OAK REGENERATION IN THE CROSS-TIMBERS OF OKLAHOMA

By

GEORGES FERDINAND BACKOULOU

Bachelor of Science

University Marien Ngouabi

Brazzaville, Congo

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I dedicate this thesis to late Paul Kalele, my brother and best friend, who always encouraged me to achieve this dream although he will never have the chance to read my thesis or see me graduate. Paul has been a part of my life in every way and this dedication is so little for the greatness he has been to me.

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PART I

INTRODUCTION

Background

The Cross-Timbers region is a mosaic of tallgrass prairie and oak woodland. This area extends from Kansas to North Texas (Fig. 1) and occupies 12 million acres (5 million ha) of Oklahoma (Engle, Bidwell, and Masters, 1996). Other names for this area are oak savanna or upland forest (Ewing, Stritzke, and Kulbeth, 1984) where blackjack oak (*Quercus marilandica* Muenchh) and post oak (*Quercus stellata* Wangenh) are the most important and widely distributed species (Rice and Penfound, 1959; Johnson and Risser, 1973). Species in the Cross-Timbers are historically maintained by disturbances such as fire (Engle, Bidwell, and Masters 1996) and their diversity is determined by the microclimate (Rice 1960, 1962). In addition, Johnson and Risser (1973) found a correlation between rainfall and growth of blackjack and post oak around the Lake Thunderbird Research Area, east of Norman, Oklahoma.

Blackjack oak and post oak in the Cross-Timbers represent the majority of the tree canopy cover and the basal area. Both species belong to the beech family (Fagaceae) and genus *Quercus* (Little, 1981). Post oak is classified in the group of white oaks, subgenus *Leucobalanus* and blackjack oak is a black oak subgenus of *Erythrobalanus* (Smith, 1993). They are monoecious plants with separate staminate catkins and pistillate flowers on the same tree. The flowering process starts in the early spring and acorns develop, mature and fall from the tree in the autumn for the white oaks, whereas red oak acorns reach maturity in the second growing season (Watt, 1979).

The growth of both species is very slow. They are sensitive to shade and competition. According to Lorimer (1993), the regeneration of oaks is a serious problem. Most of the reproduction is from sprouting (Liming, 1942; Stransky, 1990). Because of the dominance and the abundance of *Q. marilandica* and *Q. stellata* in the canopy cover of the Cross-Timbers of Oklahoma, a study on regeneration was deemed timely to help understand oak forest management. In addition, the limited number of studies on the role of fire in oak regeneration in the Cross-Timbers of Oklahoma indicated the need for further research.

Purpose of the study

The purpose of this study was to assess the effect of fire on the regeneration of oak. Two different seasons of fire, growing and dormant, were compared in three locations where fire behavior and fire seasons had been studied. The objectives of the study are to determine whether there are significant differences in densities of seedlings, saplings, and in basal area between growing season fires and dormant season fires, as compared to unburned area.

PART II

REVIEW OF LITERATURE

There are as many valid perspectives as there are researchers concerned with the Cross-Timbers. This paper does not make an exhaustive review of all the studies conducted in the Cross-Timbers. Some studies will be from other ecosystems to support findings in the Cross-Timbers research.

This literature review has been divided into three sections. Section one examines the environment that explains the vegetation type in the Cross-Timbers. Section two provides an overview of vegetation in the area. Section three gives an overview of fire in mature oak forests.

Physical Environment

Climate

The Cross-Timbers region is located in a subtropical, humid, climate zone. It is characterized by hot summers and mild-winters (Trewartha, 1968). Precipitation decreases longitudinally from east to west, from 120 to 60 cm annually (Fig. 2). Mean annual temperature varies latitudinally from 15°C in the north to 19°C in the south. Most of the rain occurs during the spring months (Harrison, 1974). The length of the growing season varies from 180 days in the north to 240 days in the south. Other characteristics include frequent drought and a high frequency of hail and tornado activity (Court, 1974). The spatial distribution of weather elements is affected by winds and the mid-troposphere pressure (Corcoran, 1982). The warm, moisture laden air that arrives from the south (Gulf of Mexico) in early summer initiates bud-break and flowering in the eastern Cross-Timbers (McClusky, 1972).

Soils

Soils in the Cross-Timbers region originated from three major geological formations: Pennsylvanian, Permian and Cretaceous sedimentation. According to Hunt (1974), these formations dip westward and strike north to south. Pennsylvanian formations are in plains and ridges in Oklahoma and Kansas. Permian shales and sandstones form hills and plains that extend westward (Curtis and Harn, 1972). The Cretaceous formations are substantial deposits of soils along the major Cross-Timbers streams and rivers that include the Arkansas, Brazos, North Canadian, Cimarron, South Canadian, Trinity and Washita Rivers (Anonymous, 1968).

Engle and Stritzke (1992) found larger trees on the Cross-Timbers growing on deep coarse texture soils. Powell and Lowry (1980) described savannas with trees in dense motts produced from heavy textured and shale derived soils. Fine textured clay soils from limestones and shale produced prairie and glade vegetation (Dyksterhuis, 1948; Rhodes, 1980).

The prominent soils throughout the Cross-Timbers are Alfisols, with minor components of Inceptisols (Godfrey, McKee and Oakes, 1973). The major soil series are Windthorst and Stephenville, which belong to the Paleustalf Great Groups and Haplustlf Great Groups respectively. Darnell soils are Inceptisols and belong to Ustochrept Great Group. In the northern Cross-Timbers, the Stephenville and Darnell soils are most prominent while Windthorst are most common in the south (Godfrey, McKee and Oakes, 1973; Aandal, 1982).

Vegetation and Species Composition

Vegetation in the Cross-Timbers

Three events are related to the origin of vegetation in the Cross-Timbers: the Miocene uplift of the Rocky Mountains, the growth of Antarctic ice sheet, and the cooling of ocean waters. These events increased the aridity in central North America and promoted the development of grasslands (Axelrod, 1985). Delcourt and Delcourt (1981) stated that jack pine and fir were displaced by the migration of oak and hickory into eastern Oklahoma flora some 12,000 years ago. During roughly the same period, prairie vegetation established on the southern plains while oak savannas were already existing in the region. The warmer and drier climate later facilitated the spread of prairie, oak, and oak-hickory into Interior Highlands (Delcourt and Delcourt, 1981). Some studies suggested that hickory species were abundant in northeastern Oklahoma and declined as oak species increased (Hall, 1982).

Presently, post oak and blackjack oak are dominant and characterize the Cross-Timbers. They represent 90 percent of the canopy cover and 50 percent of the basal area (Dyskerhuis, 1948; Rice and Penfound, 1959). Black hickory (*Carya texana*), black oak (*Quercus velutina*) and red cedar (*Juniperus virginiana)* are tree species of secondary importance in the Cross-Timbers (Rice and Penfound, 1955; Penfound, 1963; Johnson and Risser, 1972). Black hickory and post oak respond to soil fertility and moisture gradients. Black oak can tolerate low soil fertility but requires relatively high soil moisture (Johnson and Risser, 1972).

The Cross-Timbers are a mosaic of prairies, woodlands and savannas. In the prairies the dominant grass species is little bluestem (*Schizachyrium scoparium*), followed by big bluestem (*Andropogon gerardii*) and Indiangrass (*Sorghastrum nutans*) (Kuchler, 1964).

Species Composition in the Cross-Timbers

Species composition and distribution in the Cross-Timbers vary according to the topography (upland and bottomland), soil type, and climate. Bruner (1931), Rice and Penfound (1959), sampled and described the upland forests of Oklahoma. The upland was divided into the following associations: oak-loblolly pine forest, oak-hickory-pine forest, oak-hickory forest, oak hickory savanna, and oak-savanna (Rice and Penfound, 1959). Rice (1965) examined the bottomland forests of north central Oklahoma. Bruner revealed in his study that "the deciduous forest formation occurred in eastern Oklahoma and was represented along the streams westward." The diversity of species in Oklahoma decreases along the precipitation gradient while concentration of dominance species increased along a gradient of decreasing precipitation from east to west (Risser and Rice, 1971).

