Dynamics of an Old-growth Hardwood-Pinus Forest Over 98 Years

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We characterized forest change on the state-owned McCurtain County Wilderness Area (MCWA) in the Ouachita Mountain region of Oklahoma from 1896 to 1994 using historical (1896) General Land Office (GLO) survey data and 1955 and 1990 aerial photography. Surveyor notes indicated the forest was pine (*Pinus echinata*) dominated in 1896 but only 6.4% of the actual witness trees were pine. However the slope position and aspect of survey points suggest that at least 62.9% were on hardwood sites. GLO survey points were resampled in 1994 and of the 96 points revisited, 47 of the original corner stones were located in place with legible etchings. Only 6 of these possible 124 witness trees were found still standing in 1994, suggesting rapid turnover of the dominant trees in this virgin (uncut) forest. Turnover rates were likely influenced by frequent fire until the mid-1950's. Based on GLO data, stand density of trees > 11.4 cm diameter at 1.4 m height increased (*P* = 0.0001) from 71 trees/ha in 1896 to 615 trees/ha in 1994 and mean diameter at breast height decreased from 29 cm in 1896 to 22 cm in 1994, but likely density estimates from 1896 are underestimated. Dominant and codominant *P. echinata* increased (*P* = 0.0001) from 73 stems/ha to 93 stems/ha for 1955 and 1990, respectively based on aerial photo sampling. We suggest that densification was a result of near complete fire elimination after the mid-1950's. Diameter distributions from 1896 suggest that the forest was in transition from an earlier frequent fire regime following a period of less frequent fire that coincided with changes in Native American demographics. Evidence of historic high intensity fire was observed in the form of fire scars and cat faces on living trees and charred pine knots on the ground at 95 of the 96 sample points, most of which had not burned in the last 40 years.

A comparison of 1955 and 1990 vegetation cover types indicates that MCWA is becoming a more dense and homogeneous landscape. Open hardwood woodlands observed on 1955 photography had completely disappeared by 1990. Species composition of stands has largely shifted to a *P. echinata* and hardwood mixture, whereas stands of pure *P. echinata* and pure hardwood have decreased. Increase in midstory and overstory hardwood stem density of suitable open, *Pinus*-dominated habitat as a result of fire suppression is a probable cause for decline of the endangered *Picoides borealis* (red-cockaded woodpecker). Management to retain the woodpecker should emphasize a successional trajectory that moves the forest to open conditions similar to that found prior to settlement through restructuring of stands with *Picoides borealis* clusters by thinning followed by reintroduction of a frequent (<4-year interval) fire regime.

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INTRODUCTION

Protected areas such as wilderness, state parks, and national forests have been altered by active suppression of natural disturbance regimes such as fire (Christensen 1978, Buckner 1989, Masters et al 1995). Altered disturbance regimes over the last century have in some cases resulted in decreased resistance to catastrophic disturbance events and loss of suitable habitat for sensitive plant and animal species. In order to facilitate the understanding of both long-term and short-term land use patterns and temporal landscape development, efforts have been made to model general characteristics of the landscape mosaic found by early explorers and settlers, as well as for intermediate time periods (e.g. White and Mladenoff 1994, Bollinger et al 2004). Reconstructed landscapes give indication of presettlement conditions and can be used as guidance for ecosystem restoration (Wilson et al 1995, Sparks et al 1999, Whitney and DeCant 2001). As well, period photographs and time-sequence photographs bracketing a half-century or more serve as reference points of historic conditions (e.g. McGinnes et al 1991, Masters et al 1995). Both lines of evidence provide insight in understanding landscape and stand level changes and rates of change. However, quantitative evidence from forest regions without the influence of timber harvest illustrating the degree and direction of temporal landscape change from settlement to recent times is limited.

The endangered *Picoides borealis* (red-cockaded woodpecker), an endemic of the southeastern United States, is a species associated with *Pinus* spp.-grassland communities (Ligon et al 1986, Brennan et al 1995). Historic evidence indicates that the Ouachita Mountains of Arkansas and Oklahoma and other areas of southeastern USA were once comprised of a *Pinus echinata*-grassland ecosystem on many sites with varying hardwood elements, characterized by widely spaced trees, sparse midstories and ground cover that varied from grassy to shrub dominated conditions maintained primarily by frequent fire (James 1823, Lewis 1924, Nuttall 1980, Foti and Glenn 1991, Waldrop et al 1992, Masters et al 1995). Woodpecker habitat requirements include low basal area *Pinus* stands (9-18 m2/ha) with few intermediate or small sized *Pinus* and midstory hardwoods (U.S. Fish and Wildlife Service 2003). From 1974 to 1994, *Picoides borealis* declined on McCurtain County Wilderness Area (MCWA) from 29 groups composed of 86-92 individuals to 9 groups with 22 individuals (Masters et al 1995). Forest structural change through increased density and intrusion of hardwoods into the midstory and lower canopy layers have been implicated in this decline (Masters et al 1989). This purported change was hypothesized to be associated with a dramatic change in fire regime (Masters et al 1995). However, no studies have examined changes in stand density or how patch and landscape level change commensurate with fire regime change in the Ouachita Mountain ecosystem may relate to *Picoides borealis* decline. Further, current management efforts have not been examined to determine if they contribute to a closer representation of presettlement conditions.

