Am. Midl. Nat. (2012) 167:40–55

Structural Attributes of Two Old-Growth Cross Timbers Stands in Western Arkansas

DON C. BRAGG[1]
USDA Forest Service, Southern Research Station, Monticello, Arkansas 71656

AND

DAVID W. STAHLE AND K. CHRIS CERNY
Department of Geosciences, University of Arkansas, Fayetteville 72701

ABSTRACT.—Comprised of largely non-commercial, xeric, oak-dominated forests, the Cross Timbers in Arkansas have been heavily altered over the last two centuries, and thus only scattered parcels of old-growth timber remain. We inventoried and mapped two such stands on Fort Chaffee Military Training Center in Sebastian County, Arkansas. The west-facing Christmas Knob site is located on an isolated hill, while the southerly-facing Big Creek Narrows site is on a long, narrow rocky outcrop called Devil's Backbone Ridge. These sites occupied rocky, south- to southwest-facing sandstone-dominated slopes, with primarily post oak (*Quercus stellata*) and blackjack oak (*Q. marilandica*) overstories. Post oak dominated the largest size classes at both sites. Increment cores indicated that some post oaks exceeded 200 y of age, and tree-ring dating also confirmed an uneven-aged structure to these stands. Both locations had irregular reverse-J shaped diameter distributions, with gaps, deficiencies, and excesses in larger size classes that often typify old-growth stands. On average, the post oaks at the Big Creek Narrows site were taller, larger in girth, and younger than those on the Christmas Knob site, suggestive of a better quality site at Big Creek. The application of neighborhood density functions on stem maps of both sites found random patterns in tree locations. These stands are very similar in their structure to old-growth examples in other parts of the Cross Timbers ecoregion.

INTRODUCTION

The Cross Timbers ecoregion occupies southeastern Kansas, eastern and central Oklahoma, and north-central Texas and has been mapped as far east as extreme west-central Arkansas (Bruner, 1931; Rice and Penfound, 1959; Kuchler, 1964; Hoagland *et al.*, 1999). This ecoregion is considered transitional between the hardwood and pine-dominated forests of eastern North America and the prairies of the Great Plains to the west. The Cross Timbers are mostly post oak (*Quercus stellata*) and blackjack oak (*Q. marilandica*), with few other tree species contributing to total stand density. Because of their ecotonal nature, the Cross Timbers often reflect parts of adjacent ecoregions—some patches may be more mesic and therefore dominated by denser forests, while other stands include mixtures of grass-dominated woodland, savanna, and pockets of prairie.

Too poor in log quality for timber production and unsuitable for conventional row-crop agriculture, large areas of old-growth Cross Timbers can still be found, although only a small fraction is in some protected status (Stahle and Hehr, 1984; Therrell and Stahle, 1998). Old-growth remnants have been studied in the center of the range of this ecoregion (*e.g.*, Johnson and Risser, 1975; Therrell and Stahle, 1998; Peppers, 2004; Clark *et al.*, 2005; Burton *et al.*, 2010). Considerably less information is available for old-growth forests along the fringes of the ecoregion, especially on the margins of the steep east-to-west precipitation

[1] Corresponding author: Telephone: (870) 367-3464; e-mail: dbragg@fs.fed.us

gradient that helps to define the Cross Timbers. Due to relatively high precipitation, the easternmost Cross Timbers sites are usually more limited in their distribution across the landscape than those in the drier portions of the ecoregion. These xeric oak stands are found primarily along narrow sandstone-controlled ridges and prominences, especially on thin, rocky soils with south and south-westerly aspects.

Kuchler (1964) mapped the Cross Timbers ecoregion as extending into Arkansas, although not all later maps have included the state (*e.g.,* US EPA, 2011). Across this ecoregion, agriculture (primarily livestock grazing), oil and gas development, and residential growth have reduced what was once many thousands of contiguous hectares of suitable habitat for old-growth Cross Timbers. Describing the structural attributes of intact old-growth Cross Timbers stands before they are lost to development or altered by climate change or invasive species is important if they are to be protected or restored. We present an examination of two old Arkansas Cross Timber stands, including an analysis of the species composition, tree size and biomass distributions, and age structure of these stands and comparisons with known old-growth examples from Oklahoma and Texas.

MATERIALS AND METHODS

STUDY AREA

We inventoried mature Cross Timbers stands on the Fort Chaffee Maneuver Training Center (Fort Chaffee MTC) (Fig. 1). Fort Chaffee MTC covers 26,710 ha of Sebastian and Franklin counties in extreme western Arkansas near Fort Smith (Radcliff, 2008). Prior to its development as a military base in 1941, the lands of Fort Chaffee MTC were a mixture of agricultural and natural (forest, prairie, savanna, and riparian zones) ecosystems, with limited residential or commercial development. During this pre-military period, farmers and ranchers cleared most of the timber on the gentler slopes and converted them to row crops or pastures. Given past practices, it seems certain that livestock grazed most of the area not fenced to exclude them, including closed-canopy forests. Since establishment of the Fort Chaffee MTC, the agricultural lands have reverted back to forest or grassland or have been turned into military facilities, including barracks, active gunnery ranges, armored vehicle training grounds, landing zones, and combat training areas. However, the remnant old-growth Cross Timbers stands at Fort Chaffee MTC have been protected from decades of logging, land clearing, and residential development that otherwise would likely have occurred.

Fort Chaffee MTC was transferred from the US Army to the Arkansas National Guard in 1997. Live ordinance training and heavy vehicle use continues across the base, contributing to fires that periodically affect this landscape. Controlled burns are also used to manage vegetation and improve wildlife habitat, and ignitions from lightning, arson, and accidents continue. Other frequent natural disturbances at Fort Chaffee MTC include ice storms and windthrow. Invasive species are locally present, including the native eastern redcedar (*Juniperus virginiana*) that has greatly expanded its coverage in recent decades, especially on former fields, pastures, and other disturbed areas. Most of the oldest forest remaining on Fort Chaffee MTC has escaped the most damaging effects of these perturbations due to its location on steep, rocky outcrops and sheltered bluffs, particularly on xeric, low productivity south- and west-facing slopes.

