THE EFFECTS OF BURNING SEASON AND FREQUENCY ON THE VEGETATIVE CHARACTER AND INSECT ABUNDANCE OF SAND SHINNERY OAK RANGE IN WESTERN OKLAHOMA

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TABLE OF CONTENTS

LIST OF TABLES

Table Page

Chapter II

Chapter III

Chapter IV

Chapter V

LIST OF FIGURES

Figure Page

Chapter III

Chapter IV

Chapter V

Chapter VI

CHAPTER I

INTRODUCTION

This dissertation is composed of 5 manuscripts that are formatted for submission to scientific journals. Chapter II has been published as a United States Department of Agriculture-Forest Service General Technical Report. The text for this publication is not included herein but is referenced on the title page for Chapter II. Chapters III through VII are formatted for submission to the Journal of Range Management.

CHAPTER II

THE EFFECTS OF PRESCRIBED FIRE ON SHINNERY OAK (*QUERCUS HAVARDII* Rydb.) PLANT COMMUNITIES IN WESTERN OKLAHOMA

Abstract

Changes in structural and compositional attributes of shinnery oak (*Quercus havardii* Rydb.) plant communities have occurred in the 20th Century. These changes may in part relate to altered fire regimes. Our objective was to document effects of prescribed fire in fall (October), winter (February) and spring (April) on plant composition in these communities. Three study sites were located in western Oklahoma; each containing 12, 60 x 30 m plots that were designated, within site, to be seasonally burned, annually burned, or left unburned. End-of-growing season herbaceous phytomass and plant canopy cover for herbaceous and woody species were estimated in 1996 (pre-treatment) and 1997-1998 (post-treatment). Soil nutrients and percent bare ground were assessed during the same time period. Phytomass of forbs and grasses and canopy cover of 8 vegetation classes were analyzed using multivariate analysis of covariance with pre-treatment score as the covariable and season of burn, time since fire, or annual burning as the independent variable. The interactive influence of fire and soil nutrient status was determined using partial canonical correspondence analysis. Forb and grass phytomass was affected by season of burn (1997 $P = 0.0013$, 1998 $P = 0.0899$) and annual burning ($P = 0.0303$). Canopy cover of vegetation classes was influenced by season of burn (1997 $P = 0.0001$, 1998 $P = 0.0014$), time since fire ($P = 0.0224$) and annual burning ($P = 0.0335$). Fire in any season reduced affected shrub cover and spring burns reduced cover most. Winter and annual burns increased cover of rhizomatous tallgrasses, whereas burning in any season decreased little bluestem cover. Perennial forbs increased with fire in any season and most strongly with fall fire. Communities returned rapidly to pre-burn composition with increasing time since fire. Soil nutrient gradients influenced vegetation composition ($P = 0.0050$), but those gradients were confounded by fire treatment. Fire effects on herbaceous vegetation appear to be manifested through increases in bare ground and reduction of overstory shrub dominance. Fall fire may be used to increase forbs important to some wildlife species, whereas winter burning can increase forage production for livestock.

Keywords: Prescribed fire, shrub ecology, Oklahoma, multivariate analysis of covariance.

Introduction

Shinnery oak (*Quercus havardii* Rydb.) and associated vegetation occur in west central Oklahoma, northern Texas, and southeastern New Mexico. Peterson and Boyd conservatively estimated that shinnery oak rangelands covered at least 2 million hectares in those states (Peterson and Boyd 1998). Historical accounts indicate that shinnery oak communities were structurally dominated by tallgrasses with shinnery oak in the understory; oak stems did not commonly exceed 45 cm in height (Marcy 1854, Osborne

1942). Today, shinnery may constitute 80% of canopy cover (Dhillion et al. 1994), abundance of tallgrasses has decreased, and oak stems may reach 1 m in height in western Oklahoma (Peterson and Boyd 1998). This increase in oak stature and canopy cover can negatively affect recruitment of herbaceous seedlings (Holland 1994), leading to lower herbaceous plant production.

These structural and compositional changes in shinnery oak communities often have been described as products of mismanagement of grazing livestock (Duck and Fletcher 1944, Jackson and DeArment 1963, Pettit 1994). While grazing practices have undoubtedly influenced both small and large scale vegetation dynamics, it is difficult to evaluate effects of livestock grazing in any system without simultaneously considering the historical influence of fire (Box 1967). The diminutive stature of shinnery oak in historical references may indicate a somewhat reliable and strong influence of fire, given the susceptibility of this species to top-kill by fire. Prescribed spring fires may result in dramatic increases in herbaceous plant phytomass in years of adequate rainfall (McIlvain and Armstrong 1966, McIlvain and Shoop 1965), and a high percentage of shinnery oak stems may be top-killed (Slosser et al. 1985).

To evaluate the historic and potential role of fire in shaping shinnery oak community plant composition, the overall fire regime must be explored. This necessarily involves examining effects of fire frequency and season as well as the spatial scale and pattern of fire events. To date, there has been no published work on effects of growing season and winter fire in these communities. Our objective was to experimentally evaluate the role of season of burn, time since fire, and annual burning on plant composition of shinnery oak communities in western Oklahoma, and to delineate the relative influence of fire on plant community composition compared with other environmental factors.

Methods

Study Sites

Study sites were located on the Black Kettle National Grassland in Roger Mills County, Oklahoma (35° 32’ 44’’ N, 99^{O} 43’ 39’’ W), and the state-owned Packsaddle Wildlife Management Area in Ellis County, Oklahoma (36° 4’ 22’’ N, 99^{O} 54’ 5’’ W). Sites were chosen subjectively to be representative of shinnery oak communities found on sandy soils within the western Oklahoma region. All sites were lightly grazed by cattle during the growing season before study initiation and were excluded from grazing in 1995 and throughout the course of the study. Before our study, these sites had not burned on a regular basis and had not burned for at least 10 years.

Soils were fine sands (Nobscott-Brownfield Association) with no limiting layers in the top 150 cm (USDA 1982). Shinnery oak, a deciduous, clonal species, was the dominant shrub with lesser amounts of sand sagebrush (*Artemisia filifolia* Torr.) and Oklahoma plum (*Prunus gracilis* Engelm.). Dominant grasses and forbs included little bluestem (*Schizachyrium scoparium* Nash), indiangrass (*Sorghastrum nutans* Nash), switchgrass (*Panicum virgatum* L.), sand bluestem (*Andropogon gerardii* Hack.), sand lovegrass (*Eragrostis trichodes* Nutt.), sideoats grama (*Bouteloua curtipendula* Michx.), western ragweed (*Ambrosia psilostachya* DC.), erect dayflower (*Commelina erecta* L.) and sundrop (*Calylophus berlandieri* Spach). Average annual precipitation was 65.6 cm; growing season (March-August) precipitation averaged 40.6 cm (USDA 1982).

Experimental Design

We divided each of the 3 study sites (blocks) into 12 60 x 30 m plots. Plots were arranged in a 2 x 6 matrix and separated by 7 m firebreaks. We randomly assigned each of the plots within a site to the following 9 treatments: 1) no burn, 2) burn fall 1996, 3) burn fall 1997, 4) burn winter 1997, 5) burn winter 1998, 6) burn winter 1997 and 1998, 7) burn spring 1997, 8) burn spring 1998, and 9) burn spring 1997 and 1998 (Table 1). Pre-treatment data were collected during the growing season in 1996 and treatment response data during the growing season in 1997 and 1998.

Fire Ignition

All plots were burned using a strip-headfiring technique (Wright and Bailey 1982). The downwind and flank sides of the plots were ignited and allowed to burn about 5 m into the plot. We ignited a series of headfires about 10 m upwind from the backfire. All burns were conducted with relative humidity >20%, air temperature <29°C and a surface wind speed of <16 km/hr. We estimated fire behavior characteristics for all headfires and determined pre-burn fuel loading and fire consumption from quadrats clipped before and after burning. Fire behavior and fuel characteristics are discussed in Boyd (1999).

Vegetation Sampling

Because of the ignition pattern, the outer 5 m of plots were excluded from vegetation sampling to eliminate differential effects of headfires, backfires, and flankfires. We estimated canopy cover for each plot, by species, at 30 randomly located points (Daubenmire 1959). At each point, canopy cover of each species influencing a 20 x 50 cm quadrat was categorized as 0-5%, 5-25%, 25-50%, 50-75%, 75-95% or 95-100%. We averaged mid-point values to obtain an estimate of canopy cover of each species in a plot for a given sampling period. We estimated canopy cover during 3 sampling periods: 25-31 May, 6-22 June, and 8-17 August. Pretreatment data were collected during the growing season in 1996 and treatment response data during the growing seasons in 1997 and 1998. Nomenclature followed that of the Great Plains Flora Association (1986) with the exception of little bluestem (i.e. *Schizachyrium scoparium*).

We created summary variables to represent the sum of all canopy cover values for a given vegetation class, in a given plot and year (Table 2). Average seasonal canopy cover values for vegetation classes were calculated by averaging canopy cover values by plot, class, and year (West and Reese 1996). Our purpose was to combine species that respond similarly to environmental perturbation and reduce data to a meaningful level for analysis and presentation. Annual and perennial fobs may respond positively to fire (McIlvain and Armstrong 1966), but, because annual forbs may be more sensitive to other environmental factors (Bazzaz and Morse 1991), they were grouped separately. Legumes (woody and non-woody) were grouped because they often respond positively to fire (Towne and Knapp 1996) because of their ability to fix nitrogen in the nitrogen dynamic post-fire environment (Pyne 1996). Rhizomatous C_4 tallgrasses were grouped because of their similar reproductive strategy and their generally positive response to fire (Towne and Owensby 1984). Little bluestem was classified by itself because it was the dominant grass species in unburned plots. Additionally, the bunchgrass growth form of little bluestem differed from other dominant grasses, which were mainly rhizomatous, and little bluestem often declines following fire (Ewing and Engle 1988, Towne and Owensby 1984). All remaining perennial grasses, predominantly bunchgrasses, were grouped together. Dominant species in this grouping included sideoats grama, sand lovegrass, and sand dropseed (*Sporobolus cryptandrus* Torr.). All other shrub species were grouped and represent the most abundant vegetation class. The only C_3 sedge species encountered (*Cyperus schweinitzii* Torr.) was classified by itself.

We estimated herbaceous plant phytomass in August by clipping all current season growth of grasses and forbs in 10 randomly located quadrats per plot. We used a 0.10 m^2 quadrat in 1996 and a 0.25m^2 quadrat in 1997 and 1998. Clipped material was separated into grasses and forbs, oven dried to a constant weight, and weighed to the nearest 0.1g.

Environmental Variables

We collected soil samples to a depth of 15 cm from all plots during July 1996, 1997, and 1998. Soil samples were analyzed for NO_3-N, P, and K content and pH at the Oklahoma State University Soil Testing Laboratory, Stillwater, OK. We obtained precipitation data from an automated climatological recording station located about 10 km south of our study area. Growing season precipitation was calculated by summing monthly values for March-August of a given year. Bare ground was estimated concurrently with canopy cover and was defined as the percentage of the quadrat not covered by basal plant cover (Bonham 1989) or plant litter. Environmental variables and their associated data ranges are listed in Table 3.

Statistical Analysis

Multivariate Analysis of Covariance

We assessed treatment effects using multivariate analysis of covariance (Fuhlendorf and Smeins 1998, SAS Institute Inc. 1988, Stroup and Stubbendieck 1983) with canopy cover or phytomass class as the dependent variable and season of burn, time since fire, or annual burning (Table 3) as main effects and pretreatment score as the covariable. We evaluated treatment significance using the *P*-value associated with the Wilks' Lambda (Johnson and Wichern 1992) test statistic for the treatment variable effect in the model:

> Vegetation$_{\text{I-n}}$ or Phytomass Class$_{\text{j-n}}$ Score = Pretreatment Vegetation$_{\text{I-n}}$ or Pretreatment Phytomass Class$_{\text{j-n}}$ Score + Treatment Variable + Block + Treatment Variable x Block.

We did not perform univariate mean separation tests because they would violate the multivariate assumption of a lack of independence between dependent variables. We discuss numeric differences in independent variable means without attaching statistical significance to these comparisons. To test for differences in vegetation or phytomass class values between years we used the above multivariate model with response period year (1997 and 1998) as the independent variable; this analysis included unburned plots only. Due to a significant year effect in the canopy cover ($P = 0.0001$) and phytomass class ($P = 0.0302$) models, we analyzed 1997 and 1998 data separately.

Environmental Data

We evaluated effects of individual environmental variables on canopy cover using Pearson correlation analysis (SAS 1988). For this analysis, we combined data from 1997 and 1998 and analyzed data for burned plots separately from control plots, due to the potential for alterations in controlling environmental factors following burning. We used partial canonical correspondence analysis (pCCA; ter Braak 1998) to assess interactive effects of environmental and fire treatment variables on vegetation class abundance. Canonical correspondence analysis is a direct gradient analysis technique that ordinates species relative to their position along specific environmental gradients (Palmer 1993). To reduce noise and more specifically focus on treatment and environmental effects, we square-root transformed vegetation class cover data and used study site as a covariable. We evaluated the significance of the first canonical axis in CANOCO using a Monte Carlo test with unrestricted permutations (ter Braak 1998). Permutations were within blocks as defined by the covariable "site". We used CANOCO interset correlation output to calculate the intraset correlations for environmental variables. The intraset correlation was equivalent to the correlation between an environmental variable and a given axis (ter Braak 1986) and allowed determination of the environmental factors most responsible for influencing a given axis.

We used CANODRAW (Smilauer 1990) to produce graphical output (a bi-plot) of the pCCA; the bi-plot included the first 2 canonical axes, which represented the 2 strongest species-environment gradients. In the bi-plot, arrows represented the influence of continuous variables and centroids of nominal variables were indicated by closed triangles. The relative direction of arrows and position of nominal variables were representative of the correlation between a variable and a given CCA axis. The position of species groups, relative to arrows or centroids, was representative of the association between a species group and a nominal or continuous variable.

Results

Multivariate Analysis of Covariance

Season of burn influenced the cover of vegetation classes in 1997 ($P = 0.0001$) and 1998 ($P = 0.0014$; Table 4). Shrubs generally decreased in cover following fire. Spring burns decreased shrub cover more than other burn season, and decreased cover by over 50% in 1997 relative to control plots. In 1998, shrub cover was greater for spring burns than in 1997. Little bluestem cover decreased with fire in any season in 1997 and 1998. Cover of tallgrasses for winter-burned plots was higher in both 1997 and 1998 than in control plots; other grasses (GRASS) were unaffected by season of burn in 1997, and increased after winter and spring burns in 1998. Annual forb abundance was similar between all burning seasons in 1997, while burning in any season increased annual forb abundance in 1998 compared with control plots. Perennial forbs increased with fire in any season in 1998 and with fall and winter fire in 1997. Several forb and legume species were limited in occurrence to only 1 or 2 treatments. For instance, toad flax (*Linaria canadense* L.) was only found in control plots, blue false indigo (*Baptisia australis* L.) in fall and spring-burned plots, sleepy daisy (*Aphanostephus ridellii* T. & G.) in winter-burned plots, and purple coneflower (*Echinaceae angustifolia* DC.) in fall and winter-burned plots. Legumes were unaffected by burning season in 1997 or 1998. Sedge abundance was associated positively with winter and spring fire in 1997 and spring fire in 1998.

Time since fire influenced (*P* = 0.0224) abundance of vegetation classes in burned plots (Table 4). Shrub abundance increased with time since fire; and in fact, abundance of shrubs in plots 2 years after fire was comparable to control plots in 1998. Little bluestem abundance increased with time since fire and the 2-year post-fire means were similar to 1998 control plots. Abundance of other grasses increased, while sedge cover decreased with time since fire. All remaining vegetation classes did not vary with time since fire. Annual burning also influenced vegetation class abundance (*P* = 0.0335). The majority of vegetation classes were unaffected by annual burning , but tallgrasses were more abundant in annually burned plots, while sedge abundance was greater with single event fires.

Phytomass of grasses and forbs was affected by season of burn in 1997 (*P* = 0.0013) and weakly associated with season of burn in 1998 (*P* = 0.0899) (Table 5). In 1997, grass phytomass was unaffected by fall and winter fire and increased with spring fire; forb abundance increased with fire in any season. Results were similar for 1998, except for winter-burned plots, in which grass phytomass increased relative to control plots. Grass phytomass values were similar within treatment and across years, while forbs were lower in 1998. Grass and forb phytomass was not affected by time since fire (*P* = 0.8435) but was influenced by annual burning (*P* = 0.0388). Grass phytomass was higher for annually-burned plots compared with single event fires; forb abundance decreased with annual burning.

Correlation Analysis

Univariate correlation analysis revealed that bare ground was associated negatively with shrub cover and associated positively with cover of little bluestem, tallgrasses, annual forbs, and legumes in control plots, and associated negatively with cover of little bluestem and other grasses in burned plots (Table 6). Soil NO_3-N content was associated positively with cover of tallgrasses in control plots. Soil P content was correlated negatively with little bluestem cover in control plots, and correlated positively and negatively with annual forb and tallgrass cover, respectively, in burned plots. Soil K content was associated positively with cover of other grasses in control plots, other grasses, tallgrasses and legumes in burned plots, and correlated negatively with perennial forbs in burned plots. Soil pH correlated negatively with cover of other grasses and tallgrasses in control plots and positively with annual forbs in burned plots.

Canonical Correspondence Analysis

Both the first canonical axis ($P = 0.0050$), and all axes considered simultaneously ($P = 0.0050$) were significant (Table 7). Intraset correlations revealed that season of burn (control) and time since fire had the strongest positive correlation with CCA axis 1, and bare ground and season of burn (spring) were correlated most negatively with axis 1. Soil K and P were correlated most positively with CCA axis 2, and sampling year (1997) and soil NO_3 were correlated most negatively with axis 2. The soil nutrient gradient along axis 2 was associated with burning treatment in that means for soil K and P content were higher in burned plots than control plots, while mean soil NO_3 content was higher in control plots than burned plots (Table 6).

The bi-plot for the CCA (Figure 1) revealed an environmental gradient of fire treatment from control to spring burning treatments. The control treatment had a positive axis 1 score, while all burning treatments had negative scores. Bare ground also was associated negatively with axis 1. Burning treatment may have confounded that relationship, in that bare ground increased dramatically with burning in any season. Vegetation class scores indicated that shrubs and little bluestem were associated most closely with control plots and increasing time since fire. Sedges, legumes, annual and perennial forbs, tallgrasses, and other perennial grasses were associated with increasing bare ground and burning. The relatively short species gradients (compared with environmental gradients) were a result of our use of class variables as species, which served to reduce the quantity of variation among species relative to the use of individual taxa.

The environmental gradient along CCA axis 2 related to soil nutrients, burning treatment, and year of sampling. The sampling year effect along axis 2 was associated with growing season precipitation; 1997 was a relatively wet year, and 1998 a relatively dry year (Figure 2). Sedges and perennial forbs were associated most closely with spring burns and control plots, the 1997 sampling year and increasing soil NO_3-N, and annual forbs and legumes were associated with fall, winter, and annual burns, the 1998 sampling year, and increasing K, P, and pH.

Discussion

Soils of shinnery oak communities have been characterized as nutrient limited (Peterson and Boyd 1998). Nitrogen fertilization increases total herbaceous plant production (Pettit and Deering 1974) and forb abundance (Deering 1972) in shinnery communities. Microbial biomass and root growth have also been reported to increase following nitrogen additions to shinnery communities (Zhang and Zak 1998). However, in our study, the only vegetation class to be univariately correlated with soil NO_3-N content was tallgrasses in control plots. The apparent multivariate NO_3-N gradient (Figure 1) is more likely a fire-related gradient, in that soil NO_3-N decreased with burning treatment (Table 6). Similarly, the soil P and K gradient in Figure 1 may also relate to fire treatment in that soil P and K content increased in burned plots, relative to control plots (Table 6). Similar soil P and K responses to fire have been reported in other systems (Christensen 1987, Andreu et al. 1996). The decrease in soil NO_3 is somewhat unusual in that NO_3 has been reported to undergo short-term increases following fire (Pyne et al. 1996). However, Sears et al. (1982) reported a long-term (6 years post-treatment) decrease in below ground total N after herbicidal removal of the shrub component of shinnery oak communities. It is possible that fire-associated removal of leaf litter would increase water infiltration and increase leaching of soil associated NO_3, which is particularly susceptible to leaching due to its negative charge (Salisbury and Ross 1992).

Our results are somewhat unique in that late-growing season (fall) burns reduced shrub cover less than other burning seasons; other oak species are greatly reduced by growing-season fire (Fergusson 1961, Glitzenstein et al. 1995). This may relate to the fact that our burns were near the end of the growing season (October), after the period of peak carbohydrate storage in the dominant shrub shinnery oak (Boo and Pettit 1975). The relatively strong reduction in shrub canopy cover following spring fire may also relate to carbohydrate storage. Boo and Pettit (1975) reported that the low point in the carbohydrate cycle of shinnery oak was during the first 2 weeks of May, when leaf expansion was 50-75%. Our spring burns corresponded to this time period. At the time of our spring burns, leaf expansion of the two most dominant species (shinnery oak and Oklahoma plum) was about 50%. McIlvain and Armstrong (1966) noted a similar response to spring burning of shinnery communities in Ellis County, Oklahoma.

The positive association of time since fire with shrub abundance is indicative of adaptations of the dominant shrub, shinnery oak, to disturbance. Top-kill of shinnery oak stems approached 100% for all burns, but, shinnery oak reproduces vegetatively from rhizomes (Muller 1951) and re-sprouts vigorously in response to fire (Slosser et al. 1985), thus enhancing its persistence in the community following fire disturbance. The fact that shrubs were not correlated with any environmental variable, with the exception of bare ground (Table 6), is reflective of the wide ecological tolerance of the shrub component of shinnery oak communities. The negative correlation of shrubs with bare ground in control plots (Table 6) reflects the fact that bare ground decreases with increasing shrub cover (i.e. increased oak leaf litter deposition), not because bare ground is a controlling factor of shrub abundance.

The response of grasses to fire was characterized by an increase in overall grass phytomass in spring-burned plots and an increase in the ratio of tallgrass to little bluestem canopy cover with burning in any season. Other authors have noted like responses of little bluestem to fire (e.g. Ewing and Engle 1988, Towne and Owensby 1984), which may relate to the non-rhizomatous growth form of little bluestem which makes its basal growing points more susceptible to fire damage than rhizomatous co-dominants. That cover of little bluestem and other perennial grasses increased while that of rhizomatus tallgrasses remained unchanged with increasing time since fire (Table 4) suggests that frequent fire may be necessary to the maintenance of the tallgrass component of shinnery communities. In support of this generalization, canopy cover of rhizomatus tallgrasses increased in annually-burned plots relative to plots burned only once (Table 4). Rhizomatous tallgrasses were the only vegetation class in this study correlated with soil NO_3-N. This correlation was absent following fire (Table 6), while soil NO_3-N content decreased with fire, suggesting that increased cover of rhizomatous grasses following fire offset effects of limitations of soil NO_3-N. Sedges were not correlated with any of the environmental variables (Table 6) but did increase following seasonal fire suggesting that fire treatment is beneficial to the abundance of this species. The positive association of sedges with the sampling year is related to a relatively wetter spring growing period in 1997 (Figure 2); sedges are cool-season species and are actively growing during spring (Kindscher and Wells 1995). Coppedge et al. (1998) found a similar response of sedges and rushes to spring precipitation in a tallgrass prairie system.

In general, forb phytomass (Table 5) and cover of annual and perennial forbs (Table 4) increased with burning treatment relative to unburned plots. The positive association between fall fire and perennial forb canopy cover may relate to the time of burning relative to plant morphological development. Plots burned in fall were burned before growth initiation of cool season perennial forbs, winter burns coincided with the growing period of some cool season forb species, while spring burns coincided with active growth periods for cool and warm season forbs. In burned plots, annual variation in the canopy cover of annual and perennial forbs (Table 4) was associated with variable growing season precipitation (Figure 2). Perennial forb abundance was highest with increased growing season precipitation, while in fall and winter-burned plots, annual forbs were most abundant with decreased growing season precipitation. The increase in annual forbs during a relatively dry year may be due to a reduction in competition with perennial forb species. Annual species are generally very sensitive to competition with perennial species (Bazzaz and Morse 1991). If abundance of perennial species is reduced by an environmental factor (e.g. low precipitation), competing annuals may increase after this period of reduced competition for light and nutrients. Increases in annual forbs associated with burning also may relate to increased availability of germination sites (i.e. increased bare ground; Trabaud 1987) and decreased phytochemical inhibition from perennial woody species or litter (Menges and Kimmich 1996). Phytochemical inhibition of annual or perennial forb species has not been reported in shinnery oak communities, but, Matizha and Dahl (1991) reported strong reductions in shoot growth of weeping lovegrass (*Eragrostis curvula* Schrad.) with application of leaf extract from shinnery oak. The positive association between annual burning and legume abundance (Figure 1) supports the hypothesis that nitrogen fixing legumes will increase in annually-burned communities, which are generally thought to be nitrogen limited (Towne and Knapp 1996).

