THE EFFECTS OF PYRIC HERBIVORY ON FORAGE QUALITY, FORAGE MINERALS, AND CATTLE GRAZING BEHAVIOR IN PREVIOUSLY AVOIDED AREAS

By

KATHERINE ELIZABETH HAILE

Bachelor of Science in Natural Resource Management

Sul Ross State University

Alpine, Texas

2020

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December 2022

THE EFFECTS OF PYRIC HERBIVORY ON FORAGE QUALITY, FORAGE MINERALS, AND CATTLE GRAZING BEHAVIOR IN PREVIOUSLY AVOIDED AREAS

Thesis Approved:

Laura E. Goodman, Ph.D.

Thesis Adviser

Samuel D. Fuhlendorf, Ph.D

Thesis Adviser

John R. Weir, M.S.

Bryan D. Murray, Ph.D.

ACKNOWLEDGEMENTS

I would like to thank my committee members, Dr. Laura Goodman, Dr. Sam Fuhlendorf, John Weir, and Dr. Bryan Murray for their work and attention during my master's. I would also like to thank the Prairie Project and Oklahoma State University Department of Natural Resource Ecology and Management for the funding and support throughout the project. My family and friends have been instrumental during my graduate research work. My mom and dad have been tremendous support during my college career and have always been there for me. Charlie and Ann Worthington offered immense support while I was at my study site during late night, weekend, and unexpected cattle mishaps as well as making me feel at home in the area. I really appreciate everyone on the burn crews who willingly drove all the way out to Klemme and back in the same day to help with the burns. I really appreciate Cooper Sherrill's work with getting cows to my study site and offering encouragement during the data collection and writing process. Anna Moeller and her amazing knowledge of R coding helped me through several seemingly unsolvable problems. I would also like to deeply thank Liz Haymaker, office mate and amazing friend, for her support, advise, and much needed distraction during my master's. She has been incredible moral support and an incredible adventure buddy. Many other people in my office and at OSU have greatly helped me during the research process and I would also like to thank my arms for always being at my side, my legs for holding me up during tough times, and my mouth for helping to fill the frequent emptiness inside me.

Name: KATHERINE HAILE

Date of Degree: DECEMBER 2022

Title of Study: THE EFFECTS OF PYRIC HERBIVORY ON FORAGE QUALITY, FORAGE MINERALS, AND CATTLE GRAZING BEHAVIOR IN PREVIOUSLY AVOIDED AREAS

Major Field: NATURAL RESOURCE ECOLOGY AND MANAGEMENT

Abstract: Pyric herbivory is grazing behavior driven by animal selection of palatable regrowth following fire. Land managers can apply pyric herbivory by patch burning portions of a pasture and allowing cattle access to unburned and freshly burned areas simultaneously. Other studies have shown that cattle select for burn patches and that freshly burned areas have higher nutritional quality. In this study, located in the mixed grass prairie of Oklahoma, we strategically burned areas cattle avoided to modify their behavior and redistribute grazing pressure in a pasture. We also evaluated the effects of patch burn grazing on vegetation composition, forage quality, and mineral content. Five cows, individually equipped with a GPS collar, grazed one of three study pastures during the summer of 2020 and 2021. At the end of year one, cattle distribution was analyzed using a Hot Spot analysis to determine avoided areas. Burn patches were selected from avoided areas. In our second year, two patches were burned in the spring and summer within each pasture with cows released in the pastures following the dormant season burn. The vegetation composition, nutritional components, and mineral contents were sampled every two months following fire until the end of the growing season. Cows were successfully drawn to previously avoided areas using patch burning. We found 83% of the dormant season burn patches experienced an increase in cattle use. While 60% of the growing season burns showed higher cattle use with fire. Nearly all forage nutritional components measured were higher in the burned patches compared to unburned areas during the same sampling session until approximately six months after fire. Grass and forb cover and total biomass was also statistically the same as unburned areas six months post-fire. Pyric herbivory successfully altered grazing distribution, by increasing cattle use of avoided areas and increasing mineral content and quality of forage.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER I

CHAPTER II

Figure Page

Figure Page

LIST OF TABLES

CHAPTER I

CHAPTER II

CHAPTER I

NATIVE VEGETATION RESPONSES TO PYRIC HERBIVORY
IN THE MIXED GRASS PRAIRIE

ABSTRACT

Pyric herbivory, the interaction between fire and cattle grazing, provides higher quantity forage in unburned areas of a pasture, while offering areas with higher forage quality in recently burned patches. Regrowth in recently burned patches has greater nutritional quality compared to unburned areas, which is typically quantified by crude protein and fiber. Forage minerals have not been well studied in native rangeland forage but are important to cattle diets. Our project evaluated changes in minerals essential in cattle diets, tracked changes in vegetation cover and species composition, and determined biomass and species diversity effects on tested variables. The study site for this project was in the mixed grass prairie of western Oklahoma. To quantify the change in vegetation quality and mineral availability, we sampled vegetation in the burned and unburned areas every two months following the initiation of burning in our three study pastures. We recorded cover by vegetation type and clipped each plot to determine biomass and nutritional content. The project results indicated that forage quality increases with burning, declines through time since fire, and returns to unburned

levels at approximately six months post-fire. Therefore, frequent fire is needed to receive the most nutritional benefits of pyric herbivory.

INTRODUCTION

Fire is an important disturbance in North American grasslands. Historically, in the Southern Great Plains, it occurred every two to ten years (Guyette et al., 2012), but fire suppression has greatly reduced fire frequency on many rangelands (Axelrod, 1985; Bond et al., 2003; Stambaugh et al., 2009). Fire suppression in North America began with European settlement and has since caused an increase in woody plant dominance in shrubland and prairie ecosystems (Ansley et al., 1995; Archer et al., 2017). In fire-adapted ecosystems, fire suppression allows woody plants to encroach, causes a significant loss of native wildlife, and reduces livestock forage production (Archer et al., 2017). Prescribed fire is an effective control of non-resprouting woody plants and tree seedlings across rangelands, but because of concerns about fire safety and needed burning equipment, it is often difficult for land managers to reimplement burning on their property (Haines & Busby, 2001; Maguire & Albright, 2005; Melvin, 2018). However, fire has proven to be a far more economical option for maintaining healthy ecosystems through reducing mesquite and juniper species when compared to alternative methods such as mechanical or chemical control (Van Liew et al., 2012).

Pyric herbivory, through patch burning, incorporates fire into a grazing regime by burning portions of a pasture without removing grazing pressure (Allred et al., 2011; Fuhlendorf & Engle, 2001; Fuhlendorf et al., 2017), and cattle retain access to unburned and freshly burned areas simultaneously. Recently burned patches have higher nutritional quality as commonly measured by crude protein, fiber, and a few limited minerals (Mbatha & Ward, 2010; McGranahan et al., 2014). Pyric herbivory creates structural and species heterogeneity as a result of varying grazing distribution and intensities, promoted by the patch fires (Fuhlendorf & Engle, 2001). The resulting heterogeneity assists in drought mitigation because it establishes and maintains a forage stockpile in a pasture (Allred et al., 2014; McGranahan et al., 2014; Spiess et al., 2020). Once established in a pasture, pyric herbivory increases cattle weight gains in the mixed-grass prairie through increase forage productivity (Limb et al., 2011). It also improves cattle production through reducing external parasite abundance (Polito et al., 2013). Pyric herbivory offers many benefits to a cattle operation while maintaining a fire regime.

Vegetation nutritional quality, which is essential in cattle production, is affected by time since fire, structural heterogeneity, and vegetation types all of which can be managed by pyric herbivory. Higher forage quality improves cattle performance through increased conception rates, higher weaning weights, and the possibility of increasing stocking rates, while reducing needed supplementation. Cattle nutritional requirements in a cow/calf operation change during different stages of the reproductive cycle with the highest nutritional demand being during peak lactation, 40-60 days after calving (Hutjens, 2002). Because recent burns contain the highest nutritional quality, which declines through time since fire (Allred et al., 2011), patch fires can increase forage nutrition at critical times of the year for cattle, such as peak lactation. Patch burning can create areas with higher quality forage by creating shorter, lower biomass areas which have better nutritional quality than taller, higher biomass areas (Thapa et al., 2022; Welti et al., 2020). Burning patches on a landscape can also increase nutritional quality by increasing forb cover (Clark et al., 2014; Weir & Scasta, 2017) which have higher protein and digestibility than grasses (Holechek, 1984).

The objectives of our study aimed to reconfirm known and further develop vegetative responses to pyric herbivory. Our first objective was to determine the effects of dormant and summer prescribed fire on forage minerals (calcium, phosphorus, magnesium, potassium, sodium, iron, zinc, copper, manganese, and molybdenum), forage quality metrics (crude protein, acid detergent fiber, neutral detergent fiber, and total digestible nutrients), plant functional group cover (grass, forb, and woody), plant species composition, and vegetation biomass. Our second objective was to examine if these effects were consistent between mixed-grass prairie areas dominated by short grass species versus those dominated by tallgrass species. Our final objective was to determine relationships between biomass with measured nutritional and vegetative components, as well as grass cover with species richness and diversity.

We hypothesize that both dormant and summer patch burns will increase forage minerals and forage quality metrics. We believe that plant functional group cover, species composition and total biomass will not be affected by fire within six months following the fire, regardless of burn season. Secondly, we hypothesize that both shortgrass and tallgrass dominated areas will respond in a similar way. Lastly, we hypothesize that higher total biomass, longer time since fire, and lower species diversity will negatively affect forage nutritional quality, in terms of crude protein, digestibility, and mineral content.

METHODS

Study Area

The study was conducted at the Oklahoma State University Marvin Klemme Range Research Station, near Bessie, Oklahoma (35.416961, -99.060514). It comprises approximately 631 ha in Washita County, and 192 ha divided among three pastures were used for the study. It is located in the Rolling Red Hills Ecoregion of Oklahoma which is characterized by rolling hills of typically mixed grass prairie (Woods et al., 2005). Scattered throughout this ecoregion and property are heavily eroded riparian areas dominated by many woody species, including eastern red-cedar (*Juniperus virginiana*) and hackberry (*Celtis* spp.) (Bidwell et al., 2007).

The study site lies within the Western Redbed Plains which contain red Permian sandstone and shales (Bidwell et al., 2007). There are four soil types in the three study pastures including: Cordell-Rock Outcrop complex (75%), Cordell (22%), Quinlan-Obaro complex (2%), and Obaro (1%) (Web Soil Survey, 2021). There are four ecological sites associate with our study pastures: Red Shale, Loamy Upland, Sandy Loam, and Shallow Upland (Web Soil Survey, 2021). The most common site is the Red Shale which encompasses over 74% of the study pastures.

For this area, the average annual rainfall is 778.764 mm, mean minimum temperature is 9° C (48° F), mean annual temperature is 16° C (60° F), and the mean maximum temperature is 22° C (72° F) (PRISM Climate Group, 2020). Most of the rainfall occurs from March through June with another peak of rainfall in August through October with lower amounts being observed during the winter months of November, December, January, and February.

Common grass species on this site include: gramas (*Bouteloua* spp.), little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), dropseeds (*Sporobolus* spp.), threeawns (*Aristida* spp.), and cheatgrass (*Bromus tectorum* and *B. japonicus*.) (Web Soil Survey, 2021). Forbs are typically less abundant, though common, and include, but are not limited to yellow sundrops (*Calylophus serrulatus*), ragweed (*Ambrosia psilostachya*), white sagebrush (*Artemisia ludoviciana*), prairie clover (*Dalea* spp.), primrose (*Oenothera* spp.), and Illinois bundleflower (*Desmanthus illinoensis*) (Web Soil Survey, 2021). Many of the woody species are confined to the riparian areas but some are common in the upland areas. Several species that can be easily found are redberry juniper (*Juniperus virginiana*), fragrant mimosa (*Mimosa borealis*), and fragrant sumac (*Rhus aromatica*) (Web Soil Survey, 2021). All ecological sites have had a historical fire presence which keeps woody species from encroaching on the upland areas, but they are at risk of altered plant communities with modern fire suppression (Web Soil Survey, 2021).

