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A predictive model to locate ancient forests in the Cross Timbers of Osage County, Oklahoma

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Abstract. The Cross Timbers are a mosaic of upland deciduous forest, savanna, and glade that typifies the broad ecotone between the eastern deciduous forest and the grasslands of the southern Great Plains. The pre-settlement Cross Timbers may have covered some 7,909,700 ha from central Texas, across Oklahama into eastern Kansas, and today may represent the least disturbed forest ecosystem of comparable size still left in the eastern United States. Extensive tree-ring research indicates that ancient forests dominated by 200 to 400 year old post-oaks (*Quercus stellata* Wang) survive throughout the Cross Timbers, particularly in Oklahoma. These ancient forests persist largely because the Cross Timbers formation is non-commercial for timber production, and has not experienced large-scale industrial logging. Because ancient forest relics are often found on stressful non-commercial sites in the Cross Timbers and elsewhere, it is possible to design predictive models to locate the specific terrain where undisturbed forests are likely to survive. A predictive model for southern Osage County, Oklahoma, was developed based on the steep, infertile soils of the Niotaze-Darnell complex. We tested the model with field inspection and tree-ring analysis of fifty randomly selected belt transects, and 74% of the sampled terrain is still old-growth Cross Timbers woodland. This translates into 8200 ha of ancient Cross Timbers on this single site type in southern Osage County. The abundance of ancient forest in the Cross Timbers is not widely appreciated. However, large contiguous tracts of ancient Cross Timbers up to 700 ha were identified with this predictive model, strongly supporting inferences concerning the relatively undisturbed nature of this ecosystem.

Key words. Ancient forests, cross timbers, dendrochronology, old growth, predictive model.

INTRODUCTION

The development of hundreds of tree-ring chronologies in the eastern United States indicates that many relatively undisturbed ancient forest remnants still exist, even though the pre-settlement forests were heavily logged (Meko *et al.*, 1993; Stahle, Cleaveland & Hehr, 1988; Cook *et al.*, 1996). Most of these ancient forest remnants survive because it has not been economical to cut them. These 'non-commercial' ancient forests tend to be found on steep and/or infertile terrain that limits their economic value. The specific geographical distribution of non-commercial terrain variables such as poor soils on steep slopes can be used to develop predictive models to locate areas with high potential to retain ancient forest remnants. Stahle & Chaney (1994) developed and tested an *a priori* predictive model based on environmental variables associated with non-commercial forest lands, and were able to locate previously unknown ancient forests in the Ozark Mountains of western Arkansas.

The Cross Timbers are upland post oak-blackjack oak (*Quercus stellata* Wang; *Quercus. marilandica* Muenchh) dominated forests that form the broad transitional boundary between the eastern deciduous forest and the grasslands of the southern Great Plains (Johnson & Risser, 1975). The origin of the term 'Cross Timbers' is unknown, but the name may have originated when early settlers travelling west had to cross successive bands of open prairie and dense upland forest. The pre-settlement Cross Timbers may have covered nearly 8,000,000 ha (Kuchler, 1964), stretching from southeastern Kansas through eastern Oklahoma and into central Texas (Fig. 1). Duck & Fletcher (1945) identified the Cross Timbers as the 'post oak-blackjack oak cover type' and estimated the size of this formation in Oklahama, to be 4,400,000 ha, larger than all other forest types in Oklahoma combined (Fig. 2). Extensive dendrochronological field research by the University of Arkansas Tree-Ring Laboratory indicates that large intact tracts of ancient forest remain in the Cross Timbers region (Stahle & Hehr, 1984; Stahle *et al.*, 1985).

The irregular distribution of the Cross Timbers in the south-central USA appears to be controlled largely by the pattern of underlying soils. The upland Cross Timbers are confined to coarse textured soils derived from sandstone parent material, while grasslands tend to dominate the finer textured soils of this region (Bruner, 1931; Dyksterhuis, 1948; Rice & Penfound, 1959).