That several forb species were only found in 1 or 2 treatments suggests that these species may be limited to areas burned in a particular season, or areas disturbed in such a way as to create microclimate conditions similar to the treatment in which they were found. That certain forb species may be dependent on or associated with particular seasons of burn supports the notion that maintaining plant diversity may be aided by varying date of burning.

We believe that the influence of fire on the herbaceous component of shinnery oak communities is strongly related to alterations in availability of bare ground, and decreased overstory shrub dominance. The majority of the ground not covered by basal plant material in unburned plots was covered with oak leaf litter to depths of about 8 cm, and little bluestem, tallgrasses, annual forbs, and legumes are correlated positively with increasing bare ground (Table 6). Fire in any season reduces negative effects of leaf litter on herbaceous abundance by increasing availability of bare ground. Following fire, tallgrasses, annual forbs, and legumes no longer correlate with bare ground (Table 6). The negative correlations following fire between bare ground, and little bluestem and other perennial grasses may relate to competition with rhizomatous tallgrasses in the post-burn environment. In the CCA bi-plot (Figure 1), little bluestem and shrubs were the only vegetation classes not associated positively with bare ground. Bare ground represented the most important environmental variable (i.e. it largely defined the first CCA axis) of those included in this analysis. Dhillion et al. (1994) reported that density of herbaceous seedlings in a shinnery oak community was correlated positively with increasing bare ground. In undisturbed shinnery communities, the shrub component also creates a fairly continuous canopy cover and may act to decrease light availability and microclimate diversity at the ground level. Burning decreases the shading effects of overstory shrubs, thus creating light gaps in the canopy that may benefit shade intolerant herbaceous species

(Nasser and Goetz 1995, Bowles and McBride 1998). Holland (1994) reported that recruitment of herbaceous seedlings decreased with increasing cover of shinnery oak.

Conclusions and Management Implications

Shrub cover (mainly shinnery oak) dominates shinnery oak communities on the present day landscape, whereas the majority of species in these communities are herbaceous (Dhillion et al. 1994). Our results indicate that prescribed fire can be used as an effective tool for re-structuring community composition. Burning in any season can decrease shrub canopy cover and increase phytomass of grasses and forbs. Winter and annual fire can increase the canopy cover of rhizomatus perennial grasses, while little bluestem cover is decreased by fire in any season. Annual and perennial forb cover may increase with burning in any season, but fall fire generally increases forb cover the most. Although vegetation responds differentially to fire in different seasons, other fire-related factors such as increases in bare ground and reduction of shrub canopy cover may influence plant community dynamics.

The major limitation of our study is the short-term nature of our results. Other authors have stressed the temporary nature of fire-induced changes in shinnery communities (e.g., Slosser et al. 1985), as well as other shrub-dominated systems (Parsons 1976, Trabaud and Lepart 1980). In fact, our data indicate that shinnery oak communities are very elastic and show signs of a rapid return to pre-burn plant composition following fire. However, it can be argued that the immediate results of burning treatment may be important for a variety of short-term management goals, such as increasing abundance of forbs that are important for certain wildlife species or increasing the abundance of perennial grass species important to ground-nesting birds. Additional research is needed to assess long-term community response to fire, including the effects of fire frequency and the interaction of fire frequency and season of burn on plant species composition.

Literature Cited

Andreu, V., J.L. Rubio, J. Forteza and R. Cerni. 1996. Postfire effects on soil properties and nutrient losses. Int. J. Wildland Fire.6:53-58.

Bazzaz, F.A. and S.R. Morse. 1991. Potential responses of annuals to multiple stresses, p. 283-305. *In:* Mooney et al. (ed.), Response of plants to multiple stresses. Academic Press, New York.

Bonham, C.D. 1989. Frequency and Cover, p.89-135. *In:* Measurements for terrestrial vegetation. John Wiley and Sons Press, New York, NY.

Boo, R.M. and R.D. Pettit. 1975. Carbohydrate reserves in roots of sand shin oak in west Texas. J. Range Manage. 28:469-472.

Bowles, M.L. and J.L. McBride. 1998. Vegetation composition, structure, and chronological change in a decadent midwestern North American savanna remnant. Nat. Areas. J. 18:14-27.

Box, T.W. 1967. Brush, fire and west Texas rangeland. Proc, Tall Timbers Fire Ecol. Conf. 6:7-19.

Boyd, C.S. 1999.The effects of fire intensity on shinnery oak (*Quercus havardii*) plant communities in western Oklahoma. *In:* The effects of burning season and frequency on the vegetative character and insect abundance of sand shinnery oak range in western Oklahoma. Ph.D. Dissertation, Oklahoma State Univ., Stillwater.

Christensen, N.L. 1987. The biogeochemical consequences of fire and their effects on the vegetation of the coastal plain of the southeastern United States, p. 1-19. *In*: The role of fire in ecological systems. SPB Academic Publishing, Hauge, The Netherlands.

Coppedge, B.R., D.M. Engle, C.S. Toepfer, and J.H. Shaw. 1998. Effects of seasonal fire, bison grazing and climactic variation on tallgrass prairie vegetation. Plant Ecol. 0:1-12.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Sci. 33:43-64.

Deering , D.W. 1972. Effects of selected herbicides and fertilization on a sand shinnery oak community. MS Thesis, Texas Tech University, Lubbock.

Dhillion, S.S., M.A. McGinley, C.F. Friese and J.C. Zak. 1994. Construction of sand shinnery oak communities of the Llano Estacado: Animal disturbances, plant community structure, and restoration. Rest. Ecol. 2:51-60.

Duck, L.G. and J.B. Fletcher. 1944. A survey of the game and fur-bearing animals of Oklahoma. State Bull. 3. Oklahoma City: Oklahoma Game and Fish Dept. 144pp.

Ewing, A. L. and D.M. Engle. 1988. Effects of late summer fire on tallgrass prairie microclimate and community composition. Amer. Midl. Natur. 120:212-213.

Fergusson, E.R. 1961. Effects of prescribed fires on understory stems in pine-hardwood stands in Texas. J. Forestry. 59:356-359.

Fuhlendorf, S.D. and F.E. Smeins. 1998. The influence of soil depth on plant species response to grazing within a semi-arid savanna. Plant Ecol. 138:89-96.

Glitzenstein, J.S., W.J. Platt and D.R. Streng. 1995. Effects of fire regime and habitat on tree dynamics in north Florida longleaf pine savannas. Ecol. Monogr. 65:441-476.

Great Plains Flora Association. **1986**. Flora of the Great Plains. T.M. Barkley (ed.), Univ. Kansas Press, Lawrence.

Holland, M. 1994. Disturbance, environmental heterogeneity, and plant community structure in a sand shinnery oak community. MS Thesis, Texas Tech Univ., Lubbock.

Jackson, A.S. and R. DeArment. 1963. The lesser prairie chicken in the Texas Panhandle. J. Wildl. Manage. 27:733-737.

Johnson, R.A. and D.W. Wichern. 1992. Applied multivariate statistical analysis. Prentice Hall, Englewood Cliffs, New Jersey.

Kindscher, K. and P.V. Wells. 1995. Prairie plant guilds: a multivariate analysis of prairie species based on ecological and morphological traits. Vegetatio. 117:29-50.

Marcy, R.B. 1854. Explorations of the Red River of Louisiana in the year 1852. 33rd Congress, 1st Session, House Executive Document. Washington: A.O.P. Nicholson. 286pp.

Matizha, W. and B.E. Dahl. 1991. Factors affecting weeping lovegrass vigor on shinnery oak range. J. Range. Manage. 44:223-227.

Menges, E.S. and J. Kimmich. 1996. Microhabitat and time-since-fire: Effects on demography of *Eryngium cuneifolium* (Apiaceae), a Florida scrub endemic plant. Amer. J. Bot. 83:185-191.

McIlvain, E.H. and C.G. Armstrong. 1966. A summary of fire and forage research on shinnery oak rangelands. Proc. Tall Timbers Fire Ecol. Conf. 5:127-129.

McIlvain, E.H. and M.C. Shoop. 1965. Pasture and range investigations. Woodward, Oklahoma: U.S.D.A., A.R.S. 187pp.

Muller, C.H. 1951. The significance of vegetative reproduction in *Quercus*. Madrono. 11:129 137.

Nasser, N. and H. Goetz. 1995. Relationships of overstory to understory cover variables in a ponderosa pine/gambel oak ecosystem. Vegetatio 119:15-21.

Osborne, B. 1942. Prairie dogs in shinnery (oak scrub) savannah. Ecol. 23:110-115.

Palmer, M.W. 1993. Putting things in even better order: the advantages of canonical correspondence analysis. Ecology 74:2215-2230.

Parsons, D.J. 1976. The role of fire in natural communities: An example from the southern Sierra Nevada, California. Environmental Cons. 3:91-99.

Peterson, R.S. and C.S. Boyd. 1998. Ecology and management of sand shinnery oak communities: A literature review. U.S.D.A. Forest Service Gen. Tech. Rept.-16.

Pettit, R.D. 1994. Sand shinnery oak, p. 106. *In*: T.N. Shiflet, (ed.), Rangeland cover types of the United States. Soc. for Range Manage., Denver.

Pettit, R.D. and D.W. Deering. 1974. Yield and protein content of sandyland range forages as affected by three nitrogen fertilizer. J. Range Manage. 27:211-213.

Pyne, S.J., P.L. Andrews and R.D. Laven. 1996. Fire effects, p.171-212. *In*: Introduction to Wildland Fire. John Wiley and Sons, New York, NY.

Salisbury, F.B. and C.W Ross. 1992. Assimilation of nitrogen and sulfur, p. 289-307. *In*: Plant physiology. Wadsworth Publ. Co., Belmont, CA.

SAS Institute Inc. 1988. SAS procedures guide, release 6.03. Cary, NC.

Sears, W.E. 1982. Biomass and nitrogen dynamics of a herbicide converted sand shinnery oak community. MS Thesis, Texas Tech Univ., Lubbock.

Slosser, J.E., P.W. Jacoby and J.R. Price. 1985. Management of sand shinnery oak for control of boll weevil (Coleoptera: Curculionidae) in the Texas Rolling Plains. J. Econ. Entomol. 78:383 389.

Smilauer, P. 1990. CANODRAW: A companion program to CANOCO for publication quality graphical output. Microcomputer Power, New York, NY.

Stroup, W.W. and J. Stubbendieck. 1983. Multivariate statistical methods to determine changes in botanical composition. J. Range Manage. 36:208-212.

ter Braak, J. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. Ecology 67:1167-1179.

ter Braak, J. 1998. CANOCO-a FORTRAN program for canonical community ordination. Microcomputer Power. New York, NY.

Towne, G. and C. Owensby. 1984. Long-term effects of annual burning at different dates in ungrazed Kansas tallgrass prairie. J. Range. Manage. 37:392-397.

Towne, E.G. and A.K. Knapp. 1996. Biomass and density responses in tallgrass prairie legumes to annual fire and topographic position. Am. J. Bot. 83:175-179.

Trabaude, L. 1987. Fire and survival traits of plants, p. 65-89. *In*: The role of fire in ecological systems. SPB Academic Publishing, Hauge, The Netherlands.

Trabaude, L. and J. Lepart. 1980. Diversity and stability in Garrigue ecosystems after fire. Vegetatio 43:49-57.

United States Department of Agriculture. 1982. Soil survey: Roger Mills County Oklahoma. U.S. Gov. Printing Office, Washington, D.C.

West, N.E. and G.A. Reese. 1996. Comparison of some methods for collecting and analyzing data on aboveground net production and diversity of herbaceous vegetation in a northern Utah subalpine context. Vegetatio 96:145-163.

Wright, H.A. and A.W. Bailey. 1982. Fire ecology: United States and southern Canada. John Wiley and Sons, New York. 501pp.

Zhang, Q. and J.C. Zak. 1988. Effects of water and nitrogen amendment on soil microbial and fine root production in a semi-arid environment in west Texas. Soil Biol. Biochem. 30:39-45.

Table 1. Year, season of burn, burning date, and sample size for prescribed burns in western Oklahoma.

Year	Season	Burning date	n
1996	Fall	Oct. 23-24	3
1997	Winter	Feb. 4-5	6
1997	Spring	April 28-29	6
1998	Fall	Oct. 1	3
1998	Winter	Jan. 27-28	6
1998	Winter (annual)	Jan 27-28	3
1998	Spring	April 30-May1	6
1998	Spring (annual)	April 30-May1	2

Table 2. Shinnery oak community vegetation classes, acronyms, and representitive species.

Vegetation class	Acronym	Representitive species
Annual Forbs	FORBA	*Conyza canadensis* L., *Monarda punctata* L., *Pyropapus carolinianus* Walt.
Perennial Forbs	FORBP	*Ambrosia psilostachya, Calylophus berlanderii, Commelina erecta*
Legumes	LEGUME	*Amorpha canescens* Pursh., *Desmodium sessilifolium* Torr., *Lespedeza stuevei* Nutt.
Little Bluestem	LBS	*Schizachyrium scoparium*
Tallgrasses	TG	*Andropogon gerardii, Panicum virgatum, Sorghastrum nutans,*
Other Grasses	GRASS	*Bouteloua curtipendula, Eragrostis trichodes, Sporobolus cryptandrus*
Sedges	SEDGE	*Cyperus schweinitzii* Torr.
Shrubs	SHRUB	*Artemisia filifolia, Prunus gracilis, Quercus havardii*

Table 3. Variable type, acronym and data range for variables used in the statistical analysis of shinnery oak vegetation.

Variable Type	Variable	Acronym	Data Range*
Treatment	Season of Burn		
	Control (unburned)	SOBC	...
	Fall	SOBF	...
	Winter	SOBW	...
	Spring	SOBS	...
	Time Since Fire**		
	One Year	TSF1	...
	Two Years	TSF2	...
	Annual		
	Single Event Fire	ANNUAL0	...
	Annual Fire	ANNUAL1	...
Environmental	Soil Nitrate (kg/ha)	NO3	3-66
	Soil Phosphorous (kg/ha)	P	15-34
	Soil Potassium (kg/ha)	K	68-320
	Soil Ph	Ph	5.5-6.6

* Data range values for 1997-1998.

** Equivilant to the number of growing seasons since fire.

Table 4. Canopy cover for vegetation classes by year and fire treatment for experimental plots in western Oklahoma. Acroynms are from Table 2.

				Vegetation class															
	Treatment			SHRUB		LBS		GRASS		TG		FORBA		FORBP		LEGUME		SEDGE	
Year	variable	n	*P* Value*	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
				% Canopy cover															
1996	Control	36	...	53.5	*1.1*	33.9	*1.1*	14.7	*0.8*	16.6	*1.1*	1.1	*0.1*	6.9	*0.4*	0.4	*0.1*	0.31	*0.05*
1997	Season of burn	21	0.0001																
	Control	21		74.4	*2.0*	41.9	*2.6*	17.7	*1.3*	21.7	*2.3*	1.7	*0.3*	9.0	*1.0*	0.2	*0.1*	0.11	*0.04*
	Fall	3		56.5	*10.2*	22.6	*9.0*	19.2	*5.6*	29.1	*6.3*	1.2	*0.4*	18.1	*2.8*	0.3	*0.3*	0.43	*0.35*
	Winter	6		60.3	*4.7*	24.7	*4.3*	16.4	*2.8*	32.5	*7.0*	3.3	*1.3*	13.9	*2.7*	0.4	*0.4*	0.27	*0.14*
	Spring	6		30.4	*4.2*	24.8	*4.7*	16.2	*2.3*	29.5	*9.9*	1.1	*0.5*	11.5	*2.3*	0.5	*0.3*	0.79	*0.33*
1998	Season of burn	36	0.0014																
	Control	6		73.8	*6.0*	46.3	*4.8*	8.0	*1.5*	17.5	*3.2*	0.7	*0.3*	3.4	*0.6*	0.2	*0.2*	0.01	*0.01*
	Fall	6		64.4	*6.3*	28.3	*7.0*	11.6	*2.3*	23.2	*4.6*	3.6	*1.2*	8.4	*1.0*	0.4	*0.2*	0.09	*0.07*
	Winter	12		60.7	*2.4*	34.2	*3.8*	13.6	*1.5*	27.3	*4.0*	2.1	*0.7*	7.2	*0.9*	0.3	*0.1*	0.09	*0.05*
	Spring	12		41.4	*5.4*	30.8	*5.1*	13.6	*2.2*	25.2	*5.3*	3.2	*1.1*	5.7	*0.9*	0.3	*0.2*	0.22	*0.08*
	Time since fire	30	0.0224																
	One year	20		47.5	*3.7*	25.6	*2.1*	10.9	*1.1*	26.8	*3.5*	2.3	*0.6*	6.7	*0.7*	0.4	*0.1*	0.20	*0.06*
	Two years	10		66.2	*4.1*	43.9	*5.7*	17.8	*2.0*	23.4	*4.4*	4.0	*1.2*	7.2	*1.0*	0.2	*0.2*	0.03	*0.02*
	Annual	30	0.0335																
	Single event fire	25		55.3	*3.4*	32.0	*3.3*	13.0	*1.3*	23.0	*2.7*	2.7	*0.6*	6.7	*0.7*	0.3	*0.1*	0.16	*0.05*
	Annual fire	5		45.6	*9.2*	30.0	*3.3*	14.1	*1.6*	38.9	*8.1*	3.4	*1.5*	7.6	*1.0*	0.7	*0.5*	0.07	*0.04*

* P value is for the Wilks' Lambda test statistic associated with the treatment variable effect in the model : Veg. Class $_{i\text{-}j}$ = Pretreatment Veg. Class $_{i\text{-}j}$ + Treatment Variable + Block + Treatment Variable*Block .

Table 5. End-of-growing season phytomass of grasses and forbs by fire treatment for experimental plots in western Oklahoma.

				Phytomass (g/m^2)			
				Grasses		Forbs	
Year	Treatment Variable	n	*P* Value*	x̄	SE	x̄	SE
1996	Control	36	...	100.7	*6.6*	9.1	*1.2*
1997	Season of Burn		0.0013				
	Control	21		74.7	*6.3*	18.8	*2.8*
	Fall	3		68.5	*25.5*	31.0	*5.8*
	Winter	6		86.0	*28.3*	33.6	*7.9*
	Spring	6		122.3	*38.2*	28.3	*6.5*
1998	Season of Burn		0.0899				
	Control	6		65.3	*15.6*	4.4	*2.7*
	Fall	6		66.1	*19.7*	19.9	*6.2*
	Winter	12		96.7	*12.8*	11.7	*2.4*
	Spring	12		96.7	*14.9*	11.8	*3.6*
	Time Since Fire		0.8435				
	One Year	20		88.9	*10.5*	13.8	*2.6*
	Two Years	10		92.7	*16.5*	12.4	*3.8*
	Annual		0.0303				
	Single Event Fire	25		80.7	*8.2*	14.1	*2.5*
	Annual Fire	5		137.5	*25.4*	9.7	*1.8*

* P value is for with the Wilks' Lambda test statistic associated with the treatment variable effect in the model : Veg. Class i-j = Pretreatment Veg. Class i-j + Treatment Variable + Block + Treatment Variable*Block .

Table 6. Correlation coefficients of vegetation class canopy cover and environmental variables for experimental plots in western Oklahoma. Acronyms are from table 2.

Environmental variable	Treatment	n	Mean $\bar{x}$	Mean SE	Vegetation class SHRUB	LBS	GRASS	TG	FORBA	FORBP	LEGUME	SEDGE
					Correlation coefficient							
Bare ground	Control	27	6.6	*0.8*	-0.398 *	0.431 *	0.110	0.421 *	0.702 *	-0.173	0.493 *	-0.001
	Burned	45	48.6	*2.0*	-0.158	-0.298 *	-0.256 **	0.233	0.047	0.030	0.225	-0.029
Soil nitrate (kg/ha)	Control	27	27.3	*3.2*	-0.059	0.027	0.209	0.621 *	0.130	0.103	-0.049	-0.059
	Burned	45	20.2	*2.2*	-0.099	-0.084	-0.124	-0.189	0.059	-0.011	-0.098	-0.044
Soil phosphorus (kg/ha)	Control	27	16.9	*0.4*	0.219	-0.554 *	0.103	-0.236	-0.110	0.227	-0.283	0.046
	Burned	45	19.3	*0.7*	0.214	-0.106	-0.132	-0.325 *	0.362 *	0.045	-0.150	0.078
Soil potassium (kg/ha)	Control	27	167.6	*7.6*	0.065	-0.074	0.370 **	-0.103	0.220	-0.085	0.234	0.252
	Burned	45	188.9	*5.4*	-0.086	0.540 *	0.289 **	0.282 **	0.236	-0.260 *	0.482 *	-0.181
Soil pH	Control	27	6.0	*0.0*	0.255	-0.191	-0.404 *	-0.528 *	-0.283	0.064	-0.312	-0.039
	Burned	45	6.1	*0.0*	0.110	0.023	0.112	0.025	0.338 *	-0.181	-0.080	0.012

* $P \leq 0.05$

** $P > 0.05$ and ≤ 0.10

Table 7. Relationship between environmental and treatment variables in the partial canonical correspondence analysis of data from experimental plots in western Oklahoma. Acronyms are from Table 3.

	Axis 1	Axis2
Eigenvalue	0.015	0.005
Species-environment correlation	0.823	0.627
Cumulative percentage		
Variance of:		
Species data	19.8	26.9
Species-environment relation	49.5	67.1
1997	-0.264	-0.491
1998	0.264	0.491
SOBC	0.619	-0.206
SOBF	-0.184	0.167
SOBW	-0.079	0.219
SOBS	-0.490	-0.119
TSF2	0.233	0.212
ANNUAL1	-0.159	0.413
NO3	0.116	-0.221
P	-0.120	0.572
K	-0.250	0.821
Ph	0.005	0.341
BARE	-0.708	0.258

Figure 1. Bi-plot of the first two axes of the partial canonical correspondence analysis. Continuous variables are represented by their arrows, and nominal variables by solid triangles indicating their centroid. Species are represented by open circles. Arrows with dotted lines point to species locations where data are crowded. Acronyms are from tables 2 and 3.