We chose two sites on Fort Chaffee MTC minimally altered by land use practices during the last century—Christmas Knob and Big Creek Narrows. The Christmas Knob site (35°17′31″N, 94°08′41″W) is located on an isolated hill of sandstone rising >30 m above the surrounding plain to a maximum elevation of about 175 m above sea level (ASL). Our

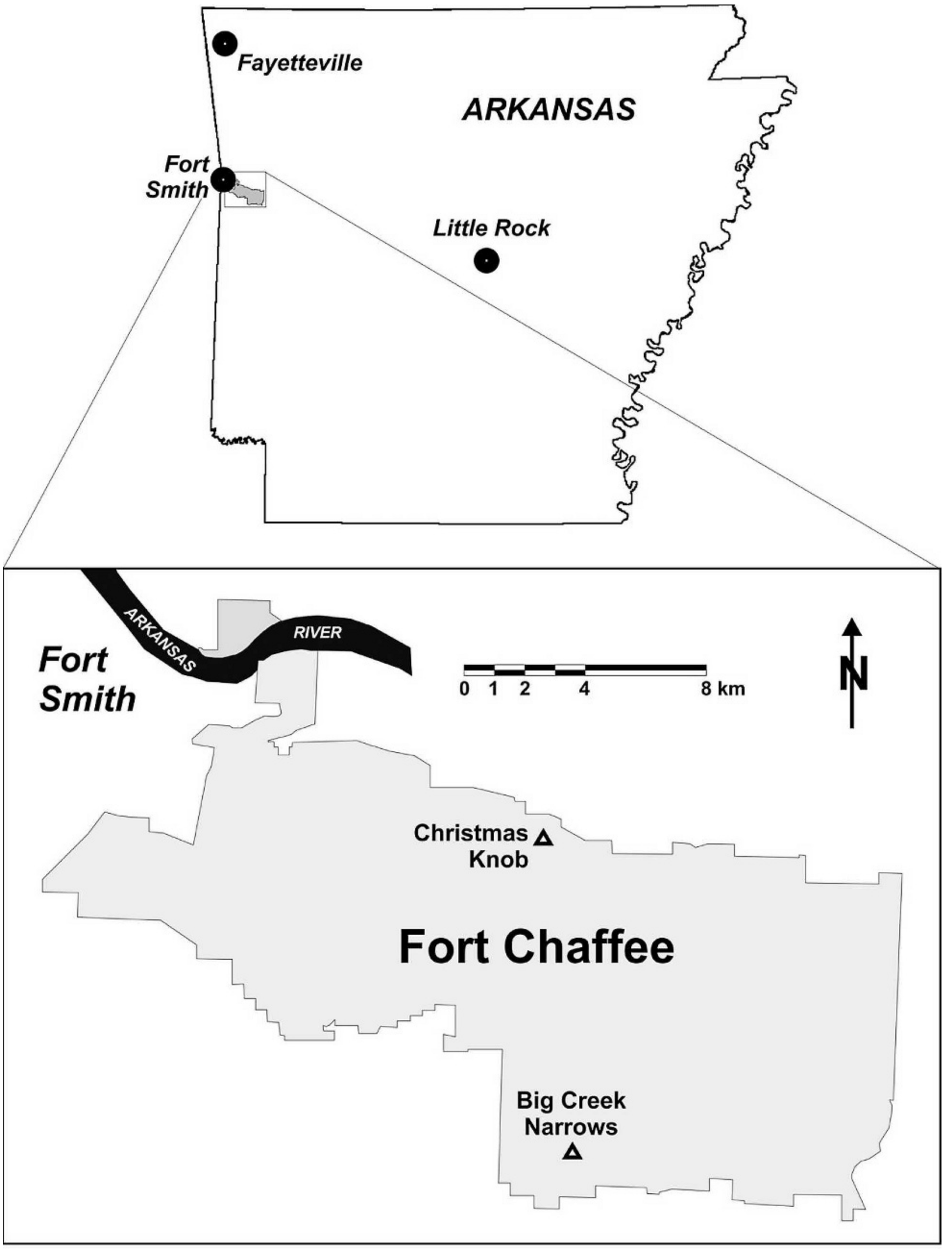

FIG. 1.—Location of Fort Chaffee Maneuver Training Center in western Arkansas, and the two sample plots, Christmas Knob and Big Creek Narrows

study site was approximately midslope on the western side of this knob, at an elevation of about 160 m ASL. The Big Creek Narrows site (35°12′05″N, 94°08′53″W) is located at about 220 m ASL just west of a gorge eroded by Big Creek through a long, narrow, steep, predominantly east-west sandstone formation called Devil's Backbone Ridge. The ground surface at the Big Creek Narrows site was somewhat steeper and stonier than the site at Christmas Knob, not surprising given its position below a talus slope at the bottom of a 10–20 m tall escarpment near the crest of Devil's Backbone. The soils on both sites are classified as the Enders-Mountainberg association of silty or sandy loams with high rock content (Cox *et al.*, 1975).

Climate data from nearby Fort Smith show a bimodal rainfall pattern between 1971 and 2000, with peaks in May (135 mm) and Nov. (122 mm) and the lowest monthly values (<66 mm) in Jan., Feb., and Aug. Annual precipitation during this period averaged 1114 mm, and mean Jan. and Jul. high temperatures were 8.9 C and 33.8 C, respectively (Southern Region Climate Center, 2010). This precipitation level is at the upper end of that found in the Cross Timbers ecoregion (Stahle and Hehr, 1984) and would typically support more mesic hardwood and pine forests. However, both study sites have xeric soils and exposed slopes, and thus support stunted oak-dominated forests and woodlands comparable to those seen in the Cross Timbers of Oklahoma or Texas.

STEM MAPPING AND FIELD SAMPLING

In Jan. 2009, we used an Impulse 200LR (Laser Technology, Inc., Centennial, CO) laser rangefinder and 100-m fiberglass measuring tapes to establish a 50 m by 50 m grid (0.25 ha) with an angular accuracy of ±0.3° and a horizontal distance accuracy of ±0.3 m (Laser Technology, Inc., 2009). The electronic inclinometer in the Impulse 200LR allowed for the stem map grid to be corrected for slope, yielding a horizontal accuracy of 0.2 to 0.5 m. After the 50 m baselines were established perpendicular to each other, they were divided into 25 m segments, producing four square grid cells. The vertices on these grid cells became fixed map stations for all live trees ≥10 cm in diameter at breast height (DBH) with at least half of their bole rooted within the plot. The open stands and accuracy of the Impulse 200LR allowed for a limited number of vertices to be used to map in the entire 0.25-ha plot, and the spatial accuracy of individual stems was helped by keeping the maximum distance between trees and the laser station <35 m (and <25 m, when possible (Peet *et al.*, 1997)). The Compass Module attachment for the Impulse 200LR acquired the bearing of every mapped tree using magnetic north. This bearing was then used in conjunction with the coordinates of the vertex, the horizontal distance to the face of the tree, and the tree's DBH to translate into grid coordinates. The neighborhood density function (NDF) from the SpPack add-in for Microsoft Excel (Microsoft Corporation, Redmond, WA) was then used to identify the spatial pattern of all live trees in each plot (Perry, 2004). We tested both plots against the null hypothesis of complete spatial randomness of stem locations using Monte Carlo simulation with 1000 replications and 95% confidence intervals, using a maximum step length of 25 m (Perry *et al.*, 2006).

In addition to live tree coordinate data, we identified each tree to species and measured DBH with a diameter tape to the nearest 0.1 cm. These inventory data were used to produce stand-level measures of density, including trees per hectare and basal area (in m^2/ha). We also measured total height (to the nearest 0.1 m) for a subset of oaks of good stem form using a TruPulse 200 (Laser Technology, Inc., Centennial, CO) laser rangefinder and the sine method (Blozan, 2006; Bragg, 2008). A visual comparison of post oak and blackjack oak heights suggested that a single equation would fit the combined data, so a Chapman-Richards equation was fit to this height-DBH relationship. Oven-dry above-ground live tree biomass estimates were made with the National Biomass Estimators from Jenkins *et al.* (2003), which were used to calculate belowground live biomass following Enquist and Niklas (2002).