Sources of Oak Regeneration and Its Problems

Sources of Oak Regeneration

Oak forests regenerate from seed and vegetatively from stump sprouts. Johnson (1993) described three forms of oak reproduction: seedlings, seedling sprouts, and stump sprouts. Seedlings result from seeds and generally have not yet experienced shoot dieback. After dieback, seedlings become seedling sprouts, and may persist for decades (Johnson, 1993). Stump sprouts originate from the stump of top cut trees or from trees killed by fire or injury. According to Johnson (1993), the number, size and spatial distribution of oak advanced reproduction and the capacity of the overstory to produce oak stump sprouts, can be used to assess a stand for oak regeneration potential. The oak regeneration potential is the capacity to establish and to dominate growing space at a specific time in the new stand (Johnson, 1993).

Problems in the Oak Regeneration

Oaks dominated the Central hardwood forest in the past In the past. However, after they are harvested, other hardwood species dominate stands (Lorimer, 1993). In his study, Lorimer (1993) examined several possible causes of regeneration failure that included acorn predation, climatic changes, and damage to seedlings by insects and animals, and competing vegetation due to decreased fire frequency. He noticed a failure of a great number of oak seedlings under mature stands even when released from competition.

Effects of Fire on Oak Regeneration

Fire plays an important role in the establishment of many stands where oak species are dominant (Crow, 1988). Byington and others, (1983) stated that fire was used as a tool to manage livestock grazing and to change the species composition for diverse purposes. Fire was said to be the dominant factor that affected species composition. The presence of oaks is associated with recurring fire over centuries of time. Oak development has occurred through ecologically dynamic disturbance conditions (Abrams, 1992).

Oaks and the Physical Environment

Oaks are midsuccessional species. On better sites (moisture and nutrients available), their replacement is predicted where the understory is composed and dominated by other tree species, such as *Celtis* and *Ulmus* (Abrams, 1986). On poor sites, there is a severe competition for limiting resources (water and nutrients). Oaks take advantage of their ability to resist drought and infertile soil conditions. They overtake less tolerant species and dominate stands. Thus, the exclusion of fire in droughty and infertile sites promotes oak species. In contrast, frequent fire promotes savannas grasses (e.g. tallgrass prairie) where species such as *Andropogon* become established and dominant (Rebertus and Burns, 1997).

Analyzing the effects of fire on oak, Van Lear and Watt (1993) stated that the establishment of oak was due to the fire history of the region, the biological adaptations of oak to fire, and the ecological functions of fire in oak ecosystems. Oak species react to fire according to their ecophysiological features. They have the ability to survive and to recover after fires, and to adapt to periodic fires (Van Lear and Watt, 1993). They protect themselves from damage by developing a fire-resistant bark, as do many other species, such as *Larix occidentalis*, *Pseudotsuga menziesii*, and *Pinus ponderosa* (Kimmins, 1996). This thick layer of dead bark develops as stems mature helping them resist and survive surface and ground fires (Brown and Davis, 1973).

Some studies have revealed that oaks have a lower mortality rate than other species competing with them in the regime of recurring fire (Swan, 1970). When tops are repeatedly killed back, oaks develop the ability to continue sprouting (Van Lear and Watt, 1993). Understory oak seedlings, top killed by fire during the dormant season, sprout from the root collar (Johnson, 1983). Sprouts from large oak stumps are fewer and more subject to butt decay than from small stumps with arise below ground (Johnson, 1983). Moreover, repeated burning results in stunted growth. Oaks resist rotting after being scarred and greatly resist drought because of their deep root system. Oak species maintain a high rate of photosynthesis during drought and survive on nutrient-poor sites (Abrams, 1992). Generally, they have low or intermediate tolerance to shade. For this reason, seedlings do not exhibit long-term survival or growth in the closed understory (Crow, 1988).

Benefits of Oak Regeneration from Fire

Fire has many functions that benefit oak regeneration: it prepares seedbed and encourages caching, discourages acorn and seedling predators, opens understory and reduces fire-intolerant competitors, xerifies sites, allows oak to dominate the advance regeneration pool, and increases flammable fuels (Van Lear and Watt, 1993).

In mixed oak-pine stands, intense fire favors the pine and oak sprouts fail to maintain initial advantage. In contrast, hot fires in the spring favors oak species and eliminates pine (Johnson, 1983). Fire can increase oak seedlings by reducing litter, or increase the proportion of oaks in advance reproduction populations (McQuilkin, 1983).

According to the fire history of the southeastern United States, and on the biological adaptations of oak and their ecological benefits, fire is suggested to be used in oak management (Engle et al., 1996). In his review, Abrams (1986) found similarities between tall grass prairie and oak savannas in their transformations to closed forests with decreased fire. He states that many of the original savannas of central Oklahoma became closed post oak–blackjack oak forests, whereas gallery oak savannas in eastern Kansas became closed forests during the first 50 years after European settlement.

Summary

The Cross-Timbers are composed of woodland and grassland that respond to many ecological factors. The majority of the vegetation is forest but livestock grazing is the primary economic use (Engle and Stritzke, 1992). Blackjack oak and post oaks are the dominant species that are ecologically adapted in the area. They are in a midsuccesional stage while grassland is a lower succesional stage that requires periodic treatment to maintain the grassland aspect (Engle and Stritzke, 1992). Fires have an important contribution in the grass management and savanna-like grassland (Johnson and Risser, 1975). Periodic occurrence of dormant season fires resulted in prolific resprouting, which increase the density of oak stems in the Cross-Timbers (Dykerhuis, 1948).

PART III

METHODS

Study Sites

Study sites were chosen in upland forest in three different locations in the vicinity of Stillwater, Oklahoma.

Lake Carl Blackwell

The first site of this study was located at 36.7° N latitude, 97.13° W longitude, and 264 meters altitude, on the south side of Lake Carl Blackwell in Payne County on the Highway 51. The site was called LCB. This area was known as an excellent habitat for wildlife species and used for hunting (Barclay and others, 1974). The Federal government purchased Lake Carl Blackwell for a Land Utilization Project. The previous purpose was a recreational center. Now Lake Carl Blackwell is used for recreational activities, water storage for the City of Stillwater, to regulate floodwater, and to provide migratory waterfowl an area to rest and feed (Barclay and others, 1974).

The name Carl Blackwell was given to the lake in honor of Dr. Blackwell, a former Dean of the College of Agriculture at Oklahoma State University. Dr.

Blackwell played an active role in the building of the reservoir. The lake was leased to OSU in 1949 for 99 years (Barclay and others, 1974). The average annual precipitation and annual snowfall are respectively, 863 millimeters and 178 millimeters (Anonymous, 1997). The temperature ranges from extremes of -10 °C in winter to 47°C degree in summer. The mean annual temperature is 15.5°C. The major soil groups that surround the lake are: reddish soils of the rolling prairie upland; light brown soils of timbered upland (Darnell and Stephenville); deep soils of the flood plains and low benches (US Soil Conservation, 1979).

Keystone Lake

The second site was near Keystone Lake in Creek County. This site was located at 36.10° N latitude, 96.26° W longitude and 253 meters altitude, at Mannford on Highway 51. It was called KEY. The history of Keystone Lake is related to the project of construction of the Keystone Dam and Reservoir at Mannford (Morgan, 1970). The project was designed and built by the Tulsa District, US Army Corps of Engineers from 1956 to 1964 (Morgan, 1970). Keystone Lake is at the junction of Cimarron and Arkansas Rivers.