Tree growth in the Cross Timbers is typically very slow due in part to the relatively low rainfall in this marginal climate zone (880 mm annually), and because Cross Timbers soils tend to be low in natural fertility (Soil Conservation

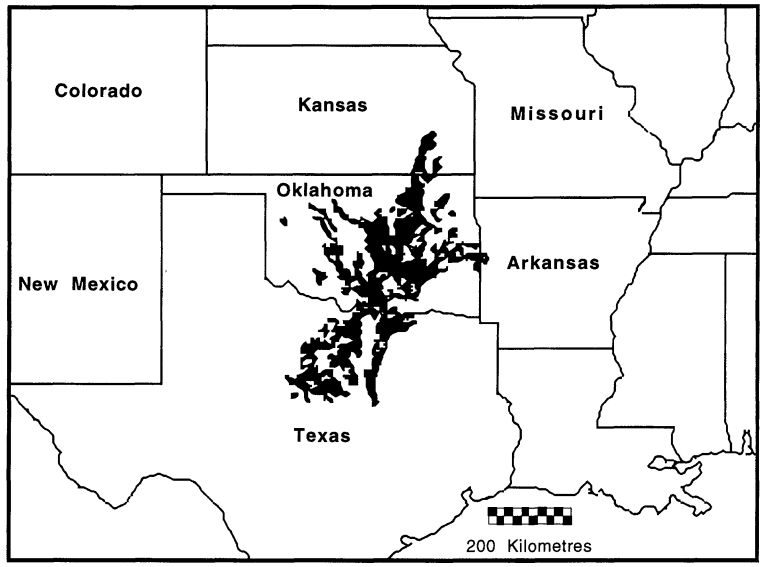

FIG. 1. The potential natural range of the Cross Timbers as mapped by Kuchler (1964) is estimated to cover an area of 7,909,700 ha. The Cross Timbers form an edaphically controlled ecotonal community between the deciduous forest of the eastern United States and the grasslands of the southern Great Plains,

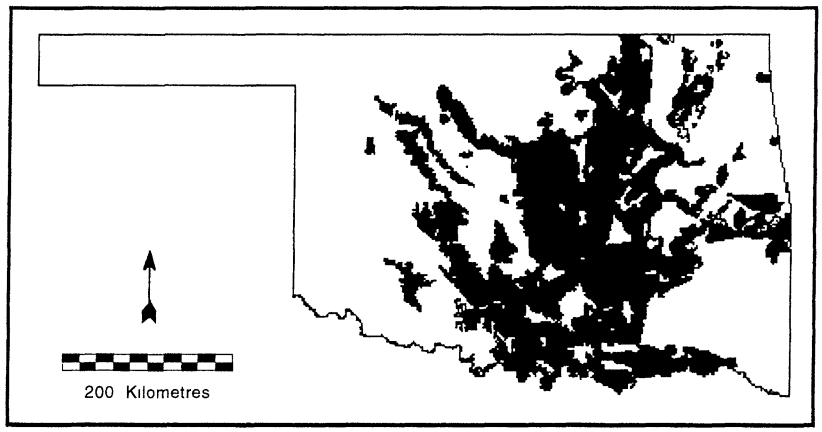

FIG. 2. Duck & Fletcher (1945) produced the first detailed map of the Oklahoma Cross Timbers which they describe as the 'post oak-blackjack oak' (*Quercus stellata* Wang; *Q. marilandica* Muenchh) forest. They estimated that this type covers over 4,400,000 ha, which is greater than all other forest types in Oklahoma combined (3,100,000 ha).

Service [SCS], 1979). Consequently, this entire forest ecosystem is essentially non-commercial for timber production (Rossen, 1994). The post oaks that dominate the canopy rarely exceed 15 m in height and 60 cm in diameter, but live for hundreds of years (Fig. 3).

