PATCH-BURNING IN MIXED GRASS PRAIRIE: ANIMAL USE OF RIPARIAN AREAS AND EFFECTS ON PLANT SPECIES RICHNESS.

By

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PATCH-BURNING IN THE MIXED PRAIRIE:

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Riparian areas comprise a minor portion of rangelands, but are environmentally sensitive areas with potential for high biological diversity. Livestock preferentially graze riparian areas, under traditional grazing management practices. Preferential grazing of riparian areas increases livestock impact, which leads to disruptions in historical riparian function. We compared livestock area selection in traditionally grazed pastures with selection in experimental patch-burn pastures. Burns were applied in sequential rotation to a quarter of each experimental pasture every year resulting in a 4-year fire return interval. Forage quality was highest on recently burned patches attracting free-roaming livestock. Results indicate burning consistently influenced forage quality by enhancing nutrient content although all results were not significant in both years. Cattle were outfitted with a GPS collar to record their location. Selectivity indices from this study indicate cattle in traditionally managed pastures selected riparian areas at a rate approximately five times greater than livestock in pastures under patch-burn grazing management. Additionally, this study indicated that patch-burn grazing may rotate grazing pressure among riparian areas based on location of burn, thus increasing the temporal and spatial heterogeneity created by grazers' disturbance of riparian areas. Forage nutrient content was analyzed for patches that varied by year of burn.

Natural disturbance regimes are critical to biological diversity. Complex interaction among disturbance processes, such as fire and grazing, promote a mosaic of plant communities that vary in structure and successional stage. Topoedaphic variability, site history, and disturbances contribute to landscape heterogeneity. Traditional grazing management that emphasizes uniform disturbance decreases heterogeneity. Variation in disturbance types and intensities may result in distinctively different post-disturbance communities. Grazing management strategies based on historical disturbances may be capable of promoting grassland biodiversity. Patch-burn grazing management mimics historical fire and grazing interactions. This study compares the results of three management treatments within the mixed grass prairie of Western Oklahoma on plant species diversity. Management treatments are 1) traditional management for the region 2) patch-burn management and 3) ungrazed, unburned management. Plant species richness did not differ between treatments. Significant differences were demonstrated by year, presumably due to differences in precipitation.

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CHAPTER I

PATCH-BURNING MANAGEMENT REDUCES CATTLE USE OF RIPARIAN AREAS

Abstract

Riparian areas comprise a minor portion of rangelands, but are environmentally sensitive areas with potential for high biological diversity. Livestock preferentially graze riparian areas under traditional grazing management practices for a variety of factors including proximity to water, topography, shade and forage quality. Preferential grazing of riparian areas increases livestock impact by altering disturbance patterns, water nutrient levels and total dissolved solids. In this study, we compare cattle selection in traditionally grazed pastures with selection in experimental patch-burn pastures. Burns were applied in sequential rotation to a quarter of experimental pastures each year resulting in a 4-year fire return interval. Forage quality was highest on recently burned patches attracting free-roaming livestock. One cow in each pasture was outfitted with a GPS collar to record livestock location, Ivlev’s selectivity index was used to determine time spent by livestock within time since fire patches, riparian areas and forage quality.

Selectivity indices from this study indicate livestock in traditionally managed pastures utilized riparian areas at a rate approximately five times greater than livestock in pastures under patch-burn grazing management. Forage nutrient content was analyzed for patches that varied by year of burn. Results indicate burning consistently influenced forage quality by enhancing nutrient content varied by year. Increased forage quality on recently burned patches lowered livestock use of riparian areas. Additionally, this study indicated that patch-burn grazing may rotate grazing pressure among riparian areas based on location of burn, thus increasing the temporal and spatial heterogeneity created by grazer’s riparian disturbances.

INTRODUCTION

Traditional grazing management, which is focused on maintaining uniform cattle distribution, has not successfully diminished selective grazing of riparian areas (Bailey et al. 1996; Fuhlendorf and Engle 2001; Bailey et al. 2006; Bailey et al. 2008; Ellison et al. 2009; Holecheck et al. 2011). Riparian areas comprise a minor portion of overall rangeland and are preferred by grazers, due to greater availability of water, higher productivity, palatability, protein and forage quantities than upland areas (Thomas et al. 1979; Kauffman and Krueger 1984; Marlow and Pogacnik 1986; Bailey et al. 1996; Patten 1998; NRCS 2007; Augustine et al. 2010). Riparian areas are considered environmentally sensitive areas, susceptible to over-grazing. Utilization of riparian areas may alter riparian condition and water quality (Parsons et al. 2003; Ellison et al. 2009; Walburger et al. 2009). During periods of higher temperatures, time spent by cattle in riparian areas is increased, due to the cooling effect of shade and use of natural water sources (Patten 1998; Parsons et al. 2003; Allred et.al 2011b). Utilization of forage generally decreases with distance from water as a result of a combination of factors, rather than any factor independently (Gillen et al. 1985; Parsons et al. 2003; Bailey et al. 2008; Whalburger et al. 2009; Gillen et al. 2009; Allred et. al 2011a). For example: in a addition to serving as a source of water riparian areas may provide more shade, wind protection, and/or forage than upland areas.

Government regulations, including the establishment of water quality standards and a desire to maintain rangeland health have made management of riparian grazing important to land managers. Overgrazing of riparian areas, as well as trampling by cattle may result in unstable stream banks, increased water temperatures, diminished riparian function, uprooted vegetation, increased water sediment loads and soil compaction which decreases water infiltration while increasing surface runoff (Kauffman and Krueger 1984; Patten 1998; Magner et al. 2008; Ellison et al. 2009). Livestock concentration in riparian areas may also introduce pathogens and influence nutrient levels, both of which may alter aquatic ecosystems (Pandey et al. 2009).

Government agencies and land managers have suggested best management practices (BMPs) based on traditional principals of grazing distribution. Practices designed to redirect grazing pressure to upland areas include construction of upland water sources, grazing exclusion fences, brush control, fertilizing upland forage, herding and selective mineral placement (Ellison et al. 2009; Pandey et.al 2009; Bailey 1996). Results of BMPs vary across rangeland regions of the world, may be costly and cause loss of grazing land. Implementation of BMPs is intended to minimize disturbances resulting in increased riparian vegetation density and diversity, stabilized stream channels, reduced total dissolved solids (TDS), and increased macro invertebrates (Ellison et al. 2009; Manger et al. 2009).

Those that advocate for the complete cessation of riparian grazing fail to consider historical disturbances. Disturbances create negative and positive feedbacks which may form a spatially and temporally shifting landscape mosaic (Fuhlendorf et al. 2009). Historical disturbances may create variations in characteristics such as vegetation density and TDS that may be critical to biodiversity and ecosystem processes on rangeland landscapes. Disturbance varied temporally and spatially creating a shifting mosaic of successional stages. Patch-burn pastures mimic historical disturbance patterns while increasing heterogeneity and grassland productivity.

Increasing upland forage quality by prescribed burning may be a cost effective method of redistributing grazing pressure. Forage may be manipulated through pyric-herbivory; the interaction of fire and selective grazing of post-fire growth by livestock (Archibald 2005; Fuhlendorf et al. 2009). Pyric-herbivory may influence forage nutrient and mineral content (Anderson et al. 2007; Mbartha and Ward 2010).

Our study focuses on a mixed grass prairie location with long term (10 years +) patch-burn management. This unique study site includes topographically variable sites with replicated pastures for patch-burn treatment and traditionally managed pastures with similar grazing but no fire. This study gives us a unique opportunity to study the attraction of cattle in mixed grass prairies to riparian areas and patch fires. The objective of this research was to determine if patch-burn management influenced livestock selection of riparian areas. We predicted 1) that cattle in patch-burn grazing pastures would spend 50% less time in riparian areas than cattle in traditionally managed pastures and 2) cattle selection of upland forage will increase due to increased upland forage quality although standing biomass decreases due to recent fires.

MATERIALS AND METHODS

STUDY AREA

Research was conducted on the Marvin Klemme Range Research Station, an Oklahoma State University Agricultural Experiment Station, located near Bessie Oklahoma. The station is approximately 630 ha of rolling uplands cut by several creeks and drainages. Vegetation in this region is classified as mixed prairie.

Dominant grasses in this area include *Bouteloua curtipendula* (Michx) Torr. *Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths, *Bouteloua dactyloides* (Nutt.) J.T. Columbus (, *Bothriochloa saccharoides* (Sw.) Rydb., *Bouteloua hirsuta* Lag, and *Aristida purpurea* Nutt. Forbs recorded in this area include; *Grindelia squarrosa* (Pursh) Dunal (, *Gutierrezia sarothrae* (Pursh) Britton & Rusby and *Amphiachyris dracunculoides* (DC.) Nutt. Dominate woody plant species include *Rhus glabra* L. and *Prunus angustifolia* Marsh (Gillen et al. 2000; Fuhlendorf et al. 2002). Riparian forb species included various species of *Carex*, *Verononia baldwinii* Torr., and *Phyla nodiflora* (L.) Greene).

Classification of areas as upland or riparian was necessary for this study to determine difference in selection by livestock. There are numerous definitions and terms used to describe riparian areas which vary in many key characteristics; size, vegetation, resources, scale and regional interpretations (Verry et al. 2004). To define a riparian area for this study we borrowed heavily from the definition of Verry et al. (2004) and F&WS (1997). We defined a riparian area as a three-dimensional area; encompassing groundwater, canopy cover, and near-slopes that serve as drainages and run along a water course or water body. Riparian areas may be seasonal and vary in width. Plant communities may differ from upland habitat by a noticeable change in species and/or production of forage, apparent by casual visual survey. Sharp drop offs, such as rock cliffs or the high water bank, where vegetation does not differ from that of upland areas will be considered the riparian area edge. It is recognized that geographic features are not always present and therefore at times determination must be made based on vegetation. Vegetation may be affected by rainfall of each year.

Marvin Klemme Range Research Station has shallow soil, comprised of weathered siltstone (Vermeire and Gillen 2000). Approximately 70 % of the research station is Cordell-Rock outcrop complex with a 2 to 15 % slope and approximately 19 % of the remaining area is classified as Cordell silty clay loam with a 3 to 5% percent slope (NRCS Soil Survey 2007). Riparian areas varied with areas of deeper sediment deposits to rocky surfaces.

July is typically the warmest month with an average high of 36 ˚C and an average low of 21 ˚C. January is typically the coldest month with an average high of 10 ˚C and an average low of -4˚ C (Vermeire and Gillen 2000). The growing season is 204 d. Average yearly precipitation is approximately 75 cm. Weather conditions during 2010 were wetter and cooler than 2011 resulting in a large year effect. July 2010 had 15.1 cm of rainfall and July 2011 had .4 cm of rainfall. Normal July rainfall for this area is 5.8 cm. Average July 2010 temperature was 27.2 ˚C. Average July 2011 temperature was 33.1˚C. The 4 inch bare soil temperature was 28.8˚C in July of 2010 and 34.2 ˚C in July 2011. More complete rainfall data is not available due to gaps in data collected by the Bessie Oklahoma Mesonet Station. [OCS 2010]

The Marvin Klemme Range Research Station has been grazed by domestic livestock for approximately 100 years. Management and stocking rate is unknown before 1988. Most of the research area is uncultivated mixed prairie, but approximately 30 % of the land area was previously farmed. Farmed areas were reseeded with native grasses or allowed to re-vegetate naturally (Gillen et al. 2000). Previously cultivated fields range in size from 3 to 27 ha and are scattered within pastures (Gillen et al. 2000).