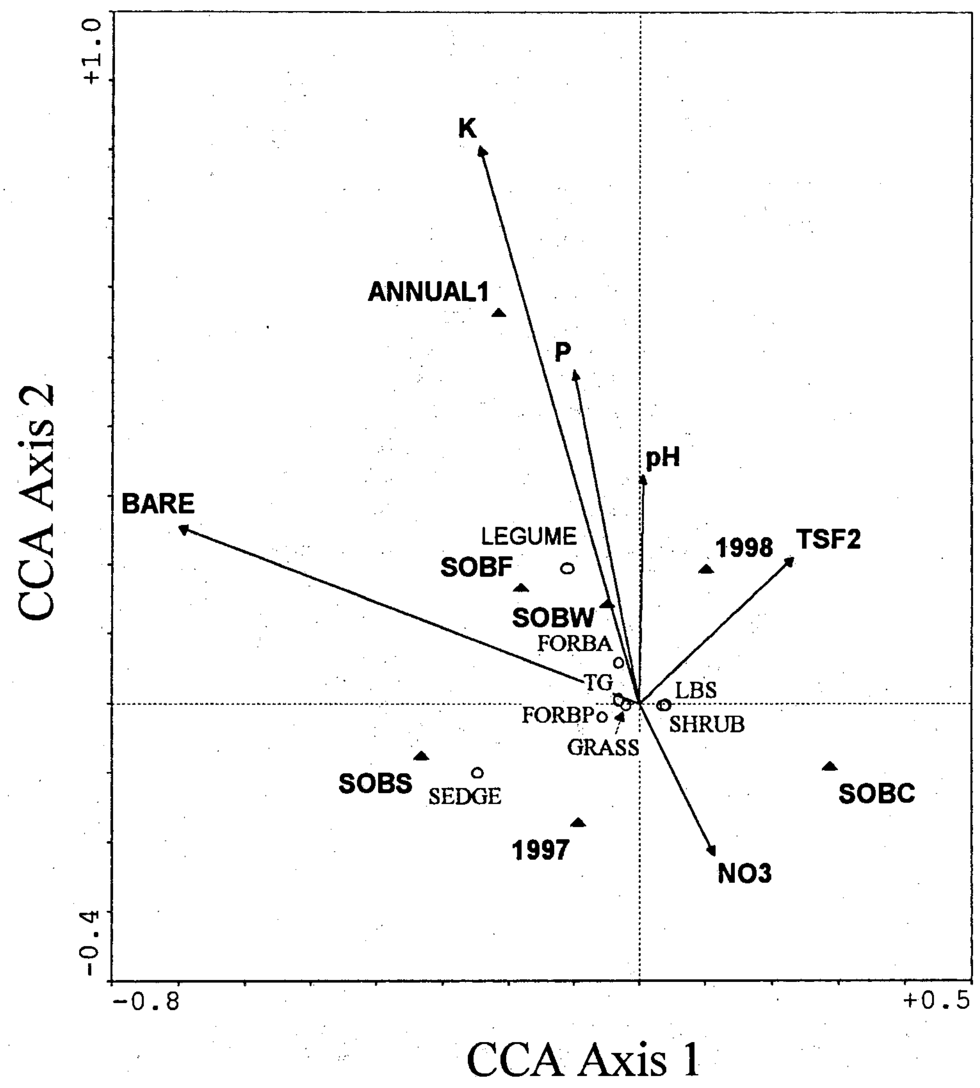
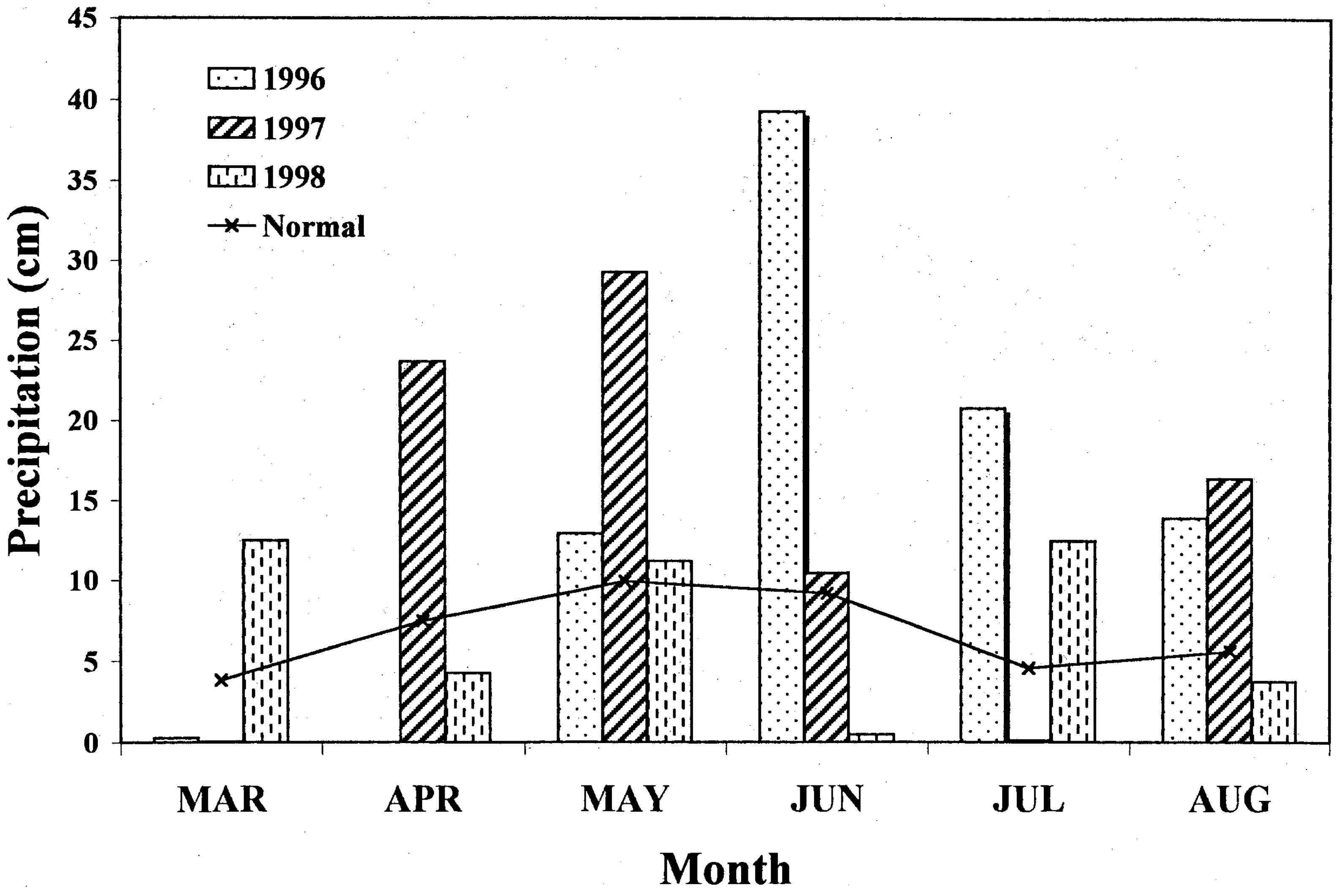

+1.0
K
ANNUAL1
P
pH
BARE
LEGUME
SOBF
SOBW
1998
TSF2
FORBA
TG
LBS
FORBP
SHRUB
GRASS
SOBS
SEDGE
SOBC
1997
NO3
-0.4
-0.8
+0.5
CCA Axis 2
CCA Axis 1

Figure 2. Growing season precipitation by month during the study period. Long-term average (normal) precipitation data are from USDA (1982).


45
40
35
30
25
20
15
10
5
0
Precipitation (cm)
1996
1997
1998
Normal
MAR
APR
MAY
JUN
JUL
AUG
Month

CHAPTER III

THE EFFECTS OF PRESCRIBED FIRE ON SHRUB ABUNDANCE IN SHINNERY OAK (*QUERCUS HAVARDII* Rydb.) PLANT COMMUNITIES IN WESTERN OKLAHOMA

Abstract

Little is known about the response of shinnery oak (*Quercus havardii* Rydb.) communities to fire. Our objective was to document effects of fall (October), winter (February), and spring (April) prescribed fire on woody plant composition in these communities and define the interacting influence of soil nutrient content. Three study sites were located in western Oklahoma; each containing 12, 60 x 30 m plots that were designated, within site, to be seasonally burned, annually burned, or left unburned. Canopy cover of woody species was estimated in 1996 (pre-treatment) and 1997-1998 (post-treatment). Soil nutrient content was assessed during the same time period. Shrub stem density (by species) and canopy height of shinnery oak and Oklahoma plum (*Prunus gracilis* Engelm.) were estimated in September 1997 and 1998. Shrub species cover, density and height were analyzed using multivariate analysis of variance with season of burn, time since fire, or annual burning as the independent variable. The interactive influence of soil nutrient content was determined using partial canonical correspondence analysis. Canopy cover of shrub species was influenced by season of burn ($P = 0.0001$)

and time since fire ($P = 0.0745$); to date, annual burning had no significant effect ($P = 0.2939$). Height of shinnery oak and Oklahoma plum was influenced by season of burn ($P = 0.0001$) but not by time since fire ($P = 0.1745$) or annual burning ($P = 0.5906$). Fire in any season negatively affected cover of most species and decreased canopy height of shinnery oak and Oklahoma plum; spring burning had the most negative affect. Shrub density was influenced by season of burn (1997, $P = 0.0001$; 1998, $P = 0.0007$) and annual fire ($P = 0.0046$) but not by time since fire ($P = 0.2592$). Density of most shrub species increased with fire in any season; spring burns produced the lowest shrub density of all burning treatments. The interactive influence of soil nutrients and burning treatment had a significant affect on species gradients ($P = 0.0100$). Shrub species of shinnery oak communities reproduce mainly through vegetative means and recovered quickly from fire. Fire may be used as a tool to decrease short-term shrub abundance and perhaps serve as an alternative to herbicide to reduce shinnery oak.

Keywords: Prescribed fire, shrub ecology, Oklahoma, multivariate analysis of variance.

Introduction

Shinnery oak (*Quercus havardii* Rydb.) and associated vegetation occur in west central Oklahoma, northern Texas, and southeastern New Mexico. Peterson and Boyd conservatively estimated that shinnery oak rangelands covered at least 2 million hectares in those states (Peterson and Boyd 1998). Historical accounts indicate that shinnery oak communities were structurally dominated by tallgrasses with shinnery oak in the understory; oak stems did not commonly exceed 45 cm in height (Marcy 1854, Osborne

1942). Today, shinnery may constitute 80% of canopy cover (Dhillion et al. 1994), the abundance of tallgrasses has decreased, and oak stems may reach 1 m in height in western Oklahoma (Peterson and Boyd 1998). This increase in oak stature and canopy cover can negatively affect recruitment of herbaceous seedlings (Holland 1994), leading to lower herbaceous plant production.

These structural and compositional changes in shinnery oak communities often have been described as products of mismanagement of grazing livestock (Duck and Fletcher 1944, Jackson and DeArment 1963, Pettit 1994). While grazing practices have undoubtedly influenced both small and large scale vegetation dynamics, it is difficult to evaluate effects of livestock grazing in any system without simultaneously considering the historical influence of fire (Box 1967). The diminutive stature of shinnery oak in historical references may indicate a somewhat reliable and strong influence of fire, given the susceptibility of this species to top-kill by fire. Prescribed spring fires may result in dramatic increases in herbaceous plant phytomass in years of adequate rainfall (McIlvain and Armstrong 1966, McIlvain and Shoop 1965), and a high percentage of shinnery oak stems may be top-killed (Slosser et al. 1985).

To evaluate the historic and potential role of fire in shaping plant composition of shinnery oak communities, the overall fire regime must be explored, which necessarily involves examining effects of fire frequency and season as well as the spatial scale and pattern of fire events. To date, there has been no published work on effects of growing season and winter fire in these communities. In previous work (Boyd 1999a), we evaluated the influence of seasonal prescribed fire on changes in plant response group abundance. Our objective here is to examine the role of season of burn, time since fire, and annual burning on species composition within the shrub component of shinnery oak communities in western Oklahoma. Additionally, we delineate the relative importance of fire within the context of soil nutrient content.

Methods

Study Sites

Study sites were located on the Black Kettle National Grassland in Roger Mills County, Oklahoma (35° 32’ 44’’ N, 99^{O} 43’ 39’’ W), and the state-owned Packsaddle Wildlife Management Area in Ellis County, Oklahoma (36° 4’ 22’’ N, 99^{O} 54’ 5’’ W). Sites were chosen subjectively to be representative of shinnery oak communities found on sandy soils within the western Oklahoma region. All sites were lightly grazed by cattle during the growing season before study initiation and were excluded from grazing in 1995 and throughout the course of the study. Before our study, these sites had not burned on a regular basis and had not burned for at least 10 years.

Soils were fine sands (Nobscott-Brownfield Association) with no limiting layers in the top 150cm (USDA 1982). Shinnery oak, a deciduous, clonal species, was the dominant shrub. Other shrub species included Oklahoma plum (*Prunus gracilis* Engelm.), sand sagebrush (*Artemisia filifolia* Torr.), fragrant sumac (*Rhus aromatica* Ait.), leadplant (*Amorpha canescens* Pursh), and netleaf hackberry (*Celtis reticulata* Torr.) (Table 1). Dominant grasses and forbs included little bluestem (*Schizachyrium scoparium* Nash), indiangrass (*Sorghastrum nutans* Nash), switchgrass (*Panicum virgatum* L.), sand bluestem (*Andropogon gerardii* Hack.), sand lovegrass (*Eragrostis trichodes* Nutt.), sideoats grama (*Bouteloua curtipendula* Michx.), western ragweed (*Ambrosia* *psilostachya* DC.), erect dayflower (*Commelina erecta* L.) and sundrop (*Calylophus berlandieri* Spach). Average annual precipitation is 65.6 cm; growing season (March-August) precipitation averages 40.6 cm (USDA 1982).

Experimental Design

We divided each of the 3 study sites (blocks) into 12 60 x 30 m plots. Plots were arranged in a 2 x 6 matrix and separated by 7 m firebreaks. We randomly assigned each of the plots within a site to the following 9 treatments: 1) no burn, 2) burn fall 1996, 3) burn fall 1997, 4) burn winter 1997, 5) burn winter 1998, 6) burn winter 1997 and 1998, 7) burn spring 1997, 8) burn spring 1998, and 9) burn spring 1997 and 1998 (Table 1). Pre-treatment data were collected during the growing season in 1996 and treatment response data during the growing seasons in 1997 and 1998.

Fire Ignition and Behavior

All plots were burned using a strip-headfiring technique (Wright and Bailey 1982). The downwind and flank sides of the plots were ignited and allowed to burn about 5 m into the plot. We ignited a series of headfires about 10 m upwind from the backfire. All burns were conducted with relative humidity >20%, air temperature <29 °C and a surface wind speed of <16 km/hr. We estimated fire behavior characteristics for all headfires and determined pre-burn fuel loading and fire consumption from quadrats clipped before and after burning. Fire behavior and fuel characteristics are discussed in Boyd (1999b).

Vegetation Sampling

Because of the ignition pattern, the outer 5 m of plots were excluded from vegetation sampling to eliminate differential effects of headfires, backfires, and flankfires. We estimated canopy cover for each plot, by species, at 30 randomly located points (Daubenmire 1959). At each point, the canopy cover of shrub species influencing a 20 x 50 cm quadrat was categorized as 0-5%, 5-25%, 25-50%, 50-75%, 75-95% or 95-100%. We averaged mid-point values to obtain an estimate of canopy cover of each species in a plot for a given sampling period. We estimated canopy cover during 3 sampling periods: 25-31 May, 6-22 June, and 8-17 August. Pretreatment data were collected during the growing season in 1996 and treatment response data during the growing seasons in 1997 and 1998. Average seasonal canopy cover values for each shrub species were calculated by averaging canopy cover values by plot, class, and year (West and Reese 1996). These average values were used in all statistical analyses. Nomenclature followed that of the Great Plains Flora Association (1986).

We estimated shrub stem density and shrub canopy height in September 1997 and 1998. We estimated density by counting the number of above-ground stems present in 10 randomly located 0.50 m^2 quadrats per plot. We defined stems as shrub plants that had a unique above-ground base. We estimated canopy height by measuring the average canopy height of the two dominant shrub species (shinnery oak and Oklahoma plum) in 10 randomly located 0.50 m^2 quadrats for each plot.

Environmental Variables

We collected soil samples to a depth of 15 cm from all plots during July 1996, 1997, and 1998. Soil samples were analyzed for NO_3-N, P, and K content and pH at the Oklahoma State University Soil Testing Laboratory, Stillwater, OK (Table 3). We obtained precipitation data from an automated climatological recording station located about 10 km south of our study area. Growing season precipitation was calculated by summing monthly values for March-August of a given year.

Statistical Analysis

Multivariate Analysis of Covariance

We assessed treatment effects using multivariate analysis of covariance for shrub canopy cover data, and multivariate analysis of variance for shrub density and shrub height (Fuhlendorf and Smeins 1998, SAS Institute Inc. 1988, Stroup and Stubbendieck 1983) with cover, height or density as the dependent variable and season of burn, time since fire, or annual burning (Table 3) as the main effect. We evaluated treatment significance using the *P*-value associated with the Wilks' Lambda test statistic (Johnson and Wichern 1992) for the treatment variable effect in the model:

$$\text{Cover for Species}_{i\text{-}j} = \text{Pretreatment Cover for Species}_{i\text{-}j} + \text{Treatment Variable} + \text{Block} + \text{Treatment Variable} \times \text{Block}.$$

We used the same model, without covariables, for analysis of shrub density and shrub height data. We used only the 2 dominant shrub species (shinnery oak and Oklahoma plum) in our shrub canopy height analysis because, in multivariate analysis of variance, all shrub species must have a score ≥ 0 in a plot in order for that plot to be included in the analysis. Due to limited occurrence of 4 of the 6 shrub species, sample size became prohibitively low with the inclusion of minor species (i.e., absence of a species in a plot yields no score since height can't equal 0). Additionally, shinnery oak, and Oklahoma plum essentially defined the upper canopy level, due to their high level of abundance. In control plots, the combined canopy cover of those 2 species constituted 94.3% of the total shrub canopy cover. We did not perform univariate mean separation tests because this would violate the multivariate assumption of a lack of independence between dependent variables. We do discuss numeric differences in independent variable means but no statistical significance is attached to these comparisons.

To test for differences in cover, density, or height values between years, we used the preceding multivariate model with response period year (1997 and 1998) as the independent variable; this analysis included unburned plots only. We used only unburned plots because the number of burned plots was higher for 1998 than 1997 and lumping data across burned and unburned treatments would bias overall response variable means between years. Due to a significant year effect in the shrub density ($P = 0.0246$) model, we analyzed 1997 and 1998 data separately. Canopy cover ($P = 0.4533$) and height ($P = 0.9173$) data from 1997 and 1998 were combined because the effect of year was not significant.

Environmental Data

We evaluated effects of individual soil nutrient variables on canopy cover of shrub species using Pearson correlation analysis (SAS 1988). For this analysis we combined 1997 and 1998 data and analyzed data for burned plots separately from control plots, due to the potential for alterations in controlling environmental factors following burning. We used partial canonical correspondence analysis (pCCA; ter Braak 1998) to assess the interactive effects of soil nutrient and fire treatment variables on shrub species abundance. Canonical correspondence analysis is a direct gradient analysis technique that ordinates species relative to their position along specific environmental gradients (Palmer 1993). To reduce noise and more specifically focus on treatment and environmental effects, we square-root transformed shrub species cover data and used study site as a covariable. We evaluated the significance of the first canonical axis in CANOCO using a Monte Carlo test with unrestricted permutations (ter Braak 1998). Permutations were within blocks as defined by the covariable "site". We used CANOCO interset correlation output to calculate the intraset correlations for environmental variables. The intraset correlation was equivalent to the correlation between an environmental variable and a given axis (ter Braak 1986) and allowed determination of the environmental factors most responsible for influencing a given axis.

We used CANODRAW (Smilauer 1990) to produce graphical output (a bi-plot) of the pCCA; the bi-plot included the first 2 canonical axes, which represented the 2 strongest species-environment gradients. In the bi-plot, arrows represented the influence of continuous variables and the centroids of nominal variables are indicated by closed triangles and open circles represent species. The relative direction of arrows and position of nominal variables was representative of the correlation between a variable and a given CCA axis. The position of species groups, relative to arrows or centroids, was representative of the association between a species and a nominal or continuous variable.

Results

Multivariate Analysis of Variance

Season of burn influenced canopy cover of shrub species ($P = 0.0001$) (Table 4). Shinnery oak cover decreased, relative to control plots, with fire in any season and most markedly with spring fire. Cover of Oklahoma plum decreased with spring fire and was unaffected by winter or fall fire. Sand sagebrush cover decreased with fall and spring burning and was not affected by winter burning. Cover of fragrant sumac decreased with fire in any season; cover values for this species were lowest with winter and spring fire. Leadplant was not recorded in fall burned plots, and its cover did not change with winter or spring fire, relative to control plots. Netleaf hackberry was not recorded in fall-burned plots; cover was higher in winter burned plots relative to spring burns. Time since fire influenced shrub species composition ($P = 0.0745$). Shinnery oak increased with increasing time since fire, but, none of the other shrub species were affected. Annual burning did not affect the cover of shrub species relative to single event fires ($P = 0.2939$).

Shrub species density was significantly influenced by season of burn in both 1997 ($P = 0.0001$) and 1998 ($P = 0.0007$) (Table 5). Overall, shinnery oak and Oklahoma plum increased in density with burning in any season, particularly winter and spring. Sand sagebrush density decreased with fall fire in 1997, was unaffected by fall or spring burning in 1998, and increased with winter fire, in either year, relative to control plots. In general, fragrant sumac density decreased with fire in any season, while fire had no clear influence on leadplant and netleaf hackberry density in either year. Time since fire did not significantly influence shrub species density ($P = 0.2592$). Annual burning significantly influenced shrub species density relative to single-event fires ($P = 0.0046$). This difference was largely due to increases in the mean density of fragrant sumac and lead plant in annually-burned plots.

Average canopy height of the two dominant shrub species was influenced by season of burn ($P = 0.0001$) (Table 6). Shinnery oak height decreased with fire in any season, most strongly with spring fire. The height of Oklahoma plum varied in a similar manner in response to seasonal fire, but did not decrease as sharply as shinnery oak. Neither time since fire ($P = 0.1745$) nor annual burning ($P = 0.5906$) affected the canopy height of these 2 species.

Correlation Analysis

Univariate correlation analysis revealed that soil NO_3-N content was not related to the abundance of most shrub species but was associated negatively with cover of Oklahoma plum in burned plots (Table 7). Soil P content was associated positively with fragrant sumac cover in control plots while shinnery oak and Oklahoma plum were, respectively, positively and negatively associated with soil P in burned plots. Soil K content was associated positively with fragrant sumac and associated negatively with netleaf hackberry in control plots, and associated positively with leadplant in burned plots. Soil pH had little influence on shrub species cover but was correlated positively with fragrant sumac in control plots.

Canonical Correspondence Analysis

Both the first canonical axis ($P = 0.0050$) and all axes considered simultaneously ($P = 0.0100$) were significant in the pCCA analysis (Table 8). The eigenvalues for the first two CCA axes were 0.021 and 0.001. Species-environment correlations were 0.641 for axis 1 and 0.342 for axis 2. Axis 1 explained 13.0% of the variance in shrub species scores and 63.5% of the shrub species-environment variation. Axis 2 explained 17.1% of the cumulative variance in shrub species scores and 83.3% of the cumulative variance in shrub species-environment variation. Intraset correlations revealed that control plots and soil K content had the strongest negative correlations with axis 1, while winter burning and time since fire had the strongest positive correlations. Control plots and fall burning were most strongly correlated with negative axis 2 scores; soil K content, annual fire, and spring fire were most strongly associated with positive scores.

The bi-plot for the CCA (Figure 1) revealed a gradient of shrub species abundance related to fire treatment and soil nutrient availability along axis 1. Positive scores were related to annual burning, burning in any season and time since fire. Negative scores were related to increasing soil nutrients and control plots. The species gradient for axis 1 is strongly related to fragrant sumac. This species was affected negatively by fire in any season and associated positively with increasing soil P, K, and pH. Leadplant was the only other species with an negative axis 1 score. Netleaf hackberry had the highest axis one score and was associated with burning and increasing time since fire. Positive axis 2 scores related to increasing soil nutrients, annual fire and spring and winter fire, while negative scores related to fall burns, control plots, and increasing soil NO_3-N. Leadplant scored relatively high on axis 2, while other species clustered near zero. Oklahoma plum, shinnery oak, and sand sagebrush were not influenced strongly by the environmental gradients on along either axis. Both sampling years oriented near the center of the bi-plot. The main difference between sampling years was that the 1998 growing season was much drier than that of 1997 (Figure 2). Thus, composition of shrub species was not strongly affected by variable precipitation, within the range of values encountered in this study. The fact that our species gradients were relatively short (compared with environmental gradients) may relate to our study design, in that sites were chosen, in part, based on initial homogeneity of species composition.

Discussion

Soils of shinnery oak communities are often characterized as nutrient poor (Deering 1972, Pettit and Deering 1974, Peterson and Boyd 1998, Zhang and Zak 1998). In our study, abundance of several shrub species was related to soil nutrients. The strong correlation between shinnery oak and soil P, post-fire, indicates that P may promote increased growth rates or re-sprouting of this species. The negative post-burn correlation of soil P and Oklahoma plum may relate more to competitive interactions with shinnery oak in the post-burn environment (i.e. shinnery oak was correlated positively with soil P). Fragrant sumac was correlated positively with soil P and K in unburned plots. This correlation became non-significant post-burn, indicating that burning treatment may erode the relationship.

In previous work (Boyd 1999a), I reported that effects of nutrient and fire gradients on overall vegetation composition (herbaceous and woody plants inclusive) were interrelated; soil P and K increased with fire, while soil NO_3-N was higher in unburned plots. However, when woody species are considered in and of themselves, effects of fire and soil nutrient gradients diverge in multivariate space (Figure 1). Thus, although some soil nutrients may increase with burning, fire and nutrient effects move shrub community species composition in opposing directions. I have also reported (Boyd 1999a) that, in multivariate space, time since fire moves overall plant composition in a similar direction to unburned plots. When only shrub species are ordinated, time since fire moves species composition in the opposite direction of unburned plots. This discrepancy may be due to the fact that the positive effect of soil K on fragrant sumac abundance was abated with burning treatment. Because fragrant sumac marked the negative species endpoint along CCA axis 1, its relationship to environmental variables would exert a strong influence on the direction of environmental effects. The association of leadplant with annual burning in the CCA bi-plot (Figure 1) may relate to the nitrogen fixing ability of this legume species. Annual burning has been reported to decrease soil nitrogen availability and increase legumes (Towne and Knapp 1996).

The overriding impact of fire on the shrub community in our study was to increase shrub stem density and decrease shrub height and canopy cover regardless of season of burn. In other shrub dominated systems, woody species often decrease in abundance with growing season fire (Fergusson 1961, Box and White 1969, Adams et al. 1982, Glitzenstein et al. 1995). In our study, burning at the beginning of the growing season (Spring) had the strongest negative impact of all burning seasons on canopy cover of most shrub species and height of shinnery oak and Oklahoma plum. This may relate to patterns of carbohydrate allocation and storage, particularly of the dominant shrub, shinnery oak. Boo and Pettit (1975) reported that carbohydrate storage in roots of shinnery oak was at a minimum during late April and early May; phenologically corresponding to one-half to two-thirds leaf expansion of this species. At the time of our spring burns, shinnery oak leaf expansion was about 50%. Regrowth of stem and leaf material in spring-burned plots would dictate that shinnery oak expend additional carbohydrate reserves at an energetically costly phenological stage. Although our end-of-growing seasons burns (Fall-October) did reduce shrub canopy cover, the decrease was not as strong as noted for spring fires. This may relate to the timing of fall burns, which occurred after the period of peak carbohydrate storage and immediately prior to the dormant season. No re-sprouting of any shrub species was noted in fall-burned plots prior to the onset of the first dormant season following fire.