Our purpose was to evaluate the degree and direction of forest change on the MCWA over the last century. Our primary objective was to assess magnitude of change on the MCWA by quantifying change in stand density, species dominance, and species distribution. Our second objective was to quantify patch level change such as patch size and extent, patch density and connectivity, and landscape level change such as overall patch size, contagion, interspersion and juxtaposition, diversity, and evenness. We compared historical (1896) General Land Office (GLO) surveys with current (1994) survey data collected at the same points in order to complete the first objective. To meet the second objective, we mapped and analyzed vegetation change over a 45-year period in a GIS using aerial photography from 1955 and 1990. We hypothesized that forests on the MCWA had increased in density across canopy strata during the intervening time period and this structural change and landscape level change was associated with changing fire regime and precipitated declines of *Picoides borealis.*

STUDY AREA

Our study was conducted in the Ouachita Mountains on the McCurtain County Wilderness Area (MCWA) (approximately 34.29ºN, 94.68ºW) of southeastern Oklahoma, USA. The Ouachita Mountains cover an area approximately 380 km east to west by 100 km north to south from central Arkansas into southeast Oklahoma (Croneis 1930). Ridges typically trend east-west, having long north-facing and south-facing slopes. Elevations range from 100 m to 900 m. Complex folding and faulting have resulted in thin, rocky soils composed of shale, slate, sandstone, novaculite, limestone, and quartzite (Croneis 1930). South-facing slopes are much drier and are more sparsely vegetated than north-facing slopes because of higher insolation. Ridge tops are exposed to high winds and colder winter temperatures, and valleys are subjected to cold air drainage (Palmer 1924). Because of extreme variation in topography, species composition tends to change with site conditions (Johnson 1986). The Ouachita Mountains support mixed stands of *P. echinata*, *Quercus* spp. and *Carya* spp. with a higher frequency of *P. echinata* on south-facing slopes and a higher frequency of hardwoods on the north slopes (Johnson 1986).

The 5,701 ha McCurtain County Wilderness Area is divided by Broken Bow Reservoir (Mountain Fork River) (Figure 1). It is the largest representative tract of virgin old-growth *P. echinata*-hardwood forest in the US (Stahle et al 1985). The area is characterized by steep and narrow ridges bearing east-west, with occasional rock outcrops. Elevation varies from 183 m to 415 m. North and South Linson Creeks are the largest of 5 perennial streams that dissect the area. Annual rainfall averages 121 cm and the mean daily temperatures range from 34°C in July to -2°C in January (Masters et al 1989). Limited evidence of several decades old timber theft is apparent near southwestern boundaries. Otherwise, this area has not been subjected to timber harvest or thinning prior to 1991.

The area has been owned by the Oklahoma Department of Wildlife Conservation (ODWC) since 1918 and has been designated as a state wilderness area since 1951 (Masters et al 1995). Prior to acquisition by the state, this area was allotted to the Choctaw Nation in 1820 (Masters et al 1989). With the development of Broken Bow Reservoir in mid-1960's, the U.S. Corps of Engineers acquired ownership of adjacent shoreline within MCWA. The entire study area encompasses approximately 6,000 ha. The MCWA contains the last known red-cockaded woodpecker population in Oklahoma. Red-cockaded woodpecker populations on MCWA have declined precipitously since mid-1970 (Wood 1975, Kelly et al 1993, Masters et al 1989, 1995). Because hardwood encroachment into the midstory and overstory due to fire suppression had been implicated in the decline (Masters et al 1989), limited midstory removal surrounding red-cockaded woodpecker clusters occurred on the area in 1991. Except for the reintroduction of fire in two areas, in 1992 and following years, all fires have been suppressed since the mid-1920's and were effectively eliminated in the mid-1950's (Masters et al 1995). Vegetation on the area has been described by Smith et al (1997) and Smith (1997).

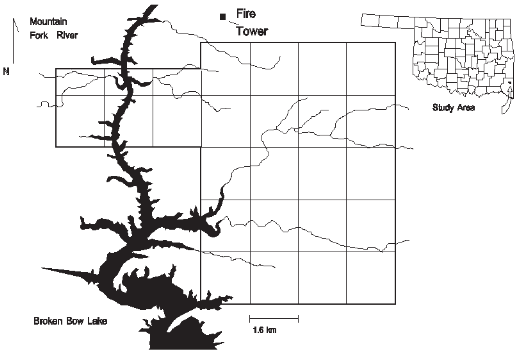

Figure 1. McCuratin County Wilderness Area, Oklahoma, USA study area and 1896 General Land Office public land survey grid.

METHODS

GLO Surveys

General Land Office (GLO) notes from the original land survey of MCWA in 1896 were obtained from the Oklahoma Department of Libraries. GLO surveyors recorded the species, diameter, distance, and azimuth for two trees at each quarter-section corner, and for four trees at section corners. In addition, timber types were described in the order of predominance, including some description of understory species. General descriptions of topology, minerals, soils, and economic values were also given.

Bearing tree data were extracted from the GLO notes for all 97 quarter-section (a section = 1.6 km2) corners on and within the boundaries of MCWA and treated as point-center quarter data (after Foti and Glenn 1991). Ninety-six of the 97 points were relocated in the summer of 1993 and 1994 by use of a compass and hip chain. One point was covered by water from Broken Bow Lake in 1994 and was not relocated. Attempts to use a global positioning system (GPS) for point relocation were unsuccessful because of poor reception caused by dense forest cover, mountainous terrain, and at the time an incomplete array of satellites. Nevertheless, the use of compass and hip chain proved to be effective in relocating original survey points.

Tree density was estimated at GLO points during the summers of 1993 and 1994 using the point-centered quarter sampling method (Cottam and Curtis 1956). At each point the distance to the nearest tree >11.4 cm diameter at breast height (DBH), azimuth, and species was measured in each of four quadrants. Slope position and aspect were also recorded. For comparative purposes, average stem density was also estimated using the variable-radius plot method (Grosenbaugh 1952, Sparks et al 2002).

