EFFECTS OF PRESCRIBED BURNING ON KING RANCH BLUESTEM AT VEGETATIVE REGROWTH AND FLOWERING STAGES

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EFFECTS OF PRESCRIBED BURNING ON KING RANCH BLUESTEM AT VEGETATIVE REGROWTH AND FLOWERING STAGES

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TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS v

LIST OF TABLES ……………………………………………………..……………..vii

LIST OF FIGURES……………………………………………………………..viii

ABSTRACT..x

CHAPTER

I. INTRODUCTION 1

II. STUDY AREA 8

III. METHODS 9

IV. RESULTS 15

V. DISCUSSION 29

VI. IMPLICATIONS 35

LITERATURE CITED 37

LIST OF TABLES

Table **Page**

1. Measures of fire behavior……………………………………………………………28

LIST OF FIGURES

Figure **Page**

1. Initial density by plot and final density 16 July 2008 and 19 September 2008 prescribed burns of King Ranch bluestem on Storm Ranch, Hays County, Texas..……………………………………………………………………16

2. Initial average basal area by plot and final average basal area 16 July 2008 and 19 September 2008 prescribed burns of King Ranch bluestem on Storm Ranch, Hays County, Texas…………………………………………………………………….17

3. Initial total basal area by plot and final total basal area 16 July 2008 and 19 September 2008 prescribed burns of King Ranch bluestem on Storm Ranch, Hays County, Texas…………………………………………………………………….18

4. Initial density vs. final density by quadrat of unburned King Ranch bluestem on Storm Ranch, Hays County, Texas in 2008…..…………………...………………19

5. Initial density vs. final density by quadrat of King Ranch bluestem prescribed burned 16 July 2008 on Storm Ranch, Hays County, Texas.…………….20

6. Initial density vs. final density by quadrat of King Ranch bluestem prescribed burned 19 September 2008 on Storm Ranch, Hays County, Texas………………….21

7. Initial average basal area vs. final average basal area by quadrat of unburned King Ranch bluestem on Storm Ranch, Hays County, Texas in 2008…..……..…...22

8. Initial average basal area vs. final average basal area by quadrat of King Ranch bluestem prescribed burned 16 July 2008 on Storm Ranch, Hays County, Texas.….23

9. Initial average basal area vs. final average basal area by quadrat of King Ranch bluestem prescribed burned 19 September on Storm Ranch, Hays County, Texas.…24

10. Initial total basal area vs. final total basal area by quadrat of unburned King Ranch bluestem on Storm Ranch, Hays County, Texas……………………….……….25

11. Initial total basal area vs. final total basal area by quadrat of King Ranch bluestem prescribed burned on 16 July 2008 on Storm Ranch, Hays County, Texas…………………………………………………………………..……..….26

12. Initial total basal area vs. final total basal area by quadrat of King Ranch bluestem prescribed burned 19 September 2008 on Storm Ranch, Hays County, Texas………………………………………………………………..………27

ABSTRACT

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by

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May 2011

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Bothriochloa ischaemum (L.) Keng var. *songarica* (King Ranch bluestem), an invasive exotic grass dominates native grasses and forbs and endemic species, lowers diversity and alters vegetative habitat structure of plant communities. My study site in the Edwards Plateau ecoregion of central Texas was a generally uniform monoculture of King

Ranch bluestem devoid of woody vegetation with slight slope and no channelized drainages, composed of Doss silty clay soils. I compared density, average basal area and total basal area in burned and unburned plots under relatively mild climatic conditions and low fuel load. I assigned four plots to each treatment according to a randomized block design to test the hypothesis that two prescribed fires, selected according to phenological cues associated with low root biomass, would significantly reduce plant vigor and cover. Fire behavior was quantified from measures of flame length and depth and rate of spread. Three mixed-effect models, which treated plot as the replicate and random variable, revealed no significant correlations between treatment type (unburned plots, a burn on 16 July, and a burn on 19 September) and three subsequent measures of King Ranch bluestem plant density and cover (density, $P = 0.79$; average basal area, $P = 0.70$; and total basal area, $P = 0.48$). Because these results showed no correlations, quadrat was then treated as the replicate in subsequent analyses, which also resulted in no correlation between treatment and final measures of density and cover ($P = 0.79$), average basal area ($P = 0.70$) and total basal area ($P = 0.48$). My study presents information for better understanding fire behavior and provides guidance for future research on controlling King Ranch bluestem. In particular, evidence indicates intense fire is likely necessary to reduce density and vigor, regardless of burn date, season or phonological cues.

CHAPTER I

INTRODUCTION

Prescribed fire is commonly used to achieve a variety of range management objectives, including reduced abundance and dominance of invasive species, reduction of woody species, increased species diversity, and increased productivity of preferred herbaceous species (Frost and Robertson 1987; Collins 1990; Vinton et al. 1993; Whelan 1995; Barbour et al. 1999; Rosiere 2000). However, much uncertainty remains about effects and varying behaviors of prescribed fire. In particular, few data address how fire behavior and timing of prescribed fire affect target species, particularly herbaceous plants.

Before European settlement, North American grasslands were created and maintained in large part by two recurring, interacting disturbances--grazing and fire. The relatively fertile soil of grasslands provided abundant grass, which supplied fuel for fires and large amounts of forage for nomadic ungulates. As fine herbaceous fuel accumulated after grazing or fire occurrences, dry lightning strikes ignited the fine fuel and set grasslands ablaze. These burns typically reduced brush and trees and prevented community succession toward shrubland or forest communities (Wright and Bailey 1982). In addition, removal of litter and vegetative cover altered plant microenvironments and stimulated vegetative regrowth while providing germination sites for establishment of new seedlings (Wright and Bailey 1982; Ewing and Engle 1988;

Hobbs et al. 1991; Ojima et al 1994; Collins et al. 1998). Also, recently burned areas attracted herds of herbivores to highly nutritious, palatable and fresh herbage, further compounding the defoliating effect of fire (Hobbs et al. 1991; Vinton et al. 1993; Archibald et al. 2004).

Although Native Americans altered the North American Plains landscape through their management practices (Mann 2005), the arrival of European immigrants further modified natural disturbance regimes via the synergistic effects of livestock introduction, fencing, agriculture and fire suppression. Landowners began fencing previously unfragmented rangeland to accommodate private ranching enterprises and containment of livestock. The enclosed animals overgrazed rangelands and adapted foraging habits, in part through more selective grazing (Hobbs et al. 1991; Fuhlendorf and Engle 2001). Overgrazing and selective grazing reduced amounts of contiguous fine fuels, which reduced frequency and intensity of fire (Frost and Robertson 1987). At the same time, tillage of fertile grasslands converted diverse grasslands into monospecific agricultural plots. Each of these changes synergistically altered species composition and productivity of grassland communities (Rosiere 2000; United States 2008).

In time ranchers and range scientists began a search for more productive forage to rectify the damage to rangelands and introduced "improved" grasses from other continents. *Bothriochloa ischaemum* (L.) Keng var. *songarica* Keng (King Ranch bluestem or "KR" bluestem) was introduced from Europe and Asia into south Texas during the 1930s as a particularly promising forage for livestock (Rosiere 2000) because of a general high tolerance of grazing (Gabbard and Fowler 2007); whereas, frequent or intense grazing limited production of many native grasses. King Ranch bluestem typically maintains a relatively high rate of vegetative regrowth even after high intensity or high frequency grazing (Rosiere 2000). King Ranch bluestem is highly productive, in some cases producing twice the shoot biomass of native grasses (Harmoney and Hickman 2004). However, researchers have discovered in recent years that production of highly nutritious and abundant King Ranch bluestem forage may be dependent upon fertilization, with the exotic grass having little to no nutritional advantage over native grasses without fertilization (Berg 1990; Berg 1993; Berg and Sims 1995). In addition to purportedly providing additional forage, its high productivity and ease of establishment (Harmoney and Hickman 2004) made King Ranch bluestem attractive for providing ground cover for restoration and erosion control projects (Rosiere 2000). King Ranch bluestem is very drought tolerant (Rosiere 2000; Simmons et al. 2008). Drought tolerance is especially important for interspecific competition in semi-arid grasslands and savannas, such as the Edwards Plateau ecoregion of central Texas, where rainfall is highly unpredictable. To those first learning of these characteristics of King Ranch bluestem, the low cost of establishment, high productivity, and adaptability seemed the perfect antidote for reduced income and erosion on overgrazed rangelands.

However, many characteristics that make King Ranch bluestem attractive as forage for livestock may also be problematic. The species is highly competitive with native grasses due to high productivity, grazing tolerance, ease of establishment, and tolerance for cool season burns (Gabbard and Fowler 2007; Simmons et al. 2008). As a result, it can quickly become the dominant herbaceous species by outcompeting desirable species such as native grasses (Rosiere 2000; Gabbard and Fowler 2007). In less productive and more biologically diverse grasslands and savannas such as the Edwards Plateau, King Ranch bluestem often dominates native grasses, forbs, and endemic species thus decreasing plant and animal species diversity and altering vegetative structure of the community (Hickman et al. 2006; Gabbard and Fowler 2007; Schmidt and Hickman 2008).

In addition to the aforementioned factors, the life cycle of King Ranch bluestem has negative consequences for control efforts. King Ranch bluestem produces a relatively high ratio of unpalatable stem tissue in the late-growing season, which cures quickly and deters grazing (Dabo et al. 1988). As grazers select more palatable and nutritious native grasses, the leaf area of selected grasses and subsequent biomass productions are reduced; thereby, promoting King Ranch bluestem dominance through high biomass production.

The dominance of King Ranch bluestem on central Texas roadsides and ranges has markedly changed the fall landscape color from bronze, the signature color of little bluestem (*Schizachyrium scoparium*), to a bright golden color indicative of mature leaves of King Ranch bluestem. Much of this has occurred from range plantings, in addition to planting along highway rights-of-way (Texas Department of Transportation 1993). Despite opinions about the aesthetic appeal of either grass, the visible change provides a dramatic display of the dominance of King Ranch bluestem.