TREATMENT DESCRIPTION

Current management practices were initiated in 1989 (Fuhlendorf et al. 2002). Four pastures were sampled in this study representing two management practices (Fig.1). Pastures sampled were two patch-burned pastures, and two continuously grazed pastures. Pastures in this study were stocked with beef cattle. Equivalent stocking rates were maintained throughout the study. All grazed pastures were stocked at a moderate rate (0.63 AUM ha-1) based on site recommendations by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). Spring burns were conducted with fixed spatio-temporal application. Within patch-burn pastures, burns were applied to a quarter of each pasture (referred to as patch) in sequential rotation that resulted in a 4-year fire return interval.

GLOBAL POSITIONING SYSTEM (GPS)

Distribution of cattle was monitored with the use of GPS collars. One cow per pasture was outfitted with a Lotek 3000 GPS collar. Collars recorded cow location every five min. Collars were removed approximately every six weeks to download data and recharge batteries. Recharge time for the batteries was approximately 24 h. Analysis excluded data from days cattle were worked.

Pastures were burned April 8, 2010 and cattle outfitted with collars on May 12, 2010. Burning for the second year of study was delayed by weather conditions. Pastures were burned May 16, 2011 and cattle were outfitted with collars on May 17, 2011. Data points used for analysis were collected from approximately the third week of May until the end of June in both 2010 and 2011. In 2011, a GPS collar in one traditionally managed pastures malfunctioned and data were not recorded. Therefore, data from both traditionally managed pastures is available from 2010 only.

FORAGE QUALITY

Forage quality was measured within 1 x 0.5-m plot. Larger plot size was used to allow adequate forage to be collected from recent burns. All vegetation, growing or senesced was clipped to ground level and collected. A total of four samples were taken from each patch (time since fire) within patch-burn pastures. Four samples were taken from each of the traditionally managed pastures. The first sampling took place at the end of April 2010 (approximately two wks post-burn) and was limited to the current year's burns and traditionally grazed pastures. Subsequent sampling was done approximately every four weeks thereafter through October 2010 and consisted of four samples from all fire patches and traditionally managed pastures. Burning was delayed in 2011 due to weather. The first forage sampling of 2011 was at the end of May (approximately two wks post-burn). Subsequent sampling was conducted monthly thereafter through July. Each sampling was done in new randomly selected locations. Clippings were collected in paper bags and dried for a minimum of 7 days at approximately 50˚C. After drying, forage samples were weighed for biomass and submitted to the Oklahoma State University Soil, Water and Forage Analytical Lab for analysis. Forage samples were analyzed for percent crude protein and percent mineral content of Phosphorous (P), Calcium (Ca), Potassium (K), Magnesium (Mg), Copper (Cu), Iron (Fe), Zinc (Zn) and (Manganese) Mn.

Crude protein is important to muscle development, weight gain and maintenance. Minerals are essential to maintaining overall livestock health. Minerals aid in muscle, bone development and reproduction. Mineral imbalances may lead to many health problems and decreases in weight gain (Agriculture National Research Council 2000, Ball et al. 2001, Parish and Rhinehart 2008). Livestock deficiency of phosphorous is a worldwide problem that effects reproduction, DNA and bone development (Dunn and Moss 1992) Calcium is needed to ensure bone health in growing animals and milk production (Ball et al. 2001). Potassium is necessary for the regulation of water within the body and enzymatic reactions (Agriculture National Research Council 2000). Magnesium and zinc also regulates enzyme activity (Parish and Rhinehart 2008). Magnesium deficiency leads to grass tetany (Parish and Rhinehart 2008). Copper deficiency is widespread within the United States resulting in decreased heart and immune system functioning (Parish and Rhinehart 2008). Iron is important in the transport of oxygen within the body (Parish and Rhinehart 2008).Manganese is important in skeletal development, growth and reproductive functions (Parish and Rhinehardt 2008).

To insure that changes in forage composition were a result of fire and not edaphic conditions, soil samples were collected from the center and corners of each clipped plot during the first year of collection. Cores were approximately five cm deep (where terrain allowed). Cores from each plot were homogenized and submitted to the Oklahoma State

University Soil, Water and Forage Analytical Lab for analysis of plant-available nitrogen (NO4, NH3) and phosphorous (P).

STATISTICAL ANALYSES

ArcMap GIS version 9.3 was used for analysis of GPS data. Polygons of pastures, patches and riparian areas were constructed from points gathered using a handheld GPS unit and aerial photographs. Individual polygons were uniquely identified in an attribute table. Riparian polygons were identified as a riparian area in an attribute table. Pasture, patch and riparian area polygons were spatially joined to create a single attribute table. GPS records within specific patches, pastures, riparian areas and combinations of these polygons were counted using attribute queries. Ivlev's selectivity index was used to calculate grazing preference within patches (Krueger 1972; Jacobs 1974). Selectivity results are on a scale from -1 to 1. A positive number indicates a patch preference; with preference increasing as the number nears 1. A negative number indicates patch avoidance; with avoidance increasing as the number nears -1. Selection of patch (time since fire), selection of riparian areas within patch, and overall selection of riparian areas within pastures (patch-burn management vs. traditional management) was determined with Ivlev's selectivity index.

$$\text{GPS\%} - \text{area of patch relative to pasture\%} \div \text{GPS\%} + \text{area of patch relative to pasture\%}$$
$$= \text{Selectivity}$$

A statistical analysis was not conducted on Ivlev's selectivity index because the experimental design provided a realistic landscape view of grazing patterns. Pastures reflect the size of typical working pastures in Western Oklahoma. Sampling consisted of two patch-burn pastures and two traditionally managed pastures; a sample size of two. Replicates were entire pastures with similar grazing management (patch-burn or traditional) not individual animals within a single pasture.

SAS software, analysis of variance, GLIMMIX procedure, was used to determine significant differences and standard errors in forage quantity and quality (SAS Institute. 2011). Crude protein in 2011 demonstrated an interaction between time since fire and season that required the standard error to be calculated separately from SAS.

RESULTS

RIPARIAN AND PATCH SELECTIVITY

Livestock in traditionally managed pastures utilized riparian areas approximately five times more than livestock in pastures under patch-burn grazing management. Current year burns were preferentially utilized by livestock within patch-burn pastures in 2010 and 2011, while Ivlev's selectivity index for patches, 1 year, 2 years and 3 years since fire were negative. Time since fire, not riparian areas, influenced selectivity of patches within patch-burn treatments. Although water availability was reduced due to drought conditions in 2011, patch selection within the traditionally managed pastures was consistently focused on riparian areas. Selectivity of riparian areas in patch-burn pastures was increased within the current year's burn patch. Patches burned and positively selected in 2010 were avoided in 2011 as livestock selected more recently burned patches (Table 1). Selection of recently burned patches resulted in a shift of grazing disturbances within riparian areas. Grazing animals that select recently burned patches continued to graze the riparian area but primarily grazed in the recently burned patch. Riparian areas in patches with greater time since fire were avoided (Table 2). There was little change in patch selectivity of traditionally managed pastures; patches that were selected in 2010 were selected in 2011. Magnitude and location of patch selection was dependent on year as a result of high variation in rainfall, but patterns were similar. Rainfall in 2010 was high, 9.26 cm above July's average and this site was followed by a severe drought in 2011, with July rainfall 14.7 cm below average. Livestock selection within patch-burn treatment consistently focused on recently burned patches, rather than proximity to water which was variable with inter-annual variation in rainfall.

FORAGE QUALITY AND QUANTITY

Standing biomass was variable across treatments and among patches within patch-burn treatment. Within patch-burn treatments, biomass was significantly related to time since fire in 2010 ($P < 0.0001$) and 2011 ($P < 0.0051$). Traditionally managed pastures had the greatest overall biomass. In patch-burn patches biomass increased with time since fire (Fig. 2). There was a large year effect, associated with variation in rainfall patterns. Percent crude protein demonstrated a negative no-linear relationship with biomass. Crude protein levels are highest at the lowest levels of biomass (Fig 3). Generally, current burns in patch-burn treatment have the lowest biomass and highest crude protein when compared to patches across both treatments (Fig. 3; Table 3 and 4). In 2010 percent crude protein in current years burn patches was significantly higher than 3 years since fire patches (P=0.05). In 2011 crude protein was highest in the current years burn patch (P=.0105). The 2011 season of sampling had a significant interaction with time since fire. Greatest differences occur immediately after fire. Generally, current year's burn patch had higher crude protein percentage than traditionally managed pasture and patches with greater time since fire (Table 3 and 4).

Most sampled forage nutrients were negatively related to increasing biomass following a pattern similar crude protein percentage. Calcium, copper, potassium, manganese and magnesium demonstrated this time since fire affect. Recent burns were usually associated with high nutrient content (Table 3 and 4). Calcium ppm was significant for time since fire in 2011 (P = 0.0288) but not in 2010. In 2011, calcium content was higher in current year's burn and 1 year since fire patches than traditionally managed pastures. Potassium levels in 2010 and 2011 were highest in current year's burn patch and lowest in traditionally managed pasture (P = 0.0001). Magnesium in 2011 was significant for time since fire (P = 0.0014) but was not significant in 2010. Copper ppm was significant for time since fire for 2010 and 2011 (P<0.006) and was highest both years in current burn patches with some variability among years and other patches. Manganese in 2010 demonstrated significance for time since fire (P = 0.0001) however, in 2011 it was significant seasonally (P = 0.0131). Zinc and iron had no significant differences in 2010 or 2011.

DISCUSSION

In this study disturbance interaction was temporally and spatially applied on working rangeland. This study evaluated livestock selection while livestock was given free access to recently burned and greater time since fire patches. Our study supports previous studies that indicate livestock preferentially graze recently burned areas, rotating grazing pressure, and promoting landscape heterogeneity (Allred et al. 2011a). This study demonstrates that increasing upland forage quality by burning may reduce livestock impact on riparian areas by focusing grazing pressure on the entire burn unit; including riparian and upland areas.

On traditionally managed rangelands, herbivores preferentially graze riparian areas because water, slope, temperature, (abiotic factors) increase forage productivity, palatability and protein content (biotic resources) (Kauffman and Kruger 1984; Marlow and Pogacnik 1986; Fleischner 1994; Stanley and Mendel 1995; Trimble and Mendel 1995; Bailey 1996, Hessburg and Agee 2003; Parsons et al. 2003, Belsky et al 2004; Bailey et.al 2008; Allred et al. 2011a). Elevated forage quality in riparian areas slow grazer movement; increasing livestock's impact (Bailey 1996; Augustine et al. 2010). Results of this study indicate utilization of riparian areas decrease within a patch-burn grazing management system and reduce overall livestock impact in these sensitive areas. Despite precipitation differences across years, grazer selection in the patch-burn treatment was positively correlated with current year's burn in both years. Selection of riparian areas was more than five times greater in traditionally managed pastures than patch-burned pastures. Grazers selected burned areas while areas of greater time since fire were negatively selected.

Spatial and temporal rotation of disturbance created by patch-burn grazing management mimic historical disturbances and may allow for greater biodiversity and recovery of ecosystem functioning as livestock rotate themselves. Patch-burn management reduces livestock selection of riparian areas within greater time since fire patches. Decreased utilization of riparian areas may allow the establishment of vegetation that offsets the negative effects discussed above. Aquatic and riparian vegetation can serve as a filtering system reducing the threat of pathogens and nutrient fluctuations.

Increased upland forage quality as a result of fire may be more influential in grazer selection than environmental conditions as livestock seek to fill nutritional needs not met by a traditional forage diet (Taylor 1984; Fuhlendorf et al. 2009; Allred et al. 2011a). Patch-burn management will not diminish and may improve livestock weight gains because of increased forage quality (Fuhlendorf and Engle 2004; Villalba et al. 2010; Limb et al. 2011). Although burned areas may have a reduction in total forage available immediately following fire, forage quality is increased throughout much of the growing season. Biomass and crude protein demonstrate an inverse relationship where greater biomass due to increased time since fire is correlated with lower percentages of crude protein. Other forage nutrients tested follow similar inverse relationships where greater biomass is correlated with lower nutrient content. We found that forage from current year’s burns generally had greater levels of potassium, calcium, copper, magnesium and percent crude protein. Although nutrients in this study demonstrated slight differences between 2010 and 2011, most likely due to precipitation differences, there were consistencies across years.