The three similar sized pastures used in the study have not been grazed by domestic herbivores since 2016. Likewise, no prescribed fire has been done in several years in two of the pastures and none has been implemented in the third pasture since 1988 when Oklahoma State University received the property. Therefore, there was a moderate amount of litter cover and fuel throughout the study pastures from a lack of grazing and fire.

Data Collection

Throughout the project, we monitored the vegetation changes and responses, in terms of both the composition and the nutritional content. We used a ¼ m^2 quadrat and vegetation cover classes (<5%, 5-25%, 25-50%, 50-75%, 75-95%, and 95-100%). In the field, we recorded cover and species composition, then clipped the plot to later dry and measure biomass. We weighed the samples after drying them for one week at 55° C then ground them through a 1 mm screen before shipping them to the Dairy One Forage Lab in Maryland for nutritional analysis. The lab tested for dry matter (Goering & Van Soest, 1970), crude protein using the nitrogen content (AOAC, 2006), neutral detergent fiber or NDF using the filter bag technique (ANKOM, 2020a; AOAC, 2005), acid detergent fiber or ADF using filter bags (ANKOM, 2020b; Van Soest et al., 1991), non-fiber carbohydrates or NFC, and net energy for maintenance, lactation, and gain. The lab analyzed our samples for many different minerals such as calcium, phosphorus, magnesium, potassium, sodium, iron, zinc, copper, manganese, and molybdenum (Dairy One, 2021) by using spectrometry on pre-digested samples.

In each pasture, we delineated a total of four burn units, two dominated by shorter, lower biomass vegetation and two dominated by taller, higher biomass vegetation. Each burn patch was 2.07 ha, approximately 2-4% of the pastures. Dormant and summer burns were conducted in March and June, respectively, of 2021. Before burning each patch, we collected 10 random samples using the same clip and weigh method sampling points to determine vegetation biomass within each patch and across treatments. The fuel loads for the spring burns averaged 3,200.0 and 1,361.8 kg/ha for the tallgrass and shortgrass patches, respectively. The summer burn patch fuel loads averaged 2,992.8 kg/ha in the tallgrass patches and 1,876.9 kg/ha in the shortgrass patches. During each burn, we recorded weather conditions and burn time and used the relative humidity to calculate fuel moisture dividing relative humidity by five (NWCG, 2021). We documented the days since and until precipitation for each burn day and volumetric soil water content at 36 cm using downloaded NEON data (NEON, 2022). We collected fuel load weather conditions, and fuel moisture prior to burning because these characteristics determine fire intensity which effects vegetation responses (Falk et al., 2007).

Once burns were completed, we sampled vegetation every two months during the summer (May, July, and September) to track the vegetation composition, biomass, and nutrition changes after the fires. We sampled three random points inside the burn patch and three random points at least 50 m outside the same patch with the same vegetation type found within the burn patch.

Weather conditions were similar for patches burned within each season as burns were conducted in one day for each of the dormant and summer burn treatments. Dormant-season burn day temperatures, humidity, and wind speeds ranged from 7.2 - 18.3 °C, 45 % to 74.6 %, and 2.1 and 7.9 km/hr., respectively (Table 1.1). Summer burn day temperatures, humidity, and wind speeds were 31.0 to 36.4 °C, 46.2 to 67.9 %, and 1.6 to 5.4 km/hr., respectively (Table 1.1).

The fuel loads ranged from 420 to 9,740 kg/ha just prior to burning (Table 1.1). The tallgrass/spring burn units averaged 3,200 kg/ha (354 SE); the shortgrass/spring burn patches averaged 1,362 kg/ha (117 SE); the tallgrass/summer burns averaged 2,993 kg/ha (311 SE) prior to fire; the shortgrass/summer burns differed from the spring burn units of the same fuel load at an average of 1,877 (114 SE). See Appendix D for fuel load distribution by burn treatment.

Data Analysis

We analyzed the vegetation composition and forage quality data by grouping sampling points by burn treatment with the three pasture replicates and determined the difference between burning in the dormant and summer in tallgrass and shortgrass dominated areas, compared to not burning. For each nutritional component, we tested for normality by group using a Shapiro Wilk test and conducted an ANOVA to determine if there were significant differences between burn treatments. For non-normal sample distributions, we used a Kruskal Wallis test which determined if significant differences existed between treatment groups. If we found significant difference between the groups ($P < 0.05$), we analyzed the treatments with a Tukey Post Hoc test after an ANOVA and a Wilcox Pairwise test after a Kruskal Wallis test. All analyses were conducted in RStudio (R Core Team, 2022; RStudio Team, 2022).

To quantify how biomass affected vegetation characteristics and nutrition, along with how grass cover affected species diversity and richness, we tested linear, quadratic, and exponential models for best within each relationship in RStudio. We used the lm function in RStudio from the stats package (R Core Team, 2022) to fit each model. All models were then tested against each other by predictor and response variable for fit with the Akaike Information Criterion using the AICctab function (Bolker & R Development Core Team, 2022). We used the summary function in RStudio to find the p-value and R^2 of each top model from each relationship to quantify the goodness of fit for each relationship.

RESULTS

Nutrition variables were significantly higher in the burned patches compared to unburned areas until six months after burning ($p < 0.05$). Grass and forb cover in both dormant and summer burn patches were significantly lower following fire ($p < 0.05$) but recovered by six months after burning. Between tallgrass and shortgrass burn patches, ADF, Magnesium, zinc, and species richness; all other components were statistically the same in both treatments. Time since fire, which also positively affected biomass, was a predictor variable in nutritional quality with longer time since fire resulting in lower levels of the tested nutritional components. All nutritional variables including crude protein, NDF, ADF, and TDN were significantly higher during the May and July sampling sessions in the spring burns and during the July and September data collection periods for the summer burns (Table1.2). In the spring burns, all forage quality metrics returned to unburned levels by September, six months post-fire, except ADF which remained lower.

Forage minerals showed a similar trend to forage quality metrics with higher levels in the spring burns until the September sampling session, when all variables returned to unburned levels. Summer burns also maintained higher forage mineral levels than unburned areas following fire (Table 1.2). Exceptions include: calcium, which was higher ($p < 0.05$) than unburned areas in the spring burns for May and July; sodium, since little to none was detected in the samples; zinc, which only differed from the unburned areas two months post-burning in the spring burns ($p < 0.05$); manganese, which was significantly higher in July for both burn seasons and in September in the summer burns

($p < 0.05$); and molybdenum, which was only higher than unburned areas in the summer patches in July ($p < 0.05$) with very low detected amounts across all samples.

After the spring burns and focal grazing, grass cover and biomass were significantly lower ($p < 0.05$) than unburned areas up to six months post-fire (Table 1.2, Figure 1.1, Figure 1.2). Forb cover was statistically the same for two-, four-, and six-months post-fire in the spring burns compared to the corresponding unburned areas (Figure 1.3). Grass cover in the summer burn patches was significantly lower ($p < 0.05$) one and three months post-fire. The summer burn forb cover was significantly lower one-month post-burning ($p < 0.05$) but had returned to unburned levels by three months after burning. Bare ground was significantly higher following fire through all sampling months and did not return to the average unburned levels of 0% cover during our sampling period of up to six months post fire.

Between tallgrass and shortgrass patches we detected four significant differences across all sampling sessions, nutritional and vegetation components, and burn seasons. Acid detergent fiber (ADF) was higher in the tall grass patch (41.5 ± 1.2 SE) compared to the shortgrass patch (36.5 ± 0.5 SE) in the summer burn units one month post fire. Magnesium was lower in the tallgrass patch (0.28 ± 0.02 SE) compared to the shortgrass patch (0.39 ± 0.03 SE) in the spring burn units two months post burning. Similarly, zinc was lower in the tallgrass patch (41.7 ± 3.1 SE) than the shortgrass patch (60.4 ± 3.2 SE) in the spring burns two months post-fire. Lastly, the tallgrass burn unit averaged few species per plot (5.0 ± 0.6 SE) compared to the shortgrass patch during the spring burn two months post-burn. Because we found very few differences between tallgrass and shortgrass patches, we grouped variables by burn season and time since fire.

Several significant relationships exist between biomass, time since fire, species diversity, species richness, grass cover, and forb cover with the nutritional variables (Table 1.3). Biomass was a significant predictor of crude protein (p<0.001, Figure 1.5), NDF (p<0.001), ADF (p<0.001), TDN (p<0.001), calcium (p = 0.044), phosphorus (p <0.001), potassium (<0.001), magnesium (p < 0.001), copper (p<0.001), manganese (p <0.001), molybdenum (p = 0.021), iron (p <0.001), and zinc (p = 0.007). Time since fire was a significant predictor of crude protein (p < 0.001), ADF (p = 0.007), calcium (p = 0.002), phosphorus (p < 0.001, Figure 1.6), potassium (p < 0.001), magnesium (p = 0.046) copper (p < 0.001), manganese (p = 0.001), and iron (p < 0.001). Shannon's species diversity was a significant predictor of ADF (p = 0.010), calcium (p = 0.004), phosphorus (p <0.001), magnesium (p = 0.002), and iron (p =0.040. Species richness was a significant predictor of crude protein (p = 0.043), ADF (p < 0.001), phosphorus (p = <0.001), potassium (p <0.001), copper (p = 0.001), and iron (p = 0.019). Grass cover was a significant predictor of Crude protein (p < 0.001), NDF (p < 0.001), ADF (p < 0.001), TDN (p < 0.001), calcium (p < 0.001), phosphorus (p < 0.001), potassium (p < 0.001), magnesium (p < 0.001), copper (p < 0.001), manganese (p < 0.001), iron (p < 0.001), and zinc (p < 0.001). Forb Cover was a significant predictor of NDF (p < 0.001), TDN (p < 0.001), calcium (p < 0.001), phosphorus (p < 0.001), magnesium (p < 0.001), iron (p = 0.041), and zinc (p = 0.003). Results from finding the top model type (linear, quadratic, or exponential) can be found in Appendix E. The vegetation characteristics of biomass, time since fire, species diversity, species richness, grass cover, and forb cover can be used to predict multiple nutritional components.

DISCUSSION

Under pyric herbivory, recently burned patches show increased crude protein and decreased fiber in recently burned patches (McGranahan et al., 2014). Our burned patches had higher crude protein and lower fiber until six months post fire which is similar to another study showing that crude protein had declined to unburned levels approximately four months following fire (Powell et al., 2018). A recent study also done in the mixed-grass prairie found an increase in phosphorus, calcium, zinc, and copper (Wanchuk et al., 2021), but did not examine other minerals. We were able to also determine that several macro minerals, and micro minerals also increased in recently burned areas compared to unburned areas and decreased through time since fire. Phosphorus is the most limiting nutrient on rangelands (McDowell, 2003), and we were able to increase its levels on our study with patch burning. Knowing many minerals were higher in the burn units compared to the unburned areas, producers can use pyric herbivory to provide higher quality forage in a pasture without additional supplementation.

Vegetation characteristics were temporarily altered following fire but returned to unburned levels after approximately six months post-burning. Grass cover was initially lower but recovered through time and was statistically the same as unburned levels at our last sampling session for the spring burns. Forb cover remained statistically the same through sampling, except for one month after the summer burns when levels were lower compared to unburned areas, likely because of the very short time since fire, while other studies have found that forb cover will increase or decrease following fire. Clark et al. (2014) found that forbs increased in September patch burns during the first year post-fire before grasses recovered from fire and become the dominant vegetation cover. Fire does reduce biomass temporarily, but plants recover quickly in six months or less (Allred et al., 2011; Powell et al., 2018).

Because higher biomass is associated with lower mineral and nutrition levels, maintaining heterogeneity in the landscape is beneficial to livestock producers while promoting wildlife habitat. The strong negative relationship between biomass and several nutritional components aligns with findings from Welti et al. (2020), which found higher biomass was associated with lower nutritional quality of vegetation. Burned areas with higher quality but lower quantity can supply animals with their nutritional requirements as can unburned areas with lower quality but higher quantity of forage (Hobbs & Swift, 1985). Managing for heterogeneity and implementing pyric herbivory promotes patchiness across the landscape creates a mosaic of high and low vegetation amounts which is beneficial to livestock and wildlife (Fuhlendorf & Engle, 2001). Having patches with lower biomass, thus higher nutrition, provides prime foraging areas for wildlife and livestock while areas with higher biomass offer forage quantity for livestock as well as cover and nesting habitat for wildlife species.

