Stand conditions immediately following a restoration harvest in an old-growth pine-hardwood remnant

D.C. Bragg

Southern Research Station, USDA Forest Service, P.O. Box 3516 UAM, Monticello, AR 71656

Correspondence: dbragg@fs.fed.us

Abstract

Portions of the Levi Wilcoxon Demonstration Forest (LWDF), a privately owned parcel of old-growth pine and hardwoods in Ashley County, Arkansas, were recently treated to restore conditions similar to some historic accounts of the virgin forest. Following a hardwood-only cut, a post-harvest inventory showed that the number of tree species in the sample area declined from 24 in 2006 (the most recent pre-harvest inventory) to 12 in 2009. Loblolly (*Pinus taeda* L.) and shortleaf (*Pinus echinata* Mill.) pine now comprise 59.2% of the remaining live trees, up from 16.2% in 2006. Between 2006 and 2009, basal area dropped from 28.2 to 16.4 m^2/ha and stem density declined from 349.2 to 72.4 stems/ha, respectively. Total live biomass also fell from 224.8 Mg/ha in 2006 to 130.1 Mg/ha in 2009. While most of the pines in the LWDF are between 100 and 200 years old, ring counts on 102 randomly selected hardwood stumps yielded only one greater than 100 years old. Two-thirds of these hardwoods were less than 70 years old, having originated after the stand was set aside by the Crossett Lumber Company. Historical documentation and recent research suggest that the LWDF is now more similar to presettlement pine-dominated forests of southern Arkansas, which generally had lower stocking and fewer hardwoods.

Introduction

Ecosystem restoration has become an emphasis for public land managers (e.g., Bosworth and Brown 2007), but has been far less important for private landowners whose primary focus is timber production, agriculture, or other commodity-based objectives. However, increasing numbers of these owners are engaging in at least some level of restoration activity on their properties. As an example from the southeastern United States, large-scale efforts to restore bottomland hardwood forests on marginal or abandoned agricultural lands have been embraced by many ownerships, including farming and timber interests (e.g., Newling 1990, King and Keeland 1999, Stanturf et al. 2000). There are also significant efforts underway to restore fire-dependent longleaf pine (*Pinus palustris* Mill.) ecosystems on private lands in this region (e.g., Masters et al. 2003, Stanturf et al. 2004). Fewer efforts have been made in less high-profile ecosystems, but this is likely to change as interest grows in alternatives to production forestry.

Unlike bottomland hardwood or longleaf pine forests, wherein the primary challenge is to return the desired tree species to a position of canopy dominance, the relative abundance of loblolly (*Pinus taeda* L.) and shortleaf (*Pinus echinata* Mill.) pine-dominated stands usually means that ecosystem restoration focuses on developing long-term sustainability. For example, it has long been recognized that in the absence of significant disturbances such as wildfire or silviculture, mesic pine-dominated forests will gradually succeed to hardwood-dominated stands (e.g., Chapman 1942, Quarterman and Keever 1962, Halls and Homesley 1966, Switzer et al. 1979, Shelton and Cain 1999).

The reintroduction of controlled burning is one of the more common land restoration approaches on public ownerships. Over time, with properly applied fire regimes, it is possible to encourage pine at the expense of hardwoods. Fire can also reduce litter and duff layers and consume large woody debris, both of which tend to accumulate under no-burn conditions. However, burning is less appealing to many industrial and private landowners, who rarely have the resources available to sustain this management strategy. Furthermore, there are a number of liability issues related to controlled burning (e.g., smoke obscuring nearby highways, causing traffic hazards; air quality impacts) that make landowners reluctant to use this approach.

Since the challenges of using fire and other natural processes to maintain desired stand conditions are considerable (e.g., Rideout et al. 2003), other human-mediated controls (e.g., cutting) may be required to sustain the restoration efforts (Bauhus et al. 2009). In particular, to ensure the perpetuation of the pine component when partial cutting is used as the primary restoration tool (e.g., Blair and Brunett 1976, Bragg 2004a), additional treatments are probably necessary. For example, Outcalt and Brockway (2010) demonstrated that targeted selection of undesired overstory species, coupled with post-harvest herbicide application and controlled burning, was the most rapid means to achieve their restoration goals in longleaf pine forests. Fortunately, private landowners often face considerably fewer regulatory and operational hurdles for using chemical or mechanical understory control (rather than adaptations of natural events such as fire) in their restoration efforts.

In the fall of 2009, the Levi Wilcoxon Demonstration Forest (LWDF), a privately owned parcel of old-growth timber located about 6 km south of Hamburg in Ashley County, Arkansas, experienced the first stage of an effort to restore the stand to conditions more closely resembling the pine-dominated virgin forests of this region. According to the management staff of Plum Creek Timber Company (the landowner), their approach is to first harvest most mid- and overstory hardwoods (retaining virtually all of the pine) in areas outside of riparian management zones. This cutting is intended to be followed by treatments to control hardwood reproduction and sprouting. If possible, fire will be introduced to limit fuel loads and hopefully permit the establishment of historical understory conditions (i.e., more graminoids, forbs, and scattered pine reproduction). This paper evaluates the success of the initial phase (partial overstory removal) in achieving a stand structure more consistent with presettlement conditions.

Methods

Study area description

The LWDF is found in the South Central Arkansas Subsection (231Ea) of the National Hierarchical Framework of Ecological Units (McNab and Avers 1994). Though not yet described to the finest resolution of this hierarchical framework, phases of the nearby North Louisiana Clayey Hills Landtype Association defined by Van Kley and Turner (2009) provide reasonable approximations of the natural vegetative communities of the LWDF. These include Shortleaf Pine-Southern Red Oak/*Callicarpa*-*Chasmanthium* Loamy Dry-Mesic Uplands and Water Oak/*Mitchella* Loamy Mesic Stream Bottoms.

The gently rolling (<2% slopes) Calloway and Grenada silt loam soils (Glossic Fragiudalfs) that dominate the study site are seasonably wet and heavily forested, usually in a mixture of pine and hardwood (Gill et al. 1979). Annual precipitation averages about 140 cm, and there are 200 to 225 frost-free days (Gill et al. 1979). The LWDF has an abundance of low, circular, natural-origin “prairie” or “pimple” mounds, some of which exceed 1 m in height and 20 m in diameter.

The LWDF was originally owned by the Crossett Lumber Company, which reserved the stand as a “natural area” in 1939 (Anonymous 1948). Management of this stand change little over the years, even after the Crossett Lumber Company was acquired by Georgia-Pacific in the early 1960s. During this period, only occasional salvage of dead or dying pines was done on the LWDF (Bragg 2004b, 2006). Georgia-Pacific eventually transferred their lands to a new entity, The Timber Company, which was soon sold to Plum Creek Timber Company. Further descriptions of the environment and history of the LWDF can be found in previous papers (e.g., Bragg 2004b, 2006).