In order to provide previously burned areas recovery time, and to maintain the benefits of patch-burn grazing, fire disturbance must vary temporally (Fuhlendorf et al. 2006, Archibald et al. 2005). Within a patch-burn system biomass is not viewed exclusively as fuel or forage but instead a spatially regulated compliment of interaction. The most recently burned areas will attract grazers that suppress biomass accumulation creating grazing lawns until a new burn becomes available (Archibald et al 2005, Allred et al. 2011a). Areas that are ungrazed accumulate biomass increasing fire probability.

With infinite combinations of variables exact outcomes of patch-burn management is undeterminable. Fire research has been predominately focused on tall grass prairies (Engle and Bidwell 2001). Responses may vary between tall, mixed and short prairies and with differences in climate (Engle and Bidwell 2001). Effects of fire also vary with grazing history, fire frequency, fire- return interval, successional stage, plant composition, herbicide use, topography, edaphic features of the landscape, landscape scale, soil water holding capabilities, precipitation, temperature and other weather conditions which influence forage growth and nutrient cycling (Tomanek and Albertson 1957; Howe 1994a; Engle and Bidwell 2001; Derner and Hart 2007; Fuhlendorf et.al 2008; Davies et.al 2009;). Timing of burn may influence forage availability and length of grazing season (Engle and Bidwell 2004).

Degraded ecosystems with changes in native species composition, presence of invasive species and change in chemical processes may respond differently to historical disturbance regimes (Suding et al. 2004). Altered ecosystems may require non-historical disturbances regimes (Davies et.al 2009; Brockett et al. 2001). If disturbances occur on too small a scale benefits will not be sufficient. Unfortunately, disturbances may have historically occurred on a scale larger than is practical for current land management practices (Fuhlendorf and Engle 2004).

IMPLICATIONS

Our research demonstrated an increase in upland forage quality within current year burns. Higher nutrients and percent crude protein found in current year's burn patches offset decreased biomass. Forage within the current year's burn demonstrated the greatest crude protein percentages and greater levels of copper, potassium, manganese and magnesium. Livestock selection was focused within current year's burn. Livestock weight gains increases were greater within patch-burning pastures than traditional pastures (Limb et al. 2011).

Selectivity indices from this study indicate cattle in traditionally managed pastures selected riparian areas at a rate approximately five times greater than livestock in pastures under patch-burn grazing management. Additionally, this study indicated that patch-burn grazing may rotate grazing pressure among riparian areas based on location of burn, thus increasing the temporal and spatial heterogeneity created by grazing disturbance in riparian areas. Reduction in selection of previously burned patches may allow for increased vegetation establishment within those areas and improved water quality. Patch-burning may eliminate the need to artificially rotate livestock and decrease investments in infrastructure.

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FIGURES AND TABLES

Fig. 1 Map of the Marvin Klemme Range Research Station (MGPB, moderately grazed, patch-burn; MGUB, moderately grazed, unburned; riparian areas in gray), which is located approximately 15 km south of Clinton, Oklahoma. Within a patch-burn pasture patches are burned on a 4 yr rotation.

Fig. 2 Average biomass of time since fire patches and traditionally managed pasture in 2010 and 2011. Biomass collected in 2010 was greater than in 2011. Clipped plots were randomly taken within pastures, included active growth and litter. Grazing was not excluded from plots. Samples were taken two weeks post burn and then every 4 weeks after first sampling. April data was only collected from 2010 burns; 2011 burns were postponed due to weather conditions. Error bars represent standard error.

Fig. 3 Biomass and percent crude protein of forage demonstrate an inverse relationship. Generally, as biomass increases, percent crude protein decreases. Each point represents values of a single forage sample.

Table 1. Ivlev's selectivity of patches, riparian areas included. Presence of fire is noted in red. Cattle selection preference was positively associated with current years burned patches. Traditionally managed pastures showed no difference in preference and avoidance between years.

Patch	Burned 2010	Burned 2009	Burned 2008	Burned 2011/2007
	———————————— Ivlev's Selectivity Index ————————————			
Patch-burn A 2010	0.3889	-0.0848	-0.5068	-0.2654
Patch-burn A 2011	-0.0257	-0.1083	-0.2948	0.2608
Patch-burn B 2010	0.3211	-0.0536	-0.333	-0.1742
Patch-burn B 2011	-0.0451	-0.0842	-0.0158	0.1166

Table 2. Ivlev’selectivity; riparian areas only. Presence of fire is noted in red. Cattle selection preference was positively associated with current years burned patches. Traditionally managed pastures showed no difference in preference and avoidance between years.

Riparian	Burned 2010	Burned 2009	Burned 2008	Burned 2011/2007
	——————————— Ivlev's Selectivity Index———————————			
Patch-burn A 2010	🟥 0.1869	-0.4318	-0.1033	-0.2823
Patch-burn A 2011	0.1224	-0.1834	0.3068	🟥 0.3772
Patch-burn B 2010	🟥 0.154	-0.186	-0.0594	-0.4394
Patch-burn B 2011	-0.0392	🟥 0.0284	0.0254	-0.0054

Table 3. 2010 values for biomass, crude protein and nutrients. Highest values are indicated in red, lowest values indicated in blur. Percent crude protein and most nutrients are highest in current year's burn patch and demonstrate an inverse relationship with biomass.

2010						
Time Since Fire						
		No Fire	Current	1 Year	2 Year	3 Year
Biomass	-----g-----	223.55	84.297	117.58	134.93	169.61
SE		8.0298	8.0298	8.0298	8.0298	8.0298
Crude Protein	-----%-----	7.2275	8.3525	7.5025	7.0975	7.18
SE		.2443	.2443	.2443	.2443	.2443
Calcium	------ppm-----	0.834	0.8965	0.863	0.6628	0.8768
SE		.1354	.1354	.1354	.1354	.1354
Copper	------ppm-----	4.96	6.2	5.1775	4.4625	4.5225
SE		.3308	.3308	.3308	.3308	.3308
Potassium	------ppm-----	0.4588	0.8778	0.6095	0.4778	0.5112
SE		.04631	.04631	.04631	.04631	.04631
Manganese	------ppm-----	72.37	102.58	79.1825	58.745	60.5425
SE		5.6433	5.6433	5.6433	5.6433	5.6433
Magnesium	-----ppm-----	0.1745	0.271	0.2073	0.1488	0.1828
SE		.0235	.0235	.0235	.0235	.0235

Table 4. 2011 values for biomass, crude protein and nutrients. Highest values are indicated in red, lowest values indicated in blue. Percent crude protein and most nutrients are highest in current year's burn patch and demonstrate an inverse relationship with biomass.

2011						
		Time Since Fire				
		No Fire	Current	1 Year	2 Year	3 Year
Biomass	-----g-----	168.33	17.54	97.03	81.23	124.37
SE		9.75	9.75	12.27	12.27	12.27
Crude Protein	-----%-----	7.9875	8.8625	8.2125	8.075	8.3042
SE		.2716	.5708	.3186	.5689	.3455
Calcium	------ppm-----	0.6542	0.7889	0.85	0.6833	0.6292
SE		.0563	.0563	.0563	.0563	.0563
Copper	------ppm-----	5.0542	7.0458	4.7625	5.0792	4.6625
SE		.03812	.03812	.03812	.03812	.03812
Potassium	------ppm-----	.4375	.6913	.4333	.625	.5792
SE		.0381	.0687	.0371	.0550	.0291
Manganese	------ppm-----	—[1]	—[1]	—[1]	—[1]	—[1]
SE		—[1]	—[1]	—[1]	—[1]	—[1]
Magnesium	-----ppm-----	0.1333	0.2764	0.2208	0.1667	0.1417
SE		.01645	.01645	.01645	.01645	.01645

[1] — data not significant

Fig. 1

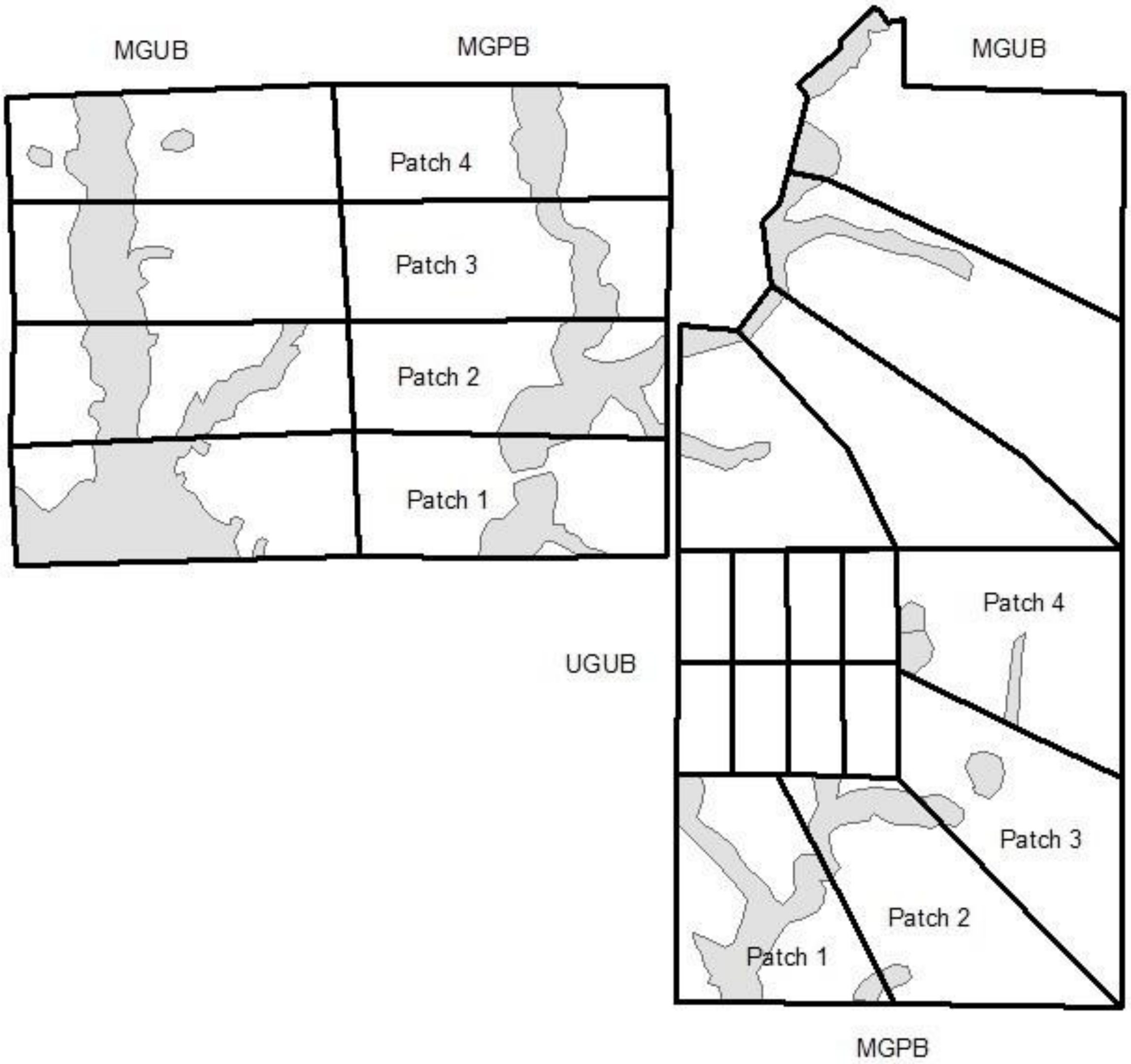

MGUB
MGPB
MGUB
Patch 4
Patch 3
Patch 2
Patch 1
UGUB
Patch 4
Patch 3
Patch 2
Patch 1
MGPB

