CASTANEA 78(1): 37–55. MARCH

Composition, Biomass, and Overstory Spatial Patterns in a Mature Pine-Hardwood Stand in Southeastern Arkansas

Don C. Bragg*

USDA Forest Service, Southern Research Station, PO Box 3516, University of Arkansas at Monticello, Monticello, Arkansas 71656

ABSTRACT A 1.21-ha plot was established in a mature pine–hardwood forest (Hyatt's Woods) along a low stream terrace in southeastern Arkansas. Compositionally, this stand had considerable arboreal richness, with 26 different tree species $\geq$9 cm in diameter. Loblolly pine (*Pinus taeda*) contributed 42% of the stand's 37.1 m^2/ha of basal area; the remaining fraction included baldcypress (*Taxodium distichum*) and 24 hardwood species (no other single taxon exceeded 12%). Only a limited volume (15.2 m^3/ha) of dead wood was encountered. The large size of the dominant conifers and abundance of high wood density hardwoods at Hyatt's Woods yielded a considerable quantity of biomass—at 317 Mg/ha, few stands in the region have more. With all species combined, tree stem location exhibited a random spatial pattern, but this changed when individual species were considered. For example, loblolly pine tended to be clustered on the higher portions of this relatively flat site, while white oak (*Quercus alba*) was well distributed across Hyatt's Woods, and baldcypress was associated with two abandoned stream channels. Unmanaged streamside forests in southeastern Arkansas usually contain high levels of arboreal diversity and biomass, and sometimes possess biological legacies that can date back centuries. These stands retain important structural and ecosystem service components in an otherwise increasingly fragmented and intensively managed landscape.

Key words: Baldcypress, coarse woody debris, loblolly pine, microtopography, oak.

INTRODUCTION Natural-origin forests in the southeastern United States are increasingly altered by changes in land use and other environmental factors including agricultural clearing, urbanization, introduction of invasive organisms, pollution, and climate change. Although total forest area in the Southeast declined only by about 2.5 million hectares between 1952 and 1999, during that same period natural seed- or sprout-origin forests of all types decreased by 13.9 million hectares (Conner and Hartsell 2002). Most of these stands were replaced by pine (*Pinus* spp.) plantations, a conversion that has accelerated in recent decades. Pine plantations have increased from 16% of southern forestlands in 1999 to 19% in 2010, and are projected to cover as much as 36% by 2060 (Wear and Greis 2012).

Describing unmanaged mature stands of natural origin, therefore, represents an important task, especially if future land managers seek to restore these forests. Current restoration efforts are hampered by inconsistent or incomplete historical documentation of forest conditions, and few of these records are adequately quantitative to assist in the development of restoration targets and management guidelines. Even relatively simple attributes, such as tree composition, are often lacking, and many historical forest reports include little to no information on hardwood species. As introduced pests and diseases continue to spread throughout eastern North America, knowledge of preimpact representation of native tree species is critical to a full assessment of the effects of invasive species. The impending arrivals of laurel wilt (*Raffaelea*

*email address: dbragg@fs.fed.us
Received September 14, 2012; Accepted January 18, 2013.
DOI: 10.2179/12-033

lauricola), dogwood anthracnose (*Discula destructiva*), and emerald ash borer (*Agrilus planipennis*) currently threaten sassafras (*Sassafras albidum*), dogwood (primarily *Cornus florida*), and ash (*Fraxinus* spp.) in the forests of southeastern Arkansas (Holzmueller et al. 2006, Poland and McCullough 2006, Fraedrich et al. 2008, Gramling 2010) and once affected, stand composition will probably never be the same.

This study reports on a number of attributes of an unmanaged, mature, pine-hardwood stand on a small stream terrace in southeastern Arkansas. Though limited in extent, this stand (Hyatt's Woods) has considerable tree richness and a substantial quantity of biomass, and displays a range of interesting spatial patterns in the overstory tree species. When combined with research on the composition and structure in other mature, natural-origin stands in this region, Hyatt's Woods can help define the characteristics of these unmanaged pine-hardwood forests near the turn of the 21st century.

METHODS

Site Description

Hyatt's Woods is a small (approx. 32 ha) privately-owned tract of mature, unmanaged timber situated on Brown's Creek in the southwestern corner of Drew County, Arkansas (33°26′37″N, 91°54′20″W, Figure 1). This stand is found on the Upper West Gulf Coastal Plain, a low, rolling landscape dominated by pine and pine-hardwood forests. Large riparian forests, such as those found along the nearby Ouachita and Saline rivers, are usually composed of mixtures of flood-tolerant hardwoods and baldcypress (*Taxodium distichum*), with a scattering of loblolly pine (*Pinus taeda*). Small drainages in this area rarely have pronounced bottomlands, and thus contain more pine (both loblolly and shortleaf [*Pinus echinata*]) and upland hardwood species. Low stream terraces along all types of riparian systems are a blend of both upland and bottomland forests, and thus tend to have high levels of tree species richness unless managed for pine monocultures.

Figure 1. Location of Hyatt's Woods in southeastern Arkansas.

Hyatt's Woods occupies a portion of a Holocene-period terrace along Brown's Creek, which flows westerly across Pleistocene alluvium from the higher and older (Tertiary) Jackson Formation just to the east of the site (Oneillon 1956, Saucier 1974). Elevation ranges between 38 and 40 m above sea level on this flat site, with most of the minor undulations in the ground surface attributable to the action of flowing water, particularly during winter/spring floods of Brown's Creek. A low (about 1 m tall) circular mound of natural origin is found in the southeastern corner of the site, which is likely either an erosional remnant or an isolated "prairie mound." Soils are primarily Ouachita silt loams (Fluventic Dystrochrepts), with a limited amount of Savannah fine sandy loams (Typic Fragiudults) along the slightly higher terrace just to the north (Larance et al. 1976). The lower terrace sites are generally quite productive: Ouachita silt loams have an estimated loblolly pine 50-year site index (SI_{50}) of 30.5 m, while the higher Savannah fine sandy loams are lower in quality (SI_{50} = 24.4 m) (Larance et al. 1976). Brown's Creek flows just south of the study area, but two former channels of this stream (sloughs) remain and often hold water well after flooding subsides (Figure 2). According to 1981–2010 climate records averaged between the three nearest weather stations, mean precipitation at Hyatt's Woods is about 1420 mm/year, and January and July average temperatures were 5.9°C and 27.2°C, respectively (NOAA 2012).

The human history of this area goes back to Paleoindian times (≥9,500 years before present [B.P.]), and archeological evidence found at Hyatt's Woods and in the immediate vicinity indicate that the natural resources of the location have attracted people for millennia. During most of the historic period (ca. 400 years BP and later), Drew County was part of the

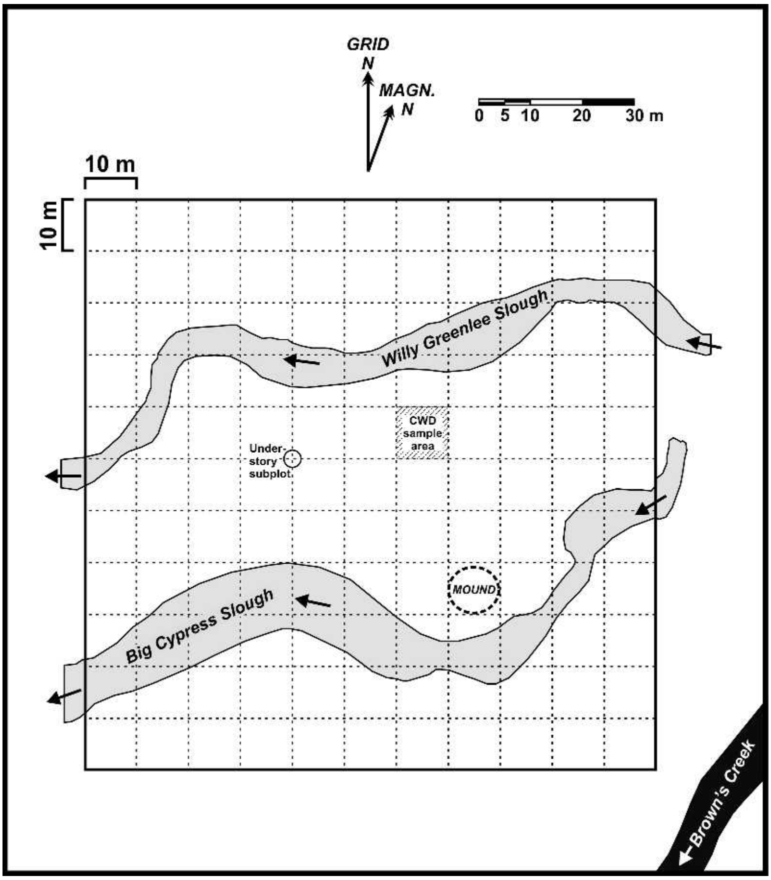

Figure 2. Schematic of 1.21-ha stem map plot at Hyatt's Woods with key environmental features labeled, including the only known circular earthen mound of natural origin found at this site. Note that the former channels (sloughs) of Brown's Creek flow during wetter periods, but are completely dry during drought, and often have only stagnant pools of water in local deep spots. In addition, examples of a 100-m^2 CWD sampling area and a 25-m^2 understory subplot are shown for scale and relative placement.

territory of the Quapaw Indians, who had likely driven the previous occupants (probably the Tunica Indians) further south (Sabo 1992). By the 1820s, the Quapaw had been relocated to reservations outside of Arkansas (Sabo 1992) and European Americans began to move into the area; General Land Office (GLO) survey records mention settlers in this area by 1830 (Bragg 2004a). An 1857 resurvey of the township identified numerous settlers and improvements within several kilometers of the study site. Later in the 19th century, much of the region was acquired by lumber companies who cut most of the virgin timber over the next few decades. However, the Hyatt's Woods tract appears to have remained with various small landowners since it was originally settled, and the family of the current owners has controlled this parcel since about 1930. According to one of these owners, the higher terrace just north of the study site was farmed until 1932 and other parts were grazed by livestock into the 1950s, but he did not recall any farming or timber cutting on the study site, save the occasional removal of dead or dying trees (Hyatt, Jr. pers. comm., 2 April 2012).