Most North American grasslands are adapted to natural fire (Wright and Bailey 1982; Collins 1990; Whelan 1995; Mann 2005; United States 2008). Therefore, many land managers implement prescribed burns to restore desirable native vegetation and habitat structure. Fires reduce brush cover in a variety of grassland ecosystem types (Wright and Bailey 1982; Collins 1990). However, relatively little is known about how fire affects herbaceous species composition.

Less is known about effects of fire behavior or seasonal fires on herbaceous species composition. Until recent years, most fires were assumed equivalent in effects on grassland vegetation. However, researchers have begun to study and understand specific variables that may be important in determining guild and species-specific responses to fires. The response to fire by a grass species may be partly due to its unique morphology. For example rhizomatous grasses with extensive below ground vegetative structures are more tolerant of fire than those with above ground apical meristems (Ewing and Engle 1988; Benning and Bragg 1993; Engle et al. 1993).

In addition to the unique morphology of each grass species, phenology may also influence specific responses to fire. The phenology of a plant corresponds to the timing and sequence of growth and reproductive stages. I hypothesized the unique phenology associated with a particular grass may be influential in determining response to timing of disturbances, as some growth or reproductive stages are correlated with increased susceptibility to negative effects of disturbances. One of the most basic premises of phenological disturbance research posits removal of above ground tissue by grazing, mowing or burning is most detrimental when below ground resources have a low proportion of total biomass (Howe 1994; Howe 1995; Whelan 1995; Ewing et al. 2005). In other words, when root carbon biomass is least, removal of photosynthetic shoot biomass is likely to limit subsequent recovery, and thus, increase the odds of mortality (Howe 1994; Howe 1995; Whelan 1995; Ewing et al. 2005).

The seasonal and environmental conditions on the day of a fire also correlate with fire behavior. Generally, summer fires under dry conditions are expected to exhibit higher temperatures than winter fires due to higher fuel loads and warmer ambient temperatures. However, in some cases, winter fires are more intense due to curing of dormant grasses. Head fires are purported to be hotter, with faster moving fire fronts than backfires, but this does not necessarily result in a greater vegetative response to fire (White and Hanselka 1991; Whelan 1995). For instance, a slower-moving fire front of a backfire may result in higher maximum temperatures at the soil surface because of a longer residence time of the flame front (Bidwell and Engle 1992).

Yet, many aspects of fire behavior remain relatively unexplored. Fire behavior is determined by fuel load, fuel moisture, fuel compaction, ambient/fuel temperatures, relative humidity, wind speed, topography, and flammability of plant communities (Whelan 1995). Researchers have attempted to quantify characteristic measures of fire behavior. Oft-used measures include fireline intensity, heat per unit area and rate of spread. Time-temperature curves based on residence time of fire and heat may be most useful for the interplay of each of these measures and the resultant movement and intensity of heat from combustion (Bidwell and Engle 1992; Engle et al. 1993; Whelan 1995).

In addition to effects of fire and other disturbances, plant species composition is determined by a number of other factors, including topography, climate, soil texture and chemistry, and interspecific competition for light, water, nutrients and soil resources (Barbour et al. 1999). In addition, the life history of each plant, largely determined by past disturbances, is an important determinant of species composition (Barbour et al. 1999).

For my study, I conducted experimental fires during growing season on plots containing a large proportion of King Ranch bluestem. Two fires were timed to coincide with two phenological stages of King Ranch bluestem hypothesized as most susceptible to effects of fire. Increased mobilization of below ground carbon reserves occurs at these times (Coyne and Bradford 1986, 1987); therefore, I hypothesized burning above ground biomass then would reduce the vigor and density of King Ranch bluestem plants.

The most rapid vegetative growth of Old World bluestems, such as King Ranch bluestem, occurs between mid-May and mid-July (White and Dewald 1996; Harmoney and Hickman 2004), so I planned the first burn for late spring to early summer. However, due to drought conditions there was little visual evidence of vegetative growth until early July, so I burned on 16 July 2008 a few days after rain when environmental conditions would ensure a safe, relatively docile burn. The second burn was planned to coincide with the most prolific flowering of King Ranch bluestem with approximately the same wind and humidity prescription as the first burn. Although I observed flowering earlier in the growing season along roadsides and in other locations, King Ranch bluestem plants on the experimental site did not flower until September 2008, likely due to grazing in April. As a result, the second prescribed burn occurred on the morning of 19 September 2008.

CHAPTER II

STUDY AREA

The experimental site encompassed approximately 3 ha in the northwestern part of Storm Ranch (N30.11859° W98.14868°, Alt 398m [NAD83]), Hays County, Texas, a 2,302-ha working cattle ranch in the Edwards Plateau ecoregion of Texas. The Natural Resources Conservation Service (NRCS) Ecological Site Inventory describes the site as a "Shallow" ecological site containing shallow Doss silty clay soils. Shallow ecological sites are representative of formerly plowed agricultural fields with improved pastures on relatively gradual slopes and few rocks at the soil surface and moderately-high water holding capacity (United States 2008). The site had low slopes and no significant drainage features.

The study pasture and adjacent pastures had been seeded with King Ranch bluestem in the 1950s (Josh Storm and Scott Storm, wildlife manager and general manager of the property, respectively, pers. comm.). King Ranch bluestem covered approximately 90% of plots. The abundance and dominance of King Ranch bluestem, in addition to the environmental homogeneity throughout the site, resulted in a corresponding scarcity of native grasses and forbs.

CHAPTER III

METHODS

I used a randomized block design with 12 plots, including four replicates of the control treatment, four replicates of plots burned during rapid vegetative regrowth on 16 July 2008, and four replicates of plots burned during flowering on 19 September 2008. Each plot measured 10 m east to west and 20 m north to south with orientation parallel to the prevailing wind direction to maximize wind effects. Four replicates of each treatment were considered sufficient to address sampling variation, and the randomized block design ensured adequate interspersion of treatments and minimized experimenter bias, chance segregation and "demonic intrusion" (Hurlbert 1984). This experimental design was intended to reduce the effects of chance events or environmental heterogeneity.

In each plot, I selected six quadrats or subplots with surface areas of 0.25 m^2 spaced at regular intervals. For each quadrat, data were recorded for two variables, density of individual King Ranch bluestem plants and basal crown widths. I collected pre-treatment data from 5 June 2008 to 10 July 2008 before the first burn. I recorded post-treatment data at the end of the growing season between 1 October 2009 and 29 October 2009.

The first burn of four plots occurred between 1000 hr and 1200 hr on 16 July 2008. Relative humidity varied between 55% and 63% with wind speed 10 to 11 km per hr. Ambient temperature was 26.1º C during each of four burns. The second burn took place on 19 September 2008. The first plot was burned at 1000 hr and the fourth plot was burned shortly before 1200 hr. At 1000 hr, the ambient temperature was 20º C, with 65% relative humidity, and a wind speed of 8 km per hr. From 1000 hr to 1200 hr, relative humidity decreased, and wind speed and temperature increased until humidity was 50%. Ambient temperature was 24.4º C and wind speed 11.3 km per hour. Fine fuel load averaged 2,223 kg / ha based on dry weights of two randomly selected clip-plots per plot, with hay added as necessary to increase fuel load in plots with less vegetation to where fuel loads were relatively similar for all plots. The relatively moderate environmental conditions and low fuel load resulted in relatively cool burns in comparison to typical summer burns, as evidenced by fire behavior estimates.

I quantified fire behavior by calculating fireline intensity, residence time and energy release (heat per unit area) from measures of flame length, flame depth and rate of spread (Rothermel and Deeming 1980; Whelan 1995). I estimated flame length, and flame depth by placing distance markers at 1-m intervals along the length of plots. Each fire was filmed using a Canon PowerShot SD870 IS Digital ELPH 8 MP digital camera from the time it was ignited until extinguished, which provided measures of flame length, flame depth, and rate of spread. I attempted to film parallel to the direction of spread, but wind direction was variable, particularly during the 19 September burn. Rate of spread was also estimated from the video. Residence time (t_r) was calculated by dividing flame depth (D) by rate of spread (R). Finally, I estimated energy release (E) by

$E = 60\ I/t_r$ (kJ/m^2)

where:

t_r = residence time = D/R (min)

where:

D is flame depth (m), and

R = rate of spread (m/min),

I = fireline intensity = 258 $F_L{}^n$ (kW/m)

where:

F_L= flame length (m), and

n = 2.17

(Rothermel and Deeming 1980; Whelan 1995).

Plots of all treatments were over-seeded after the 19 September burn with a mixture of native grasses of local ecotypes from Native American Seed (6.8 kg of "Prairie Starter" mix, 4.99 kg of "Caliche" mix, 91 g of *Pascopyrum smithii*, 68 g of *Aristida purpurea*; Native American Seed, Junction, TX). I selected grasses known to germinate late in the warm season or in the fall (shortly after burns), with a high germination rate, and/or an ability to quickly produce abundant leaf biomass (Tinsley et al. 2006). Of these, I anticipated *Bouteloua gracilis* (blue grama), *Bouteloua curtipendula* (sideoats grama), *Sporobolus cryptandrus* (sand dropseed), *Aristida* *purpurea* (purple three-awn) and *Leptochloa dubia* (green sprangletop) were most likely to germinate quickly the following spring and produce substantial leaf biomass. The mixture of grasses also included cool season grasses *Pascopyrum smithii* (western wheatgrass) and *Elymus canadensis* (prairie wildrye), as cool season species are more likely to germinate and provide vegetative cover during fall and winter (Barbour et al. 1999).

I analyzed three surrogate measures of plant vigor (density, average basal area and total basal area) of King Ranch bluestem plants in each quadrat to determine whether a correlation existed between treatment and vigor of King Ranch bluestem. I measured basal width of individual plants at the widest point with calipers. I estimated basal area, assuming basal crowns were elliptically shaped with the length of the ellipse being one-half the measured width. I calculated basal area of individual plants as follows: π x basal width^2 x 0.5. I calculated total basal area per quadrat by summing all individual basal areas within each quadrat. I calculated average basal area per quadrat by dividing total basal area per quadrat by plant density within each quadrat. Plots, rather than quadrats, were the experimental replicates, so I summed measures for quadrats of plots to derive replicate variables.