While much of the Cross Timbers on level ground has been cleared for agriculture or sprayed with herbicide to release native grasses for pasture, stands on rugged or steep terrain often escaped such treatment (Fig. 4). Therefore, we propose that literally thousands of ha of ancient Cross Timbers survive in Oklahoma and to a lesser extent in Texas and southeastern Kansas. To test this hypothesis in north-central Oklahoma, we developed a simple predictive model to locate tracts of ancient Cross Timbers vegetation based solely on the distribution of poor soils on steep slopes which support Cross Timbers forests in Osage County, Oklahoma (Fig. 5). Cross Timbers are extensive in southern and eastern Osage County occurring on at least three separate soil associations that make up about 34% of the county as a whole and at least 60% of the study area (SCS, 1979). These soils are typically coarse textured, shallow, and low in natural fertility (SCS, 1979). We predict that soils found on the steepest (15–45%) slopes of the Niotaze-Darnell complex have a high potential to still retain ancient forests, regardless of exposure. Niotaze-Darnell soils which constitute our predictive model, cover an area of 11,308 ha within the 150,000 ha study area in southern Osage County (Fig. 6).

METHODS

To test the predictive model we developed a computerized Geographic Information System (GIS) using Geographic

FIG. 3. A typical mature to old growth post oak (*Quercus stellata* Wang) some 30 cm in diameter and 8 m tall. Dendrochronological analysis indicates that this tree is over 250 years old. It displays many of the morphological features characteristic of ancient trees. Notice the restricted canopy composed of only a few heavy limbs, the lateral twist of the bole, old branch scars, lightning scar, and the broken and partially hollow top.

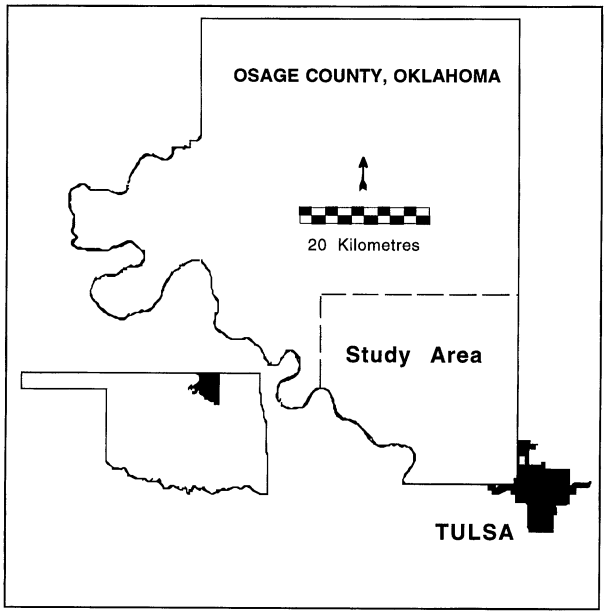

FIG. 5. Osage County is the largest county in Oklahoma (601,546 ha; map adapted from Goodman 1977), and until 1907 was the Osage Indian Reservation. We limited our study to an area of approximately 150,000 ha south of 36° 30′ N latitude (study area indicated by dashed lines in southern Osage County).

Resource Analysis Support System software (GRASS; United States Army Corps of Engineers, 1988), and digital soil data provided by the Soil Conservation Service (SCS, 1979). The digital soil data are in raster format with a cell size of 4 ha. In the first stage of analysis we used the GIS to identify and combine all cells representing the two Niotaze-Darnell soil types with slopes of 15–25% nd 25–45% and to eliminate all other cells. A clumping routine was then used to merge the selected cells into contiguous polygons. We

FIG. 4. The non-commercial nature of the Cross Timbers is due to the marginal climate, infertile soil, and rugged terrain, which often result in the stunted and mis-shapen growth of post oak (*Quercus stellata* Wang) trees which dominate this forest type.