The average annual rainfall was 1100 millimeters in 1997. The temperature ranges from extreme of –16.6° C to 35.5°C. The annual average temperature is 15.3° C. Major soil groups are moderately deep, shallow, and well drained. They are grayish-brown or light brown, sloping and stony. Forest grows on sandy soil where post oak and blackjack oak are the dominant species (Soil Survey, 1950).

Tall Grass Prairie Preserve

Located at 36.40' N latitude, 96.21W longitude and 255 meters in Osage County, the Tall Grass Prairie Preserve, TGP, was the third site of this study. It comprises the former Barnard Ranch, which was purchased in 1989 by the Nature Conservancy to restore the tallgrass prairie ecosystem (Anonymous, 1993)

The annual average rainfall and temperature are respectively, 1200 millimeters and 15° C (Anonymous, 1997). The snowfall is 258 millimeters. The soils are deep, loamy and sandy on flood plains. On prairie uplands, soils are deep, loamy or shallow. On wooded uplands soils are loamy and sandy (Darnell, Stephenville, Dougherty, Euphala) (Soil survey, 1979).

Treatments

Three treatments were applied at each site: no burn or control, dormant season burn, and growing season burn. Each treatment contained 25 subplots within which data were collected. The treatments were randomly assigned to contiguous plots ranging from 4 to 20 ha, each divided by drainage at KEY and vehicle trails at LCB and TGP.

The Control Treatment

The control treatment consisted of an undisturbed tract of land that remained unburned for the duration of the study. These sites had not been recently disturbed. In reality all of the study areas had received some level of previous, sometime undocumented, disturbance.

The Dormant Season Burn

The dormant season burn was the area burned during the winter or early in spring. The areas at Lake Carl Blackwell and Keystone Lake sites were each burned once in February 1995. Tall Grass Prairie Preserve was burned in March 1993, March 1994 and again in March 1995 (Engle et al., 1996).

The Growing Season Burn

The growing season burn was the area burned during the summer or early fall. The areas were burned in July 1993 at Lake Carl Blackwell and in September 1994 at Keystone Lake. At Tall Grass Prairie Preserve, the area was burned in September 1993 and 1994.

Data collection

In this study, seedlings were defined as one-year old oak plants on which the cotyledon was still attached and the roots were easy to pull out from the soil by hand. Saplings were plants more than one year old with a more extensive root system and no larger than 2.5 cm diameter at breast height.

Forest Understory

Circular subplots were used to collect data on density of seedlings and saplings in the forest understory. The number of seedlings and saplings were counted in one-meter radius subplot (3.14 m^2) and 2 meter radius subplots (12.56 m^2) respectively. The subplots were randomly chosen along parallel transects along axis of the forest. They were assigned within the transect by three-digit numbers. The first number indicated the number of spaces from the starting point on the transect. The second indicated the direction, left or right, off the transect. The third number indicated the number of paces perpendicular to the transect, where the sampling was performed. Seedlings were first identified and counted in the one-meter radius, and saplings were then identified and counted in the two meters radius of the subplot. The forest litter and soil depths were evaluated at three or four different spots of the subplot using a metal stick of 25 cm depth. The presence of rocks in the subplot indicated shallow soils. The litter was evaluated by three numbers: zero for the litter depth between zero and one cm, two for litter depth between one and three, and three for the litter depth greater than three cm.

Forest Overstory

The point sampling method was utilized in measuring forest overstory. The prism (BAF=2.5 $m^2\ ha^{-1}$) was used to estimate the basal area at each subplot. The diameter of each counted tree was measured at breast height.

The canopy cover at each subplot was evaluated with a device developed by Dr. Ron Masters (Personal communication). This device consisted of a box 9 x 9 x 24 cm. The top of the box was open with nine intersections formed by a square grid of three strings. An oblique mirror was located at the base of the box and was positioned at an angle facing an opening from which to view the image. It was possible to hold the box perfectly level by using the two carpenter's levels installed inside the box. The desired image then consisted of the overstory to be measured overlaid with the reflection of the string grid from the top of the box. From this image, the number of grid intersection points covered by branches or leaves was counted within the overstory reflection (Fig. 12).

Data Analysis

The data collected for seedlings and saplings were squared root transformed ($\sqrt{y+0.5}$), as has been suggested for analysis of count data (Steel, Torrie & Dickey, 1997). SAS was use to analyses data collected. Means and standard errors of seedling density, sapling density, and basal area for each treatment were computed and plotted. Analysis of variance ($p<0.05$) was used to determine the effects of site and burning treatment on seedling and sapling densities, and tree basal areas. The experimental layout was a randomized complete block design with 3 replicates. Regression analysis was used to determine whether the soil type, litter depth and canopy cover had an effect on the density of seedlings and saplings and on the basal area.

PART IV

RESULTS

The regression analysis showed no significant relation between canopy cover, soil type, and litter depth and seedling and sapling densities or basal area. The results presented below concern effects of season of burn on seedling and sapling densities and basal area.

Seedlings

No post oak seedlings were found at any of the three sites. Blackjack oak seedlings were found only at Lake Carl Blackwell (Fig. 3) Most of the seedlings at Lake Carl Blackwell were found on shallow soils that did not have litter. Although analysis of variance for seedling density showed no significant difference among sites and treatments (Table 1), the data suggested there were more seedlings in the unburned treatment than in either of the burned treatments.

Saplings

Blackjack Oak

Analysis of variance showed site and burning treatment did not affect blackjack oak sapling density (Table 1). The mean values showed large variation which could have masked treatment and site differences (Fig. 4). It appeared that the greatest sapling density occurred in the growing season burn treatment at the Tall Grass Prairie Preserve. At Keystone Lake, the average sapling density was almost the same in the three treatments. At Lake Carl Blackwell, the mean density of saplings in the dormant season burn treatment was much greater than the control treatment and growing season burn.

Post Oak

The post oak density showed differences among sites (Table 2). The treatments were not significantly different. Post oak sapling densities at Keystone Lake and Lake Carl Blackwell were not significantly different. The greatest sapling density was found at Keystone Lake in the control treatment (Fig. 5). At Lake Carl Blackwell aand thhe Tallgrass Prairie Preserve, the post oak sapling density was similar among the three treatments.

Basal area

Blackjack oak

The blackjack oak basal area did not exceed 6 m^2 ha^{-1} at the nine Cross-Timbers stands of this study (Fig. 6). The lowest oak basal area was observed in the growing season burn at the Tall Grass Prairie Preserve and the largest was in the growing season burn at Keystone Lake.

The diameter distribution in terms of trees per hectare by dbh class was different in the nine stands (Fig. 9, 10, 11). The smaller the diameter the greater the tree density. The greatest density of small dbh tree was found at TGP (Fig. 9, 10, 11). At this site, the density of trees per hectare was comparatively very high after the growing season burn.

Post oak

Post oak had the highest basal area of both speciesl (Fig. 7). At Lake Carl Blackwell, post oak basal area reached nearly 25 m^2 ha^{-1} in the growing season burn. The basal area at Keystone Lake was similar in the three treatments. No measurable post oak trees were observed at Tall Grass Prairie Preserve except in the control treatments. The diameter distribution in terms of trees per hectare by dbh class for post oak showed the classic reversed J-shape of an uneven-aged stand in most of the stands at Lake Carl Blackwell and Keystone Lake (Fig. 9, 10, 11). The greatest densities and smallest trees were found at theTall Grass Prairie Preserve (Fig. 11) .