While analyzing data, I determined four data collectors recorded biased measurements by recording significantly larger average basal areas and smaller densities than other observers. I confirmed this using a two-sample *t*-test. Thus, I removed data for nine quadrats affected by observer bias. I used 63 quadrats within 12 plots in analyses. The subsequent analysis grouped by plot indicated removal of quadrats from plots with observer bias did not degrade sample size significantly.

I used a mixed-effect model in Program R (R version 2.8.1, The R Foundation for Statistical Computing) to analyze correlations between independent variables and response variables, treating plot as the random variable, thereby accounting for inter-plot variation. The independent variables for each of three regressions were treatment (a dummy variable) and one of the following initial measures: initial density, initial average basal area or initial total basal area. The dependent variable in each regression was the final or post-treatment dependent variable, final density in the first regression, final average basal area in the second regression, and final total basal area in the third regression. The null hypothesis was, for all treatments, there would be no change between initial and final measures (represented by the diagonal lines in Figs. 1-3). The alternative hypothesis was that final measures would be significantly correlated with treatment. The three regressions analyzed were as follows:

$$\text{Final Density} = \beta_0 + \beta_{1*}\text{Initial Density} + \beta_{2*}\text{Treatment} + \beta_{3*}\text{Initial Density}_*\text{Treatment} + \varepsilon \quad \textbf{[1]}$$

$$\text{Final Average Basal Area} = \beta_0 + \beta_{1*}\text{Initial Average Basal Area} + \beta_{2*}\text{Treatment} + \beta_{3*}\text{Initial Average Basal Area}_*\text{Treatment} + \varepsilon \quad \textbf{[2]}$$

$$\text{Final Total Basal Area} = \beta_0 + \beta_{1*}\text{Initial Total Basal Area} + \beta_{2*}\text{Treatment} + \beta_{3*}\text{Initial Total Basal Area}_*\text{Treatment} + \varepsilon \quad \textbf{[3]}$$

I then analyzed the above relationships between treatment or initial measures and final measures again, this time treating subplots (quadrats) rather than plots as the replicate. I conducted analyses by quadrat so that I might gain further insight into fine-scale responses or patterns related to King Ranch bluestem plants within specified ranges of initial conditions.

Looking at scatter plots comparing initial versus final measures for quadrats, I selected ranges of initial measures where quadrat data from the three treatments' regressions appeared to fit a regression line, or where slopes of regression lines for each of the three treatments appeared to differ visually. I visually examined relationships between initial and final measures from all quadrats and differences in slopes among the three treatments for quadrats and final measures (Figs. 4-12). As in previous analyses where I grouped by plot initial measures and final measures of density, initial measures and final measures included density, average basal area and total basal area. In all, I examined three sets of scatter plots for each treatment (nine scatter plots) with each corresponding to relationships between initial density versus final density, initial average basal area versus final average basal area, and initial total basal area versus final total basal area. For example, for quadrats with initial densities above 100, three scatterplots (Figs. 4-6, each corresponding to one of the three treatments) were visually suggestive of unique relationships between initial density and final density, so I used a mixed-effect model that grouped by plot to analyze relationships between initial density and final density and treatment and final density. Also, for those quadrats with initial densities between 50 and 100 King Ranch bluestem plants, the second burn (Fig. 6) appeared to have the highest final densities, so I used a mixed-effect model to determine whether the second burn actually resulted in a greater increase in density than the other two treatments (Figs. 4-6).

CHAPTER IV

RESULTS

In the aforementioned analyses where I treated plot as the replicate and random factor, treatment did not correlate with any response variables, including final density ($\bar{X}$ = 87.6 ± 29.4 SD, P = 0.79), final average basal area ($\bar{X}$ = 0.92 ± 0.59 SD, P = 0.70) and final total basal area ($\bar{X}$ = 73.8 ± 52.2 SD, P = 0.48). Initial density ($\bar{X}$ = 97.9 ± 31.9 SD) did not correlate with final density (P = 0.25; Fig. 1). Initial average basal area ($\bar{X}$ = 1.41 ± 1.10 SD) did not correlate with final average basal area (P = 0.30; Fig. 2). Initial total basal area ($\bar{X}$ = 143.0 ± 150.3 SD) did not correlate with final total basal area (P = 0.14; Fig. 3).

The initial analyses by plot failed to identify significant relationships in densities and basal area for King Ranch bluestem, so I then repeated my analyses of the relationships between treatment and final measures, and between initial measures and final measures, but instead treated quadrat (subplot) as the replicate. Again, the null hypothesis (represented by the diagonal line in Figs. 4-12) indicated no change between initial measures and final measures. The alternative hypothesis was final measures would be significantly correlated with treatment. These analyses also did not yield remarkable relationships, with one exception. For those quadrats with initial densities above 100 plants per quadrat, there was a significant positive linear relationship between initial density and final density (Figs. 4-6, $P < 0.0001$). One might expect initial and final conditions for most variables to be significantly correlated unless there is a treatment effect. Therefore, it is interesting that this was not the case for any analyses, with the exception of those quadrats with initial densities above 100.

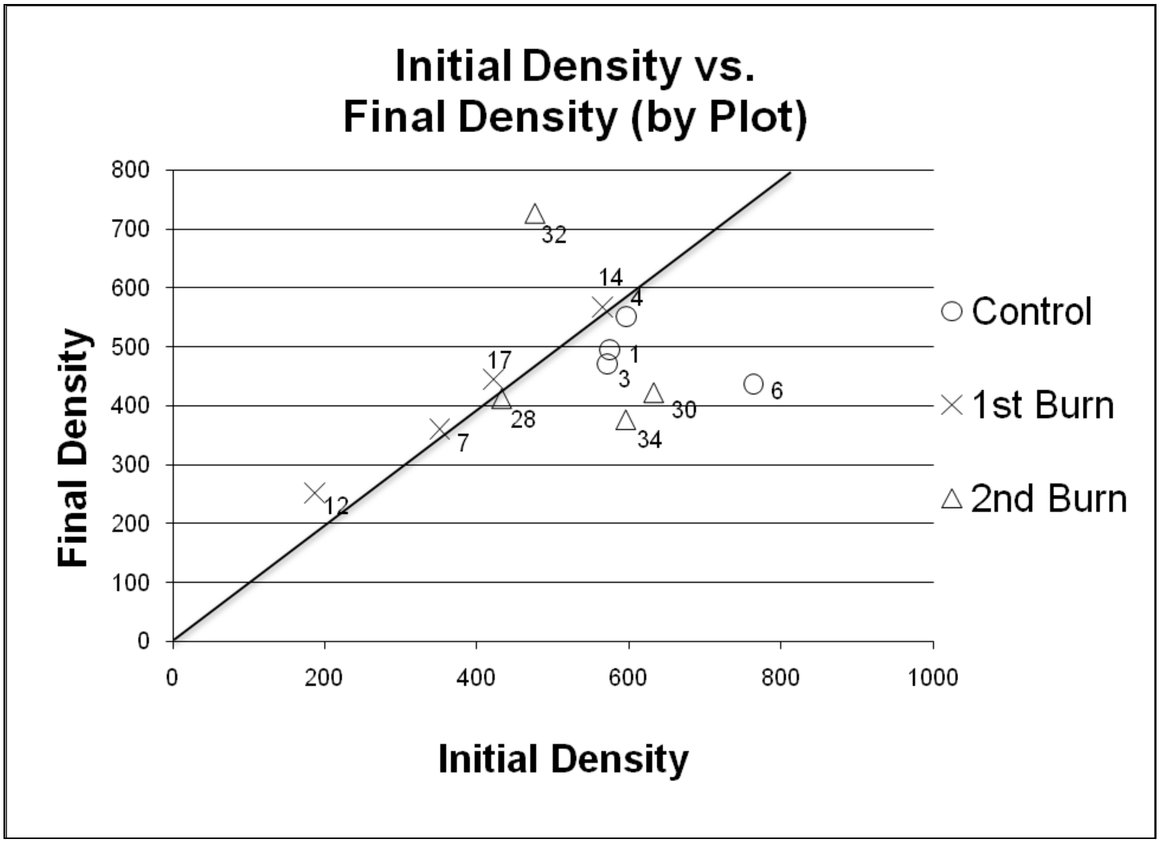

Figure 1. Initial density by plot and final density 16 July 2008 and 19 September 2008 prescribed burns (Treatment: $P = 0.79$; Initial Density: $P = 0.25$) of King Ranch bluestem on Storm Ranch, Hays County, Texas. Plot numbers are labeled adjacent to their respective data points. The diagonal line represents the null hypothesis of no difference between initial density and final density.