In 1994, four trees were recorded at each sample point, although surveyors recorded only two at quarter-section corners. Thus, the number of trees sampled was 266 in 1896 and 384 in 1994. Data from 1896 and 1994 were treated as point-centered quarter samples to calculate the average distance to nearest tree, stem density, frequency, absolute frequency, dominance ranking, diameter distribution, and basal area for all trees as well as for individual species (after Mueller-Dombois and Ellenberg 1974). Student's t (Steel and Torrie 1980) was used to assess differences between surveys in average distance to nearest tree, tree diameters, and basal area. To examine diameter distributions, we grouped species for both years into four categories by 5 cm diameter classes for: P. echinata, Quercus spp., Carya spp., and other hardwoods. Because of disturbance from differing adjacent land use, and timber theft near some boundaries of MCWA, analyses were also performed for interior (non-edge) and undisturbed points in 1994.

Aerial Photography

Black and white aerial photographs were obtained from the United States Department of Agriculture Aerial Photography Field Office, Salt Lake City, Utah. Photographs were acquired for April, 1955 at a scale of 1:7,920, and for December, 1990 at a scale of 1:3,960. Aerial photographs for both years included all portions of MCWA. The western portion of the 1955 photo set was from the month of May, making stand delineations difficult because of spring foliage. Thus, only the eastern 5,515 ha of MCWA were included for this analysis (Figure 1).

Vegetation was mapped for both years by placing clear acetate on each photograph and marking boundaries around each cover type. Cover types included the following categories: *Pinus* (80 - 100 % *Pinus* dominated); hardwood (80 - 100% hardwood dominated); *Pinus* - hardwood (60 - 80% *Pinus* dominated); hardwood - *Pinus* (60 - 80% hardwood dominated); *Pinus* - hardwood, low to medium density (60 - 80% *Pinus* dominated, grassy ground cover); hardwood woodlands (80 - 100% hardwood, low density, grassy ground cover); glade (80 - 100% grassland); water; and developed/disturbed.

Completed maps were digitized using a digital scanner. Scanned images were edited, rectified, and imported into ARC/INFO (Environmental Systems Research Institute, Redlands, CA, USA) GIS. Limited ground truthing was performed for the 1990 layer using permanent plot data (Masters, unpublished data) at 77 points. Spatial pattern analysis was performed using ARC/INFO and FRAGSTATS (McGarigal and Marks 1995). FRAGSTATS was used to generate patch and landscape level metrics for all cover types identified on the MCWA. Transition analyses were performed with a simple COMBINE operation in the GIS in order to identify specifically where gains and losses of each type occurred. Change was analyzed and described in a class-by-class basis in terms of increase or decrease in total area, patch density, patch size and connectivity (after Hessburg et al 1999). The landscape level metrics; Shannon's diversity index, Modified Simpson's evenness index, interspersion and juxtaposition, interspersion, and mean patch size were compared in the same manner as class level metrics.

Aerial photography for both years was also sampled using 0.18 ha circular plots scaled to each set of photographs to estimate stem density for codominant and dominant *P. echinata*. Three north-south transects were placed in each 1.6 km^2 (section) of the area at a random distance from the east section line. Thirty samples per 1.6 km^2 (600 samples for the entire study area) were taken by four different observers and averaged for each sample. Dominant and codominant *P. echinata* stem density from variable radius plots collected in 1994 were also calculated for comparison with stem density estimated from aerial photos. Sample means for stem density of *P. echinata* were compared using Student's *t*-test at the 0.05 confidence level to determine if there were differences in dominant and codominant *P. echinata* density between 1955 and 1990. Data were compared to stem density values derived from variable radius plots sampled in 1994 to determine reliability of estimates (after Sparks et al 2002).

RESULTS

Land Survey Descriptions: 1896 – 1994

General Land Office survey notes provided both qualitative and quantitative descriptions of the presettlement landscape. General descriptions given for each township made numerous references to the landscape:

> "The surface of this township is mountainous, the mountains and hills ranging from 50 to 600 feet high and are covered with broken stone. The soil of same being classed as 4th rate. Mountain Fork River runs through the central portion of the township. It is a very rapid stream and contains a number of large boulders. In some places there are narrow bottoms, but in the majority of instances the bluffs extend down to the water's edge. The timber that predominates is pine, oak, elm, ash, hickory, and gum. Sandstone, quartz, and limestone are found on ridges. There are no towns or villages and no farms were noted. December 10th, 1896. J. E. Joy and J. Scott Harrison - U.S. Surveyors."

Additional references were given at each quarter-section corner:

> "Set a sandstone 18 x 6 x 6 inches in the ground for corner of sections 5, 6, 7, and 8. Marked with 5 notches on the south and east edges. From which: A white oak 6 inches diameter bears N 35 E, 65 links distance marked T3S R25E S5 B.T. A post oak 6 inches diameter bears S34 E, 65 links distance marked T3S R25E S8 B.T. A post oak 6 inches diameter bears S49 W, 66 links distance marked T3S R25E S7 B.T. A white oak 6 inches diameter bears N42 W, 18 links distance marked T3S R25E S6 B.T. Land broken and mountainous, soil 4th rate. Timber pine, oak, and undergrowth."

Three surveyors were responsible for the original survey of MCWA. Two of the surveyors invariably noted predominant forest as "pine, oak, and hickory" or "pine and oak". The third surveyor consistently noted predominant species as "oak, pine, and hickory", or "oak and pine". Approximately one-third of the mile summaries catalog *Quercus* spp. oak as the dominant species, whereas two-thirds of the summaries catalog *Pinus* as dominant. Several areas were described as "pine and undergrowth" and one area was described as "pine, oak, and cedar". *Pinus* was listed first for over 90 percent of the mile summaries given by two of the three surveyors, indicating *Pinus* as the dominant species because the species were listed in order of prevalence.