Overstory Sampling

The study area comprised only a small (1.21-ha) interior section of the least disturbed portion of Hyatt's Woods. A 10-m by 10-m mapping grid was laid out along a portion of the stream terrace encompassing the oldest and most intact part of Hyatt's Woods (Figure 2), producing a square grid 110 m long on a side, with a buffer of at least 50 m to the nearest forest edge. Within this grid, species and diameter at breast height (DBH, to the nearest 0.1 cm) of every live stem >9 cm DBH and at least halfway rooted in the plot were recorded. A stem map was created by measuring distance and bearing of each live stem from the corners of the fixed grid points using an Impulse 200LR® laser rangefinder (Laser Technology, Centennial, Colorado) mounted on a tripod. The Impulse 200LR has a horizontal distance accuracy of ±0.3 m, and using the MapStar Compass Module® attachment, an angle accuracy of ±0.3° (Laser Technology, Inc. 2012). Overstory data were entered into a spreadsheet and live tree spatial pattern was analyzed using the neighborhood density function (NDF) in SpPack (Perry 2004). With this univariate technique, I tested the null hypothesis of complete spatial randomness of all tree locations and for subsets of species groups using Monte Carlo simulations with 1,000 replications, 95% confidence intervals, a step increment (w) of 0.2 m, and a maximum step length of 55 m (Perry et al. 2006).

This stand was mature but not ancient (sensu Pederson 2010), so extensive age determination was not attempted. Previous stump ring counts done by earlier visitors to the site had dated a number of trees of various species to 200–300 years old, and perhaps even older (Hyatt, Jr., pers. comm., 2 April 2012). Dendrochronology was not a focus of this study, as the landowners are interested in protecting the standing timber from any kind of damage. Hence, we cored only a limited number of trees with external signs of advanced age (Pederson 2010) using a 5-mm increment corer. Once collected, increment cores were taken back to the laboratory, sanded with progressively finer sandpaper until the rings were obvious, and tree age determined by counting rings (not cross-dated due to the limited sample).

Digital scans of the GLO public land survey notes (Daniels 2000) were consulted for descriptions of presettlement vegetation patterns in the immediate proximity of the Hyatt's Woods site.

Understory Sampling

Understory (live stems <9 cm DBH) trees, shrubs, and woody vines rooted within 25-m^2 (2.82-m radius) circular subplots plots established at each map unit vertex were tallied (144 subplots in total). Each understory stem was placed into one of six size categories: A (15–75 cm tall); B (76–136 cm tall); C (≥137 cm tall and <1.5 cm DBH); 1 (≥137 cm tall and 1.5–3.9 cm DBH); 2 (≥137 cm tall and 4.0–6.4 cm DBH); and 3 (≥137 cm tall and 6.5–8.9 cm DBH).

Importance value (IV) scores were calculated for each understory taxon by summing its relative frequency (RF, or the percent of the taxon's number of stems compared to all understory stems), relative abundance (RA, or the percentage of subplots the taxon was found on, compared to the 144 total understory subplots), and relative dominance (RD, or the percentage of the taxon's basal area compared to the total understory basal area). Size classes A and B were shorter than where DBH is measured (1.37 m above the ground line), so that technically they did not have a DBH: to include them in the RD calculation, they were arbitrarily assigned stem diameters of 0.125 and 0.25 cm, respectively. All other understory size classes (C, 1, 2, and 3) that had measured diameters were assigned fixed values for each stem in those classes (0.75, 2.65, 5.10, and 7.65 cm DBH, respectively).

Coarse Woody Debris (CWD) Inventory

A random subsample (43 of 121, or 35.5%) of the 100-m^2 grid cells within the plot was chosen for a CWD inventory. In this survey, every piece of downed dead wood, stump, and snag at least 10 cm in small-end diameter and at least 0.5 m long was evaluated for end diameters and length, cut status (evidence of cutting with a saw), and decay class. Pieces that extended beyond the plot boundaries were not measured beyond the edge of the plot, and stumps/snags were required to be rooted at least halfway into the plot. To calculate piece volume (V), I applied Smalian's formula:

$$V = \frac{\pi(D^2 + d^2)L}{8}, \tag{1}$$

where D is large-end piece diameter (m), d is small-end piece diameter (m), and L = piece length (m). Because many of the pieces were well decomposed, only a portion of the CWD in this site could be identified to species (some were only discernible as hardwoods or conifers). Three decay classes were also distinguished: 1 = freshly dead; 2 = some bark loss due to time since death, limited decay, but wood still sound;

Table 1. Stand-level species attributes for the overstory trees of Hyatt's Woods in southwestern Drew County, Arkansas

				Diameter at Breast Height (DBH)			
Common Name	Scientific Name[a]	Live Stems (#/ha)	Basal Area (m^2/ha)	Min. (cm)	Max. (cm)	Avg. (cm)	SD (cm)
Loblolly pine	*Pinus taeda*	54.5	15.74	17.5	86.9	59.3	12.9
White oak	*Quercus alba*	20.7	4.43	10.9	80.8	46.3	24.7
Baldcypress	*Taxodium distichum*	5.8	3.62	20.3	163.6	74.3	53.3
Sweetgum	*Liquidambar styraciflua*	23.1	2.48	9.1	96.0	30.2	21.7
Mockernut hickory	*Carya tomentosa*	32.2	1.98	10.2	58.4	25.0	12.7
Cherrybark oak	*Quercus pagoda*	18.2	1.36	12.7	65.3	26.7	15.7
Winged elm	*Ulmus alata*	60.3	1.35	9.1	45.2	15.3	7.2
Shumard oak	*Quercus shumardii*	9.1	1.05	20.3	64.8	35.6	14.8
Swamp chestnut oak	*Quercus michauxii*	3.3	0.93	37.3	79.2	57.8	17.1
Blackgum	*Nyssa sylvatica*	11.6	0.76	10.2	68.6	23.4	17.7
Post oak	*Quercus stellata*	2.5	0.50	35.6	61.2	49.6	13.0
Eastern hophornbeam	*Ostrya virginiana*	38.0	0.46	9.4	25.1	12.0	2.9
Water hickory	*Carya aquatica*	7.4	0.37	10.7	38.6	23.4	10.2
Bitternut hickory	*Carya cordiformis*	0.8	0.27	64.5	64.5	64.5	0.0
American hornbeam	*Carpinus caroliniana*	19.0	0.24	9.1	22.1	12.3	2.7
Sassafras	*Sassafras albidum*	4.1	0.22	14.0	47.0	22.7	13.7
Willow oak	*Quercus phellos*	1.7	0.21	28.4	49.5	39.0	14.9
Water oak	*Quercus nigra*	3.3	0.20	18.3	33.0	27.1	6.3
Green ash	*Fraxinus pennsylvanica*	3.3	0.20	10.9	34.5	25.7	11.2
Black hickory	*Carya texana*	2.5	0.17	13.7	38.9	27.7	12.8
Red maple	*Acer rubrum*	2.5	0.17	17.8	41.9	27.6	12.7
Red mulberry	*Morus rubra*	0.8	0.14	47.0	47.0	47.0	0.0
American holly	*Ilex opaca*	3.3	0.11	13.0	26.9	19.7	6.0
Common persimmon	*Diospyros virginiana*	2.5	0.07	15.2	21.6	19.2	3.5
Black cherry	*Prunus serotina*	1.7	0.04	17.5	19.3	18.4	1.3
Flowering dogwood	*Cornus florida*	1.7	0.02	10.4	12.4	11.4	1.4
TOTALS		333.9	37.1				

[a]Species nomenclature from Moore (1999).

and 3 = most bark missing, considerable decay, little to no structural integrity.

Biomass Calculations

Using the live tree inventory collected for the stem map, aboveground biomass was calculated using the National Biomass Estimators of Jenkins et al. (2003). Their equation:

$$B_{AG} = \exp[\beta_0 + \beta_1 \times \ln(DBH)], \tag{2}$$

yields aboveground biomass in oven-dry terms (kg) for individual stems. In equation (2), β_o and β_1 are species group-specific parameters, which were adapted for the species found at Hyatt's Woods (Jenkins et al. [2003], their Table 4). Belowground live tree biomass was determined as a proportion of aboveground live biomass with the following relation (adapted from Enquist and Niklas [2002]):

$$B_{BG} = \left(\frac{B_{AG}}{3.88}\right)^{0.9803922}. \tag{3}$$

Total individual live tree biomass (B) is the sum of the above- and belowground components (i.e., $B = B_{AG} + B_{BG}$). All live trees were assumed to be sound, and although mature, this stand is not particularly decadent, with very few hollow or heavily decayed stems present. This assumption will also allow for more direct comparisons with other estimates of biomass in nearby stands of mature timber that likewise presumed all trees were sound.