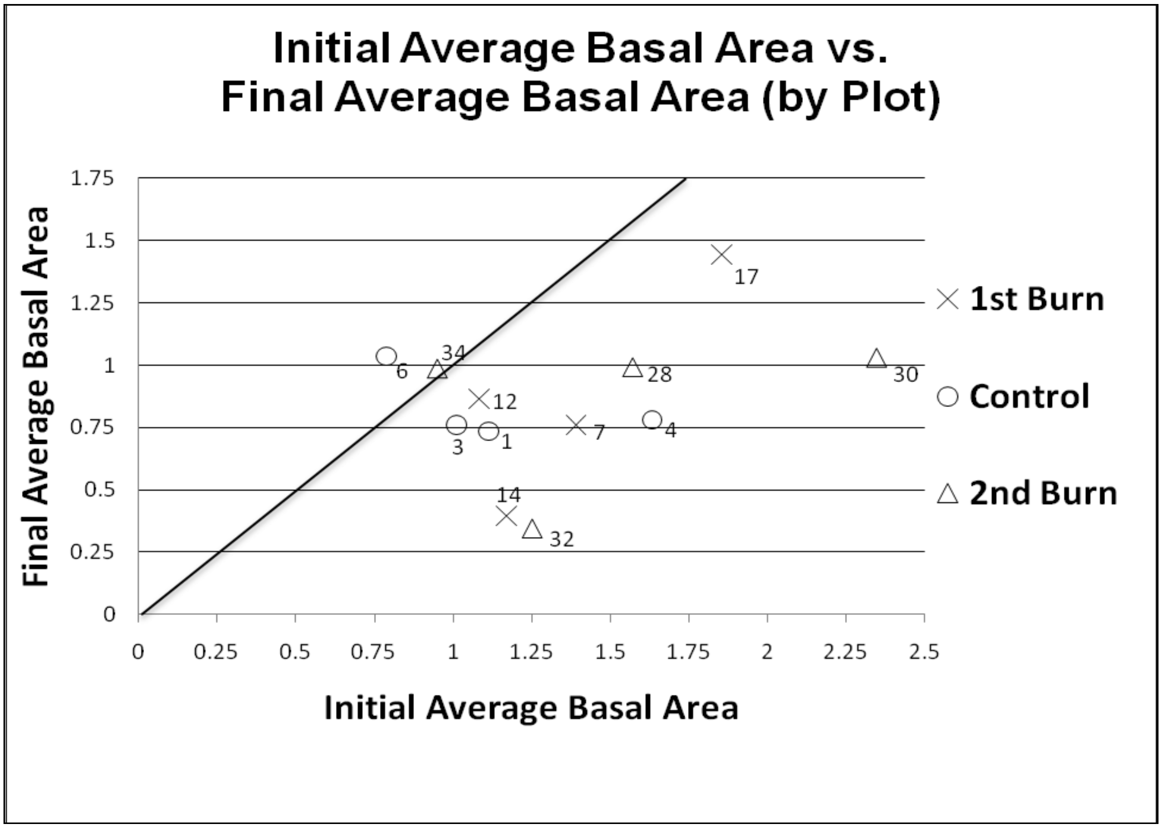

Figure 2. Initial average basal area by plot and final average basal area 16 July 2008 and 19 September 2008 prescribed burns (Treatment: P = 0.70; Initial average basal area: P = 0.30) of King Ranch bluestem on Storm Ranch, Hays County, Texas. Plot numbers are labeled adjacent to their respective data points. The diagonal line represents the null hypothesis of no difference between initial average basal area and final average basal area.

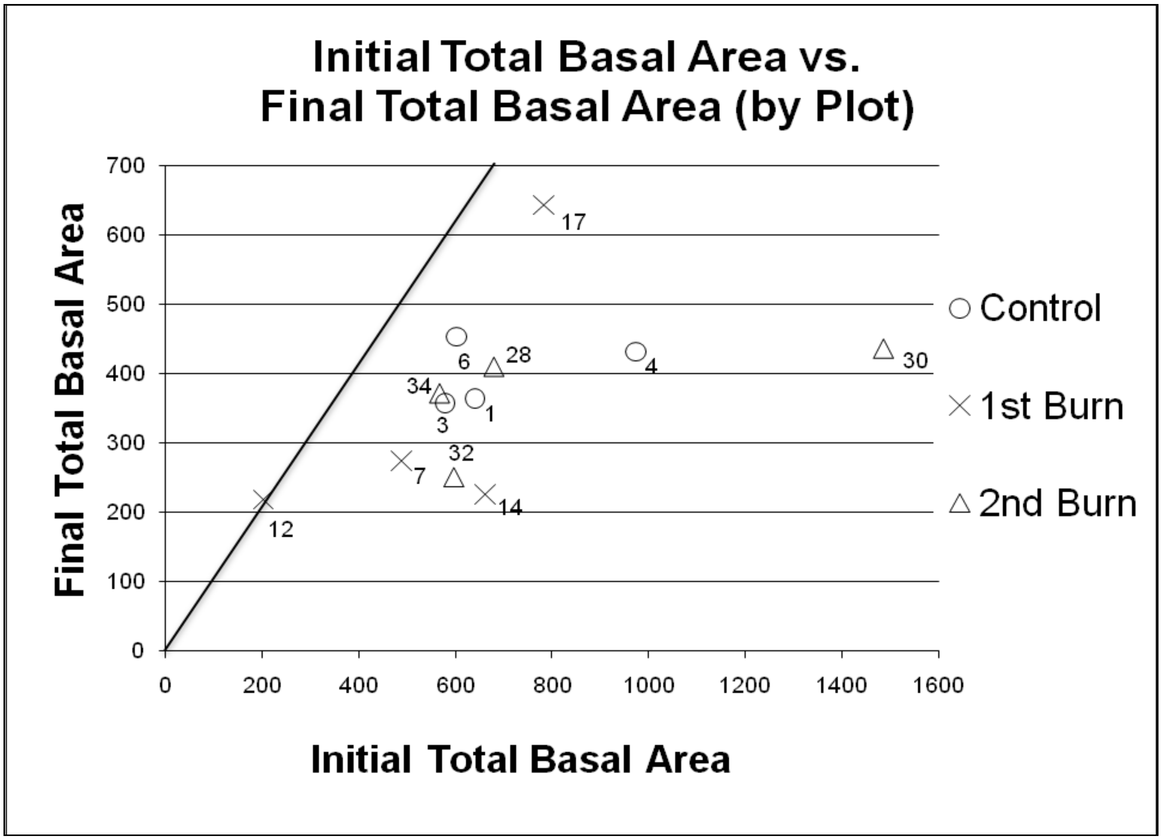

Figure 3. Initial total basal area by plot and total basal area of 16 July 2008 and 19 September 2008 prescribed burns (Treatment: $P = 0.48$; Initial total basal area: $P = 0.14$) of King Ranch bluestem on Storm Ranch, Hays County, Texas. Plot numbers are labeled adjacent to their respective data points. The diagonal line represents the null hypothesis of no difference between initial total basal area and final total basal area.

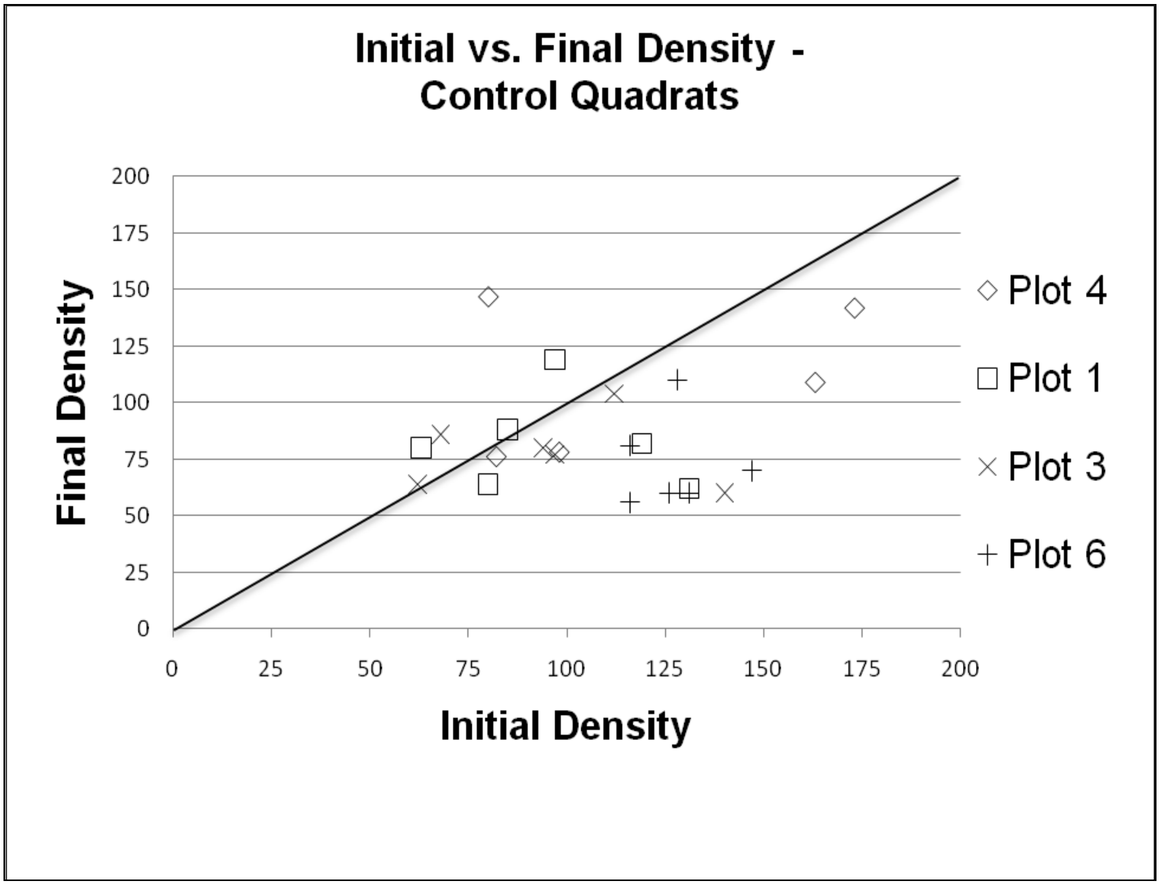

Figure 4. Initial density vs. final density by quadrat of unburned King Ranch bluestem on Storm Ranch, Hays County, Texas in 2008 (Quadrats with initial densities between 50 and 100: Treatment *P* = 0.57, Initial density *P* = 0.72; Quadrats with initial densities above 100: Treatment *P* =0.43, Initial density *P* < 0.0001). The diagonal line represents the null hypothesis of no difference between initial density and final density.

