Publications of the Oklahoma Biological Survey
2nd Series
Volume 12:1-14, 2013

Vegetation patterns in Wichita Mountains National Wildlife Refuge, Oklahoma; an analysis of General Land Office Survey records from 1874 and 1905.

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ABSTRACT.—The cross timbers is a region of forest, woodland, and grassland vegetation occupying much of central Oklahoma. The dominant trees in the region are *Quercus stellata and Q. marilandica*. Although several contemporary studies of the cross timbers exist, historical data sources have not been used in the analysis of species composition and vegetation structure. This study employed Public Land Survey data from 1874 to analyze pre-settlement vegetation of the Wichita Mountains National Wildlife Refuge. It was determined that historically forest vegetation predominated in the study area. Dominant tree species were *Q. stellata and Q. velutina*.

INTRODUCTION

The cross timbers is a mosaic of forest (woody vegetation with interlocking crowns), woodland (woody vegetation lacking interlocking crowns), and grassland vegetation extending from southeastern Kansas through Oklahoma and into north central Texas (Dyksterhuis 1948, Hoagland et al 1999). At an estimated 2.5 million hectares, the cross timbers are the most broadly distributed woody vegetation type in Oklahoma (Rice and Penfound 1959, Dwyer and Santelmann 1964).

Forest and woodland vegetation in the cross timbers is characterized by the predominance of two species of woody plant: post oak (*Quercus stellata*) and blackjack oak (*Quercus marilandica*). In woodland physiognomy or intervening grasslands big bluestem (*Andropogon gerardii*), switchgrass (*Panicum virgatum*), little bluestem (*Schizachyrium scoparium*), and indiangrass (*Sorghastrum nutans*) are common (Hoagland et al 1999).

Although these woody and grass species can be found throughout the cross timbers, there is variation in woody plant composition along an east to west gradient. For example, black hickory (*Carya texana*) and black oak (*Quercus velutina*) are common in the central and eastern portions of the cross timbers, but absent in the west. Likewise in the western extent of the cross timbers, little walnut (*Juglans microcarpa*) and woodland vegetation (referred to as savanna by some authors, see Penfound 1962) is more prevalent then dense, closed canopy forests.

The composition and structure of woody vegetation in the modern cross timbers has been well documented. Post oak and blackjack oak constitute up to 90% of the canopy cover and 50% of the basal area in cross timber stands (Rice and Penfound 1959, Kennedy 1973). The stem ratio of post oak to blackjack oak ranges from 2:1 to 3:1, depending on slope, aspect, and/or geographic location (Luckhardt and Barclay 1938, Kennedy 1973). Although stem density of blackjack oak may surpass post oak on south-facing slopes, blackjack oak rarely exceeds 30 cm in diameter, so basal area values of the two species are roughly equivalent (Luckhardt and Barclay 1938, Rice and Penfound 1955, 1959).

Globally, forest structure and composition have been altered by direct and indirect effects of human agency (Dupouey et al. 2002). The result in North America has been an increase in mesic species due to fire suppression (Nowacki and Abrams 2008) and habitat fragmentation (Bennett and Saunders. 2010). The upland forests of Oklahoma also have been subject to structural changes, as recently documented by Desantis et al. (2010). Their analysis of vegetation data collected from 30 of the original Rice and Penfound (1959) sites lead to the following conclusions: 1) stem density and basal area has increased, 2) eastern red cedar abundance has increased substantially, 3) mesophytic tree species has increased in prevalence (i.e., elm spp., hackberry spp., gumbully, red mulberry and other species not encountered in the GLO notes), and 4) the predominance of *Quercus* species has declined. So what was the structure and composition of cross timbers forests prior to this time?

Some insight can be gained by reference to the accounts of 19th century travelers in Indian Territory. For example, the literary luminary Washington Irving (1956) wrote in 1832: "I shall not easily forget the mortal toil, and the vexations of flesh and spirit, that we underwent occasionally, in our wanderings through

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the Cross Timber. It was like struggling through forests of cast iron," implying densely forested stands. Captain Randolph Marcy wrote: "At six different points where I have passed through it [the cross timbers], I have found it characterized by these peculiarities; the trees, consisting primarily of post-oak and black-jack, standing at such intervals that wagons can without difficulty pass between them in any direction (Foreman 1947)", implying open woodland vegetation. These descriptions present a challenge for those engaged in restoration and management of cross timbers vegetation. Many management objectives require quantitative data for the establishment of performance benchmarks. For this reason, the General Land Office (GLO) records are a valuable source for quantitative spatial and species composition data.

The GLO was responsible for conducting the Public Land Survey (PLS) in the United States, as first set forth by the Continental Congress in the Land Ordinance of 20 May 1785. The ordinance called for the survey of territories of the United States into square townships of 36 mi2 (9,323 hectares), or 6 miles (9.6 km) on each side. As surveyors demarcated townships and sections, they described vegetation and physical features encountered in both written notes and on mapped plats (Brothers 1991, Stewart 1935). The surveyors were also required to mark "witness trees" to aid in the relocation of survey landmarks. The procedure involved measuring the distance from the survey landmark to the nearest tree: one tree in each of four quarters where section-lines intersect and one on opposites sides of the survey line for quarter sections. The species name, stem diameter, and distance were recorded for each witness tree (Whitney and DeCant 2001).

Although the intent of the PLS was not to gather ecological data, these records have been useful for evaluating the composition and distribution of vegetation and land-use of the past (Bourdo 1956, Whitney and DeCant 2001). As such, the PLS data can be used to develop a baseline of environmental conditions prior to extensive European settlement and aid in the analysis of land cover change over time (Galatowitsch 1990).

The PLS began in Oklahoma with the establishment of the Initial Point in the Arbuckle Mountains in 1871 (Hoagland 2006). Though lagging behind other states in the analysis of PLS data (Fagin and Hoagland 2002), several recent studies have analyzed these data for locations in the cross timbers region. Shutler and Hoagland (2004) analyzed the distribution of vegetation using the PLS plats and witness tree data for Carter County. Fagin and Hoagland (2010) modeled the distribution of witness trees in the Arbuckle Mountains. Thomas (2009) used the PLS plats and witness tree data to investigate the role of rivers as landscape barriers to the spread of fire and the resulting difference in vegetation composition.

In each of these studies, the PLS data were used to address questions regarding historical condition of the cross timbers; what was the species composition and vegetation structure in the 19th century? Were invasive species reported in the surveys and if so, where were they located? This question specifically addresses interest in the past distribution and abundance of eastern red cedar (*Juniperus virginiana*) and honey mesquite (*Prosopis glandulosa*), both of which are a modern ecological and economic threat (Van Auken 2000, 2008).

