (Table 4). Most trees were found in the two smallest size classes (those $<$ 1.37 m tall). Few individuals occupied the subcanopy, and these were almost exclusively shade-tolerant species like red maple, American holly (*Ilex opaca* Ait.), flowering dogwood, sassafras, and winged elm. Virtually no pine seedlings were encountered in the understory plots, and all of them fell into the smallest size class. Less shade-tolerant species like sweetgum, southern red oak (*Quercus falcata* Michx.), and white oak decreased across the understory size classes and some were absent from the largest understory size classes (Table 4).

COARSE WOODY DEBRIS. CWD was relatively abundant in the sample area, averaging 33 $m^3 \cdot ha^{-1}$ and 191 pieces per hectare (standard deviations = 16.9 $m^3 \cdot ha^{-1}$ and 96.7 pieces/ha, respectively). Individual pieces ranged from small branches, stumps, and shards displacing 0.01 m^3 to snags and logs up to 2.7 m^3 in volume. Most of the identifiable woody debris was pine snags, stumps, boles, or branches. Of the 458 pieces tallied, pine comprised almost 60% of the CWD, followed by oak (9.0% undifferentiated oak, 3.5% red oak group, 3.1% white oak group) and gum (sweetgum + blackgum = 7.4% of total pieces). The other hardwood species (including any unidentifiable hardwoods) contributed the remaining 17.3%, with no single taxa providing more than 5% of the total amount of CWD.

Discussion. COMPARISON WITH OTHER REGIONAL EXAMPLES. Overall, dimensional, compositional, and age-related trends of the LWDF are consistent with contemporary observations of old, unmanaged forests in the southern United States (e.g., Jones et al. 1981, Glitzenstein et al. 1986, Shelton and Murphy 1990, Pederson et al. 1997, Battaglia et al. 1999, Harcombe et al. 2002, Heitzman et al. 2004). For example, the increasing scarcity of pine in all diameter classes (Fig. 4) is a common feature of protected old pine remnants (e.g., Jones et al. 1981, Pederson et al. 1997, Shelton and Cain 1999, Harcombe et al. 2002, Heitzman et al. 2004) since conditions are rarely favorable enough for pine seedlings to establish and persist, while larger individuals are continuously lost through attrition.

Table 5 contrasts reconstructed historical upland forest conditions with the LWDF and two other old-growth pine-hardwood remnants on the UWGCP in southern Arkansas. Compared to a recent inventory of the Reynolds Research Natural Area (RRNA) on the nearby Crossett Experimental Forest and the Lost Forty, an old-growth remnant in Calhoun County, Arkansas, the LWDF has similar overstory richness (23 to 27 species). In all cases, the lack of natural pine and a proliferation of hardwood regeneration indicate that the historical dominance of pine is gradually ending, and pine will virtually disappear from these stands over the next few decades.

Loblolly pine is the predominant conifer in all of the contemporary examples of upland old-growth remaining in southern Arkansas. However, the LWDF possesses three times the basal area of shortleaf pine (5.0 $m^2 \cdot ha^{-1}$ versus 1.6 $m^2 \cdot ha^{-1}$) found in the RRNA, and no shortleaf pine was reported in the Lost Forty (Table 5). Hence, the abundance of shortleaf pine in the LWDF is closer to presettlement levels than either the RRNA or the Lost Forty. This discrepancy probably arose from differences in composition associated with stand origin. The LWDF was preserved before any substantive logging had occurred, while the RRNA was extensively high-graded and then allowed to grow back. Additionally, the salvage of dead and dying pines in the LWDF provides limited protection for the somewhat more vulnerable shortleaf from southern pine beetle (*Dendroctonus frontalis* Zimm.) outbreaks that periodically affect the RRNA. Wetter terrace sites on the UWGCP of southern Arkansas also tend to be predominantly loblolly pine, with much less shortleaf (Vanatta et al. 1916). An inability to tolerate sustained high soil moisture and considerably less fire probably accounts for the lack of shortleaf pine in the Lost Forty. A similar paucity of shortleaf was also reported from a wet pine-hardwood stand arising from an unknown disturbance in the mid-1800s (Bragg 2004b).