That all shrub species in our study were recorded in burned and unburned plots suggests not only a fire-tolerant suite of shrub species but also a certain degree of niche partitioning. All shrub species in our study resprout in response to topkill by fire. Three of these species (leadplant, netleaf hackberry, and sand sagebrush) re-sprout from basal buds or reproduce from seedlings, while the remaining species are clonal and reproduce mainly by the spread of underground rhizomes. Matlack et al. (1993) suggested that resource partitioning among rhizomatous shrubs in the New Jersey Pine Barrens related to the density of resprouts and percentage of buds along a rhizome that are activated following top-kill of the associated clone. In our study, fragrant sumac was usually found in homogenous, well-defined "clumps" (Lacey and Johnston 1990) that were sufficiently dense to curtail invasion by other species (Petranka and McPherson 1979). Oklahoma plum and shinnery oak clones covered a larger horizontal area, but stem density within clones was usually much less than that fragrant sumac. Non-rhizomatus shrubs encountered in our study typically occurred in low abundance and had a scattered distribution relative to their rhizomatous counterparts. This pattern of distribution suggests that seedlings of non-rhizomatous species colonize and establish themselves on microsites where competition with rhizomatous shrubs is minimal.

The overwhelming pre- and post-burn dominance of shinnery oak is probably related to its well-developed root system. Shinnery oak produces a thick growth of rhizomes and shallow roots in the top 30 cm of the soil profile (Sears 1982, Sears et al. 1986) and may produce deep roots capable of exploiting water resources at depths of 7 m (McIlvain 1954). Such a root system allows shinnery oak to maximize capture of nutrients at a variety of soil depths and maintain large stores of carbohydrates. Shinnery oak was the only shrub species in this study to increase in abundance (cover) with increasing time since fire (Table 4), suggesting that canopy dominance of oak is maintained partly by a rapid return of this species to pre-burn cover levels. Although density of oak and other shrub stems does not significantly decrease with increasing time since fire (Table 5), the numerical trend is downward, and we predict that self-thinning will eventually decrease oak stem density to a level approximating that of unburned plots.

We believe that the dominance of vegetative reproduction by shrubs in shinnery oak communities may represent an adaptation to what was likely a fire-prone environment prior to European settlement. Vegetative reproduction has several advantages in fire-prone environments including lack of dependence on successful flowering and germination (Bradstock and Myerscough 1988), increased ability of juvenile plants to survive environmental stress (Thomas and Davis 1989), and fire tolerance at an earlier age (Hoffmann 1998). Shinnery oak is a good example of how vegetative reproduction can increase survival and persistence of a woody species in a disturbance prone environment. Although genetic variability between shinnery oak clones suggests that this species at one time reproduced sexually (Mayes et al. 1998), today shinnery oak reproduces predominantly (perhaps exclusively) from resprouts from buds located along rhizomes (Mueller 1951). Although fire may topkill all or most of the above-ground oak stems in a clone, the below ground buds will remain protected, allowing for rapid recovery of this species post-fire (Slosser et al. 1985). Resprouting also is hastened by an extremely high root:shoot ratio, perhaps 13:1 (Pettit and Deering 1971). Similar strategies are employed by woody plants in other fire-prone systems (reviewed by Lacey and Johnston 1990). Other less fire-tolerant oak species in Oklahoma reproduce predominantly through sexual reproduction and historically occurred in savannahs (Johnson and Riser 1975) or scattered forests that resulted from chance protection from fire events (Rice and Penfound 1960) (compared with the more continuous spatial coverage of shinnery oak).

Conclusions and Management Implications

Shrub cover (mainly shinnery oak) dominates shinnery oak communities on the present day landscape. Our data indicate that prescribed fire in fall, winter, or spring will increase density, and decrease canopy cover and height of shrub species in these communities. Shrub cover and height are most negatively affected by spring fire, and least by fall or winter fire, while shrub density increases most with fall and winter fire and least with spring burning. Fire-induced alterations in shrub composition of shinnery communities are due to top-kill of shrubs by fire and subsequent re-sprouting, either from rhizomes are basal buds. Our data indicate that cover of the dominant shrub, shinnery oak, returns rapidly to pre-burn levels, implying that frequent fire (e.g. ≤ 5 year fire return interval) may be necessary to maintain fire-induced alterations in abundance of this species. The resiliency of this shrub community to fire is highlighted by the fact that only 1 of the 6 shrub species decreased in abundance (cover) with annual burning, relative to single-event fires.

In a regional context, the land area covered by shinnery oak communities has decreased markedly relative to its hypothesized pre-European distribution, in part due to herbicidal treatment of lands that are grazed by domestic livestock (Peterson and Boyd 1998). Herbicidal treatment may severely reduce shinnery oak abundance (Pettit 1979, Jones and Pettit 1984). This decrease in spatial extent of shinnery communities has ramifications to wildlife habitat and biodiversity, as well as soil stability given the soil-stabilizing role of shinnery oak (Lotspeich and Everhart 1962). Our data indicate that the use of properly-timed prescribed fire may be short-term alternative to the use of herbicides in shinnery oak reduction programs. The use of fire would allow land managers to have some control over the abundance of shrub species, without drastically reducing their abundance. Additional work is needed to determine the efficacy such efforts over an extended temporal horizon.

Literature Cited

Adams, D.E., R.C. Anderson and S.L. Collins. 1982. Differential response of woody and herbaceous species to summer and winter burning in an Oklahoma grassland. Southwest Nat. 23:623-632.

Boo, R.M. and R.D. Pettit. 1975. Carbohydrate reserves in roots of sand shin oak in west Texas. J. Range Manage. 28:469-472.

Box, T.W. 1967. Brush, fire and west Texas rangeland. Proc. Tall Timbers Fire Ecol. Conf. 6:7-19.

Box, T.W. and R.S. White. 1969. Fall and winter burning of South Texas brush ranges. J. Range. Manage. 85:21-31.

Boyd, C.S. 1999a. The effects of prescribed fire on shinnery oak (*Quercus havardii*) plant communities in western Oklahoma. *In:* The effects of burning season and frequency on the vegetative character and insect abundance of sand shinnery oak range in western Oklahoma. Ph.D. Dissertation, Oklahoma State Univ., Stillwater.

Boyd, C.S. 1999b.The effects of fire intensity on shinnery oak (*Quercus havardii*) communities in western Oklahoma. *In:* The effects of burning season and frequency on the vegetative character and insect abundance of sand shinnery oak range in western Oklahoma. Ph.D. Dissertation, Oklahoma State Univ., Stillwater.

Bradstock, R.A. and P.J. Myerscough. 1988. The survival and population response to frequent fires of two woody resprouters *Banksia serrata* and *Isopogon anemonifolius*. Aus. J. Bot. 36:415-431.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Sci. 33:43-64.

Deering , D.W. 1972. Effects of selected herbicides and fertilization on a sand shinnery oak community. MS Thesis, Texas Tech University, Lubbock.

Dhillion, S.S., M.A. McGinley, C.F. Friese and J.C. Zak. 1994. Construction of sand shinnery oak communities of the Llano Estacado: Animal disturbances, plant community structure, and restoration. Rest. Ecol. 2:51-60.

Duck, L.G. and J.B. Fletcher. 1944. A survey of the game and fur-bearing animals of Oklahoma. State Bull. 3. Oklahoma City: Oklahoma Game and Fish Dept. 144pp.

Fergusson, E.R. 1961. Effects of prescribed fires on understory stems in pine-hardwood stands in Texas. J. Forestry. 59:356-359.

Fuhlendorf, S.D. and F.E. Smeins. 1998. The influence of soil depth on plant species response to grazing within a semi-arid savanna. Plant Ecol. 138:89-96.

Glitzenstein, J.S., W.J. Platt and D.R. Streng. 1995. Effects of fire regime and habitat on tree dynamics in north Florida longleaf pine savannas. Ecol. Mono. 65:441-476.

Great Plains Flora Association. 1986. Flora of the Great Plains. T.M. Barkley (ed.), Univ. Kansas Press, Lawrence.

Hoffmann, W.A. 1998. Post-burn reproduction of woody plants in a neotropical savanna: the relative importance of sexual and vegetative reproduction. J. Appl. Ecol. 1998: 422-433.

Holland, M. 1994. Disturbance, environmental heterogeneity, and plant community structure in a sand shinnery oak community. MS Thesis, Texas Tech Univ., Lubbock.

Jackson, A.S. and R. DeArment. 1963. The lesser prairie chicken in the Texas Panhandle. J. Wildl. Manage. 27:733-737.

Johnson, F.L. and P.G. Risser. 1975. A quantitative comparison between an oak forest and an oak savannah in central Oklahoma. Southwest. Nat. 20:75-84.

Johnson, R.A. and D.W. Wichern. 1992. Applied multivariate statistical analysis. Prentice Hall, Englewood Cliffs, New Jersey.

Jones, V.E. and R.D. Pettit, 1984. Low rates of tebuthiuron for control of sand shinnery oak. J. Range Manage. 37:488-490.

Lacey, C.J. and R.D. Johnston. 1990. Woody clumps and clumpwoods. Aus. J. Bot. 38:299-334.

Lotspeich, F.B. and M.E. Everhart. 1962. Climate and vegetation as soil forming factors on the Llano Estacado. J. Range Manage. 15:134-141.

Marcy, R.B. 1854. Explorations of the Red River of Louisiana in the year 1852. 33rd Congress, 1st Session, House Executive Document. Washington: A.O.P. Nicholson. 286pp.

Matlack, G.R., D.J. Gibson, and R.E. Good. 1993. Clonal propagation, local disturbance, and the structure of vegetation: Eriaceous shrubs in the Pine Barrens of New Jersey. Biol. Cons. 63:1-8.

Mayes, S.G., M.A. McGinley, and C.R. Werth. 1998. Clonal population structure and genetic variation in sand-shinnery oak, *Quercus havardii* (Fagaceae). Am. J. Bot. 85:1609-1617.

McIlvain, E.H. 1954. Interim report on shinnery oak control studies in the southern Great Plains. pp. 95-96. *In*: Proceedings, Eleventh Annual Meeting, North Central Weed Cont. Conf., Dec. 6-9, 1954. Fargo, ND.

McIlvain, E.H. and C.G. Armstrong. 1966. A summary of fire and forage research on shinnery oak rangelands. Proc. Tall Timbers Fire Ecol. Conf. 5:127-129.

McIlvain, E.H. and M.C. Shoop. 1965. Pasture and range investigations. Woodward, Oklahoma: U.S.D.A., A.R.S. 187pp.

Muller, C.H. 1951. The significance of vegetative reproduction in *Quercus*. Madrono. 11:129 137.

Osborne, B. 1942. Prairie dogs in shinnery (oak scrub) savannah. Ecology 23:110-115.

Palmer, M.W. 1993. Putting things in even better order: the advantages of canonical correspondence analysis. Ecology 74:2215-2230

Parsons, D.J. 1976. The role of fire in natural communities: An example from the southern Sierra Nevada, California. Environmental Cons. 3:91-99.

Peterson, R.S. and C.S. Boyd. 1998. Ecology and management of sand shinnery oak communities: A literature review. U.S.D.A. Forest Service Gen. Tech. Rept.-16.

Petranka, J.W. and J.K. McPherson. 1979. The role of *Rhus copallina* in the dynamics of the forest-prairie ecotone in north-central Oklahoma. Ecology 60: 956-965.

Pettit, R.D. 1979. Effects of picloram and tebuthiuron pellets on sand shinnery oak communities. J. Range Manage. 32:196-200.

Pettit, R.D. 1994. Sand shinnery oak, p. 106. *In*: T.N. Shiflet, (ed.), Rangeland cover types of the United States. Soc. for Range Manage., Denver.

Pettit, R.D. and D. Deering. 1971. Root-shoot studies on shin oak. *In*: Noxious brush and weed control highlights-1971. 51:1.

Pettit, R.D. and D.W. Deering. 1974. Yield and protein content of sandyland range forages as affected by three nitrogen fertilizer. J. Range Manage. 27:211-213.

Rice, E. and W. Penfound. 1959. The upland forests of Oklahoma. Ecology. 50:593-

608.

SAS Institute Inc. 1988. SAS procedures guide, release 6.03. Cary, North Carolina.

Sears, W.E. 1982. Biomass and nitrogen dynamics of a herbicide converted sand shinnery oak community. MS Thesis, Texas Tech Univ., Lubbock.

Sears, W.E., C.M. Britton, D.B. Wester, and R.D. Pettit. 1986. Herbicide conversion of a sand shinnery oak (*Quercus havardii*) community: effects on biomass. J. Range Manage. 39:399-403.

Slosser, J.E., P.W. Jacoby and J.R. Price. 1985. Management of sand shinnery oak for control of boll weevil (Coleoptera: Curculionidae) in the Texas Rolling Plains. J. Econ. Entomol. 78:383 389.

Smilauer, P. 1990. CANODRAW: A companion program to CANOCO for publication quality graphical output. Microcomputer Power, New York, NY.

Stroup, W.W. and J. Stubbendieck. 1983. Multivariate Statistical Methods to determine changes in botanical composition. J. Range Manage. 36:208-212.

ter Braak, J. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. Ecology. 67:1167-1179.

ter Braak, J. 1998. CANOCO-a FORTRAN program for canonical community ordination. Microcomputer Power. New York, NY.

Thomas, C.M. and S.D. Davis. 1989. Recovery patterns of three chaparral shrubs after wildfire. Oecologia. 80:309-320.

Town, E.G. and A.K. Knapp. 1996. Biomass and density responses in tallgrass prairie legumes to annual fire and topographic position. Am. J. Bot. 83:175-179.

United States Department of Agriculture. 1982. Soil survey: Roger Mills County

Oklahoma. U.S. Gov. Printing Office, Washington, D.C.

West, N.E. and G.A. Reese. 1996. Comparison of some methods for collecting and analyzing data on aboveground net production and diversity of herbaceous vegetation in a northern Utah subalpine context. Vegetatio 96:145-163.

Wright, H.A. and A.W. Bailey. 1982. Fire ecology: United States and southern Canada. John Wiley and Sons, New York. 501pp.

Zhang, Q. and J.C. Zak. 1988. Effects of water and nitrogen amendment on soil microbial and fine root production in a semi-arid environment in west Texas. Soil Biol. Biochem. 30:39-45.

Table 1. Common, scientific names, and acronyms of shrub species found in study plots in western Oklahoma.

Common name	Scientific name	Acronym
Shinnery Oak	*Quercus havardii*	QUHA
Oklahoma Plum	*Prunus gracilis*	PRGR
Sand Sagebrush	*Artemisia filifolia*	ARFI
Fragrant Sumac	*Rhus aromatica*	RHAR
Lead Plant	*Amorpha canescens*	AMCA
Netleaf Hackberry	*Celtis reticulata*	CERE

Table 2. Year, season of burn, burning date, and sample size for prescribed burns in western Oklahoma.

Year	Season	Burning date	n
1996	Fall	Oct. 23-24	3
1997	Winter	Feb. 4-5	6
1997	Spring	April 28-29	6
1998	Fall	Oct. 1	3
1998	Winter	Jan. 27-28	6
1998	Winter (annual)	Jan 27-28	3
1998	Spring	April 30-May1	6
1998	Spring (annual)	April 30-May1	2

Table 3. Variable type, acronym and data range for variables used in the statistical analysis of shinnery oak vegetation.

Variable type	Variable	Acronym	Data range*
Treatment	Season of burn		
	Control (unburned)	SOBC	...
	Fall	SOBF	...
	Winter	SOBW	...
	Spring	SOBS	...
	Time since fire**		
	One year	TSF1	...
	Two years	TSF2	...
	Fire frequency		
	Single event fire	ANNUAL0	...
	Annual fire	ANNUAL1	...
Environmental	Soil nitrate (kg/ha)	NO3	3-66
	Soil phosphorous (kg/ha)	P	15-34
	Soil potassium (kg/ha)	K	68-320
	Soil pH	pH	5.5-6.6

* Data range values for 1997-1998.

** Equivilant to the number of growing seasons since fire.

Table 4. Canopy cover for shrub species by year and fire treatment for experimental plots in western Oklahoma. Acroynms are from Table 1.

				Species											
	Treatment			QUHA		PRGR		ARFI		RHAR		AMCA		CERE	
Year	variable	n	*P* Value*	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
				% Canopy cover											
1996	Control	36	...	40.0	1.6	10.8	1.5	1.5	0.2	1.2	0.5	0.3	0.2	0.01	0.01
1997-1998	Season of burn	72	0.0001												
	Control	27		55.6	*2.2*	14.5	*2.2*	1.9	*0.3*	2.2	*0.7*	0.1	*0.1*	0.03	*0.03*
	Fall	9		49.5	*5.7*	10.0	*2.3*	1.0	*0.4*	1.2	*1.0*	0.0	*0.0*	0.00	*0.00*
	Winter	18		45.1	*3.2*	12.9	*2.3*	2.0	*0.4*	0.5	*0.3*	0.2	*0.1*	0.05	*0.03*
	Spring	18		29.1	*3.0*	7.5	*1.8*	0.7	*0.2*	0.4	*0.2*	0.3	*0.2*	0.01	*0.01*
1997-1998	Time since fire	46	0.0745												
	One year	37		36.4	*2.5*	10.3	*1.4*	1.2	*0.2*	0.6	*0.3*	0.2	*0.1*	0.02	*0.02*
	Two years	9		52.0	*4.4*	10.3	*2.7*	1.2	*0.5*	0.3	*0.2*	0.1	*0.1*	0.02	*0.02*
1997-1998	Annual	46	0.2939												
	Single event fire	41		40.1	*2.5*	10.6	*1.3*	1.3	*0.2*	0.6	*0.3*	0.1	*0.1*	0.02	*0.02*
	Annual fire	5		36.4	*9.1*	7.7	*4.5*	1.0	*0.4*	0.5	*0.5*	0.5	*0.5*	0.00	*0.00*

* P value is for with the Wilks' Lambda test statistic associated with the treatment variable effect in the model : Species $_{i\text{-}j}$ = Treatment Variable + Block + Treatment Variable*Block .

Table 5. Stem density for shrub species by year and fire treatment for experimental plots in western Oklahoma. Acroynms are from Table 1.

				Species											
	Treatment			QUHA		PRGR		ARFI		RHAR		AMCA		CERE	
Year	variable	n	*P* Value*	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
				Stem density (stems/m^2)											
1997	Season of burn	36	0.0001												
	Control	21		22.3	*1.4*	2.5	*0.4*	0.6	*0.2*	0.2	*0.1*	0.0	*0.0*	0.0	*0.0*
	Fall	3		49.5	*9.8*	4.7	*2.5*	0.0	*0.0*	0.0	*0.0*	0.0	*0.0*	0.0	*0.0*
	Winter	6		39.5	*5.8*	7.3	*2.6*	2.6	*1.4*	0.0	*0.0*	0.0	*0.0*	0.0	*0.0*
	Spring	6		37.5	*7.2*	9.2	*4.2*	0.3	*0.2*	2.1	*2.1*	0.0	*0.0*	0.0	*0.0*
				0.0											
1998	Season of burn	36	0.0007												
	Control	6		17.8	*3.3*	2.9	*0.8*	0.3	*0.3*	0.9	*0.6*	0.0	*0.0*	0.0	*0.0*
	Fall	6		42.3	*4.2*	6.4	*2.2*	0.4	*0.4*	0.0	*0.0*	0.0	*0.0*	0.0	*0.0*
	Winter	12		36.9	*3.6*	9.6	*2.5*	4.4	*1.3*	0.0	*0.0*	0.0	*0.0*	0.3	*0.3*
	Spring	12		34.2	*3.9*	6.8	*1.8*	0.8	*0.4*	0.3	*0.3*	0.8	*0.8*	0.0	*0.0*
	Time since fire	30	0.2592												
	One year	21		38.0	*3.0*	8.7	*1.7*	2.3	*0.8*	0.2	*0.2*	0.5	*0.5*	0.0	*0.0*
	Two years	9		34.3	*2.6*	5.8	*1.5*	1.8	*1.0*	0.0	*0.0*	0.0	*0.0*	0.0	*0.0*
	Annual	30	0.0046												
	Single event fire	25		36.6	*2.3*	7.5	*1.2*	2.4	*0.7*	0.0	*0.0*	0.0	*0.0*	0.0	*0.0*
	Annual fire	5		38.7	*8.6*	9.2	*5.5*	0.9	*0.9*	0.6	*0.6*	1.9	*1.9*	0.0	*0.0*

* P value is for with the Wilks' Lambda test statistic associated with the treatment variable effect in the model : Species $_{i\text{-}j}$ = Treatment Variable + Block + Treatment Variable*Block .

Table 6. Average canopy height for shinnery oak and Oklahoma plum by year and fire treatment for experimental plots in western Oklahoma. Acroynms are from Table 1.

				Species			
	Treatment			QUHA		PRGR	
Year	variable	n	*P* Value*	$\bar{x}$	SE	$\bar{x}$	SE
				Canopy height (cm)			
1997-1998	Season of burn	57	0.0001				
	Control	21		66.5	*1.5*	48.0	*2.6*
	Fall	6		42.0	*3.0*	37.6	3.8
	Winter	14		44.3	*1.5*	39.3	*2.1*
	Spring	16		38.3	*1.1*	34.4	*1.8*
1997-1998	Time since fire	37	0.1745				
	One year	30		40.6	*1.1*	35.9	*1.5*
	Two years	7		46.2	*2.1*	43.0	*1.5*
1997-1998	Annual	37	0.5906				
	Single event fire	32		42.0	*1.1*	38.0	*1.2*
	Annual fire	5		39.6	*4.2*	32.3	*6.5*

* P value is for with the Wilks' Lambda test statistic associated with the treatment variable effect in the model : Species$_{i\text{-}j}$ = Treatment Variable + Block + Treatment Variable*Block .

Table 7. Correlation coefficients for shrub species canopy cover and environmental variables for experimental plots in western Oklahoma. Acronyms are from Table 1.

Environmental variable	Treatment	n	Mean $\bar{x}$	SE	QUHA	PRGR	ARFI	RHAR	AMCA	CERE
					Correlation coefficient					
Soil nitrate (kg/ha)	Control	27	27.3	*3.2*	-0.235	0.279	-0.210	-0.073	0.084	0.273
	Burned	45	20.2	*2.2*	0.139	-0.452 *	0.077	-0.179	-0.064	-0.037
Soil phosphorus (kg/ha)	Control	27	16.9	*0.4*	0.294	-0.322	0.263	0.527 *	-0.313	0.388
	Burned	45	19.3	*0.7*	0.420 *	-0.437 *	0.303	0.218	-0.123	-0.056
Soil potassium (kg/ha)	Control	27	167.6	*7.6*	-0.240	0.133	0.140	0.450 *	0.093	-0.109 **
	Burned	45	188.9	*5.4*	-0.093	0.013	-0.157	0.054	0.384 *	0.083
Soil pH	Control	27	6.0	*0.0*	0.315	-0.254	0.301	0.348 **	-0.700	0.071
	Burned	45	6.1	*0.0*	0.110	0.008	0.010	0.108	-0.159	-0.193

* $P \leq 0.05$

** $P > 0.05$ and ≤ 0.10

Table 8. Relationship between environmental and treatment variables in the partial canonical correspondence analysis of data from experimental plots in western Oklahoma. Acronyms are from Table 3.

	Axis 1	Axis2
Eigenvalue	0.021	0.001
Species-environment correlation	0.641	0.342
Cumulative percentage		
Variance of:		
Species data	13.0	17.1
Species-environment relation	63.5	83.3
1997	-0.019	-0.069
1998	0.019	0.069
SOBC	-0.596	-0.332
SOBF	0.040	-0.400
SOBW	0.470	0.270
SOBS	0.198	0.452
TSF2	0.312	-0.077
ANNUAL1	0.040	0.459
NO3	-0.108	-0.173
P	-0.199	0.172
K	-0.448	0.618
Ph	-0.242	0.052

Figure 1. Bi-plot of the first two axes of the partial canonical correspondence analysis. Continuous variables are represented by their arrows, and nominal variables by solid triangles indicating their centroid. Species are represented by open circles. Acronyms are from tables 2 and 3.