PART V

DISCUSSION AND CONCLUSIONS

Although differences appeared to exist among treatment and site means, the analysis of variance indicated there were no significant effects. There are three main reasons to explain the lack of significant effects: 1.) the pretreatment differences among plots were very large. 2.) the burn treatments had been conducted only once at two sites of the three sites; 3.) there were only a small number of replications. The effects of fire should become larger after the sites have been burned several times. Large pretreatment differences among plots were caused by earlier cultural treatments that could have obscured treatment effects. The experiment should be replicated at a larger number of sites, perhaps 10.

The results of this study are preliminary. Despite the lack of significant effects, there were some interesting trends. I can also make suggestions about further study.

Seedlings

The distribution of seedlings was scattered on the study sites. Blackjack oak seedlings were found only occasionally on one of the sites; on the other sites there were none. Post oak seedlings were not found at all. This contradicts the observations by Anderson and Butler (personal communication to Steve Hallgren) who found seedlings of both species at some sites in their study. In my study, the difference between blackjack oak and post oak seedling density could have been due to four factors: 1.) the difference in the production of acorns; 2.) the maturity of seed trees; 3.) the characteristics of each site, and 4.) the fire intensity in the burned areas.

1 - The difference in the production of acorns between both species.

The cycle of the flowering process in blackjack oak and post oak occurs differently. It is completed after one year in the white oaks (*Leucobalanus*) such as post oak, and after two years for the red oaks (*Erythrobalnus*), blackjack oak (Watt, 1979). The flowering process could have been` damaged by the heat during the burning that could have delayed the flowering process in some trees. The acorn production was not measured, but it is possible that these two oak species do not produce equal numbers of acorns.

2 - The maturity of the trees at certain sites

It takes a long time between two oak generations. The minimum seed bearing age for most oaks is 15 to 25 years (Cecich, 1993). Yield increases with age and size (Beck, 1993). Young trees are not capable of flowering because they are not able to respond to environmental stimuli such as photoperiod that can induce flowering. In contrast, some mature trees cannot flower because of they have lost the capacity to respond to stimuli or because genetic control can cause sterility (Cecich, 1993). According to the history of each site, the youngest trees were at the Tall Grass Prairie Preserve where trees are exposed to high competition, especially in the control treatment. This situation would not allow the crowns to develop for good flowering. In the burn treatments, the trees were small and may not have been mature enough to produce acorns. The frequency of burning on the burn treatments kept killing the trees and causing them to resprout. In this way they were constantly rejuvenated.

3 – The site characteristics.

The sites were different in their geographical position, climate, rainfall, temperature, snowfall, and their species composition. The canopy cover at Lake Carl Blackwell was much denser than it was at the two other sites (Fig. 8). Soil was rockier at Lake Carl Blackwell and Keystone than at the Tall Grass Prairie Preserve. The soil was not deep enough to allow animals and birds to bury some acorns that could germinate.

4 – The intensity of fire.

The fire intensity is an indicator of the exposure of the tree crowns to direct flames and hot convective gases (Engle et al. 1996). In the study by Engle et al, the two fires at Lake Blackwell were of low intensity (Engle et al. 1996). It would be possible that any intensity low or high could be damaging for the seed production.

Saplings

Saplings of both species were found at each treatment and site. Saplings were older than seedlings. They were produced from stump sprouts. Some were resprouts from young trees. Several early studies reported that vegetative regeneration was more important seed regeneration in oak (Dooley and Collins, 1984; Dysterhuis, 1948). Sprouting capacity differs greatly among species (Diller and Marshall, 1937). Most oak sprouts originate from dormant buds that remain alive and become active when part of the shoot above them is removed (Diller and Marshall, 1937).

The data from this study suggest that blackjack oak sapling density was enhanced after burning at Tall Grass Prairie Preserve in the growing season and the dormant season (Fig. 4). Fire may have stimulated blackjack oak sprouting more than it did for post oak at the Tall Grass Prairie Preserve (Fig. 5). The observations at Keystone Lake did not reveal an increase of sapling density for either species after burning (Fig. 4 and 5). There appeared to be a slight tendency for dormant season burning to increase sapling density for both species at Lake Carl Blackwell and Tall Grass Prairie Preserve. The analysis of variance did not detect any significant effects. Thus, burning during the dormant season could be useful in encouraging sprouting. Engle et al. (1996) stated that the stand burned in the growing season at the Tall Grass Prairie Preserve had more understory woody plant cover than the stand in the dormant season burn. The results appeared to confirm this observation (Fig. 4).

In summary, fire may have enhanced blackjack oak sprouting at the Tallgrass Prairie Preserve. Growing season burns may stimulate sprouting in both species. Further study is necessary to confirm these effects.

Basal area

Post oak had the greatest basal area at Lake Carl Blackwell and Lake Keystone, but not at Tall Grass Prairie Preserve. At Lake Carl Blackwell the basal area was greater than the two other sites (Fig. 7). No large post oak trees were observed at the Tall Grass Prairie Preserve (Fig. 11). Blackjack oak was present in all treatments at all sites.

It would be too hazardous to make conclusion the effects of fire on basal area at Lake Carl Blackwell and Keystone Lake. The past fire history at the Tallgrass Prairie Preserve is better known than at the other sites. Fire at Lake Carl Blackwell has been excluded for a long period such that the trees were bigger and more mature than those trees at the other sites (Fig. 9, 10, and 11). The effects of the burn treatment at Lake Carl Blackwell cannot necessarily explain the large trees found in the different treatment sites. A single fire applied at Lake Carl Blackwell and Keystone Lake could not reduce the basal area at these sites. Over time, with the regularity of burning and fuel available, it could be possible to reduce basal area at Lake Carl Blackwell and Keystone Lake. According to Rice and Penfound (1959), the accumulation of fuel on certain sites can support intense fires and cause high tree mortality. In this case severe fire can convert forest to Savannah. The presence of grass in the Keystone Lake understory stands indicated an influence of fire in those stands. Grassland is a lower successional stage in the post-settlement vegetation (Engle and Stritzke, 1992). The regularity of the burning did not allow the site at the Tallgrass Prairie Preserve to develop big trees. It could be possible that the repeated burning reduced the basal area of post oak more than blackjack oak. Post oak may be more sensitive to fire than blackjack oak.

In sum, the effects of fire on basal area were more obvious at the Tall Grass Prairie Preserve. Fire had reduced basal area for both blackjack oak and post oak. At this site, the repeated burning applied over time since 1992, appeared to have greater effect than the single burns at other sites.

Conclusions

In this study, the small number of replications (sites) and the high variability among sites and made it difficult to detect treatment effects . However, the results led to following tentative conclusions:

- Seedling production is very low and erratic;
- Sprouting was abundant with or without fire;
- Dormant season burn increased sprouting in blackjack oak;
- Sprouting appeared to be less affected by fire in post oak than in blackjack oak;
- Fire stimulated sprouting and inhibit growth of saplings into trees;
- Fire during the dormant season produced the most oak saplings;
- There was plentiful regeneration of both, post and blackjack oaks regardless the presence of fire;
- Further study is needed on a larger number of sites after several burning cycles to develop more conclusive results about the effect of fire on oak regeneration.