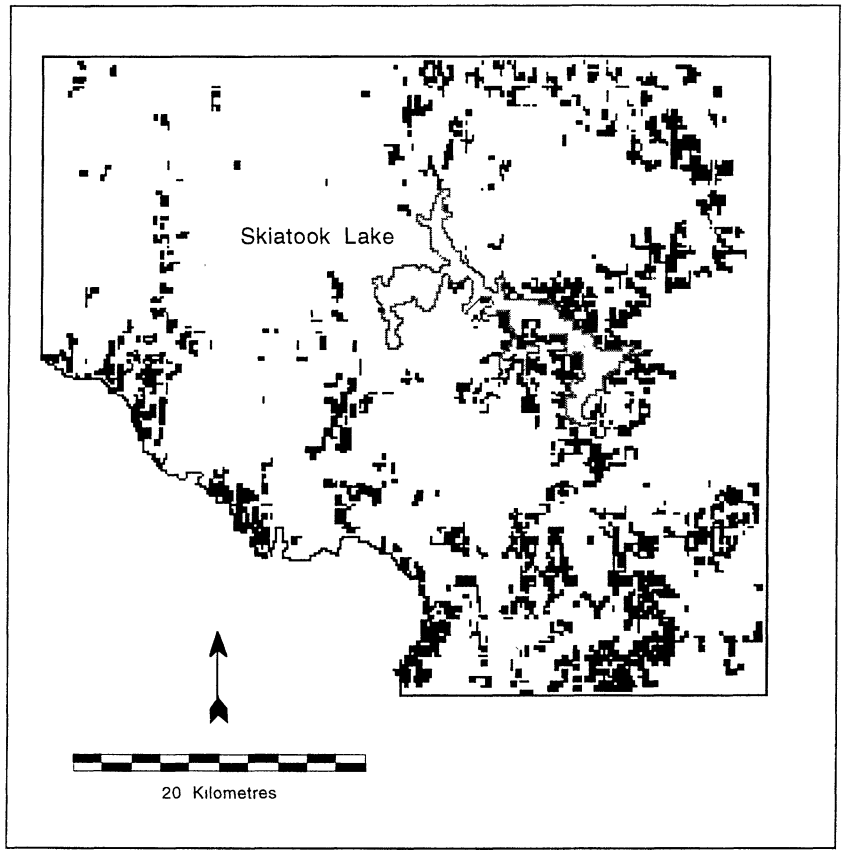

FIG. 6. Black shading indicates areas predicted to retain ancient Cross Timbers forests. This predictive model is based on the distribution of the soils of the Niotaze-Darnell association on slopes of 15–45%, which covers approximately 11,308 ha within the study area. Field testing of fifty randomly selected belt transects, and tree-ring analysis indicate that 74% (8225 ha) of these steep Niotaze-Darnell soils still retain undisturbed ancient forests.

also eliminated polygons less than 8 ha in size. The retained polygons of steep Niotaze-Darnell soils cover 11,308 ha, and represent the specific area predicted to retain ancient Cross Timbers in southern Osage County (Fig. 6). Fifty belt transects were used to field test the predictive model (Table 1). These belt transects were established by randomly selecting 100 points from within the 11,308 ha area predicted to retain ancient Cross Timbers (100 transects were selected sequentially with replacement, in case access to private property was denied at particular transects). An azimuth bearing from 1° to 360° was then randomly generated for each selected point, and the midlines of the 60 m wide transects were drawn on 1:24,000 scale topographic maps. The midlines extend through the cell centres to the margin of the soil polygon along the random aximuth (and its inverse). In two cases where transects overlapped within a polygon, the shorter transect was deleted.