Other native species of interest included populations of the disjuncts plateau live oak (*Quercus fusiformis*) and sugar maple (*Acer saccharum*); were these species recorded by the GLO surveyors? And finally, what were the major land cover types and how were they distributed in the late 19th and early 20th centuries?

Given the ever changing nature of Oklahoma upland forests, the objective of this study was to analyze PLS records for the Wichita Mountains National Wildlife Refuge (WMNWR) and establish a baseline of landscape and vegetation conditions for the use of refuge personnel. We reviewed, evaluated, and analyzed both qualitative and quantitative components of the PLS data from surveys in 1874, 1901-902, and 1905. Qualitative data consisted of written timber descriptions, each of which lists predominant and co-occurring species and the physical setting in which they were found. Quantitative data consisted of both bearing tree records (e.g. point-to-plant distance, diameter-at-breast height) and plats for determination (e.g., land cover types and extent). The bearing tree data will provide insight regarding the species composition and vegetation structure (e.g., basal area and stem density). The plats will be utilized to create a series of seamless maps for the WMNWR from the three survey dates.

STUDY AREA

The WMNWR is located in southwest Oklahoma (Figure 1) in Comanche County. The climate is subtropical Humid (Trewartha 1968), with warm to hot summers (average temperature of 23.9oC) and mild relatively short winters (average temperature of 9.4oC). Mean annual precipitation is 83 cm (Oklahoma Climatological Survey 2010). Unlike the surface geology of the majority of southwest Oklahoma, which is primarily Permian marine deposits of sandstones and

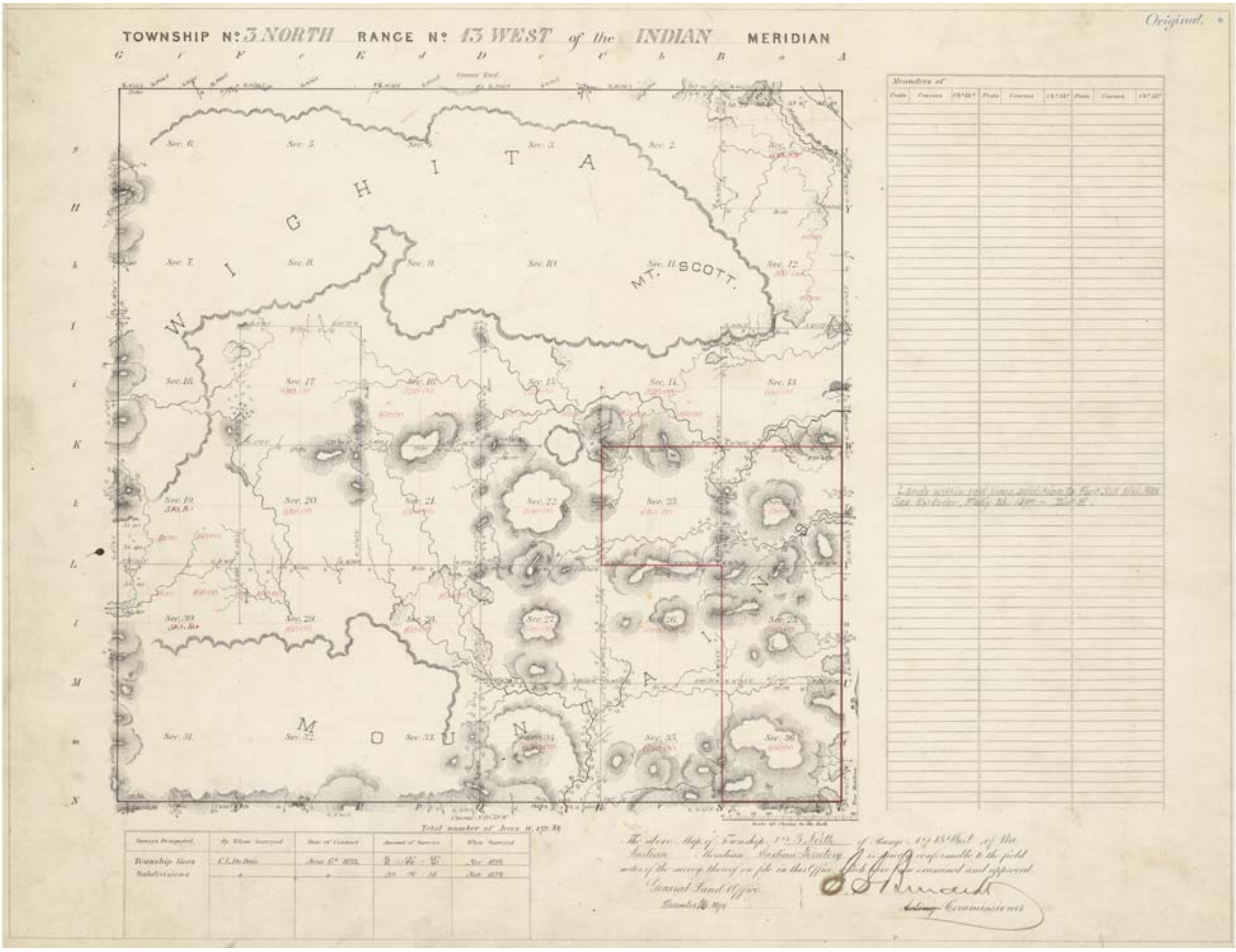

FIG. 1. An example of a plat as mapped by the General Land Office in 1874. The township is 3 north and Range 13 west and is located on the Wichita Mountains National Wildlife Refuge.

shales, the WMNWR consists of Cambrian age outcrops of granite and rhyolite (Johnson 2008). The soils are mollisols that are interrupted by extensive rock outcrops and tend to be deepest in low-slope positions and bottomlands (Carter and Gregory 2008).

As mapped by Duck and Fletcher (1943), the predominate vegetation types on the WMNWR are post oak and blackjack forest (cross timbers) and mixed-grass eroded plains. Secondary woody plant species in this western extent of the cross timbers include eastern red cedar, redbud (*Cercis canadensis*), roughleaf dogwood (*Cornus drummondii*), Mexican plum (*Prunus mexicana*), coralberry (*Symphoricarpos orbiculatus*), smooth sumac (*Rhus copallina*), and shining sumac (*R. glabra*) (Hoagland 2000). Buck's (1962, 1964) study of woody vegetation at WMNWR yielded 24 species of woody plants, chief among them were post oak, blackjack oak, eastern red cedar, little walnut (*Juglans microcarpa* [synonym = *J. rupestris*]), netleaf hackberry (*Celtis laevigata* var. *reticulata* [syn.=*C. laevigata*]), gumbully (*Sideroxylon lanuginosa*), American elm (*Ulmus americana*), chinkapin oak (*Quercus muehlenbergii*), sugar maple (*Acer saccharum*), and pecan (*Carya illinoinensis*).