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Table 1. The results of the analysis of variance to determine the significance of site and treatment effects on seedling and sapling densities, and basal area for *Quercus marilandica*

		Seedlings		Saplings		Basal area	
SOURCE	DF	F	Pr > F	F	Pr > F	F	Pr > F
SITE	2	2.56	0.192	2.27	0.219	0.30	0.756
Treatment	2	1.00	0.444	0.88	0.480	0.26	0.784
MSE	4	45,077.3		35,773,425.56		5.76	

Table 2. The results of the analysis of variance to determine the significance of site and treatment effects on seedling and sapling densities, and basal area for *Quercus stellata*

		Saplings		Basal area	
SOURCE	DF	F	Pr > F	F	Pr >F
SITE	2	10.26	0.026	16.54	0.011
Treatment	2	2.38	0.208	0.86	0.489
MSE	4	2,549,573.793		13.265	

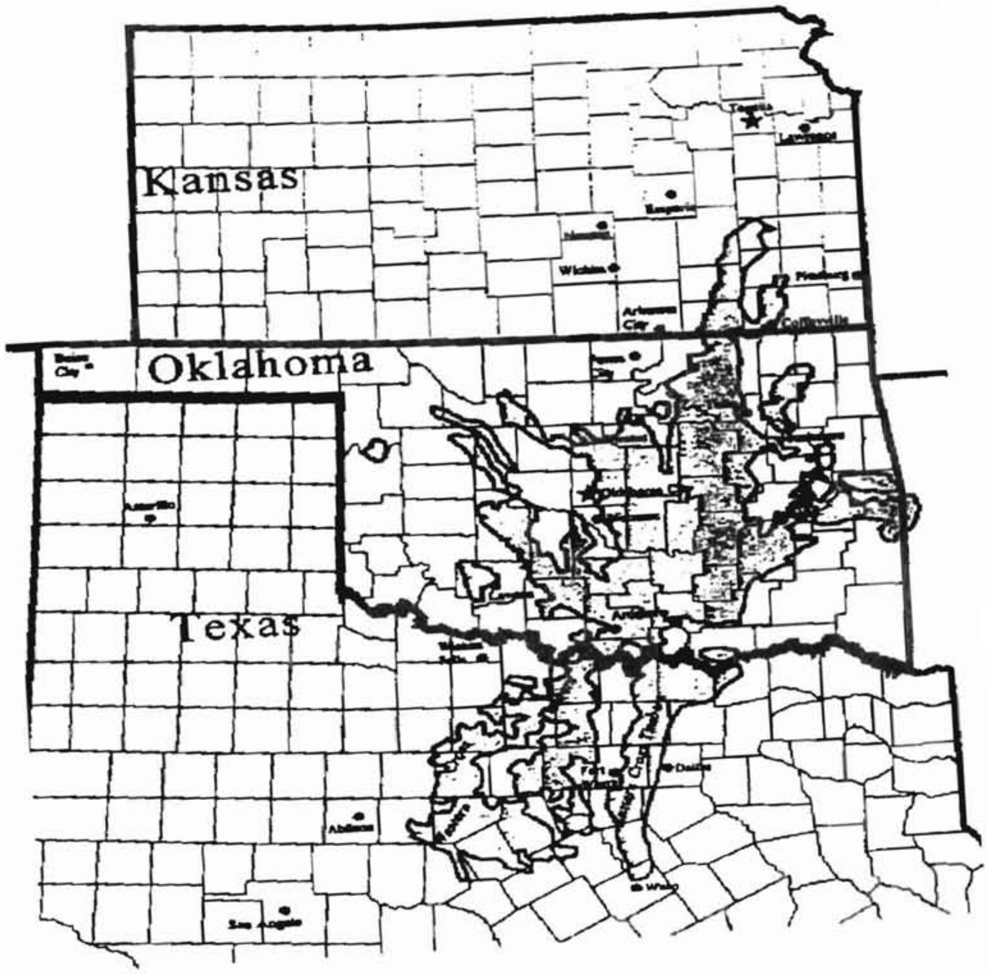

Figure 1. Extent of the Cross-Timbers

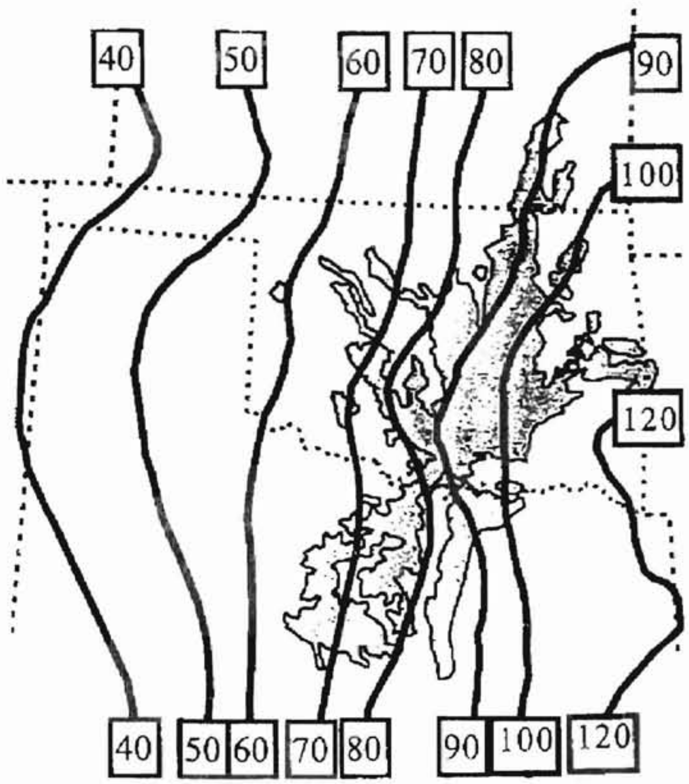

Figure 2. Average Annual Precipitation (cm year $^{-1}$) in the Cross-Timbers.

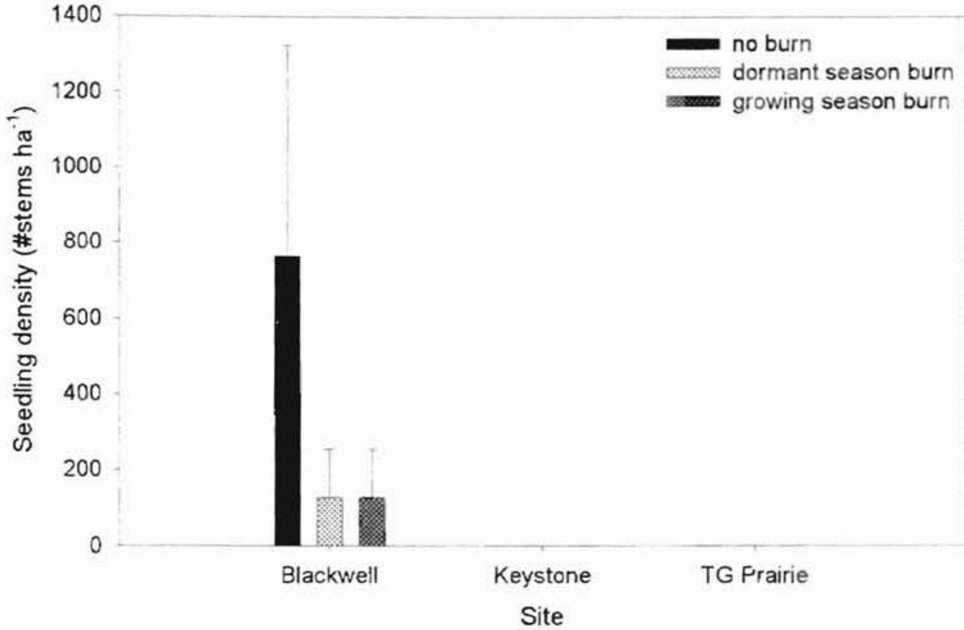

Figure 3. Seedling Density at the three Cross-Timbers sites for *Quercus marilandica* (bar = standard error of the mean for 25 subplots).