Adequate nutrition is important to herd health through reproduction rates, disease prevention, and cattle gains (National Academies of Sciences Engineering Medicine, 2016). Mineral supplement is often used to compensate for vegetation that lacks adequate mineral levels. Our results align with other findings that recently burned patches experience an increase in crude protein, digestibility, and minerals compared to unburned areas (Mbatha & Ward, 2010; Wanchuk et al., 2021). Pyric herbivory can be implemented to help reduce needed mineral supplementation, which can reduce operation cost. Our study showed by burning twice per year in different areas, managers can extend the availability of highly digestible forage and minerals, decreasing the proportion of the year when supplement must be provided. For our study area, sodium would still need to be supplemented because of the trace amounts detected in our vegetation points. Higher mineral concentrations may also increase cattle productivity and could be especially useful during high nutrient requirement times of the year, such as during peak lactation, which is 40-60 days after calving (Hutjens, 2002). Pyric herbivory systems have been shown to increase cattle weight gains in the mixed-grass prairie by 18 kg once established (Limb et al., 2011). Pyric herbivory also increases species and structural diversity which is important for mitigating negative drought effects (Allred et al., 2014; Farney et al., 2017).

Pyric herbivory can accommodate changing nutritional requirements in cattle during different life and reproductive stages throughout the year. In the mixed-grass prairie of western Oklahoma, many producers operate on a spring calving system, though also maintain fall calvers. Peak lactation, when cows' nutritional requirements are highest, occurs in late spring or early summer. During lactation, a cow needs a diet of at least 9.4% crude protein, 0.27% calcium, 0.27% phosphorus, 0.2% Magnesium, 0.7% potassium, 0.1% sodium, 10 ppm copper, 50 ppm iron, 40 ppm manganese, and 30 ppm zinc (National Academies of Sciences Engineering Medicine, 2016). No requirements of molybdenum are established for cattle though there is little evidence that it is deficient in most diets (National Academies of Sciences Engineering Medicine, 2016). During our May sampling session, when spring calving cows would be in or entering peak lactation: crude protein and magnesium requirements were met in spring burns but not unburned areas. During the September sampling session, when fall calving cows would have the highest nutritional demand, nutritional demands for crude protein, magnesium, and potassium were met in summer burned versus unburned areas. Cattle managers can use patch burns to help meet cattle requirements during lactation, which is the highest nutritional demand time for cow.

It has been hypothesized that cattle are attracted to recent burns because of the high crude protein found in regrowth following fire. Our study found that there may be more to attraction, with lower forage ADF, NDF, and increase TDN, macro- and microminerals can also be contributing to cattle focal grazing of recently burned patches. This study also confirms that forage quality in tallgrass areas respond positively to fire and tend to return to pre-burn levels more quickly, short grass areas also benefit from burning by increasing in both forage quality and macro and micro minerals. To further investigate the impacts in relation to different stocking rates, grazing regimes, and ecoregions. Other rangeland types may have different mineral responses. For instance, grazing lawns inherently have higher protein, phosphorus, and digestibility compared to tall grasses (Thapa et al., 2021). Therefore, an ecosystem dominated by tallgrass species would likely have different mineral content responses to burning compared to our study site. Also, grasses in warm, arid environments have lower nutritional quality compared to those in more temperate, wetter regions (Lee, 2018), which could also lead to varying results in different ecoregions. The pastures used for this study were deferred from grazing for several years prior to research, and conservatively stocked to allow animals free choice for grazing locations. A moderately stocked pasture in our study ecoregion would likely have extended the increase in forage quality longer in the season with more grazing animals focusing grazing pressure on recently burned areas and causing additional regrowth post-fire.

CONCLUSION

Pyric herbivory is an effective way to increase mineral and nutritional content in native rangeland forage by as much as tripling some components. Higher levels of nutritional quality only persist for approximately six months, but additional burn patches within the same pasture could maintain high forage quality for longer periods across the year. Time since fire and biomass are important determining factors for many nutritional components with an often-negative relationship. Fire did initially reduce vegetation cover and biomass, but vegetation recovered to unburned levels after about six months with an average of 11% of the pastures being burned. Further work should be done in other vegetation types outside of the mixed-grass prairie to determine if minerals in recently burned areas increase with pyric herbivory.

FIGURES

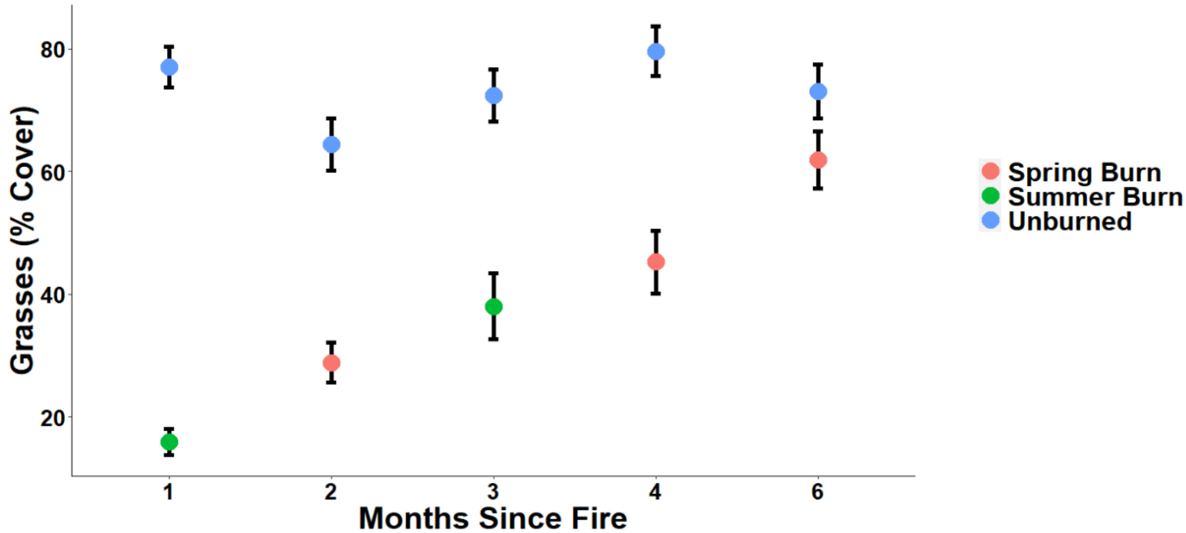


Figure 1.1. Change in biomass by burn treatment through time since fire. Error bars represent standard error between points across all burn units and pastures. Fuel loads grouped because of insignificant differences between tallgrass and shortgrass patches.

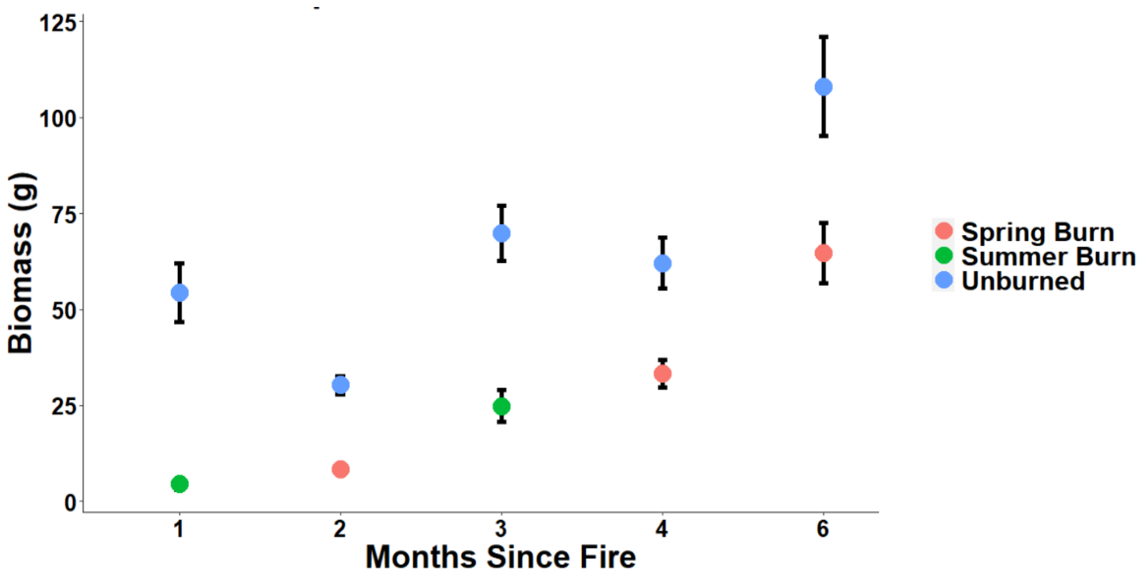


Figure 1.2. Change in percentage grass cover by burn treatment through time since fire. Error bars represent standard error between points across all burn units and pastures. Fuel loads grouped because of insignificant differences between tallgrass and shortgrass patches.

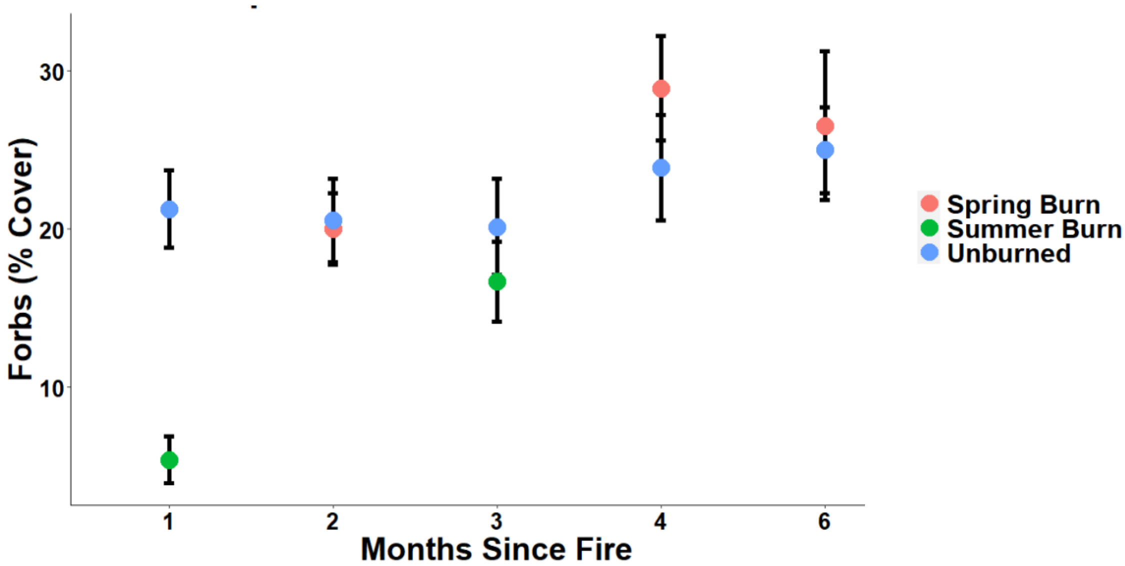


Figure 1.3. Change in percentage forb cover by burn treatment through time since fire. Error bars represent standard error between points across all burn units and pastures. Fuel loads grouped because of insignificant differences between tallgrass and shortgrass patches.