Coarse woody debris biomass was calculated using specific gravity estimates by decay class modified from Vose et al. (1999). The following oven-dry weights (in kg/m^3) were assigned: class 1 = 500; class 2 = 400; and class 3 = 300. Species differences in specific gravity were not included in this design because of the degree of uncertainty in CWD taxonomy (particularly for old pieces) and the imprecision of the decay classes. The class 1 estimate of 500 kg/m^3 is conservative: average oven-dry weight for species commonly found in the area range from 460

Table 2. Live woody understory composition of Hyatt's Woods, Drew County, Arkansas

Taxonomic Group[a] Species or Genus	Total Stems per Hectare	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 (totals by size class for all in group)	**418.4**	**375.9**	**13.0**	**15.9**	**11.8**	**1.4**	**0.4**				
Virginia creeper (*Parthenocissus quinquefolia*)	19.9	18.0	0.0	1.1	0.4	0.0	0.4	1.4	2.9	17.4	7.2
Blackberry (*Rubus* spp.)	2.5	2.5	0.0	0.0	0.0	0.0	0.0	0.2	<0.1	3.5	1.2
Grape (*Vitis* spp.)	0.7	0.7	0.0	0.0	0.0	0.0	0.0	0.1	<0.1	1.4	0.5
Muscadine (*Vitis rotundifolia*)	189.0	175.7	2.9	9.0	0.7	0.7	0.0	13.6	0.4	57.6	23.9
Greenbrier (*Smilax* spp.)	126.4	108.4	9.4	8.6	0.0	0.0	0.0	9.1	0.1	67.4	25.5
Honeysuckle (*Lonicera* spp.)	1.1	0.4	0.0	0.7	0.0	0.0	0.0	0.1	<0.1	2.1	0.7
Poison ivy (*Toxicodendron radicans*)	71.9	64.4	0.7	4.7	1.4	0.7	0.0	5.2	0.4	29.9	11.8
Rattan (*Berchemia scandens*)	6.9	5.8	0.0	0.4	0.7	0.0	0.0	0.5	0.1	9.0	3.2
Shrubs (totals by size class for all in group)	**288.9**	**246.0**	**17.6**	**20.2**	**2.9**	**2.2**	**0.0**				
Vaccinium spp.	270.4	238.7	12.2	15.5	2.2	1.8	0.0	19.5	0.9	59.7	26.7
American beautyberry (*Callicarpa americana*)	9.0	4.0	3.6	1.4	0.0	0.0	0.0	0.6	<0.1	11.1	3.9
Winged sumac (*Rhus copallinum*)	0.4	0.0	0.0	0.0	0.0	0.4	0.0	<0.1	0.1	0.7	0.3
Devil's walkingstick (*Aralia spinosa*)	0.7	0.7	0.0	0.0	0.0	0.0	0.0	0.1	<0.1	0.7	0.3
American witch-hazel (*Hamamelis virginiana*)	7.2	2.2	1.4	2.9	0.7	0.0	0.0	0.5	0.1	7.6	2.8
Privet (*Ligustrum* spp.)	1.2	0.4	0.4	0.4	0.0	0.0	0.0	0.1	<0.1	2.1	0.7
Trees (totals by size class for all in group)	**678.1**	**526.8**	**49.3**	**41.1**	**31.5**	**18.4**	**11.0**				
Loblolly pine	3.2	2.9	0.4	0.0	0.0	0.0	0.0	0.2	<0.1	4.9	1.7
Red maple	23.4	22.3	0.0	0.0	1.1	0.0	0.0	1.7	0.1	23.6	8.5
American hornbeam	92.3	47.9	11.2	14.8	12.2	4.0	2.2	6.7	19.6	50.7	25.7
Shagbark hickory (*Carya ovata*)	97.7	90.0	4.0	1.8	1.1	0.4	0.4	7.1	3.1	63.2	24.4
Black hickory	0.4	0.4	0.0	0.0	0.0	0.0	0.0	<0.1	<0.1	0.7	0.2
Mockernut hickory	2.6	1.1	0.4	0.0	0.7	0.0	0.4	0.2	2.9	3.5	2.2
Flowering dogwood	1.8	1.4	0.0	0.0	0.4	0.0	0.0	0.1	<0.1	3.5	1.2
Haw (*Crataegus* spp.)	32.8	27.7	0.4	1.8	1.8	1.1	0.0	2.4	0.5	31.9	11.6
Common persimmon	0.8	0.4	0.0	0.0	0.0	0.0	0.4	0.1	2.9	1.4	1.4
Green ash	6.5	4.3	1.4	0.0	0.4	0.4	0.0	0.5	0.2	9.7	3.5
American holly	24.9	15.5	4.7	2.5	1.1	1.1	0.0	1.8	0.5	29.2	10.5
Sweetgum	23.8	22.3	1.1	0.0	0.0	0.4	0.0	1.7	0.1	20.1	7.3
Blackgum	4.4	3.2	0.0	0.4	0.4	0.4	0.0	0.3	0.2	5.6	2.0
Eastern hophornbeam	60.1	28.4	2.5	6.8	8.3	7.9	6.1	4.3	52.1	56.2	37.6
Black cherry	0.4	0.4	0.0	0.0	0.0	0.0	0.0	<0.1	<0.1	0.7	0.2
White oak	102.3	99.7	1.1	0.7	0.0	0.4	0.4	7.4	3.0	41.0	17.1
Southern red oak (*Quercus falcata*)	7.9	7.9	0.0	0.0	0.0	0.0	0.0	0.6	<0.1	11.1	3.9
Cherrybark oak	4.0	4.0	0.0	0.0	0.0	0.0	0.0	0.3	<0.1	6.2	2.2
Swamp chestnut oak	47.9	45.7	1.8	0.0	0.0	0.0	0.4	3.5	2.9	23.6	9.5

Table 2. Continued

Taxonomic Group[a] Species or Genus	Total Stems per Hectare	Number of Stems per Hectare by Size Class Code[b] A	B	C	1	2	3	RF[c] (%)	RD[c] (%)	RA[c] (%)	IV[c] Score
Water oak	1.1	0.7	0.4	0.0	0.0	0.0	0.0	0.1	<0.1	2.1	0.7
Willow oak	22.7	22.7	0.0	0.0	0.0	0.0	0.0	1.6	<0.1	25.7	9.1
Post oak	2.2	1.1	0.0	0.7	0.0	0.4	0.0	0.2	0.1	3.5	1.2
Sassafras	3.3	2.9	0.0	0.0	0.4	0.0	0.0	0.2	<0.1	2.8	1.0
Winged elm	8.4	5.8	0.4	0.4	0.7	0.4	0.7	0.6	5.9	11.1	5.9
American elm (*Ulmus americana*)	0.8	0.4	0.0	0.0	0.0	0.4	0.0	0.1	0.1	1.4	0.5
Pawpaw (*Asimina triloba*)	42.3	29.2	7.6	4.0	1.1	0.4	0.0	3.0	0.3	11.1	4.8
Horse-sugar (*Symplocos tinctoria*)	60.1	38.5	11.9	7.2	1.8	0.7	0.0	4.3	0.4	9.0	4.6

[a]Species nomenclature from Smith (1988) and Moore (1999).

[b]Size class codes: A = 15–74 cm tall; B = 75–136 cm tall; C = ≥137 cm tall, <1.5 cm DBH; 1 = ≥137 cm tall, 1.5–3.8 cm DBH; 2 = ≥137 cm tall, 3.9–6.3 cm DBH; and 3 = ≥137 cm tall, 6.4–8.9 cm DBH.

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

(baldcypress), 510 (loblolly and shortleaf pine), and 520 (sweetgum), to 680 (white oak) and 690 (cherrybark oak), to as much as 730 (flowering dogwood) and 740 (persimmon) (Miles and Smith 2009). Average oven-dry weight was multiplied by the cubic meter volume estimates for each individual piece, summed for the entire plot, and expressed in units per hectare (Mg/ha).

RESULTS Most field sampling was conducted during the spring and summer of 2009. However, due to resource constraints and high water, tree age data were collected in the summer of 2010. Although heart rot and their large size made dating difficult, four trees were aged on the plot or in the immediate vicinity: a baldcypress (a minimum ring count of 212), two overcup oaks (*Quercus lyrata*; minimum ring counts of 144 and 199), and one white oak (minimum ring count of 160).

Overstory Composition

The 1.21-ha study area in Hyatt's Woods had 26 different tree species ≥9 cm DBH (Table 1). Of the 334 live overstory trees per hectare, the majority were hardwoods, including winged elm (*Ulmus alata*, 18.1% of stems), eastern hophornbeam (*Ostrya virginiana*, 11.4%), mockernut hickory (*Carya tomentosa*, 9.6%), sweetgum (*Liquidambar styraciflua*, 6.9%), white oak (6.2%), American hornbeam (*Carpinus caroliniana*, 5.7%), and cherrybark oak (*Quercus pagoda*, 5.5%). Loblolly pine (16.3%) was the only conifer with >5% abundance. However, in terms of basal area, loblolly pine was the most dominant species in this parcel, constituting 42.4% of total stand basal area. White oak (11.9%), baldcypress (9.8%), sweetgum (6.7%), and mockernut hickory (5.3%) were the other species that individually contributed ≥5% to the basal area.