Dooley and Collins (1984) resampled the Buck sites at WMNWR and encountered the same dominant species, though the relative abundances were different. A numerical classification of these data yielded three forest types: 1) post oak-blackjack, 2) post oak, and 3) mesophtyic forests. In the seedling layer, however, four types were reported; 1) blackjack, 2) post oak-blackjack-eastern red cedar, 3) American elm (*Ulmus americana*)-netleaf hackberry-gum bully, 4) sugar maple.

As part of their statewide study of upland forests, Rice and Penfound (1959) collected data at six locations in northwest Comanche County (Hoagland and Hough 2009; appendix 1), four of which were located on the WMNWR (appendix 2). They reported 16 taxa of trees in Comanche County, ranging from 3 to 8 species per site. The only species that occurred at all sample sites were post oak and blackjack oak. Chinkapin oak was reported from only one site, but was the third most abundant species there. Likewise, little walnut occurred at only one site, but scored a higher abundance than post oak.

MATERIALS AND METHODS

We utilized the three data sources available in the PLS records, the timber summaries, witness tree records, and township plats. Timber summaries and bearing tree data were extracted from the written surveyor notes for each township studied, which included all or part of townships 2N13W, 3N13W, 3N14W, 3N15W, 4N14W, and 4N15W. Surveyor notes were acquired from the Bureau of the Land Management (http://www.glorecords.blm.gov). Each timber summary was recorded verbatim into a spreadsheet. Timber summaries contain descriptions of habitat and physical setting that provide detail of past landscapes.

All interior and exterior bearing tree records were transcribed to include the surveyor's identification of the plant, diameter, and distance from survey landmark. Basal area was calculated according to Wenger (1984) for each species to determine predominance. Many analyses of bearing tree data include attempts to calculate stem density using point to plant distances. Distance measures were assigned to subclasses of 0.1-5.0m, 5.1 - 10m, etc.

Township plats were also downloaded from the Bureau of the Land Management (http://www.glorecords.blm.gov). Plat images files were georeferenced and digitized using ArcInfo GIS. All information digitized from a plat was attributed to one of the following data layers: vegetation (forest, grassland, and wetland), hydrology (streams, rivers, springs, and ponds), agriculture (cultivated fields), transportation (roads, trails, and railroads), and settlement (residences, schools, and other cultural features). Once a township was digitized, each data layer was edited, attributed, and joined with adjacent plats.

Patch Analyst (Elkie et al. 1999), a landscape ecology software package, was used to determine landscape composition, defined here as the number of occurrences and area occupied by each land cover type. Patch Analyst metrics calculated were class area, number of patches, and mean patch size. Class area is a measure of the total area occupied by a particular land cover type. Number of patches is a measure of individual occurrences of a given land cover type. Mean patch size averages the area occupied by each land cover.

RESULTS AND DISCUSSION

The 19th century GLO surveys for the study area began on 2 November 1874 with Township 3 North, Range 13 West. Surveyors of record were Charles L. DuBois (Deputy Surveyor), W. A. Butterfield, J. M. Miller, H. L. Gaines, J. J. Jones, E. Alton, F. Hobby, A. Akins, G, Shryock, W. E. Rush, and D. W. Sutherland. Surveys ended on 8 December 1874 with Township 4 North, Range 15 West, surveyors included C. L. DuBois, E. W. Hartough, B. Hartough, E. C. Mitchele, W. L. Jaggers, C. Kipp, H. Dillman, F. L. Davis, and R. H. Elsworth.

The surveyors recorded 140 timber summaries. These written accounts described species composition and habitat in sufficient detail to allow for the recognition of upland and bottomland vegetation. Examples of upland vegetation descriptions include "scrubby post oak and black oak," "white oak and blackjack," "white oak, black oak and jack oak," "post oak and black oak." The repeated description of "black oak and blackjack with brush, briars & vines" is reminiscent of Washington Irving's cross timbers in northeast Oklahoma. One description reads enigmatically "lone black oak and post oak on slope of mountain south of [section] corner." Bottomland or riparian vegetation was described as "elm, cottonwood and pecan along creek banks, "white oak and black oak with walnut and mulberry along creek banks," "white oak with elm along creek banks," and "scattering of mesquite brush with elm, cottonwood and hackberry along creek banks."

The 1874 timber summaries (Table 1) repeatedly note the occurrence of cedars and mesquite. Cedars are mentioned in five summaries, all of which list oaks as co-occurring species; "black jack, white oak, cedar," "scattering black oak and cedar," "scattering post oak, black oak cedar," "white oak and cedar," and "white oak with scattering jack oak & cedar." Mesquite is listed in 20 timber summaries in both upland and lowland settings. " A few mesquite along line" or "scattering of mesquite along line" were the most common descriptions. The description "scattering of mesquite along line with a few elm along creek banks" indicates that mesquite was encountered on bottomlands as well. Only one description lists an oak as co-occurring: "scrubby black oak and scattering mesquite."

The second survey began on 20 June 1901 and ended on 17 June 1902. The survey team consisted of F. M. Johnson, A. D. Kidder, and W. F. Evans. There are numerous reasons to question the quality of these data, as articulated by Surveyor J.P. Walker in 1905: "The original surveys of 1874 are very good. The resurveys of 1901 and 1902 are not so good. It appears that return courses were wrongly computed, as east and west lines reported N of W are invariably S of W and vice versa, which is also the case on N lines. The two sets of retracement notes one for bearings only and one for measurement only, seem to indicate a fudged survey, as lines are in error in nearly all cases when so reported (General Description of T4N, R14W)."

Walker also called into question the location and distance measurements of trees in the 1902 survey: "My copy of notes calls for post oak, 12 ins. diam., N 89o E. 217 lks. dist., is evidently the description of some other corner, as there are ample trees much nearer and ones found marked bear every evidence of being original bearing trees of 1902, and position of corner agrees with returns for distance and further is certified to by W. N. Rose as being in same position as set in 1902 (General Description of Sec 18, 19 of T3 N 13 W)." Both these comments must be taken into account when interpreting both the plat and bearing tree data from the 1901-1902 survey. Given the questionable nature of distance measures and location data in the 1901-1902 survey and the possibility that the results will be spurious, that analysis of stand structure data was limited to the 1874 and 1905 surveys (Table 2). The timber descriptions for 1901-1902, however, are reviewed below.