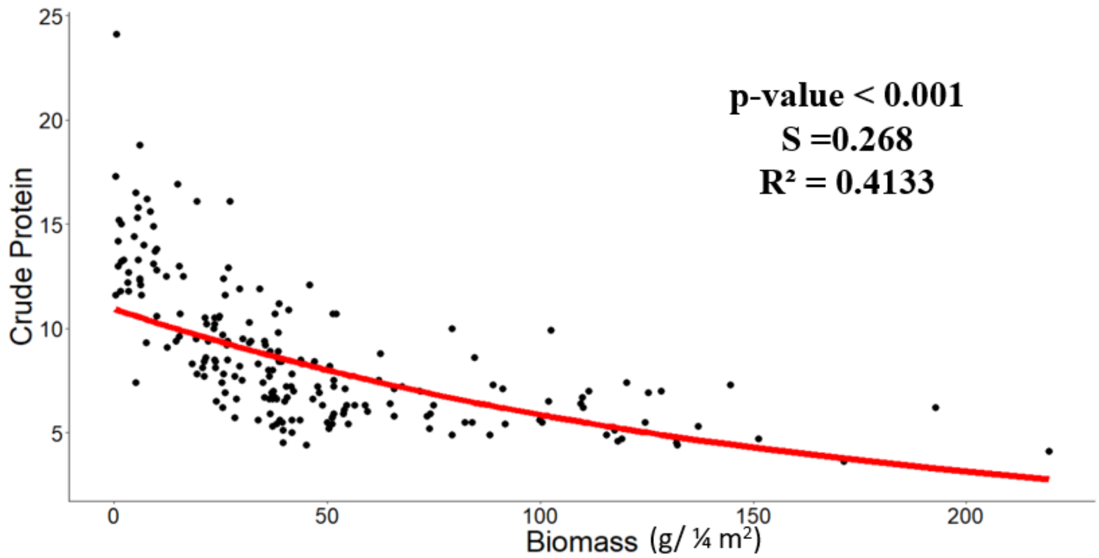


Figure 1.4. Relationship between biomass and crude protein for all vegetation samples (burned and unburned). Biomass was a significant predictor of crude protein ($p < 0.001$) with a negative exponential relationship ($R^2 = 0.4675$).

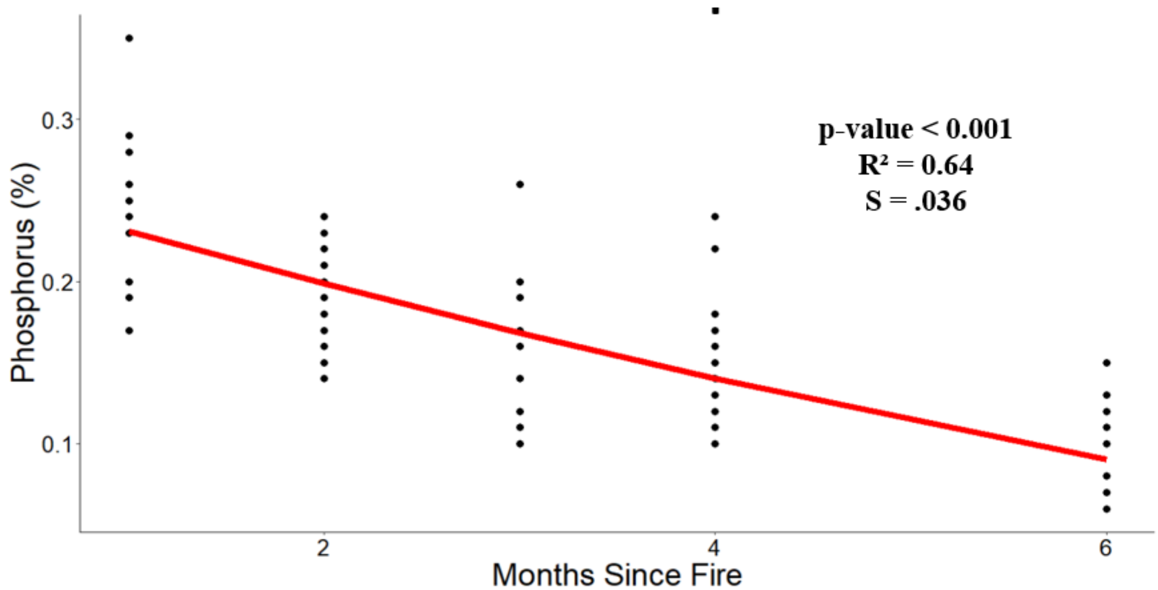


Figure 1.5. Relationship between time since fire and phosphorus for all vegetation samples (burned and unburned) with the best fitting line. Time since fire was a significant predictor of phosphorus ($p < 0.001$) with a linear relationship ($R^2 = 0.64$, S = 0.036) where shorter time since fire results in higher phosphorus levels.

TABLES

	Tallgrass/ Spring	Shortgrass/ Spring	Tallgrass/ Summer	Shortgrass/ Summer
Burn Date	3-19-2021	3-19-2021	6-14-2021	6-14-2021
Unit Area (ha)	2.17 (1.84-2.34)	1.99 (1.78-2.16)	2.09 (2-2.27)	2.02 (1.91-2.13)
Fuel Load (kg/ha)	3,200 (528-9,740)	1,361.8 (420-3,052)	2,992.8 (1,268-7,788)	1,876.9 (492-3,332)
Temperature (°C)	12.3 (7.2-15.2)	16.3 (14.5-18.3)	34.5 (31.9-36.4)	34.9 (33.0-36.4)
Relative Humidity (%)	57.6 (49-74.6)	47.2 (45-49.7)	54.8 (46.2-67.9)	51.4 (46.2-56)
Wind Speed (km/hr.)	4.7 (2.1-7.9)	4.1 (3.1-5.5)	2.7 (1.6-4.2)	3.5 (1.6-5.4)
Wind Gust (km/hr.)	5.9 (4.2-8.4)	7.2 (4.7-8.5)	2.8 (2.2-3.9)	3.3 (2.2-5.4)
Wind Direction	NW-NNW	ENE-N	ESE-SE	SE
Burn Time (min.)	44 (40-50)	28 (25-30)	30 (17-40)	40 (35-46)
Fine Dead Fuel Moisture (%)	14.92 (9.8-14.92)	13.6 (9.24-13.58)	9.94 (9-9.94)	11.2 (9.24-11.2)
Volumetric Soil Water Content at 36 cm (cm^3/cm3)	0.110 (0.109-0.110)	0.109 (0.109-0.109)	0.090 (0.089-0.090)	0.0896 (0.089-0.090)
Fine Fuel Load (kg/ha)	3,200.0 (528-9,740)	1,361.8 (420-3,052)	2,992.8 (1,268-7,788)	1,876.9 (492-3,332)
Pre-burn Time Since Rain (days)	2	2	1	1
Post-burn Time Since Rain (days)	3	3	7	7

Table 1.1. Burning conditions burn unit characteristics for each tallgrass and shortgrass patches and dormant and summer burn patches. Variable measurements were recorded just prior to burning each individual unit and averaged across treatment with the minimum and maximum values given in parentheses, when applicable.

	May		July			September			
	Dormant	Unburned	Dormant	Growing	Unburned	Dormant	Growing	Unburned	*p*-value
				Vegetation					
Species Diversity *	1.54^{abd}	1.74^{a}	1.64^{ab}	0.83^{c}	1.54^{abd}	1.52^{abd}	1.23^{d}	1.49^{bd}	<0.001
Grass Cover (%) *	37.5^{d}	62.5^{e}	37.5^{a}	15.0^{b}	85.0^{c}	62.5^{e}	37.5^{ad}	73.8^{ce}	<0.001
Forb Cover (%) *	15.0^{ac}	15.0^{ac}	37.5^{a}	2.5^{b}	15.0^{ac}	15.0^{ac}	15.0^{c}	15.0^{ac}	<0.001
Biomass (%) *	7.3^{d}	33.5^{a}	28.3^{a}	2.0^{b}	51.3^{c}	50.7^{ce}	21.5^{f}	74.6^{e}	<0.001
Bare Ground (%) *	15.0^{a}	0^{d}	15.0^{ab}	37.5^{c}	0^{d}	15.0^{a}	26.25^{bc}	0^{d}	<0.001
				Nutrition					
Crude Protein (%) *	14.2^{b}	8.4^{a}	9.2^{a}	12.9^{b}	6.8^{c}	5.6^{d}	10.5^{e}	5.9^{d}	<0.001
NDF (%) *	51.3^{a}	62.6^{ce}	53.4^{ab}	61.2^{c}	67.3^{d}	63.6^{ce}	58.9^{bc}	65.1^{de}	<0.001
ADF (%)*	34.1^{d}	44.8^{ab}	40.2^{c}	37.6^{c}	46.4^{a}	39.6^{bc}	37.9^{c}	45.0^{a}	<0.001
TDN (%) *	64^{a}	62^{ce}	64^{ab}	62^{c}	61^{d}	61^{ce}	63^{bc}	61^{de}	<0.001
				Minerals					
Calcium (%) *	1.16^{a}	0.57^{b}	1.08^{a}	0.56^{b}	0.61^{b}	0.66^{b}	0.61^{b}	0.53^{b}	<0.001
Phosphorus (%) *	0.21^{d}	0.09^{e}	0.14^{a}	0.24^{b}	0.08^{c}	0.08^{cef}	0.17^{a}	0.07^{f}	<0.001
Magnesium (%) *	0.32^{b}	0.15^{d}	0.29^{ab}	0.24^{ac}	0.16^{de}	0.19^{ce}	0.21^{ac}	0.15^{de}	<0.001
Potassium (%) *	1.79^{c}	0.81^{b}	1.27^{a}	1.48^{a}	0.70^{b}	1.00^{b}	1.53^{a}	0.65^{b}	<0.001
Sodium (%) *	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0.04
Iron (ppm) *	563^{ad}	535^{ad}	519^{a}	1128^{b}	289^{c}	364^{cd}	708^{a}	284^{c}	<0.001
Zinc (ppm) *	51^{c}	34^{ab}	35^{abc}	36^{ab}	29^{a}	35^{ab}	42^{bc}	36^{ab}	<0.001
Copper (ppm) *	9^{b}	5^{c}	7^{a}	9^{b}	5^{c}	5^{c}	9^{b}	5^{c}	<0.001
Manganese (ppm) *	77^{ab}	63^{b}	73^{ab}	95^{a}	44^{c}	62^{bd}	80^{ab}	48^{cd}	<0.001
Molybdenum (ppm) *	1.0^{b}	0.9^{b}	1.1^{ab}	1.4^{a}	1.0^{b}	1.3^{ab}	1.0^{ab}	1.1^{b}	0.003

Table 1.2. Forage nutritional and vegetation characteristic differences for each treatment and sampling session. Forage quality was higher following fire in the burn patches compared to the unburned areas for most components until six months post fire. Vegetation cover and species index was lower after fire but recovered to unburned levels six months post-burning. Distribution was tested for normality using a Shapiro Wilke test in RStudio. All variables were non-normal ($p < 0.05$), indicated by a star (*). Median given for all variables as non-normal distributions. A Kruskal Wallis test was done to determine if significant differences existed between treatments and sampling times. All variables were significantly different ($p < 0.05$). We used a pairwise Wilcox test to determine which groups were significantly different from each other ($p < 0.05$). Differences between columns denoted by letter superscripts.