There have been no formal reconstructions of presettlement vegetation patterns in this part of Drew County, Arkansas. Examination of the earliest (1827) GLO survey notes (Daniels 2000) for the immediate proximity of the Hyatt's Woods site describe the location as "Land—Level Stiff and Swampy, or wet, Timber Pine, Oak ... undergrowth Pine whortleberry green briers vines [and] not fit for cultivation" and nearest to the site, the line was "level and mostly creek bottom 2d rate Soil Timber Oak gum some Pine [etc.] undergrowth cane vines & fit for cultivation" and "creek bottom rather inclines to be wet or Spouty, Timber Swamp white Oak Red Oak hickory gum [etc.] undergrowth cane briers [etc.] on the hills Pine Oak ... undergrowth maple ... fit for cultivation." The allusions to farming in the last two quotes were realized when the same line was resurveyed in 1857, as the surveyor then repeatedly crossed cleared ground, including cotton and corn fields and other corners where he had to construct a mound of soil to monument the location because the trees had been "deadened" (killed). Other tree species mentioned in the 1827–1857 survey work in the vicinity included post oak (*Quercus stellata*), black oak (though not likely *Quercus velutina*, which is uncommon in southeastern Arkansas), chinkapin (*Castanea pumila*), elm (*Ulmus* spp.), pawpaw (*Asimina triloba*), lynn (*Tilia americana*), pignut hickory (*Carya glabra*), and blackgum (*Nyssa sylvatica*). Pine and various oaks were most commonly mentioned in the GLO notes near Hyatt's Woods, although it is hard to draw inferences from this abundance given the limited number of trees mentioned along the survey transects. No baldcypress were used by the GLO surveyors in the immediate proximity of Hyatt's Woods, although they were certainly there, given the age and size of modern-day baldcypress in the study plot.

Understory Composition

Relatively open, the understory of Hyatt's Woods was dominated by shrubs and woody vines, with a significant quantity of a few tree species (Table 2). *Vaccinium* spp., muscadine (*Vitis rotundifolia*), greenbrier (*Smilax* spp.), and white oak were the only taxa with >100 stems/ha. Other species with high importance values (IVs) included American hornbeam, shagbark hickory (*Carya ovata*), and eastern hophornbeam, primarily because they had a number of larger stems evenly distributed across the site, thereby increasing their relative dominance and relative abundance scores (Table 2). Most of the 40+ understory woody taxa were noticeably less important. Loblolly pine, for instance, though the dominant overstory tree at Hyatt's Woods, constituted <0.25% of the understory stems (3.2/ha), with none larger than size class B (<137 cm tall).

Historic understory composition, as mentioned by the GLO surveyors, differed somewhat. In the vicinity of Hyatt's Woods, the GLO surveyors reported undergrowth as "pine sumach [sic] & oak bushes," "Spicewood Dog w[oo]d bushes briers vines," "Pine Whortleberry & Sweet gum bushes," and "witch hazle [sic] some cane and briars." One nearby traverse mentioned "land high dry and level thin soil open grassy woods timber oak and pine scrubby growth." The sumac (*Rhus* spp.), spicewood (probably *Lindera benzoin*), whortleberry (*Vaccinium* spp.), cane (*Arundinaria gigantea*), and American witch-hazel (*Hamamelis virginiana*) were the only reasonably identifiable nontree understory species noted in this area, and a number of these are suggestive of frequent surface fires. Particularly important is the mention of "open grassy woods," which is often noted by the GLO surveyors where frequent burning has encouraged the dominance of graminoids. Also indicative of fire are mentions of "oak bushes" and "scrubby" pine growth, commonly used terms of trees stunted by frequent burning (Bragg 2002, 2003).

Size Class Distribution

The biggest trees in Hyatt's Woods were baldcypress growing in the sloughs—two individuals were 163.6 cm and 135.4 cm DBH. With the exception of a single sweetgum, no other tree exceeded 90 cm DBH (Figure 3). Most baldcypress and loblolly pines were on the larger end of the size class distribution, with only a few trees <45 cm DBH. The vast majority of hardwood stems were small to intermediate in diameter, but these constituted the largest quantity of stems, and given their dominance of these classes (and relative absence of shade-intolerant conifers), it is apparent that hardwoods are poised to take over this site. Overall, the diameter class distribution of Hyatt's Woods is a rotated sigmoid often seen in mature, naturally regenerated stands with multiple age classes (e.g., Zenner 2005, McCarthy and Weetman 2006). The wide diameter distribution of certain species, such as loblolly pine and oaks, suggests a range of different age classes are present, although without more detailed testing of the age class structure it is premature to assume that they are uneven-aged.

The largest pines mentioned in the historical land survey notes around Hyatt's Woods were between 75 and 100 cm in diameter, with hardwoods generally being smaller. GLO land surveyors probably did not select the largest individuals of any species to be witness trees, given the difficulty in scribing these typically

Table 3. Live biomass of overstory trees by species in Hyatt's Woods, Drew County, Arkansas

		Aboveground Live Biomass[b]		Belowground Live Biomass[c]		Total Live Biomass
Common Name	Species Group[a]	(Mg/ha)	(% of total)	(Mg/ha)	(% of total)	(Mg/ha)
Loblolly pine	loblolly	96.7	30.5	22.1	7.0	118.8
White oak	white oak	46.0	14.5	10.4	3.3	56.4
Baldcypress	baldcypress	21.1	6.6	4.7	1.5	25.8
Sweetgum	gums	18.5	5.8	4.2	1.3	22.8
Mockernut hickory	hickories	12.0	3.8	2.8	0.9	14.8
Cherrybark oak	other (red) oaks	11.8	3.7	2.7	0.9	14.5
Winged elm	other spp	6.5	2.0	1.6	0.5	8.0
Shumard oak	other (red) oaks	9.4	3.0	2.2	0.7	11.5
Swamp chestnut oak	other (white) oaks	9.6	3.0	2.2	0.7	11.8
Blackgum	gums	5.2	1.6	1.2	0.4	6.4
Post oak	other (white) oaks	4.8	1.5	1.1	0.4	5.9
Eastern hophornbeam	other spp	1.7	0.5	0.4	0.1	2.1
Water hickory	hickories	2.1	0.7	0.5	0.2	2.5
Bitternut hickory	hickories	2.2	0.7	0.5	0.2	2.7
American hornbeam	other spp	0.9	0.3	0.2	0.1	1.1
Sassafras	other spp	1.3	0.4	0.3	0.1	1.6
Willow oak	other (red) oaks	1.9	0.6	0.4	0.1	2.3
Water oak	other (red) oaks	1.5	0.5	0.3	0.1	1.8
Green ash	other spp	1.1	0.4	0.3	<0.1	1.4
Black hickory	hickories	1.0	0.3	0.2	<0.1	1.2
Red maple	other spp	1.2	0.4	0.3	<0.1	1.4
Red mulberry	other spp	1.0	0.3	0.2	<0.1	1.2
American holly	other spp	0.5	0.2	0.1	<0.1	0.6
Common persimmon	other spp	0.3	0.1	<0.1	<0.1	0.4
Black cherry	other spp	0.2	<0.1	<0.1	<0.1	0.2
Flowering dogwood	other spp	<0.1	<0.1	<0.1	<0.1	<0.1
TOTALS		258.2		59.1		317.3

[a]Species groupings used in stem mapping and spatial analysis (Figure 4).
[b]Aboveground live tree oven-dry biomass calculated using the National Biomass Estimators of Jenkins et al. (2003).
[c]Belowground live tree oven-dry biomass calculated following Enquist and Niklas (2002).

thick-barked individuals (Bragg 2003), so it is likely that even bigger trees were present. Undoubtedly, the largest of the trees in the area at that time were baldcypress but, because of their infrequent use as witness trees, it is hard to know how big the baldcypress grew locally. In southeastern Arkansas, cypress >365 cm DBH have been found in the GLO notes (Bragg 2003). Pine (almost certainly loblolly), sweetgum, water tupelo (*Nyssa aquatica*), and a number of oak species have also been reported to exceed 175 cm DBH in historical references from this area (Bragg 2002, 2003, 2004b).

The sparseness of trees in the understory reflected the reduced light environment created by the relatively intact over- and midstory at Hyatt's Woods. Very few shade-intolerant loblolly pines (3.2 stems/ha) were found in the stand, and these were only in the smallest understory size classes (Table 2). Shade-tolerant understory tree species such as American hornbeam, eastern hophornbeam, pawpaw, American holly, and horse-sugar (*Symplocos tinctoria*) were present in most if not all understory size classes, indicative of their ability to persist in diminished light conditions. Woody vines such as muscadine, greenbrier, and poison ivy (*Toxicodendron radicans*) were abundant in the smallest size classes, although a few grew into the larger classes. The most common woody shrubs at Hyatt's Woods were *Vaccinium* of various species. American beautyberry (*Callicarpa americana*) and privet (*Ligustrum* spp.) are very common across much of the managed landscapes of southern Arkansas (Cain and Shelton 2001), but were only very minor components of this relatively undisturbed study site.