Witness tree data from 1896 showed that only 17 of the 266 trees recorded or 6.4%

were *Pinus* (Table 1). Oaks composed 234 trees or 88.0% of the total trees recorded. The remaining 15 trees were other hardwood species (Table 1). GLO points that were south, southwest, and west facing slopes (sites with highest probability of pine occurrence) composed 37.1% of the points. Because of slope position, 5.2% of these might be considered hardwood sites. At least 62.7% of the GLO points would ordinarily be considered hardwood sites and possibly as many as 67.9% of the GLO points could be considered hardwood sites based on topographic position (after Johnson 1986).

Of the 96 points revisited, 47 had original corner stones in place with legible etchings. Some corner stones were covered with litter, broken into several pieces, or found lying loose on the surface. Average measurement error to relocated corner stones from our points of measurement using a hip chain and compass was 12.9$\pm$4.1 m ($\pm$SE). Of 266 witness trees surveyed in 1896, only six of a possible 124 trees (at points where corner stones were located in 1994) were found still standing in 1994, two of these were no longer living. Evidence of 1896 witness trees remained as large depressions or mounds of soil at the distance and azimuth where the witness tree once stood. Species composition between years was similar, with 5 additional species encountered in 1994 (Table 1).

Increment cores were collected for large *P. echinata* near approximately 50% of the sample points and occasional hardwoods that might have been alive at a shorter distance from the corner marker. This was done to determine if there was a bias for or against particular species, *Pinus* in particular, or if there was a size class bias evidenced. We found that none of these potential witness trees were alive at the time of the survey. Very few trees surveyed in 1896 were still in place in 1994, suggesting fire history on MCWA from 1896 to 1955 affected witness tree survival (See Masters et al 1995).

General field observations in 1994 showed little or no *P. echinata* recruitment on MCWA. *P. echinata* seedlings were found only on disturbed sites such as roadsides and blow downs, and were sometimes dense in these areas. Herbaceous undergrowth was seldom encountered and was found

Table 1. Frequency, diameter at breast height (DBH), basal area (BA), density by species, absolute frequency, and dominance ranking derived by the point-center quarter method (n=97) for McCurtain County Wilderness Area, Oklahoma, 1896 and 1994.

	Absolute Frequency		Frequency		Dominance Ranking		Mean DBH (cm)		Basal Area (m^2)		Trees/ha	
Species	1896	1994	1896	1994	1896	1994	1896	1994	1896	1994	1896	1994
Acer spp.	2	3	1.0	3.1	11	12	17.8	16.7	>0.0	0.1	0.5	4.8
Amelanchier arborea	0	1	0.0	1.0	-	15	0.0	21.3	0.0	0.1	0.0	1.6
Carya spp.	7	61	7.2	35.4	7	2	24.0	17.8	0.1	2.7	1.9	97.8
Cornus florida	0	1	0.0	1.0	-	16	0.0	12.6	0.0	>0.0	0.0	1.6
Fraxinus Americana	0	3	0.0	3.1	-	10	0.0	20.5	0.0	0.2	0.0	4.8
Juniperus virginiana	0	3	0.0	3.1	-	11	0.0	19.6	0.0	0.2	0.0	4.8
Liquidambar styraciflua	1	2	1.0	2.1	12	17	35.0	12.5	>0.0	>0.0	0.3	2.1
Nyssa sylvatica	1	9	1.0	7.3	9	8	20.3	19.0	>0.0	0.5	0.3	14.4
Pinus echinata	17	149	14.4	70.8	5	1	32.0	27.0	0.4	15.9	4.5	238.9
Prunus serotina	1	9	1.0	9.4	13	7	15.2	21.0	>0.0	0.5	0.3	14.4
Quercus alba	58	48	33.0	33.3	2	3	29.8	21.1	1.2	3.1	15.4	77.0
Quercus falcata	0	8	-	5.2	-	9	0.0	19.3	0.0	0.4	0.0	12.8
Quercus marilandica	7	3	5.2	2.1	8	13	21.4	15.2	0.1	0.1	1.9	4.8
Quercus rubra	41	36	33.0	20.8	3	4	28.4	20.3	0.8	2.1	10.9	57.7
Quercus stellata	38	24	25.8	18.8	4	5	26.7	17.1	0.6	1.0	10.1	38.5
Quercus velutina	23	22	14.4	13.5	6	6	27.5	17.0	0.4	0.9	6.1	35.3
Quercus spp.	67	0	27.8	-	1	-	32.3	0.0	1.6	0.0	17.8	0.0
Ulmus spp.	3	2	3.1	2.1	10	14	17.8	16.3	>0.0	0.1	0.8	3.2
TOTAL	266	384							5.2	24.6	70.8	614.5

only on a few remnant glades on south-facing slopes. Ground cover on most sites was composed of a thick leaf litter and scattered shrubs, vines, or sparse herbaceous vegetation (see also Smith et al 1997). We found evidence of fire in the form of fire scars and cat faces on living trees, and charred pine knots on the ground at 95 of the 96 sample points.