The timber descriptions from 1901-1902 consisted of 169 entries. In comparison to the 1874 timber summaries, these are lacking in useful details. No descriptions were discernible as bottomland vegetation and seventeen entries read "no timber." Typical entries include "timber," "post oak," or "oak." Variants of "dense and scattering scrub oak and brush" and "scattering scrub oak and brush" were the most common timber description (n=67).

Cedars and mesquite were encountered in the 1901-1902 survey, but with fewer records for mesquite. Cedars were mentioned in ten entries, usually as co-occurring with oaks, for example "dense cedar and oak brush," "oak and scattering cedar," and "mountains covered with dense or scattering scrub oak, cedar and brush." Mesquite is mentioned three times as opposed to 20 in the 1874 survey; "post oak and mesquite," " post oak, scattering scrub oak & brush with scattering mesquite," and "walnut, oak, and mesquite."

The final survey considered commenced on 14 December 1904 and was completed on 19 January 1905. John P. Walker, J. J. Elliot, P. W. Railey, J. L. Hoover, F. Trask, R. D. McInturf, and W. C. Hogue conducted the survey. Timber summaries from 1905 are fewer than previous surveys, but do provide more detail than the 1901-1902 records. Of the 64 timber descriptions, post oak is most frequently mentioned (n = 51), followed by black oak (n = 46) and they are usually listed together. The only other oak species listed is Spanish oak. No reference is made to black jack or jack oak. Only four entries allude to bottomland vegetation, such as "oak, elm and hackberry along creek bank," or "post oak, black oak some elm and ash."

As with previous surveys, the 1905 surveyors recorded the presence of both cedar and mesquite. Eight entries record cedars, for example "post oak and some cedar along cliff," "cedar on cliffs" and "post oak and black oak with some cedar on mountains." Only four entries note mesquite; "scattering mesquite" and "post oak, black oak and mesquite."

Regarding Plant Identifications by surveyors. As with other GLO studies in Oklahoma (Shutler and Hoagland 2004, Batterson 2009, Thomas 2009, Fagin and Hoagland 2010), surveyors provided only common names of trees in both the timber summaries and bearing tree records. Our attempts to attribute a scientific binomial to the listed common name were in some cases confounded by identifications to only the genus (e.g., elm, mulberry, oak).

In the bearing tree data, GLO surveyors reported 14 taxa in 1874 and eight in 1905 (Tables 1 and 2). In 1874, four taxa were identified to only the genus level (Table 1) and three in 1905 (Table 2). Assigning scientific names to these trees can be accomplished by using ecological and/or geographical criteria. The Oklahoma Vascular Plants Database (Hoagland et al. 2010) served as a geographic reference, and Rice and Penfound (1959) and Buck (1962, 1964) as ecologic references. In some cases, making a species determination could be accomplished with relative ease. For example, only two species of mulberry occur in Oklahoma, red mulberry (*Morus rubra*) and white (*Morus alba*). White mulberry is a native of China that was introduced to Long Island in 1827 and did not become naturalized until much later. This fact in conjunction with the habitat description for mulberries in the timber summaries led to the conclusion that surveyors encountered red mulberry.

Geographic criteria led to resolution of a binomial for "cedar". There are five species of *Juniperus* in Oklahoma; ashe juniper (*J. ashei*), one-seed juniper (*J. monosperma*), redberry or Pinchot's juniper (*J. pinchotti)*, rocky mountain juniper (*J. scopulorum*), and eastern red cedar. Both one-seed and Rocky Mountain junipers can be excluded on geographic basis and ashe (a calciophile) and redberry (a gyposphile) on ecologic. Furthermore, only eastern red cedar has records from Comanche County in the Oklahoma Vascular Plants

TABLE 1. Woody plant species recorded by General Land Office surveyors circa 1874 at the Wichita Mountains National Wildlife Refuge. The scientific name was derived from the common name recorded by surveyors.

Scientific Name	**Surveyor Identification**	**Number of Stems Recorded**	**Mean Distance**	**Distance Range**	**Mean Diameter**	**Total Basal Area (m2)**	**Relative Basal Area (%)**	**Basal Area (m2/ha)**
Carya *illinoinensis*	Pecan	1		24.1	15.2	0.24	0.28	0.02
Celtis spp.	Hackberry	2	10.4	5.4-15.3	14	0.80	0.95	0.04
Juglans sp.	Walnut	3	17.4	4.2-43.3	25.4	1.20	1.42	0.16
Juniperus virginiana	Cedar	5	21.4	6.6-57.5	18.3	1.44	1.70	0.19
Morus rubra	Mulberry	1		58.2	30.5	0.48	0.57	0.07
Populus deltoides	Cottonwood	2	31.1	9.7-52.2	30.5	0.96	1.13	0.15
Prosopis glandulosa	Mesquite	32	26.9	3.2-56.9	13	6.54	7.75	0.51
Quercus alba	White oak	74	16.6	1.8-55.1	23.4	27.17	32.19	3.83
Quercus marilandica	Blackjack or jack oak	29	19.6	2.0-23.5	12.3	5.61	6.64	0.44
Quercus palustris	Pin oak	1		15.9	76.2	1.20	1.42	0.45
Quercus spp.	Oak	2	4.8	4.4-5.2	8.9	0.28	0.33	0.01
Quercus stellata	Post oak	61	12.4	0.6-52.7	22.6	21.64	25.65	2.99
Quercus velutina	Black oak	44	17.1	1.8-56.2	17.1	11.81	13.99	1.18
Ulmus spp.	Elm	13	16.6	2.2-46.9	16.8	3.43	4.07	0.39
	Tree	10	33.9	25.6-33.9	10.2	1.6	1.89	0.10
Total		**280**				**84.40**		

TABLE 2. Woody plant species recorded by General Land Office surveyors circa 1905 at the Wichita Mountains National Wildlife Refuge. The scientific name was derived from the common name recorded by surveyors.