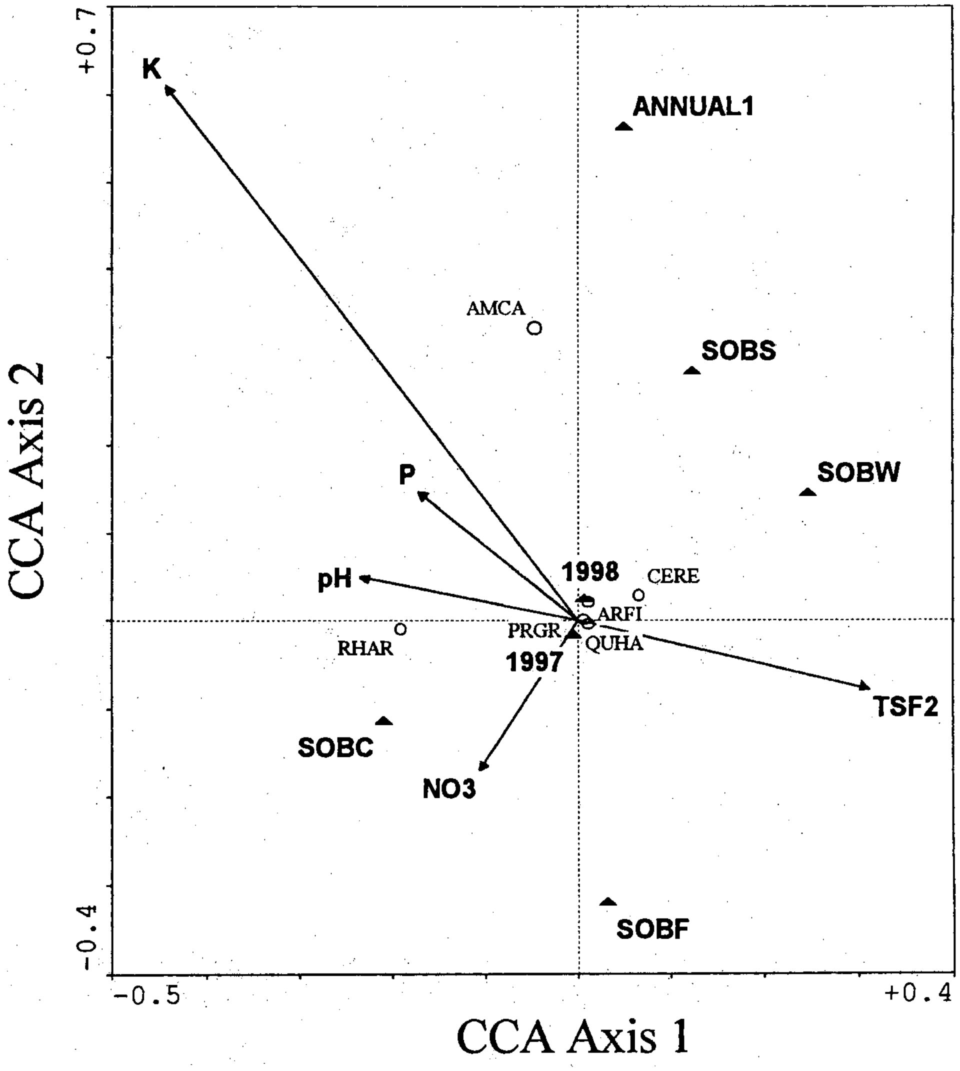
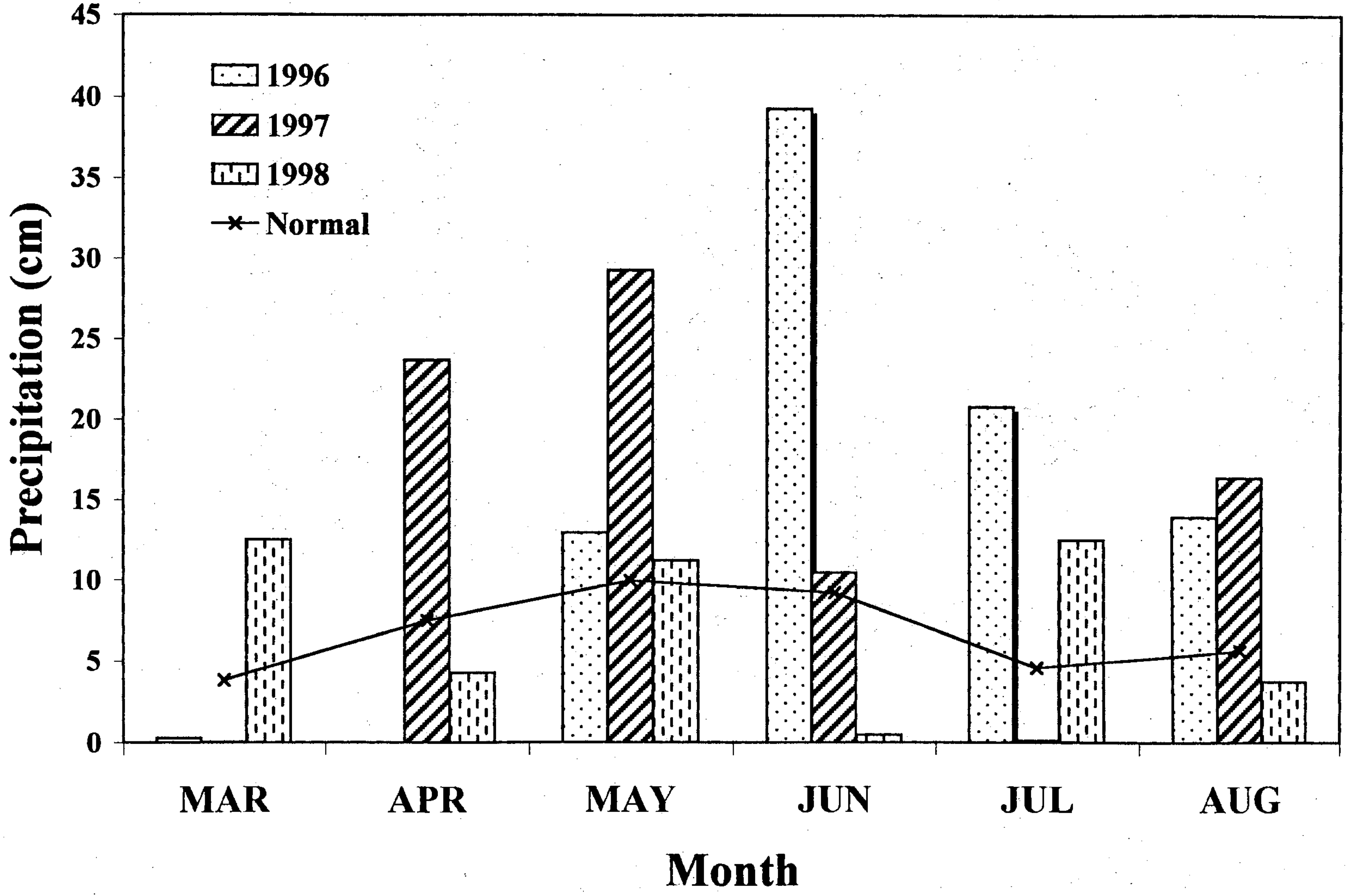

+0.7
K
ANNUAL1
AMCA
SOBS
SOBW
P
pH
1998
CERE
ARFI
PRGR
QUHA
RHAR
1997
TSF2
SOBC
NO3
SOBF
-0.4
-0.5
+0.4
CCA Axis 2
CCA Axis 1

Figure 2. Growing season precipitation by month during the study period. Long-term average (normal) precipitation data are from USDA (1982).


45
40
35
30
25
20
15
10
5
0
Precipitation (cm)
1996
1997
1998
Normal
MAR
APR
MAY
JUN
JUL
AUG
Month

CHAPTER IV

THE EFFECTS OF FIRE BEHAVIOR ON SHINNERY OAK (*QUERCUS HAVARDII* Rydb.) PLANT COMMUNITIES IN WESTERN OKLAHOMA

Abstract

Knowledge of the response of shinnery oak (*Quercus havardii* Rydb.) communities to fire is limited. Our objective was to document behavior of fall (October), winter (January-February), or spring (April-May) prescribed fires and explore the influence of fire behavior on vegetation dynamics of shinnery oak communities. Three study sites were located in western Oklahoma; at each site, 10 60 x 30 m plots were burned during 1997-1998. Weather and fuel loading data were collected immediately prior to burning and residual fuels were estimated after burning. Flame depth (F_D) and rate of spread (R) were estimated during burning, and fireline intensity (I_B), heat per unity area (H_A), fuel consumption (C_F), and reaction intensity (I_R) were calculated post-fire. Canopy cover for herbaceous and woody species, and stem density of woody species was estimated during the first growing season after fire. Effects of fire behavior variables on canopy cover of 8 vegetation classes were analyzed using multivariate analysis of variance. Individual vegetation classes were related to fire behavior variables using Pearson correlation analysis. The influence of fire behavior on shrub stem density was evaluated using simple regression. Fuel loading was similar across burning seasons but more 1 hour live and less 1 hr dead fuel was found in fall burn plots relative to winter and spring. Fireline intensity, H_A, C_F, and I_R were highest with spring and fall burning and F_D was lowest for fall burns ($P \leq 0.1000$). Fuel load and wind speed had a strong influence on fire behavior. Shrubs, little bluestem, rhizomatous tallgrass, and other perennial grass cover were correlated with fire behavior ($P \leq 0.1000$). Heat per unit area ($P = 0.0415$) and C_F ($P = 0.0462$). influenced multivariate community composition. Heat per unit area ($P = 0.0172$, $r^2 = 0.1865$), C_F ($P = 0.0178$, $r^2 = 0.1846$) and I_R ($P = 0.0585$, $r^2 = 0.1309$) were positively related to shrub stem density. Specific influences of fire behavior appear less important than the influence of burning *per se*. Season of burn and fire behavior may interact to influence both shrub canopy cover and shrub stem density.

Key words: Oklahoma, prescribed fire, multivariate analysis of variance, shrub ecology.

Introduction

Shinnery oak (*Quercus havardii* Rydb.) and associated vegetation occur in west central Oklahoma, northern Texas, and southeastern New Mexico. Peterson and Boyd conservatively estimated that shinnery oak rangelands covered at least 2 million hectares in those states (Peterson and Boyd 1998). Historical accounts indicate that shinnery oak communities were structurally dominated by tallgrasses with shinnery oak in the understory; oak stems did not commonly exceed 45 cm in height (Marcy 1854, Osborne 1942). Today, shinnery may constitute 80% of canopy cover (Dhillion et al. 1994), the abundance of tallgrasses has decreased, and oak stems may reach 1 m in height in western Oklahoma (Peterson and Boyd 1998). This increase in oak stature and canopy cover can negatively affect recruitment of herbaceous seedlings (Holland 1994), leading to lower herbaceous plant production.

Structural and compositional changes in shinnery oak communities have often been described as being the products of mis-management of grazing livestock (Duck and Fletcher 1944, Jackson and DeArment 1963, Pettit 1994). While grazing practices have undoubtedly influenced both small and large scale vegetation dynamics, it is difficult to evaluate the effects of livestock grazing in any system without simultaneously considering the historical influence of fire (Box 1967). The diminutive stature of shinnery oak in historical references may indicate a somewhat reliable and strong influence of fire, given the susceptibility of this species to top-kill by fire. Prescribed spring fires may result in dramatic increases in herbaceous plant phytomass in years of adequate rainfall (McIlvain and Armstrong 1966, McIlvain and Shoop 1965), and a high percentage of shinnery oak stems may be top-killed (Slosser et al. 1985).

To evaluate the historic and potential role of fire in shaping shinnery oak community plant composition, the overall fire regime must be explored. This involves examining effects of fire frequency, season of burn, and fire behavior on plant community dynamics. Fire behavior has been shown to influence post-burn plant community dynamics in a wide variety of vegetation types (Armour et al. 1984, Engle and Stritzke 1995, Glitzenstein et al. 1995). I have previously discussed the influence of season of burn and fire frequency on vegetation dynamics in shinnery oak communities (Boyd 1999a, 1999b). To date, there has been no published work on effects of fire behavior on shinnery oak vegetation. Our objective was to document fire behavior characteristics for different burning seasons and explore the influence of fire behavior on vegetation dynamics in shinnery oak communities in western Oklahoma.

Methods

Study Sites

Study sites were located on the Black Kettle National Grassland in Roger Mills County, Oklahoma (35° 32' 44'' N, 99^{O} 43' 39'' W), and the state-owned Packsaddle Wildlife Management Area in Ellis County, Oklahoma (36° 4' 22'' N, 99^{O} 54' 5'' W). Sites were chosen subjectively to be representative of shinnery oak communities found on sandy soils within the western Oklahoma region. All sites were lightly grazed by cattle during the growing season before study initiation and were excluded from grazing in 1995 and throughout the course of the study. Before our study, these sites had not burned on a regular basis and had not burned for at least 10 years.

Soils were fine sands (Nobscott-Brownfield Association) with no limiting layers in the top 150 cm (USDA 1982). Shinnery oak, a deciduous, clonal species, was the dominant shrub with lesser amounts of sand sagebrush (*Artemisia filifolia* Torr.) and Oklahoma plum (*Prunus gracilis* Engelm.). Dominant grasses and forbs included little bluestem (*Schizachyrium scoparium* Nash), indiangrass (*Sorghastrum nutans* Nash), switchgrass (*Panicum virgatum* L.), sand bluestem (*Andropogon gerardii* Hack.), sand lovegrass (*Eragrostis trichodes* Nutt.), sideoats grama (*Bouteloua curtipendula* Michx.), western ragweed (*Ambrosia psilostachya* DC.), erect dayflower (*Commelina erecta* L.)

and sundrop (*Calylophus berlandieri* Spach). Average annual precipitation was 65.6 cm; growing season (March-August) precipitation averaged 40.6 cm (USDA 1982).

Experimental Design

We divided each of the 3 study sites (blocks) into 12 60 x 30 m plots. Plots were arranged in a 2 x 6 matrix and separated by 7m firebreaks. We randomly assigned each of the plots within a site to control treatment (unburned) or burning in fall, winter, or spring of 1997 or 1998. Treatment response data was collected during the growing seasons of 1997-1998. Only data from burned plots, for the first growing season following fire, were used in our analyses herein. Response data from 1997 and 1998 were combined for statistical analysis.

Fire Ignition and Behavior

We conducted all burns with ambient weather conditions of air temperature ≤ 30°C, ground wind speed ≤16 km/hr, and relative humidity of ≥20% (Table 1). We burned the plots using a strip-headfiring technique (Wright and Bailey 1982). We ignited the downwind and flank sides of the plots and allowed the fire to burn about 5 m into the plot. We then ignited a headfire about 10 m upwind from the backfire; we recorded fire behavior for 3 such headfires on each plot. Immediately prior to igniting the first head fire on a plot, we measured temperature and humidity using a sling psychromter and windspeed at 2 m aboveground was measured using a totalizing anemometer. We estimated rate of spread of the headfire (m/sec) by timing movement of the fire front between 2 m stakes placed in the path of the fire prior to ignition. The stakes were placed

5 m apart and oriented perpendicular to the path of the headfire. Flame depth (m) was estimated concurrent with rate of spread by visually estimating the width of the active flaming zone as the fire passed between the stakes.

We measured fuel loading just prior to burning by clipping all herbage and collecting all litter present in 5 randomly placed 0.25 m^2 quadrats at each plot. All fuels except live shrub material were collected. Fuels were separated into 1 hr live (< 0.6 cm diameter), 1 hr dead, 10 hr dead (0.6 to 2.5 cm diameter), and 100 hr dead (>2.5 cm diameter) classes (Table 2). We collected plant residue immediately post-fire from 5 paired 0.25 m^2 quadrats; we dried and weighed this material and calculated fuel consumption (kg/m^2) as the weight of post-burn residue (kg/m^2) subtracted from the pre-burn fuel load (kg/m^2). Fuel moisture was calculated on a dry weight basis.

We estimated fireline intensity (kW/m) using the Byram (1959) equation: $I = Hwr$, where H is the low heat of combustion (kJ/kg^{-1}), w is the weight (kg) of fuel consumed per unit area (m^2), and r is the rate of fireline spread (m/s). Low heat of combustion was calculated by subtracting values for latent heat absorption (1263 Kj/kg; Alexander 1982) and fuel moisture content (23.9 Kj/kg for every percentage point of moisture content; Roberts et al. 1988). We calculated heat per unit area (kJ/m^2; i.e., the amount of energy release per unit of active flaming zone) by dividing fireline intensity (kW/m) by rate of spread (m/sec; Rothermel and Deeming 1980). We calculated reaction intensity (kW/m^2; i.e., the rate or energy release per unit of active flaming zone) by dividing fireline intensity (kW/m) by flame depth (m; Alexander 1982). Reaction intensity values for 2 plots which were >4 standard deviations from the mean value were not used in statistical analyses.

Vegetation Sampling

Because of the ignition pattern, the outer 5 m of plots were excluded from vegetation sampling to eliminate differential effects of headfires, backfires, and flankfires. We estimated canopy cover for each plot, by species, at 30 randomly located points (Daubenmire 1959). At each point, canopy cover of each species influencing a 20 x 50 cm quadrat was categorized as 0-5%, 5-25%, 25-50%, 50-75%, 75-95% or 95-100%. We averaged mid-point values to obtain an estimate of canopy cover of each species in a plot for a given sampling period. We estimated canopy cover during 3 sampling periods: 25-31 May, 6-22 June, and 8-17 August of 1997-1998. We estimated shrub stem density in September of 1997 and 1998 by counting the number of above-ground stems present in 10 randomly located 0.50 m^2 quadrats per plot. We defined stems as shrub plants having a unique above-ground base. Nomenclature followed that of the Great Plains Flora Association (1986) with the exception of little bluestem (i.e. *Schizachyrium scoparium*).

We created summary variables to represent the sum of all canopy cover values for a given vegetation class, in a given plot and year (Table 2). Average seasonal canopy cover values for vegetation classes were calculated by averaging canopy cover values by plot, class, and year (West and Reese 1996). Our was to combine species that respond similarly to environmental perturbation and reduce data to a meaningful level for analysis and presentation. Annual and perennial fobs may respond positively to fire (McIlvain and Armstrong 1966), but, because annual forbs may be more sensitive to other environmental factors (Bazzaz and Morse 1991), they were grouped separately. Legumes (woody and non-woody) were grouped because they often respond positively to fire (Towne and Knapp 1996) because of their ability to fix nitrogen in the nitrogen dynamic post-fire environment (Pyne 1996). Rhizomatous C_4 tallgrasses were grouped because of their similar reproductive strategy and their generally positive response to fire (Towne and Owensby 1984). Little bluestem was classified by itself because it was the dominant grass species in unburned plots. Additionally, the bunchgrass growth form of little bluestem differed from other dominant grasses, which were mainly rhizomatous, and little bluestem often declines following fire (Ewing and Engle 1988, Towne and Owensby 1984). All remaining perennial grasses, predominantly bunchgrasses, were grouped together. Dominant species in this grouping included sideoats grama, sand lovegrass, and sand dropseed (*Sporobolus cryptandrus* Torr.). All other shrub species were grouped and represent the most abundant vegetation class. The only C_3 sedge species encountered (*Cyperus schweinitzii* Torr.) was classified by itself.

Statistical Analysis

We assessed fire behavior effects on vegetation canopy cover using multivariate analysis of variance (Stroup and Stubbendieck 1983, SAS Institute Inc. 1988) with vegetation $\text{class}_{i\text{-}j}$ as the dependent variables and fire behavior variables as the main effects. We evaluated treatment significance using the *P* value associated with the Wilks' Lambda test statistic (Johnson and Wichern 1992) for the fire behavior variable. We used one-way analysis of variance (SAS Institute Inc. 1988) to test for differences in fire behavior between seasons of burning. When significant F-values were found, we used protected multiple comparisons (LSD) (Steel and Torrie 1980) to detect differences between seasons of burn. We evaluated the relationship between fire behavior variables and individual vegetation classes, fuel loading and weather using Pearson correlation analysis

(SAS 1988). Simple regression (SAS 1988) was used to determine the effects of fire behavior variables on shrub stem density.

Results

Except for rate of spread, all fire behavior variables were affected by season of burn ($P = \leq 0.1000$) (Table 4). Flame depth was lower for the fall burning season but did not differ between winter and spring. Fireline intensity, heat per unit area, and fuel combustion were highest for fires in spring and fall but did not differ between fires in fall and winter. Reaction intensity was lower for winter burns but did not differ between fires in spring and fall.

Flame depth was negatively associated with relative humidity, fuel moisture, and 1 hr live fuel weight (Table 5). Rate of spread and fireline intensity were associated positively with wind speed and fireline intensity correlated positively with 100 hr dead fuel weight. Heat per unit area was associated positively with air temperature, total fuel load, and 1, 10, and 100 hr dead fuel weights. Reaction intensity was correlated positively with total fuel load and 100 hr dead fuel weight. Generally speaking, rate of spread and fireline intensity were most influenced by weather. Heat per unit area, fuel consumption, and reaction intensity were most influenced by fuel loading. Flame depth was influenced by weather, fuel moisture, and fuel loading.

Shrub cover was associated negatively with rate of spread (Table 6). Little bluestem cover was associated positively with rate of spread and associated negatively with heat per unit area, fuel consumption, and reaction intensity. Cover of tallgrasses was correlated positively with rate of spread. Other perennial grasses were related negatively to flame depth, heat per unit area, and fuel consumption. None of the remaining vegetation classes, or bare ground, were correlated with any of the fire behavior variables.

Flame depth ($P = 0.3115$), rate of spread ($P = 0.1991$), fireline intensity ($P = 0.5832$) and reaction intensity ($P = 0.6149$) did not affect the multivariate abundance of vegetation classes, while the effect of heat per unit area ($P = 0.0415$) and fuel consumption ($P = 0.0462$) was significant (Table 7). Flame depth ($P = 0.6743$, $r^2 = 0.0064$), rate of spread ($P = 0.2957$, $r^2 = 0.0390$), and fireline intensity ($P = 0.4878$, $r^2 = 0.0173$) did not influence post-burn shrub density, but heat per unit area ($P = 0.0172$, $r^2 = 0.1865$), fuel consumption ($P = 0.0178$, $r^2 = 0.1846$) and reaction intensity ($P = 0.0585$, $r^2 = 0.1309$) were associated positively with shrub density (Figure 1).

Discussion

Fuel loading and fire behavior in shinnery oak communities have not been previously reported. In our study, the weight of 1 hr dead fuels comprised the majority of the total fuel load. Fuels in this category included herbaceous matter, shrub leaf litter, and twigs. As a fuel type, shrub leaf litter is often associated with low intensity fires (Engle and Stritzke 1995). In shinnery oak communities, oak leaf litter often accounts for the majority of the 1 hr dead fuel load, but fireline intensity values may remain high if sufficient herbaceous litter is present. Herbaceous litter ignites more readily than oak leaf litter and may increase combustion of the leaf litter component. Decreased availability of 1 hr dead fuels in our fall burns relative to burns in winter and spring (Table 2) was related to plant phenology because fall burns took place prior to the end of the growing season. Thus, herbaceous plant matter and shrub leaves that were green during the fall burning period had senesced prior to the spring and winter burning period. Correspondingly, 1 hr live fuels were most available during the fall burning period.

The severity of fire behavior measures was generally higher for spring and fall burns compared with winter burns (Table 2). Less severe fire behavior in winter may relate to air and fuel temperatures, although our correlation analysis (Table 5) indicated that only heat per unit area and fuel consumption were correlated significantly with ambient air temperature. The relatively shallow flame depth of fall fires (Table 4) relates to increased availability of 1 hr live fuels for the fall burning period (Table 2). One hr live fuel availability was correlated negatively with flame depth (Table 5) in our study, reflecting higher energy inputs needed to maintain combustion of a fuel with high moisture content (Pyne et al. 1996). Although availability of 100 hr dead fuels was negligible, 4 fire behavior variables were correlated positively with availability of this fuel class (Table 5). The influence of fuels in this time lag class on fire behavior may relate to total fuel accumulation. Presence of 100 hr dead fuels indicates a relatively long disturbance-free period during which fuels of all size classes may increase. Heat per unit area, fuel consumption, and reaction intensity were correlated positively with total fuel load (Table 5).

Fireline intensity and heat per unit area are often used to characterize fire behavior in a vegetation type. Values for these parameters (Table 4) were generally higher than reported for other woody plant dominated systems in North America (Armour et al. 1984, Engle and Stritzke 1995, Glitzenstein et al. 1995), with the exception of California chaparral. Our results may relate to the fuel architecture of shinnery oak communities. Shinnery oak, the dominant shrub species in our study plots, is a low-growing (0.5 to 1 m) shrub underlain by herbaceous plants. The canopy height of fine fuels is high enough to heat and ignite fuels in the shrub overstory. Thus, fires in these communities are often characterized by simultaneous combustion of ground-level fine fuels and the overstory shrub component, increasing the amount of fuel that is combusted. It should be noted that fire behavior measurements in our study were taken from 10 m strip headfires that were contained within the boundaries of relatively small plots (60 x 30 m). Pyne et al. (1996) reported that fire behavior may become more extreme as a function of time-since-ignition until fire behavior reaches a "quasi-steady-state." Thus, management burns encompassing larger areas may exhibit more extreme fire behavior than recorded in our experimental plots.