	Independent variables								
	Biomass			Time Since Fire			Species Diversity		
Dependent variables	P-value	S	R^2	P-value	S	R^2	P-value	S	R^2
Forage Quality									
Crude protein (%)	<0.001*	0.268	0.45	<0.001*	0.186	0.76	0.052*	-	-
Neutral detergent fiber (%)	<0.001*	0.141	0.08	0.355*	-	-	0.221*	-	-
Acid detergent fiber (%)	<0.001*	0.116	0.19	0.007*	0.121	0.07	0.010*	0.127	0.03
Total digestible nutrients (%)	<0.001*	0.031	0.11	0.186*	-	-	0.221*	-	-
Macronutrients									
Calcium (%)	0.044‡	0.471	0.02	0.002†	0.523	0.11	0.004‡	0.466	0.03
Phosphorus (%)	<0.001†	0.045	0.40	<0.001‡	0.036	0.64	<0.001‡	0.055	0.07
Potassium (%)	<0.001*	0.453	0.08	<0.001*	0.335	0.29	0.002*	0.461	0.30
Magnesium (%)	<0.001‡	0.113	0.06	0.046†	0.127	0.05	0.835‡	-	-
Micronutrients									
Copper (ppm)	<0.001*	0.338	0.13	<0.001*	0.246	0.42	0.058*	-	-
Manganese (ppm)	<0.001*	0.443	0.11	0.001*	0.391	0.10	0.721*	-	-
Molybdenum (ppm)	0.021*	0.375	0.02	0.714*	-	-	0.291*	-	-
Iron (ppm)	<0.001*	0.502	0.44	<0.001*	0.507	0.23	0.04*	0.664	0.02
Zinc (ppm)	0.007*	0.455	0.04	0.874*	-	-	0.959*	-	-

* Exponential

† Quadratic

‡ Linear

	Independent variables								
	Species Richness			Grass Cover			Forb Cover		
Dependent variables	P-value	S	R^2	P-value	S	R^2	P-value	S	R^2
Forage Quality									
Crude protein (%)	0.043*	0.358	0.02	<0.001*	0.236	0.57	0.361*	-	-
Neutral detergent fiber (%)	0.566*	-	-	<0.001*	0.116	0.38	<0.001*	0.136	0.14
Acid detergent fiber (%)	<0.001*	0.125	0.05	<0.001*	0.104	0.35	0.767*	-	-
Total digestible nutrients (%)	0.902*	-	-	<0.001*	0.026	0.38	<0.001*	0.031	0.13
Macronutrients									
Calcium (%)	0.137‡		-	<0.001‡	0.427	0.20	<0.001‡	0.400	0.29
Phosphorus (%)	<0.001†	0.052	0.21	<0.001†	0.036	0.62	<0.001†	0.056	0.09
Potassium (%)	<0.001*	0.446	0.11	<0.001*	0.356	0.42	0.144*	-	-
Magnesium (%)	0.370‡		-	<0.001‡	0.094	0.36	<0.001‡	0.109	0.12
Micronutrients									
Copper (ppm)	0.001*	0.352	0.05	<0.001*	0.269	0.45	0.491*	-	-
Manganese (ppm)	0.486*		-	<0.001*	0.420	0.21	0.781*	-	-
Molybdenum (ppm)	0.073*		-	0.089*	-	-	0.078*	-	-
Iron (ppm)	0.019*	0.661	0.04	<0.001*	0.587	0.24	0.041*	0.663	0.02
Zinc (ppm)	0.835*		-	<0.001*	0.446	0.07	0.003*	0.452	0.04

* Exponential

† Quadratic

‡ Linear

Table 1.3. Table showing best fitting regression models that estimate the prediction power of biomass on vegetation characteristics, nutrition, macrominerals, and microminerals as well as the strength of grass cover as a predictor of species diversity and richness. Linear, quadratic, and exponential models were tested for each relationship for best fit. Biomass was a significant predictor of grass and forb cover, and all nutritional components ($p < 0.05$). Calcium ~ biomass was linear, phosphorus ~ biomass was quadratic, and magnesium ~ biomass was linear while all other biomass relationships were exponential. Grass cover was a significant predictor of species richness ($p = 0.011$) with an exponential relationship and weak R^2 value (0.03) but not of species diversity ($p = 0.722$).

CHAPTER II

CATTLE DISTRIBUTION RESPONSES TO BURNING KNOWN AVOIDED AREAS

ABSTRACT

Pyric herbivory modifies grazing patterns with cattle selecting for the most recently burned and more palatable forage while having access to higher quantity of forage in the unburned areas. Though other studies have found that cattle select for patch burns, burn units are typically randomly selected in a pasture, and cattle's interaction with the burned areas are monitored following fire. To supplement previous research and determine if cattle grazing can be refocused to previously avoided areas, we delineated burn units in known avoidance areas using cattle distribution information from the growing season prior to burning. The study was conducted in the mixed-grass prairie of western Oklahoma. Within each pasture we burned two patches in the dormant season and two patches in the growing season. Two weeks after the dormant season burn, the same cows were again outfitted with the GPS collars and released into the individual pastures for the duration of the post-burn growing season. Data from the GPS units was analyzed to determine how the grazing patterns changed from year one to year two with the addition of the patch burn units. We analyzed the cattle's interaction with the different burn units.

by grazing period (from collar deployment to summer burn and from summer burn to the end of data collection) using Ivlev's Electivity to determine selection or avoidance Results indicated that cattle significantly increased their selection of the known avoided areas with under 5% of their time in delineated burn units during the pre-burn summer to almost 20% of their time in burned areas during the post-burn season. The spring burn electivity index was 0.34 during grazing period one and the summer index was similar at 0.35 during grazing period two while unburned area indexes were -0.05 and -0.03 for the respective grazing periods. Pyric herbivory can be a less expensive, useful grazing alteration tool, which also implements a regular fire frequency to benefit ecological processes and habitats.

INTRODUCTION

North American grasslands have been predominantly shaped by climate, fire, and grazing (Anderson, 2006). Many grassland plant species, adapted to frequent fire intervals, are also adapted to grazing pressure through grazing avoidance and tolerance characteristics (Briske, 1991). A regular fire frequency maintains grasslands by removing decadent previous years grass growth and discourages woody species by removing above ground growth meristems on shrubs and trees. Fire suppression during the 20th century has caused woody plant encroachment in many grassland ecosystems (Archer et al., 2017). Historically, shifting disturbances, including fire and grazing, across the landscape created a mosaic and inherent structural heterogeneity (Kay, 1998). However, pasture scale management has created a homogeneous landscape, reducing biodiversity within grassland communities (Fuhlendorf et al., 2006; Fuhlendorf et al., 2010).

Applying prescribed fire across an entire pasture creates a more homogeneous landscape, but burning patches produces a shifting mosaic across the landscape at the pasture scale. Though traditional views of range management promote uniformity, maintaining patchiness and heterogeneity is beneficial to many ecosystem functions (Fuhlendorf et al., 2012). Heterogeneity refers to the patchiness on the landscape which is characterized by varying vegetation structures at a relatively small scale, thus promoting greater plant and animal biodiversity. Burning a portion of a pasture at one time establishes diversity in structure and plant species with differing time since fire and grazing intensities (Fuhlendorf & Engle, 2004). Resulting species and structural heterogeneity adds stability and resiliency to the ecosystem (Allred et al., 2014). Heterogeneity can be derived from inherent, abiotic factors on the landscape, such as topography, soil types and climate. It can also develop from disturbances such as fire and grazing, their varying intensities and frequencies, and how they interact with the abiotic factors.

Pyric herbivory, the interaction between fire and grazers, provides many livestock management benefits because of cattle's interaction with fire. Cattle will spend up to 70% of their time in burned areas and will travel 1,600 m away from water in order to graze recently burned patches (Vermeire et al., 2004; West et al., 2016). Grazers select for burned versus unburned areas because of the more palatable and higher quality forage on freshly burned patches (Allred et al., 2011; McGranahan et al., 2014). Though other factors such as topography and climate influence grazing patterns, fire is one of the principal, manageable driving factors behind grazing selection on the landscape (Allred et al., 2011). Cattle may select against a certain portion of a pasture due to distance to water, difficult terrain, or low forage quality. Because it applies fire to a portion of the pasture followed by subsequent burns in other areas, cattle can graze unburned areas if drought conditions impede vegetative recovery of burn patches. Seasonal burning can prolong grazing seasons through increasing palatability of forage once plant communities reach reproductive maturity and are burned. Alternating the grazing pressure between highly selected and avoided areas creates a shifting mosaic within a landscape of varying times since fire and grazing intensities (Fuhlendorf & Engle, 2004). Pyric herbivory could be an even more effective tool if it could attract cattle to known avoided areas in a pasture.

The primary objectives of our study were to 1) determine if patch fires focused on previously ungrazed areas can alter grazing distribution., 2) to assess whether seasonality of prescribed fire affects cattle selectivity of previously avoided areas, 3) whether pyric herbivory will affect cattle usage of riparian areas, 4) quantify changes in cattle movement behavior pre-burn and burning, 5) and finally to determine whether cattle prefer burned portions of the pasture dominated by tall grasses vs. areas dominated by short grasses. We believe that cattle will refocus their grazing pressure to previously avoided areas following the application of patch fires. We believe that cattle will not show a preference dormant versus summer fires. With patch fires available, we believe cattle will spend less time in riparian areas. We hypothesize that cattle will travel less with the addition of burn units to a pasture. Lastly, we believe cattle will prefer tallgrass patches over shortgrass patches due to higher forage potential.

METHODS

Study Area

The study stie for this project was the Oklahoma State University Marvin Klemme Range Research Station, near Bessie, Oklahoma, in Washita County (35.416961, -99.060514). Of the total 631 ha at station, we used three pastures totaling 192 ha for this study. It is located in the Rolling Red Hills Ecoregion of Oklahoma which is characterized by rolling hills of typically mixed grass prairie (Woods et al., 2005). Scattered throughout this ecoregion and property are heavily eroded riparian areas dominated by many woody species, including eastern red-cedar (*Juniperus virginiana*) and hackberry (*Celtis* spp.) (Bidwell et al., 2007).

There are four soil types in the three study pastures including: Cordell-Rock Outcrop complex (75%), Cordell (22%), Quinlan-Obaro complex (2%), and Obaro (1%) (Web Soil Survey, 2021). There are four ecological sites associate with our study pastures: Red Shale, Loamy Upland, Sandy Loam, and Shallow Upland (Web Soil Survey, 2021). The most common site is the Red Shale which encompasses over 74% of the study pastures. Many of these ecological sites share the same most common grass, forb, and woody plant species. Some of the common grass species include: gramas (*Bouteloua* spp.), little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), dropseeds (*Sporobolus* spp.), threeawns (*Aristida* spp.), and cheatgrass (*Bromus tectorum* and *B. japonicus*) (Web Soil Survey, 2021). Forbs are typically less abundant, though common, and include but are not limited to: yellow sundrops (*Calylophus serrulatus*), ragweed (*Ambrosia psilostachya*), white sagebrush (*Artemisia ludoviciana*), prairie clover (*Dalea* spp.), primrose (*Oenothera* spp.), and Illinois bundleflower (*Desmanthus illinoensis*) (Web Soil Survey, 2021). Many of the woody species are confined to the riparian areas but some are common in the upland areas. Several species that can be easily found are eastern redcedar (*Juniperus virginiana*), fragrant mimosa (*Mimosa borealis*), and fragrant sumac (*Rhus aromatica*) (Web Soil Survey, 2021). All ecological sites have had a historical fire presence which keeps woody species from encroaching on the upland areas, but they are at risk of altered plant communities with modern fire suppression (Web Soil Survey, 2021).

For this area, the average annual rainfall is 778.764 mm, mean minimum temperature is 9° C, mean annual temperature is 16° C, and the mean maximum temperature is 22° C (PRISM Climate Group, 2020). Most of the precipitation is received from March through June with another peak of rainfall in August through October with lower amounts being observed during the winter months.

The three pastures used were similar sized, and have not been grazed by domestic herbivores since 2016. Likewise, no prescribed fire has been used in several years in two of the pastures and none has been implemented in the third pasture since 1991, when Oklahoma State University began managing it. For the first summer, water was supplied via a water trough in two of the three pastures, and the third pasture was able to use a stock pond. The beginning of the burn summer was characterized by higher precipitation which led to more water availability and distribution in two of the pastures Water was still accessible in the same locations as the first summer across all three pastures.

Data Collection

A total of 15 cows were used for this project, and they were the same individuals from the first summer to the second, except for one animal. All cattle research methods were submitted and approved by the Institutional Animal Care and Use Committee (IACUC, 06-2020). All cattle were non-lactating, unbred cows that ranged from never bred, two-year old heifers up to nine-year-old cows. All cattle were kept without calves during the project to ensure there was no distribution variation between nursing and dry cows. The cows were grouped into the three study pastures based on weight and age in order to have a similar average cow in each pasture which balanced any varying grazing distribution tendencies that might exist due to cattle demographics. During the first summer, one cow contracted listeria, and she was replaced with another cow the following summer. Free choice loose mineral was provided in all pastures near the water source in order to not influence cattle distribution. Because the stocking rate was relatively low across pastures and we did not want to influence cattle movement, we did not provide regular supplemental feed.