Restoration harvest treatments

Conventional timber management in this region usually involves the clearcutting, followed by intensive site preparation (e.g., ripping and bedding, then herbicide use and/or fertilization) and the planting of genetically improved loblolly pine seedlings. Because of the special status of the LWDF, the current landowner chose not to follow this industrial silvicultural regime, but rather decided to try to restore the stand to a semblance of the pine-dominated presettlement forests of the region. Hence, most hardwoods, except those along riparian management zones, were harvested.

Because the landowner intends to reintroduce controlled burning to this stand and does not want accumulations of logging slash to lead to excessively hot fires and fire-related mortality in the pine overstory, most of the tops and branches of cut trees were also hauled to the landing and chipped for fuel at a local mill. The net result of these treatments was to produce an open, pine-dominated stand with a sparse understory and considerable exposure of mineral soil (Figure 1).

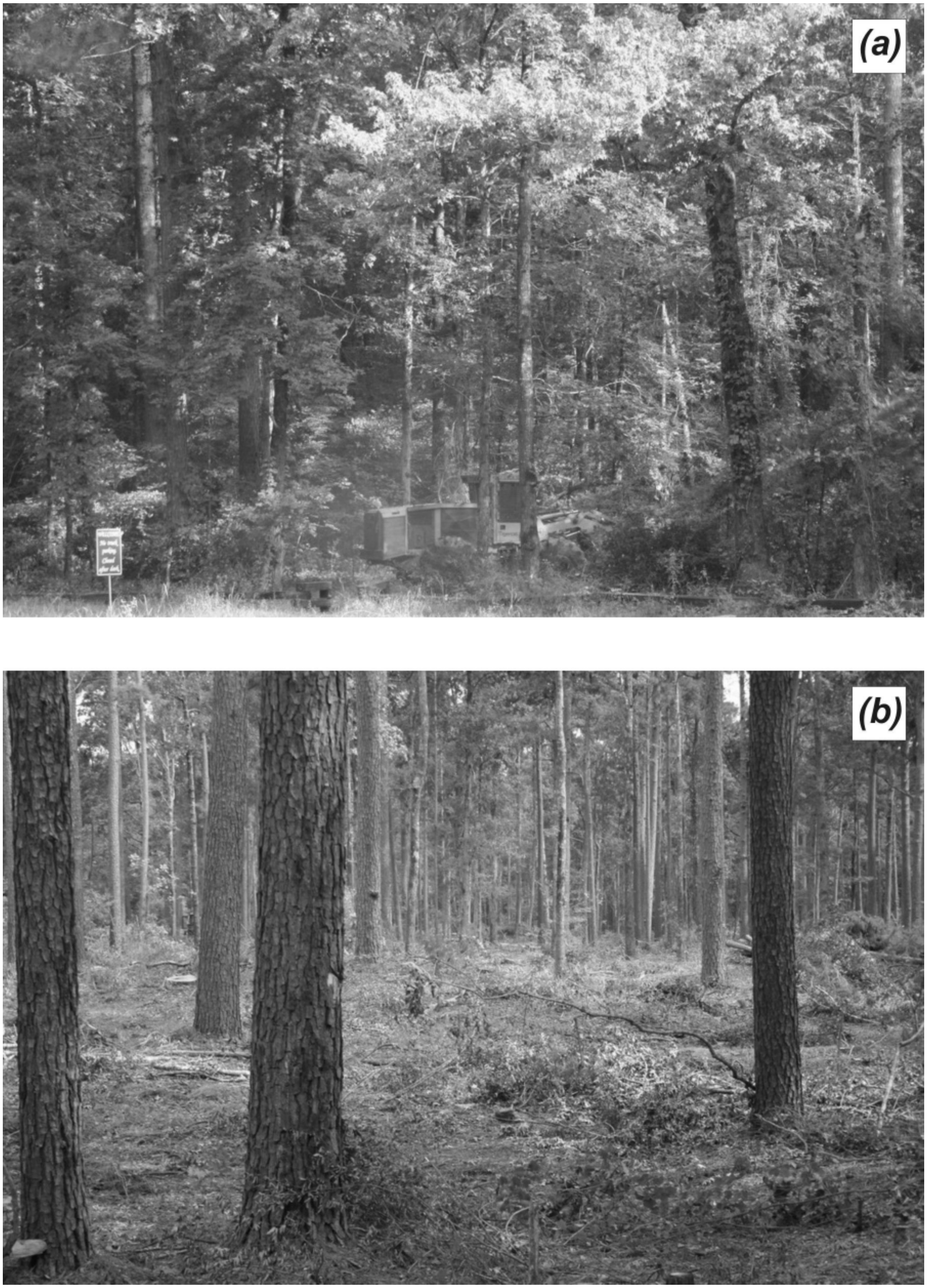

Figure 1. Pre- *(a)* and post-restoration *(b)* views of LWDF stand conditions, taken from different vantage points.

Plot establishment and sampling

The original set of twenty-four 0.1-ha study plots had been established by the author on the LWDF in the summer of 2000 and remeasured in 2006 (Bragg 2004b, 2006). The logging of this restoration began in August of 2009 and has destroyed most of these original plots. Hence, a new set of sample plots were placed in the same general area of the LWDF. Three transects, running parallel to Highway 425 and spaced 40 m apart, were established just southwest of the parking area along the highway and extend northeasterly to the first major stream drainage. Along each transect, six to eight 0.1-ha circular plots were established at staggered 80-m intervals to ensure no overlap between these new plots.

All live trees with diameter at breast height (DBH) of at least 9.1 cm were included in the 2009 inventory, with their species and DBH (to the nearest 0.1 cm) recorded. Measures of stand density (basal area, in m^2/ha and frequency, in stems/ha) were determined using the tallies of the 21 overstory plots. Within each overstory plot, 5 stumps of all species created by the restoration harvest were selected to approximate tree age. These stumps were a minimum of 15 cm in diameter, and were required to be intact (not excessively damaged by the logging) and visible to the pith (no missing rings due to decay). To randomize their selection, the first eligible stump encountered in each of 4 quadrats (NE, SE, SW, and NW) while traveling in a clockwise direction was chosen regardless of the distance from plot center (so long as the stump was within the plot). A fifth stump, the one closest to plot center that had not yet been sampled in any quadrat, was then selected from the remaining uncounted eligible stumps. If possible, species of the stumps were identified, and rings were counted in situ (no cross-dating was performed, so these are only approximate tree ages). Of the 105 ring-counted stumps, 102 were used to describe hardwood overstory age (in 3 quadrats, the only stumps were a few small pines cut during the restoration harvest). Pine ring count data for this stand can be found in Bragg (2004b, 2006).