The influence of fire behavior variables on shrub stem density in this study is somewhat unique, in that 3 variables had no effect on stem density, while heat per unit area, fuel consumption, and reaction intensity were related positively to stem density (Figure 1). Increased stem density following fire is a common response of vegetatively reproducing shrub species (Lacy and Johnson 1990, Matlack et al. 1993, Petranka and McPherson 1979). Shinnery oak and Oklahoma plum, the dominant shrubs in our study, reproduce predominantly through vegetative means and increase in density following fire in any season. However, the increase in stem density with increasing values of heat per unit area, fuel consumption, and reaction intensity is perplexing. In other woody plant dominated systems, stem density is often negatively related to fire behavior variables. For instance, Sparks (1996) reported that increasing rate of spread, reaction intensity, and fireline intensity decreased woody plant stem density in *Quercus*-associated understory communities in Arkansas. Working with sandhill oak communities in Florida, Glitzenstein et al. (1995) found increasing top-kill of oak with increasing fire temperature. Trollope (1984) showed that fireline intensity was correlated positively with mortality of trees and shrubs in South African savannah systems.

The increase in post-burn stem density with increasing heat per unit area, fuel consumption, and reaction intensity noted in this study may be related to the negative affects of these fire variables on competing vegetation. Little bluestem, the dominant grass species in unburned plots was correlated negatively with all 3 variables (Table 6). Post-burn shrub density was correlated negatively with little bluestem canopy cover ($P = 0.0668$, $R = -0.339$). Thus, a reduction in cover of the dominant grass species may increase the area available for colonization by shrubs and the subsequent density of shrub re-sprouts. An alternative explanation would be that top-kill of rhizomatous shrubs increased with increasing values of these 3 fire behavior variables, thus promoting re-sprouting and increasing shrub density. However, fires on plots in this study were generally continuous and top-kill of above-ground shrub stems was nearly complete, regardless of fire behavior, making this hypothesis less tractable.

The most influential fire behavior variables on canopy cover of individual vegetation classes were rate of spread, heat per unit area, and fuel consumption (Table 6). The decrease in shrub canopy cover with increasing rate of spread may be a by-product of increases in cover of little bluestem and tallgrasses with increasing rate of spread. These two vegetation classes comprise the majority of herbaceous canopy cover and may compete with shrub re-sprouts in the post-burn environment. The positive correlation of rate of spread and little bluestem is puzzling in that this species is thought to decline with extreme fire behavior (e.g. Ewing and Engle 1988); conversely, little bluestem was correlated negatively with heat per unit area and fuel consumption, as were other grasses (mainly bunchgrasses; Table 6). These relationships suggest that bunchgrasses in this study were more sensitive to fire behavior measures that incorporate the rate and amount of energy release on a per unit area basis.

The lack of correlation of forbs or sedges with any measure of fire behavior (Table 6), combined with the fact that only 2 of the 6 fire behavior variables significantly affected overall plant community composition (Table 7), suggests that factors other than fire behavior are influencing the post-burn plant community. One such factor may be the influence of fire on shrub canopy cover and bare ground. In unburned shinnery oak communities, the ground-level interspaces are often covered with oak leaf litter to depths of 8 cm, shrub canopy may exceed 70% (Boyd 1999a), and abundance of many grass and forb species is correlated positively with bare ground (Dhillion et al. 1994, Holland 1994, Boyd 1999a). Fire greatly increases bare ground, and herbaceous vegetation classes are released from control by leaf litter (Boyd 1999a). Additionally, fire reduces overstory shrub cover which may temporarily elevate incoming solar radiation to the understory and benefit shade intolerant herbaceous species (Bowles and McBride 1998, Nasser and Goetz 1995). Within our study, bare ground increased and overstory shrub cover decreased in all burns, regardless of associated fire behavior. In fact, none of the fire behavior variables in this study were correlated with availability of bare ground and only rate of spread correlated with shrub canopy cover (Table 6). Thus, burning *per se* may be a more important influence on bare ground and overstory shrub cover than fire behavior at the time of burning.

I previously reported that season of burn can influence post-fire plant community composition (Boyd 1999a). The major plant community differences between burns in fall, winter, and spring were decreased shrub cover with spring burns, and an increase in forb canopy cover with fall burning. In the present work, we report that fire behavior varies by season of burn. This raises the question of whether season of burn and fire behavior interact to influence post-fire vegetation composition. We found no relationship between any fire behavior variable and forb abundance, suggesting that season of burn is more important in influencing this component of the plant community. Canopy cover of shrubs was correlated negatively with rate of spread (Table 6) and although rate of spread did not vary between burning seasons (Table 4), the numerical trend indicates highest values with spring fire. This relationship suggests that low canopy cover values for shrubs in spring-burned plots may be related to fire behavior. For shrub density, we would predict (Figure 1) that spring burns, which had the highest heat per unit area and fuel consumption, would produce the highest post-burn shrub stem density values and winter burns, which had the lowest values for these behavior variables, would produce the lowest post-burn shrub densities. However, shrub density did not differ by season, and the numerical trend was actually the opposite of that predicted above (i.e., lowest shrub stem density with spring fire; Boyd 1999b). Thus, it is possible that high heat per unit area and fuel consumption values for spring burns acted to moderate the opposing influence of season of burn on shrub density.

Conclusions

Our results indicate seasonal differences in fire behavior in shinnery oak communities. Fall and spring burning produced higher fireline intensity, heat per unit area, fuel consumption, and reaction intensity than winter burns, while flame depth was lowest for fall burns. In general, grass cover increased with increasing rate of spread and decreased with increasing heat per unit area, fuel consumption, and reaction intensity. Shrub cover was inversely related to rate of spread, while shrub density increased with increasing heat per unit area, fuel consumption, and reaction intensity. The influence of fire behavior on post-burn plant community composition was minimal in this study. We believe that this lack of influence of fire behavior relates to the removal of ground leaf litter and overstory shrub cover with fire, regardless of fire behavior. Our data indicate that season of burn and fire behavior may have an interactive effect on canopy cover and stem density of shrubs. Additional research is needed to clarify ramifications of this relationship to the use of prescribed fire as a management tool in shinnery oak communities.

Literature Cited

Alexander, M.E. 1982. Calculating and interpreting forest fire intensities. Can. J. Bot. 60:349-357.

Armour, C.D., S.C. Bunting and L.F. Neuenschwander. 1984. Fire intensity effects on the understory in ponderosa pine forests. J. Range Manage. 97:44-49.

Bazzaz, F.A. and S.R. Morse. 1991. Potential responses of annuals to multiple stresses, p. 283-305. *In:* Mooney et al. (ed.), Response of plants to multiple stresses. Academic Press, New York.

Bowles, M.L. and J.L. McBride. 1998. Vegetation composition, structure, and chronological change in a decadent midwestern North American savanna remnant. Nat. Areas. J. 18:14-27.

Box, T.W. 1967. Brush, fire and west Texas rangeland. Proc. Tall Timbers Fire Ecol. Conf. 6:7-19.

Box, T.W. and R.S. White. 1969. Fall and winter burning of South Texas brush ranges. J. Range. Manage. 85:21-31.

Boyd, C.S. 1999a. The effects of prescribed fire on shinnery oak (*Quercus havardii*) plant communities in western Oklahoma. *In:* The effects of burning season and frequency on the vegetative character and insect abundance of sand shinnery oak range in western Oklahoma. Ph.D. Dissertation, Oklahoma State Univ., Stillwater.

Boyd, C.S. 1999b. The effects of prescribed fire on shrub dynamics in shinnery oak (*Quercus havardii*) plant communities in western Oklahoma. *In:* The effects of burning season and frequency on the vegetative character and insect abundance of sand shinnery oak range in western Oklahoma. Ph.D. Dissertation, Oklahoma State Univ., Stillwater.

Byram, G.M. 1959. Combustion of forest fuels. *In* K.P. Davis (ed.), Forest fire: control and use. McGraw-Hill, New York. pp.61-69.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Sci. 33:43-64.

Dhillion, S.S., M.A. McGinley, C.F. Friese and J.C. Zak. 1994. Construction of sand shinnery oak communities of the Llano Estacado: Animal disturbances, plant community structure, and restoration. Rest. Ecol. 2:51-60.

Duck, L.G. and J.B. Fletcher. 1944. A survey of the game and fur-bearing animals of Oklahoma. State Bull. 3. Oklahoma City: Oklahoma Game and Fish Dept. 144pp.

Engle, D.M. and J.F. Stritzke. 1995. Fire behavior and fire effects on eastern redcedar in hardwood leaf-litter fires. J. Wildland Fire. 5:135-141.

Ewing, A. L. and D.M. Engle. 1988. Effects of late summer fire on tallgrass prairie microclimate and community composition. Amer. Mid. Nat. 120:212-213.

Glitzenstein, J.S., W.J. Platt and D.R. Streng. 1995. Effects of fire regime and habitat on tree dynamics in north Florida longleaf pine savannas. Ecol. Mono. 65:441-476.

Great Plains Flora Association. 1986. Flora of the Great Plains. T.M. Barkley (ed.), Univ. Kansas Press, Lawrence.

Holland, M. 1994. Disturbance, environmental heterogeneity, and plant community structure in a sand shinnery oak community. MS Thesis, Texas Tech Univ., Lubbock.

Jackson, A.S. and R. DeArment. 1963. The lesser prairie chicken in the Texas Panhandle. J. Wildl. Manage. 27:733-737.

Johnson, R.A. and D.W. Wichern. 1992. Applied multivariate statistical analysis. Prentice Hall, Englewood Cliffs, New Jersey.

Lacy, C.J. and R.D. Johnston. 1990. Woody clumps and clumpwoods. Aus. J. Bot.

38:299-334.

Marcy, R.B. 1854. Explorations of the Red River of Louisiana in the year 1852. 33rd Congress, 1st Session, House Executive Document. Washington: A.O.P. Nicholson. 286pp.

Matlack, G.R., D.J. Gibson., and R.E. Good. 1993. Clonal propagation, local disturbance, and the structure of vegetation: Eriaceous shrubs in the Pine Barrens of New Jersey. Biol. Cons. 63:1-8.

McIlvain, E.H. and C.G. Armstrong. 1966. A summary of fire and forage research on shinnery oak rangelands. Proc. Tall Timbers Fire Ecol. Conf. 5:127-129.

McIlvain, E.H. and M.C. Shoop. 1965. Pasture and range investigations. Woodward, Oklahoma: U.S.D.A., A.R.S. 187pp.

Nasser, N. and H. Goetz. 1995. Relationships of overstory to understory cover variables in a ponderosa pine/gambel oak ecosystem. Vegetatio 119:15-21.

Osborne, B. 1942. Prairie dogs in shinnery (oak scrub) savannah. Ecology 23:110-115.

Peterson, R.S. and C.S. Boyd. 1998. Ecology and management of sand shinnery oak communities: A literature review. U.S.D.A. Forest Service Gen. Tech. Rept.-16.

Petranka, J.W. and J.K. McPherson. 1979. The role of *Rhus copallina* in the dynamics of the forest-prairie ecotone in north-central Oklahoma. Ecology 60: 956-965.

Pettit, R.D. 1994. Sand shinnery oak, p. 106. *In*: T.N. Shiflet, (ed.), Rangeland cover types of the United States. Soc. for Range Manage., Denver.

Pyne, S.J., P.L. Andrews and R.D. Laven. 1996. Introduction to Wildland Fire. John Wiley and Sons, New York. 769pp.

Roberts, F.H., C.M. Britton, D.B. Wester and R.G. Clark. 1988. Fire effects on tobosagrass and weeping lovegrass. J. Range Manage. 41:407-408.

Rothermel, R.C. 1983. How to predict the spread of intensity of forest and range fires. USDA, Forest Service Gen. Tech. Rept.-143.

Rothermel, R.C. and J.E. Deeming. 1980. Measuring and interpreting fire behavior for correlation with fire effects. USDA, Forest service Gen. Tech. Rept.-93.

SAS Institute Inc. 1988. SAS procedures guide, release 6.03. Cary, North Carolina.

Slosser, J.E., P.W. Jacoby and J.R. Price. 1985. Management of sand shinnery oak for control of boll weevil (Coleoptera: Curculionidae) in the Texas Rolling Plains. J. Econ. Entomol. 78:383-389.

Sparks, J.C. 1996. Effects of growing-season and dormant-season prescribed fire on vegetation in red-cockaded woodpecker clusters. MS Thesis, Oklahoma State Univ., Stillwater.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and procedures of statistics, a biometrical approach: second edition. McGraw-Hill Book Co., New York. 633pp.

Stroup, W.W. and J. Stubbendieck. 1983. Multivariate Statistical Methods to determine changes in botanical composition. J. Range Manage. 36:208-212.

Towne, E.G. and A.K. Knapp. 1996. Biomass and density responses in tallgrass prairie legumes to annual fire and topographic position. Am. J. Bot. 83:175-179.

Towne, G. and C. Owensby. 1984. Long-term effects of annual burning at different dates in ungrazed Kansas tallgrass prairie. J. Range. Manage. 37:392-397.

Trollope, W.S.W. 1984. Fire in Savannah, *In* P. de V. Booysen and N.M. Tainton (eds.), Ecological effects of fire in South African ecosystems. Springer-Verlag, New York. pp.151-175

United States Department of Agriculture. 1982. Soil survey: Roger Mills County Oklahoma. U.S. Gov. Printing Office, Washington, D.C.

West, N.E. and G.A. Reese. 1996. Comparison of some methods for collecting and analyzing data on aboveground net production and diversity of herbaceous vegetation in a northern Utah subalpine context. Vegetatio 96:145-163.

Wright, H.A. and A.W. Bailey. 1982. Fire ecology: United States and southern Canada. John Wiley and Sons, New York. 501pp.

Table 1. Sample size, burning dates, and weather variables for precribed burns in western Oklahoma.

Year	Season	n	Burning date	Air temp^{O}C	% Relative humidity	Wind speed (km/hr)
1997-1998	Fall	6	Oct. 1-24	16 - 30	21 - 50	6 - 11
1997-1998	Winter	12	Jan 27 - Feb. 5	-1 - 16	24 - 72	5 - 16
1997-1998	Spring	12	April 28 - May 1	18 - 29	20 - 59	3 - 16

Table 2. Means and standard errors for fuel loading and fuel moisture for prescribed burns in western Oklahoma.

			1 Hour live		1 Hour dead		10 Hour dead		100 Hour dead	
Year	Season	n	Fuel load (kg/m^2)	% Fuel moisture	Fuel load (kg/m^2)	% Fuel moisture	Fuel load (kg/m^2)	% Fuel moisture	Fuel load (kg/m^2)	% Fuel moisture
1997-1998	Fall	6	0.14+/-0.03	66.56 +/- 18.33	1.08 +/- 0.11	17.04 +/- 1.56	0.15 +/- 0.05	27.39 +/- 8.07	0	...
1997-1998	Winter	12	0	...	1.34 +/-0.06	18.88 +/-2.30	0.09 +/- 0.02	34.27 +/- 9.35	0	...
1997-1998	Spring	12	0.013+/-0.003	137.42 +/- 34.56	1.31+/-0.09	14.72 +/- 1.87	0.08 +/- 0.02	21.32 +/- 2.91	0.01 +/- 0.01	1.97 +/- 1.97

Table 3. Shinnery oak community vegetation classes, acronyms, and representitive species.

Vegetation Class	Acronym	Representitive species
Annual Forbs	FORBA	*Conyza canadensis* L., *Monarda punctata* L., *Pyropapus carolinianus* Walt.
Perennial Forbs	FORBP	*Ambrosia psilostachya, Calylophus berlanderii, Commelina erecta*
Legumes	LEGUME	*Amorpha canescens* Pursh., *Desmodium sessilifolium* Torr., *Lespedeza stuevei* Nutt.
Little Bluestem	LBS	*Schizachyrium scoparium*
Tallgrasses	TG	*Andropogon gerardii, Panicum virgatum, Sorghastrum nutans,*
Other Grasses	GRASS	*Bouteloua curtipendula, Eragrostis trichodes, Sporobolus cryptandrus*
Sedges	SEDGE	*Cyperus schweinitzii* Torr.
Shrubs	SHRUB	*Artemisia filifolia, Prunus gracilis, Quercus havardii*

Table 4. Fire behavior means and standard errors, by season of burn, for experimental plots burned in western Oklahoma.

Year	Season of burn	n	Flame depth (m)			Rate of spread (m/sec)			Fireline intensity (kW/m)			Heat per unit area (kJ/m^2)			Fuel consumption (kg/m^2)			Reaction intensity (kW/m^2)*		
			$\bar{x}$		se	$\bar{x}$		se	$\bar{x}$		se	$\bar{x}$		se	$\bar{x}$		se	$\bar{x}$		se
1997-1998	Fall	6	1.34	A**	0.23	0.196	A	0.049	2987.63	AB	695.52	15,923.63	AB	2069.64	0.943	AB	0.123	1938.72	A	587.63
1997-1998	Winter	12	2.76	B	0.39	0.223	A	0.033	2562.11	B	447.95	11,966.48	B	1192.38	0.704	B	0.070	973.97	B	125.47
1997-1998	Spring	12	2.44	B	0.27	0.274	A	0.036	4334.87	A	663.95	16,131.97	A	1604.44	0.946	A	0.093	1679.73	A	285.22

* n = 5 (Fall), n = 11 (Spring)

** Means within a column that do not share a common letter are different (LSD) at alpha = 0.10.

Table 5. Correlations of fuel, weather, and fire behavior variables for experimental plots in western Oklahoma.

Fire behavior variable	n	Air temp. (°C)	Wind speed (km/hr)	% Relative humidity	Weighted % fuel moisture	Total fuel load (kg/m^2)	1 Hour live (kg/m^2)	1 Hour dead (kg/m^2)	10 Hour dead (kg/m^2)	100 Hour dead (kg/m^2)
		Correlation coefficient								
Flame depth (m)	30	0.115	0.138	-0.453 *	-0.340 **	0.137	-0.456 *	-0.058	0.013	-0.036
Rate of spread (m/sec)	30	-0.126	0.451 *	-0.154	-0.124	-0.283	-0.013	-0.251	-0.225	0.055
Fireline intensity (kW/m)	30	0.079	0.366 *	-0.214	-0.051	0.232	0.083	0.179	0.132	0.324 *
Heat per unit area (kJ/m^2)	30	0.396 *	0.007	-0.243	-0.187	0.660 *	0.236	0.512 *	0.497 **	0.386 *
Fuel consumption (kg/m^2)	30	0.395 *	0.010	-0.233	-0.162	0.665 *	0.238	0.513 *	0.504 *	0.386 *
Reaction intensity (kW/m^2)	28	0.306	0.285	-0.103	0.109	0.345 *	0.399 *	0.199	0.312	0.371 **

* $P \leq 0.0500$

** $P > 0.0500, \leq 0.1000$

Table 6. Correlations coefficients of vegetation class canopy cover and fire behavior variables for experimental plots in western Oklahoma. Acronyms are from Table 3.

Fire behavior variable	n	Vegetation class								Bare ground
		SHRUB	LBS	TG	GRASS	FORBP	FORBA	LEGUME	SEDGE	
		Correlation coefficient								
Flame depth (m)	30	-0.240	-0.187	0.238	-0.338 **	0.048	-0.232	0.033	0.077	0.068
Rate of spread (m/sec)	30	-0.320 **	0.348 *	0.391 **	0.291	-0.147	-0.222	0.199	-0.092	0.065
Fireline intensity (kW/m)	30	0.109	0.020	-0.074	0.030	-0.263	-0.115	-0.128	0.020	0.170
Heat per unit area (kJ/m^2)	30	0.077	-0.643 *	-0.207	-0.346 **	0.186	-0.065	-0.196	0.204	0.078
Fuel consumption (kg/m^2)	30	0.079	-0.639 *	-0.202	-0.346 **	0.179	-0.064	-0.189	0.196	0.076
Reaction intensity (kW/m^2)	28	-0.369	-0.369 **	0.152	-0.094	0.184	-0.18	-0.146	0.02	0.025

* $P \leq 0.0500$

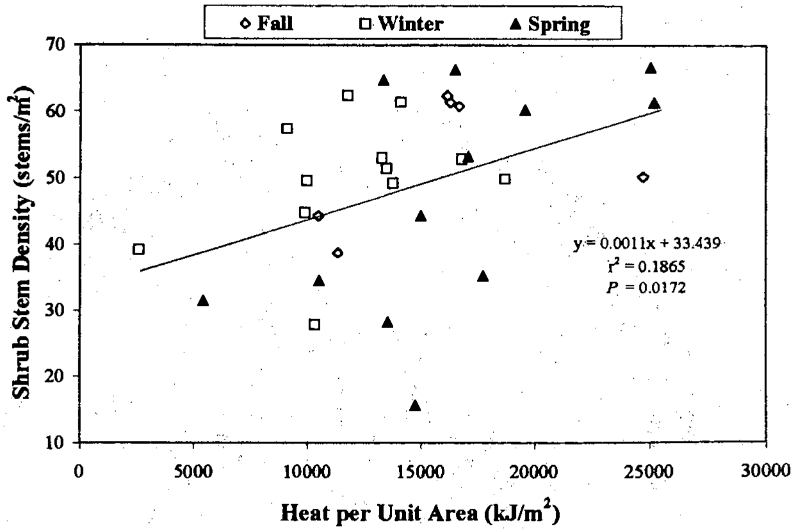
** $P > 0.0500, \leq 0.1000$

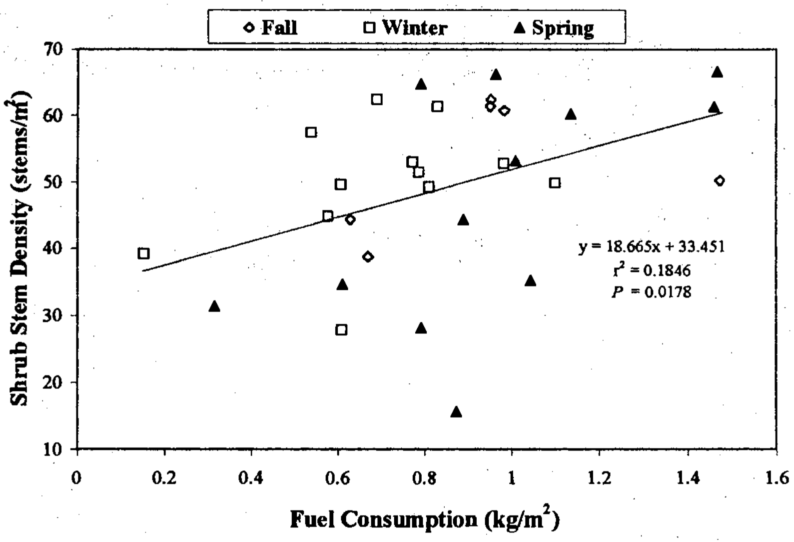
Table 7. *P* values for the effect of fire behavior variable on post-burn vegetation composition of experimental plots in western Oklahoma.

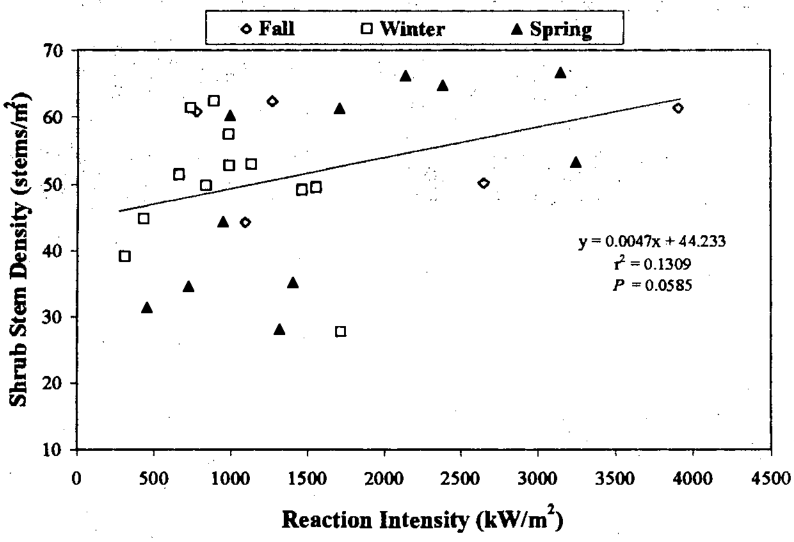
Fire behavior variable	n	*P* Value*
Flame depth (m)	30	0.3115
Rate of spread (m/sec.)	30	0.1991
Fireline intensity (kW/m)	30	0.5832
Heat per unit area (kJ/m^2)	30	0.0415
Fuel consumption (kg/m^2)	30	0.0462
Reaction intensity (kW/m^2)	28	0.6149

* P value is for the Wilk's Lambda test statistic in the model Vegetation Class$_{i\text{-}j}$ = Fire behavior variable.

Figure 1. Post-burn shrub stem density (stems/^{2}) as a function of heat per unit area (kJ/m^2), fuel consumption (kg/m^2), and reaction intensity (kW/m^2) for experimental plots in western OK.