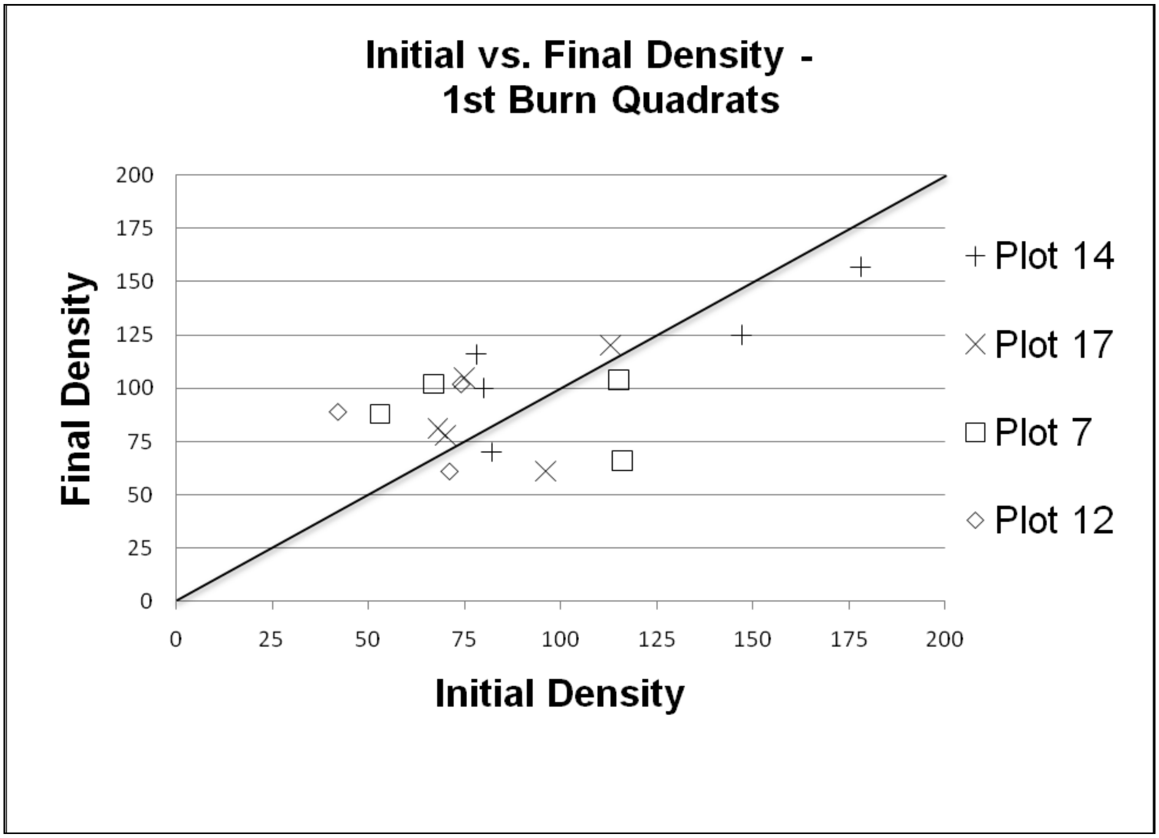

Figure 5. Initial density vs. final density by quadrat of King Ranch bluestem prescribed burned 16 July 2008 on Storm Ranch, Hays County, Texas (Quadrats with initial densities between 50 and 100: Treatment $P = 0.57$, Initial density $P = 0.72$; Quadrats with initial densities above 100: Treatment $P = 0.43$, Initial density $P < 0.0001$). The diagonal line represents the null hypothesis of no difference between initial density and final density.

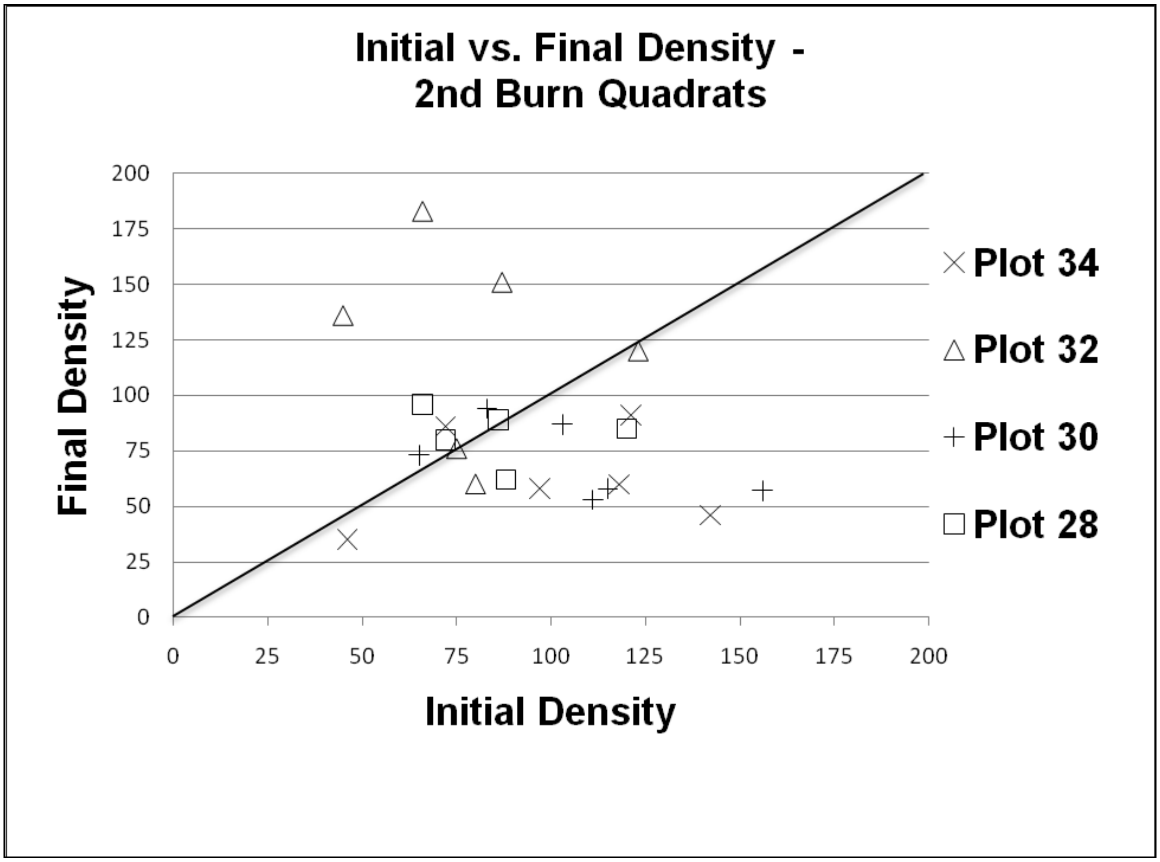

Figure 6. Initial density vs. final density by quadrat of King Ranch bluestem prescribed burned 19 September 2008 on Storm Ranch, Hays County, Texas (Quadrats with initial densities between 50 and 100: Treatment *P* = 0.57, Initial density *P* = 0.72; Quadrats with initial densities above 100: Treatment *P* =0.43, Initial density *P* < 0.0001). The diagonal line represents the null hypothesis of no difference between initial density and final density.

There were no apparent significant correlations or patterns in scatterplots showing relationships between initial average basal area, treatment and final average basal area (Fig. 7-9). As a result, we did not analyze those relationships at any range of initial values.

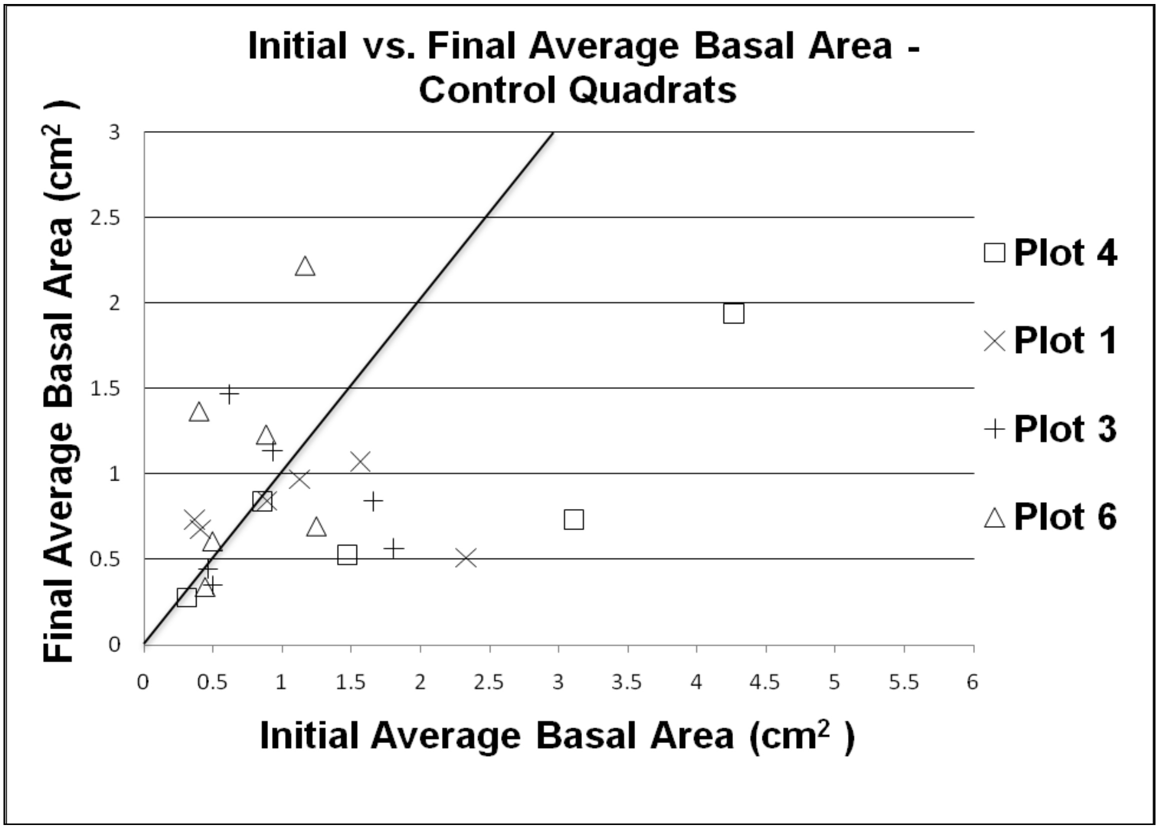

Figure 7. Initial average basal area vs. final average basal area by quadrat of unburned King Ranch bluestem on Storm Ranch, Hays County, Texas in 2008. The diagonal line represents the null hypothesis of no difference between initial average basal area and final average basal area. Scatter plots did not indicate correlations at any range of initial values, so no analyses were performed.