Scientific Name	Surveyor Identification	Number of Stems Recorded	Mean Distance	Distance Range	Mean Diameter	Total Basal Area (m2)	Mean Basal Area (%)
Celtis spp.	Hackberry	2	25.9	22.1-29.6	22.9	0.72	1.29
Juglans sp.	Walnut	1		11.9	30.5	0.48	0.86
Juniperus virginiana	Cedar	8	10.9	7.0-22.9	29.5	3.71	6.67
Prosopis glandulosa	Mesquite	2	29.7	18.7-40.6	27.9	0.88	1.58
Quercus falcata	Spanish oak	1		19.7	20.3	0.32	0.57
Quercus stellata	Post oak	92	13.4	1.0-71.4	26.3	38.34	68.89
Quercus velutina	Black oak	38	16.8	0.8-47.9	17.4	10.41	18.71
Ulmus spp.	Elm	2	32.1	22.5-41.6	25.4	0.80	1.43
Total		**146**				**55.66**	

Database (Hoagland et al. 2010) and was reported as a significant component of the vegetation at WMNWR by Rice and Penfound (1959) and Buck (1962, 1964). Thus we concluded that the cedars observed by surveyors were eastern red cedar.

Neither criterion, however, can resolve all situations. Such is the case with walnuts (*Juglans*), elms (*Ulmus*), and hackerries (*Celtis*). Walnuts are represented by two species in Comanche County; black (*J. nigra*) and little (*J. microcarpa*). Both species have similar habitat requirements so confidently determining a species name was not possible. It should be noted, however, that Rice and Penfound (1959) and Buck (1964) only reported little walnut at the WMNWR. Elms are similar in that the two species known to occur in Comanche County (American elm and slippery elm) share habitat requirements.

The taxa of hackberries that occur in Comanche County span a range of ecologic conditions and have a complex taxonomy. Only two species of hackberry are reported from Comanche County, but the situation is confounded by subspecific taxa. Of the two species, southern hackberry or sugarberry (*C. laevigata*) and northern hackberry (*C. occidentalis*), sugarberry is represented by netleaf hackberry (*C. l.* var. *reticulata*) and Texas sugarberry (*C. l.* var. *texana*) (Hoagland et al. 2010). Buck (1962) lists *C. reticulata*, a synonym for *C. l.* var. *reticulata*. Thus we conclude that surveyors could have encountered any of these taxa.

Surveyors repeatedly identified some trees simply as "oak." Because eight oak species were reported in the WMNWR by Rice and Penfound (1959), Buck (1962, 1964), and Hoagland et al. (2010), no attempt was made to discriminate these entries to species. All references to oaks by the surveyors were simply attributed as *Quercus*.

Possible misidentifications of trees by surveyors are a difficult issue to resolve. Although likely misidentifications exist for all trees in the records, it is most evident for species that are outside their known geographic range. The number of these misplaced species in the WMNWR surveys is lower than in other GLO studies in Oklahoma, but two tree species regularly reported by GLO surveyors in central and western Oklahoma are pin oak (*Q. palustris*), Spanish oak (*Q. falcata*), and white oak (*Q. alba*) (Shulter and Hoalgand

2004, Fagin and Hoagland 2010, Thomas 2010).

Pin oak is known only from bottomland hardwood forests of eastern Oklahoma, however it is likely the surveyor's encountered Shumard's oak (*Q. shumardii*), which has numerous records from the WMNWR (Hoagland et al. 2010). The trees identified as pin oak could also be buckley oak (*Q. buckleyii*), which was reported by Rice and Penfound (1950) at the WMNWR and by Hoagland et al. (2010) in Comanche County. Since only one stem of pin oak was reported in 1874, it is considered of limited importance in the vegetation.

Of greater concern is the numerous trees recorded as white oak or black oak. White oak is an important tree of the eastern deciduous forest, and occurs primarily in the Ozark and Ouachita Mountains in Oklahoma. White oaks were reported in the 1874 and 1901-1902 surveys. It is possible that surveyors were referring to chinkapin oak, a deciduous forest species whose range extends the length of Oklahoma, and was reported by Rice and Penfound (1959) and Buck (1962, 1964) from WMNWR. It is also possible that some surveyors were using white oak and post oak synonymously. Regardless, the trees reported as white oak in the surveys were not *Q. alba*.

Black oak was reported in 1874, 1901-1902, and 1905. Although there are three records for black oak at WMNWR in the Oklahoma Vascular Plants Database (Hoagland et al. 2010), it was not listed by either Rice and Penfound (1959) or Buck (1962, 1964). In a GLO study from central Oklahoma it was demonstrated that surveyors often reported black oak at locations where blackjack oaks were the more likely species (Thomas and Hoagland 2009). In fact, townships in which only blackjacks were recorded bordered some townships that consisted entirely of records for black oak. It is difficult to discern if this is the case in WMNWR, but it is apparent that black oak has a disproportionately high percentage of the total basal area when compared to studies of modern cross timbers vegetation.

Bearing Tree Data. Surveyors recorded 280 stems in 1874 (Table 1), 284 in the 1901-1902, and 146 in 1905 (Table 2). Surveyors in 1901-1902 encountered several bearing from the 1874 survey as well as adding new trees. They noted that many of the 1874 trees were in a "good state of preservation" and opted not to remeasure them. The trees measured in the 1874 survey most likely increased in diameter during the intervening 17 years, so it was decided not to calculate basal area values for the 1901-1902 data. To do so would require combining diameter measurements from 1874 with the 1901-1902 data, which would misrepresent stand conditions in 1901-1902.

In the 1901-1902 survey, 88 trees were noted as having been measured in 1874, including black jack oak (7), black oak (28), cedar (1), elm (7), hackberry (1) honey mesquite (18), pin oak (1), post oak (25). The surveyors in both 1901-1902 and 1905 added trees that were not surveyed in 1874 (Table 3). These trees were noted by the surveyors and could be tracked between years. Not surprisingly, the greatest number of stems added was for dominant species such as post oak and black oak. The 1901-1902 survey added 168 (59%) trees of the 284 sampled. The 1905 five survey reported 101 (64%) new bearing trees of the 158 measured.

Bearing in mind the taxonomic caveats presented above, the most abundant tree species in 1874 were white oak with 74 stems (26.4%) and post oak with 61 stems (21.8%). Post oak (63%) and black oak (26%) were predominant trees in 1905 survey. Neither white oak nor blackjack was listed. The absence of blackjack is most likely the result of surveyor bias against this species. The findings for both survey years appear contrary to the data of Rice and Penfound (1959), Buck (1962, 1964), and Dooley and Collins (1984) that list post oak, blackjack oak, and eastern red cedar as the most common tree species.

In contrast to the explosive growth of eastern red cedar in the 20th century (Van Auken 2008), GLO surveyors reported only 5 (1.8%) stems in 1874 and 8 (5.5%) in 1905. Eastern red cedar is an aggressive grassland invader that is susceptible to fire (Rice and Penfound 1959, Johnson and Risser 1975). Historically, eastern red cedar probably was sheltered from fire in the rugged canyons and declivities of the Wichita Mountains, as confirmed timber descriptions such as "scrubby Oak & cedar" (1874) and "post oak & scattering cedar" (1905).