Fig. 2

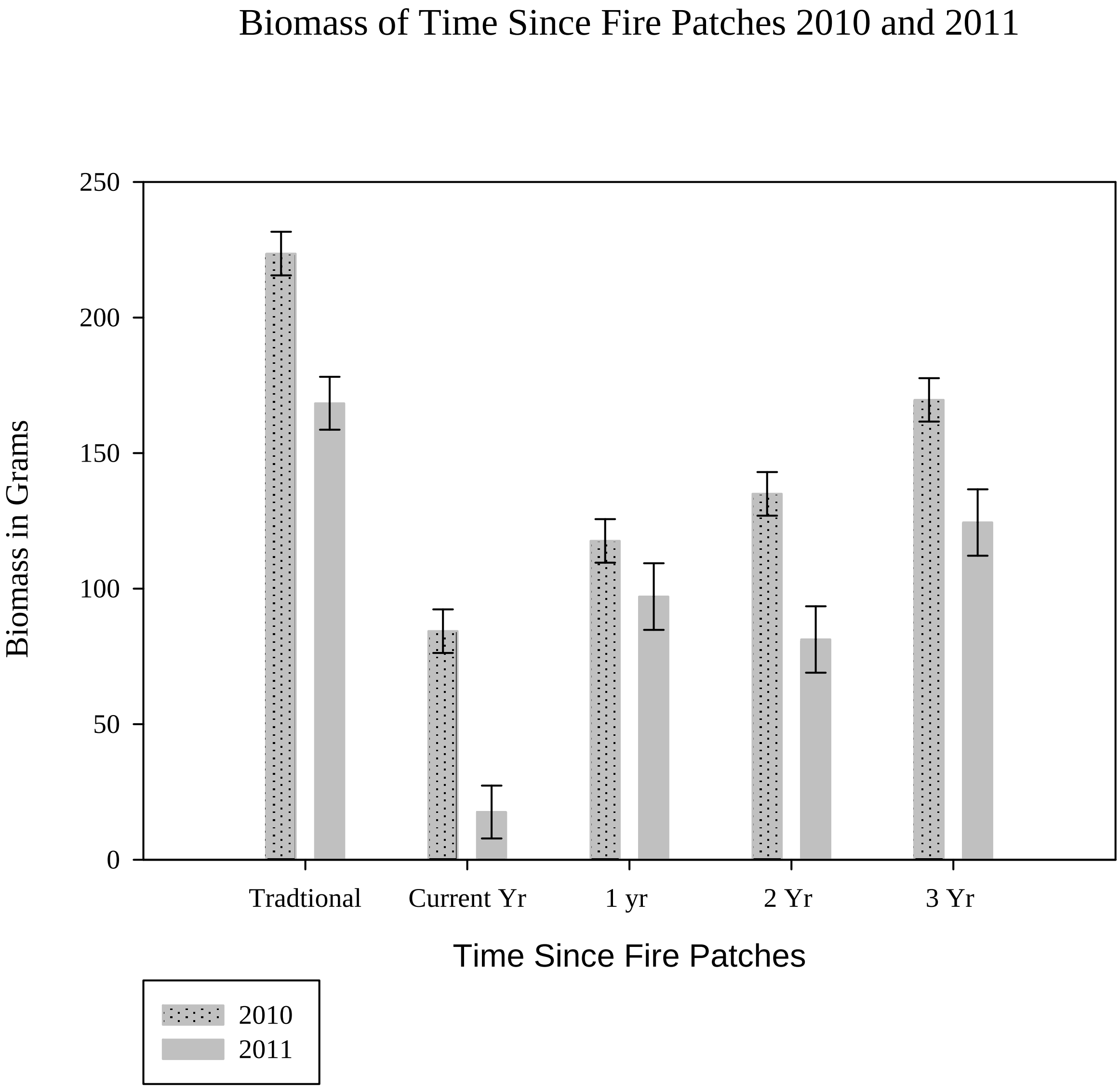
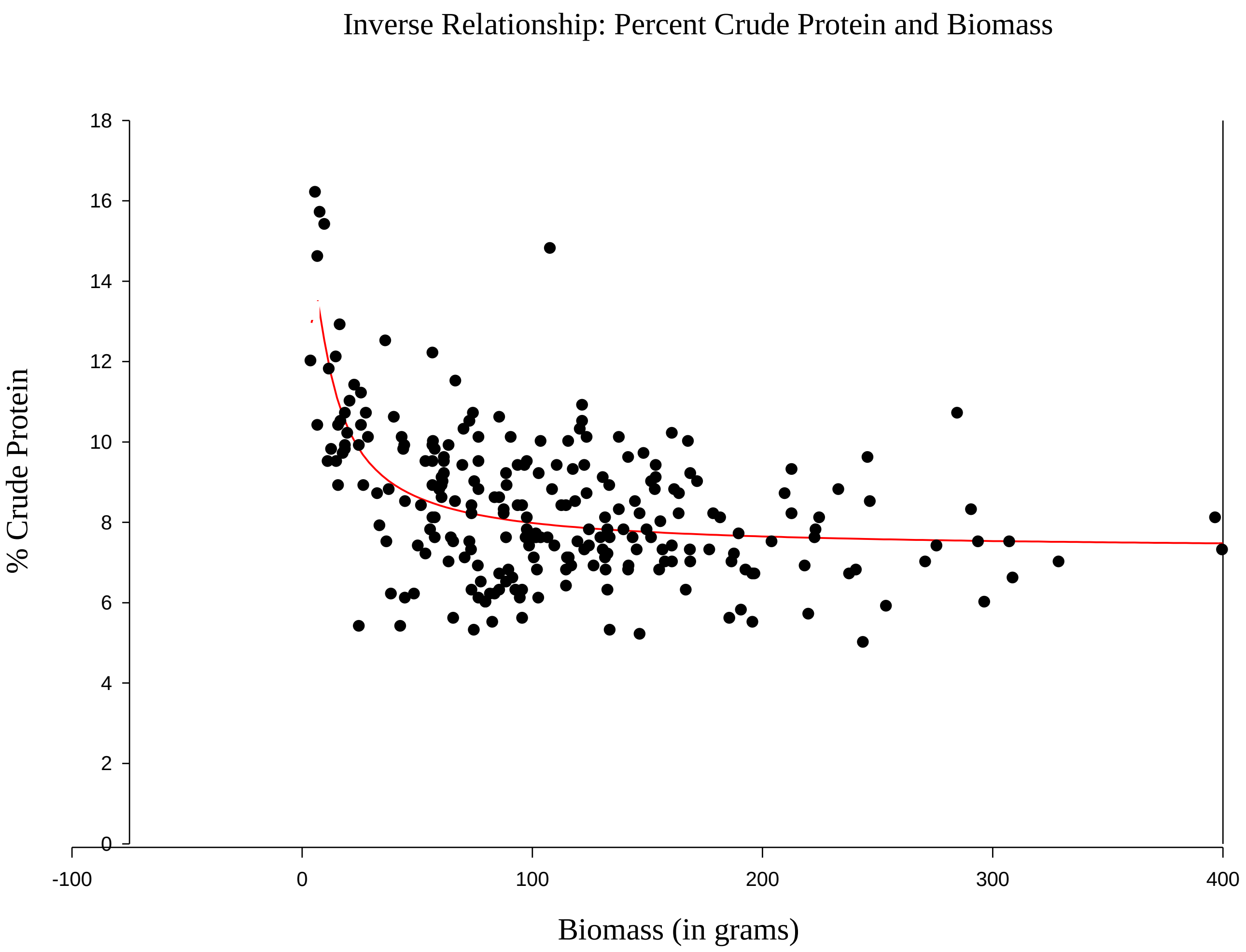

Biomass of Time Since Fire Patches 2010 and 2011

Fig. 3


Inverse Relationship: Percent Crude Protein and Biomass
% Crude Protein
18
16
14
12
10
8
6
4
2
0
-100
0
100
200
300
400
Biomass (in grams)

CHAPTER II

FORB AND SUCCULENT SPECIES RESPONSE TO PATCH-BURN GRAZING MANAGEMENT

Abstract

Natural disturbance regimes may be critical to biological diversity. Complex interactions among disturbance processes, such as fire and grazing, promote a mosaic of plant communities that vary in structure and successional stage. Topoedaphic variability, site history, and disturbances contribute to landscape heterogeneity. Grazing management strategies based on historical disturbances may be capable of promoting grassland biodiversity. Patch-burn grazing management mimics historical fire and grazing interactions. Traditional grazing management that emphasizes uniform disturbance decreases heterogeneity. Variation in disturbance types and intensities may result in distinctively different post-disturbance communities. This study compares the results of three management treatments within the mixed prairie of Western Oklahoma on plant species diversity. Management treatments are 1) traditional management for the region 2)

patch-burn management and 3) ungrazed, unburned management. Species area curves and canopy coverage measurements were used as diversity measures. Results indicate that management type does not significantly influence plant species diversity.

INTRODUCTION

Declining diversification of life processes, living organisms, genetics, communities, ecosystems and landscapes collectively referred to as biodiversity, is recognized as a global concern (West 1993; United Nations 2012). Biodiversity may be enhanced by heterogeneity, which is the interaction of multiple disturbances and site factors at multiple scales that create variation in landscape structure (Fuhlendorf et al. 2006). Heterogeneity may be critical to the persistence of native plant species by promoting a mosaic of plant communities that vary in structure, and successional stage based upon disturbances vary in space and time. Heterogeneity may also be inherent to landscapes due to topoedaphic variability, abiotic factors, and site history. Manipulating disturbance scale, severity and availability of resources may promote or reduce heterogeneity (Fuhlendorf and Smeins 1998; Fuhelendorf et.al 2001).

Grazing disturbance, fire disturbance and the fire-grazing interaction may increase or decrease diversity (Archibald et al. 2005, Fuhlendorf et al. 2006, Fuhlendorf and Engle 2004; Veen et al. 2008; Hartnett et al. 1996, Engle and Bidwell 2001, Archibald et.al 2005, Brudvig et. al 2006). Grazing may result in divergent plant communities depending on livestock distribution, stocking rate, edaphic features, grazing history, climate and disturbance history (Tomanek and Albertson 1957; Fuhlendorf and Smeins 1998; Milchunas et al. 1988; Fuhelendorf et al. 2001; Fuhlendorf et al. 2009). Traditional grazing management has focused on uniform distribution of livestock, and uniform disturbance which reduces landscape heterogeneity (Bailey et al. 1996; Fuhlendorf and Engle 2001; Bailey et al. 2006; Bailey et al. 2008; Ellison et al. 2009, Holecheck et al.

2011).Temporal and spatial distribution of fire potentially increases heterogeneity and landscape health, being the principal determent of vegetation (Collins 1987; Hessburg and Agee 2003; Holecheck et al. 2004; Fuhlendorf and Engle 2004, Archibald et al. 2005; Fuhlendorf et al. 2006). European American settlement altered natural fire regimes and disturbance patterns thus altering species compositions and heterogeneity (Belsky and Blumenthal 1997; Hessburg and Agee 2003; Archibald et al. 2005; Fuhlendorf et al. 2006).

Disturbance effects should be considered collectively rather than independently. Disturbance combinations create negative and positive feedbacks which increase heterogeneity (Fuhlendorf et al. 2009). Burned areas may demonstrate increased grazing uniformity within the burn, thereby decreasing grazing pressure on specific plant species (Vinton et. al 1993; Hobbs et al. 1993; Wright 1974; Collins et al. 1998; Fuhlendorf et al. 2006; Fuhlendorf and Engle 2004). Grazer attraction to burns reduces biomass on current burns while allowing biomass to accumulate on unburned areas increasing landscape structural heterogeneity (Archibald et al. 2005, Fuhlendorf and Engle 2001, Fuhlendorf et al. 2006).