AGE DETERMINATION PROCEDURES

Of the limited selection of species available, only post oak had the combination of adequate representation and longevity needed to develop a chronology that could extend to pre-Euroamerican settlement. At Christmas Knob, a random age sample of 42 post oak trees was taken. Because there were considerably fewer stems at Big Creek Narrows, all sound post oak trees were sampled in the study plot (50 trees). A small hammer was used on the exterior of each post oak to locate the soundest portion of the trunk from which to extract a core. We cored all trees with a small diameter (5 mm) increment borer at or near breast height. Although some have advised coring Cross Timbers oaks as near to the base as possible (*e.g.,* Clark and Hallgren, 2004), extensive lower bole decay at these study sites would have produced too many unusable cores. We air-dried the cores for several days and glued them to a wood core mount. Final preparation for dating required sanding the exposed surface of the core with a series of increasingly finer-grit sandpapers until the surface was highly polished. A stereo-zoom microscope (Bausch & Lomb, Rochester, NY) was used to analyze the ring sequence of polished cores.

To begin the chronology, three high quality cores were chosen from each site and a skeleton plot was created for each core to represent the time series sequence of wide and narrow rings (Stokes and Smiley, 1996). Once the skeleton plots were analyzed and found to agree with one another, true calendar dates were assigned to each annual ring proceeding back in time from the known date of the outermost bark ring. A dated, composite chronology was then created for each site by averaging the three individual plots. This composite was compared with other post oak and white oak (*Quercus alba*) chronologies from the region to verify the accuracy of the dating (time series matching with other regional chronologies was very good for both sites). The remaining cores were visually dated by a comparison with the dated chronology, and the exact calendar dating of selected frost rings helped ensure accuracy (Stahle, 1990). A small number of cores from each site could not be exactly dated due to rot or poor matching to the chronology and were assigned a simple ring count. Because of the prevalence of heart rot and the nature of sampling cores at or near breast height, all results indicate the minimum age of each tree.

RESULTS

OVERSTORY COMPOSITION

Our study sites exhibited the low overstory richness typical of the Cross Timbers, with each having only five tree species. Both Christmas Knob and Big Creek Narrow plots were dominated by post oak, which comprised 49.0% and 67.1% of the overstory stems, respectively (Table 1). Blackjack oak contributed almost as many stems (48.4%) on the Christmas Knob plot as did post oak but was less common (11.4%) on the Big Creek Narrows plot than mockernut hickory (*Carya tomentosa*, 15.2%). Winged elm (*Ulmus alata*) comprised less than 2% of stems on either plot, and mockernut hickory contributed 0.6% of the overstory on the Christmas Knob plot. A small quantity (5.0% of live stems) of black hickory (*C. texana*) was found at Big Creek Narrows, and eastern redcedar (1.3%) was tallied only on the Christmas Knob plot.

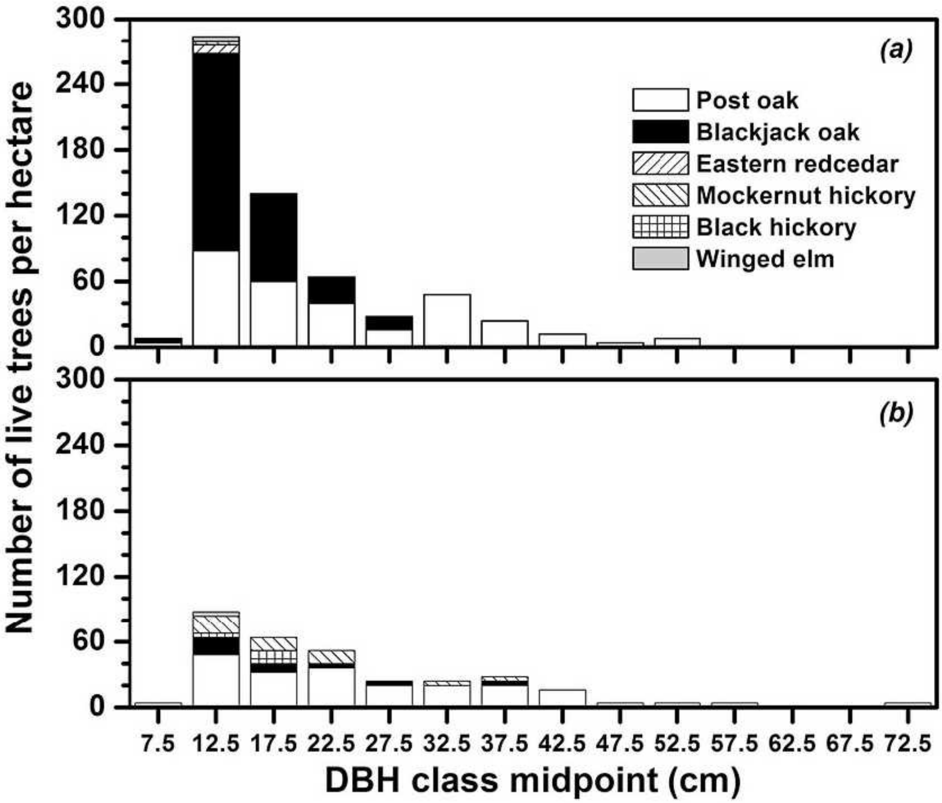

FIG. 2.—Size class distribution by DBH class midpoints for all live trees ≥10 cm DBH for the Christmas Knob (a) and Big Creek Narrows (b) sites on the Fort Chaffee Maneuver Training Center

DIAMETER AND AGE STRUCTURE

Post oak was found in virtually every diameter class present at Christmas Knob and Big Creek Narrows, and dominated the upper size classes at both sites (Fig. 2). Only post oak exceeded 40 cm DBH, and only a handful of blackjack oak and mockernut hickory were ≥25 cm DBH. Almost all trees other than post oak were <20 cm DBH, and most of these were blackjack oak. The abundance of small blackjack oak at the Christmas Knob site, particularly in the 10–15 and 15–20 cm DBH classes, strongly influenced the greater stocking at this site (Table 2).