To determine the avoided areas in a pasture during the first field season, five head of cattle in each of the three pastures were outfitted with low-cost GPS collars that fixated a point every 10 minutes during August through October. GPS collars were built utilizing Mobile Action iGotU GT-600 Sports Loggers with two Tenergy Li-Ion 3.7V 5200mAh Rechargeable Batteries that replaced the original battery from the unit (Knight et al., 2018). The Tenergy batteries were soldered to the iGotU unit by a parallel circuit which retains the same voltage but increases the unit's working time to approximately six months. After installing them on the unit, the batteries should be charged using the GPS units charging cable, even if the batteries are new. The unit and batteries were secured in plastic cases mounted to cattle collars, which were repurposed from a previous study using this same design. The accuracy of this GPS unit model is 9.2 m (Morris & Conner, 2017). These units can be built relatively inexpensively compared to other livestock GPS collars, which allowed us to increase the number of study animals.

At the end of the pre-burn data collection period, after downloading the data from the iGotU GPS units, we selected which areas of the pastures to burn by determining the avoided areas and evaluating each individual pasture. All cattle GPS points were compiled by pasture and a column was added to identify which cow each datapoint originated from. Time blocks were excluded for the first five days after turning the cows into the pastures allowing them time to adjust to the new area before collecting distribution data that we would analyze. Points were excluded during and an hour after cattle were penned to be doctored or perform maintenance on a collar. These data point files were loaded into ArcMap 10.8 by clicking File > Add Data > Add XY Data, with X being longitude and Y being Latitude, projected to the coordinate system of the rest of the map, NAD 1983 UTM Zone 14N, and clipped to remove points that fell outside of the respective pasture boundaries. We then analyzed the points by pasture using the Hot Spot Analysis tool. The tool divides each pasture into a grid of 9 m^2 pixels, which is derived from the GPS units error, and determines if the area was significantly selected for (hot spot), significantly selected against (cold spot), or not selected for (neutral) to a 95% confidence interval based on how many points were in each pixel. After determining the avoided and selected areas to a 95% confidence interval based on the analysis, we placed the burn patches in avoided areas, predominantly. Because of topographical challenges and limited avoided areas, some of the individual burn units included areas that were not significantly avoided or selected for, but none of the burn units contained hot spots where the cattle spent a significant amount of time during the pre-burn data collection period. In each pasture, we selected a tallgrass and a shortgrass patch to burn during both the dormant and summers, with each individual patch being approximately 2.1 ha with a standard deviation of 0.2 ha. The fuel load was determined with visual methods and then sampled to quantify the mean fuel load within each patch. A shortgrass patch was predominantly short and/or low vegetative grasses such as blue grama (*Bouteloua gracilis*) and white tridens (*Tridens albescens*) while tallgrass patches contained mostly tall and/or high vegetative plants including little bluestem (*Schizachyrium scoparium*) and big bluestem (*Andropogon geradii*). To make the burns safer and easier to control, we utilized natural fire breaks such as bare ground, gullies, or roads, when possible, which resulted in some irregularly shaped burn units in some cases. Burn patches were placed at least 50 meters away from each other and the cattle distribution hot spots, whenever feasible with the layout of each pasture.

After planning the burn units, we conducted the burns during the two respective seasons and turned the cows out into the individual pastures during the summer to collect post-burn distribution data. We completed the spring burns on March 19, 2021, and the cows were released into the pastures on April 2nd. During the summer months, we waited for weather conditions to be favorable for burning, and conducted the summer burn on June 14th while the cows were still grazing in the pastures. The cows were again pulled from the pastures around the time of the first frost at the research station which was October 30th for the burn field season. We created mowed fire breaks around the burn units approximately 5 m wide and used wet lines for additional safety in containing the fire. We collected current weather conditions and calculated fuel moisture based on relative humidity in order to determine varying fire intensities across burn units as a result of present weather conditions. The weather conditions for each of the burn days can be found in Table 1.1. Using the weather conditions from these burns, we can compare our results to other studies, since differing fire intensities can have varying effects on the vegetation responses (Falk et al., 2007). We employed a ring fire technique unless another method was deemed more appropriate for the current weather conditions and burn patch. The ring fire method of prescribed burning involves lighting a back fire on the downwind side of the burn unit, allowing it to back into the wind until an adequate black line was achieved, and then proceeding to ignite the head fire that travels with the wind until the two fires come together (Weir, 2009).

Data Analysis

The post-burn data collection period in the summer of 2021 was divided into two grazing periods for analysis. The first grazing period was the beginning of data collection, April 7th, to the day before the summer burns which were done June 14th. The second grazing period was June 14th through October 30th, the day of the summer burns through the last day the cattle were in the pastures. Data from the collars was downloaded from the units using the @trip PC software from Mobile Action. All other data processing, analysis, and visualizations were done in ArcMap 10.8 (ESRI, 2019), RStudio (R Core Team, 2022; RStudio Team, 2022), and Microsoft Excel (Microsoft Corporation, 2018). After the burn data collection period, we followed a similar process of extracting the data from the GPS units and analyzing them in ArcMap. We again created distribution maps by pasture and grazing period using the Hot Spot Analysis Tool and compared it to the first year's data to determine how grazing distribution changed after adding the burn units.

We calculated the percentage of GPS points within each of the individual burn units for both field seasons. We then used Ivlev's Electivity via the ivlev_electivity function in RStudio to determine selection or avoidance for each individual burn treatment during the burn summer by grazing period and week (Lechowicz, 1982; Quintans, 2019). It uses the percentage of points in a given area and what proportion that area makes up of the total area to quantify significant selection or avoidance for each area.

Using the processed GPS points, we calculated multiple cattle movement factors for each year. Distance travelled was calculated using a formula in Excel to find the difference between the latitude and longitude of the previous point and find the straight-line distance. The formula and more complete instructions can be found in Appendix B. We used the distance travelled, in meters, to find the rate of travel, in meters/hour, by multiplying the distance by six since the units were set to take a point every ten minutes. We grouped the points by location in RStudio to calculate the average moving speed in riparian and upland areas for pre-burn and burn years. Using the sunrise and sunset times for each day, we grouped the distance travelled by sunrise-sunset, sunset-midnight, and midnight-sunrise for each summer (Hemphill, 2020; Thieurmel & Elmarhraoui, 2019). We calculated the daily area explored by each cow using the Minimum Bounding Geometry Tool, CONVEX_HULL Geometry Type option, in ArcMap and using date and cow ID as grouping fields (Hemphill, 2020). For two of the pastures, the polygon included areas outside the pasture boundary. Therefore, we clipped the newly created file to the associated pasture boundary. The area of each polygon was calculated by opening the attribute table, adding a new attribute field, right clicking the new field, clicking "Calculate Geometry", and choosing "Area" for Property and "Square Meters" for Units. The attribute tables were exported as CSV files to be imported into RStudio for further analysis. We divided the area explored for each cow and day by the total pasture area to find the percentage of pasture explored. We calculated the spatial search pattern by dividing the grazable area (daily distance travelled * 1 m which is the approximate side-to-side neck reach of a grazing cow) by the area explored for each day (Wesley et al., 2012).

For determining riparian area usage change with pyric herbivory, we determined the difference between the percentage of points in the delineated riparian areas from the first summer compared to the burn summer with the addition of burn patches. Riparian areas were delineated by hand in ArcMap by creating a feature class and tracing the areas in riparian zones which was determined. An area was included in the riparian zone if it was in a flood zone or was dominated by woody vegetation near a flood plain. We evaluated the effect of temperature on riparian area selection for each year using daily Ivlev's Electivity for the riparian areas and maximum daily temperature extracted from the National Ecological Observatory Network (NEON) repository database (NEON, 2022). NEON data collection tower is located at the study site between the northernmost study pasture and the two adjacent southern study pastures.

To classify cattle activity, we used the speed travelled from each subsequent fixation using classifications from Nyamuryekung'e et al. (2020). Speeds less than 138 meters per hour were associated with resting; speeds of 138 to 1,500 meters per hour were classified as grazing; speeds of greater than 1,500 meters per hour were designated as travelling (Nyamuryekung'e et al., 2020). We then determined in which area each point was located, riparian or upland and calculated what percent of each cow's day was spend for each of the three activities for both areas. We averaged all cows and days for each summer and determined differences in cattle activity for riparian and upland areas between pre-burn and burn summers.

RESULTS

During the pre-burn grazing distribution data collection season, we collected a total of 122,494 points across the three pastures, excluding erroneous and excluded points, with an average of 40,831 per pasture during the 12 weeks the cows were collared. Each cow travelled approximately 3,821 m (± 29 m) per day. At about week two of the pre-burn summer, one cow was removed from the study due to illness and was not replaced for the rest of the summer. She was replaced for the post-burn data collection. During the post-burn summer, we obtained a total of 340,697 usable points during the 31-week deployment season with an average of 113,566 in each pasture. With the addition of burns in the pastures, each cow travelled an average of 3,578 m (± 17 m) each day across the summer. See Table 2.3 for pre-burn and burn cattle movement changes.

Across all three pastures, cattle significantly increased their selection of burn units placed in avoided areas. We found no significant differences in cattle usage classifications between years, but the post-burn summer had lower usage variance between pastures compared to the pre-burn summer (Figure 2.1). The area selected for and against was significantly altered between years with the percentage of points in the area delineated as burn units increased with the addition of fire (Figure 2.2).

Cattle selected for the spring burns during the first grazing period, prior to the summer burn (Figure 2.3). During the second grazing period, cattle switched their selection to the more recently burned summer burns. Cattle selected less for shortgrass patches compared to tallgrass burn units for both burn seasons, but results were not significant except for more selection against spring/shortgrass patch compared to the tallgrass patch of the same season in grazing period two ($p < 0.05$). Ivlev's electivity index with cattle selection divided by weeks shows that cattle began selecting for burned patches three to four weeks after fire (Figure 2.4).

Figure **2.5** shows cattle's increase, decrease, and same grazing use of the three study pastures. Through the first grazing period, dormant burn units transitioned to more cattle use. During grazing period two, all but one of the nine summer burn units experienced an increase in use compared to the pre-burn summer. Three of the spring burns also had an increase, to a 95% confidence interval, in use during the second grazing period from the previous summer. During grazing period one, both tallgrass and shortgrass burn units saw a significant increase in cattle use from pre-burn to post-burn grazing data collection ($p < 0.001$) (**Error! Reference source not found.**). The second grazing period showed similar increase in cattle use in the more recently burned summer burn units while the effect of fire had declined in the spring burns (**Error! Reference**

source not found.). The tallgrass and shortgrass patches experienced an increase in cattle

	Spring Burn		Unburned
	Tallgrass	**Shortgrass**	
	Increase in Use		
Cold to Hot	46.05 ± 23.05	22.76 ± 19.9	0.92 ± 0.46
Cold to Neutral	11.77 ± 10.58	43.15 ± 26.66	12.61 ± 6.57
Neutral to Hot	32.36 ± 20.94	6.42 ± 6.42	5.4 ± 2.68
	Decrease in Use		
Hot to Cold	-	-	1.27 ± 0.65
Hot to Neutral	-	-	7.17 ± 3.15
Neutral to Cold	-	3.14 ± 3.14	22.59 ± 10.74
	Same Use		
Hot to Hot	-	-	7.61 ± 1.75
Neutral to Neutral	9.83 ± 9.32	23.77 ± 23.77	24.87 ± 8.19
Cold to Cold	-	0.75 ± 0.75	17.56 ± 9.56

use in 93% and 67%, respectively, of the burn unit areas.

Table 2.1 and Table 2.2 shows the average and variance of probability for each cattle use transition in each burn treatment from the pre-burn summer to each grazing period.

Distances traveled and rate of travel between pre-burn and burn summers were significantly different for nearly all of our variables as seen in Table 2.3. On average during the burn summer each day, cattle traveled about 242 m less each day ($p < 0.001$), 185 m less during the day ($p < 0.001$), 45 m less between sunset and midnight ($p = 0.006$), and 81 m less between midnight and sunrise ($p < 0.001$) compared to the pre-burn summer. Cattle traveled 56 m/hr. slower in riparian areas ($p < 0.001$) and 21 m/hr. slower in upland areas ($p < 0.001$).