Grazing driven by fire may be referred to as pyric-herbivory and has been historically significant in maintaining grassland ecosystems (Archibald et al. 2005, Fuhlendorf et.al 2008). Pyric-herbivory may create variations in vegetation characteristics critical to biodiversity and ecosystem processes on rangeland landscapes. Grazing animals preferentially select burned areas, because the forage quality of recently burned sites is more desirable than the quantity available on undisturbed sites (Fuhlendorf and Engle 2004; Fuhlendorf et al. 2006; Allred et al. 2012; Vinton et. al 1993, Hobbs et al. 1993; Archibald 2005; Fuhlendorf et al. 2009; Engle and Bidwell 2001; Wright 1974). Historic disturbances may favor native species that are dependent on fire for resource cycling and are adapted to particular spatial and temporal regimes (Fuhlendorf and Engle 2004, Fuhlendorf et al. 2006; Hessburg and Agee 2003; Fuhlendorf and Engle 2001, Fleischner 1994; Hobbs and Schimel 1984).

Our study focuses on a mixed prairie location with long term (10 years +) patch-burn management. This unique study site includes topographically variable sites with replicated pastures for patch-burn treatment, traditionally managed pastures with similar grazing but no fire and an unburned, ungrazed management. The objective of this unique research opportunity was to evaluate patch-burn grazing management influences on diversity of native forb species. Diversity of native plant species and functional groups are indicators of ecosystem health and a community’s capacity to self-regulate (Magurran 1955, Diaz 2006, Davies et.al 2007, Levine and HillisRisLambers 2009). We predicted that spatial and temporal application of fire and grazing would influence forb species composition and abundance.

MATERIALS AND METHODS

STUDY AREA

Research was conducted on the Marvin Klemme Range Research Station, an Oklahoma State University Agricultural Experiment Station, located near Bessie Oklahoma. The station is approximately 630 ha of rolling uplands cut by several creeks and drainages. Vegetation in this region is classified as mixed prairie with wooded drainages. Dominant grasses in this area include *Bouteloua curtipendula* (Michx) Torr., *Bouteloua gracilis*

(Willd. ex Kunth) Lag. ex Griffiths , *Bouteloua dactyloides* (Nutt.) J.T. Columbus, *Bothriochloa saccharoides* (Sw.) Rydb., *Bouteloua hirsuta* Lag, and *Aristida purpurea* Nutt. Forbs recorded in this area include; *Grindelia squarrosa* (Pursh) Dunal, *Gutierrezia sarothrae* (Pursh) Britton & Rusby and *Amphiachyris dracunculoides* (DC.) Nutt. Dominate woody plant species include *Rhus glabra* L. and *Prunus angustifolia* Marsh (Gillen 2000; Fuhlendorf et al. 2002).

Marvin Klemme Range Research Station has shallow soil, comprised of weathered siltstone (Vermeire and Gillen 2000). Approximately 70 % of the research station is Cordell-Rock outcrop complex with a 2 to 15 % slope and approximately 19 % of the remaining area is classified as Cordell silty clay loam with a 3 to 5% percent slope (NRCS Soil Survey 2011). July is typically the warmest month with an average high of 36 ˚C and an average low of 21 ˚C. January is typically the coldest month with an average high of 10 ˚C and an average low of -4˚ C (Vermeire and Gillen 2000). The growing season is 204 d. Average yearly precipitation is approximately 75 cm. Weather conditions during 2010 were wetter and cooler than 2011 resulting in a large yr effect. July 2010 had 15.1 cm of rainfall and July 2011 had .4 cm of rainfall. Average July 2010 temperature was 27.2 ˚C. Average July 2011 temperature was 33.1˚C. The 4 inch bare soil temperature was 28.8˚C in July of 2010 and 34.2 ˚C in July 2011. More complete rainfall data is not available due to gaps in data collected by the Bessie Oklahoma Mesonet Station. [OCS 2011]

ASSIGNMENT OF TREATMENTS

The Marvin Klemme Range Research Station has been grazed by domestic livestock for approximately 100 yrs. Management and stocking rate is unknown before 1988. Most of the research area is uncultivated mixed prairie, but approximately 30 % of the land area was previously farmed. Farmed areas were reseeded with native grasses or allowed to re-vegetate naturally (Gillen et al. 2000). Previously cultivated fields range in size from 3 to 27 ha and are scattered within pastures (Gillen et al. 2000). Current management practices were initiated in 1989 (Fuhlendorf et al. 2002). Five pastures were sampled in this study representing three management practices. Sampled pastures; two patch-burned pastures, two continuously grazed pastures, and one ungrazed/unburned pasture. During the decade previous to this study pastures were stocked with yearlings. Pastures were stocked with cow/calf at the time of this study. Equivalent stocking rates were maintained. All grazed pastures were stocked at a moderate rate (approximately .63 AUM ha-1) based on site recommendations by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). Spring burns were conducted with fixed spatio-temporal application. Within patch-burn pastures, burns were applied to a quarter of each pasture (referred to as patch) in sequential rotation that resulted in a 4-yr fire return interval.

STUDY DESIGN AND DATA COLLECTION

Plant community was sampled in June, and July during the summers of 2010 and 2011. Patch-burn pastures and traditionally managed pastures were divided into four corresponding patches of approximately the same area. Unburned, ungrazed patches were of smaller area. Patches in the patch-burn pasture varied in time since fire (current year's burn, one year since fire, two years since fire and three years since fire).

SPECIES AREA CURVES

A transect method was used for vegetation sampling (Canfield 1941). Each upland patch had two permanently marked transects; 75 m in length and 2 m in width, with a north-south orientation. Species were recorded at first observation within the transect line and total accumulation of species was recorded. Species area curves were formed from the transect data (Gleason 1922). Sampling order was random; however, one transect per patch was sampled until all treatments had been sampled once. This was done to minimize variation in seasonal growth.

SPECIES ABUNDANCE

A modified nested plot survey was used for sampling of canopy cover and species abundance (Canfield 1941). The modified nested plot survey was a 5 m square area subdivided into 1 m square plots, referred to as subplots. Canopy coverage was recorded for every other subplot in a checkerboard pattern. In each subplot percent canopy cover (bareground, forb, succulent, litter, grass) and species cover were recorded. Subplot values were combined to obtain a value for the entire plot. The subplot design compensates for any small scale topoedaphic variables that may exist. Broad scale samples are generally not as susceptible to fine scale spatial and temporal variables (Fuhlendorf and Smeins 1996, Fuhlendorf and Smeins 1998).

Each patch contained two upland plots. Plots were offset one meter to the west of the north transect marker. Sampling was done in a random order. One upland plot per patch was sampled until all treatments had been sampled once.

STATISTICAL ANALYSES

Transect data was analyzed using ANOVA, GLIMMIX procedure (SAS Institute. 2011). Species area curves were formed by determining significant differences between species accumulation values at transect lengths 1, 2, 4, 8, 16, 32, 64 and 75 m.

Species coverage data within modified nested plots was averaged to produce a single sample value for each treatment and time since fire patch. Plot values were averaged by year. Data was analyzed using PC-ORD Software (McCune and Mefford 2006). Detrended Correspondence Analysis ordination (here after referred to as DCA) was used with default options, with a down rating for rare species (Fuhlendorf and Engle 2004). DCA arranges sites by compositional similarity, which reflects total environmental variation. Patch-level heterogeneity was accessed using DCA site scores and standard deviations. Potentially influential individual forb species were identified from species loading scores. Heterogeneity within each pasture was analyzed using standard deviations of vegetation among time since fire patches, traditional management and ungrazed, unburned treatments.

RESULTS

SPECIES AREA CURVES

A year effect was demonstrated as species area curves demonstrated greater accumulation in 2010 than 2011 (Fig. 2). Generally, species area curves were higher in June than July, demonstrating a seasonal affect. Pasture scale species area curves (patch-burn, traditional and ungrazed, unburned treatments) were produced from transect data. The June 2010 species area curve was the only curve to demonstrate a significant difference ($P > .0338$) among patch-burn, traditional and the ungrazed, unburned treatment (Fig. 2). Greatest species accumulation occurred within traditional treatment, followed by ungrazed, unburned and patch-burn treatment. Species area curves in July 2010, June 2011 and July 2011 demonstrated no significant differences at the pasture scale.

Species area curves within patch-burn treatments and separated by current year burn, 1 year, 2 years and 3 years since fire for June 2010, July 2010, June 2011, and July 2011 did not demonstrate significant difference between times since fire patches.

SPECIES RICHNESS

All treatments demonstrated a significant decrease in forb species richness from 2010 to 2011 most likely associated with a significant decrease in precipitation. June and July sampling periods were combined to provide values for 2010 and 2011. Generally, plant species richness does not demonstrate a difference between grazed and ungrazed (Fig. 3). Average 2010 species richness between grazed and ungrazed treatments did not demonstrate significant differences. Average species richness in 2011 within grazed treatments was 6.71 (± 1.24) and average species richness within ungrazed treatments was 7.13 (±.48). Species richness was greater in traditional treatments than patch-burn treatments (Fig. 4). Among time since fire patches sub-plot averages within traditional treatments were 15.95 (± .89) in 2010 and 10.16 (±1.48) in 2011. Current year burn demonstrated the least forb and succulent species richness with an average of 9.63 (±.79) in 2010 and 3.38 (±.56) in 2011 (Fig.5). Unburned, ungrazed treatment, and 1 yr, 2 yr and 3 yr time since fire demonstrated species richness of values between current year burn and traditional management.

PERCENT GROUND COVER

Generally, percentages of forb, grass, and litter increased with time since fire as bare ground decreased. Our first comparison demonstrated percent cover of bare ground was greater in grazed (patch-burn and traditional) treatments than ungrazed treatments. Within ungrazed treatments percent cover of litter, forb, and succulent were greater than grazed. A comparison demonstrated a greater percentage of forb and succulents within ungrazed, unburned management than patch-burn and traditional treatments. Succulent abundance within ungrazed, unburned management was approximately 7 times greater than patch-burn and traditional treatments. Traditional management demonstrated the greatest percentage of grass and litter with the smallest percentage of bare ground. Ungrazed, unburned management demonstrated greater grass abundance than current year burn but was similar to 1 year, 2 year and 3 years since fire. One year since fire demonstrated the smallest percentage of forb and succulents. One year since fire burn demonstrated the greatest percentage of bare ground (Table 1).

MULTIVARIATE ANALYSES

Greater heterogeneity within patch-burn treatments is suggested by greater variability of DCA axes. The range of patch site scores along DCA axes within treatments is an indicator of variability in forb species composition. Comparisons were made between 1) patch-burn and traditional and 2) grazed and ungrazed treatments. Heterogeneity (as indexed by standard deviation among patches) maintained higher variability within the patch-burn treatment than the traditional and ungrazed, unburned treatments. Cover differences by treatment at the pasture scale were minimal, with the exception of litter and bare ground. Grass and litter within patch-burn treatment increased with time since fire while bare ground decreased. All treatments and comparisons demonstrated a decrease in plant species richness from 2010 to 2011.