Live Tree Biomass

Hyatt's Woods contained a considerable quantity of live tree biomass (above- and belowground). Aboveground live tree biomass at this site

Table 4. Coarse woody debris attributes measured in 2009 in Hyatt's Woods, Drew County, Arkansas (some totals may not sum due to rounding error)

Attribute	Count per Hectare	% of Total	Large-End Diameter (cm)	Small-End Diameter (cm)	Piece Length (m)	Piece Volume (m^3)	Piece Biomass (kg)
Species							
Loblolly pine	30.7	27.6					
Hickory (undifferentiated)	19.3	17.2					
Hardwood (species unknown)	17.2	15.5					
White oak	13.5	12.1					
Sweetgum	7.7	6.9					
Cherrybark oak	5.8	5.2					
Sassafras	5.8	5.2					
American elm	4.0	3.4					
Shumard oak	4.0	3.4					
Flowering dogwood	1.9	1.7					
Red maple	1.9	1.7					
Volume (m^3) and oven-dry biomass (Mg/ha)							
Total volume, all species	15.2	100.0					
Loblolly pine volume	2.5	16.7					
All other species volume	12.7	83.3					
Total biomass, all species	6.1	100.0					
Loblolly pine biomass	1.0	16.5					
All other species biomass	5.1	83.5					
Piece values							
Minimum			10.5	10.0	0.5	0.005	1.9
Maximum			53.6	45.0	10.2	0.733	293.0
Average			20.4	16.5	2.6	0.113	45.1
Standard deviation			9.4	8.3	2.4	0.187	77.2

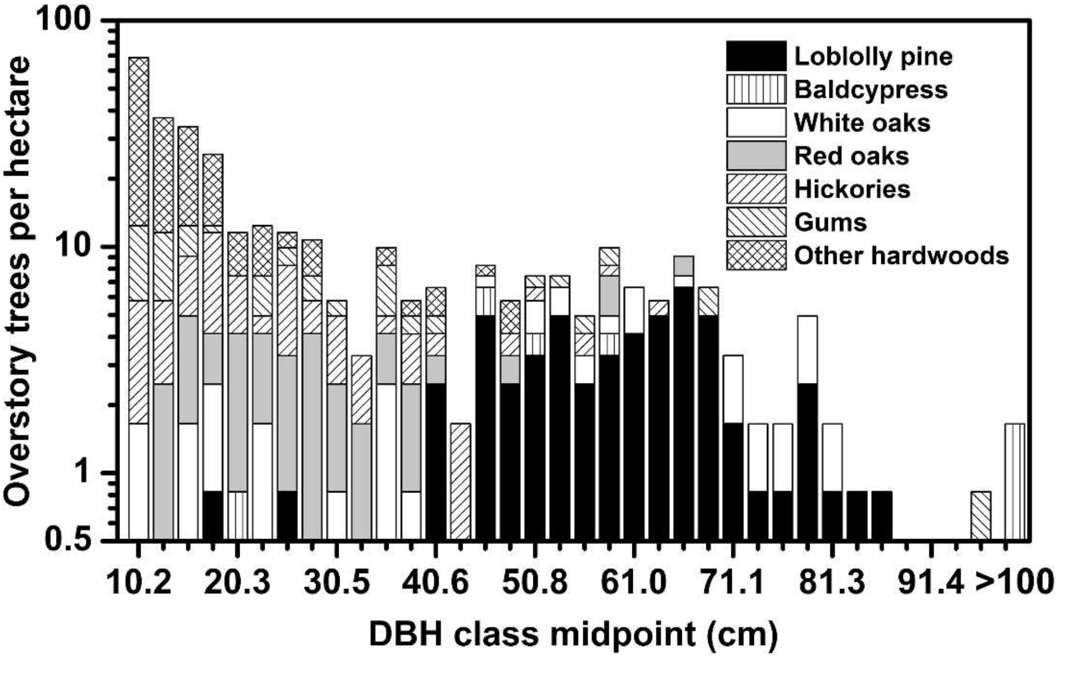

Figure 3. Semilog overstory abundance by 2.54-cm diameter classes at Hyatt's Woods by species/species groups. For this figure, the white oak group includes *Quercus alba*, *Quercus michauxii*, and *Quercus stellata*. Other species group assignments can be found in Table 3.

totaled 258.2 Mg/ha and belowground live tree biomass contributed another 59.1 Mg/ha, for a total live tree biomass of 317.3 Mg/ha (Table 3). Even though the largest trees at this site were baldcypress, their portion of total stand biomass was a distant third to the much more abundant loblolly pine and white oak. Loblolly pine, which dominated the stand basal area of Hyatt's Woods, yielded 119 Mg/ha of total live tree biomass, or 37.5% of the total. White oak produced 56 Mg/ha of total live biomass, followed by baldcypress (26 Mg/ha) and sweetgum (almost 23 Mg/ha). These four species alone accounted for 70% of the total live biomass at Hyatt's Woods.

Coarse Woody Debris

When measured in 2009, Hyatt's Woods did not have a large quantity of CWD. On the 43 100-m^2 grid cells sampled, only 58 pieces of CWD were tallied, or an estimated 111.4 pieces/ha. Of this large dead wood, no cut stumps were identified, and only four were standing dead trees (snags). The CWD was small in dimension, with an average large-end diameter of 20 cm, an average piece length of 2.6 m, and a mean biomass of 45.1 kg (Table 4). For the CWD that could at least be identified to genera, most were loblolly pine (31/ha), followed by unidentified hickories (*Carya* spp., 19/ha), white oak (14/ha), and sweetgum (8/ha). Even though the landowner has salvaged some dead and dying trees, there remains almost no evidence of this on the study site: only 1 of 58 pieces tallied (1.7%) showed evidence of being cut. A range of decay classes was present in the plot, but the majority (83%) was classified as class 2: only 12% were class 3 and 5% were class 1. Coarse woody debris volume (all species) totaled 15.2 m^3/ha, or approximately 6 Mg/ha oven-dry biomass. Although loblolly pine constituted >25% of the pieces, it contributed only 17% to the total CWD volume (2.5 m^3/ha) and biomass (1 Mg/ha).

Spatial Pattern

Using a neighborhood density function (NDF) on the entire set of live overstory trees at Hyatt's Woods produced a spatial pattern that was primarily random (Figures 4 and 5). The NDF exceeded either the lower or upper 95% confidence intervals (CIs) at only a few points, indicating that for most spatial scales the null hypothesis of complete spatial randomness (CSR) could not be rejected (Figure 5). In the few instances when the NDF did exceed (aggregated spatial patterns) or fall below (overdispersed spatial patterns) the 95% CIs, the NDF just barely crossed these thresholds, suggesting the weaknesses of these patterns.

Naturally regenerated forests often show some nonrandom spatial patterns, so seven species groups (loblolly pine, baldcypress, white oak, other oaks, gums, hickories, and all other species; see Table 3 for group assignments) were aggregated from the 26 observed species at Hyatt's Woods for group-based tests of spatial pattern. A range of patterns by species group quickly became apparent; Figure 6 provides examples of group-based stem maps and their corresponding NDFs. Below 25 m, loblolly pine typically appeared to be clustered at most distances, with CSR at scales greater than this range. White oak showed a similar pattern with pronounced clustering at scales below 12 m and almost exclusively CSR at all other distances. Unlike loblolly pine, which was concentrated primarily in the northern half of the study site, white oak was more evenly distributed, with small distinct clusters in a few locations contributing to the aggregation values at those scales (2–7 m, Figure 6). The limited numbers of baldcypress associated with the former stream channels of Brown's Creek were also clustered at multiple scales corresponding to their proximity to certain stream segments.

DISCUSSION

In most aspects, Hyatt's Woods is consistent with other unmanaged mature to old-growth remnants along minor stream terraces in other parts of southeastern Arkansas (e.g., Shelton and Cain 1999, Bragg 2004c, Grell et al. 2005, Bragg and Heitzman 2009, Lockhart et al. 2010).

Stand Structure and Diversity

The structural patterns of Hyatt's Woods reflect the gradient of forest composition found along minor riparian systems in the Upper West Gulf Coastal Plain. Throughout the Holocene, Brown's Creek has continuously reworked the Pleistocene alluvium and produced a relatively flat and poorly drained terrace. Localized areas of higher ground along this terrace support overstory species (particularly loblolly pine and white oak) more consistent with the uplands of the coastal plain, while the more poorly drained flats support a variety of bottomland hardwoods,