Two of the study pastures showed an insignificant change in riparian area usage while the riparian area usage in the third pasture increased five times that of the pre-burn year (Figure 2.6) ($p < 0.05$). Cattle grazed less and rested more in the riparian areas during the post-burn summer while activity in the upland areas was unaffected by fire (Figure 2.7 and **Error! Reference source not found.**). We found daily high temperature to be a significant determining factor during the post-burn summer ($p < 0.00001$, $R^2 = 0.2689$) while it was a non-significant factor during the pre-burn summer (**Error! Reference source not found.** and Appendix C).

DISCUSSION

Since fire was an important ecological disturbance that helped shape many North American landscapes, various species and ecosystems depend on its occurrence. The fire and grazing interaction of pyric herbivory mimics what occurred with wild herbivores and Native American fires prior to widespread settlement of North America where wild grazers, such as bison, would have free, unlimited access to freshly burned regions (Fuhlendorf et al., 2009). Fire would draw grazing pressure to burned areas and away from other sections of the landscape, thus allowing fuel buildup for the next wildfire in the area with reduced pressure. Pyric herbivory applies the grazing and fire interaction to the pasture level with prescribed fire and cattle instead of at the landscape scale with wildfire and bison.

Other studies have found a strong relationship between fire and grazing selection with cattle selecting for recently burned patches (Clark et al., 2014; Fuhlendorf & Engle, 2004; Vermeire et al., 2004), but it was previously unknown if using pyric herbivory would make cattle select for known avoided areas. Because cattle significantly select for recently burned patches, we theorized that selection would remain high when known avoided areas are burned. Our findings of cattle selecting for known avoided areas with the addition of burn patches further quantified cattle's predilection for recently burned areas. Fire significantly altered grazing distribution in the three study pastures, but we found no difference in total area of different use categories between areas, suggesting that burning can redistribute grazing without altering the total area of heavily and lightly grazed regions in a pasture.

Strong grazing preference for recently burned patches is likely the result of higher nutritional quality, mineral levels, and better palatability following fire (McGranahan et al., 2014; Wanchuk et al., 2021; Table 1.3). Though higher quality forage after fire often diminish after 120-180 days (Powell et al., 2018; Table 1.2), Clark et al. (2014) found that grazing distribution alteration from pyric herbivory can remain for up to five years which is long after forage nutrition has returned to unburned levels. The prolonged change in cattle locations is likely to changes in vegetation characteristics resulting in less browse species and more grass species which are predominantly compose cattle diets. Therefore, longevity of cattle selection of burn patches depends to an extent on vegetation types. Because burn patches return to unburned levels relatively quickly after fire, cattle operations need frequent fire to achieve the higher nutritional benefits from fire.

Cattle use of riparian zones is often managed against because of the damaging effects they can have on these sensitive areas (Belsky et al., 1999). Fencing animals out of riparian areas and strategically placing supplementation away from them can reduce negative impacts from cattle presence (Larson et al., 2016). Though we were unable to conclude pyric herbivory discourages cattle use of riparian areas, other factors in our study likely affected our results. Due to higher rainfall at the beginning of the burn study year, water was better distributed in two of the study pastures in riparian areas and stock ponds, including the pasture with a much higher riparian area selection post-burning. Though fire did increase the forage quality in the burned patches, time since fire is of lower importance to herbivores when compared to other climatic factors, such as water availability and temperature regulation (Allred et al., 2011).

Though burning portions of a pasture does temporarily remove forage quantity, it creates patches with higher quality forage while maintaining areas with unburned vegetation. Pyric herbivory does not negatively affect cattle weight gains (Farney et al., 2017; Winter et al., 2014). Therefore, it can be incorporated into a grazing regime to alter grazing distribution and mitigate drought without decreasing production (Allred et al., 2014; Vermeire et al., 2004). While improving a pasture for cattle production, pyric herbivory also provides ecological benefits and wildlife habitat improvement (Fuhlendorf & Engle, 2001; Teague et al., 2008).

Further research on this topic could be conducted by applying pyric herbivory at different scales and ecosystem types. Much larger pastures with bigger burn patches may have different results with the same study design. The effect of cattle grazing pressure on known avoided areas with the addition of fire may be amplified if cattle have a greater distance to travel to graze burned patches, depending still on water availability, though cattle have been shown to travel at least 1,600 m to graze a patch burn (Vermeire et al., 2004). In our results, cattle travelled less post-burning compared to pre-burning which equates to less maintenance energy expenditures, but distance travelled could increase with larger pastures sizes. Larger scales also result in varying fire intensity and behavior through fuel types, topography, and climatic conditions which effect recovery rates, fire frequency, and vegetation responses (Falk et al., 2007; Kerby et al., 2006). Prescribed fire literature is lacking in the effects of fire with varying spatial as well as temporal scales (Limb et al., 2016).

CONCLUSION

Pyric herbivory's ecological, grazing, and economical benefits can be achieved without a reduction in stocking rates or weight gains. Other studies have observed that pyric herbivory does not affect cattle weight gains, positively or negatively, which illustrates even though a portion of available grazable forage is removed by burning, overall cattle weight gains are not affected. Burned patches may reduce the quantity of forage in the pasture in the short term but increase the overall quality of the vegetation at the pasture scale. Moreover, prescribed fire increases forage production over the long term because it promotes tillering and prevents woody plant encroachment. Pyric herbivory is an effective management tool because cattle receive the most nutritional benefit from fire by grazing freshly burned patches as the forage plants are regrowing. The project results indicated that the nutritional benefits realized from implementing fire in a pasture began to decline as the patch recovered and returned to unburned levels at approximately six months post fire. Therefore, a frequent fire regime is needed to receive the most nutritional benefits of pyric herbivory. The exact frequency would depend on the rangeland setting and vegetation type. However, as with any grazing system, it is still crucial to maintain the correct stocking rate to prevent overgrazing pastures. Pyric herbivory is not meant to result in increased stocking rate but to better manage what is already being grazed more sustainably by achieving many ecological and economic benefits without reducing cattle production.

FIGURES

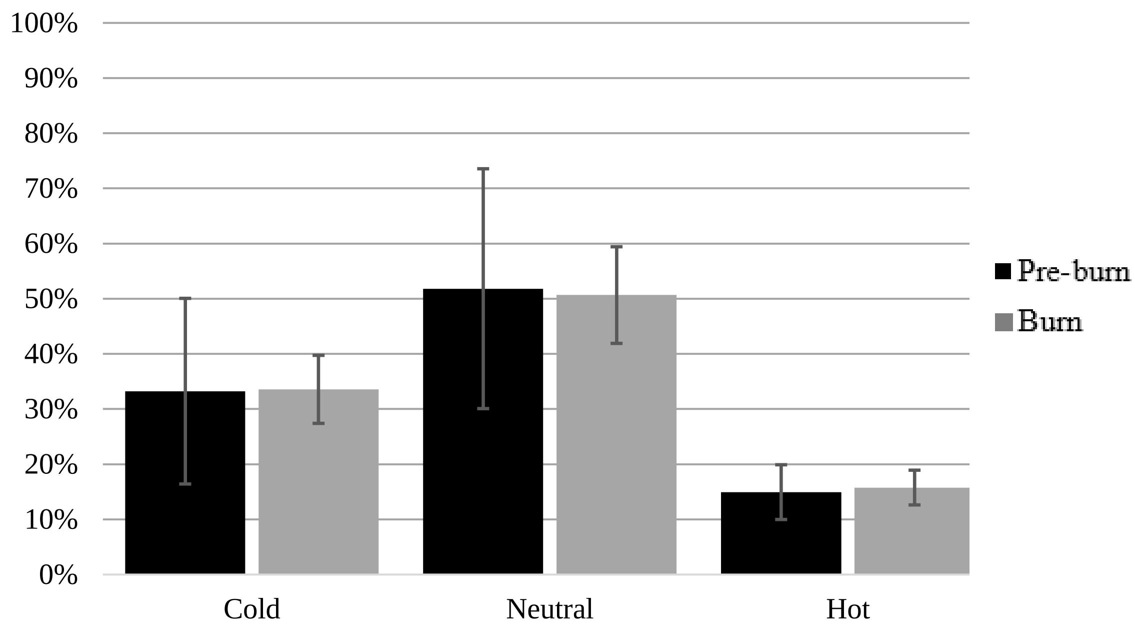


Figure 2.1 Percentage of total area of significantly cold, neutral, and hot spots to a 95% confidence interval based on results of an Optimized Hot Spot Analysis in ArcMap with a pixel size of 9 m^2 for pre-burn and burn years with error bars representing standard error across all three pastures

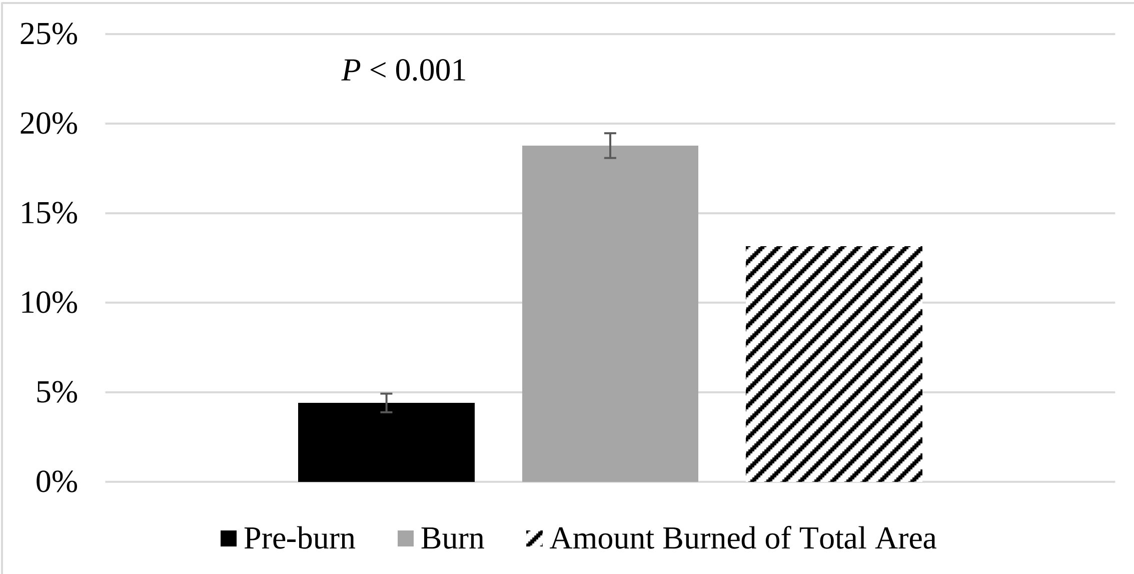


Figure 2.2. Percentage of GPS points in designated burned areas pre-burn and burning and the percentage of the total area burned over all pastures. Error bars indicate standard error across pastures. 27% of the unburned area decreased in use with the addition of burn units to the pastures.

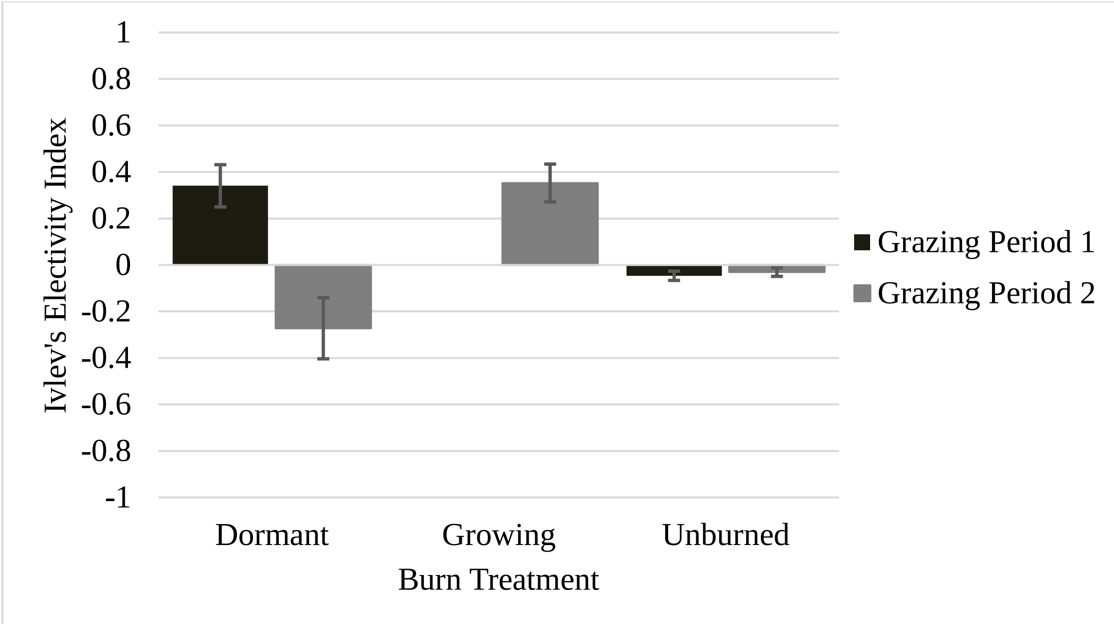


Figure 2.3. Ivlev's Electivity Index for dormant and summer burn patches and unburned areas during g for grazing period one with error bars representing standard error across six burn patches and all area outside the burn patch by pasture.