Individual corner data provide a simple means of quantifying temporal change in stem density and diameter. We found the average distance from a corner point to the nearest tree decreased ($P = 0.001$) from 11.2 m in 1896 to 4.0 m in 1994 and average diameter was 31.4% less (Table 2). A near 10-fold difference in average stem density was found between 1896 (71 stems/ha) and 1994 (615 stems/ha) (Table 1). When all 1994 boundary edge and timber theft areas were excluded from the analysis, average stem density was slightly less (589.7 stems/ha) than when these areas were included. Basal area and diameter for *Carya* spp. and *Quercus* spp. were different ($P < 0.05$) between years with and without edge and disturbed sites removed. Generally, removal of edge and disturbed sites had little influence on the results (Kreiter 1995). Variable-radius plot samples also gave similar stem density estimates in 1994 as point center-quarter data (Table 3). From period photo samples, we found dominant and codominant *P. echinata* increased ($P = 0.001$) from 73 stems/ha to 93 stems/ha for 1955 and 1990 respectively.

Average diameter for all trees declined significantly (P=0.001) between 1896 and 1994 from 29 cm to 22 cm (Table 2). With all 1994 edge and disturbed sites excluded, average diameter was 23 cm. Diameter distributions in 1994 were skewed to smaller diameter classes in all 4 species groups: *P. echinata*, *Quercus* spp., *Carya* spp., and other hardwoods (Figure 2). Many more large-diameter *P. echinata* were also found in 1994 versus 1896 (Figure 2). *Carya*, a fire intolerant genus, occurred less frequently in 1896 with a larger average diameter than in 1994 (Figure 2). Large *Quercus* occurred

Table 3. Frequency, density (trees/ha), basal area (BA), and totals based on variable radius plot sampling methodology by species for McCurtain County Wilderness Area, Oklahoma, in 1994.

Species	Freq	Trees/ha	BA(m^2)
Acer rubrum	6	9.8	0.1
Acer saccharum	1	0.9	>0.0
Amelanchier arborea	1	0.7	>0.0
Carya cordiformis	1	1.4	>0.0
Carya texana	7	5.2	0.2
Carya tomentosa	82	84.2	2.0
Cornus florida	1	2.0	>0.0
Fraxinus americana	3	2.5	0.1
Juniperus virginiana	3	1.2	0.1
Liquidambar styraciflua	3	5.4	0.1
Nyssa sylvatica	11	13.4	0.3
Pinus echinata	437	222.4	10.5
Prunus serotina	15	10.3	0.4
Quercus alba	87	71.1	2.1
Quercus falcata	13	9.3	0.3
Quercus marilandica	12	11.2	0.3
Quercus rubra	71	60.0	1.7
Quercus stellata	40	30.6	1.0
Quercus velutina	40	39.0	1.0
Ulmus alata	7	5.6	0.2
TOTAL	841	586.2	20.4

Table 2. Comparison of 1896 and 1994 diameter breast height (DBH) and mean distance (DIST) to the nearest tree at 96 General Land Office Survey points on McCurtain County Wilderness Area, Oklahoma, USA.

	Year					
	1896		1994			
Parameter	Mean	SE	Mean	SE	*T*	*P*
DBH (cm)	28.94[a]	0.74	22.02[b]	0.58	7.24	0.0001
DIST (m)	11.22[a]	0.55	4.03[b]	0.13	13.35	0.0001

[a] Row means followed by different letters were significantly different.

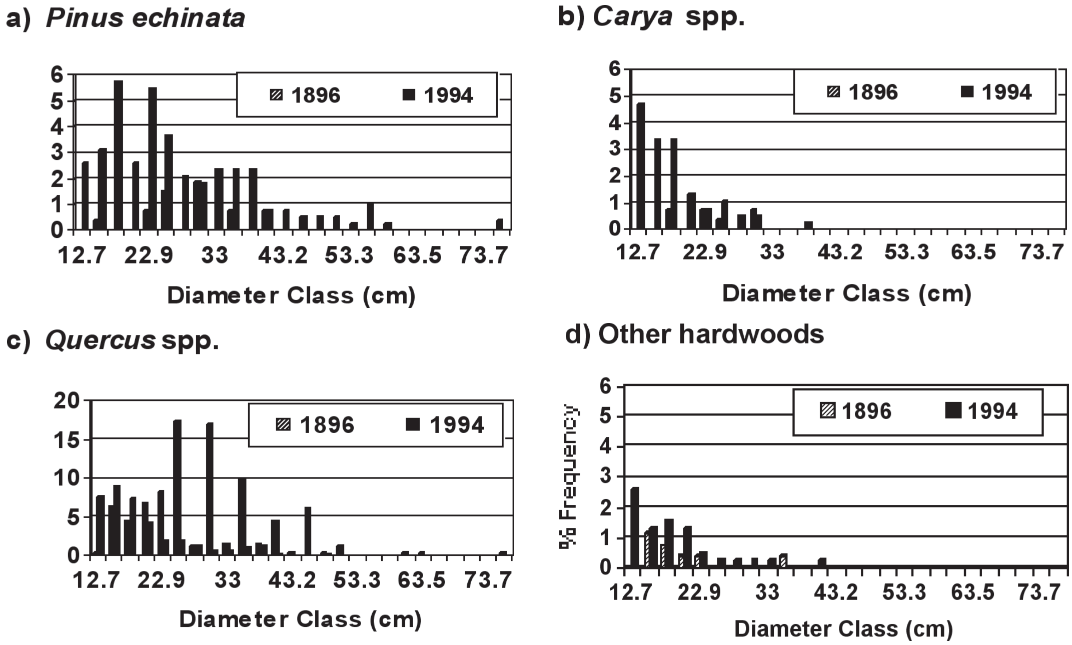

Figure 2. Diameter distributions in 1896 and 1994 for dominant tree species ≥ 11.4 cm at General Land Office survey points on the McCurtain County Wilderness Area, Oklahoma, USA.

more frequently in 1896 than in 1994, with a much wider diameter distribution (Figure 2). Other hardwood species in 1994 averaged slightly smaller than in 1896 (Figure 2). When diameter distributions were summarized with disturbed and edge plots removed, only minor differences were noted (See Kreiter 1995).