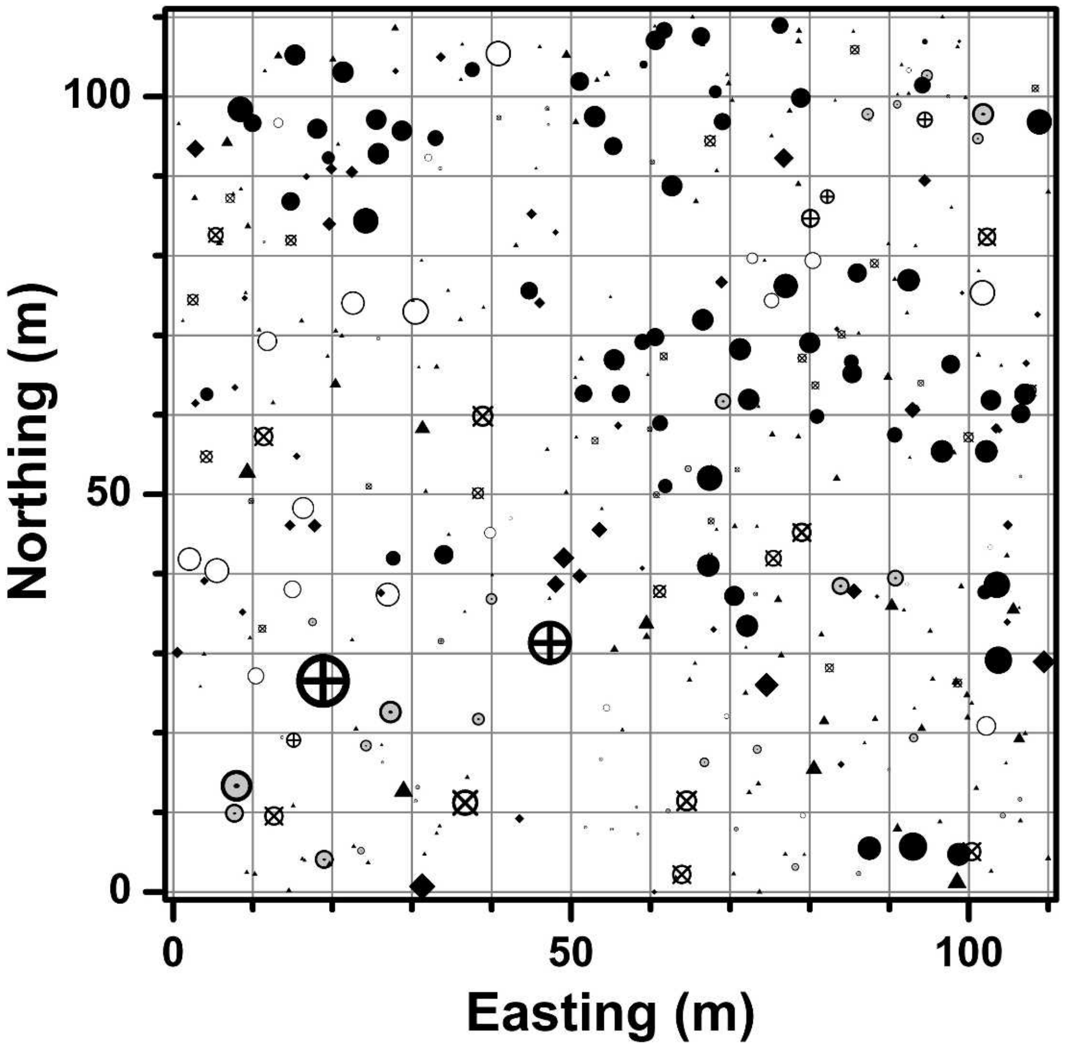

Figure 4. Stem map of all live overstory trees at Hyatt's Woods. For easier interpretation, species were grouped into one of seven categories (see group assignments in Table 3): loblolly pine (●), baldcypress (⊕), white oak (○), other red and white oaks (⊗), gums (⊙), hickories (◆), and all other species (▲). The size of the symbol is scaled to be proportional to diameter.

and baldcypress occupy parts of the abandoned stream channels.

In these terraces, microtopography often plays a key role in determining the dominance of pines and upland hardwoods versus bottomland hardwoods and baldcypress (Grell et al. 2005, Lockhart et al. 2010). The taxonomic and structural richness of these active landforms reflects the complex interactions of channel formation, upland erosion, edaphic features, groundwater flow, and sediment deposition, coupled with periodic disturbances and their ecotonal nature. In many places, poor surface drainage produces localized patches of bottomland species and limited rooting zones that foster windthrow and pit-and-mound microtopography. Even slight (in terms of centimeters) increases in elevation can have profound impacts on species abundances in these systems (Grell et al. 2005). Loblolly pine, for example, is commonly found in many of these stream terrace sites because it can tolerate prolonged inundation better than shortleaf pine.

However, it is often confined to topoedaphic features such as scroll bars, tip-up mounds, or other slight elevations with coarser soils, where loblolly has been noted to reach its greatest dimensions (Record 1907, Chapman 1942, Pederson et al. 1997).

Although the small spatial extent of the Hyatt's Woods study site limits the number of possible overstory tree species, the quantity identified (26 currently in the overstory [Table 1], with at least 2 others capable of ascending into the overstory present in the understory [Table 2]) is consistent with the richness reported in other, considerably larger study locations nearby. For instance, the most recent inventory of the 32-ha Reynolds Research Natural Area (RRNA) on the Crossett Experimental Forest, located approximately 50 km south of Hyatt's Woods, noted 25 tree species (Bragg and Shelton 2011); a 6-ha area of the Levi Wilcoxon Demonstration Forest (LWDF), located 30 km south of Hyatt's Woods, had 27 tree species (Bragg 2004c); the 16-ha "Lost Forty" Natural Area (NA) bottomland hardwood-pine stand in nearby Calhoun County, Arkansas, had 27 different tree species (Heitzman et al. 2004); and the Moro Creek Bottoms NA just north of the Lost Forty NA had 33 tree species (Lockhart et al. 2010). If placed along a site moisture gradient, Hyatt's Woods falls between the drier and more pine-dominated LWDF and RRNA stands in Ashley County and the wetter Lost Forty and Moro Creek NAs, which are primarily bottomland hardwoods with scattered loblolly pine.

Understory Dynamics and Spatial Patterning

A number of observations can be made on the understory pertaining to long-term stand dynamics. First, loblolly pine and baldcypress seedlings were conspicuously rare or absent—not surprising, given the shade intolerance of these species and the dense canopy found at Hyatt's Woods. Second, few trees were apparent in the sapling size classes, also likely due to the dense shade and their inability to persist under these conditions. However, a number of shade-tolerant species such as American hornbeam, eastern hophornbeam, horse-sugar, pawpaw, and American holly were found in most understory size classes and are thus capable of recruiting into the midstory as small gaps appear. These low-stature hardwoods can also serve as a lattice supporting woody vines (e.g., muscadine), whose foliage further deepens the shade at the ground level. Without adequately severe large-scale canopy disturbance, Hyatt's Woods will continue to progress towards an increasingly shade-tolerant hardwood composition, as predicted for most of the pine-dominated forests in the Gulf Coastal Plain (e.g., Quarterman and Keever 1962, Halls and Homesley 1966, Blair and Brunett 1976, Switzer et al. 1979, Cain and Shelton 1995, Bragg and Shelton 2011).

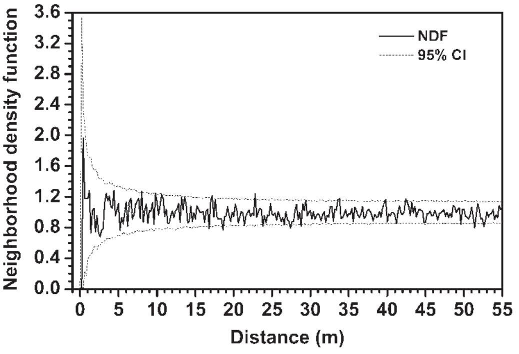

Figure 5. Neighborhood density function (NDF, solid line) as a function of distance for all live overstory trees in Hyatt's Woods, with 95% confidence intervals (CIs, dashed lines). The strong tendency for the NDF to fall between the CIs across the range of distances indicates a random spatial pattern at all observed scales if species groups are not differentiated.

The horizontal (spatial) patterning of Hyatt's Woods reflects the interaction of terrace microtopography and influences from adjoining uplands, possibly including large-scale disturbance propagation. The abundance of mature loblolly pine along the northern (adjacent to the upland) portions of this study site (Figure 4) suggests a major disturbance event in the past (possibly lumbering, farming, windthrow, or fire) that permitted this shade-intolerant conifer to establish and dominate this portion of the stand (see also Turner 1937, Pederson et al. 1997). The more intermittent distribution of loblolly across much of the rest of the stand suggests more limited regeneration success, probably due to a more intact residual canopy and perhaps the degree of extended inundation experienced in these lower, more poorly drained and flood-prone areas (Turner 1937). Floods during the winter and spring may also wash away the light loblolly pine seeds during certain years.

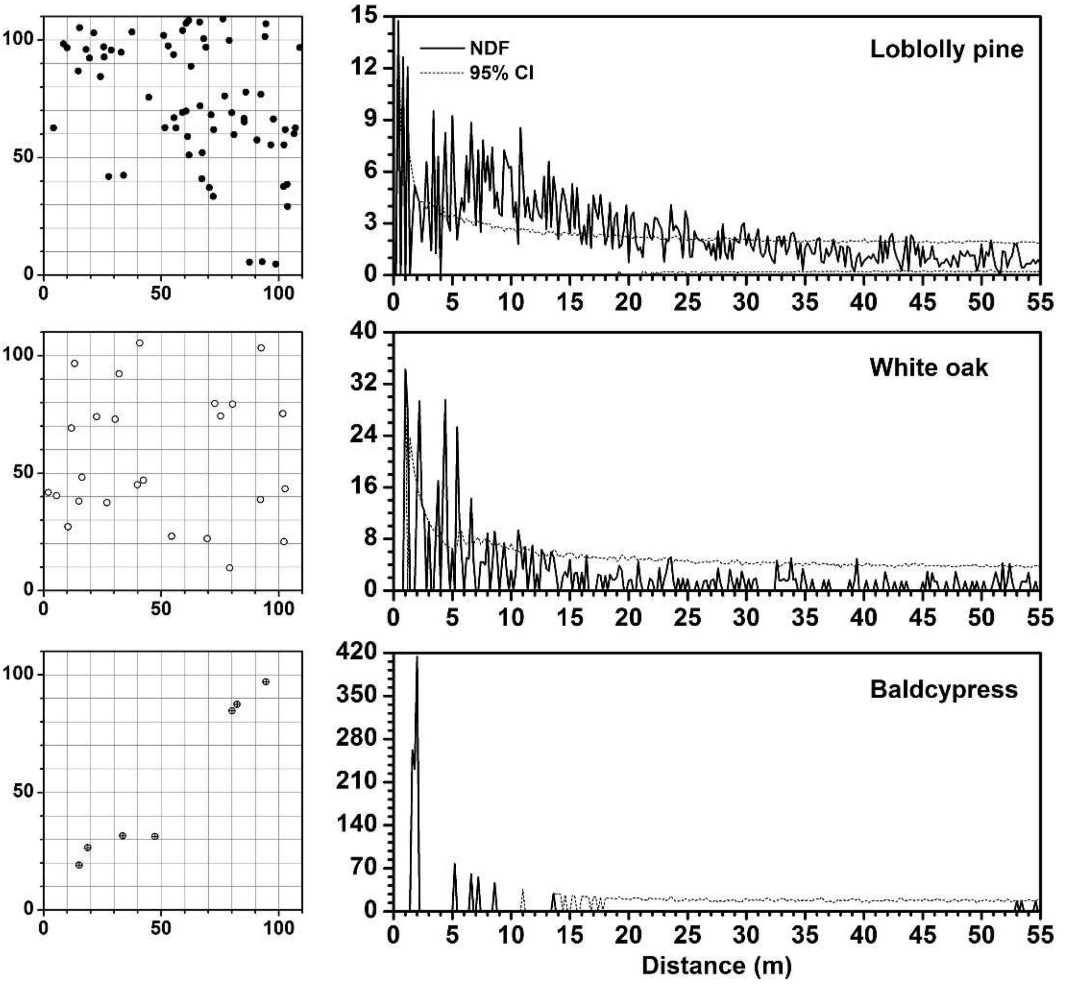

Figure 6. Species spatial patterns (here, exemplified by loblolly pine, white oak, and baldcypress) differ at a variety of scales. On the left, the stem maps of these species are reflected by their corresponding neighborhood density function (NDF, solid line on graph at right). Loblolly pine displayed clustering at small to intermediate scales (0- to 25-m), while white oak were more likely to be randomly distributed, especially at scales >12 m. Baldcypress showed clustering at fine scales only.