◇ Fall
□ Winter
▲ Spring
Shrub Stem Density (stems/m²)
70
60
50
40
30
20
10
0
5000
10000
15000
20000
25000
30000
Heat per Unit Area (kJ/m²)
y = 0.0011x + 33.439
r² = 0.1865
P = 0.0172


◇ Fall
□ Winter
▲ Spring
Shrub Stem Density (stems/m²)
70
60
50
40
30
20
10
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Fuel Consumption (kg/m²)
y = 18.665x + 33.451
r² = 0.1846
P = 0.0178


◇ Fall
□ Winter
▲ Spring
Shrub Stem Density (stems/m²)
70
60
50
40
30
20
10
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Reaction Intensity (kW/m²)
y = 0.0047x + 44.233
r² = 0.1309
P = 0.0585

CHAPTER V

THE INFLUENCE OF PRESCRIBED FIRE ON LESSER PRAIRIE CHICKEN (TYMPANUCHUS PALLIDICINCTUS) HABITAT IN SHINNERY OAK (*QUERCUS HAVARDII* Rydb.) PLANT COMMUNITIES IN WESTERN OKLAHOMA

Abstract

Little is known of the effects of fire on lesser prairie chicken (*Tympanuchus pallidicinctus*) habitat in sand shinnery oak (*Quercus havardii*) communities.
Our objective was to document effects of fall (October), winter (February) and spring (April) prescribed fire on important elements of lesser prairie chicken habitat. Three study sites were located in western Oklahoma; each containing 12 60 x 30 m plots that were designated, within site, to be seasonally burned, annually burned, or left unburned. We measured canopy cover of important forage and seed-producing plants in the growing seasons of 1996 (pre-treatment) and 1997-1998 (post-treatment). Growing season insect abundance was estimated using suction sampling and flush counts in 1997-1998. Shinnery oak mast, catkin, bud, and leaf gall abundance were measured in 1997-1998. Visual obstruction was estimated in January and May of 1997-1998, and winter forb and grass frequency were measured in January of 1997-1998. Canopy cover of preferred nesting

grasses decreased with fall and spring fire ($P \leq 0.1000$) and was unaffected by winter fire. Visual obstruction decreased with burning in any season ($P = 0.1000$). Burning in any season increased warm season forbs ($P \leq 0.1000$) and grasshopper abundance ($P \leq 0.1000$) associated with brooding and foraging habitat. Oak mast production failed the year following burning but was unaffected in the subsequent growing season. Winter frequency of forbs and grasses increased with burning treatment ($P \leq 0.1000$) in the year following fire treatment. Cool season forb production increased with fire in any season ($P \leq 0.1000$) and was highest after fall burning. Production of catkins and buds failed in the year following burning and was lower in burned plots the second spring following fire ($P \leq 0.1000$). Prescribed fire has promise as a management tool to increase important forage plants and insects associated with lesser prairie chicken habitat.

Keywords: Insect abundance, nesting cover, brooding habitat, forb.

Introduction

The lesser prairie chicken (*Tympanuchus pallidicinctus*) was historically abundant throughout much of the southern Great Plains region (Taylor and Guthery 1980a). In the 20th century, populations of this species have declined dramatically. Crawford (1980) estimated that chicken abundance has been decreased by over 90% in the last century, and Taylor and Guthery (1980a) estimated a 92% decrease in range for the same time period. Loss of habitat to cultivation (Crawford and Bolen 1976a), overgrazing by domestic livestock (Lee 1950), and brush control programs (Jackson and DeArment 1963) are thought to have reduced chicken populations.

Across the majority of its present day range, lesser prairie chickens are strongly associated with shinnery oak plant communities (Peterson and Boyd 1998). Historical accounts indicate that shinnery oak communities were structurally dominated by tallgrasses with shinnery oak in the understory; oak stems did not commonly exceed 45 cm in height (Marcy 1854, Osborne 1942). Today, shinnery may constitute 80% of canopy cover (Dhillion et al. 1994), abundance of tallgrasses has decreased, and oak stems may reach 1 m in height in western Oklahoma (Peterson and Boyd 1998).

As habitat availability for lesser prairie chickens decreases, proper management of existing habitat increases in importance. The role of biotic and abiotic disturbances in affecting structure and composition of shinnery oak plant communities is relatively unexplored as compared with many other shrub-dominated systems in North American. In previous work, I have addressed the influence of fire on vegetation structure and composition in shinnery oak communities (Boyd 1999a, 1999 b, 1999c). Our objective in this paper is to discuss the ramifications of prescribed fire-induced changes in shinnery oak communities to habitat quality for the lesser prairie chicken. Specifically, we document effects of prescribed, seasonal fires on nesting and brooding habitat, thermal and escape cover, and availability of important food plants and insects.

Methods

Study Sites

Study sites were located on the Black Kettle National Grassland in Roger Mills County, Oklahoma (35° 32’ 44” N, 99° 43’ 39” W), and the state-owned Packsaddle Wildlife Management Area in Ellis County, Oklahoma (36° 4’ 22” N, 99° 54’ 5” W).

Sites were chosen subjectively to be representative of shinnery oak communities found on sandy soils within the western Oklahoma region. All sites were lightly grazed by cattle during the growing season before study initiation and were excluded from grazing in 1995 and throughout the course of the study. Before our study, these sites had not burned on a regular basis and had not burned for at least 10 years.

Soils were fine sands (Nobscott-Brownfield Association) with no limiting layers in the top 150 cm (USDA 1982). Shinnery oak, a deciduous, clonal species, was the dominant shrub with lesser amounts of sand sagebrush (*Artemisia filifolia* Torr.) and Oklahoma plum (*Prunus gracilis* Engelm.). Dominant grasses and forbs included little bluestem (*Schizachyrium scoparium* Nash), indiangrass (*Sorghastrum nutans* Nash), switchgrass (*Panicum virgatum* L.), sand bluestem (*Andropogon gerardii* Hack.), sand lovegrass (*Eragrostis trichodes* Nutt.), sideoats grama (*Bouteloua curtipendula* Michx.), western ragweed (*Ambrosia psilostachya* DC.), erect dayflower (*Commelina erecta* L.) and sundrop (*Calylophus berlandieri* Spach). Average annual precipitation was 65.6 cm; growing season (March-August) precipitation averaged 40.6 cm (USDA 1982).

Experimental Design

We divided each of the 3 study sites (blocks) into 12 60 x 30m plots. Plots were arranged in a 2 x 6 matrix and separated by 7m firebreaks. We randomly assigned each of the plots within a site to the following treatments: 1) no burn, 2) burn fall 1996, 3) burn fall 1997, 4) burn winter 1997, 5) burn winter 1998, 6) burn winter 1997 and 1998, 7) burn spring 1997, 8) burn spring 1998, 9) burn spring 1997 and 1998. Growing season canopy cover of plant species and bare ground was estimated for all plots. Pre-treatment canopy cover data was collected during the growing season in 1996 and treatment response data during the growing season in 1997 and 1998. All other data in this study were collected from a sub-set of plots which included the fall-burn (1996) plot from each site (n = 3), and one randomly chosen control plot, winter-burn (1997) plot, and spring-burn 1997 plot from each site (n = 3 for each treatment).

Fire Ignition and Behavior

All plots were burned using a strip-headfiring technique (Wright and Bailey 1982). The downwind and flank sides of the plots were ignited and allowed to burn about 5 m into the plot. We ignited a series of headfires about 10 m upwind from the backfire. All burns were conducted with relative humidity >20%, air temperature <29°C and a surface wind speed of <16 km/hr. We estimated fire behavior characteristics for all headfires and determined pre-burn fuel loading and fire consumption from quadrats clipped before and after burning. Fire behavior and fuel characteristics are discussed in Boyd (1999c).

Canopy Cover and Frequency

Because of the ignition pattern, the outer 5 m of plots were excluded from vegetation sampling to eliminate differential effects of headfires, backfires, and flankfires. We estimated canopy cover for each plot, by species, at 30 randomly located points (Daubenmire 1959). At each point, canopy cover of each species influencing a 20 x 50 cm quadrat was categorized as 0-5%, 5-25%, 25-50%, 50-75%, 75-95% or 95-100%. We averaged mid-point values to obtain an estimate of canopy cover of each species in a plot for a given sampling period. We estimated canopy cover during 3 sampling periods: 25-31

May, 6-22 June, and 8-17 August. Pretreatment data were collected during the growing season in 1996 and treatment response data during the growing seasons in 1997 and 1998. We estimated the percent frequency of occurrence of forbs and grasses, at 30, randomly located points per plot. At each point we recorded presence or absence of living forbs and grasses in a 20 x 50 cm quadrat. Frequency data were collected in January of 1997 and 1998. Nomenclature followed that of the Great Plains Flora Association (1986) with the exception of little bluestem (i.e. *Schizachyrium scoparium*).

We created summary variables to represent the sum of all canopy cover values for a given vegetation class, in a given plot and year. These vegetation classes included, shrubs as a group, grasses important for nesting habitat, as well as shrubs, forbs, grasses and sedges that have been reported to be eaten by lesser prairie chickens. Important plant species were compiled from previous dietary and habitat research in shinnery oak communities, namely, Crawford and Bolen (1976b), Davis et al. (1980), Doerr and Guthery (1983), and Riley et al. (1993) (Table 1). Average seasonal canopy cover values for vegetation classes were calculated by averaging canopy cover values by plot, vegetation class, and year (West and Reese 1996). These average values were used in statistical analysis.

Shinnery Oak Mast, Buds, Catkins and Leaf Galls

We estimated the abundance of oak acorns and leaf galls in the first week of August, 1997-1998, and oak catkins and buds in the first week of April, 1997-1998. We made estimates by counting number of acorns, buds, catkins, and leaf galls associated with shinnery oak shrubs rooted within 10 randomly located 0.5 m^2 quadrats for each plot. We counted mast, buds, and leaf galls directly; catkin abundance was estimated by counting number of catkins associated with the first 5 buds encountered in each quadrat (50 buds/plot). We then multiplied the average number of catkins per bud by bud density for the plot to obtain an estimate of catkin density.

Visual Obstruction

We estimated visual obstruction in January and May of 1997 and 1998 using a density board (Nudds 1977) as modified by Guthery et al. (1981) for use in shinnery oak communities. The density board measured 120 x 6.8 cm and was marked in alternating black and white 10 cm strata. We numbered the strata consecutively from the ground up to facilitate visual reference. We estimated percent visual obstruction every other meter along a 50 m transect through the center of the long axis of each plot. We made estimates at 7 m on both sides of the transect with the observer kneeling over the permanent transect (50 observations/plot). We averaged scores of each strata to obtain percent visual obstruction for each strata in a plot.

Insect Sampling

We assessed insect abundance using a suction harvester similar to that described by Stewart and Wright (1995). The harvester consisted of used a hand-held gas-powered (31 cc) leaf vacuum fitted with a 10 cm diameter flexible hose and collection bucket. At 6 randomly selected points in each plot, we used the harvester to thoroughly scrub the vegetation and ground strata contained in a 100 x 60 cm plastic cylinder. We covered the top of the cylinder with a nylon mesh to prevent escape of insects and inserted the vacuum hose through a slit in the mesh. Collections were made in during the last week of June and July, 1997-1998. Factory specifications indicate that this leaf vacuum exceeds the minimum air velocity of 96 km/hr recommended by Southwood (1978) for adequate sampling of ground and vegetative strata insect populations. We placed debris and insects in plastic bags and froze the samples until analysis. We identified insects to order; total insect density (per 6 samples) was used in statistical analysis.

We estimated grasshopper density in the last week of June, July, and August, 1997-1998, by counting the number of grasshoppers flushed from 16 1 m^2 quadrats/plot. We arranged quadrats systematically within plots in a 2 x 8 grid; quadrat boundaries were marked with pin flags 2 days prior to counts. We used a dowel rod to disturb vegetation and flush all grasshoppers in a quadrat.

Statistical Analysis

We assessed treatment effects on canopy cover data using analysis of covariance (SAS Institute Inc. 1988) with vegetation class as the dependent variable, pre-treatment vegetation class score as the covariate, and season of burn, time since fire, or annual burning as the main effect. When significant model and treatment variable effects were found, we used protected multiple comparisons (LSD, alpha = 0.1000) to detect differences between treatment means. Model and treatment effects were considered significant at $P \leq 0.1000$.

We determined fire effects on catkins, acorns, galls, buds, insects and forb and grass frequency using analysis of variance (SAS 1988). We compared treatment means as described above (LSD). We determined the effects of season of burn on visual obstruction using multivariate repeated measures analysis of variance (Stroup and Stubbendieck 1983). For this analysis, we set values for strata 1 through 12 as dependent variables, and season of burn as the main effect. Strata 1 through 12 were treated as a repeated measure in this model, such that we were testing for treatment differences in the response curve of visual obstruction across the 12 strata. We determined the significance of season of burn using the *P*-value associated with the strata x treatment interaction.

Results and Discussion

Nesting Habitat

Lesser prairie chickens prefer to nest in areas with an abundance of perennial grasses (Copelin 1963). Riley et al. (1992) found that basal cover of perennial tallgrass (*Andropogon hallii*) was higher around successful as compared to unsuccessful nests. Copelin (1963) noted that standing dead grass litter is important for overhead cover because nesting takes place prior to or very near the time of initiation of spring grass growth. Overhead cover and horizontal visual obstruction interact to influence concealment of nesting hens and may influence nesting success. Haukos and Smith (1989) found that hens selected nests sites with >75% visual obstruction in the first 33 cm and 50% overhead cover.

Our data indicate (Table 2) that nesting grasses decreased in fall and spring-burned plots relative to control plots, during the first growing season following fire ($P \leq 0.1000$). Nesting grass abundance did not differ between winter burns and control plots in either year ($P \leq 0.1000$). Nesting grass abundance increased with time since fire ($P = 0.0001$) and values 2 growing seasons after fire were similar to control plots. Nesting grasses abundance in annually burned plots was similar to control plots and was greater than that recorded for single event fires (P = 0.0003) (Table 2). In previous research (Boyd 1999a), I reported that winter burning increased cover of rhizomatous tallgrasses and little bluestem cover decreased with fire in any season. In the present study, the negative influence of fall and spring burning on the cover of nesting grasses as a group was due mainly to a decrease in little bluestem.

Spring (May) visual obstruction profiles differed across burning treatments (P = 0.1000; Figure 1). Obstruction values for burned plots were generally lower than those for controls both the year of burning (1997) and the second spring following fire treatment (1998). Using the findings of Haukos and Smith (1989) as a guideline, visual obstruction values for control plots are adequate for nesting purposes, as are values for burned plots in 1998, while values for burned plots in the spring following fire (1997) are inadequate. Although we did not directly measure overhead cover, the canopy cover of dominant vegetation may serve as a guide to changes in overhead cover. Little bluestem, rhizomatus tallgrasses, and shrubs made-up >90% of the total canopy cover recorded in our plots. Canopy cover of these grass species was influenced as described above, while shrub cover decreased with fire in any season relative to control plots ($P \leq 0.1000$) (Table 2). In fact, shrub cover was reduced by 50% in spring-burned plots, indicating the potential for a substantial reduction in overhead cover.

Brooding Habitat

Brooding habitat for lesser prairie chickens is characterized by a high forb availability and abundant bare ground (Jones 1963, Riley et al. 1992). Forb communities are important both for the forage they contain, as well as the increased insect abundance typically associated with these areas (Doerr and Guthery 1980). In New Mexico, chicks and juveniles had summer diets consisting of 100% and 99.3% insect material, respectively. Sixty two percent of the chick diet and 88% of the juvenile diet was composed of grasshoppers (Davis et al. 1980).

In our study, warm season forbs increased with winter and spring burning, and were unaffected by fall fire in 1997 ($P \leq 0.1000$; Table 2). In 1998, fall and spring burning increased warm season forb abundance, relative to control plots, while winter burns had no affect ($P \leq 0.1000$). Cool-season forb cover increased with fall and winter fire in 1997 and fall fire in 1998 ($P \leq 0.1000$). Bare ground increased with burning in any season, relative to control plots ($P \leq 0.1000$) (Table 2). The most significant increase was with fall burning, perhaps because these plots had the longest time interval between burning, and the following growing season. Bare ground decreased with increasing time since fire ($P = 0.0004$).

Insect density from suction samples was not strongly affected by fire (Table 3). The only difference was for burned plots in 1998, which had a higher insect density per plot than unburned plots ($P = 0.1000$). Insect density per plot decreased markedly from 1996 (pre-treatment) to 1998. We believe that this may be a result of fire-related mortality. Our plots were relatively small and located in close proximity within a site. This, combined with the fact that only 2 plots per site remained unburned by the 1998 growing season, may have decreased immigration of insects from unburned plots to burned plots. Warren et al. (1987) stated that the size of burned areas influences immigration from unburned areas and that zeric microclimates and decreased vegetative may increase insect mortality due to exposure and predation. More mobile insects such as grasshoppers may escape direct combustion and immigrate more easily from unburned areas. Chamrad and Dodd (1973) found that grasshoppers made-up a larger proportion of the insect population on burned plots relative to controls.

Grasshopper density in June 1997 increased with all seasons of burn, relative to control plots ($P \leq 0.1000$; Figure 2). Grasshopper density in June 1998 was similar except winter burn density did not differ from control plots. Density values for burned and control plots were similar for the July and August sampling periods in 1997. In July 1998, grasshopper density increased with fall and spring fire ($P \leq 0.1000$) and was unaffected by winter fire, relative to control plots. In the August 1998 sampling period, density values were higher for spring burns than in control plots ($P \leq 0.1000$), while fall and winter-burned plots did not differ from controls.

Foraging Habitat

In shinnery oak habitat, the diet of lesser prairie chickens varies strongly by season. In spring, diets are dominated by vegetative material, mainly forbs, and shinnery oak catkins and buds (Davis et al. 1980, Doerr and Guthery 1983). Catkins and buds may represent a valuable food source during the mid-spring period given that availability of other food sources is usually limited (Peterson and Boyd 1998). Additionally, unpublished data from our laboratory indicates that catkins and buds are high in crude protein (catkins = 22.3%, buds = 19.1). Summer diets consist of roughly equal amounts of vegetative material and insects. Important plant materials include mainly warm season forbs (shinnery oak acorns and leaf galls also may be consumed), while insect consumption is largely grasshoppers (Davis et al. 1980, Doerr and Guthery 1983). In fall, insect and forb consumption continues, but oak acorns, seeds from herbaceous plants, and leaf galls may become important dietary items (Crawford and Bolen 1976b, Doerr and Guthery 1983, Riley et al. 1993). Oak acorns and seeds from herbaceous plants dominate winter diets; vegetative material may comprise 25-30% of the winter diet (Doerr and Guthery 1983, Riley et al. 1993).

In our study, catkin and bud production was eliminated in the spring following burning (Table 4). Catkin and bud density was similar between control plots and the 3 burning seasons for the second spring following fire, but, burned plots as a group had a lower catkin density than control plots ($P = 0.0618$). Increased forb abundance, particularly cool-season forbs, associated with fire treatment should improve spring foraging habitat. Fall burns produced the highest canopy cover of cool season forbs in both years of data collection (Table 2). Growing season foraging habitat also should benefit from increased forb and grasshopper abundance associated with fire. The decrease in other insect groups with fire (as discussed above) may be offset by increases in grasshopper abundance, because grasshoppers make up the bulk of the insect matter consumed by lesser prairie chickens (Davis et al. 1980, Doerr and Guthery 1983).

Production of mast by shinnery oak was eliminated in the first growing season following fire (Table 5) but did not differ between treatments in the second growing season following fire. Abundance of leaf galls was unaffected by fire treatment (Table 5), which may be related more to the high variability of gall abundance between burned plots and less to the influence of fire on gall production. Our visual observations indicate that plots in their first growing season after fire typically have heavy gall infestations compared with control plots or plots burned in years previous. Initially high gall infestations following burning may be related to fire-induced plant stress; Dobson (1987) reported that insect gall abundance was correlated positively with plant physiological stress. Although abundance of forage and seed-producing grasses was not affected by fire, increased forb production in burned plots should promote seed availability in fall and winter (Table 2). Seeds of sedges also may be consumed during that time period. Sedges increased in abundance with fire in any season ($P \leq 0.1000$) and were most abundant in spring-burned plots (Table 2).

Forb and grass frequency data for winter and spring burns were not available in 1997 because these plots had not yet been burned (Table 6). Although forbs and grasses were not recorded in fall burn plots in 1997, the means for control plots were not significantly different from zero, so no treatment differences were found. In 1998, the second winter sampling season following fire, frequency of forbs was higher in burned plots relative to controls ($P = 0.0009$), but there were no differences between burning treatments Grass frequency also was higher for burned plots relative to controls (P $=0.0902$).

Thermal and Escape Cover

Thermal and escape cover refer to areas with horizontally and vertically dense vegetation that offer concealment (mainly for broods) and protection from temperature extremes. Donaldson (1969) noted that broods used shinnery oak, little bluestem, and sand bluestem as thermal cover in summer and that height of vegetation used by broods was correlated positively with ambient temperature. Copelin (1963) reported that broods in

Oklahoma used taller oak mottes to escape mid-day summer temperature extremes. Taylor and Guthery (1980b) found that lesser prairie chickens selected areas of dense grass or evergreen shrubs for winter cover. Loss of shrub cover associated prescribed fire, particularly spring burns, may decrease availability of summer thermal cover. Additionally, areas burned in winter or fall lack winter cover in the year of burning. Our data indicate that differences in visual obstruction values among burning treatments in winter (January) are detectable ($P = 0.0001$) a year or more after burning (Figure 1).

Conclusions and Management Implications

We believe that prescribed fire may be a useful management tool for lesser prairie chicken habitat in the shinnery oak region. Fire can be used to increase forb and grasshopper production associated with quality foraging and brooding sites, and can increase abundance of vegetative food production during winter. Season of burn can influence effects of fire on habitat quality. Fall burns produce the highest post-burn abundance of cool-season forbs. Spring and fall burns may negatively influence nesting habitat by decreasing abundance of preferred nesting grasses and decreasing both horizontal and overhead cover. Our data indicate that negative affects of burning on nesting habitat subside with increasing time since fire. We predict that nesting habitat structure and composition will be similar between burned and unburned communities by 3 years following fire. Spring burning can dramatically decrease canopy cover of shrubs, which decreases availability of thermal and escape cover. Negative effects of fire on thermal and escape cover may be offset by burning in seasons other than spring, decreasing burn size, or plowing fire breaks around oak mottes prior to burning.

It is important to note that our study was designed to characterize short-term impacts of fire on habitat elements, in communities that have not experienced fire on a regular basis for at least the past decade. Further research is needed to quantify the long term effects of fire frequency and season of burn on habitat dynamics. Additional research also is needed to determine the spatial extent and interspersion of habitat elements necessary to optimize lesser prairie chicken habitat at different spatial scales.

Literature Cited

Boyd, C.S. 1999a. The effects of prescribed fire on shinnery oak (*Quercus havardii*) plant communities in western Oklahoma. *In:* The effects of burning season and frequency on the vegetative character and insect abundance of sand shinnery oak range in western Oklahoma. Ph.D. Dissertation, Oklahoma State Univ., Stillwater.

Boyd, C.S. 1999b. The effects of prescribed fire on shrub dynamics in shinnery oak (*Quercus havardii*) plant communities in western Oklahoma. *In:* The effects of burning season and frequency on the vegetative character and insect abundance of sand shinnery oak range in western Oklahoma. Ph.D. Dissertation, Oklahoma State Univ., Stillwater.

Boyd, C.S. 1999c.The effects of fire intensity on shinnery oak (*Quercus havardii*) plant communities in western Oklahoma. *In:* The effects of burning season and frequency on the vegetative character and insect abundance of sand shinnery oak range in western Oklahoma. Ph.D. Dissertation, Oklahoma State Univ., Stillwater.

Chamrad, A.D. and J.D. Dodd. 1973. Prescribed burning and grazing for prairie chicken habitat manipulation in the Texas Coastal Prairie. Proc. Tall Timbers Fire Ecol. Conf. 12:257-276.

Copelin, F.F. 1963. The lesser prairie chicken in Oklahoma. Oklahoma Wildl. Cons. Dept. Tech. Bull. 6. 58pp.

Crawford, J.A. 1980. Status, problems, and research needs of the lesser prairie chicken. *In*: Proceedings of the prairie grouse symposium. Oklahoma State Univ., Stillwater.

Crawford, J.A. and E.G. Bolen. 1976a. Effects of land use on lesser prairie chickens in Texas. J. Wildl. Manage. 40:96-104.

Crawford, J.A. and E.G. Bolen. 1976b. Fall diet of lesser prairie chickens in west Texas. Condor. 78:142-144.

Davis, C.A., T.Z. Riley, R.A. Smith, and M.D. Wisdom. 1980. Spring-summer foods of the lesser prairie chicken in New Mexico. *In*: Proceedings of the prairie grouse symposium. Oklahoma State Univ., Stillwater.