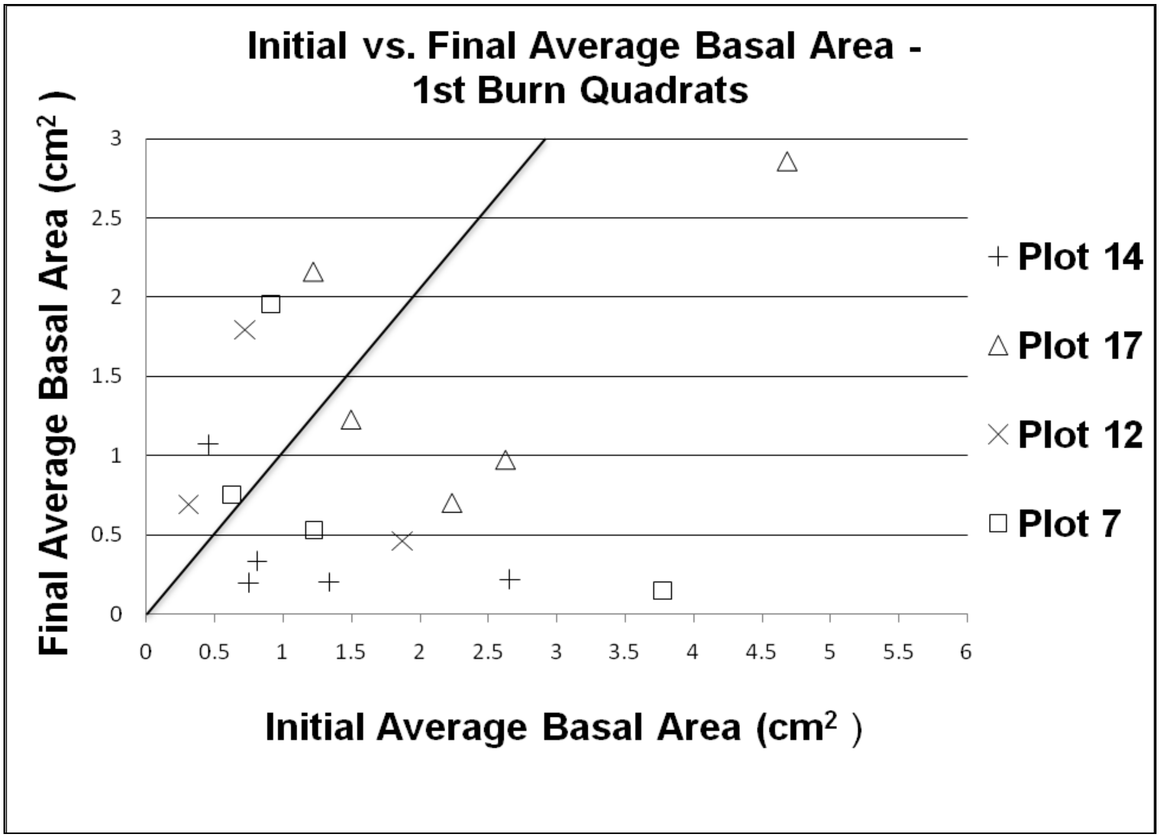

Figure 8. Initial average basal area vs. final average basal area by quadrat of King Ranch bluestem prescribed burned 16 July 2008 on Storm Ranch, Hays County, Texas. The diagonal line represents the null hypothesis of no difference between initial average basal area and final average basal area. Scatter plots did not indicate correlations at any range of initial values, so no analyses were performed.

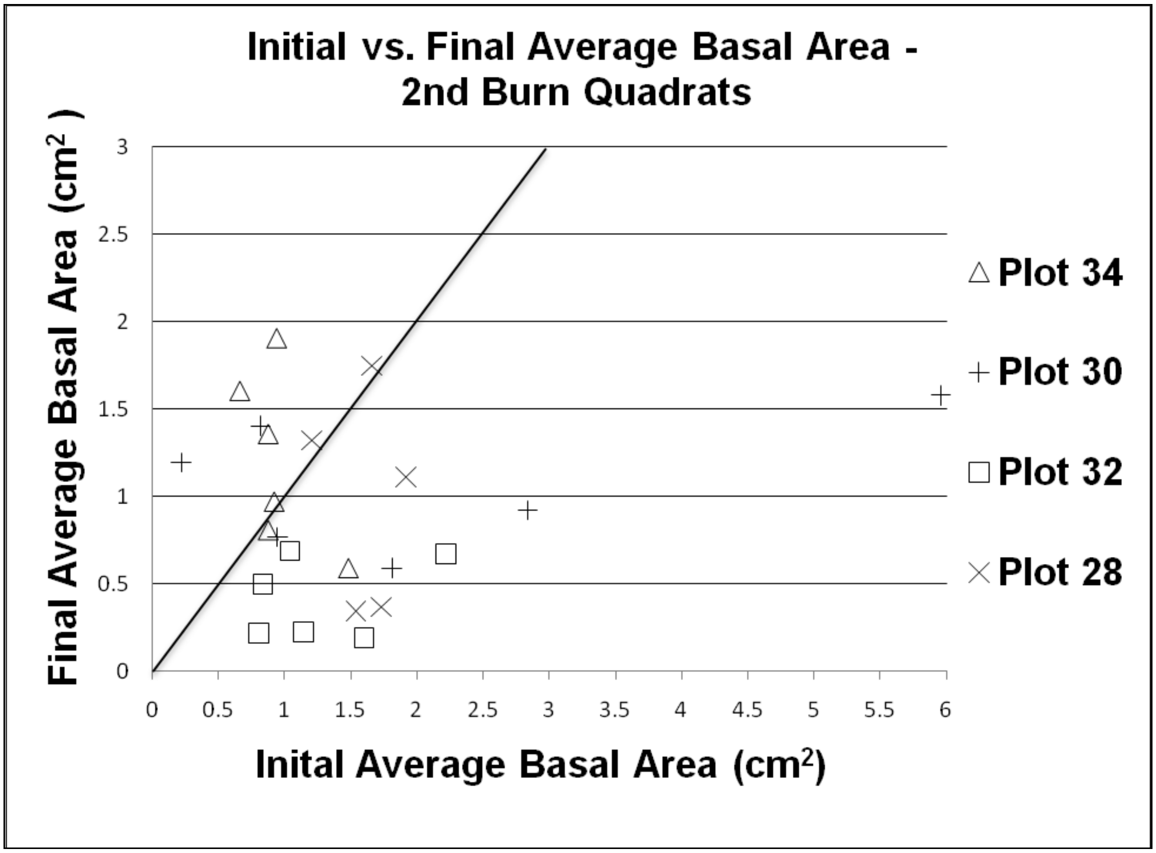

Figure 9. Initial average basal area vs. final average basal area by quadrat of King Ranch bluestem prescribed burned 19 September on Storm Ranch, Hays County, Texas. The diagonal line represents the null hypothesis of no difference between initial average basal area and final average basal area. Scatter plots did not indicate correlations at any range of initial values, so no analyses were performed.

After generating the scatter plots for initial vs. final total basal area, I noted a few outlying quadrats that resulted in skewed scatter plots. I removed those quadrats from scatter plots, which provided for easier visual examination of the three scatter plots at the same scale. The following scatter plots (Figs. 10-12) do not include those outliers.