Comparisons of traditional and patch-burn demonstrated approximately 30% to 80% times greater variability within the patch-burn treatment than the traditional treatment and had eigenvalues of 0.51935 and 0.30026. Among grazed treatments, the range of axis 1 site scores, across all patches and years, within the patch-burn treatment were 40% greater, than the traditional treatments. Among grazed and ungrazed treatments axis 1 species loading ranged from -221 to 320 with an average of 93.20. On DCA axis 1, the order of influence of plant species, based on the species loading scores, were *Triodanis holzingeri* (-221), tree (-221), *Vernonia baldwinni* Torr. (-221), *Smilax rotundifolia* L. (-221), *Solanum dimidiatum* Raf. (-124), *Psoralidium Lanceolatum* (Pursh) Rydb. (-114), and *Dalea purpurea* Vent. (320). Range of axis 2 site scores within the patch treatment were 80% greater, across all patches and years, than traditional treatment. For DCA axis 2, the order of influence of plant species based on the species loading scores were an unidentified forb (-198), *Evolvulus nuttallianus* (Sw.) Rydb. (-170), *Astragalus* (-48), *Tragia ramosa* Torr. (-40) and *Psoralidium lanceolatum* (Pursh) (995). Axis 3 site scores within the patch-burn treatment were 30% greater across all patches and years than in the traditional treatment. Among grazed and ungrazed treatments axis 3 species loading ranged from -414 to 913 with an average of 66.04. For DCA axis 3, the order of influence of plant species based on the species loading scores were *Symphyotrichum falcatum* (Lindl.) G.L. Nesom (-414), *Dalea enneandra* Nutt. (-291), *Stenosihpon linifolius* (Nutt. Ex James) Heynh. (-284), *Solidago missouriensis* Nutt. (-273), *Erigeron bellidiastrum* Nutt. (-245), *Helianthus* (-245), *Asclepias stenophylla* A. Gray (-239), *Oxalis Stricta* L. (-200) and *Solanum elaeagnifolium* Cav. (913).

A comparison of grazed (patch-burn, traditional) and ungrazed (unburned) treatments indicated greater heterogeneity within grazed treatments by a greater range of variability. Axis 1 and axis 2 demonstrated greater variability within the grazed treatment (Fig. 6). Eigenvalues were 0.49207 and 0.28633. The range of axis 1 site scores within the grazed treatment was almost twice as great as the ungrazed treatment. On DCA axis 1, influential plant species, based on the species loading scores, include *Melilotus officinalis* (L.) Lam (-181), Triodanis holzingeri (-161), tree (-161), *Vernonia baldwinni* Torr. (-161), *Solanum dimidiatum* Raf. (-129), *Ipomoea lindheimeri* A. Gray (-90) and *Dalea purpurea* Vent. (330). Range of axis 2 site scores within the grazed treatment was approximately 10% greater across all patches and years than the ungrazed treatment. Axis 2 species loading ranged from -84 to 459 with an average of 180.07. On DCA axis 2, influential plant species, based on the species loading scores, include *Acacia angustissima* (Mill.) Kuntze (-84), *Glandularia bipinnatifida* (Nutt.) Nutt. (344), *Pediomelum cuspidatum* (Pursh) Rydb. (383)and *Psoralidium Lanceolatum* (Pursh) Rydb.

(459). Among grazed and ungrazed treatments axis 3 species loading ranged from -188 to 472 with an average of 100.16. Range of axis 3 site scores within the ungrazed treatment was almost 70% greater across all patches and years than the grazed treatment. On DCA axis 3, influential plant species, based on the species loading scores, include *Echinocereus reichenbachii* Terscheck ex Walp. (-188), *Evolvulus Nuttallianus* (Sw.) Rydb. (-138), *Solanum elaeagnifolium* Cav. (-128), *Tragia ramosa* Torr. (-120), *Astragalus* (-95), *Sisyrinchium angustifolium* Mill. (-44), *Yucca glauca* Nutt. (374) and *Polygala alba* Nutt. (472). It should be noted that *Silphium laciniatum* L. was observed in one of the patch-burn pastures although not within the measurement area. Forb and succulent species abundance demonstrated the greatest variability within the ungrazed, unburned treatment and the least variation within the traditional treatment.

DISSCUSSION

Heterogeneity may be the root of ecological processes that support biological diversity at all trophic levels but is rarely incorporated into application of ecological theory (Christensen 1997; Ostfeld et al. 1997; Wiens 1997; Fuhlendorf and Engle 2004; Fuhlendorf et al. 2006). Landscape heterogeneity is inherent at multiple scales due to variation in topo-edaphic features, species composition, species interaction and vegetation structure. Landscapes historically varied by time since disturbance promoting heterogeneity through positive and negative feedbacks (Fuhlendorf and Engle 2004; Fuhlendorf et al. 2006). Traditional land management and conservation practices based on the intermediate disturbance hypothesis attempt to reach a single ecological state with diminished heterogeneity (Collins et al. 1995; Bailey et al. 1998; Fuhlendorf and Engle 2001; Holecheck et al. 2003; Fuhlendorf and Engle 2004; Bailey 2005, Vavra 2005; Fuhlendorf et al. 2006). Uniform disturbance may decrease heterogeneity and biodiversity throughout an entire ecosystem, altering; species population densities, nutrient cycling, community organization and ecosystem functioning (Fleischner 1994; Belsky and Blumenthal 1997; James et al. 1999; Fuhlendorf and Engle 2004; Fuhlendorf et al 2006; Allred et al. 2011b). Plant community heterogeneity influences diversity at higher trophic levels including; invertebrates, small mammals, large ungulates and birds (Wiens 1976; Archibald and Bond 2004; Fuhlendorf et al. 2006, 2009, 2010; Coppedge et al. 2008; Engle et al. 2008; Debinski et al. 2010; Moranz et al. 2012).

Heterogeneity and sustainability of grasslands may be dependent on the shifting mosaic of disturbances created by pyric-herbivory (Fuhlendorf et al. 2006; Fuhlendorf and Smeins 1997). Patch-burn grazing promotes pyric-herbivory, and may mimic historical temporal and spatial disturbances (Collins 1987; Hessburg and Agee 2003; Fuhlendorf and Engle 2004; Holecheck et al. 2004; Archibald et al. 2005; Fuhlendorf et al. 2006). Some native flora and fauna have evolved with and may be dependent on historical disturbance regimes (Fuhlendorf et al. 2009). Pyric-herbivory may be a management tool for species or communities that have demonstrated species specific responses to disturbance (Fuhlendorf et al. 2010, Moranz et al. 2012). Individual species may respond differently to disturbance and require a unique resource combination at which performance is optimized (Hartnett et al. 1996; Fuhlendorf and Smeins 1997, 1998; Tilman 1999; Brudvig et al. 2006; Ruthven III 2006; Ruthven III 2007; Scheintaub 2009). Heterogeneity may promote resource partitioning that stabilizes communities, conserves diversity, benefits species of small biomass and provides safe sites for sensitive species (Connell 1978; Fuhlendorf and Smeins 1997; Tilman 2000; Wacker et al. 2008; Tylianakis et al. 2008; Levine and HilleRisLambers 2009; Isbell et al. 2009). Decreased diversity may result in a loss of partitioning and productivity (Isbell et al. 2009). Species diversity and species composition influences on productivity may vary with context and may be interactive (Cardinale et al. 2000). Variation in community assemblages may be enhanced in mixed prairie by the presence of short and tall grass species.

Abundance of forb or succulent species on the landscape level in this study demonstrated a significant yearly difference across all treatments. The year effect may indicate that precipitation is more influential on forb species diversity than disturbance (Fuhlendorf and Smeins 1997). Plant species functional groups may respond differently to the variability of spatial and temporal water availability (Debinski et al. 2010). This study demonstrated no significant difference in forb or succulent species abundance between patch-burn, traditional and ungrazed, unburned treatments. Previous research has demonstrated a limited and inconsistent response on plant species composition between management types (Engle et al. 2000; Townsend II and Fuhlendorf 2010).

Understanding disturbances and site factor interaction may be foundational to grazing management strategies capable of promoting biodiversity, and sustainable grasslands utilization. Patch-burn grazing is not the only factor influencing forb species diversity. The June 2010 species area curve was the only sampling period that demonstrated a significant difference. Sampling periods from July 2010, June 2011 and July 2011 demonstrated no significant differences. Pre-treatment differences due to previous land management may produce legacy effects that influence results (Debinksi et al. 2011). Uniform applications of disturbance in the tall prairie have been associated with species abundance shifts, decreased heterogeneity and decreased species richness (Collins et al. 1995; Collins 2000, Fuhlendorf and Engle 2001). Previous studies in the tall prairie and worldwide have demonstrated a decrease in forbs under uniform fire regimes (Kucera and Koelling 1964; Collins 1987; Peet et al. 1999). Species that have not evolved with fire may decrease with increasing numbers of burns.

Interactive effects of pyric-herbivory may be more important than individual effects of fire or grazing (Fuhlendorf and Engle 2001; Fuhlendorf et al. 2009). Grazing may affect species composition however, other disturbances, precipitation, topography, soil water holding capabilities and season of grazing are also influential (Tomanek and Albertson 1957; Derner and Hart 2007). Focal grazing of burned areas may promote forb abundance by decreasing graminoid species dominance and litter which increases plant available light and bareground for utilization by forb species (Collins 1992; Briggs and Knapp 1995; Engle et al 2000; Fuhlendorf and Engle 2004; Fuhlendorf et al. 2006; Fuhlendorf et al. 2010). Patch mosaics created by grazer activity may favor new species colonization by releasing patches from strongly competitive dominants (Hartnett et al. 1996). Focal grazing promoted by burning may favor grazing tolerant species and reduce targeted grazing of palatable species (Archibald 2005; Fuhlendorf et al. 2008). Variation in species abundance and richness within time since fire treatments may also indicate edaphic factors are greater than treatment effect. Previous research suggests that land use legacies may have a greater effect than current management practices (Moranz et al. 2012). Post-disturbance communities may be distinctly different based on variation in disturbance type, disturbance interactions, intensities, precipitation, time since disturbance, season of burn, degree of succession, edaphic factors, land use and historical disturbance regimes (Hartnett et al. 1996; Engle et al. 2000; Brudvig et al. 2006; Ruthven III 2007). Our research site was grazed by domestic livestock for approximately 100 yrs with current management practices initiated in 1989 (Fuhlendorf et al. 2002). Approximately 30 % of the land area was previously farmed and re-vegetated (Gillen et al. 2000). It appears from a visual survey that species abundance of *Dalea purpurea* Vent. may be greater within the previously farmed areas of some pastures. *Dalea purpurea* Vent. is an indicator species in our DCA comparison of patch-burn and traditional treatment (320), as well as, grazed and ungrazed treatment (330). Presence of this species may be from legacy effects rather than current management.

Our research demonstrates structural heterogeneity is increased due to differences in vegetation structure (percent bare ground and grass cover) between treatments and patches of time since fire**.** Heterogeneity in vegetation structure created within a patch-burning system may increase variation in plant functional groups, habitat diversity and overall rangeland biodiversity (McGranahan et al. 2012a; Moranz et al. 2012). Percentage of plant functional groups, bareground, leaf litter, vegetation height and angle of obstruction vary with time since fire (Fuhlendorf et al. 2006**;** Townsend II and Fuhlendorf 2010; McGranahan et al. 2012b). Patch contrast and plant functional groups have not demonstrated a correlation with geographical gradient, pasture size, number of patches or fire regime (McGranahan et al. 2012a).

We utilized two sampling methods; transect data which generated species area curves and modified plot data for species richness and cover. Two sampling methods provided a better analysis because grazing and scale may influence sampling results

(Fuhlendorf and Smeins 1999; McGranahan et al. 2012b). The two species data sets were done in generally the same area but produced slightly varying results. In June 2010 the species area curves demonstrated a significant difference between treatments where species richness values demonstrated no significant differences between treatments. Variation of results demonstrates the influence of micro-site characteristics on species presence.