We examined the full length of each transect and classified the vegetation cover into one of four categories. The linear extent of each cover category within every transect was measured using a hip-chain device. The four vegetation cover categories identified in the fifty belt transects were: unaltered ancient forest, cull forest, second growth, and cleared land (Table 1). Our criteria for the classification of 'unaltered ancient forest' included the presence of 150 to over 300 year old trees in an unaltered forest canopy. Ancient forests were also identified based on other characteristics such as the presence of all age classes (from juvenile to overmature trees), standing dead snags, coarse woody debris in all stages of deterioration, and the absence of human disturbances such as stumps, roads, or structures. An abundance of disturbance indicating species would also not be consistent with undisturbed old growth conditions. Areas identified as 'cull forest' had evidence of past human disturbance, and old defective cull trees were scattered throughout a younger second-growth forest. The 'second growth' category refers to forest stands dominated by young trees (<100 years old) where post human disturbance is abundant and no old trees (>100 years) are present. 'Cleared land' refers to formerly wooded terrain that has been cleared for agriculture, range, or development.

All fieldwork was conducted under leaf-off conditions during the winter of 1995 (Jan.–Feb.), to facilitate the identification of structural features typical of ancient forests and the other cover classes. In each sample transect where ancient forest cover was identified, increment cores were

TABLE 1. The total length (m) of each randomly selected belt transect is listed along with the linear distance (and present total transect length) for each forest cover category identified within each transect. Each transect was 60 m wide, so the total area sampled was 20888 × 60 = 1,253,280 m^2 or 125 ha. Ancient forest was measured on 15,534 m within the sample transects, which totals an area of 93 ha (i.e. 15534 × 60 = 932,040 m^2), which is 74% of the total transect area. Ancient forest was found on part or all of thirty-nine out of the 50 belt transects, and seventeen transects were 100% ancient forest. The criteria used to classify vegetation cover into each of the four categories are explained in the text.

Transect number	Transect length	Ancient forest		Cull forest		Second growth		Cleared land	
		m	(%)	m	(%)	m	(%)	m	(%)
01	347	347	100						
02	1300	1300	100						
03	1100	950	86	150	14				
04	250	250	100						
05	625	625	100						
08	400	400	100						
09	1300	1250	96					50	04
11	595	452	76			37	06	106	18
12	589	475	81	45	08	37	06	32	05
13	250	40	16	162	65			48	19
14	850	840	99					10	01
15	479	461	96					18	04
16	204	204	100						
17	544	281	52	88				175	32
18	165			165	100				
19	144			144	100				
20	71					71	100		
22	171	156	91					15	09
23	576	576	100						
24	177					177	100		
25	160							160	100
26	310	310	100						
27	770					770	100		
28	200	50	25	150	75				
29	534	277	52	125	23	54	10	78	15
30	192	132	69	60	31				
31	118	118	100						
32	190							190	100
33	55	55	100						
34	91			91	100				
35	74			74	100				
36	331	178	54	56	17			97	29
37	830	760	92	50	06			20	02
38	526	526	100						
39	406	406	100						
41	1192	1087	91					105	
44	288	288	100						
45	566							566	100
47	192							192	100
48	510	261	51	127	25	122	24		
49	210			210	100				
50	186	186	100						
51	65	65	100						
53	272	211	78	40	15			21	08
54	316	316	100						
55	308	158	51	141	46			9	03
56	263	136	52					127	48
57	956	911	95					45	05
58	144			144	100				
59	496	496	100						
Total	20888	15534	74	2022	10	1268	06	2064	10