Within each overstory plot, a 1-m^2 sampling frame was placed halfway along the radii of the plot following the 4 cardinal directions. This sampling frame delineated the search area for the immediate post-harvest woody plant understory. Tree reproduction, shrubs, and lianas were identified to species or taxonomic group and placed into one of six size classes: A (stems 15-74 cm tall); B (stems 75-136 cm tall); C (stems ≥ 137 cm tall but < 1.5 cm at DBH); 1 (stems 1.5-3.8 cm DBH); 2 (stems 3.9-6.3 cm DBH); and 3 (stems 6.4-9.0 cm DBH). The 1-m^2 sampling frames also defined the area used to estimate percent ground coverage of a number of different substrates, including mineral soil, live vegetation, large woody debris, litter and duff, and water. This assessment was made just prior to leaf drop in the fall of 2009. Since it was not possible to sample preharvest ground cover conditions for comparison, three transects, each containing twelve 1-m^2 sample plots were placed in March of 2010 in adjacent, unharvested portions of the LWDF with the same overstory as the treated area (the delay was due to circumstances beyond our control). With the exception of the hardwood ring counts and ground cover estimates, each of these measurements were compared to samples collected during the last inventory of the LWDF in 2006 (Bragg 2006).

Live tree biomass determination

Total live tree biomass was calculated using DBH as the main predictor. Jenkins et al. (2003) developed the following general equation for aboveground live tree biomass (LTB_{AG}) for each of these species groups based on published allometric relationships:

$$LTB_{AG} = e^{\beta 0+\beta 1(ln(DBH))} \qquad (1)$$

where $\beta 0$ and $\beta 1$ are species group parameters. Belowground live tree biomass (LTB_{BG}) is treated as a near-linear relation with LTB_{AG} (Enquist and Niklas 2002):

$$LTB_{BG} = 3.88(LTB_{AG}^{1.02}) \qquad (2)$$

Because LTB_{AG} is an exponential function of DBH, LTB_{BG} also behaves as such. Live tree size class distributions from a number of existing studies and historical reports were used to contrast contemporary and historical estimates of biomass using equations (1) and (2).

Results and Discussion

Species presence

A post-harvest inventory (Table 1) showed that the number of overstory species in the sample area declined from 24 in 2006 (the most recent pre-harvest inventory) to 12 in 2009, with loblolly and shortleaf pine now comprising 59.26% of the remaining live trees (up from 16.24% in 2006). Two taxa not present in 2006, black hickory (*Carya texana* Buckl.) and white ash (*Fraxinus americana* L.), were found on the

2009 sample plots. These species were present in the LWDF prior to the restoration harvest, but simply were not tallied because they did not occur in the 2006 plots. Note that this current study did not sample the riparian management zone buffers along the main drainage of the LWDF. If this had been done (the 2006 study included plots in this zone), it is likely that a number of species would be added to the list.

The reduction of overstory diversity across much of this stand makes the LWDF more consistent with the patterns observed for the pine-dominated virgin forest of this region (Bragg 2002, 2004b). Historical records document a local (α) tree diversity of between 10 and 20 overstory species in upland forests (e.g., Olmsted 1902, Zon 1905, Garver and Miller 1933), although landscape (γ) diversity does not appear to have changed much over time, with scores of species found regionally in both the past and present (e.g., Bragg 2002, 2003).

Change in understory species composition is harder to quantify, since many of the taxa affected by the logging may actually remain but were covered by logging slash, while others were only top-killed. Additionally, many of the hardwood stumps were still alive and will probably sprout during the next growing season.

The dominance (>95%) of live woody plants remaining in the smallest understory size class (Table 2) will also prove to be fleeting, as the newly increased site resources produced by the opening of the canopy and removal of overstory competitors should permit advance reproduction and new germinants to grow rapidly. Historically, frequent fires maintained open understories in this portion of southern Arkansas, with patchy areas of pine and hardwood reproduction scattered amongst grasses, forbs, and areas of exposed mineral soil (e.g., Olmsted 1902, Record 1907, Bragg 2002, 2003).

Table 1. Species presence change (for live trees > 9.0 cm DBH) in the LWDF between the 2006 inventory (Bragg 2006) and the 2009 inventory conducted following the first restoration treatment of this stand.

	Relative abundance (percent of total stems) in:	
Species	2006	2009
Shortleaf pine (*Pinus echinata* Mill.)	4.18	17.13
Loblolly pine (*Pinus taeda* L.)	12.06	42.13
Red maple (*Acer rubrum* L.)	5.01	0.00
American hornbeam (*Carpinus caroliniana* Walt.)	0.37	0.00
Bitternut hickory (*Carya cordiformis* (Wang.) K. Koch))	0.72	0.00
Black hickory (*Carya texana* Buckl.)[a]	0.00	0.69
Mockernut hickory (*Carya tomentosa* Nutt.)	1.09	0.69
Sugarberry (*Celtis laevigata* Willd.)	0.11	0.00
Flowering dogwood (*Cornus florida* L.)	2.26	0.00
Green ash (*Fraxinus pennsylvanica* Marsh.)	0.11	0.00
White ash (*Fraxinus americana* L.)[a]	0.00	0.69
American holly (*Ilex opaca* Ait.)	0.23	0.00
Sweetgum (*Liquidambar styraciflua* L.)	20.65	13.12
Red mulberry (*Morus rubra* L.)	0.49	0.00
Blackgum (*Nyssa sylvatica* L.)	7.99	0.00
Eastern hophornbeam (*Ostrya virginiana* (Mill.) Koch)	0.37	0.00
Black cherry (*Prunus serotina* Ehrh.)	1.66	0.00
White oak (*Quercus alba* L.)	13.12	9.81
Southern red oak (*Quercus falcata* Michx.)	9.31	11.88
Cherrybark oak (*Quercus pagoda* Raf.)	1.20	0.69
Water oak (*Quercus nigra* L.)	2.26	1.93
Post oak (*Quercus stellata* Wang.)	0.60	0.69
Black oak (*Quercus velutina* Lam.)	1.80	0.00
Sassafras (*Sassafras albidum* (Nutt.) Nees.)	1.66	0.00
Winged elm (*Ulmus alata* Michx.)	11.57	0.69
Slippery elm (*Ulmus rubra* Muhl.)	1.20	0.00

[a] Since many of the original plot locations had been destroyed by the logging, a new series of plots were established during the fall, after many leaves had dropped. These "new" species could either be differences in identification between the inventories, or the inclusion of previously untallied taxa.

Table 2. Abundance of the live understory woody plants in the LWDF following the 2009 restoration harvest.