Landscape Patterns: 1955 – 1990

Hardwood-*Pinus* and low-medium density *Pinus*-hardwood cover types increased in percent area, patch density, and patch size from 1955 to 1990, indicating an increase in overall connectivity of the type (Table 4). Hardwood-P*inus* types increased in total area by 114.1 percent. This is the largest change observed for any type. A large portion of the increase in low-medium density *Pinus*-hardwood cover types resulted from decreased density in mixed hardwood-*Pinus* stands as well as *Pinus* stands. Decreases in *Pinus*-hardwood, open *Pinus*-hardwood, and hardwood types contributed to increases in hardwood-*Pinus* types.

Table 4. Comparison of historical (1955), current (1990) and percent difference (%D) in the class level landscape indices percentage of landscape, patch density, and mean patch size, for vegetation cover types on the McCurtain County Wilderness Area, Oklahoma.

	Percentage of Landscape			Patch Density			Mean Patch Size		
Cover type	1955	1990	%D	1955	1990	%D	1955	1990	%D
Pinus-hardwood	26.8	19.3	-28.0	7.1	5.3	-25.4	3.8	3.6	-5.3
Hardwood-*Pinus*	17.1	36.6	114.0	5.5	6.9	25.5	3.1	5.3	71.0
Pinus	2.9	1.4	-51.7	1.1	2.7	59.3	2.6	0.5	-80.8
Hardwood	30.5	26.7	-12.5	2.8	11.3	303.6	10.9	2.4	-78.0
Glade/Grassland	1.5	0.3	-80.0	1.7	0.7	-58.8	0.9	0.5	-44.4
Low/med *Pinus*-hardwood	10.1	14.0	38.6	3.4	4.3	26.5	3.0	3.3	10.0
Low density hardwood	8.6	0.0	-100.0	1.1	0.0	-100.0	7.6	0.0	-100.0
Water	1.0	1.6	60.0	0.3	0.3	0.0	3.3	6.4	93.9
Flood zone	0.0	0.1	100.0	0.0	0.1	100.0	0.0	0.2	100.0
Developed/disturbed	1.5	0.0	-100.0	0.2	0.0	-100.0	8.14	0.0	-100.0

Pinus-hardwood, *Pinus*, and hardwood cover types decreased from 1955 to 1990 in percent area (Table 4). While *Pinus*-hardwood patch density and patch size decreased, *Pinus* or mostly *Pinus* stands increased in patch density and decreased in patch size. *Pinus* types decreased due to hardwood encroachment. The hardwood cover type increased in patch density by 303.6 percent but decreased in mean patch size, by 78.3 percent (Table 4). Transition analyses showed that *Pinus*-hardwood types also changed to hardwood types, where 41.9 percent of the type was described as hardwood-*Pinus*, and 12.2 percent was described as hardwood in the 1990 coverage. Historical hardwood types largely changed to mixed hardwood-*Pinus* types. The decrease in area and patch size for these cover types generally suggests an overall decrease in connectivity.

The type classified as low-density hardwood was found only in the 1955 representation of the MCWA. This type constituted 8.6 percent of the area but was gone by 1990. Patch density of the type was 1.1 patches/100 ha, and mean patch size was 7.6 ha. Open hardwood stands generally succeeded to dense hardwood stands or dense mixed hardwood-*Pinus* stands.

Glade/grassland cover types decreased in total area by 77.0 percent, and patch density and mean patch size also decreased by 61.0 percent and 41.9 percent respectively (Table 4). The combined decrease in each metric suggests a decrease in connectivity among glade/grassland types. About 50 percent of open glade types from the 1955 coverage were delineated as hardwood or mixed hardwood-*Pinus*. About 23 percent changed to low-medium density *Pinus*-hardwood from 1955 to 1990.

For the landscape level metrics; we found decreases in diversity, evenness, and interspersion, and an increase in contagion indicating that the number of patch types is decreasing and the MCWA is being occupied by larger more contiguous units (Table 5). Shannon diversity increases as the number of patch types increases or as the area and distribution of a type increases (McGarigal and Marks 1995). Because diversity decreased, we would expect a slight decrease in evenness as well because evenness rates the abundance and distribution of a type. From 1955 to 1990, evenness decreased by 14.3 percent.

Table 5. Comparison of historical (1955) and current (1990) landscape level indices including Mean Patch Size, Shanon's Diversity Index , Modified Simpson's Evenness Index, Interspersion/Juxtaposition Index, Contagion, and percent difference (%D), for all cover types of the McCurtain County Wilderness Area, Oklahoma, USA.

Landscape metric	1955	1990	%D
Mean Patch size (ha)	4.3	3.2	-25.6
Shannon's Diversity Index	1.7	1.5	-11.8
Modified Simpson's Evenness Index	0.7	0.6	-14.3
Interspersion/ Juxtaposition Index	77.8	66.7	-14.3
Contagion	51.0	55.0	7.8

The interspersion and juxtaposition index evaluates patch adjacencies for like patches. High values for interspersion indicate well-interspersed patches (McGarigal and Marks 1995). Cover types on the MCWA in 1990 were more interspersed than in 1955 as the interspersion and juxtaposition index decreased by 14.3 percent.

Unlike interspersion, contagion approaches 0 when the distribution of adjacent patches becomes increasingly uneven (McGarigal and Marks 1995). Thus, a higher degree of interspersion would suggest lower contagion. However, contagion increased by 7.8 percent (Table 5). The observed inconsistency between contagion and interspersion may be due to observed high variability of patch sizes.