Dobson, G. 1987. *Xanthoteras* sp. (Hymenoptera: Cunipidae) gall abundance on shinnery oak (*Quercus havardii*) in New Mexico: an indicator of plant stress? Southwest. Nat. 32:463-468.

Doerr, T.B. and F.S. Guthery. 1980. Effects of shinnery oak control on lesser prairie chicken habitat. *In:* Proceedings of the prairie grouse symposium. Oklahoma State Univ., Stillwater.

Doerr, T.B. and F.S. Guthery. 1983. Food selection by lesser prairie chickens in northwest Texas. Southwest. Nat. 28:381-383.

Donaldson, D.D. 1969. Effect on lesser prairie chickens of brush control in western Oklahoma. Ph.D. Dissertation, Oklahoma State Univ. Stillwater.

Great Plains Flora Association. 1986. Flora of the Great Plains. T.M. Barkley (ed.), Univ. Kansas Press, Lawrence.

Haukos, D.A. and L.M. Smith. Lesser prairie chicken nest site selection and vegetation characteristics in Tebuthiuron –treated and untreated sand shinnery oak in Texas. Great Basin. Nat. 49:624-626

Jackson, A.S. and R. DeArment. 1963. The lesser prairie chicken in the Texas Panhandle. J. Wildl. Manage. 27:733-737.

Jones, R.E. 1963. Identification and analysis of lesser and greater prairie chicken habitat. J. Wildl. Manage. 27:757-777.

Lee, L. 1950. Kill analysis for the lesser prairie chicken in New Mexico, 1949. J. Wildl. Manage. 14:475-477.

Marcy, R.B. 1854. Explorations of the Red River of Louisiana in the year 1852. 33rd Congress, 1st Session, House Executive Document. Washington: A.O.P. Nicholson. 286pp.

Merchant, S.S. 1982. Habitat use, reproductive success, and survival of female lesser prairie chickens in two years of contrasting weather. MS Thesis, Oklahoma State Univ., Stillwater.

Nudds, T.D. 1977. Quantifying the vegetative structure of wildlife cover. Wild. Soc. Bull. 5:113-117.

Osborne, B. 1942. Prairie dogs in shinnery (oak scrub) savannah. Ecology 23:110-115.

Peterson, R.S. and C.S. Boyd. 1998. Ecology and management of sand shinnery oak communities: A literature review. U.S.D.A. Forest service Gen. Tech. Rept-16.

Riley, T.Z., C.A. Davis, M. Oritiz and M.J. Wisdom. 1992. Vegetative characteristics of successful and unsuccessful nests of lesser prairie chickens. J. Wildl. Manage. 56:383:387.

Riley, T.Z., C.A. Davis and R.A. Smith. 1993. Autumn-winter foods of the lesser prairie-chicken (*Tympanuchus pallidicinctus*) (Galliformes: Tetraonidae). Great Basin Nat. 53:186-189.

SAS Institute Inc. 1988. SAS procedures guide, release 6.03. Cary, North Carolina.

Southwood, T.R.E. 1978. Absolute population estimates by sampling in a unit of habitat-Air, plants, plant products and vertebrate hosts. *In*: Ecological Methods. Chapman and Hall, London.

Stewart, A.J.A. and A.F. Wright. 1995. A new inexpensive suction apparatus for sampling arthropods in grassland. Ecological Entomol. 20:98-102.

Stroup, W.W. and J. Stubbendieck. 1983. Multivariate Statistical Methods to determine changes in botanical composition. J. Range Manage. 36:208-212.

Taylor, M.A. and F.S. Guthery. 1980a. Status, ecology and management of the lesser prairie chicken. U.S.D.A. Forest Service Gen. Tech. Rept-77.

Taylor, M.A. and F.S. Guthery. 1980b. Fall-winter movements, ranges and habitat use of lesser prairie chickens. J. Wildl. Manage. 44:521-524.

United States Department of Agriculture. 1982. Soil survey: Roger Mills County Oklahoma. U.S. Gov. Printing Office, Washington, D.C.

Warren, S.D., C.J. Scifres and P.D. Teel. 1987. Response of grassland arthropods to burning: a review. Agric., Ecosys. and Environ. 19:105-130.

West, N.E. and G.A. Reese. 1996. Comparison of some methods for collecting and analyzing data on aboveground net production and diversity of herbaceous vegetation in a northern Utah subalpine context. Vegetatio 96:145-163.

Wright, H.A. and A.W. Bailey. 1982. Fire ecology: United States and southern Canada. John Wiley and Sons, New York. 501pp.

Table 1. Plant genera used in analyisis of prescribed fire effects on lesser prairie chicken habitat in western Oklahoma. This list was compiled from Crawford and Bolen 1976b, Davis et al. 1980, Doerr and Guthery 1983, and Riley et al. 1993).

		Category of use		
Category	Genus	Forage	Seeds	Nesting
Warm-season forb				
	Cassia	X	X	
	Commeliana	X		
	Croton	X		
	Eriogonum	X		
	Euphorbia	X	X	
	Evovulus	X		
	Helianthus		X	
	Heterotheca	X		
	Hymenoxys	X		
	Krameria	X		
	Oenothera	X		
	Penstemon	X		
Cool-season forb				
	Dithyrea	X	X	
	Linum	X	X	
	Lithospermum	X	X	
Warm-season grasses				
	Paspalum		X	
	Sporobolus		X	
	Leptoloma	X		
	Schizachyrium			X
	Andropogon			X
	Panicum (virgatum)			X
	Sorghastrum			X
Sedges				
	Cyperus			X
Shrubs				
	Quercus	X	X	
	Artemisia	X		

Table 2. Growing season canopy cover for vegetation classes by year and fire treatment for experimental plots in western Oklahoma. Plant species used in vegetation classes are listed in Table 1. Preferred forbs grasses and sedges include both forage and seed producing species.

			Group															
			Shrubs		Preferred shrubs		Preferred warm season forbs		Preferred cool season forbs		Preferred grasses		Preferred nesting grasses		Preferred sedges		%Bare ground	
Year	Treatment category	n	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
											% Canopy cover							
1997	Season of burn																	
	Control	21	74.5	*1.9* A	58.2	*2.7* A	0.7	*0.1* A	0.093	*0.033* AC	1.2	*0.2*	63.6	*3.8* A	0.114	*0.035* A	7.0	*0.9* A
	Fall	3	56.5	*10.2* B	46.2	*10.2* B	0.7	*0.3* A	0.556	*0.194* B	1.4	*0.7*	51.6	*9.4* B	0.426	*0.346* B	55.9	*9.1* B
	Winter	6	60.6	*4.6* B	43.7	*6.3* B	1.9	*0.8* B	0.241	*0.104* C	1.5	*0.3*	57.2	*9.2* AB	0.269	*0.135* AB	50.0	*5.1* C
	Spring	6	30.6	*4.1* C	22.4	*2.8* C	2.0	*0.8* B	0.176	*0.093* AC	1.9	*0.8*	54.2	*12.3* B	0.792	*0.330* C	44.5	*0.7* D
1998	Season of burn**																	
	Control	6	74.0	*5.9* A	54.9	*5.6* A	0.2	*0.1* A	0.004	*0.004* A	0.2	*0.1*	63.8	*6.7* A	0.004	*0.004* A	5.3	*1.4* A
	Fall	3	60.5	*9.2* B	46.1	*28.8* B	3.7	*1.8* B	0.241	*0.113* B	0.9	*0.5*	39.3	*14.3* B	0.185	*0.113* B	72.2	*2.9* B
	Winter	6	58.1	*1.5* B	46.4	*5.0* B	0.4	*0.1* A	0.014	*0.009* A	0.5	*0.4*	56.5	*5.9* A	0.185	*0.099* B	48.7	*4.8* C
	Spring	6	32.1	*2.4* C	25.8	*3.8* C	1.6	*0.5* C	0.140	*0.140* A	0.4	*0.1*	41.0	*5.1* B	0.319	*0.139* C	53.1	*4.8* C
	Time since fire																	
	One year	15	48.2	*4.0* A	38.1	*4.1* A	1.5	*0.5*	0.059	*0.032*	0.5	*0.2*	46.9	*4.4* A	0.239	*0.069* A	55.2	*3.5* A
	Two years	10	66.3	*4.1*	54.3	*4.0*	0.6	*0.1*	0.092	*0.041*	0.7	*0.1*	67.2	*6.3*	0.033	*0.022* B	34.4	*2.8*
	Annual																	
	Single event fire	15	48.2	*4.0*	38.1	*4.1*	1.5	*0.5*	0.059	*0.032*	0.5	*0.2*	46.9	*4.4* A	0.239	*0.069*	55.2	*3.5*
	Annual fire	5	46.1	*8.8*	37.4	*9.5*	0.9	*0.3*	0.072	*0.041*	0.4	*0.1*	68.9	*9.5*	0.067	*0.041*	55.9	*5.2*

* Means within a year and treatment category with no letters or without different letters are not significantly different (LSD) at alpha = 0.1000.

** Plots burned in 1998.

Table 3. Relative composition of dominant insect orders, and insect sampling density by season of burn and year for suction samples taken on experimental plots in western Oklahoma.

	Treatment		% Relative composition						Insect density per plot	
Year	category	n	Araneae	Coleoptera	Hemiptera	Homoptera	Hymenoptera	Other	$\bar{X}$*	SE
1996			13.5	6.6	4.6	3.3	51.6	20.4	25.3	*5.9*
1997	Season of burn									
	Control	3	6.7	1.7	0.0	11.7	65.0	15.0	10.0	*3.8*
	Fall	3	9.1	3.0	6.1	15.2	24.2	42.4	5.5	*2.3*
	Winter	3	10.3	4.4	0.0	10.3	51.5	23.5	11.3	*1.9*
	Spring	3	6.5	4.8	3.2	27.4	32.3	25.8	10.3	*3.8*
	Burn vs. no burn									
	Control	3	6.7	1.7	0.0	11.7	65.0	15.0	10.0	*3.4*
	Burned	9	8.6	4.3	2.5	17.8	38.7	28.2	9.1	*1.6*
1998	Season of burn**									
	Control	3	18.2	0.0	0.0	18.2	18.2	45.5	1.8	*0.5*
	Fall	3	0.0	0.0	16.7	50.0	0.0	33.3	5.0	*2.0*
	Winter	3	5.9	8.8	26.5	23.5	8.8	26.5	5.7	*1.3*
	Spring	3	8.0	0.0	12.0	32.0	20.0	28.0	4.2	*1.0*
	Burn vs. no burn									
	Control	3	18.2	0.0	0.0	18.2	18.2	45.5	1.7	*0.5* A
	Burned	9	4.5	3.4	19.1	34.8	9.0	29.2	4.9	*0.8*

* Means within a year and treatment category with no letters or without different letters are not significantly different (LSD) at alpha = 0.1000.

** Second growing season following fire.

Table 4. April shinnery oak bud and catkin density by season of burn and year for experimental plots in western Oklahoma. No Data is presented for spring burns in 1997 because these plots were not yet burned at the time of sampling.

Year	Treatment category	n	Buds/m^2 $\bar{X}$	Buds/m^2 SE	Catkins/m^2 $\bar{X}$	Catkins/m^2 SE
1997	Season of burn					
	Control	6	403.2	*57.0* A*	962.5	*190.6* A
	Fall	3	0.0	*0.0* B	0.0	*0.0* B
	Winter	3	0.0	*0.0* B	0.0	*0.0* B
	Spring	0	....	....	....	....
1998	Season of burn**					
	Control	3	250.7	*82.3*	517.4	*196.0*
	Fall	3	281.3	*62.1*	249.4	*94.3*
	Winter	3	208.8	*70.8*	290.2	*155.7*
	Spring	3	186.9	*20.4*	13.6	*13.6*
	Burn vs. no burn					
	Control	3	250.7	*82.3*	517.4	*196.0* A
	Burned	9	225.6	*31.3*	184.4	*68.1*

* Means within a year and treatment category with no letters or different letters are not significantly different (LSD) at alpha = 0.1000.

** Second growing season following fire.

Table 5. August shinnery oak mast and leaf gall density by season of burn and year for experimental plots in western Oklahoma.

Year	Treatment category	n	Mast/m² X̄	Mast/m² SE		Leaf galls/m² X̄	Leaf galls/m² SE
1997	Season of burn						
	Control	3	0.6	*0.2*	A*	2.9	*1.5*
	Fall	3	0.0	*0.0*	B	29.4	*26.9*
	Winter	3	0.0	*0.0*	B	13.2	*5.3*
	Spring	3	0.0	*0.0*	B	14.7	*5.7*
	Burn vs. no burn						
	Control	3	0.6	*0.2*	A	2.9	*1.5*
	Burned	9	0.0	*0.0*	B	19.1	*8.5*
1998	Season of burn**						
	Control	3	8.0	*7.3*		1.0	*0.6*
	Fall	3	11.5	*5.9*		3.8	*1.9*
	Winter	3	5.8	*4.3*		1.9	*1.4*
	Spring	3	0.1	*0.1*		2.0	*1.5*
	Burn vs. no burn						
	Control	3	8.0	*7.3*		1.0	*0.6*
	Burned	9	5.8	*2.7*		2.6	*0.9*

* Means within a year and treatment category with no letters or different letters are not significantly different (LSD) at alpha = 0.1000.

** Second growing season following fire.

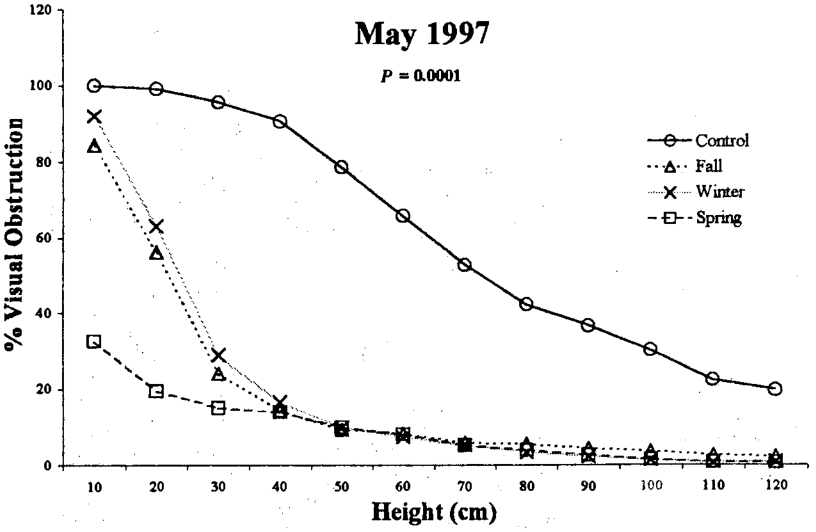
Table 6. January forb and grass frequency ($0.1 m^2$ quadrat) by season of burn and year, for experimental plots in western Oklahoma. No data is presented for winter and spring burns in 1997 because these plots were not yet burned at the time of sampling.

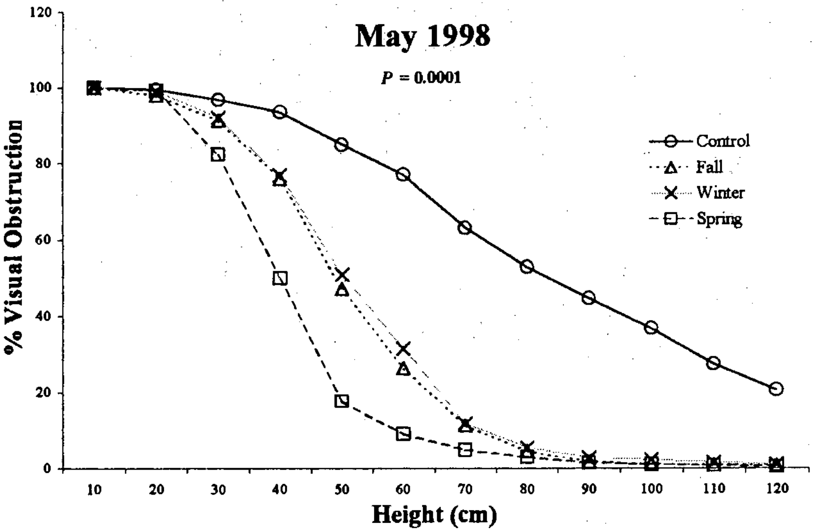
			% Frecuency of occurrence					
	Treatment		Forbs			Grasses		
Year	category	n	$\bar{X}$	SE		$\bar{X}$	SE	
1997	Season of burn							
	Control	9	3.6	*1.4*		0.4	*0.4*	
	Fall	3	0.0	*0.0*		0.0	*0.0*	
	Winter	0	....	....		....	....	
	Spring	0	....	....		....	....	
1998	Season of burn*							
	Control	3	16.0	*2.3*	A**	0.0	*0.0*	
	Fall	3	46.7	*5.8*	B	8.0	*4.0*	
	Winter	3	48.0	*10.1*	B	2.7	*1.3*	
	Spring	3	52.0	*6.1*	B	4.0	*4.0*	
	Burn vs. no burn							
	Control	3	16.0	*2.3*	A	0.0	*0.0*	A
	Burned	9	48.9	*3.9*		4.8	*1.5*	

* Second sampling season following fire.

** Means within a year and treatment category with no letters or different letters are not significantly different (LSD) at alpha = 0.1000.

Figure 1. Visual obstruction values for experimental plots in western OK. Values for 1997 represent scores for the year of burning, while 1998 scores are the second sampling season following burning. *P* values are associated with the strata by treatment interaction term in the model: *Strata* $_{i\text{-}j}$ = *Season of Burn.*


May 1997
P = 0.0001
% Visual Obstruction
120
100
80
60
40
20
0
Height (cm)
10
20
30
40
50
60
70
80
90
100
110
120
Control
Fall
Winter
Spring


May 1998
P = 0.0001
% Visual Obstruction
120
100
80
60
40
20
0
Height (cm)
10
20
30
40
50
60
70
80
90
100
110
120
Control
Fall
Winter
Spring

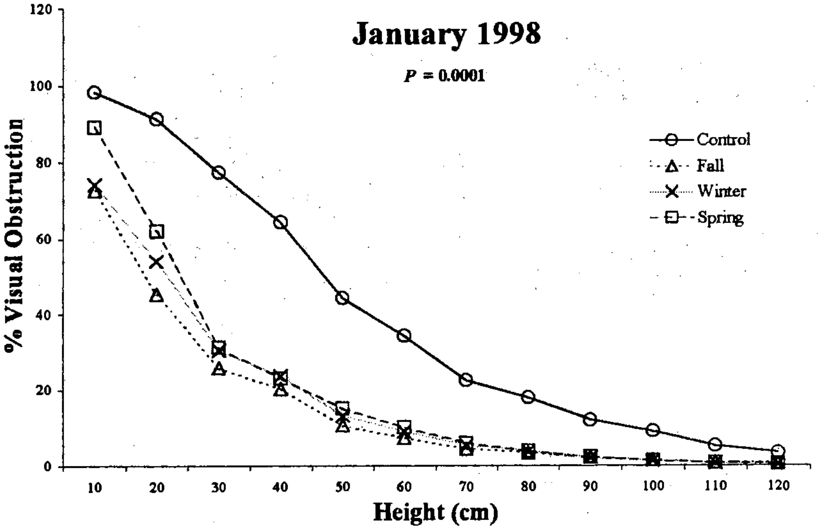
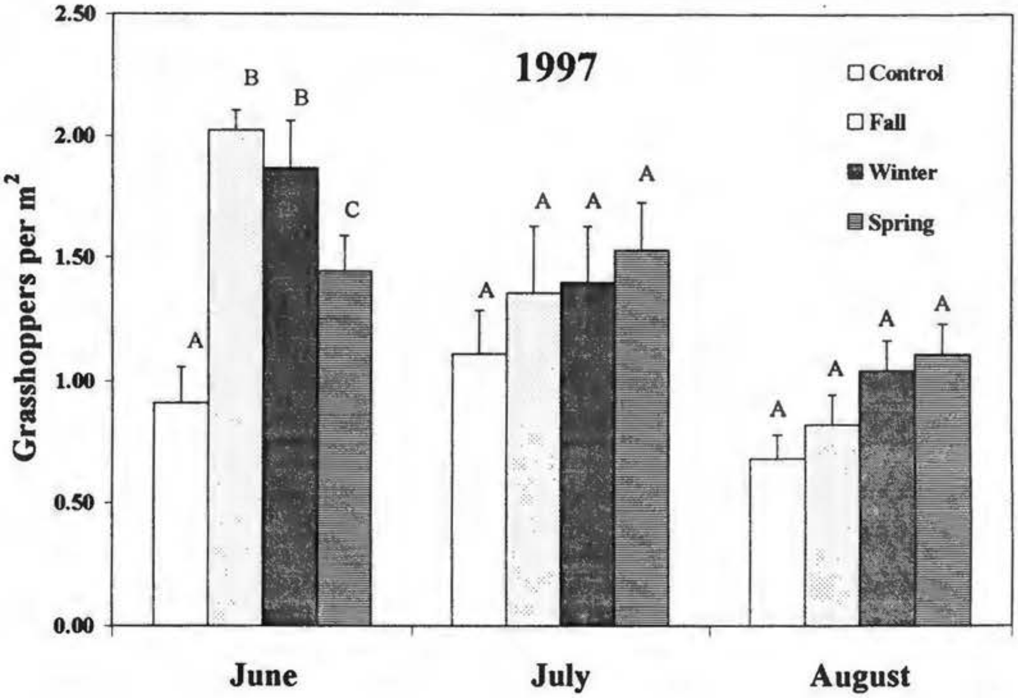
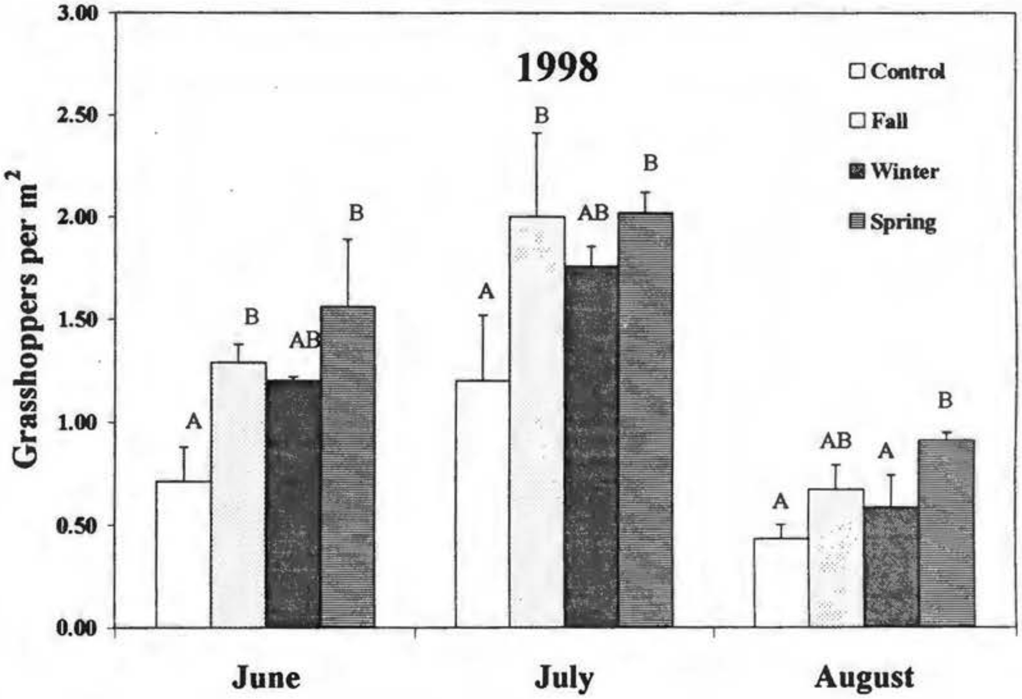

January 1998
P = 0.0001
% Visual Obstruction
120
100
80
60
40
20
0
Height (cm)
10
20
30
40
50
60
70
80
90
100
110
120
Control
Fall
Winter
Spring

Figure 2. Grasshoppers (grasshoppers/m^2) by year and month of sampling for experimental plots in western OK. Values for 1997 represent scores the year of treatment, and 1998 values are the second sampling season following treatment. Bars within a year and sampling month without a common letter are significantly different (LSD) at alpha = 0.1000.


1997
□ Control
□ Fall
▨ Winter
▤ Spring
Grasshoppers per m^2
2.50
2.00
1.50
1.00
0.50
0.00
A
B
B
C
A
A
A
A
A
A
A
A
June
July
August


1998
□ Control
□ Fall
▨ Winter
▤ Spring
Grasshoppers per m^2
3.00
2.50
2.00
1.50
1.00
0.50
0.00
A
B
AB
B
A
B
AB
B
A
AB
A
B
June
July
August

VITA

Chad Stephen Boyd

Candidate for Degree of

Doctor of Philosophy

Thesis: THE EFFECTS OF BURNING SEASON AND FREQUENCY ON THE VEGETATIVE CHARACTER AND INSECT ABUNDANCE OF SAND SHINNERY OAK RANGE IN WESTERN OKLAHOMA

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Professional Memberships: Society for range Management, Wildlife Society.