Species	Number of stems per hectare by size class code						Totals by species
	A[a]	B	C	1	2	3	
Woody vines							
Virginia creeper (*Parthenocissus quinquefolia* (L.) Planchon)	357.1	0.0	0.0	0.0	0.0	0.0	357.1
Muscadine (*Vitis rotundifolia* Michx.)	1428.6	0.0	0.0	0.0	0.0	0.0	1428.6
Greenbrier (*Smilax* spp.)	2261.9	238.1	0.0	0.0	0.0	0.0	2500.0
Honeysuckle (*Lonicera* spp.)	357.1	0.0	0.0	0.0	0.0	0.0	357.1
Poison ivy (*Toxicodendron radicans* (L.) Kuntze)	1190.5	0.0	0.0	0.0	0.0	0.0	1190.5
Rattan (*Berchemia scandens* (Hill) K. Koch)	119.0	0.0	0.0	0.0	0.0	0.0	119.0
Shrubs							
Vaccinium spp.	952.4	0.0	0.0	0.0	0.0	0.0	952.4
American beautyberry (*Callicarpa americana* L.)	0.0	119.0	0.0	0.0	0.0	0.0	119.0
Trees							
Red maple	476.2	0.0	0.0	0.0	0.0	0.0	476.2
Blackgum	119.0	0.0	0.0	0.0	0.0	0.0	119.0
Black cherry	0.0	0.0	0.0	119.0	0.0	0.0	119.0
White oak	1190.5	0.0	0.0	0.0	0.0	0.0	1190.5
Southern red oak	357.1	0.0	0.0	0.0	0.0	0.0	357.1
Water oak	119.0	0.0	0.0	0.0	0.0	0.0	119.0
Post oak	119.0	0.0	0.0	0.0	0.0	0.0	119.0
Winged elm	952.4	0.0	0.0	0.0	0.0	0.0	952.4
Totals by size class	10000.0	357.1	0.0	119.0	0.0	0.0	10476.2

[a] Size class definitions: A (stems 15-74 cm tall); B (stems 75-136 cm tall); C (stems ≥ 137 cm tall but < 1.5 cm at DBH); 1 (stems 1.5-3.8 cm DBH); 2 (stems 3.9-6.3 cm DBH); and 3 (stems 6.4-9.0 cm DBH).

Tree size class distributions

While large pines were largely unaffected by the restoration, logging activities that targeted hardwoods seems to have reduced the small individuals of all species (Figure 2, Table 3). Of the nearly 350 live stems > 9.0 cm DBH per hectare in the 2006 inventory, only about 20% of these remained following the restoration treatment, of which most were pine (Table 4). The differences in pine abundance patterns between the 2006 and 2009 inventories (Figure 2) have several explanations—but not harvesting, because only a very small number of pines were cut. First, the sample plots were not in the same location between these inventories, which likely produced some of the pine differences. The LWDF sample of 2009 had a somewhat higher level of shortleaf pine (about 2 more stems per hectare, Table 4), but these did not arise as ingrowth since the last measurement. Second, there have been a number of pine that have died over the last few years, including canopy dominants killed by lightning strikes, windthrow, and bark beetles. Both loblolly and shortleaf pines experienced mortality during this period, but the data to compare which species may have succumbed at a higher rate are not available.

The absence of small diameter individuals of either pine species in the LWDF (Figure 2) is a well-documented phenomena witnessed in numerous mature, unmanaged pine-dominated forests across the region (e.g., Shelton and Cain 1999, Heitzman et al. 2004, Bragg and Heitzman 2009). In these stands, the hardwood under- and midstories have formed a closed canopy over the years, thereby shading out the shade-intolerant pine germinants. Coupled with a thick litter layer that inhibits pine seed germination, overstory recruitment of pine has all but ceased under these conditions. Presumably, the restoration treatment on the LWDF will open the canopy and prepare the seedbed sufficiently to trigger enough pine recruitment so the pine overstory can be sustained into the future.