DISCUSSION

Taken at face value the GLO data suggest a forest transition from *Quercus* dominated to *P. echinata* dominated over a 98-year period. Although GLO data were not collected for ecological reasons or in a rigorous sampling design, they do provide valuable insight about presettlement vegetation when bias is identified and taken into account (Bourdo 1956, Whitney and Decant 2001, Farley et al 2002). Surveyors were instructed to select from "the most durable wood" and therefore may have selected trees further from the corner marker, such as *Quercus* spp. in this study (Bourdo 1956, Nelson 1997, Whitney and Decant 2001) thus biasing species dominance and increasing tree-to-marker distance. This would cause tree density to be underestimated.

Pinus were often recorded as the predominant species in the 1.6 km summaries, but were rarely recorded as witness trees (Table 2). However, on these poor sites *P. echinata* attains greater heights than many of the hardwoods. It could be considered as super-dominant canopy status based on our observations of the magnitude of differences in height of individuals above the surrounding hardwood canopy. As a result; surveyors may have identified *Pinus* as being dominant simply because canopy height was greater. To address this potential for bias toward *Quercus* we age-sampled *Pinus* near GLO stone markers at approximately 50 percent of our sample points to determine if *Quercus* might have been selected over *Pinus*. No *P. echinata* or hardwood species over 100 years of age were found between corner markers and bearing locations recorded by surveyors for witness trees. However, because of the frequent fire regime from 1896-1940s (Masters et al 1995) and the observed rapid turnover in witness trees, it is likely that few hardwood trees present in 1896 would have survived.

Another line of evidence we examined included the slope position and aspect of the physical locations of the GLO survey points. Topography plays an important influence on the distribution of tree species in the Ouachita Highlands (Johnson 1986, Kreiter 1994). Therefore the physical location of survey points could introduce bias as points were not selected at random but rather spaced on a regular grid based on the established survey pattern. Hardwoods have a higher probability of occurrence on north and easterly aspects and in drainages and otherwise sheltered slope positions while *P. echinata* has a distinct tendency to predominate on drier southern and western exposures (Johnson 1986, Kreiter 1995). Because the survey point locations were predominantly on sites with a much higher probability of hardwood occurrence than *Pinus*, we believe that at least some level of bias toward hardwood predominance in the 1896 data may have been introduced. This bias would also be present in 1994 data, but *Pinus* was much more prevalent in 1994 versus 1896.

The evidence from period photos and section summaries is consistent with a *Pinus* dominated system therefore, we remain somewhat skeptical of species dominance rankings shown in the 1896 data (Table 1). *Picoides borealis* occurrence on the area also suggests that at least a portion of the area was *P. echinata* dominated as this woodpecker only excavates cavities in living *Pinus* and has low immigration and reproductive rates (U.S. Fish and Wildlife Services 2003). The likelihood of this species' population expanding into a transitioning *Quercus* to *Pinus* dominated forest in the period from 1896 to 1974 seems unlikely given that average age of *P. echinata* used for cavity trees was 149 years old with range of 95–301 (Wood 1983).

Further evidence that these density estimates are reasonable also comes from period photo graphs circa 1900–1925 within 50 km (Doolin 1912, Honess 1923) and approximately 150 km east of the area (Masters et al 1998). Two photo points on the area taken in 1930 and later in 1981 illustrate graphically the open nature of the forest at that time (Masters et al 1995). We recognize that likely density estimates may be underestimated but this is not so serious a problem as to discard all the density information based on the comparison of photos of known density to structure of historic photos (see Masters et al 1995, 1998 for photos and Sparks et al 2002 for density based on total tree count of a restructured stand). Although reconstruction from GLO data may not reflect absolute density, it does allow for relative comparison (Nelson 1997).

We found an increase in the number of species and an increase in stem density for all species. Others have demonstrated that hardwood encroachment over several decades results in a decrease in shortleaf pine in the absence of fire (e.g., Cain 1987). However, our random sample of aerial photography showed that dominant and codominant shortleaf pine increased rather than decreased. This may be a result of decreased frequency and areal extent of fire on MCWA by 1955 (Masters et al 1995). With open stand conditions and decreasing fire frequency, the stage was set for seedling and sapling pines to grow to codominant status. Our diameter distribution data are consistent with this hypothesis.

With low *P. echinata* recruitment resulting from closed canopy conditions, most of the 1994 population was made up of intermediate, codominant, and dominant individuals. Because *P. echinata* tends to be shorter lived than most hardwoods in this study, as older pines die they will be replaced by more shade tolerant hardwoods. This replacement may be hastened by periodic outbreaks of *Dendroctonus frontalis* (southern pine beetle) on the area (Masters et al 1989).

Trees in 1896 generally had a wider range of diameters than those found in 1994. Particularly interesting was the large range of *P. echinata* and *Quercus* spp. diameters, because this is consistent with survival patterns from an ongoing 20 year study of fire frequency in the Ouachita Mountains of Oklahoma (Masters, unpublished data) and a 35 year study in Florida (Hermann 1995). Diameter distributions from 1896 suggest that the forest was in transition from an earlier frequent fire regime to that following a period of less frequent fire. This change in fire regime coincided with changes in Native American demographics and settlement patterns (Masters et al 1995). High frequency of smaller trees in 1994 suggests that the MCWA landscape in 1896 was composed of a more uneven-aged structure than in 1994, and that vertical structure of the forest has changed significantly. The large number of smaller hardwoods in 1994 supports the hypothesis that decreased fire frequency may have contributed to increased hardwood development in the midstory and intermediate canopy classes. Increases in fire intolerant species such as *Carya* spp. provide further support. Midstory development is well documented to cause population declines on *Pinus*-grassland obligate songbird species including *Picoides borealis* and negatively affect other species (Wilson et al 1995; Masters et al 1996, 2002).