Loblolly and shortleaf pines in the UWGCP that date to before 1850 are very uncommon (Bragg 2002). The presence of trees > 200 years old is a notable difference between the LWDF and other remnant stands (Table 5). Once again, this reflects differences in stand history. For instance, the RRNA was subjected to diameter-limit cutting before 1915 that removed most of the mature pine and oak, hence very few individuals are older than 140 years. Other contemporary old-growth loblolly pine-dominated remnants in the region have been aged at 140 to 180 years old (Jones 1971, Tompkins 2000, Heitzman et al. 2004). The multiple age class structure found in the pines of the LWDF and some of the other old forest remnants could have arisen from episodic or continuous recruitment, but either pathway would have required long periods of relatively open canopies with favorable seedbeds.

RESERVE ESTABLISHMENT PATTERNS AND DYNAMICS. Many of the timber company "set-asides" were established decades ago by visionaries like Henry Hardtner and Levi Wilcoxon who recognized that virgin forests had been virtually eliminated. Others, like the former Bienville Pines Scenic Area in central Mississippi, were preserved because they were inconvenient to log (Jones 1971). Still others were spared accidentally. The Lost Forty, for instance, was not cut during the original logging period because its remote, oft-flooded location made ownership determination and access difficult. By the time proper ownership was established, the landowner had decided to retain the Lost Forty in its pristine form (O'Neal 2000, Heitzman et al. 2004). Their origins notwithstanding, the post-reservation management of these preserves has strongly influenced their current conditions and future development.

Alteration of Disturbance Regimes. Open forests, presumably maintained by frequent surface fires, dominated the presettlement uplands across much of the UWGCP, with considerably grassier understories (e.g., Olmsted 1902, Record 1907, Morbeck 1915, Maxwell and Martin 1970). For example, General Land Office (GLO) surveyors in the Ashley County area encountered brushy patches along stream bottoms, but upland forests or the woodlands near prairies rarely displayed much of an understory unless recently affected by windthrow (Bragg 2003). Most modern UWGCP forests develop a dense and persistent woody understory unless frequently burned or treated with herbicides. Thickets of American beauty berry and Japanese honeysuckle (*Lonicera japonica* Thunb.) can lead to the localized absence of virtually all other understory plants. Interestingly, although poison ivy (*Toxicodendron radicans* (L.) Kuntze), yellow jessamine (*Gelsemium sempervirens* (L.) Jaume St.-Hil.), and Japanese honeysuckle are locally very common, none were found on any of the understory subplots. To some degree, this may suggest only a limited amount of disturbance has affected the reserved area of the LWDF.

Fire was critical for maintaining pine abundance in the UWGCP, especially on better quality sites. Bragg (2002) determined that many of the upland pine-dominated forests in the region were an almost equal mixture of loblolly and shortleaf pine, with relatively few hardwoods. Many of the poorer or fire-prone sites had an even higher proportion of shortleaf pine. Fire exclusion has diminished natural pine reproduction as more fire-sensitive hardwoods, vines, briars, and forbs invade the understory (Chapman 1952, Blair and Brunett 1976, Cain and Shelton 1995, Shelton and Cain 1999). Further evidence of a reduction in fire frequency and intensity can

FIG. 5. Abundance of vines in the LWDF (left) is noticeably greater than shown in most historical photographs (right) from the UWGCP (photograph on left by D.C. Bragg, photograph on right from Anonymous (1905)).

be observed by the absence of lianas in overstory trees from many historical photographs of upland timber in the UWGCP (Fig. 5). Even low-intensity surface fires can sever woody vines, suggesting their abundance has increased markedly since presettlement times (Bragg 2002).

Fire was not the only major influence affecting the development of the LWDF. Numerous ice storms have struck the region, resulting in deformed tops, the occasional loss of a large overstory individual, and sometimes extensive damage to smaller diameter trees. In recent years, droughts have killed understory species such as flowering dogwood, while lightning, disease, and insects claim a small number of trees of all sizes every year. Tornadoes, downbursts, and straight-line winds arising from severe thunderstorms have long perturbed the forests of southeastern Arkansas (Cole 1927, Turner 1935, Bragg 2003), producing dramatic localized effects. Windthrow is playing an increasingly substantial role in the dynamics of the LWDF. Over the last decade, the forest adjacent to the LWDF has been cleared and replanted. This has left the narrow strip of old, tall forest that constitutes the LWDF exposed to strong winds, especially since its north-south orientation is perpendicular to the prevailing direction of most storm fronts. In May of 2003, severe straight-line windstorms struck the region, creating many small and a few large (> 1 ha) gaps. Most of the individuals felled by these recent wind events suffered from extensive root and butt rot, while others had limited rooting due to high water tables. However, these storms were also severe enough to snap the boles on apparently healthy and sound pines.