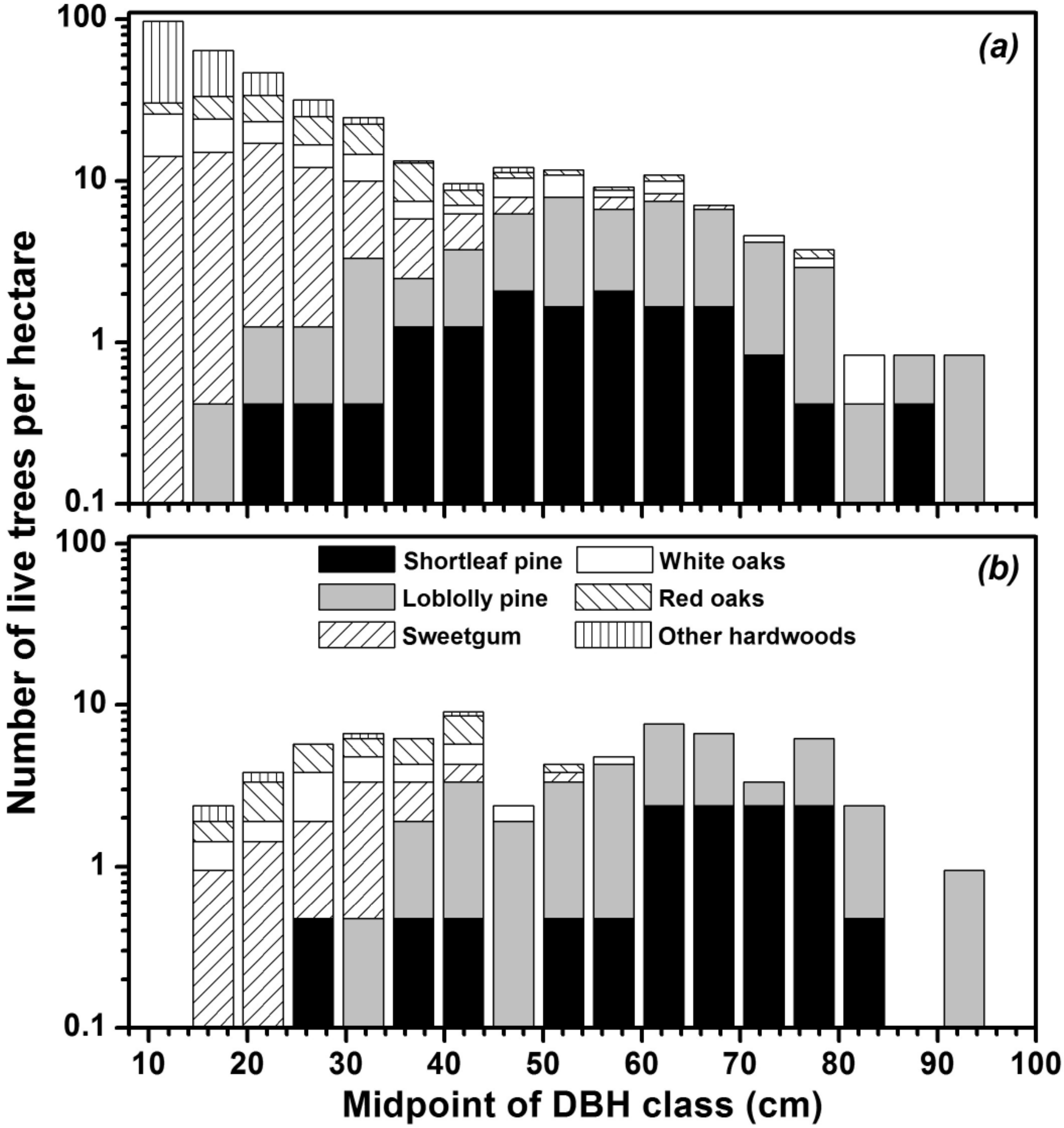

Figure 2. Live tree size class distribution of a number of distinct taxonomic groups in the LWDF from before the restoration treatment *(a)* and immediately afterwards *(b)*.

In the treated area, a much reduced fraction of hardwoods of all size categories remains, with most of these left to ensure that large canopy openings were not created by the harvest. Initially few in number in the 2006 inventory (Figure 2a), large diameter hardwoods were virtually eliminated in the treated area (Figure 2b)—very few were retained because of their value as sawtimber. Historical documentation (e.g., Zon 1905, Chapman 1913) of the virgin pine-dominated forests of this area rarely noted large (> 50 cm DBH) diameter hardwoods in the uplands. Rather, large hardwoods (many exceeding 100 cm DBH) tended to be much more common in the bottomlands and first terraces along minor streams, presumably where they received greater protection from the frequent surface fires of the presettlement period (Bragg 2002, 2003). Current

Table 3. Comparison of the statistics of sampled live trees > 9.0 cm DBH in the LWDF.

	Prior to restoration (2006)				Immediately after restoration (2009)			
Species	Average DBH (cm)	Standard deviation (cm)	Min. DBH (cm)	Max. DBH (cm)	Average DBH (cm)	Standard deviation (cm)	Min. DBH (cm)	Max. DBH (cm)
Shortleaf pine	53.5	14.5	20.6	85.1	64.5	13.4	24.9	80.7
Loblolly pine	55.9	15.6	17.8	93.5	61.5	14.3	33.2	92.7
Red maple	12.3	3.7	9.1	25.7	0.0	0.0	0.0	0.0
American hornbeam	16.1	5.0	12.7	21.8	0.0	0.0	0.0	0.0
Bitternut hickory	22.7	17.1	10.7	49.0	0.0	0.0	0.0	0.0
Black hickory	-- [a]	--	--	--	43.2	0.0	43.2	43.2
Mockernut hickory	22.4	8.4	12.4	38.1	29.3	0.0	29.3	29.3
Sugarberry	12.7	0.0	12.7	12.7	0.0	0.0	0.0	0.0
Flowering dogwood	12.3	2.7	9.1	18.3	0.0	0.0	0.0	0.0
Green ash	10.7	0.0	10.7	10.7	0.0	0.0	0.0	0.0
White ash	-- [a]	--	--	--	16.8	0.0	16.8	16.8
American holly	14.5	3.6	11.9	17.0	0.0	0.0	0.0	0.0
Sweetgum	23.5	11.2	9.1	64.8	31.0	9.0	17.7	52.7
Red mulberry	21.2	4.5	15.7	25.9	0.0	0.0	0.0	0.0
Blackgum	15.4	6.5	9.1	43.2	0.0	0.0	0.0	0.0
Eastern hophornbeam	11.4	0.9	10.4	11.9	0.0	0.0	0.0	0.0
Black cherry	15.9	5.1	9.7	25.9	0.0	0.0	0.0	0.0
White oak	26.3	15.8	9.1	81.8	33.9	10.8	15.9	59.4
Southern red oak	26.5	10.3	10.2	60.7	32.8	9.5	18.3	52.0
Cherrybark oak	24.2	5.6	17.5	31.5	27.3	0.0	27.3	27.3
Water oak	34.2	17.4	12.4	76.5	40.0	2.5	37.6	42.5
Post oak	44.5	28.5	9.7	78.5	48.3	0.0	48.3	48.3
Black oak	19.8	5.9	11.9	30.5	0.0	0.0	0.0	0.0
Sassafras	17.4	4.3	10.2	26.4	0.0	0.0	0.0	0.0
Winged elm	15.1	6.1	9.1	46.0	21.1	0.0	21.1	21.1
Slippery elm	12.8	6.0	9.1	29.7	0.0	0.0	0.0	0.0

[a] Taxa not reported in the inventory of Bragg (2006).

plans for this restoration include the retention of streamside management zones along the larger of the drainages crossing this site, which should protect a limited number of the larger hardwoods.

Stand density and biomass

Between 2006 and 2009, overall stand density dropped from 28.2 m^2/ha of basal area to 16.4 m^2/ha (Table 4). Actual pine basal area changed little, with slightly more shortleaf and slightly less loblolly measured in 2009 (see earlier discussion on pine abundance). From a relative perspective, pine is now much more important overall—loblolly pine now constitutes 58% of stand live basal area, and shortleaf pine contributes 26%, for a total of 84% of the 16.4 m^2/ha in the treated area. In 2006, loblolly made up 39% of stand basal area, and shortleaf constituted just 12%—hardwoods were truly codominant in the LWDF. Hardwood basal area declined most precipitously as a consequence of the restoration harvest deliberately targeting this group. For example, the three hardwoods with the highest basal areas in 2006 (sweetgum, 3.8 m^2/ha; white oak, 3.4 m^2/ha; and southern red oak, 2.1 m^2/ha) were all reduced to between 0.7-0.8 m^2/ha after the 2009 treatment, and none of the other hardwoods present exceeds 0.3 m^2/ha.

As with historical accounts of species presence and abundance, the treated LWDF now better aligns with the virgin forest. While it is certain that past forest conditions covered a wide range of stand densities, historic pine forests seem less well stocked than contemporary examples. Most references (e.g., Mohr 1897, Olmsted 1902, Chapman 1913, Forbes and Stuart 1930) report between 10 and 20 m^2/ha of basal area in presettlement pine-dominated forests, with occasional mention of higher totals (Bragg 2002, 2008). Bruner (1930, p. 23) identified frequent damaging fires as one of the principle reasons that old-growth pine forests in southeastern Arkansas averaged only about 50% “of their capacity”, with some stands only capable of one-third the stocking of protected stands. Given the multiple examples of unmanaged, old pine-hardwood forests in the vicinity of the LWDF that

Table 4. Stand-level attributes for sampled live trees > 9.0 cm DBH on the LWDF.