Biomass Structure and Disturbance

Large-scale studies of biomass in the eastern United States have rarely reported forests that exceed 225 Mg/ha (e.g., Brown et al. 1997, 1999; Schroeder et al. 1997, Shoch et al. 2009). However, Hyatt's Woods and several other mature, unmanaged pine-hardwood stands in southern Arkansas exceed 230 Mg/ha biomass (Table 5). These high totals can be attributed to a number of factors, including the possibility that this relatively small stand has been sheltered from perturbations that may have otherwise reduced its biomass, a large fraction of high wood density (and therefore heavier) hardwoods, the large size of dominant overstory trees, and the presence of many different size classes occupying multiple canopy levels within the forest. It seems unlikely that historic pine-dominated stands in this area developed such biomass levels, primarily because of different disturbance regimes (Bragg 2012). Silvicultural intervention dramatically reduces arboreal carbon storage in these pine-hardwood stands (Table 5), particularly when they are managed to ensure perpetuation of shade-intolerant taxa.

Table 5. Examples of live overstory tree biomass quantities among selected mature, pine-dominated forests in southeastern Arkansas

Stand Name (location)	Stand History	Live Tree Biomass[a]			Basal Area	Source
		AG (Mg/ha)	BG (Mg/ha)	Total (Mg/ha)	(m^2/ha)	
Hyatt's Woods (Drew County)	Unmanaged second-growth with old-growth residuals	258.2	59.1	317.3	37.1	This study
Reynolds Research Natural Area, CEF[b] (Ashley County)	Unmanaged second-growth	254.3	55.7	310.0	36.9	Bragg and Shelton (2011)
Lost Forty (Calhoun County)	Unmanaged old-growth	233.7	51.0	284.7	31.4	Heitzman et al. (2004)
POW Camp Natural Area (Drew County)	Unmanaged second-growth	212.7	46.7	259.4	34.5	Bragg and Heitzman (2009)
1930s pine-hardwood stand (Ashley County)	Unmanaged second-growth	188.7	44.8	233.5	32.0	Bragg (2004d)
Levi Wilcoxon Demonstration Forest (Ashley County)	Pre-restoration (circa 2006)	184.2	40.6	224.8	28.2	Bragg (2010)
	Post-restoration (2009)	106.8	23.3	130.1	16.4	
Good Forty Demonstration Area, CEF (Ashley County)	Managed uneven-aged	80.3	20.7	101.0	15.8	Unpublished 2008 cruise
Poor Forty Demonstration Area, CEF (Ashley County)	Managed uneven-aged	81.5	21.0	102.5	16.1	Unpublished 2008 cruise
Compartment 12, CEF (Ashley County)	Managed, even-aged second growth	99.9	24.3	124.2	16.9	Unpublished 2007 cruise

[a]Oven-dry values for trees >9 cm DBH; AG = aboveground and BG = belowground, all calculated using the same equations and assumptions as this study.
[b]CEF = Crossett Experimental Forest.

Though poorly documented in this region, CWD also impacts biomass accumulation in pine-dominated forests. The quantity of CWD biomass found at Hyatt's Woods (6.1 Mg/ha) is a small fraction (<2%) of the live biomass at this site. A comparison of CWD volume with other natural-origin pine-dominated stands in southeastern Arkansas places Hyatt's Woods (15.2 m^3/ha) lower than most other unmanaged sites, which ranged from 29 m^3/ha to 310 m^3/ha (Zhang 2000, Bragg 2004c, Bragg and Heitzman 2009). High CWD biomass has been considered an indicator of old-growth in many ecosystems (e.g., Martin 1992). However, because of the small size of this study site, it is hard to generalize much from this low quantity of CWD. Disturbance (particularly windthrow and timber harvest) is common in the adjacent forest. For example, a number of large hardwoods were toppled by Tropical Storm Gustav (early September 2008) in the riparian stands just upstream of Hyatt's Woods. Limited salvage by the landowners has also lessened CWD stocks, although there was very little evidence of cutting on the CWD encountered (Table 4). Mature stands with abundant hardwoods tend to have less CWD than either younger or older examples of similar composition because they often lack the biological legacies from prior disturbances and hardwood tends to break down quickly in the warm, humid, termite-filled woods of southeastern Arkansas (Cain 1996, McMinn and Hardt 1996, Van Lear 1996, Spetich et al. 1999).

CONCLUSIONS Hyatt's Woods is a structurally diverse stand and would rate high on many scales of complexity (e.g., McElhinny et al. 2005). The ability to support large numbers of tree species in a relatively limited spatial extent makes the conservation of riparian zones, even along small streams, an important issue in the Upper West Gulf Coastal Plain. However, the ecological evidence found at Hyatt's Woods suggests that this stand, though mature, is not what most people would classify as old growth. The limited number of truly ancient trees, coupled with the paucity of other biological legacies (e.g., CWD) and relative vigor of the overstory suggest that this stand contains a handful of surviving "cull" and submerchantable trees left after the lumbering of the virgin forest (probably in the early 20th century) followed by many decades of uninterrupted regrowth.

Even though it is not a textbook example of old growth, Hyatt's Woods represents an increasingly uncommon example of unmanaged mature pine-hardwood forest on private property. Across the southeastern United States, most large landowners on the Atlantic and Gulf Coastal Plains, particularly in the timber industry, have converted their upland forests from a mixture of naturally regenerated pine and hardwood to short-rotation pine plantations (Conner and Hartsell 2002). In these stands, management intensity produces species-poor overstories with reduced structural complexity and much shorter stand replacement periods. This trend is expected to continue into the foreseeable future, as demand for wood products continues to grow and accessible timber supplies from other regions diminish (Wear and Greis 2002, 2012).

Naturally regenerated stands are increasingly limited to areas along small stream terraces protected from more intensive silvicultural treatments largely due to concerns over best management practices and accessibility. Their relative rarity means that the documentation of these mature, unmanaged, naturally regenerated pine-dominated stands is important as a record of their structural patterns, richness, biological legacies, and biomass storage capacity. These stands can also help serve as a baseline for future restoration work, particularly if maximizing carbon storage is one of the objectives.

ACKNOWLEDGMENTS I thank David Taylor Hyatt, Jr. and the rest of his family for providing access and field assistance in the implementation of this study. Special thanks also to Kirby Sneed (US Forest Service) for his assistance on this project. Mike Shelton (US Forest Service, retired) and Nancy Koerth (US Forest Service) graciously provided helpful review comments on earlier drafts of this paper.

LITERATURE CITED

Blair, R.M. and L.E. Brunett. 1976. Phytosociological changes after timber harvest in a southern pine ecosystem. Ecology 57:18–32.

Bragg, D.C. 2002. Reference conditions for old-growth pine forests in the Upper West Gulf Coastal Plain. J. Torrey Bot. Soc. 129:261–288.

Bragg, D.C. 2003. Natural presettlement features of the Ashley County, Arkansas area. Amer. Midl. Naturalist 149:1–20.

Bragg, D.C. 2004a. General Land Office surveys as a source for Arkansas history: the example of Ashley County. Arkansas Historical Quarterly 63:166–184.

Bragg, D.C. 2004b. Dimensionality from obscurity: revisiting historical sources of big tree size. p. 440–447. *In:* Yaussy, D., D.M. Hix, P.C. Goebel, and R.P. Long (eds.). Proceedings of the 14th central hardwood forest conference. Gen. Tech. Rep. NE-316. USDA Forest Service, Northeastern Research Station, Newtown Square, Pennsylvania.

Bragg, D.C. 2004c. Composition, structure, and dynamics of a pine-hardwood old-growth remnant in southern Arkansas. J. Torrey Bot. Soc. 131:320–336.

Bragg, D.C. 2004d. Composition and structure of a 1930s-era pine-hardwood stand in Arkansas. S. E. Naturalist (Steuben) 3:327–344.

Bragg, D.C. 2010. Stand conditions immediately following a restoration harvest in an old-growth pine-hardwood remnant. Journal of the Arkansas Academy of Science 64:57–69.

Bragg, D.C. 2012. Developing contemporary and historical live tree biomass estimates for old pine-hardwood stands of the Midsouth, U.S.A. Forest Ecol. Managem. 281:32–40.

Bragg, D.C. and E. Heitzman. 2009. Composition, structure, and dynamics of a mature, unmanaged, pine-dominated old-field stand in southeastern Arkansas. S. E. Naturalist (Steuben) 8: 445–470.

Bragg, D.C. and M.G. Shelton. 2011. Lessons from 72 years of monitoring a once-cut pine-hardwood stand on the Crossett Experimental Forest, Arkansas, U.S.A Forest Ecol. Managem. 261:911–922.

Brown, S., P. Schroeder, and R. Birdsey. 1997. Aboveground biomass distribution of US eastern hardwood forests and the use of large trees as an indicator of forest development. Forest Ecol. Managem. 96:37–47.