A striking feature of these data and other GLO studies in the Oklahoma cross timbers is the low number of stems and basal area reported for blackjack. In fact, the 1905 survey did not record blackjack as a bearing tree. Cross timbers stands have long been characterized by the co-dominance of post oak and blackjack oak (Hoagland et al 1999). Although the ratio of post oak and blackjack oak approaches 2:1 in 1874, as typically reported for the cross timbers (Luckhardt and Barclay 1938), both species are surpassed in total number of stems and basal area by *Q. alba*. It could be assumed the white oak (as identified by the surveyors) is actually chinkapin oak, but Buck (1962, 1964) and Dooley and Collins (1984) reported chinkapin oak as a minor forest component that is

TABLE 3. Tree species recorded in the resurveys of the Wichita Mountains National Wildlife Refuge. Surveyors re-measured bearing trees recorded in previous surveys and added new specimens. The columns stems 1902 and stems 1905 are a count of the total number of stems for each species reported by surveyors. The columns Added 1902 and 1905 Added refer to the number and percentage of stems added since the original General Land Office survey of 1874.

	Stems 1902	**Added 1902**	**% Increae**	**Stems 1905**	**Added 1905**	**% Increase**
Black oak	36	8	22.2%	38	32	84.2%
Blackjack oak	8	0	0.0%	0	0	0.0%
Cedar	5	4	80.0%	9	6	66.7%
Elm	8	1	12.5%	2	2	100.0%
Hackberry	1	0	0.0%	2	2	100.0%
Mesquite	19	1	5.3%	2	2	100.0%
Oak	22	22	100.0%	1	0	0.0%
Pin oak	1	0	0.0%	0	0	0.0%
Post oak	156	131	84.0%	102	55	53.9%
Spanish oak	0	0	0.0%	1	1	100.0%
Tree	2	0	0.0%	0	0	0.0%
Walnut	0	0	0.0%	1	1	100.0%
White oak	26	1	3.8%	0	0	0.0%
Totals	**284**	**168**	**59.2%**	**158**	101	**63.9%**

most abundant along drainage ways.

The presence of honey mesquite in the GLO records is noteworthy in light of modern concerns about woody plant encroachment. Throughout its range, honey mesquite is considered an invasive species, causing both ecologic and economic harm (Van Auken, 2000), but the historical distribution of honey mesquite in Oklahoma has not been well documented. Captain Randolph Marcy, in 1853, noted extensive "mezquite [sic] woodlands" in what is now southwestern Oklahoma (Foreman, 1937), but it was not reported from northwest Oklahoma until the 1920s (Tate 1928).

During both survey years, the highest total basal area values were scored by oaks, particularly white, black, and post oaks (Table 1 and 2). The highest basal area for individual tree species was scored by pin oak and post oak (4.56m^2 each) in 1874 and by post oak (2.45m^2) in 1905 (Table 2). The total mean basal area for all stems was less in 1905 (2.45m^2) than in 1874 (101.2m^2; Tables 1 and 2).

Six of the sites sampled by Rice and Penfound (1959) occurred within the WMNWR and in each of these stands, post oak and blackjack were the dominant species. Of the average basal area of 12.97 m^2/ha reported for Comanche County, 7.23 m^2/ha was post oak and 2.78 m2/ha for blackjack. A direct comparison between the GLO data and Rice and Penfound, however, is not possible because the GLO basal area values cannot be calculated by unit area. Nevertheless, Rice and Penfound did report a high basal area value for blackjack, which was negligible in

Although Dooley and Collins (1984) and Collins and Klahr (1991) collected DBH data, they did not report basal area values. Dooley and Collins (1984) do confirm the overwhelming dominance of eastern red cedar, blackjack, and post oak in the WMNWR. Although Collins and Klahr (1991) sampled over a broad expanse of Oklahoma, two sample sites were within the WMNWR. Like previous studies, they report blackjack and post oak as the dominant trees. Other constituent species listed were black hickory, gum bully, netleaf hackberry, northern hackberry, and American elm. Notably absent, however, is eastern red cedar.

Stem density is a basic forest stand measurement and numerous attempts have been to derive absolute stem density from bearing tree data (Bourdo 1956, Anderson et al. 2006). One of the greatest, or possibly insurmountable, hindrances is the scale of the data themselves; data are collected at 0.5 mile (0.8 km) intervals. Nevertheless, the point-to-plant distance measures can provide insight regarding plant spacing and density.

Point-to-plant distances between the 1874 and 1905 surveys had a comparable range, 0.6m to 58.2m in 1874 and 0.8m to 48.5m in 1905. Mean values 17.8m (standard deviation = 14.5, median = 13.1m, mode = 7.2m) for 1874 and 14.6m (standard deviation = 11.4, median = 11.0m, mode = 8.7m) in 1905. In 1874, the highest mean distance was scored by black jack oak, black oak, white oak, and post oak (Table 2). Distance values for 1905 greatest for post oak and black oak (Table 3).

The majority of point-to-plant distances fell between 0.1m-35 meters in 1874 (85.7%) and 0.1-20 (78.5%) in 1905. Most point-to-plant measurements were in 5-10 meter distance class for both surveys; 72 (25.7%) in 1874 and 51 (32.3%)in 1905 (Figure 2). There was a second peak in the 45.1-50m distance class (n=15) for 1874.

Collins and Klahr (1991) reported mean point-to-plant distances ranging from 1.25m to 2.83m for oak trees at 17 sites in central and western Oklahoma. The two stands sampled in the WMNWR had the greatest mean point-to-plant distances; 2.55m and 2.83m. These values fall in the lowest distance class of the GLO data, which possibly reflects the trend of decreasing point-to-plant distance between the 1874 and 1905.