	Prior to restoration (2006)				Immediately after restoration (2009)			
	Tree	Basal	Biomass		Tree	Basal	Biomass	
Species	frequency (stems/ha)	area (m^2/ha)	AG [a] (Mg/ha)	BG [a] (Mg/ha)	frequency (stems/ha)	area (m^2/ha)	AG [a] (Mg/ha)	BG [a] (Mg/ha)
Shortleaf pine	14.6	3.5	20.936	4.578	12.4	4.2	26.741	5.810
Loblolly pine	42.1	11.1	68.078	14.847	30.5	9.5	59.875	13.020
Red maple	17.5	0.2	1.119	0.260	0.0	0.0	0.000	0.000
American hornbeam	1.3	0.0	0.116	0.027	0.0	0.0	0.000	0.000
Bitternut hickory	2.5	0.1	0.939	0.208	0.0	0.0	0.000	0.000
Black hickory	-- [b]	--	--	--	0.5	0.1	0.460	0.102
Mockernut hickory	3.8	0.2	0.877	0.198	0.5	0.0	0.175	0.039
Sugarberry	0.4	0.0	0.019	0.005	0.0	0.0	0.000	0.000
Flowering dogwood	7.9	0.1	0.369	0.086	0.0	0.0	0.000	0.000
Green ash	0.4	0.0	0.013	0.003	0.0	0.0	0.000	0.000
White ash	-- [b]	--	--	--	0.5	0.0	0.044	0.010
American holly	0.8	0.0	0.056	0.013	0.0	0.0	0.000	0.000
Sweetgum	72.1	3.8	22.227	4.967	9.5	0.8	4.648	1.037
Red mulberry	1.7	0.1	0.290	0.066	0.0	0.0	0.000	0.000
Blackgum	27.9	0.6	2.834	0.648	0.0	0.0	0.000	0.000
Eastern hophornbeam	1.3	0.0	0.044	0.010	0.0	0.0	0.000	0.000
Black cherry	5.8	0.1	0.556	0.128	0.0	0.0	0.000	0.000
White oak	45.8	3.4	29.408	6.457	7.1	0.7	5.908	1.304
Southern red oak	32.5	2.1	16.103	3.580	8.6	0.8	6.381	1.413
Cherrybark oak	4.2	0.2	1.412	0.318	0.5	0.0	0.199	0.045
Water oak	7.9	0.9	8.266	1.806	1.4	0.2	1.519	0.335
Post oak	2.1	0.4	4.466	0.963	0.5	0.1	0.799	0.175
Black oak	6.3	0.2	1.369	0.310	0.0	0.0	0.000	0.000
Sassafras	5.8	0.1	0.647	0.149	0.0	0.0	0.000	0.000
Winged elm	40.4	0.8	3.791	0.869	0.5	0.0	0.078	0.018
Slippery elm	4.2	0.1	0.280	0.064	0.0	0.0	0.000	0.000
Totals	349.2	28.2	184.2	40.6	72.4	16.4	106.8	23.3

[a] AG = aboveground; BG = belowground. All biomass values represent oven-dry weights.
[b] Taxa not reported in the inventory of Bragg (2006).

exceed 30 m^2/ha (e.g., Heitzman et al. 2004, Bragg 2004c, Bragg and Heitzman 2009, Bragg and Shelton *in press*), the treated area of the LWDF now represents a unique reflection of past conditions.

Total live biomass also fell from 224.8 Mg/ha in 2006 to 130.1 Mg/ha in 2009 (Table 4). Prior to the restoration, pine comprised just over 48% of total live biomass, or slightly less than the pine:hardwood basal area ratio found in 2006, a difference largely attributable to the higher specific gravity of hardwoods. Following the harvest treatments, pine now dominates the live tree biomass on the LWDF, with 81% of the total (Table 4). The ~225 Mg/ha of live tree biomass in the preharvest LWDF is somewhat lower than the quantity calculated for a number of other nearby mature, unmanaged pine-dominated stands (234-317 Mg/ha, e.g., Heitzman et al. 2004, Bragg 2004c, Bragg and Heitzman 2009, Bragg and Shelton *in press*). This difference is not dramatic, and may have arisen because of recent losses in the LWDF from windthrow and bark beetles (Bragg 2006). The post-restoration biomass total (~130 Mg/ha) is within the 54-170 Mg/ha range derived from the more detailed historical accounts of pine-dominated virgin stands in this region (e.g., Olmsted 1902, Zon 1905, Chapman 1913, Forbes and Stuart 1930, Garver and Miller 1933).

Hardwood age structure

While most of the pines in the LWDF are between 100 and 200 years old (Bragg 2006), a ring count sample of 102 randomly selected freshly cut hardwood stumps produced only one greater than 100 years. Two-thirds of these hardwoods were less than 70 years old, having originated after the stand was set aside by the Crossett Lumber Company in 1939 (Figure 3). It appears that the vast majority of hardwoods appeared between 1930 and 1970, after which the recruitment of hardwoods declined. The start of this pulse (the 1930s, represented by the 71-80 year age class) coincides with the implementation of effective fire control in the Ashley County area by the Crossett Lumber Company and the then newly created Arkansas State Forestry Commission (Reynolds 1980). Note that it is likely that logging impacts and the sample design have caused underestimates in the number of young (<21 year old) hardwoods.

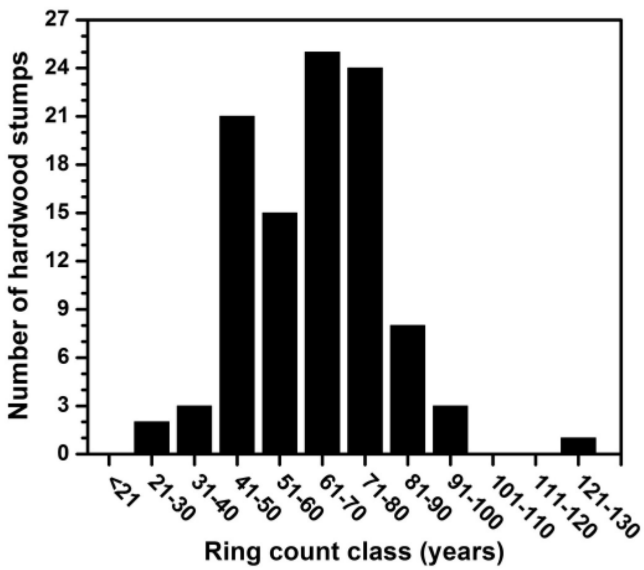

Figure 3. Hardwood stump ring counts from the LWDF by 10-year age classes.