Both locations had irregular reverse-J shape diameter distributions, with gaps, deficiencies, and excesses in larger size classes that often signify old-growth stands (Smith *et al.*, 1997). Dendrochronology confirmed the uneven-aged structure of at least the post oak component of these stands. Cross-dated increment cores taken from both sites indicated that post oaks >200 y old were present at the Christmas Knob site, and numerous post oaks ≥175 y old were found at Big Creek Narrows (Fig. 3). The two oldest post oaks found at Christmas Knob had inner ring dates of A.D. 1787 and 1789, while the two oldest at Big Creek Narrows dated to at least A.D. 1819 and 1825 (Fig. 4). These still understate maximum stand age, however, because they are estimates of tree age taken at DBH, which is

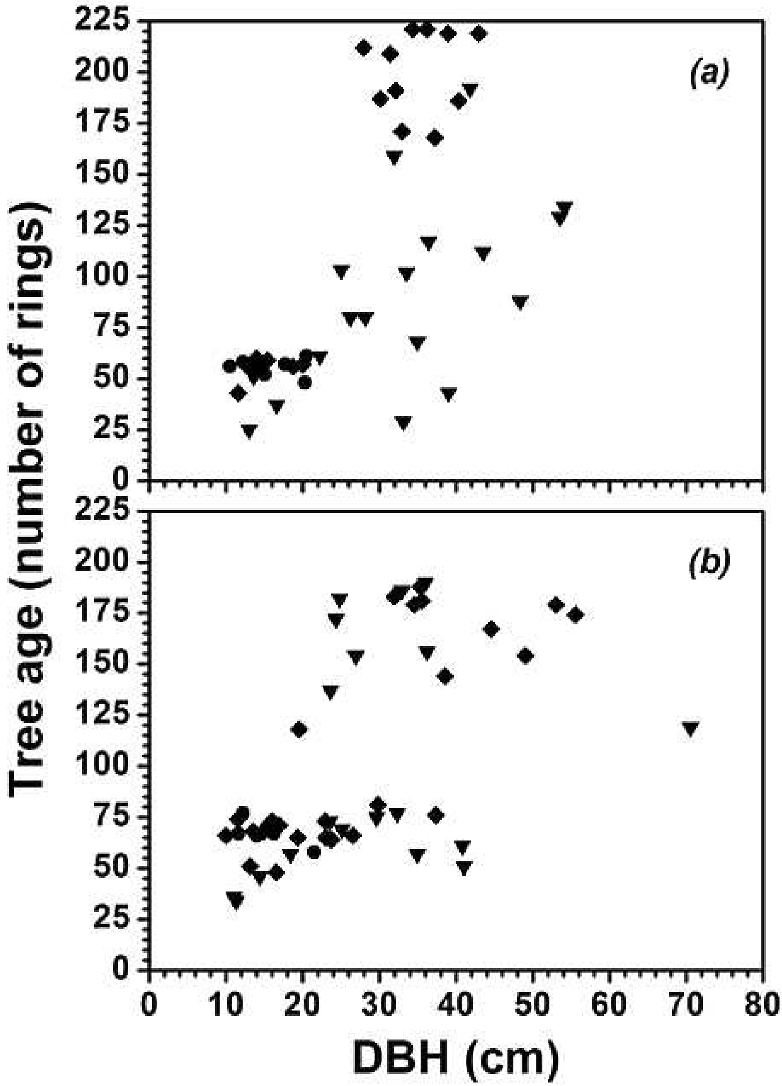

FIG. 3.—Age class distribution for the subsets of sample live post oaks for the Christmas Knob (a) and Big Creek Narrows (b) sites on the Fort Chaffee Maneuver Training Center. Symbols represent different levels of reliability of the age data: ● = actual cross-dated pith ages; ◆ = near-pith cross-dated ages; ▼ = poorest quality data, ages represent minimum values

notably lower than that taken at the base of the stem (Clark and Hallgren, 2004). Other post oaks on both sites had ring counts ≥190 but were too decayed or eccentric to get reliable samples close to or including the pith. There was little evidence of pronounced cohorts in the age data, with the possible exception of a period during the early 1940s at Big Creek

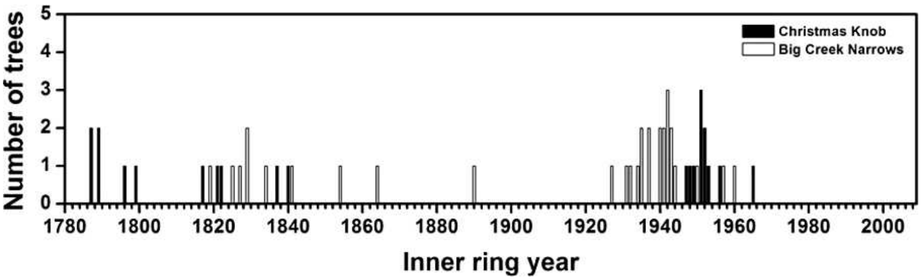

FIG. 4.—A combined likely year of origin histogram for the Christmas Knob and Big Creek Narrows stem map plots on the Fort Chaffee Maneuver Training Center. Only post oaks with high-quality age values were used

Narrows and late 1940s to early 1950s at Christmas Knob when a substantial number of post oaks were recruited.

VERTICAL STRUCTURE

An almost universal trait of Cross Timber stands is their low stature relative to the potential height of the species present (*e.g.,* Stahle and Hehr, 1984). For example, post oak can exceed 30 m in the more mesic portion of its range, although it is rarely taller than 15 to 20 m across most of the Cross Timbers ecoregion (Stransky, 1990). Blackjack oak tends to be even lower in stature. Nonlinear regression of the selected oaks from these Cross Timbers stands on Fort Chaffee MTC suggested a typical upper canopy height of 14 to 16 m, with occasional individuals approaching 20 m (Fig. 5). Though their morphology differs somewhat, both blackjack and post oak can be approximated using the same total tree height function:

$$HT = 1.37 + 14.5077\left(1 - e^{-0.071052\,DBH}\right)^{1.62852} \quad (1)$$

which explained most (coefficient of determination (R^2) = 0.8785, mean squared error = 2.13) of the variation in the combined data.

BASAL AREA AND BIOMASS DISTRIBUTIONS

Basal area on both sites was dominated by post oak, which constituted 73.5% of the 21.9 m^2/ha and 80.8% of the 17.7 m^2/ha of basal area on the Christmas Knob and Big Creek Narrow sites, respectively (Tables 1 and 2). Blackjack oak comprised 25.6% of the basal area at the Christmas Knob site, but only 6.8% at Big Creek Narrows. All other non-oak taxa individually contributed between 0.4 and 10.2% of the basal area found on these sites. Total live biomass (aboveground plus belowground, oven-dried) was higher at the Christmas Knob site than at the Big Creek Narrows site (Table 2).

SPATIAL PATTERN

Visual examination of the stem maps for both sites did not reveal prominent spatial patterns of the trees in these stands (Fig. 6). Statistical tests using spatial analysis with a NDF on the Christmas Knob site found a weak amount of over-dispersion at a scale of about 2 to 3 m (Fig. 7a). The Big Creek Narrows site showed some aggregation at the 1 m scale (Fig. 7b), corresponding to some apparent fine-scale clustering of trees (Fig. 6b). Given that post oak and blackjack oak can sprout prolifically from the stump and this is probably their primary mode of regeneration in the Cross Timbers (Clark and Hallgren, 2003), clumps of