Our research demonstrated that species richness (although not significant) and forage nutrient content, as described in chapter 1, was lowest within 3 years time since fire patches. This may indicate historical return intervals however, severity of burn, season, size, patchiness and growth form may influence species return and regeneration rates (Engle et al. 2000). Responses may vary between tall, mixed and short prairies and with climate (Engle and Bidwell 2001). Effects of fire also vary with grazing history, stocking rate, fire frequency, fire- return interval, successional stage, plant composition, invasive species, herbicide use, topography, edaphic features of the landscape, landscape scale, soil water holding capabilities, precipitation, temperature and other weather conditions which influence forage growth and nutrient cycling (Tomanek and Albertson 1957; Howe 1994a; Engle et al 2000; Engle and Bidwell 2001; Derner and Hart 2007; Fuhlendorf et.al 2008; Davies et.al 2009; McGranahan et al 2012a; Moranz et al. 2012) Yearly affects should be anticipated as precipitation and temperature may influence species response. Disturbances that are too frequent may reduce the seed sources and threaten reproduction (Abrams 1988; Fuhlendorf and Smeins 1998).

Species area curves in this study demonstrated the accumulation of species did not vary significantly between treatments except in June 2010's sampling. Species area curves of forb and succulent species do not account for “desirable” or “undesirable species”. Area curves did not examine individual species response within each treatment. Degraded ecosystems with changes in native species composition, presence of invasive species and change in chemical processes may respond differently to historical disturbance regimes (Suding et.al 2004). Stocking rate and invasive species may also influence vegetation structure and herbivore patch selection (McGranahan et al 2012a). Altered ecosystems may require non-historical disturbances regimes (Brockett et al. 2001, Davies et.al 2009). Species response to disturbance may be dependent on scale and disturbances may have historically occurred on scales too large to replicate on today’s landscape (Fuhlendorf and Engle 2004).

IMPLICATIONS

Management did not demonstrate significant differences in plant species diversity among treatments. Heterogeneity benefits from patch-burn management are most likely a result of structural variation created by a temporally and spatially shifting mosaic of disturbances. The variation in PC-ORD axis between treatments in this study may be influenced by structural differences within treatments. Structural heterogeneity has demonstrated greater influences on higher trophic species diversity than plant species diversity if necessary plant functional groups are represented (Tews et al. 2004). Therefore, increasing structural heterogeneity may accomplish management goals of increased biodiversity and productivity.

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FIGURES AND TABLES

Fig. 1 Diagram of the Marvin Klemme Range Research Station (UGUB, un-grazed, unburned; MGPB, moderately grazed, patch-burn; MGUB, moderately grazed, unburned; riparian areas in gray). Within a patch-burn pasture patches are burned on a 4 yr rotation.

Fig 2. June 2010 species area curves of treatments (patch-burn, traditional, and ungrazed, unburned). Numbers of species present within a transect 75 meters length by 2 meters in width. June 2010 species area curve demonstrated a significant difference ($P > .0338$).

Fig 3. Forb species richness in 2010 and 2011 sampling periods in ungrazed and grazed treatments. Error bars indicate standard errors. Forb species richness was greater in 2010.

Fig 4. Forb species richness in 2010 and 2011 by traditional vs. patch-burn treatments. Error bars indicate standard errors. Forb species richness was greater in 2010.

Fig 5. Forb species richness in 2010 and 2011 sampling periods in the patch traditional treatment and ungrazed, unburned treatments. Error bars indicate standard errors across patch-by-year combinations. Traditional treatment demonstrated the greatest forb species richness. Current year burn demonstrated the least species richness.

Fig 6. Average DCA axis value of ungrazed and grazed treatments. Axis represents variation between treatment pastures but does not identify individual factors contributing to the variation. Values are combined for 2010 and 2011. Error bars indicate standard errors.

Table 1. Percent cover of plant functional groups (grass, forb, succulent), litter and bare ground observed in 2010 and 2011 sampling periods in the patch-burn treatment (grouped by times since fire), traditional treatment and ungrazed, unburned treatments. Standard errors are across patch-by-year combinations. Greatest percentages are indicated in red, smallest percentages are indicated in blue.

Combined Values: 2010 and 2011							
Time Since Fire							
		Ungrazed/ Unburned	Traditional	Current	1 Year	2 Year	3 Year
Bare Ground	-----%-----	24.54	21.68	63.92	64.52	34.85	35.89
SE		2.75	2.37	4.26	3.71	3.71	5.62
Litter	-----%-----	50.25	53.63	16.47	37.02	44.24	47.97
SE		4.29	5.35	3.35	5.93	6.17	7.67
Grass	-----%-----	41.67	58.44	26.32	41.42	46.79	45.93
SE		2.28	1.81	4.31	3.96	4.74	5.71
Forb	-----%-----	35.41	25.80	12.54	11.86	17.07	18.49
SE		6.46	1.37	2.68	2.57	3.46	3.69
Succulent	-----%-----	3.44	.44	.18	.06	.2	.13
SE		.59	.011	.08	.05	.05	.06

Fig. 1

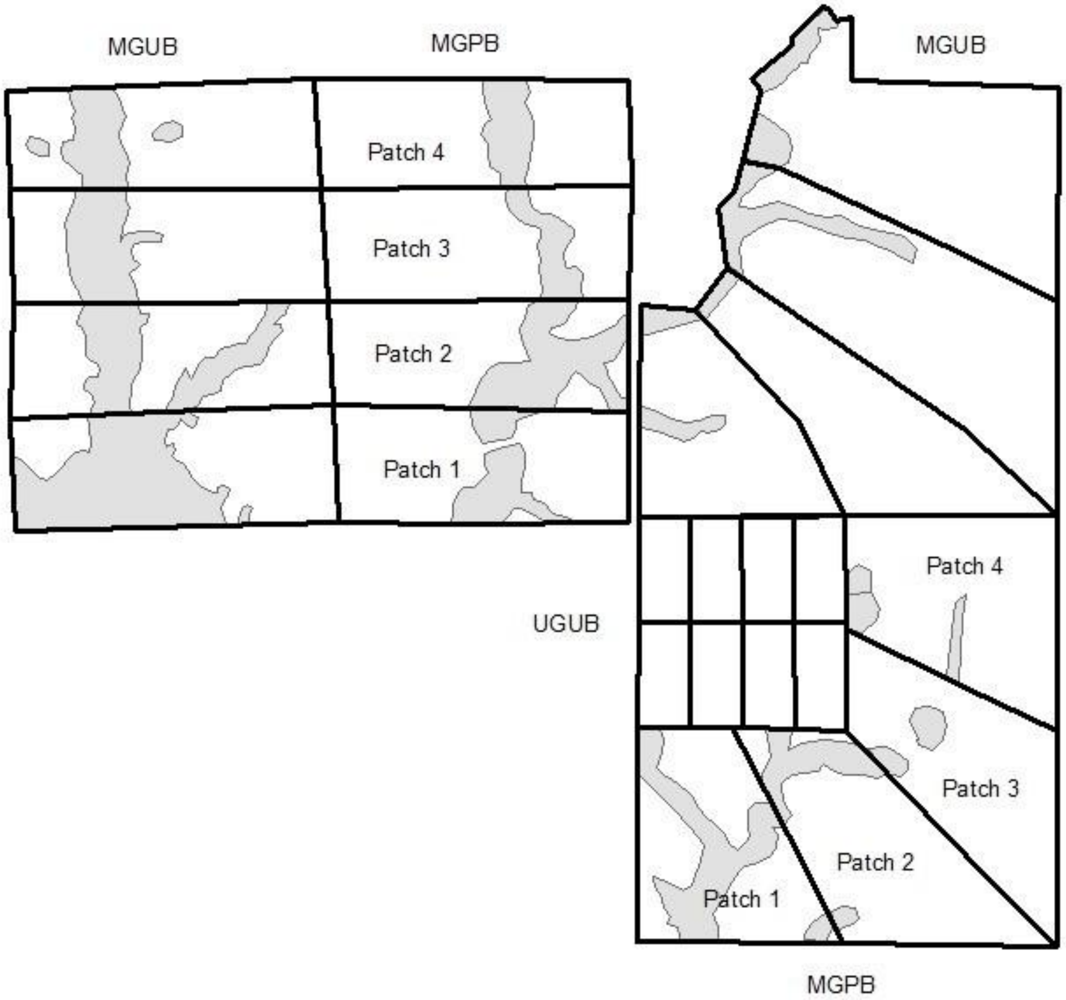
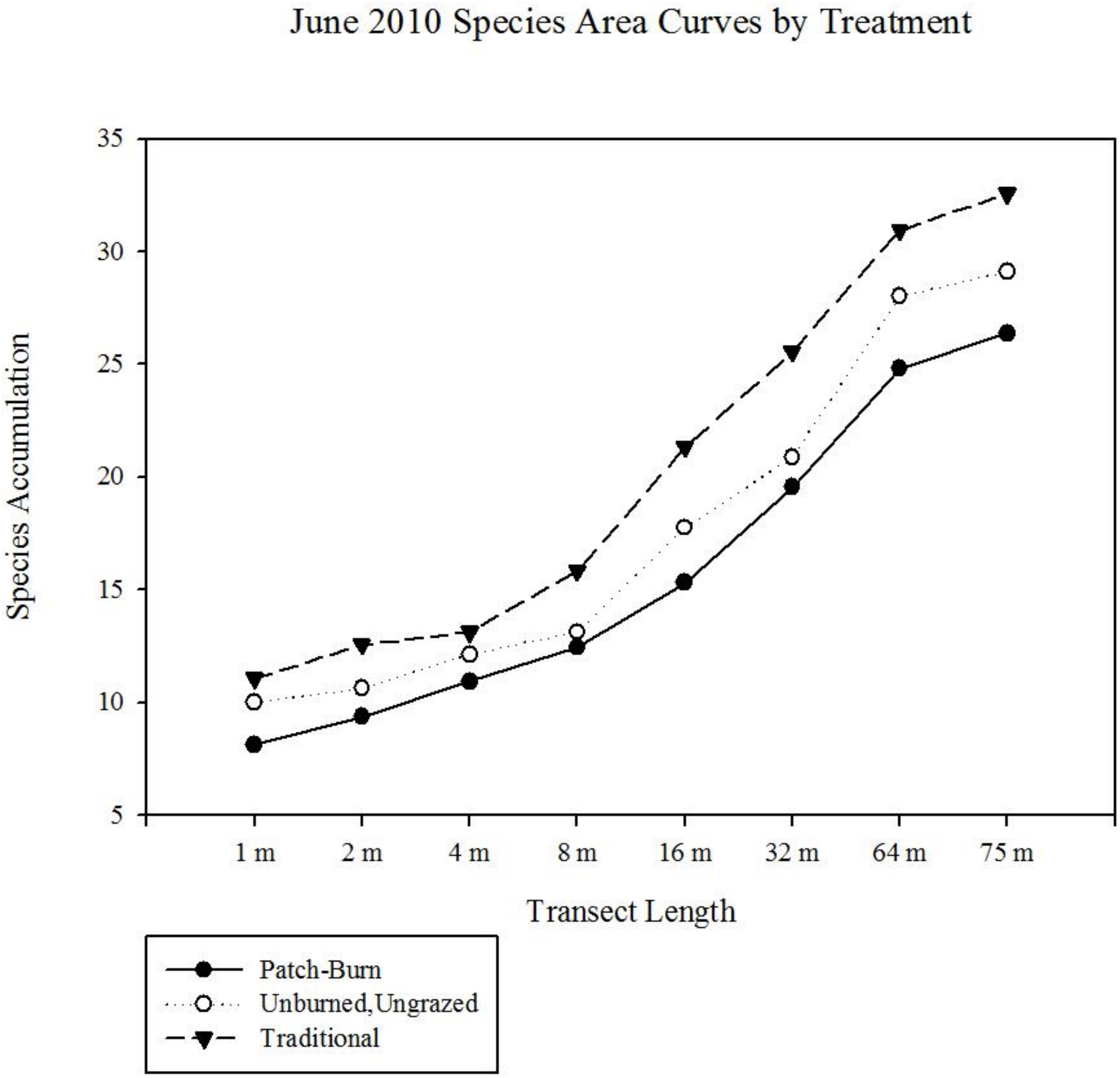