The limited hardwoods found in the LWDF prior to 1939 were present either as recent germinants or scattered large trees contemporaneous with the pine overstory. The sample of hardwood stumps examined for this study did not find any with more than 127 rings, but given the presence of large hardwoods (primarily oaks) with external indications of old age (e.g., gnarled branches and boles, large cavities, smoothed bark) in other parts of the LWDF, it is apparent that at least a few hardwoods greater than 150-200 years old are present.

Ground cover

True before-and-after comparisons of ground cover are not possible, given that the data collected in this study were taken in different locations at different times. However, the approximations possible by comparing the treated and untreated areas of the LWDF suggest that these differences in ground cover resulted from the restoration treatment. The key attribute of the ground coverage is the proportion of exposed mineral soil found during the post-harvest inventory—prior to this logging, there would have been virtually no exposed soil on this site, save the occasional tree tip-up mound or washed-out spot along the small streams that drain this area. As apparent in Table 5, substrate condition has changed considerably as a function of this harvest activity.

Table 5. Estimates of ground cover in unharvested areas and in plots after restoration harvest in the LWDF.

Substrate	------- Percent cover ------- Before [a]	After
Mineral soil	0.1	13.6
Live vegetation	3.7	4.7
Large woody debris	0.5	4.2
Litter	95.6	76.9
Standing water	0.0	0.5

[a] "Before" coverage estimate actually uses nearby untreated parts of the stand to proxy preharvest conditions.

From almost 96% coverage in the uncut areas, litter and duff declined to just under 77%, with marked increases in mineral soil exposure (up to 13.6% from 0.1%) and large woody debris (up to 4.2% from 0.5%). Both of these are to be expected—the process of felling and skidding trees abrades the ground surface, exposing soil in many places and varying the thickness of the leaf litter in others (by either scraping it off or piling it up). Logging also adds a considerable quantity of branches, tops, and large pieces of waste wood to the site, although this was not as pronounced in this particular treatment due to the removal of much of this material for chipping.

Harvest activities also likely increased the number of places (e.g., tire ruts, log skid marks) for water to collect compared to untreated portions of the stand, but the small increase of this substrate (Table 5) also reflects differences in stand wetness due to precipitation patterns. The slight difference in live vegetation cover probably arose from the timing of the sampling—the post-harvest treatment was done in the fall when much of the live vegetation still had foliage, whereas the untreated sample was collected in early spring prior to leaf-out.

Conclusions

Native hardwood encroachment (densification) is one of the most significant concerns facing those managing for pine-dominated ecosystems. For instance, Masters et al. (2007) reported the loss of pure pine stands in an old-growth preserve in southeastern Oklahoma over the last half-century following effective fire suppression. Similar changes have been reported across the southeastern U.S. (e.g., Quarterman and Keever 1962, Halls and Homesley 1966), usually in conjunction with the alteration of historic fire regimes. However, growing human populations, landscape fragmentation, smoke management issues, and air quality concerns are likely to limit the extensive use of controlled burning as an ecosystem management tool. In many instances, especially in more developed areas, land managers will need to work with other means to restore their properties.

One of the most obvious outcomes of this particular restoration effort is that the LWDF has experienced dramatic decreases in overstory richness, stand density, and live tree biomass, all of which may have consequences for other large-scale ecosystem management goals. For example, recent studies have promoted the retention of multi-aged, complex, species-rich old-growth forests in certain areas because of their capacity for *in situ* carbon storage and role as biodiversity reserves (e.g., Harmon et al. 1990, Carey et al. 2001, Luyssaert et al. 2008, Keith et al. 2009). However, it is possible that the restoration of some forests to conditions similar to presettlement stand structure, such as done in this example, may reduce arboreal diversity and carbon storage. If this is the case, then measures of the relative success or failure of the treatments must be judged accordingly, especially when done on a large scale.

Regardless of these measures of restoration efficacy, the mechanical manipulation of the forest via partial cutting appears to have been effective in achieving certain goals. Although logging does not duplicate many of the ecological attributes of fire and imposes other influences (e.g., soil disturbance) not typically seen with burning, it did permit the landowner to rapidly change stand structure and composition in a controlled, smoke-free process. Once established, large hardwoods are also very hard to eliminate from a stand with fire, requiring a burn intensity that often kills large pines as well. The LWDF will also experience a strong woody understory response during the next few years, requiring the use of additional treatments to maintain the open, herbaceous cover that dominated presettlement stands.

Historical documentation and more recent research, combined with this preliminary assessment, suggests that the arboreal component of the LWDF is now more comparable in status to presettlement pine-dominated forests of southern Arkansas, which generally had lower stocking, less biomass, and fewer hardwoods than mature, unmanaged pine-hardwood stands of the present-day.

Acknowledgments

I would like to recognize the efforts of Kirby Sneed (US Forest Service) on the field measurements of this study. Richard Stich and Conner Fristoe of Plum Creek Timber Company graciously allowed access to this site and described their restoration plans. Mike Shelton and Nancy Koerth reviewed this paper and provided many helpful comments. This manuscript was written by a US government employee on official time, and is therefore in the public domain.

Literature cited

Anonymous. 1948. Levi Wilcoxon Forest. Forest Echoes 8(6):10, 15-16.

Bauhus J, **K Puettmann**, and **C Messier**. 2009. Silviculture for old-growth attributes. Forest Ecology and Management 258:525-37.

Blair RM and **LE Brunett.** 1976. Phytosociological changes after timber harvest in southern pine ecosystems. Ecology 57:18-32.

Bosworth D and **H Brown**. 2007. Investing in the future: ecological restoration and the USDA Forest Service. Journal of Forestry 105(4):208-11.

Bragg DC. 2002. Reference conditions for old-growth pine forests in the Upper West Gulf Coastal Plain. Journal of the Torrey Botanical Society 129(4):261-88.

Bragg DC. 2003. Natural presettlement features of the Ashley County, Arkansas area. American Midland Naturalist 149:1-20.

Bragg DC. 2004a. A prescription for old-growth-like characteristics in southern pines. *In* Shepperd WD and LG Eskew, compilers. Silviculture in special places: the Proceedings of the 2003 National Silviculture Workshop. USDA Forest Service Proceedings RMRS-P-34. p 80-92.

Bragg DC. 2004b. Composition, structure, and dynamics of a pine-hardwood old-growth remnant in southern Arkansas. Journal of the Torrey Botanical Society 131(4):320-36.

Bragg DC. 2004c. Composition and structure of a 1930s-era pine-hardwood stand in Arkansas. Southeastern Naturalist 3(2):327-44.

Bragg DC. 2006. Five years of change in an old-growth pine-hardwood remnant in Ashley County, Arkansas. Journal of the Arkansas Academy of Science 60:32-41.