Brown, S.L., P. Schroeder, and J.S. Kern. 1999. Spatial distribution of biomass in forests of the eastern USA. Forest Ecol. Managem. 123: 81–90.

Cain, M.D. 1996. Hardwood snag fragmentation in a pine-oak forest of southeastern Arkansas. Amer. Midl. Naturalist 136:72–83.

Cain, M.D. and M.G. Shelton. 1995. Thirty-eight years of autogenic, woody understory dynamics in a mature, temperate pine-oak forest. Canad. J. Forest Res. 25:1997–2009.

Cain, M.D. and M.G. Shelton. 2001. Secondary forest succession following reproduction cutting on the Upper Coastal Plain of southeastern Arkansas, USA. Forest Ecol. Managem. 146:223–238.

Chapman, H.H. 1942. Management of loblolly pine in the pine-hardwood region in Arkansas and in Louisiana west of the Mississippi River. Bull. 49. Yale University School of Forestry, New Haven, Connecticut.

Conner, R.C. and A.J. Hartsell. 2002. Forest area and conditions. p. 357–402. *In:* Wear, D.N. and J.G. Greis (eds.). Southern forest resource assessment. Gen. Tech. Rep. SRS-53. USDA Forest Service, Southern Research Station, Asheville, North Carolina.

Daniels, C. 2000. Arkansas original General Land Office survey notes and plats. Arkansas State Land Office, Little Rock, Arkansas.

Enquist, B.J. and K.J. Niklas. 2002. Global allocation rules for patterns of biomass partitioning in seed plants. Science 295:1517–1520.

Fraedrich, S.W., T.C. Harrington, R.J. Rabaglia, M.D. Ulyshen, A.E. Mayfield, J.L. Hanula, J.M. Eickwort, and D.R. Miller. 2008. A fungal symbiont of the redbay ambrosia beetle causes a lethal wilt in redbay and other Lauraceae in the southeastern United States. Pl. Dis. 92:215–224.

Gramling, J.M. 2010. Potential effects of laurel wilt on the flora of North America. S. E. Naturalist (Steuben) 9:827–836.

Grell, A.G., M.G. Shelton, and E. Heitzman. 2005. Changes in plant species composition along an elevation gradient in an old-growth bottomland hardwood-*Pinus taeda* forest in southern Arkansas. J. Torrey Bot. Soc. 132:72–89.

Halls, L.K. and W.B. Homesley. 1966. Stand composition in a mature pine-hardwood forest of southeastern Texas. J. Forest. 64:170–174.

Heitzman, E., M.G. 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. Nat. Areas J. 24:177–187.

Holzmueller, E., S. Jose, M. Jenkins, A. Camp, and A. Long. 2006. Dogwood anthracnose in eastern hardwood forests: what is known and what can be done? J. Forest. 104:21–26.

Jenkins, J.C., D.C. Chojnacky, L.S. Heath, and R.A. Birdsey. 2003. National-scale biomass estimators for United States tree species. Forest Sci. 49:12–35.

Larance, F.C., H.V. Gill, and C.L. Fultz. 1976. Soil survey of Drew County, Arkansas. USDA Soil Conservation Service and the Arkansas Agricultural Experiment Station.

Laser Technology, Inc. 2012. Products for professional field measurement (http://www.lasertech.com/Professional-Measurement-Products.aspx, 6 February 2012). Laser Technology, Inc., Centennial, Colorado.

Lockhart, B.R., J.M. Guldin, and T. Foti. 2010. Tree species composition and structure in an old bottomland hardwood forest in south-central Arkansas. Castanea 75:315–329.

Martin, W.H. 1992. Characteristics of old-growth mixed mesophytic forests. Nat. Areas J. 12: 127–135.

McCarthy, J.W. and G. Weetman. 2006. Age and size structure of gap-dynamic, old-growth boreal forest stands in Newfoundland. Silva Fenn. 40:209–230.

McElhinny, C., P. Gibbons, C. Brack, and J. Bauhus. 2005. Forest and woodland stand structural complexity: its definition and measurement. Forest Ecol. Managem. 218:1–24.

McMinn, J.W. and R.A. Hardt. 1996. Accumulations of coarse woody debris in southern forests. p. 1–9. *In:* McMinn, J.W. and D.A. Crossley, Jr. (eds.). Biodiversity and coarse woody debris in southern forests. Gen. Tech. Rep. SE-94. USDA Forest Service, Southeastern Forest Experiment Station, Asheville, North Carolina.

Miles, P.D. and W.B. Smith. 2009. Specific gravity and other properties of wood and bark for 156 tree species found in North America. Res. Note NRS-38. USDA Forest Service, Northern Research Station, Newtown Square, Pennsylvania.

Moore, D.M. 1999. Trees of Arkansas. Arkansas Forestry Commission, Little Rock, Arkansas.

National Oceanic and Atmospheric Administration (NOAA). 2012. 1981–2010 climate normals for Arkansas. (http://www.srh.noaa.gov/lzk/?n=wxcntl3.htm, 12 September 2012). National Weather Service Weather Forecast Office, Little Rock, Arkansas.

Oneillon, F.E. 1956. Geology and ground-water resources of Drew County, Arkansas. Water Resources Circ. 4. Arkansas Geological and Conservation Commission, Little Rock, Arkansas.

Pederson, N. 2010. External characteristics of old trees in the eastern deciduous forest. Nat. Areas J. 30:396–407.

Pederson, N.A., R.H. Jones, and R.R. Sharitz. 1997. Age structure and possible origins of old *Pinus taeda* stands in a floodplain forest. J. Torrey Bot. Soc. 124:111–123.

Perry, G.L.W. 2004. SpPack: spatial point pattern analysis in Excel using Visual Basic for Applications (VBA). Environ. Modell. Softw. 19:559–569.

Perry, G.L.W., B.P. Miller, and N.J. Enright. 2006. A comparison of methods for the statistical analysis of spatial point patterns in plant ecology. Plant Ecol. 187:59–82.

Poland, T.M. and D.G. McCullough. 2006. Emerald ash borer: invasion of the urban forest and the threat to North America's ash resource. J. Forest. 104:118–124.

Quarterman, E. and C. Keever. 1962. Southern mixed hardwood forest: climax in the southeastern coastal plain, U.S.A. Ecol. Monogr. 32: 167–185.

Record, S.J. 1907. The forests of Arkansas. Forest. Quart. 5:296–301.

Sabo, G., III. 1992. Paths of our children: Historic Indians of Arkansas. Popular Series 3. Arkansas Archeological Survey, Fayetteville, Arkansas.

Saucier, R.T. 1974. Quaternary geology of the Lower Mississippi Valley. Research Series 6. Arkansas Archeological Survey, Fayetteville, Arkansas.

Schroeder, P., S. Brown, J. Mo, R. Birdsey, and C. Cieszewski. 1997. Biomass estimation for temperate broadleaf forests of the United States using inventory data. Forest Sci. 43: 424–434.

Shelton, M.G. and M.D. Cain. 1999. Structure and short-term dynamics of the tree component of a mature pine-oak forest in southeastern Arkansas. J. Torrey Bot. Soc. 126:32–48.

Shoch, D.T., G. Kaster, A. Hohl, and R. Souter. 2009. Carbon storage of bottomland hardwood afforestation in the lower Mississippi Valley, USA. Wetlands 29:535–542.

Smith, E.B. 1988. An atlas and annotated list of the vascular plants of Arkansas. 2nd ed. Department of Botany and Microbiology, University of Arkansas, Fayetteville, Arkansas.

Spetich, M.A., S.R. Shifley, and G.R. Parker. 1999. Regional distribution and dynamics of coarse woody debris in Midwestern old-growth forests. Forest Sci. 45:302–313.

Switzer, G.L., M.G. Shelton, and L.E. Nelson. 1979. Successional development of the forest floor and soil surface on uplands sites of the East Gulf Coastal Plain. Ecology 60:1162–1171.

Turner, L.M. 1937. Growth of second-growth pine on the coastal plain soils of Arkansas. Bull. 342. University of Arkansas Agricultural Experiment Station, Fayetteville, Arkansas.

Van Lear, D.H. 1996. Dynamics of coarse woody debris in southern forest ecosystems. p. 10–17. *In:* McMinn, J.W. and D.A. Crossley, Jr. (eds.). Biodiversity and coarse woody debris in southern forests. Gen. Tech. Rep. SE-94. USDA Forest Service, Southeastern Forest Experiment Station, Asheville, North Carolina.

Vose, J.M., W.T. Swank, B.D. Clinton, J.D. Knoepp, and L.W. Swift. 1999. Using stand replacement fires to restore southern Appalachian pine-hardwood ecosystems: effects on mass, carbon, and nutrient pools. Forest Ecol. Managem. 114:215–226.

Wear, D.N. and J.G. Greis (eds.). 2002. Southern forest resource assessment. Gen. Tech. Rep. SRS-53. USDA Forest Service, Southern Research Station, Asheville, North Carolina.

Wear, D.N. and J.G. Greis (eds.). 2012. The Southern Forest Futures Project: summary report. Gen. Tech. Rep. SRS-168. USDA Forest Service, Southern Research Station, Asheville, North Carolina.

Zenner, E.K. 2005. Development of tree size distributions in Douglas-fir forests under differing disturbance regimes. Ecol. Applic. 15:701–714.

Zhang, M. 2000. Quantification of snags and downed wood in the R.R. Reynolds Research Natural Area and Good Forty Demonstration Area in southeastern Arkansas. M.S. thesis, University of Arkansas-Monticello, Monticello, Arkansas.