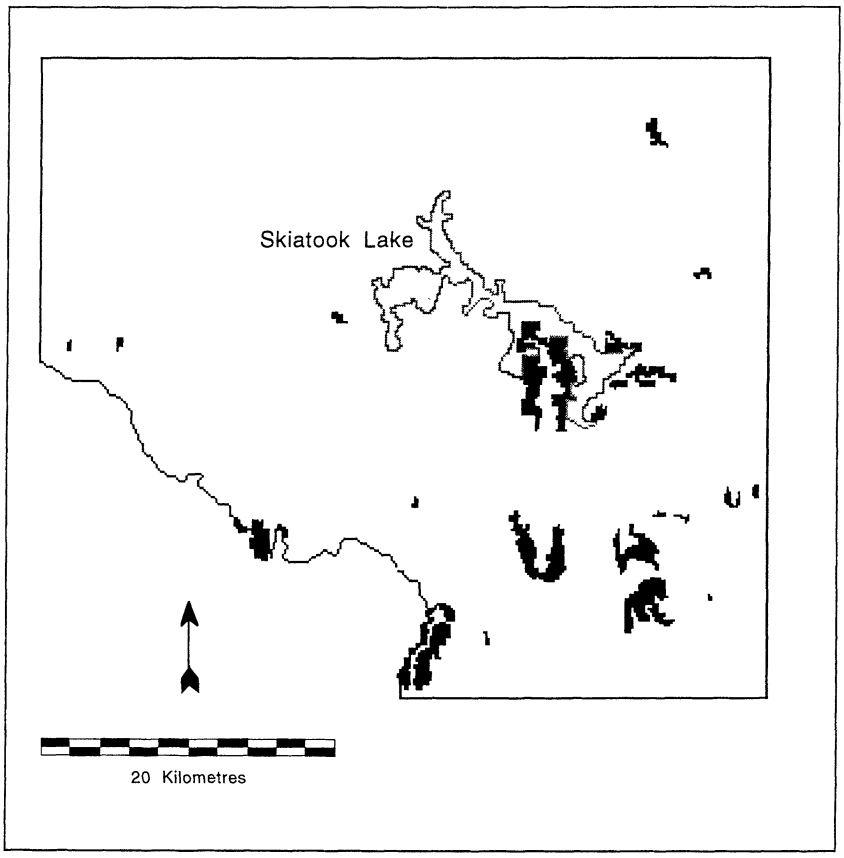

FIG. 7. This map shows the actual size of the twenty-four ancient forest parcels located during field examination of the fifty belt transects (black polygons). These parcels were completely surveyed and total 3032 ha, but we estimate that a total of 8225 ha of ancient Cross Timbers still survive throughout the study area. Although these areas may contain small pockets of disturbed landscape, at least 90% of these parcels are undisturbed ancient forest. Six of these parcels are more than 200 hectares in size.

extracted from at least three trees which appeared to be mature canopy dominants. All increment cores were crossdated against regional tree-ring chronologies to establish exact calendar dating and determine minimum tree age (Stokes & Smiley, 1968).

To help document the size range of ancient forest parcels within the study area we visually inspected the full extent of all ancient forests located within the random transects, and mapped the boundaries of these parcels on 1:24,000 scale topographic maps (not shown). Some of the ancient forests mapped outside the 60 m wide transects included small areas of human disturbance such as dirt roads or oil exploration clearings. However, we estimate that these impacts constitute less than 10% of the ancient forest parcels and do not seriously detract from the natural character of these large contiguous remnants of the ancient Cross Timbers. The full size of these ancient forest parcels was then computed manually off the 1:24,000 scale topographic maps, and the distribution of these parcels is plotted on a scale map of the study area (Fig. 7).

RESULTS

Ancient forest cover was identified on 92 ha of the 125 ha specificially surveyed within the fifty randomly selected belt transects (Table 1). This represents 74% of the random sample of steep Niotaze-Darnell soils that are the basis of this ancient forest predictive model. Because the population of steep Niotaze-Darnell soils that was randomly sampled covers 11,308 ha, we estimate that 74%, or 8,255 ha, still retain ancient Cross Timbers forest in the southern Osage County study area. In addition, ancient forests were found on at least part of thirty-nine out of the fifty belt transects sampled, and nineteen transects were completely covered with ancient forest. The success of this simple predictive model provides emphatic evidence of the widespread survival of ancient Cross Timbers on non-commercial sites in Osage County. These results also support, but do not prove, the notion that the Cross Timbers may be one of the least disturbed forest types in the eastern United States (Stahle, 1996).