Bragg DC. 2008. The prominence of pine in the Upper West Gulf Coastal Plain during historical times. *In* Hardy LM, editor. Freeman and Custis Red River Expedition of 1806: Two hundred years later. Bulletin of the Museum of Life Sciences 13. Shreveport, LA: Louisiana State University-Shreveport. p 29-54.

Bragg DC and **E Heitzman**. 2009. Composition, structure, and dynamics of a mature, unmanaged, pine-dominated old-field stand in southeastern Arkansas. Southeastern Naturalist 8(3):445-470.

Bragg DC and **MG Shelton**. 2010. Lessons from 72 years of monitoring a once-cut pine-hardwood stand on the Crossett Experimental Forest, Arkansas, U.S.A. Forest Ecology and Management *in press*.

Bruner EM. 1930. Forestry and forest fires in Arkansas. University of Arkansas Agricultural Extension Service Circular 281. 30 p.

Carey EV, **A Sala**, **R Keane**, and **RM Gallaway.** 2001. Are old forests underestimated as global carbon sinks? Global Change Biology 7:339-344.

Chapman HH. 1913. Prolonging the cut of southern pine. I. Possibilities of a second cut. Yale University School of Forestry Bulletin 2:1-22.

Chapman HH. 1942. Management of loblolly pine in the pine-hardwood region in Arkansas and in Louisiana west of the Mississippi River. Yale University School of Forestry Bulletin 49. 150 p.

Enquist BJ and **KJ Niklas**. 2002. Global allocation rules for patterns of biomass partitioning in seed plants. Science 295:1517-20.

Forbes RD and **RY Stuart**. 1930. Timber growing and logging and turpentining practices in the southern pine region. USDA Technical Bulletin 204. 114 p.

Garver RD and **RH Miller**. 1933. Selective logging in the shortleaf and loblolly pine forests of the Gulf States region. USDA Technical Bulletin 375. 53 p.

Gill HV, **DC Avery**, **FC Larance**, and **CL Fultz**. 1979. Soil survey of Ashley County, Arkansas. USDA Soil Conservation Service, USDA Forest Service, and the Arkansas Agricultural Experiment Station. 92 p.

Halls LK and **WB Homesley**. 1966. Stand composition in a mature pine-hardwood forest of southeastern Texas. Journal of Forestry 64:170-174.

Harmon ME, **WK Ferrell**, and **JF Franklin**. 1990. Effects on carbon storage of conversion of old-growth forests to young forests. Science 247(4943):699-702.

Heitzman E, **MG Shelton**, and **A Grell**. 2004. Species composition, size structure, and disturbance history of an old-growth bottomland hardwood-loblolly pine (*Pinus taeda* L.) forest in Arkansas. Natural Areas Journal 24:177-187.

Jenkins JC, **DC Chojnacky**, **LS Heath**, and **RA Birdsey**. 2003. National-scale biomass estimators for United States tree species. Forest Science 49(1):12-35.

Keith H, **BG Mackey**, and **DB Lindenmayer**. 2009. Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. Proceedings of the National Academy of Science 106(28):11635-40.

King SL and **BD Keeland**. 1999. Evaluation of reforestation in the Lower Mississippi River Alluvial Valley. Restoration Ecology 7(4):348-59.

Luyssaert S, **E –Detlef Schulze**, **A Börner**, **A Knohl, D Hessenmöller**, **BE Law**, **P Ciais**, and **J Grace.** 2008. Old-growth forests as global carbon sinks. Nature 455:213-5.

Masters RE, **SD Kreiter**, and **MS Gregory**. 2007. Dynamics of an old-growth hardwood-*Pinus* forest over 98 years. Proceedings of the Oklahoma Academy of Science 87:15-29.

Masters RE, **K Robertson**, **B Palmer**, **J Cox**, **K McGorty**, **L Green**, and **C Ambrose**. 2003. Red Hills forest stewardship guide. Tall Timbers Research Station Miscellaneous Publication 12. 78 p.

McNab WH and **PE Avers**. 1994. Ecological subregions of the United States: section descriptions. USDA Forest Service Administrative Publication WO-WSA-5. 267 p.

Mohr C. 1897. The timber pines of the southern United States. USDA Division of Forestry Bulletin 13. 176 p.

Newling CJ. 1990. Restoration of bottomland hardwood forests in the Lower Mississippi Valley. Restoration & Management Notes 8(1):23-28.

Olmsted FE. 1902. A working plan for forest lands near Pine Bluff, Arkansas. USDA Bureau of Forestry Bulletin 32. 48 p.

Outcalt KW and **DG Brockway**. 2010. Structure and composition changes following restoration treatments of longleaf pine forests on the Gulf Coastal Plain of Alabama. Forest Ecology and Management 259(8):1615-23.

Quarterman E and **C Keever**. 1962. Southern mixed hardwood forest: climax in the southeastern coastal plain, U.S.A. Ecological Monographs 32(2):167-85.

Record SJ. 1907. The forests of Arkansas. Forestry Quarterly 5:296-301.

Reynolds RR. 1980. The Crossett story: the beginnings of forestry in southern Arkansas and northern Louisiana. USDA Forest Service General Technical Report SO-32. 40 p.

Rideout S, **BP Oswald**, and **MH Legg**. 2003. Ecological, political and social challenges of prescribed fire restoration in east Texas pineywoods ecosystems: a case study. Forestry 76(2):261-9.

Shelton MG and **MD Cain.** 1999. Structure and short-term dynamics of the tree component of a mature pine-oak forest in southeastern Arkansas. Journal of the Torrey Botanical Society 126:32-48.

Stanturf JA, **ES Gardiner**, **PB Hamel**, **MS Devall,** **TD Leininger**, and **ME Warren**. 2000. Restoring bottomland hardwood ecosystems in the Lower Mississippi Alluvial Valley. Journal of Forestry 98(8):10-6.

Stanturf, JA, **ES Gardiner**, **K Outcalt**, **WH Conner**, and **JM Guldin.** 2004. Restoration of southern ecosystems. *In* Rauscher HM and K Johnsen, editors. Southern forest science: past, present, and future. USDA Forest Service General Technical Report SRS-75. p 123-31.

Switzer GL, **MG Shelton**, and **LE Nelson**. 1979. Successional development of the forest floor and soil surface on upland sites of the East Gulf Coastal Plain. Ecology 60(6):1162-1171.

Van Kley JE and **RL Turner**. 2009. An ecological classification systems for the national forests and adjacent areas of the West Gulf Coastal Plain. Southeastern Naturalist 8(Special Issue 2):1-30.

Zon R. 1905. Loblolly pine in eastern Texas, with special reference to the production of cross ties. USDA Forest Service Bulletin 64. 53 p.