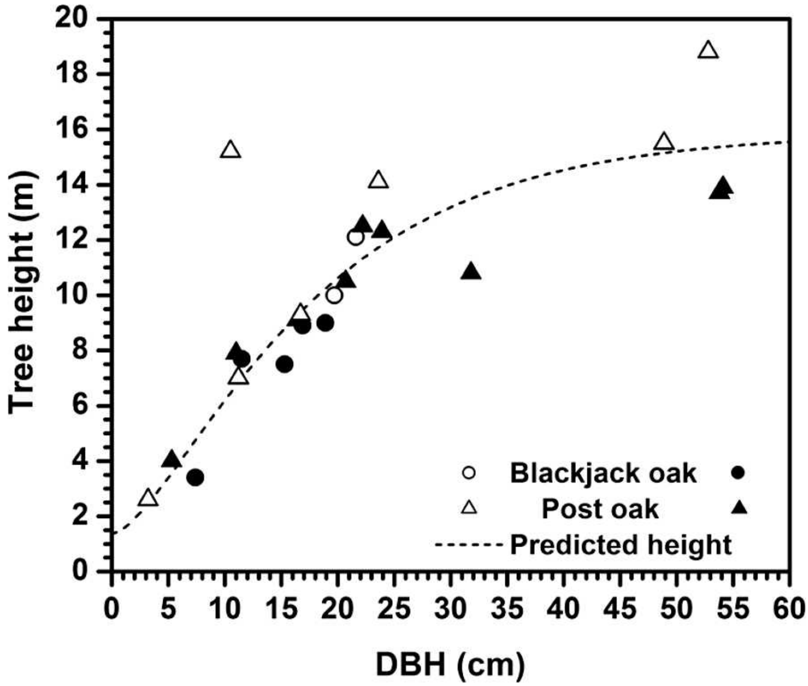

FIG. 5.—Unified height-DBH model for post and blackjack oaks from the Christmas Knob (filled symbols) and Big Creek Narrows (open symbols) sites on the Fort Chaffee Maneuver Training Center

overstory trees were expected. With these two limited exceptions, the plots of the NDF primarily fell within the 95% confidence intervals and thus we could not reject the null hypothesis, indicating that, for the scales we tested, tree stems were randomly located. An individualized examination of post oak and blackjack oak on the Christmas Knob site (data not shown) also indicated complete spatial randomness for both taxa.

DISCUSSION

OVERSTORY COMPOSITION

Overstory dominance by post oak and blackjack oak in the Cross Timbers, often exceeding 75% of all trees, has been repeatedly noted (*e.g.,* Rice and Penfound, 1959; Johnson and Risser, 1972, 1975; Peppers, 2004; Clark *et al.*, 2005; Burton *et al.*, 2010; Cerny, 2010) and our data were similar. Post oak and blackjack oak are not identical in their ecological preferences. For example, Johnson and Risser (1972) found indications that post oak had somewhat higher demands for moisture and nutrients than blackjack oak. Better site conditions certainly play a role in the representation of other species, as stand richness can increase dramatically if locations with noticeably increased levels of moisture (*e.g.,* seeps, stream channels, sheltered coves) are included. Disturbances also affect the relative abundance of different tree species in xeric, oak-dominated stands. Frequent surface fires and drought may increase the importance of the more fire-tolerant post and blackjack oaks at the expense of mesophytic species (Burton *et al.*, 2010; DeSantis *et al.*, 2010). Severe

TABLE 1.—Descriptive statistics for live trees ≥10 cm DBH on the Fort Chaffee Maneuver Training Center old-growth Cross Timbers plots

Location Species	Trees per ha	Basal area (m^2/ha)	Min. DBH (cm)	Max. DBH (cm)	Avg. DBH (cm)	Standard deviation (cm)
Christmas Knob						
Post oak (*Quercus stellata*)	304	16.1	10.0	54.1	23.5	11.11
Blackjack oak (*Q. marilandica*)	300	5.6	10.0	26.6	15.0	3.88
Eastern redcedar (*Juniperus virginiana*)	8	0.1	11.2	12.0	11.6	0.57
Mockernut hickory (*Carya tomentosa*)	4	0.1	13.4	13.4	13.4	0.00
Winged elm (*Ulmus alata*)	4	<0.1	11.0	11.0	11.0	0.00
Big Creek Narrows						
Post oak	212	14.3	10.0	70.5	26.2	13.28
Mockernut hickory	48	1.8	10.2	39.3	20.4	8.87
Blackjack oak	36	1.2	10.2	38.6	18.9	8.86
Black hickory (*C. texana*)	16	0.3	10.5	18.1	15.5	3.46
Winged elm	4	0.1	12.9	12.9	12.9	0.00

windstorms may also affect species composition in old Cross Timbers stands via differential mortality among species and size classes (Shirakura *et al.*, 2006).

The low proportion of eastern redcedar in the studied stands most likely was the result of our avoidance of areas with high density of this species, whose presence we assumed was an environmental proxy for disturbance(s). Once limited to microsites protected from fire, eastern redcedar has dramatically increased its abundance and extended its range in the Cross Timbers ecoregion (Schmidt and Leatherberry, 1995; Bidwell *et al.*, 1996; Shutler and Hoagland, 2004). Other studies of relatively undisturbed old-growth Cross Timber stands have also found a comparative absence of eastern redcedar beyond sheltered rock outcrops and cliffs (*e.g.*, Clark *et al.*, 2005; Cerny, 2010), suggesting that the Fort Chaffee MTC sites were similar. However, we observed high densities of eastern redcedar on the lower slopes and in the valley below Christmas Knob, especially on lands previously row-cropped. This

TABLE 2.—Stand-level statistics for live trees ≥10 cm DBH from the Fort Chaffee Maneuver Training Center old-growth Cross Timbers plots

	Christmas Knob			Big Creek Narrows		
Stand attribute	All species	Post oak only	Post oak %	All species	Post oak only	Post oak %
Stem abundance (trees/ha)	620	304	49.0	316	212	67.1
Basal area (m^2/ha)	21.9	16.1	73.5	17.7	14.3	80.8
Aboveground biomass (Mg/ha)[a]	156.9	123.7	78.8	137.4	117.9	85.8
Belowground biomass (Mg/ha)[b]	35.8	28.0	78.2	31.0	26.5	85.5
Total tree biomass (Mg/ha)	192.7	151.7	78.7	168.4	144.4	85.7

[a] Aboveground oven-dry biomass equations and coefficients from Jenkins *et al.* (2003)
[b] Belowground oven-dry biomass calculated from equation in Enquist and Niklas (2002)