The diversity of the ancient Cross Timbers woodlands found in the belt transects was surprising for these dry upland forests, and appears to reflect the dissected terrain which strongly mediates insolation and soil moisture by aspect. Dry south-facing slopes often support stands of stunted post oak and blackjack oak in the study area. Ancient eastern red cedar (*Juniperus virginiana* L.) 200 to 500 years old are common on sandstone cliffs and large rock outcrops where the hardwood canopy is especially

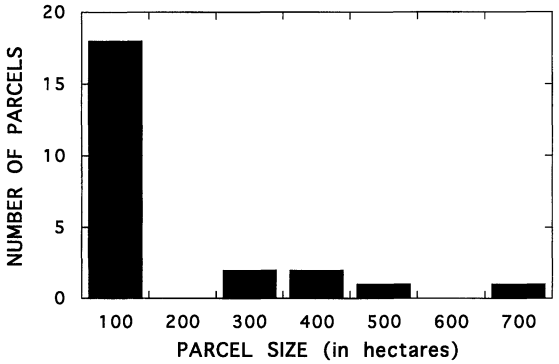

FIG. 8. The size of each ancient forest parcel illustrated in Fig. 7 was measured by overlaying a one ha grid on the 1:24,000 scale maps of these parcels. This is by no means all the ancient Cross Timbers in southern Osage County, which we estimate to cover over 8000 ha. This is only the size data for the parcels actually located and mapped during the field examination of the 50 randomly selected belt transects. Nevertheless, these twenty-four parcels were located randomly, and do provide an interesting preliminary estimation of the size distribution of ancient Cross Timbers forests still left in southern Osage County.

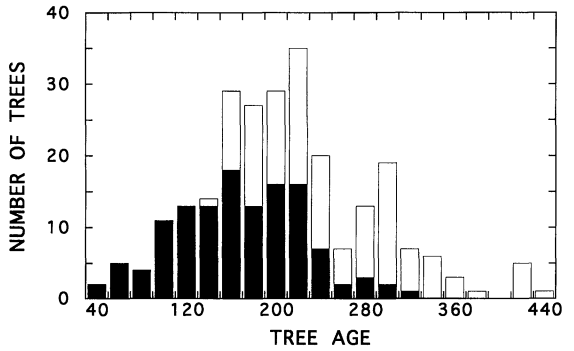

FIG. 9. Age distribution of selected mature to old-growth post oaks based on dendrochronological analysis of annual growth rings obtained from 123 increment cores from the thirty-nine transects where ancient forest cover was encountered (black). Because many trees were partially hollow, the true age was also estimated (white).

open and the cedars are somewhat protected from fire. Black oaks (*Quercus velutina* Lam.) and occasionally shumard oaks (*Quercus shumardii* Buckl.) up to 150 years old were common on relatively mesic north-facing slopes, and in deep ravines. Many small grasslands that appear to be edaphically controlled native glades were also found within these ancient woodlands.

The three artificially disturbed cover classes (cull; second growth; cleared land, [Table 1]) only amounted to 26% of the land area within the transects. Much of the cull forest type appears to have experienced intensive grazing, selective logging, and changes in fire frequency (e.g. Rice and Penfound, 1959). These pressures tend to produce an open understory and gaps in the overstory canopy.

The aerial application of broad-leaf herbicides has also been widely used on relic Cross Timbers to release understory grasses. The frequent result of this spraying is a rather grotesque landscape of half-dead skeletal trees with stunted leaves sprouting from their trunks. When found within a transect this artificially disturbed forest type was included in the cull category. The cleared land category included woodland converted to rangeland, housing developments, roads, and oil wells.