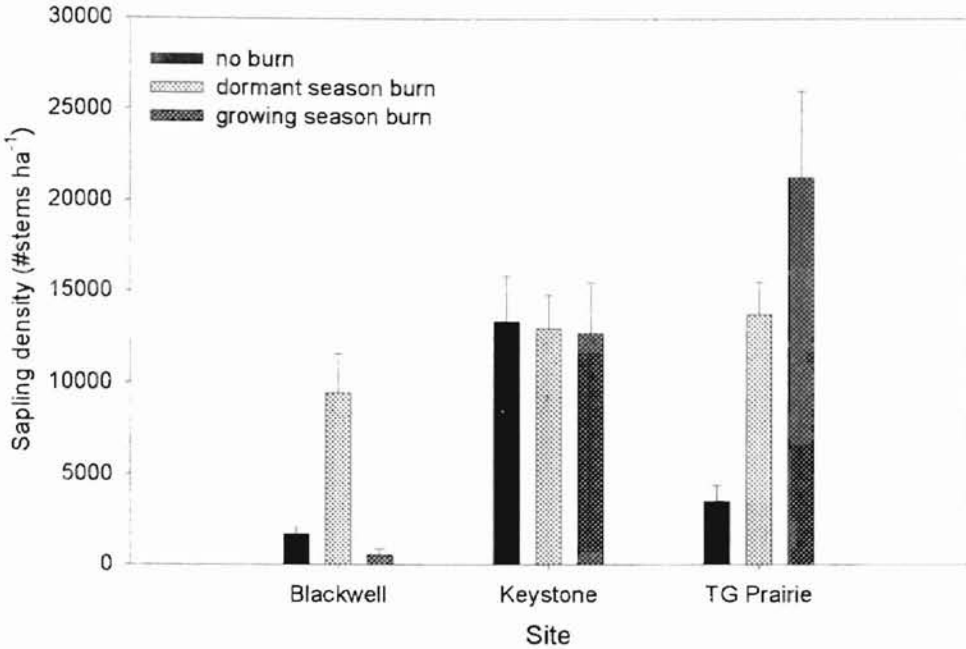

Figure 4. Sapling Density at the three Cross-Timbers sites for *Quercus marilandica* (bar = standard error of the mean for 25 subplots).

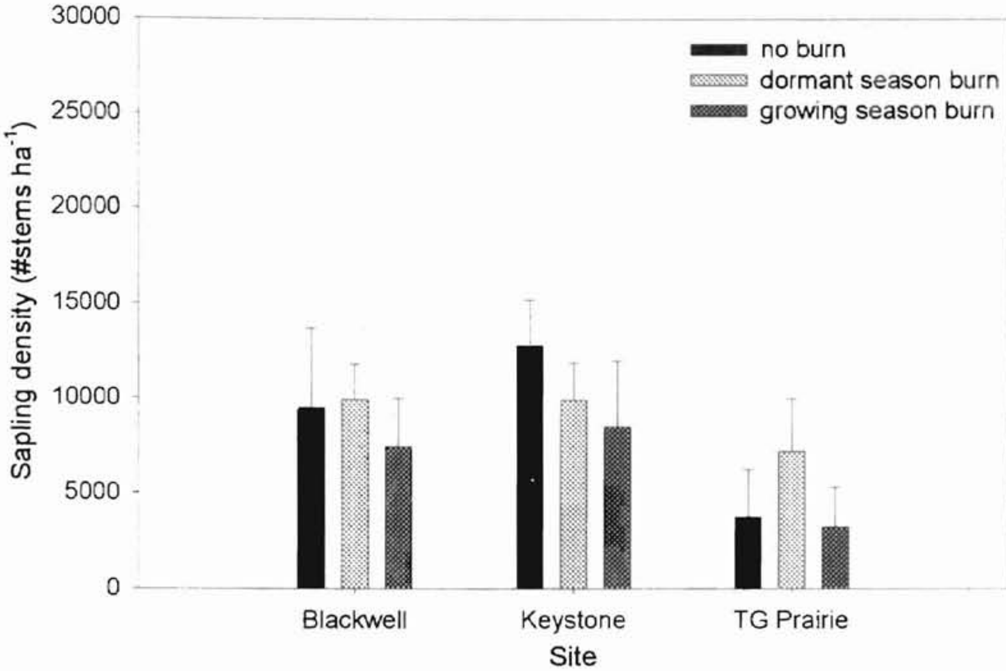

Figure 5. Sapling Density at the three Cross-Timbers Sites for *Quercus stellata* (bar = standard error of the mean for 25 subplots).

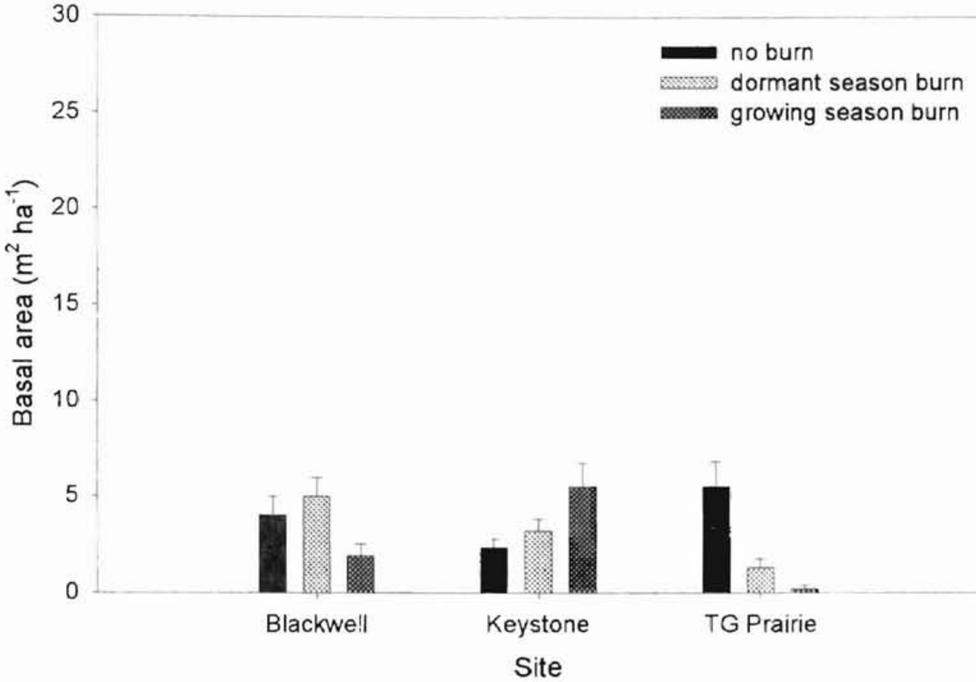

Figure 6. Basal Area at the three Cross-Timbers Sites for *Quercus marilandica* (bar = standard error of the mean for 25 subplots).