Along with stand density, dominant species have changed over time in site distribution. Hardwoods increased in frequency on relatively steep (19° - 36°) xeric south-facing slopes by 1994. *Carya* spp., *Q. rubra, Q. stellata,* and *Q. velutina* were all found more frequently than expected on relatively steep south slopes in 1994 versus a distinct tendency toward predominance on steep north slopes in 1896 (Kreiter 1995) which is the norm (Johnson 1986). This again suggests that decreased fire frequency has permitted more mesic and less fire tolerant species, particularly *Carya* spp. to expand into much more xeric, fire prone areas. *Pinus echinata* was found more frequently on all sites in 1994 but was prevalent on relatively steep south slopes in 1896 (Kreiter 1995). This is consistent with mid-century change in fire regime and at that time, open forest conditions.

We do not suggest that the entire MCWA area was *Pinus* dominated, but that it certainly was on specific sites such as those previously mentioned. Period photographs (e.g. Doolin 1912) clearly show that north slopes in the Ouachita Mountains were hardwood dominated and may have been in fact a fire shadow relict in some areas because of insolation influences of slope and topography on fuel moisture. On these sheltered sites higher fuel moisture and less suitable fuels (hardwood leaf litter) may have predisposed these sites against frequent fire.

Landscape changes observed in this study are supported by observations from other studies in the region. Analysis of GLO data elsewhere in the Ouachitas (Foti and Glenn 1991) as well as graphic historical accounts by botanist Thomas Nuttall in 1819 among others also indicate dramatic density increases in stands and landscape-level changes in the Ouachita Mountain region over a time period of nearly 2 centuries (Lewis 1924, Nuttall 1980, Foti and Glenn 1991, Masters et al 1995). Furthermore, the landscape changes are supported by comparison of photo points on MCWA from 1930 to 1991 and period photographs from the Ouachita Mountain Region (Masters et al 1995). In the neighboring Ozark Plateau Region to the north, Beilmann and Brenner (1951) discuss such sweeping landscape level change moving from a landscape matrix dominated by prairie with forested drainages and 500 years later a forest dominated landscape, based on their interpretation of various explorer accounts.

Spatial pattern analyses indicate further change in the vegetation mosaic has taken place from 1955 to 1990. In general, cover types of the MCWA in 1955 were more connected and were larger in size than in 1990, with the exception of the hardwood-*Pinus*, and medium density pine-hardwood types. Based on photo interpretation, mixed hardwood-*Pinus* types have increased significantly in the landscape since 1955, as also suggested by GLO survey results.

CONCLUSIONS

Our study is consistent with Oliver's (1981) hypothesis that disturbance severity and frequency determine which species will dominate the forest and that stand physiognomy and species dominance will change over time after disturbance. It is evident that forests of the MCWA continue in a state of flux dependant on the fire regime as opposed to some steady state or climax. Weather patterns on the wilderness area have been relatively non-directional over the last 2 centuries (Stahle et al 1985) and likely are not responsible for the observed landscape changes based on the current state of knowledge regarding fire frequency and stand development. We suggest that change in the fire regime from periodic frequent fire to fire elimination has directly influenced the forest at both stand and landscape levels (Masters et al 1995). Forest turnover on this area was rapid and probably driven by the historic frequent fire regime (Masters et al 1995). The rapid change in structure and density of cover types on the MCWA suggests that inclusion of natural disturbance regimes should be considered as a component of the management program (See also Niering 1987).

This study provides baseline data for use in ecosystem restoration efforts currently underway in the Ouachita Mountains (e.g., Wilson et al 1995). Analysis of change in spatial pattern of vegetation types allows us to evaluate potential risk to wildlife that may be sensitive to habitat loss and/or increased isolation from other individuals in the population (Jurgensen et al 1993, Sinclair et al 1995). Densification of the forest and homogenization of the landscape as a result of fire suppression has had direct consequences on the red-cockaded woodpecker, which is associated with open *Pinus* habitats and other wildlife species adapted to *Pinus*-grassland types (Masters et al 1995, 1998, 2002; Wilson et al 1995).

Restoration of MCWA presettlement landscape should focus on reconstruction of original landscape components found at the time of settlement. This could best be accomplished by reintroduction of an anthropogenic and lightning fire regime known to be present before active suppression because this regime initially shaped the system (Christensen 1978, Buckner 1989, Masters et al 1995). This regime generally averaged less than 4-year intervals and was bimodal in distribution with both documented dormant and growing season (early and late) fire. Reintroduction of fire would likely decrease stand density and change stand structure over time. To be most effective, land managers should consider topographic differences in restoring open forest types along xeric ridges and south facing slopes, where hardwood encroachment has had the most impact. Drainages, bottoms, and north-facing slopes would likely remain hardwood-dominated but should not be protected from fire.

Landscape managers must continue to develop plans that incorporate or approximate natural processes. More importantly, managers must become more knowledgeable of the ecological effects of natural disturbances such as fire. Future research should assess different landscape management configurations and desired future conditions for MCWA. Efforts should be made to study how the use of varying season fires and large-scale burns could be initiated to better mimic the anthropogenic and lightning-caused fire events that historically shaped the system. Additional research also should determine how changes in landscape pattern have affected the potential spread of fire, insects, and disease across the system with changes in fuel bed composition commensurate with overstory change (Masters et al 1995).

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