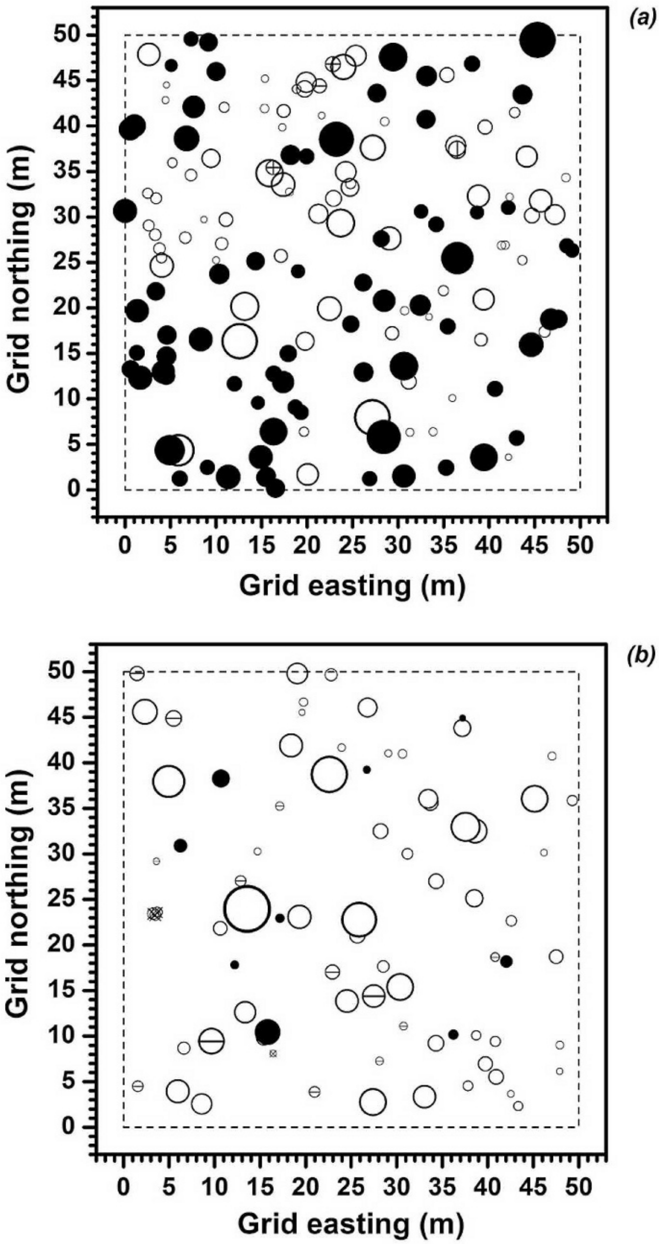

FIG. 6.—Stem maps of the (a) Christmas Knob and (b) Big Creek Narrows sites on the Fort Chaffee Maneuver Training Center. To improve their visibility, the tree markers have been scaled up and are proportional to stem DBH. Species are represented by the following markers: ○ = post oak; ● = blackjack oak; ⦶ = mockernut hickory; ⊗ = black hickory; ⊖ = winged elm; and ⊕ = eastern redcedar

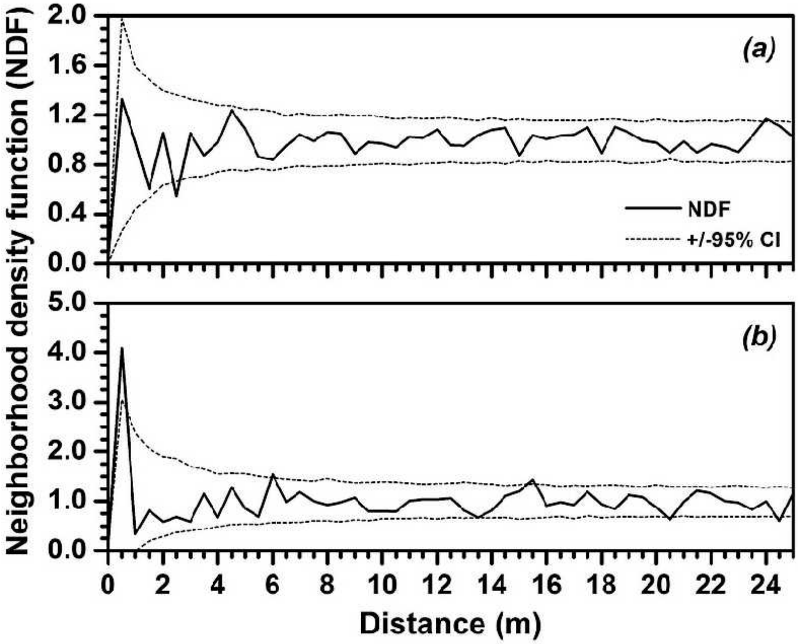

FIG. 7.—Spatial patterning of the overstory trees at (a) Christmas Knob and (b) Big Creek Narrows on the Fort Chaffee Maneuver Training Center. Solid line is the neighborhood distribution function (NDF), while the two dashed lines represent 95% confidence intervals estimated via Monte Carlo simulation (1000 replicates with a 25 m maximum step length, Perry *et al.*, 2006)

local abundance may signal a future invasion of eastern redcedar into this site, if not limited by disturbances or otherwise controlled.

DIAMETER AND AGE STRUCTURE

Many different factors have helped to structure the size and age classes of trees on our two studies sites over time. Some of this structuring may arise from differences in site productivity. On average, the post oaks at the Big Creek Narrows site were larger in girth and taller but younger than those on the Christmas Knob site, indicating better site quality at Big Creek (this may also be suggested by the higher abundance of blackjack oak at Christmas Knob, sensu Johnson and Risser (1972)). Disturbances have also likely played a role. DeSantis *et al.* (2010) recently reexamined a series of plots originally established by Rice and Penfound (1959) across the Oklahoma Cross Timbers and noted large increases in saplings and overstory specimens of several mesic tree species, which they attributed to an overall decline in fire frequency and a reduced number of severe droughts during the past 50 y. In the Okmulgee Wildlife Management Area in Oklahoma, Burton *et al.* (2010) reported that increased fire frequency resulted in a decrease in the number of saplings of all species in these stands. Both Fort Chaffee MTC sites had few stems <10 cm DBH, yet were well stocked in most other small tree size classes (10–25 cm DBH, Fig. 2). Coupled with age data collected for this study (Fig. 3), this structural pattern may have arisen from a period of oak recruitment following a reduction of fire and/or livestock grazing after the establishment of the military base, coupled with more frequent burning in recent years.

BIOMASS DISTRIBUTION

Because of their complex tree architectures, old-growth Cross Timbers stands provide a unique challenge for estimating biomass quantities. Although some post oak biomass models have been developed, they were either specifically designed for young, sound trees (*e.g.,* Oswald *et al.*, 2010) or are unclear about bole conditions and other specifics of their derivation (*e.g.,* Johnson and Risser, 1974). We know of no models that account for the proportion of woody biomass absent due to decay (hollow stems), severely broken tops, or irregular stem form in these old-growth post oak stands, all of which are known to significantly affect biomass estimates for other forest ecosystems (*e.g.,* Nogueira *et al.*, 2006). We collected no data on the number of hollow stems or malformed trees on our study sites, but they were present and thus make it likely that our biomass values (Table 2) are overestimated, since the Jenkins *et al.* (2003) biomass model assumes a solid tree with an even, consistently tapered bole and a relatively intact crown.

However, the biomass found at these sites is comparable to that noted by other researchers in similar closed-canopy xeric oak stands from this ecoregion (*e.g.,* Johnson and Bell, 1976; Brown *et al.*, 1999). For example, Johnson and Risser (1974) reported 218.2 Mg/ha of live tree biomass in stems ≥2.5 cm DBH in a mixed-age Cross Timbers stand in central Oklahoma. The biomass on our study sites is predominantly in post oak (Table 2), resulting from a combination of its abundance and dominance in the largest size classes, a common occurrence in the Cross Timbers ecoregion (Hoagland *et al.*, 1999).