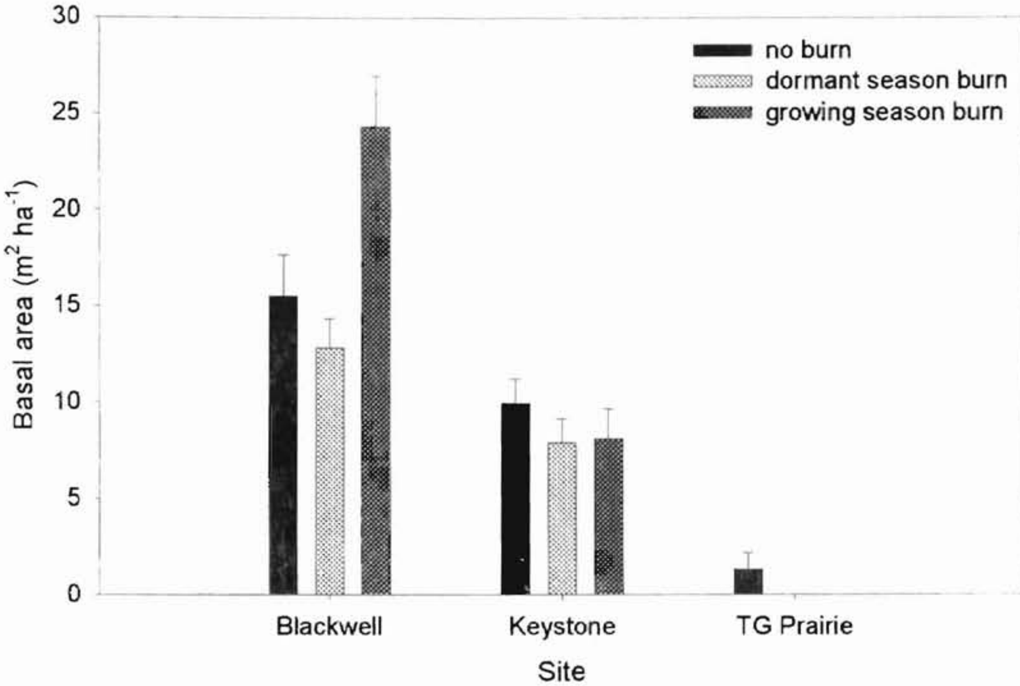

Figure 7. Basal area at the three Cross-Timbers sites for *Quercus stellata* (bar = standard error of the mean for 25 subplots).

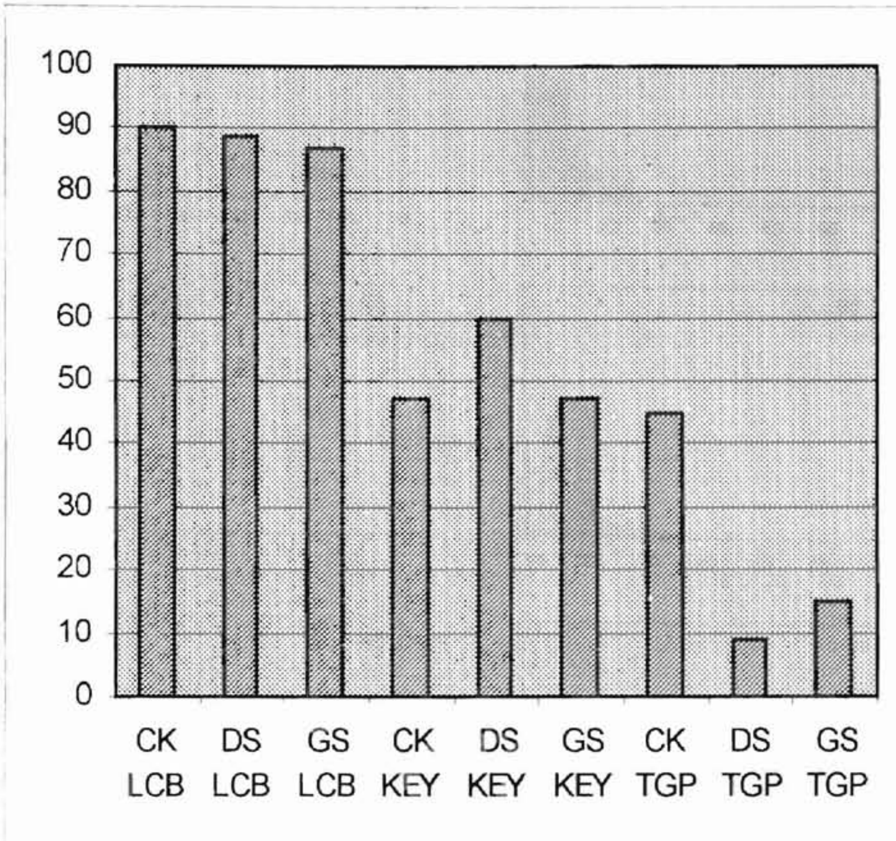

Figure 8. Total Canopy Cover at the three Cross-Timbers sites (GS = Growing season. DS = Dormant season. CK= Control. LCB = Lake Carl Blackwell. KEY= Keystone Lake. TGP = Tall Grass Prairie Preserve.

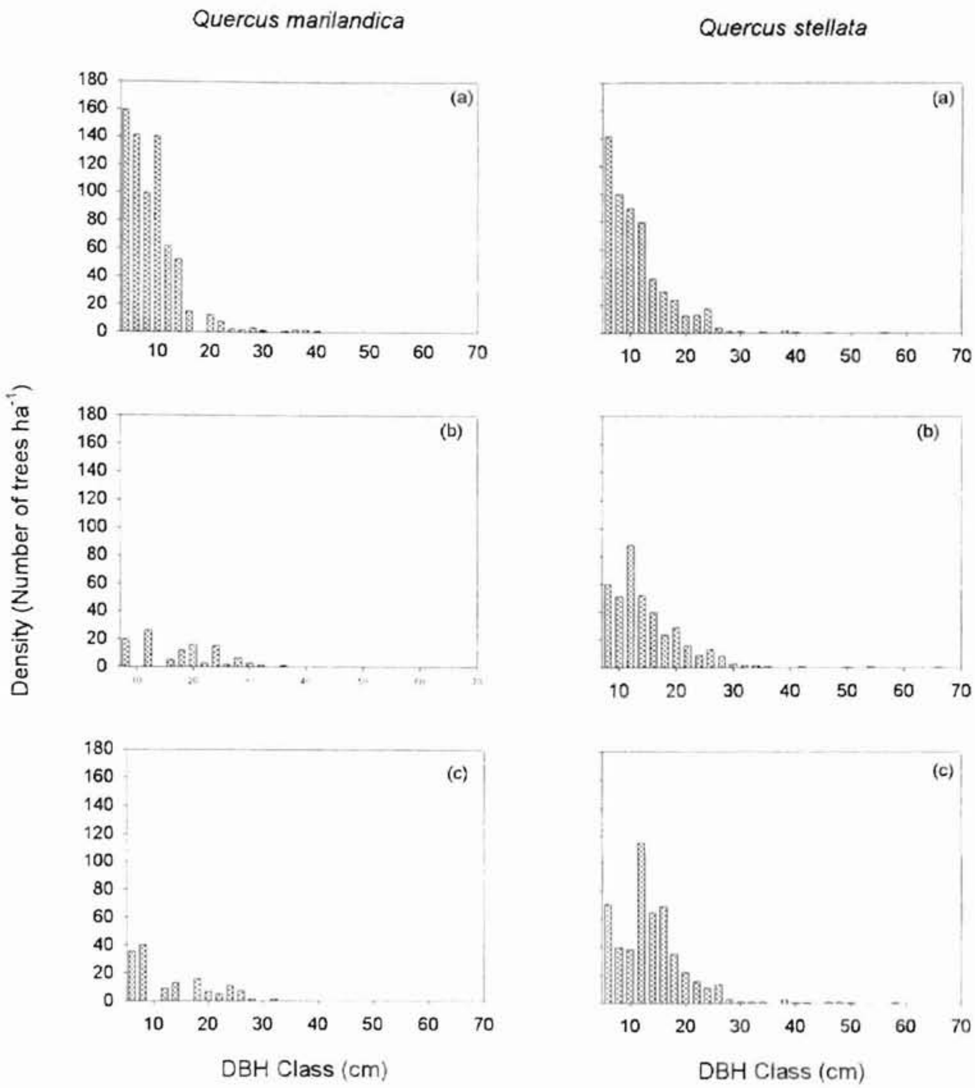

Figure 9. Diameter Distribution at Lake Carl Blackwell in the (a) Control (b) Dormant season, and (c) Growing Season.