The true boundaries of all ancient forest parcels located within the fifty belt transects were mapped within and beyond the transects on 1:24,000 scale topographic maps during fieldwork. The median size of these parcels was 51 ha and ranged from 1 ha to 700 ha (Fig. 8). Six parcels of ancient Cross Timbers are over 200 ha in size. Small areas of human disturbance were identified within some ancient forest parcels, but we estimate that these disturbances represent less than 10% of the land area included in the ancient forest parcels and do not seriously detract from the natural character and function of these old-growth forests. Twenty-four parcels of ancient Cross Timbers specifically mapped during fieldwork include over 3100 ha of previously undocumented ancient Cross Timbers forest, but represent less than half of the 8300 ha estimated by the predictive model to still exist in southern Osage County.

Tree-ring dating of increment cores from 123 mature post oak trees found in the ancient forest transects indicates that the canopy dominant trees average at least 221 years in age, and some post oak trees survive for 350–400 years (Fig. 9). Selected core sampling indicates that some of the *Juniperus virginiana* trees exceed 500 years in age. These tree-ring analyses strongly confirm our visual assessments concerning the presence of ancient forest within the belt transects, and incidate that many of the individual trees in these ancient Cross Timbers woodlands predate the European settlement of the central United States.

DISCUSSION

Field testing indicates that this simple predictive model is very accurate at locating ancient Cross Timbers woodlands in southern Osage County, and certainly supports the notion that the Cross Timbers is one of the least disturbed forest ecosystems still left in the eastern United States. Our results indicate that the steep Niotaze-Darnell soils in this portion of Oklahma still retain 74% of their original old-growth Cross Timbers cover, which represents a total ancient forest area of approximately 8200 ha on this single soil type. Had we used recent aerial photography to eliminate cleared land, the accuracy of this predictive model may have increased by 10% (note the fraction of cleared lands in Table 1).

The diversity of these ancient woodlands appeared to be strongly mediated by the effects of aspect and substrate. Post oak in the 200 to 400 year age class was the clear dominant on most positions. Blackjack oak was present on virtually all stands but rarely appeared to be dominant. Eastern red cedar 200 to over 500 years old were common on rock outcrops and as canopy co-dominants with post oak on certain steep rocky exposures. Also, protected north-facing slopes were often dominated by black oak and shumard oak. Although limited increment core sampling indicates that these trees do not live as long as post oak, these black and shumard oak stands showed no evidence

for human disturbance, and included or were surrounded by ancient post oak trees.

The predictive model was restricted to the large area in Osage County, but if the study area is at all representative of the Oklahoma Cross Timbers in general, then many thousands of ha of relatively undisturbed woodlands may survive in the non-commercial forests of this ecosystem. Because the ancient Cross Timbers mosaic includes numerous savannas and small glades, the largest quantity of relatively undisturbed savanna and glade vegetation left in the eastern United States may exist within the ancient Cross Timbers. Unfortunately, our first hand experience indicates that awareness of the true abundance and antiquity of the Cross Timbers is low among scientists, land managers, and the public. At the same time, the ancient Cross Timbers face an increased risk of destruction as the economics of rural land use change in response to factors such as suburbanization and the rising demand for hardwood fiber by the wood products industry. These results demonstrate that predictive models developed to locate relatively undisturbed ancient forests are potentially valuable land management tools, particularly where the distribution of non-commercial forests is dictated by the occurrence of unfavorable soils or terrain. Candidates for the development of old-growth predictive models might include chestnut oak (*Quercus prinus* L.) dominated ridge lines in the Appalachian Mountains; nutrient-poor bald cypress (*Taxodium distichum* L.) swamps on blackwater streams in the southeastern United States; blue oak (*Quercus douglassii* Hook. & Arn.) woodlands in California; white and black spruce (*Picea gluaca* Moench and *Picea mariana* Mill) in the boreal forests of North America; and *Juniperus procera* (Hochst. ex Endl.) bush on the Rift Valley Escarpment of East Africa.

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