SPATIAL PATTERNS

Spatial patterns in the Cross Timbers have been qualitatively described for landscapes, with numerous references to the juxtaposition of forest, woodland, savanna, and prairie in this ecoregion associated with differences in soils, depth to bedrock, slope and aspect, and disturbance regimes (*e.g.,* Hill, 1887; Luckhardt and Barclay, 1938; Dyksterhuis, 1948; Buck, 1964; Bell and Hulbert, 1974; Hoagland *et al.*, 1999). Fine-scale tree spatial patterns in these xeric, oak-dominated stands also likely result from microsite differences in moisture and nutrient availability, presence of root obstructions (*e.g.,* surface bedrock or boulders), propagule dispersal, plant interactions, disturbance events, and the tendency of many hardwoods to sprout. Parent materials, for instance, have a strong influence on a number of soil properties in the Cross Timbers that can affect spatial pattern in these stands (Bell and Hulbert, 1974).

Other analyses of tree stem locations have found a range of possible spatial distributions in hardwood-dominated old-growth stands (*e.g.,* Chokkalingam and White, 2001; Hao *et al.*, 2007; Lin and Augspurger, 2008), and we suspect that Cross Timbers stands could also exhibit a similar range of distributions. There were small areas lacking overstory trees on both sites, especially at the base of the talus slope at Big Creek Narrows, but small (0.25 ha) stem maps from a limited sample of old-growth Cross Timber remnants are not likely to reflect intermediate-scale patterns in site moisture, nutrients, soil depth, aspect, elevation, or disturbance history. Under some circumstances, there may also be some interspecific association of understory trees with overstory oaks in the Cross Timbers. Edmondson (2006) noted the clustering of eastern redcedar saplings under larger oaks. This pattern may have arisen from a sheltering effect of the overstory (*e.g.,* protecting seedlings from excessive insolation or perhaps ice accumulation) or possibly is related to seed dispersal (*e.g.,* perching birds disseminating viable redcedar seeds via their droppings) or even perhaps a limited number of favorable seedbed locations.

ECOREGIONAL CONTEXT

This study described the age, size, and fine-scale spatial structure of old-growth xeric oak remnants on the Fort Chaffee MTC. Though somewhat more productive than more westerly locations, the dominance of stunted post and blackjack oaks on our study area coupled with their accompanying suites of grass- and shrub-dominated understories, suggested that the Arkansas examples of xeric Cross Timbers stands are comparable to those in Oklahoma and Texas. Further, this study confirms the map of Kuchler (1964) that extended the Cross Timbers ecoregion into western Arkansas, expanding the range of environmental conditions of sites eligible for further research and/or protection. We have yet to fully describe this extension, however.

The large-scale distribution of old-growth post oak-dominated forest remnants, due to their predictable affinity for certain combinations of environmental factors, have been readily modeled across much of the Cross Timbers (*e.g.,* Stahle and Chaney, 1994; Therrell and Stahle, 1998; Peppers, 2004). To date, our efforts to develop a comparable predictive system, or habitat suitability model, for western Arkansas have not been as successful, probably due to a more extensive history of recent human disturbance. Because of the abundance of steep, rocky, south- to southwest-facing terrain, we believe that a considerable quantity of reasonably intact, old-growth xeric oak forests occur in the Fort Chaffee MTC, and probably elsewhere in western Arkansas. These stands represent a unique opportunity to study ecological dynamics.

Acknowledgments.—We would like to thank the following people and organizations for their contributions to this effort: the Fort Chaffee Maneuver Training Center; Carl Carlson (Fort Chaffee MTC); Kirby Sneed and Saul Serna (US Forest Service); Jesse Edmondson, Allan Edmondson, Mark Spond, Grant West, and Dr. Jason Tullis (University of Arkansas). Dr. George Perry of the University of Aukland (New Zealand) kindly shared his SpPack add-in with us, for which we are very grateful.

LITERATURE CITED

BELL, E. L. AND L. C. HULBERT. 1974. Effect of soil on occurrence of Cross Timbers and prairie in southern Kansas. *Trans. Kansas Acad. Sci.*, **77**(4):203–209.

BIDWELL, T. G., D. M. ENGLE, M. E. MOSELEY AND R. E. MASTERS. 1996. Invasion of Oklahoma rangelands and forests by eastern redcedar and Ashe juniper. Oklahoma Coop. Extension Service Circular E-947.

BLOZAN, W. 2006. Tree measuring guidelines of the Eastern Native Tree Society. *Bull. East. Native Tree Soc.*, **1**(1):3–10.

BRAGG, D. C. 2008. An improved tree height measurement technique tested on mature southern pines. *South. J. Appl. For.*, **32**:38–43.

BROWN, S. L., P. SCHROEDER AND J. S. KERN. 1999. Spatial distribution of biomass in forests of the eastern USA. *For. Ecol. Manage.*, **123**:81–90.

BRUNER, W. E. 1931. The vegetation of Oklahoma. *Ecol. Mono.*, **1**(2):99–188.

BUCK, P. 1964. Relationships of the woody vegetation of the Wichita Mountains Wildlife Refuge to geological formations and soil types. *Ecology*, **45**(2):336–344.

BURTON, J. A., S. W. HALLGREN AND M. W. PALMER. 2010. Fire frequency affects structure and composition of xeric forests of eastern Oklahoma. *Nat. Areas J.*, **30**(4):370–379.

CERNY, K. C. 2010. A frontier shortleaf pine stand in the old-growth Cross Timbers of Oklahoma. M.S. thesis, Dept. Geosciences, Univ. Arkansas, Fayetteville, Arkansas.

CHOKKALINGAM, U. AND A. WHITE. 2001. Structure and spatial pattern of trees in old-growth northern hardwood and mixed forests of northern Maine. *Plant Ecol.*, **156**(2):136–160.

CLARK, S. L. AND S. W. HALLGREN. 2003. Dynamics of oak (*Quercus marilandica* and *Q. stellata*) reproduction in an old-growth cross timbers forest. *Southeast. Nat.*, **2**(4):559–574.

——— AND ———. 2004. Age estimation of *Quercus marilandica* and *Quercus stellata*: applications for interpreting stand dynamics. *Can. J. For. Res.*, **34**:1353–1358.

———, ———, D. W. STAHLE AND T. B. LYNCH. 2005. Characteristics of the Keystone Ancient Forest Preserve, and old-growth forest in the Cross Timbers of Oklahoma, USA. *Nat. Areas J.*, **25**(2):165–175.

COX, J. B., B. A. GARNER AND F. M. VODRAZKA. 1975. Soil survey of Sebastian County, Arkansas. U.S.D.A. Soil Cons. Serv., U.S.D.A. For. Serv., and Ark. Agric. Exp. Sta., Fayetteville, Arkansas.

DESANTIS, R. D., S. W. HALLGREN, T. B. LYNCH, J. A. BURTON AND M. W. PALMER. 2010. Long-term directional changes in upland *Quercus* forests throughout Oklahoma, USA. *J. Veg. Sci.*, **21**(3):606–615.