MGUB
MGPB
MGUB
Patch 4
Patch 3
Patch 2
Patch 1
UGUB
Patch 4
Patch 3
Patch 2
Patch 1
MGPB

Fig. 2



June 2010 Species Area Curves by Treatment
Species Accumulation
35
30
25
20
15
10
5
1 m
2 m
4 m
8 m
16 m
32 m
64 m
75 m
Transect Length
Patch-Burn
Unburned,Ungrazed
Traditional

Fig. 3

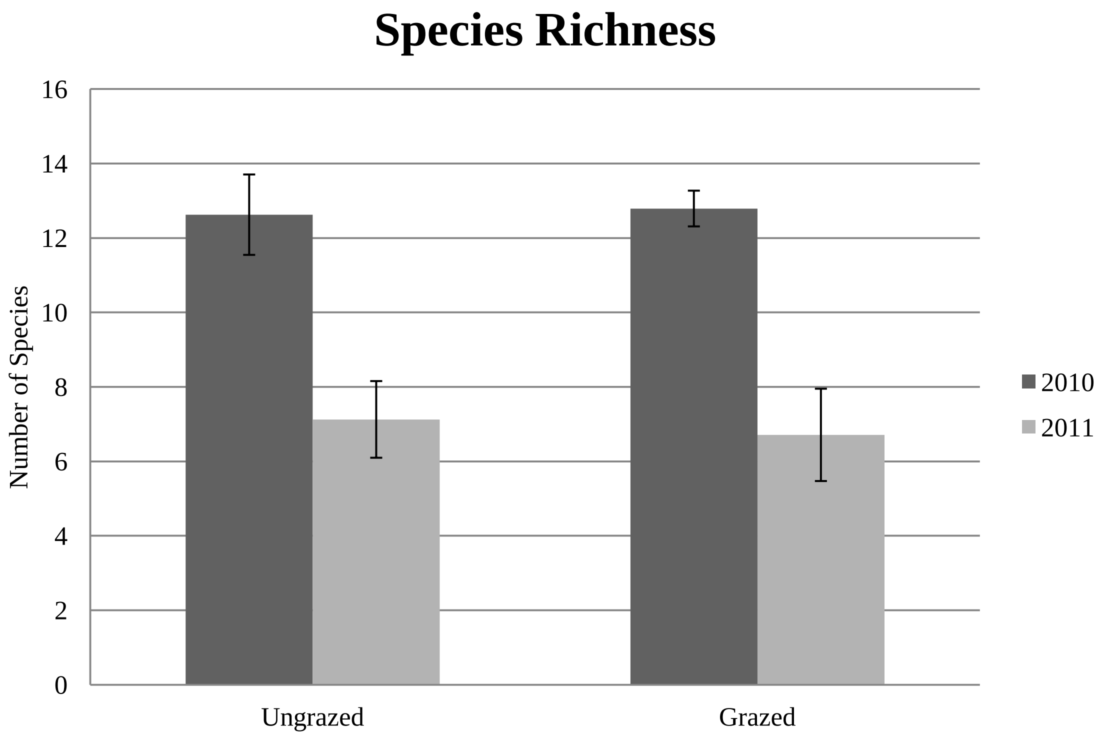

Species Richness
16
14
12
10
8
6
4
2
0
Number of Species
Ungrazed
Grazed
2010
2011

Fig. 4

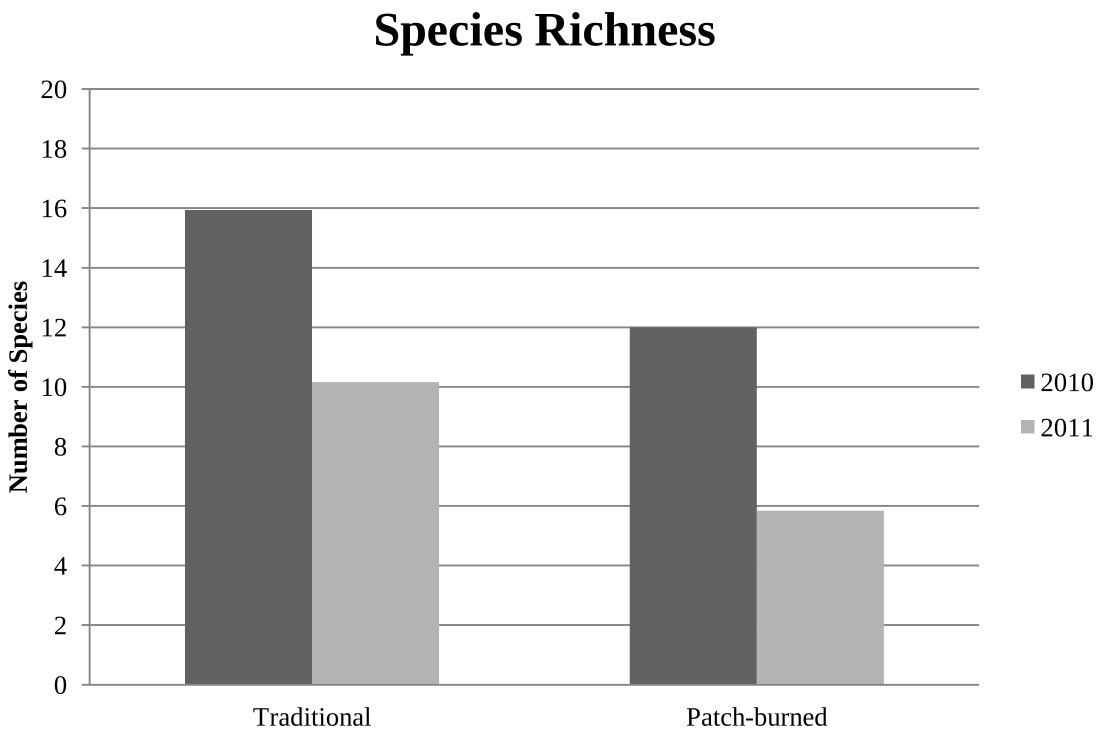

Species Richness
Number of Species
20
18
16
14
12
10
8
6
4
2
0
Traditional
Patch-burned
2010
2011

Fig. 5

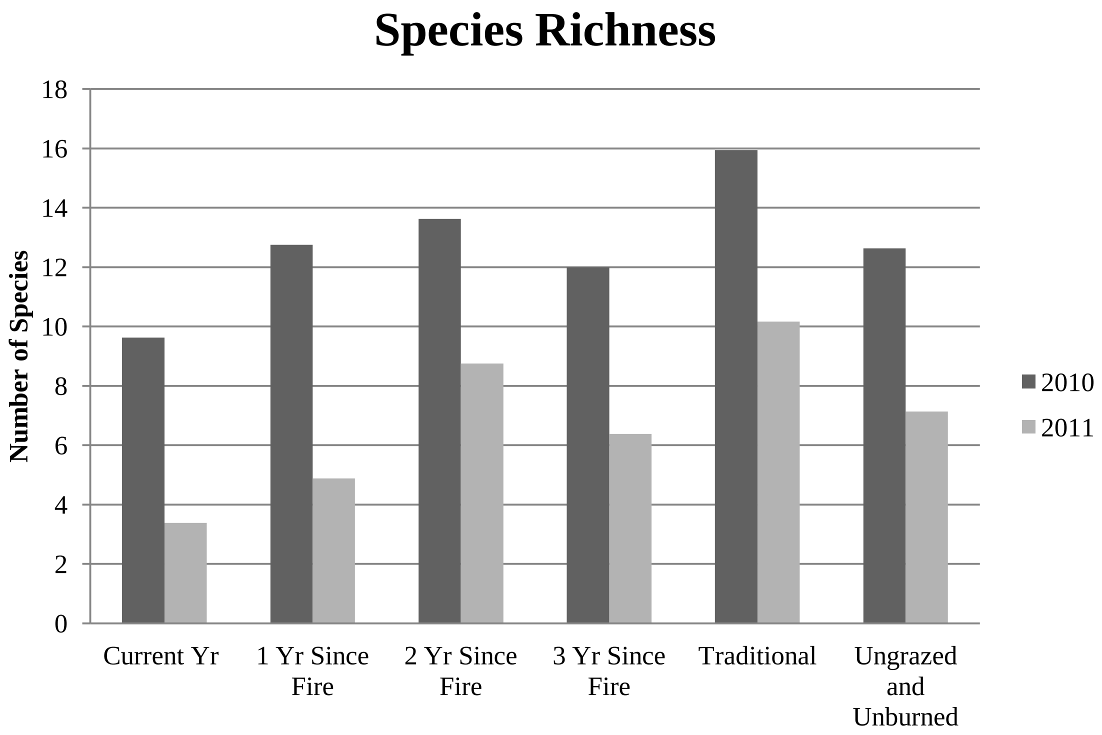
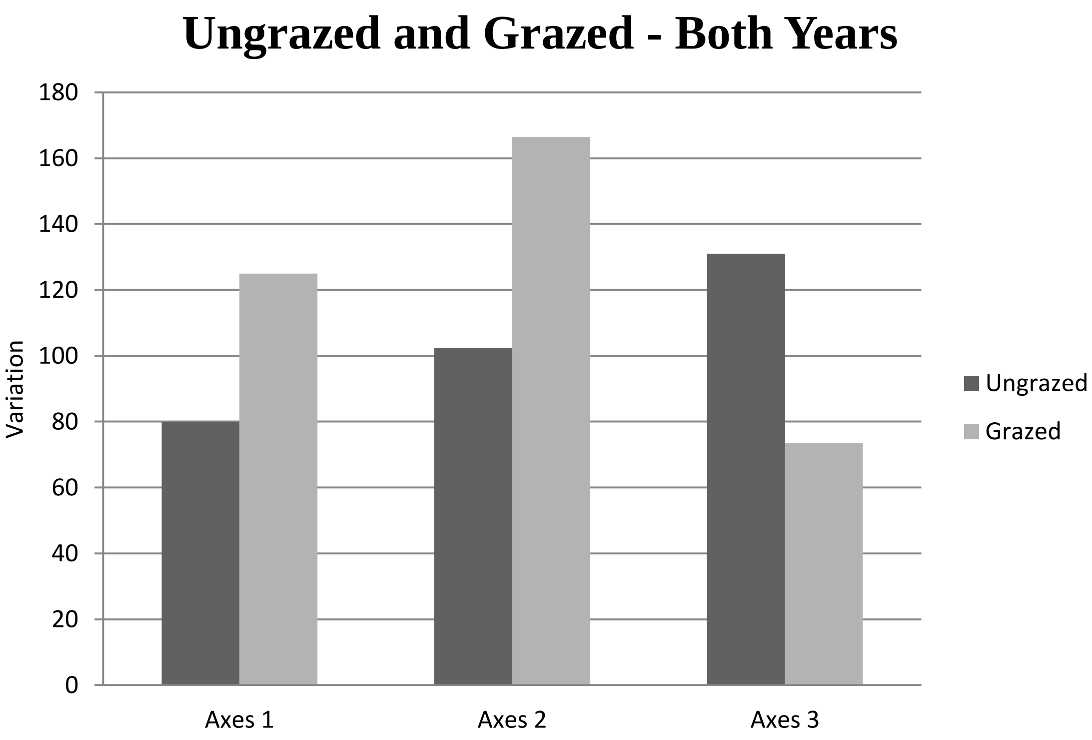

Species Richness
Number of Species
0
2
4
6
8
10
12
14
16
18
Current Yr
1 Yr Since Fire
2 Yr Since Fire
3 Yr Since Fire
Traditional
Ungrazed and Unburned
2010
2011

Fig. 6



Ungrazed and Grazed - Both Years
180
160
140
120
100
80
60
40
20
0
Variation
Axes 1
Axes 2
Axes 3
Ungrazed
Grazed

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