A shift from a fire-based to wind- or selective logging-based disturbance regime has important consequences for long-term stand development, especially once the preserve has been invaded by hardwoods. Glitzenstein et al. (1986) found evidence suggesting that under these circumstances, even a severe natural disturbance may not halt the transition to hardwood-dominated forests because of the ability of hardwoods to sprout following top-killing. Frequent burning of loblolly-shortleaf pine dominated stands with well established hardwood understories may reduce the size of hardwoods, but probably would not significantly reduce their density (Cain 1993). Under these conditions, maintaining pine reproduction, establishment, and canopy ascension will be very difficult without the deliberate use of fire or chemicals, or both.

The Potential Impacts of Salvaging. Even though salvage cutting runs counter to the strictest definitions of natural areas (see Povilitis 2002), its application has probably sheltered the overstory pines in the LWDF from much of the insect mortality found in more protected natural areas (e.g., Cain and Shelton 1996, Harrington et al. 2000). However, sparing the survivors from insect outbreaks has introduced a suite of factors that can permanently alter the integrity of the remnant. The salvage of timber with heavy equipment and the development of skid roads, fire protection, and the invasion of exotic species have undoubtedly altered the developmental trajectory of the LWDF. For instance, small-scale soil disturbance and canopy opening associated with salvage logging coupled with fire protection have likely accelerated the transition of this pine-dominated remnant towards more shade-tolerant hardwoods (see Blair and Brunett (1976) and Glitzenstein et al. (1986)).

The removal of salvaged logs also impacts the nature of the LWDF. The quantity of dead wood in the LWDF was similar to that reported in second-growth stands in the eastern United States, but noticeably less than that reported for unmanaged old-growth (e.g., Spetich et al. (1999), although see Harcombe et al. (2002)). Two managed second-growth parcels on the Crossett Experimental Forest (D.C. Bragg, unpublished data; Zhang 2000) averaged approximately 15 $m^3 \cdot ha^{-1}$ of CWD, while the RRNA exceeded 120 $m^3 \cdot ha^{-1}$ (Zhang 2000). The intermediate level of CWD on the LWDF is a product of the salvage of dead and dying timber (cut marks were noted on 22.3% of the pieces). Sawtimber-sized material was usually taken, and since bigger pieces contribute more to CWD volume than branches or small logs, their removal dramatically lowered average woody debris loads.

Unfortunately, there is very little quantitative data on the amount or size class distribution of dead wood in presettlement upland forests of this region. CWD volumes were probably highly variable, depending on stand density and disturbance frequency (Bragg 2002). Rapid decay and/or consumption by insects and fire would have limited the long-term accumulation of dead wood, but large individual contributions from the massive virgin pines and hardwoods would have produced locally elevated levels. A high degree of spatial heterogeneity in debris loading is likely to have been the norm, associated with variation in stand stocking and age class distribution. The quantity (33 $m^3 \cdot ha^{-1}$) of CWD observed in the LWDF would certainly have fallen within the range of expectations for presettlement upland forests in this area, although the evenness and relatively small size of the dead wood may not be characteristic.

Conclusions. Though not as well known as some of their counterparts on public lands, industrially-owned tracts of old-growth like the LWDF have often been maintained for decades by their owners. The overstory of the LWDF is dominated by large pine, oak, and gum, with some of the oldest and biggest pines exceeding 100 cm in diameter and 200 years old. Over the years, the understory of the LWDF has become increasingly dominated by shade-tolerant, fire-intolerant hardwoods, shrubs, and wood vines. With the notable exception of edges along the major highways that bisect the LWDF, virtually no pine saplings have emerged to replace the overstory pine. Thus, the pine overstory is gradually being eliminated, hastening the conversion to closed canopy hardwood-dominated forests.

As with many such protected forests, the isolated LWDF embedded in a matrix of commercial timberlands has meant that fire exclusion has been practiced for decades. In addition, decades of periodic salvaging of dead and dying overstory pines at the LWDF has further altered stand structure, composition, and dynamics by improving conditions for shade-tolerant shrubs and hardwoods. The harvest of adjacent forests has also left the stand exposed to windthrow and vulnerable to invasion by exotic species. Nevertheless, the LWDF still retains many of the characteristics of the virgin forest that once covered millions of hectares in the UWGCP.

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