Landcover Analysis. The same five landcover categories were recorded by surveyors in 1874 and 1905, forest-woodland, grassland, brush prairie, riparian forest, and mountains (Figures 3 and 4, Table 4). The term forest-woodland is used here on the assumption that polygons mapped as forest also contain woodland vegetation as is typical of the cross timbers. Unlike other areas in the cross timbers (Shutler and Hoagland 2004,

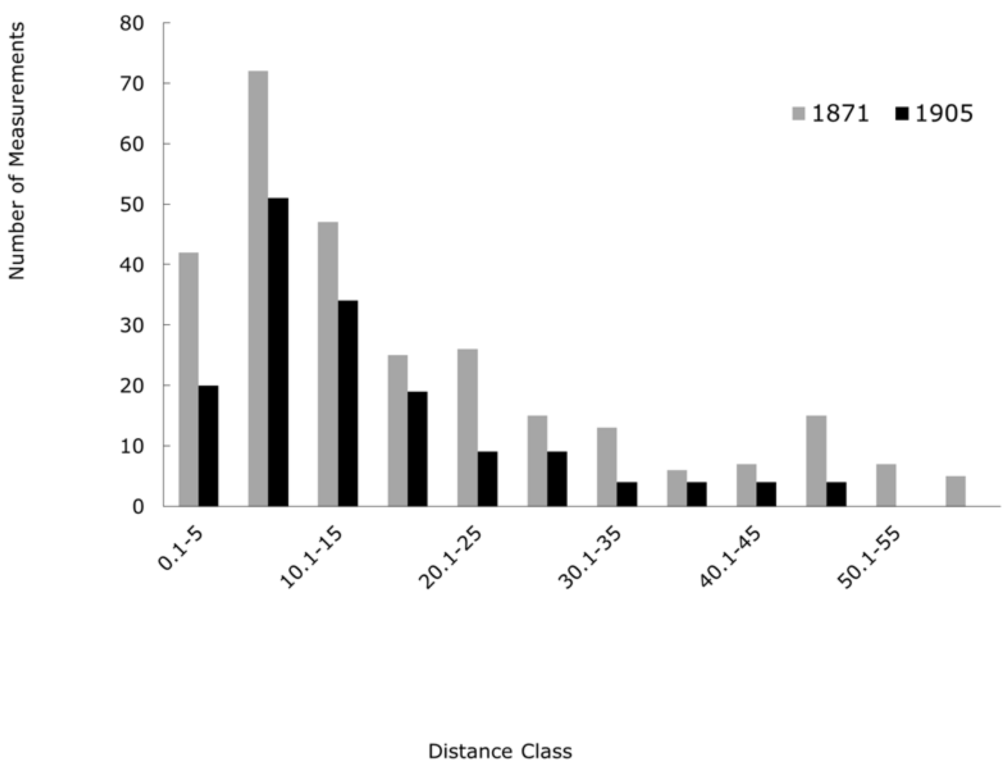

FIG. 2. Point-to-plant distance classes derived from the 1874 and 1905 bearing tree data for the Wichita Mountains National Wildlife Refuge.

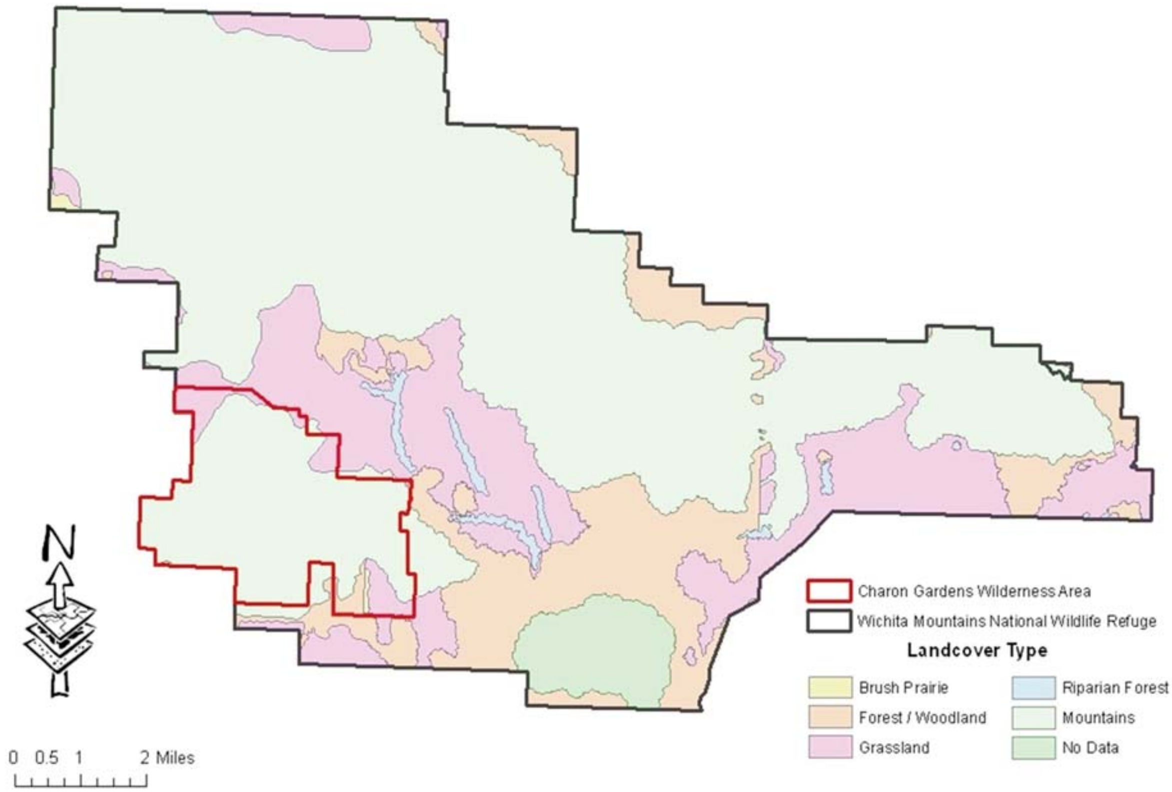

FIG. 3. Land cover of the Wichita Mountains National Wildlife Refuge compiled General Land Office plats from 1874.