DYKSTERHUIS, E. J. 1948. The vegetation of the Western Cross Timbers. *Ecol. Mono.*, **18**(3):325–376.

EDMUNDSON, J. R. 2006. An ancient red cedar woodland in the Oklahoma Cross Timbers. Unpubl. honors thesis, Geology Dept., Univ. Ark.-Fayetteville, available online at: http://www.uark.edu/misc/xtimber/rna/Edmondson%202006.pdf; last accessed 11 Jan. 2011.

ENQUIST, B. J. AND K. J. NIKLAS. 2002. Global allocation rules for patterns of biomass partitioning in seed plants. *Science*, **295**:1517–1520.

HAO, Z., J. ZHANG, B. SONG, J. YE AND B. LI. 2007. Vertical structure and spatial associations of dominant tree species in an old-growth temperate forest. *For. Ecol. Manage.*, **252**:1–11.

HILL, R. T. 1887. The topography and geology of the Cross Timbers and surrounding regions in northern Texas. *Am. J. Sci.*, **33**:291–303.

HOAGLAND, B. W., I. H. BUTLER, F. L. JOHNSON AND S. GLENN. 1999. The Cross Timbers, p. 231–245. *In:* R. C. Anderson, J. S. Fralish and J. M. Baskin (eds.). Savannas, barrens, and rock outcrop plant communities of North America. Cambridge Univ. Press, Cambridge, UK.

JENKINS, J. C., D. C. CHOJNACKY, L. S. HEATH AND R. A. BIRDSEY. 2003. National-scale biomass estimators for United States tree species. *For. Sci.*, **49**(1):12–35.

JOHNSON, F. L. AND D. T. BELL. 1976. Plant biomass and net primary production along a flood-frequency gradient in the streamside forest. *Castanea*, **41**(2):156–165.

——— AND P. G. RISSER. 1972. Some vegetation-environment relationships in the upland forests of Oklahoma. *J. Ecol.*, **60**(3):655–663.

——— AND ———. 1974. Biomass, annual net primary production, and dynamics of six mineral elements in a post oak-blackjack oak forest. *Ecology*, **55**:1246–1258.

——— AND ———. 1975. A quantitative comparison between an oak forest and an oak savannah in central Oklahoma. *Southwest. Nat.*, **20**(1):75–84.

KUCHLER, A. W. 1964. Potential natural vegetation of the conterminous United States. Special Publ. 36, American Geographical Soc, Washington, DC. 116 p.

LASER TECHNOLOGY, INC. 2009. Professional measuring products. Available online at: http://www.lasertech.com/Professional-Measurement-Products.aspx; last accessed 27 Mar. 2009.

LIN, Y. AND C. K. AUGSPURGER. 2008. Long-term spatial dynamics of *Acer saccharum* during a population explosion in an old-growth remnant forest in Illinois. *For. Ecol. Manage.*, **256**:922–928.

LUCKHARDT, R. L. AND H. G. BARCLAY. 1938. A study of the environment and floristic composition of an oak-hickory woodland in northeastern Oklahoma. *Proc. Okla. Acad. Sci.*, **18**:25–32.

NOGUEIRA, E. M., B. W. NELSON AND P. M. FEARNSIDE. 2006. Volume and biomass of trees in central Amazonia: influence of irregularly shaped and hollow trunks. *For. Ecol. Manage.*, **227**:14–21.

OSWALD, B. P., R. R. BOTTING, D. W. COBLE AND K. W. FARRISH. 2010. Aboveground biomass estimation for three common woody species in the post oak savannah of Texas. *South. J. Appl. For.*, **34**(2):91–94.

PEET, F. G., D. J. MORRISON AND K. W. PELLOW. 1997. Using a hand-held electronic laser-based survey instrument for stem mapping. *Can. J. For. Res.*, **27**:2104–2108.

PEPPERS, K. 2004. Old-growth forests in the western Cross Timbers of Texas. Ph.D. dissertation, Dept. Biol. Sci., Univ. Ark., Fayetteville, Arkansas.

PERRY, G. L. W. 2004. SpPack: spatial point pattern analysis in Excel using Visual Basic for Applications (VBA). *Environ. Mod. Software*, **19**:559–569.

———, 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.

RADCLIFF, M. 2008. Fort Chaffee. Encyclopedia of Arkansas History & Culture. Available online at: http://www.encyclopediaofarkansas.net/encyclopedia/entrydetail.aspx?entryID=2263, last accessed 27 Mar. 2009.

RICE, E. L. AND W. T. PENFOUND. 1959. The upland forests of Oklahoma. *Ecology*, **50**(4):593–608.

SCHMIDT, T. L. AND E. C. LEATHERBERRY. 1995. Expansion of eastern redcedar in the Lower Midwest. *North. J. Appl. For.*, **12**(4):180–183.

SHIRAKURA, F., K. SASAKI, J. R. ARÉVALO AND M. W. PALMER. 2006. Tornado damage of *Quercus stellata* and *Quercus marilandica* in the Cross Timbers, Oklahoma, USA. *J. Veg. Sci.*, **17**(3):347–352.

SHUTLER, A. AND B. W. HOAGLAND. 2004. Vegetation patterns in Carter County, Oklahoma, 1871. *Proc. Okla. Acad. Sci.*, **84**:19–26.

SMITH, D. M., B. C. LARSON, M. J. KELTY AND P. M. S. ASHTON. 1997. The practice of silviculture. 9th ed. John Wiley & Sons, Inc., New York.

SOUTHERN REGION CLIMATE CENTER. 2010. Fort Smith, Arkansas Regional Airport climate data. Available online at: http://www.srcc.lsu.edu/stations/index.php?action=metadata&network_station_id=032574, last accessed 2 Nov. 2010.

STAHLE, D. W. 1990. The tree-ring record of false spring in the southcentral USA. Ph.D. dissertation, Arizona State Univ., Tempe, Arizona.

——— AND P. L. CHANEY. 1994. A predictive model for the location of ancient forests. *Nat. Areas J.*, **14**(3):151–158.

——— AND J. G. HEHR. 1984. Dendroclimatic relationships of post oak across a precipitation gradient in the southcentral United States. *Ann. Assoc. Am. Geogr.*, **74**(4):561–573.

STOKES, M. A. AND T. L. SMILEY. 1996. An introduction to tree ring dating. Univ. Arizona Press, Tucson, Arizona.

STRANSKY, J. J. 1990. Post oak (*Quercus stellata* Wangenh.), p. 738–743. *In:* R. M. Burns and B. H. Honkala (tech. coords.). Silvics of North America: Vol. 2, Hardwoods. USDA For. Serv. Agric. Handb. 654.

THERRELL, M. D. AND D. W. STAHLE. 1998. A predictive model to locate ancient forests in the Cross Timbers of Osage County, Oklahoma. *J. Biogeogr.*, **25**(5):847–854.

US ENVIRONMENTAL PROTECTION AGENCY (US EPA). 2011. Level III ecoregions of the continental United States. Available online at: http://www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm, last accessed 12 August 2011.

SUBMITTED 21 JUNE 2011 ACCEPTED 8 SEPTEMBER 2011