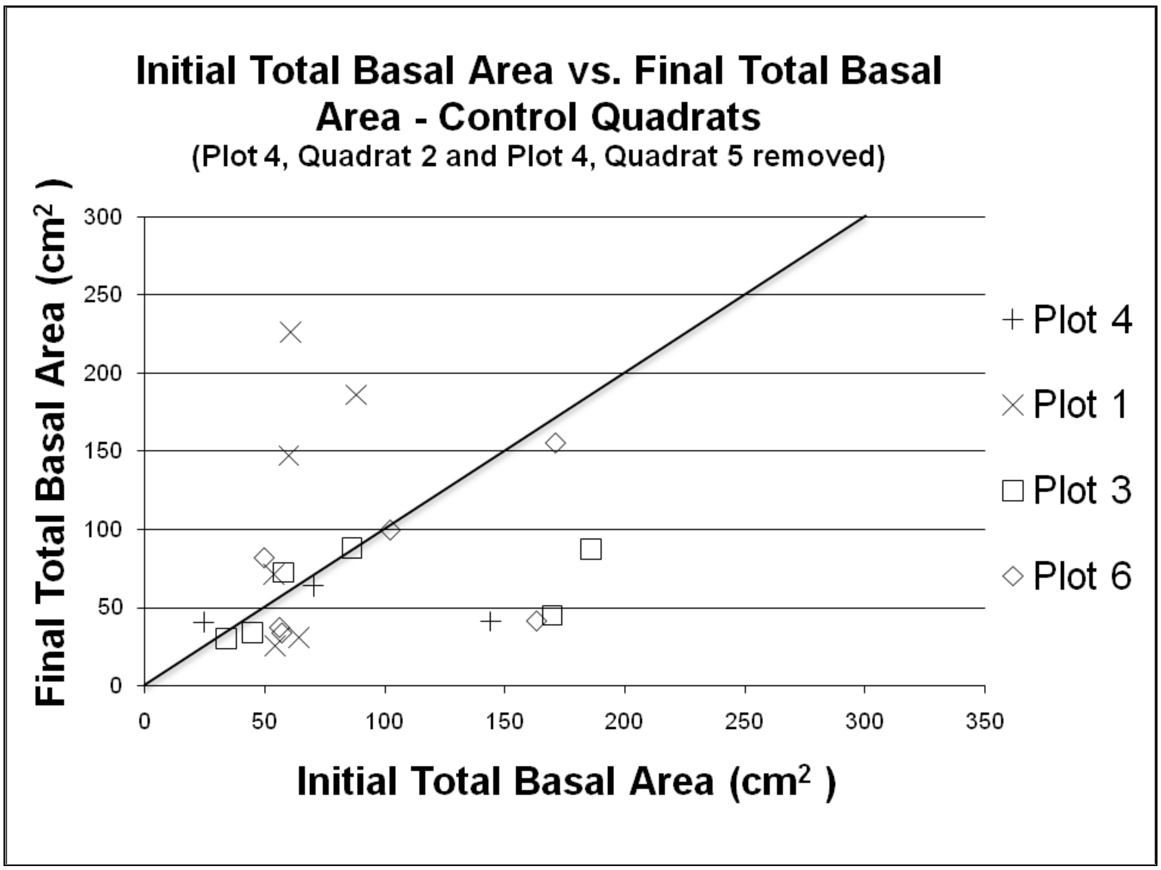

Figure 10. Initial total basal area vs. final total basal area by quadrat of unburned King Ranch bluestem on Storm Ranch, Hays County, Texas in 2008. (Quadrats with initial total basal area < 100 cm^2: Treatment $P = 0.17$, Initial total basal area $P = 0.47$). The diagonal line represents the null hypothesis of no difference between initial total basal area and final total basal area.

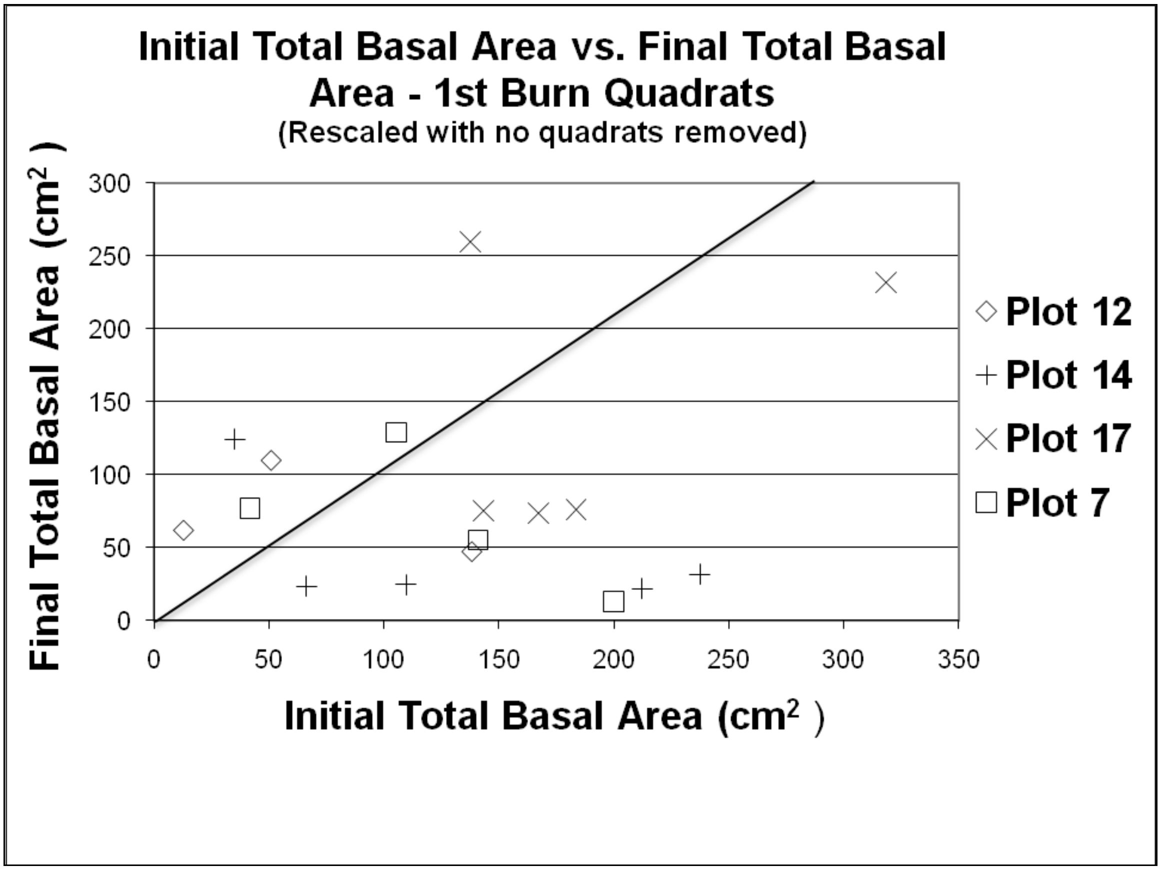

Figure 11. Initial total basal area vs. final total basal area by quadrat of King Ranch bluestem prescribed burned on 16 July 2008 on Storm Ranch, Hays County, Texas. (Quadrats with initial total basal area < 100 cm^2: Treatment *P* = 0.17, Initial total basal area *P* = 0.47.) The diagonal line represents the null hypothesis of no difference between initial total basal area and final total basal area.

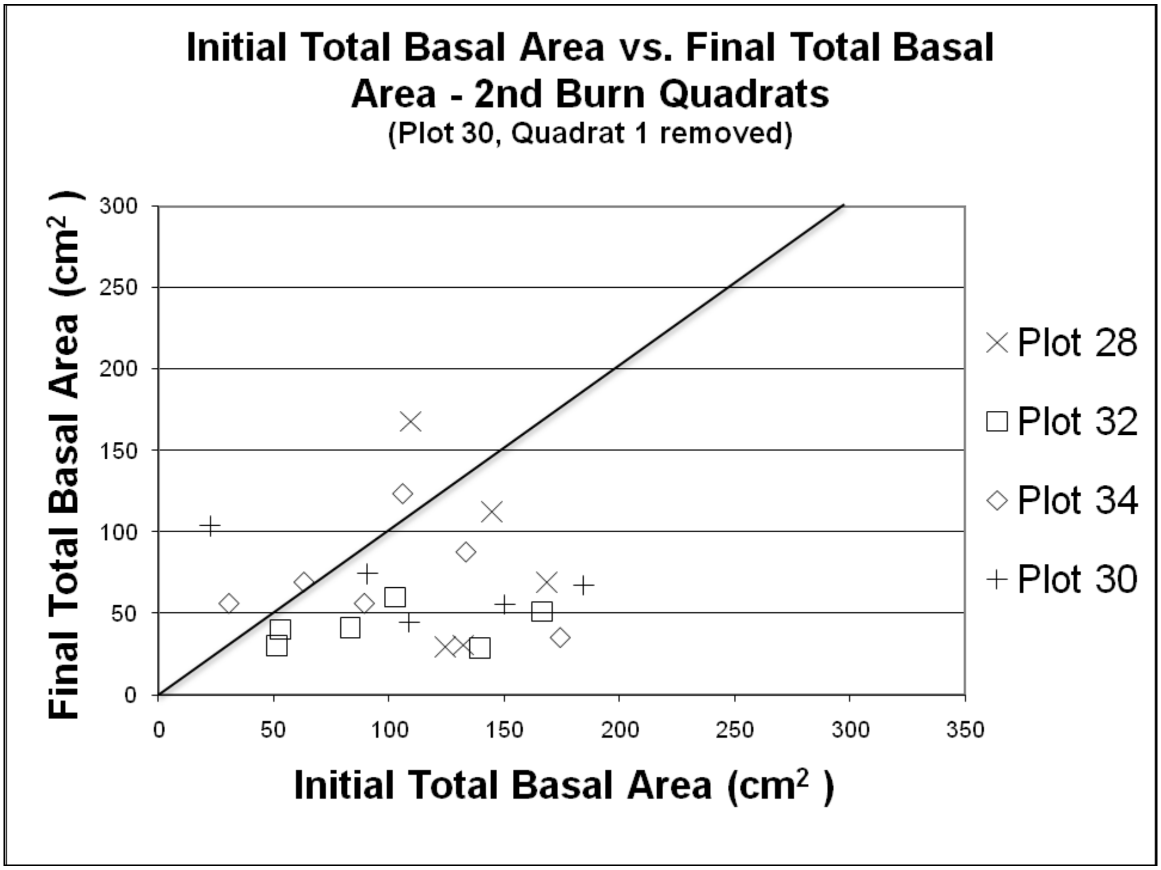

Figure 12. Initial total basal area vs. final total basal area by quadrat of King Ranch bluestem prescribed burned 19 September 2008 on Storm Ranch, Hays County, Texas. (Quadrats with initial total basal area < 100 cm^2: Treatment $P = 0.17$, Initial total basal area $P = 0.47$). The diagonal line represents the null hypothesis of no difference between initial total basal area and final total basal area.

Generally, fire behavior was relatively mild, which like contributed to the benign nature of the burns (Table 1). Fuel load, wind speed and wind direction were somewhat variable among the burns and plots, which resulted in the variations in residence time, fireline intensity, and energy release (Table 1).

Table 1. Measures of fire behavior. Residence time (t_r), fireline intensity (I), and energy release (E) were calculated from measures of flame depth (D), rate of spread (R), and flame length (F_L).