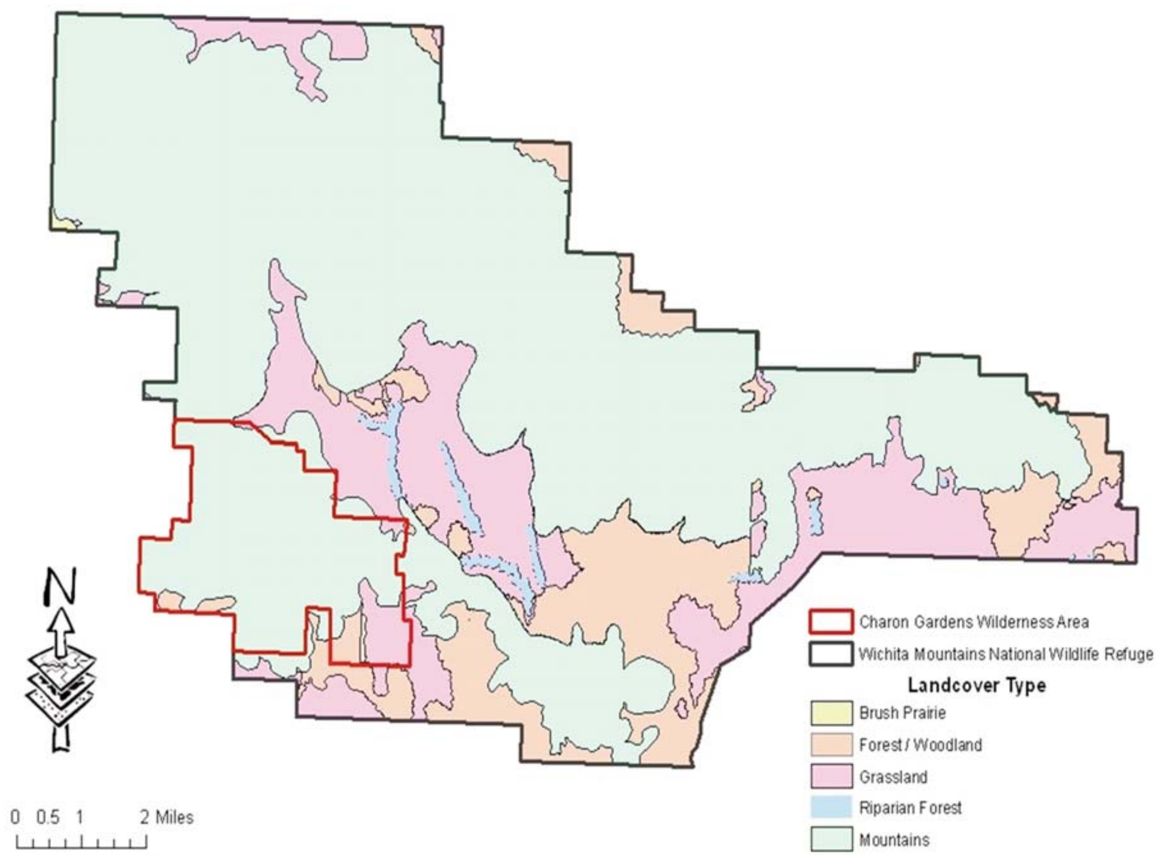

FIG. 4. Land cover of the Wichita Mountains National Wildlife Refuge compiled General Land Office plats from 1905.

TABLE 4. Landscape metrics for cover types mapped from General Land Office plats occurring within the Wichita Mountains National Wildlife Refuge.

Cover Class 1871	Number of Patches	Mean Patch Size	Class Area
No Data	1	782.1	782.1
Forest / Woodland	27	124.2	3,354.7
Grassland	19	239.0	4,541.8
Brush Prairie	2	17.8	35.7
Riparian Forest	10	22.9	229.2
Mountains	2	7,484.8	14,969.7
Total	**61**		**23,913**
Cover Class 1905			
Forest / Woodland	31	100.0	3,097.1
Grassland	22	199.1	4,379.3
Brush Prairie	3	9.4	28.3
Riparian Forest	10	22.0	220.1
Mountains	1	16,188.9	16,188.9
Total	**67**		**23,913**

the cross timbers. Unlike other areas in the cross timbers (Shutler and Hoagland 2004, Fagin and Hoagland 2010, Thomas 2010), no agricultural features or settlements were mapped by surveyors in either year.

The cover type referred to as mountains occupied the greatest total area in both years, 65.9% in 1874 and 67.7% in 1905. The discrepancy between the two years is negligible and does not represent an increase in that cover class. As might be expected, few polygons of this cover type were mapped; three in 1874 and 1 in 1905. (Note the category “no data” was combined with mountains for this analysis). This is fortunate, because no spatial information is provided for vegetation that occurred within those polygons. As noted above, the surveyors did not run section lines through these areas, so witness tree data are absent and we must infer vegetation composition from the timber descriptions.

Of the mapped vegetation types, grasslands are most extensive in both years. In fact, there is little difference between the calculated area and number of patches between survey years. In 1874, 19% of the land cover was mapped as grassland and 14% as forest-woodland, and in 1905, grasslands constituted 18% and forest-woodland 13% (Tables 3 and 4). The remaining vegetation categories represent less than 1% of the land cover.

Mean patch size does change substantially between survey years. Twenty-seven patches of forest woodland averaged 124.2 hectares were mapped in 1874. By 1905, the number of patches had increased to 31, with a substantial decrease in mean patch area. Grasslands occupied 19 patches averaging 239 hectares in 1874, but the number increased to 22 in 1905 and mean patch size decreased to 199 hectares. Are the differences in patch size and number a product of ecological forces? Possibly, but a more likely explanation is differences in mapping approach. As noted much earlier in this paper, GLO surveyors were not collecting ecological data and were not required to map changes in ecological condition.

CONCLUSIONS

As noted in the introduction, the upland forests of Oklahoma have been subjected to significant changes in structure since the 19th century. Desantis et al. (2010) listed four changes: 1) stem density and basal area has increased, 2) eastern red cedar abundance has increased substantially, 3) mesophytic tree species has increased in prevalence (i.e., elm spp., hackberry spp., gumbully, red mulberry and other species not encountered in the GLO notes), and 4) the predominance of Quercus species has declined. These statewide changes in forest composition were attributed to drought and fire suppression (Desantis et al. 2010).

Like all of Oklahoma, vegetation at the WMNWR has experienced drought at regular intervals and fire frequencies have been altered. Stambaugh et al. (2009) analyzed dendrochronological reconstructions and concluded that both fire frequency and intensity have decreased at WMNWR. Of particular relevance to this study is the finding that during the Civil War drought (1855-1880), tree growth rates decreased and fire frequency increased. Stambaugh et. al (2009) note that stem growth rates lagged until the early 20th century, which encompasses the time of the GLO surveys in Comanche County.

Conclusions cannot be drawn solely from GLO bearing tree data regarding a trend toward mesophication. Several mesophytic taxa were reported in 1874, including cottonwood, elms, hackberry, mulberry, pecan, and walnut (Table 1). None of these trees, however, were abundant and were mostly encountered where survey lines crossed a stream. In the 1905 data, interestingly, only two mesophytic taxa were reported; elm and hackberry.

As noted earlier, the surveyors under represented the abundance of eastern red cedar. We reached this conclusion by simply comparing the number of eastern red cedar trees recorded as bearing trees and the number of times it was mentioned in the timber summaries, so we encourage increased use of the summaries when making management recommendations rather than relying solely on the bearing tree data.

ACKNOWLEDGMENTS

This project was funded by U.S. Fish and Wildlife. We thank Ralph Godfrey and Jeremy Dickson of the Wichita Mountains National Wildlife Refuge and two reviewers for constructive comments.

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