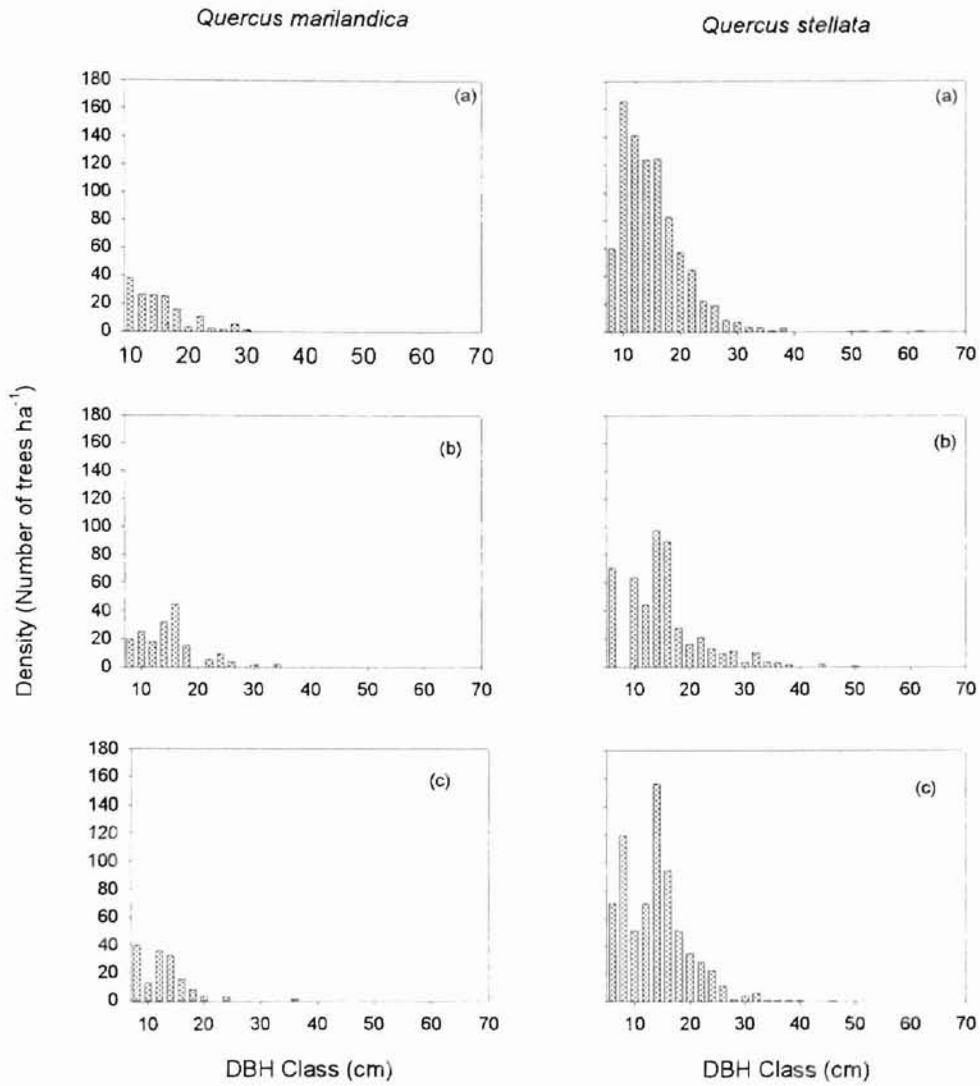

Figure 10. Diameter Distribution at Keystone Lake in the (a) Control (b) Dormant Season, and (c) Growing Season.

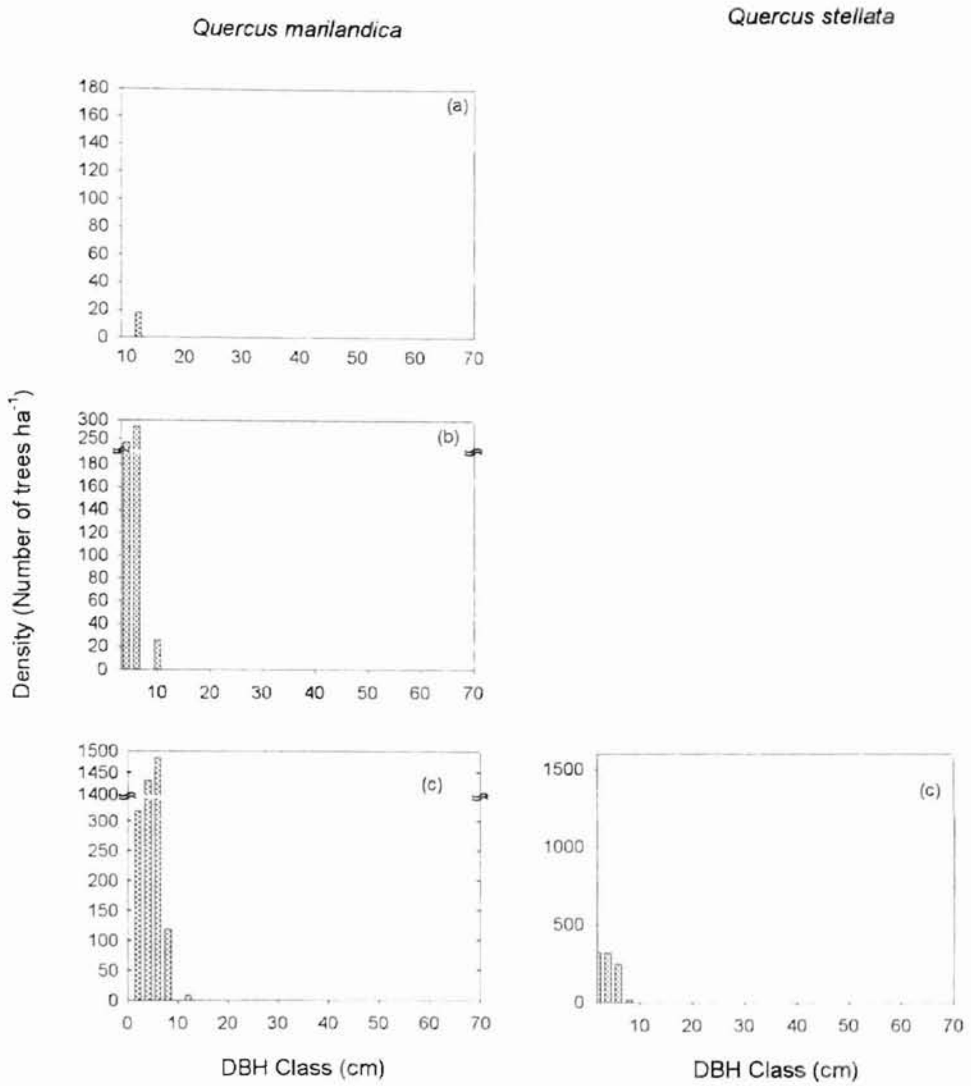

Figure 11. Diameter Distribution at Tall Grass Prairie Preserve in the (a) Control, (b) Dormant Season, and (c) Growing Season.

VITA

Georges Ferdinand Backoulou

Candidate for the Degree of

Master Of Science

Thesis: OAK REGENERATION IN THE CROSS-TIMBERS OF OKLAHOMA

Major Field: Forest Resources

Biographical:

Education: Graduated from Victor Augagneur High School (Lycee Victor Augagneur) in Pointe-Noire, Congo in 1979; received bachelor of science in the Rural Development Institute of Marien Ngouabi University in Brazzaville, Congo in 1986; completed the requirements for a master's of science degree with a major in forestry at Oklahoma State University in December 1998.

Experience: Employed as engineer at the clonal plantations of eucalyptus at Pointe-Noire, Congo; in charge of agroforestry and silvicuture projects in Forests and Water Minister of Congo; employed as Forest Researcher at Loudima and Pointe-Noire, Republic of Congo.

Professional Memberships: Society of American Foresters.