Date	16 July 2008				19 Sept 2008			
Plot #	17	7	14	12	30	32	28	34
D	0.21 m	0.24 m	0.21 m	0.14 m	0.13 m	0.09 m	0.12 m	0.15 m
R	4.0 m/min	10.0 m/min	8.0 m/min	6.2 m/min	2.2 m/min	4.0 m/min	3.5 m/min	5.5 m/min
F_L	0.19 m	0.20 m	0.24 m	0.24 m	0.15 m	0.13 m	0.18 m	0.17 m
t_r	0.053 min	0.024 min	0.026 min	0.023 min	0.061 min	0.022 min	0.034 min	0.027 min
I	7.02 kW/m	7.43 kW/m	11.66 kW/m	11.45 kW/m	4.08 kW/min	3.03 kW/min	6.25 kW/min	5.52 kW/min
E	7,947 kJ/m^2	18,575 kJ/m^2	26,908 kJ/m^2	31,227 kJ/m^2	4,017 kJ/m^2	8,459 kJ/m^2	11,029 kJ/m^2	12,267 kJ/m^2

CHAPTER V

DISCUSSION

Although previous studies have shown summer burning reduced dominance of King Ranch bluestem (Simmons et al. 2008; Ruckman 2009), burning during vegetative regrowth or flowering in my study did not substantially reduce abundance or dominance of this invasive grass. There was no difference in density, average basal area, or total basal area of King Ranch bluestem in plots as a result of treatment by prescribed burns. This was likely due to relatively mild fire behavior, as evidenced by low fireline intensity and energy release measures.

Land managers and practitioners commonly oversimplify complex research findings by over-generalizing results. In the case of prescribed fire, this issue commonly arises from assuming most fires behave in a reliable fashion with predictable results. However, the results of my study serve as a reminder that effects of fire, and how they are related to fire behavior, are incredibly complex and remain poorly understood.

A number of varying factors may help to explain the results of my study and guide future research. My mixed-effects model analyses failed to reject the null hypothesis of no differences between responses to treatments and the control. However, the lack of fit to the 1:1 line (representing the null hypothesis of no differences between pre-treatment and post-treatment measurements) in some scatter plots indicate the null hypothesis may have been rejected if a different analysis was conducted. For instance, initial density and treatment appeared to influence final density (Figs. 4-6). Control quadrats and those burned 19 September 2008 with initial densities above 100 had reduced final densities; whereas, those with initial densities below 100 typically had increased final densities. In contrast, quadrats burned 16 July 2008 fit the 1:1 null hypothesis line more closely than the aforementioned treatments, further suggesting an influential factor, such as treatment, was not detected by my mixed effects analyses.

Also, in scatter plots the relationship between initial total basal area and final total basal area of quadrats appeared to differ between treatments and in different ranges of initial total basal area (Figs. 10-12). Quadrats with initial total basal areas > 100 cm2 within all treatments typically had reduced final total basal areas, in contrast, quadrats with initial total basal areas < 100 cm2 typically had increased final total basal areas. This bias was especially evident in quadrats burned 19 September 2008, possibly suggestive of a treatment effect or effect of another factor.

Other confounding factors which were not included as independent variables may have influenced final measures. Among these are climatic conditions before, during and after fire; characteristics of the site; fire behavior and associated fuel load; and interspecific competition. Moisture is a primary confounding factor contributing to susceptibility of vegetation for ignition, and thus effects of fire. Accordingly, climate has a supremely important influence on plant biomass production, with influence being more pronounced after fire (Abrams et al. 1986; Gibson and Hulbert 1987; Briggs and Knapp 1995). Thus, precipitation in days, weeks, months, and, in some cases, years, before a fire can impact the results. In addition, precipitation immediately after a burn, or ensuing weeks or months may influence the effects of a burn (Abrams et al. 1986; Gibson and Hulbert 1987; Briggs and Knapp 1995). On a parallel note, soil moisture and plant moisture may also influence effects of fire (Briggs and Knapp 1995). In regards to this experiment, which occurred during drought, there was relatively little precipitation before and after burns. According to the National Climatic Data Center historical data from a nearby weather station in Wimberley, TX, annual cumulative rainfall as of 16 July 2008 at the time of the first burn was approximately 181 mm, less than half of the average of 470 mm. About 23 mm of that precipitation had occurred in the 20 days prior, after an extended period with very little rainfall. Rainfall as of 19 Sept 2008 at the time of the second burn was approximately 390 mm, also below the average of 610 mm. There was only 9 mm precipitation on the site in the 20 days prior. There was about 42 mm of rainfall in the 20 days after the first burn and 17 mm in the 20 days after the second burn, so it less clear whether rainfall after burns might have impacted the results. Because root biomass of King Ranch bluestem increases as a result of drought and decreased soil moisture (Coyne and Bradford 1986, 1987), and is an important "buffer" that may lessen a plant's susceptibility to stressors such as fire, the lack of antecedent precipitation may have lessened the impact of both fires. Plant moisture, directly related to soil moisture, is likely also influential.

Fire behavior is a critically important consideration and is directly influenced by fuel load and climate, and likely influenced the results of my study. Because fire is a somewhat rarely used tool in the region, I intended for my study to provide practical guidance to land managers and practitioners with significant safety concerns or little experience with prescribed fire. Therefore, I planned for climatic conditions and fire behavior that could be readily duplicated by most landowners and fire managers. In comparison to other fires examining effects of summer fire on King Ranch bluestem, I conducted two experimental fires under relatively humid and cool conditions, resulting in low measures of fireline intensity and energy release (Table 1). These conditions provided relatively benign and predictable fire behavior, while still allowing me to select the date to burn based on phenological cues, which I hypothesized as an important influence on effects of fire. The relatively benign conditions of this burn were furthered by relatively low fuel load (~ 2,223 kg / ha), likely a result of grazing a few months prior to the 16 July 2008 burn. Furthermore, the grazing that occurred in early spring months before the burns may have influenced impacts of the burns. For instance, Old World bluestems have demonstrated increased leaf area index after severe leaf defoliation, which may provide for more effective photosynthesis after grazing (Coyne and Bradford 1985). On the other hand, defoliation later in the growing season reduced root biomass, which would increase susceptibility to subsequent defoliation (Coyne and Bradford 1986).

In contrast to my study, previous studies demonstrated burns conducted in the growing season, particularly those conducted earlier in the growing season, decreased vigor of King Ranch bluestem (Simmons et al. 2008; Ruckman 2009). In this case, although I conducted both fires during the growing season, relatively high humidity and low ambient temperatures likely resulted in relatively docile conditions when compared to many summer fires, so it is possible a burn conducted under hotter, drier, or windier conditions with a greater fuel load may have yielded different results. Considering this, a study exploring effects of fires conducted under hotter, drier, or windier climatic conditions and larger fuel loads, but on the same calendar day, would help to isolate the impact of fire behavior. The results of my study strongly suggest hotter, more intense fires would have been more effective at reducing King Ranch bluestem vigor and density.

In addition, every burn site has unique characteristics that may contribute to a fire's impact on vegetation. Soil type may provide a competitive advantage by affecting water-holding capacity or nutrient concentrations, thereby influencing each species' response to fire (Reich et al. 2003). Slopes, hills or mountains may affect drainage or sun exposure of a burn site, resulting in more mesic or xeric conditions (Barbour et al. 1999). Finally, as detailed above, competing plant species may reduce abundance and dominance of a particular species by using limited resources such as light, water and nutrients (Barbour et al. 1999).

Also, interspecific competition may influence effects of fire. King Ranch bluestem is highly competitive, and little is known about which species effectively compete with it, particularly on burned sites. Some grass species may compete effectively due to their morphology or phenology being similar to King Ranch bluestem (Tinsley et al. 2006). If present on a site due to seeding or an existing seed bank, these species may compete effectively when moisture is sufficient during or after a burn. The unique dormancy mechanisms of a particular species may also influence how effectively its seedlings germinate. Timing of germination and vegetative regrowth are particularly important in this regard, as species that germinate or rapidly emerge soon after defoliation have a competitive advantage over those species with delayed production (Rathcke and Lacey 1985). Not surprisingly, anecdotal reports on effectiveness of summer fires to control King Ranch bluestem suggest interspecific competition is an important factor.

CHAPTER VI

IMPLICATIONS

Based on previous studies and anecdotal reports, one might conclude growing season burns are generally effective for controlling King Ranch bluestem. However, it is wise to avoid over-generalizing results of a particular study or burn. In contrast to previous research (Simmons et al. 2008; Ruckman 2009), my study showed neither of the two growing season burns significantly impacted the density or vigor of King Ranch bluestem plants. This may have been due to a variety of factors, including the analyses used, which may not have adequately detected the impact of treatment or patterns between initial and final measures. Other confounding factors, such as the relatively low fuel load and relatively humid weather with low winds leading to relatively benign fire behavior, may have influenced my results. In addition, characteristics of the site, such as the high water holding capacity of the soil and dominance of King Ranch bluestem on the site prior to the burn may have been influential. Finally, impacts of drought both before and after the fire were likely important as well.

I advise researchers and land managers conducting future studies and burns to control the aforementioned variables to the maximum extent achievable, with each study experimenting with a minimum number of variables. In particular, fires conducted according to the same phenological cues - under hotter, windier or less humid conditions, with a greater fuel load - would be particularly useful for better understanding the influence of fire behavior. In time, the resulting body of data and anecdotal reports will help to unravel the myriad of questions remaining about using fire to better manage King Ranch bluestem and other invasive plants.

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VITA

Frank Davis first fell in love with the Texas Hill Country at the Barton Creek Wilderness Park near downtown Austin. After losing his mother to cancer, he frequently took to the trails on foot and on his mountain bike, finding solace in the easy escape from the urban rat race. Since then, Frank has learned a great deal about the culture and natural resources that distinguish the Texas Hill Country. In 2003, Frank returned to college for his second undergraduate degree, majoring in Geography and specializing in conservation and natural resources management. Soon after graduating, he had the good fortune of finding part-time work with the Hill Country Conservancy, a non-profit organization committed to preserving the special places and natural resources of the Texas Hill Country. After five years with HCC, Frank is now their Director of Land Stewardship, working directly with landowners and diverse partners to permanently conserve sensitive private lands and ensure the ongoing health and beauty of our regional landscape. While working with HCC, Frank returned to his studies again in 2007, in order to gain practical knowledge on wildlife and landscape ecology and watershed protection. His Master's studies at Texas State included a range of subjects such as fire ecology, plant ecology, urban wildlife issues, limnology, watershed management and statistics, among others.

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