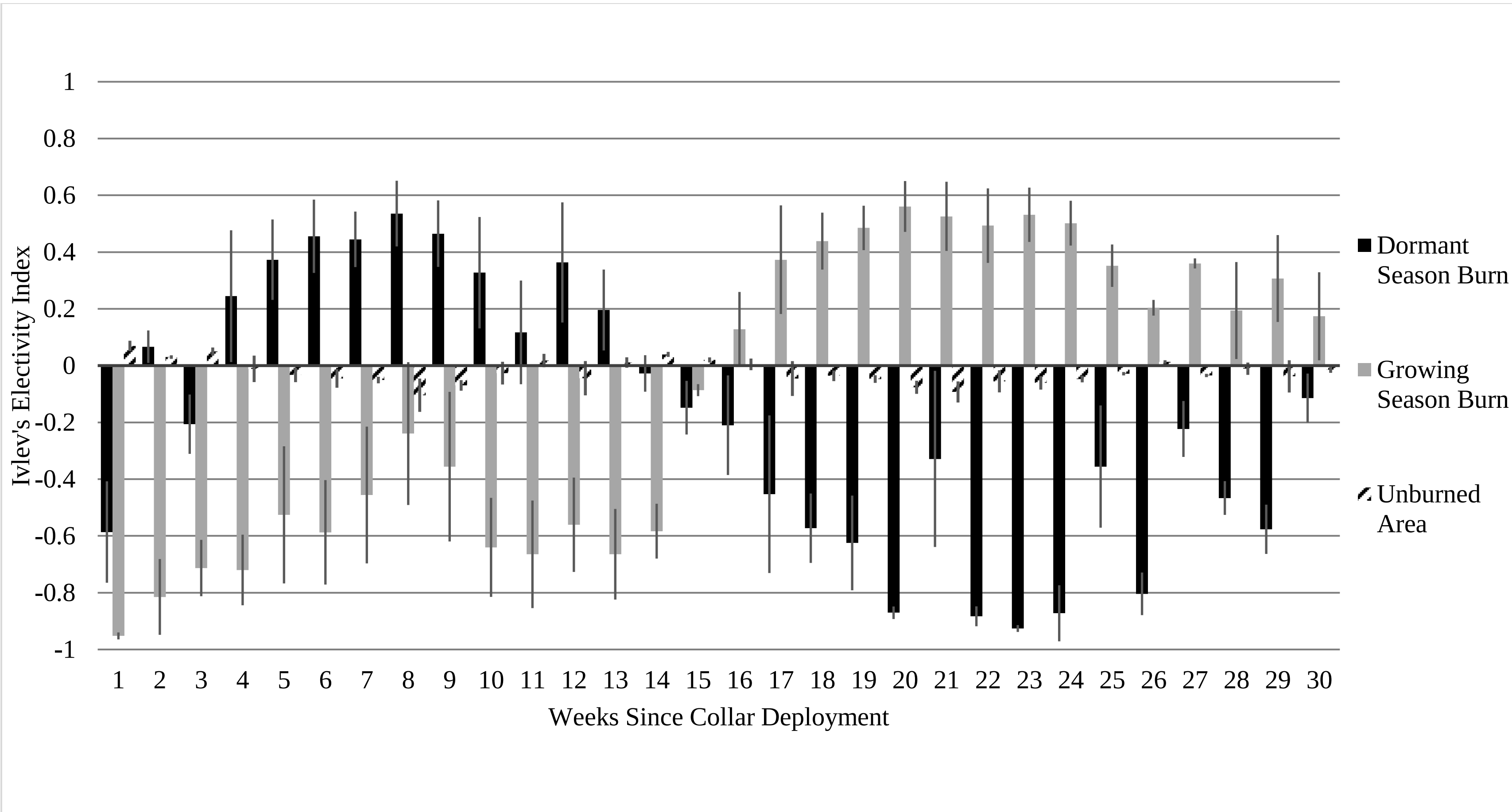


Figure 2.4. Ivlev's Electivity Index by season of burn and weeks since collar deployment for post-burn summer with error bars representing standard error across pastures. Spring burns were conducted just prior to collar deployment and summer burns were completed during week 12. Positive Ivlev's Electivity Indexes indicate selection while negative numbers represent avoidance for each area denoted.

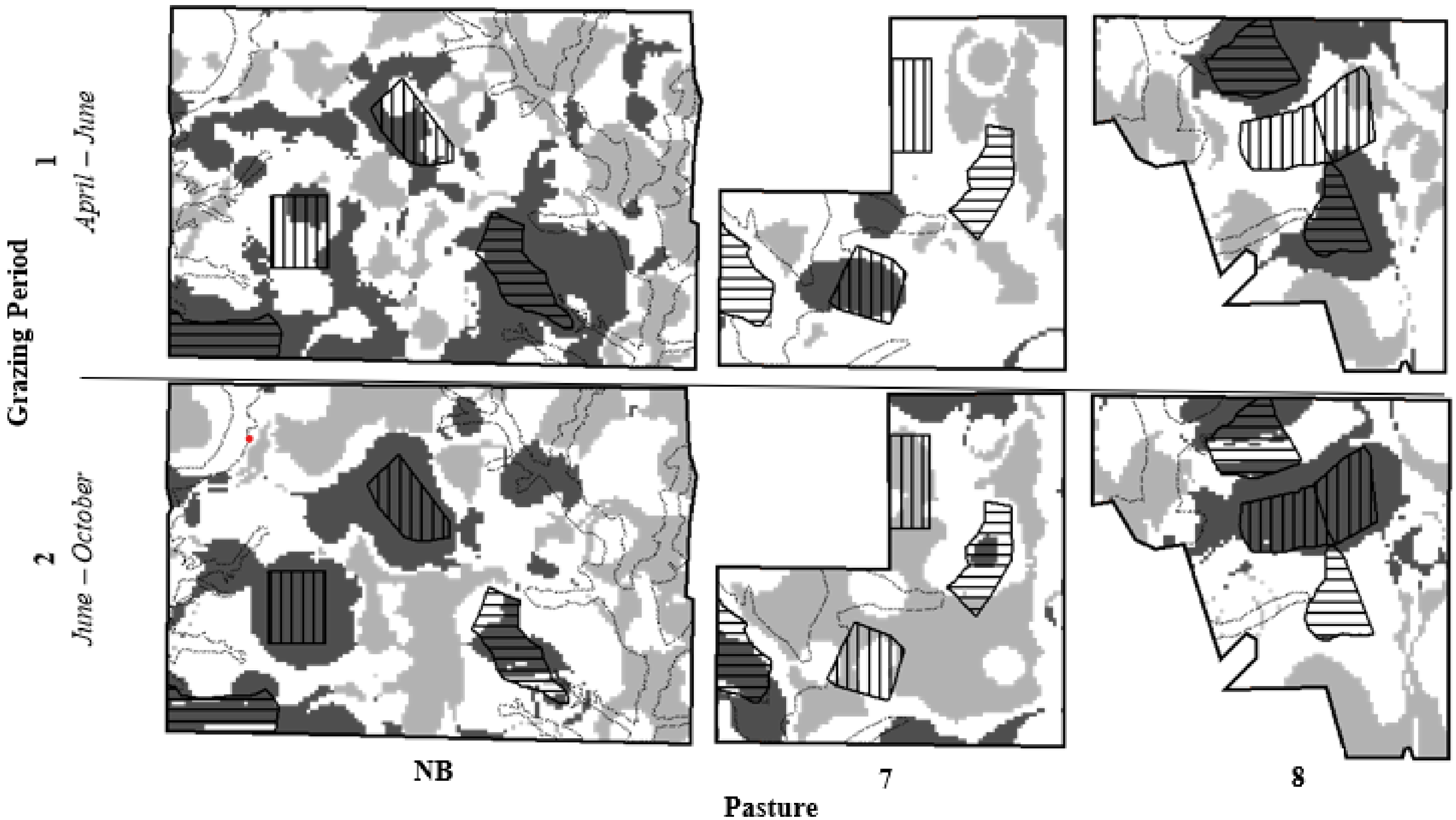


Figure 2.5. Cattle use changes from pre-burn field season to Grazing Period 1(April – June) and 2 (June – October). Transitions obtained from hot spot analysis of pre-burn GPS points compared to each grazing period hot spot analysis in each pasture. Possible transitions include increase in use (cold to hot, cold to neutral, and natural to hot), decrease in use (hot to cold, neutral to cold, and hot to neutral), and same use (hot to hot, neutral to neutral, and cold to cold). Transitions were grouped by increase (dark gray), decrease (light gray), .and same use (white). Spring burns are shown with horizontal black lines and summer burns are shown with vertical black lines. Hash marks outline riparian zones.

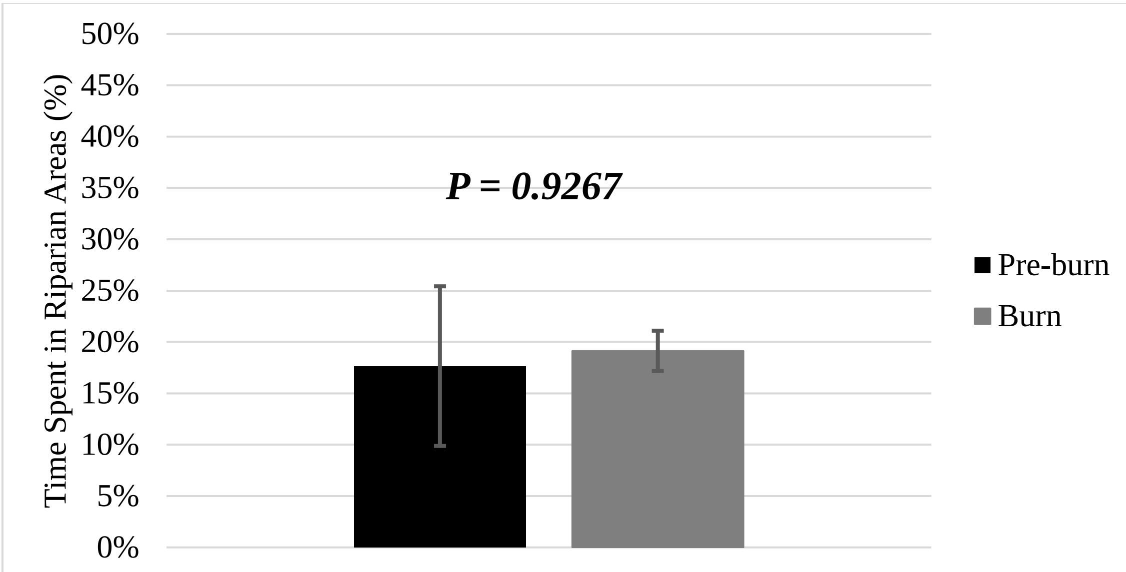


Figure 2.6. Average percentage of GPS points in designated riparian zones by field season across all. Two pastures showed slightly lower but insignificant usage of riparian areas while one pasture showed a significant increase in cattle time spent in riparian zones. Riparian areas delineated by hand using ArcMap imagery to delineate areas within and adjacent to flood zones.

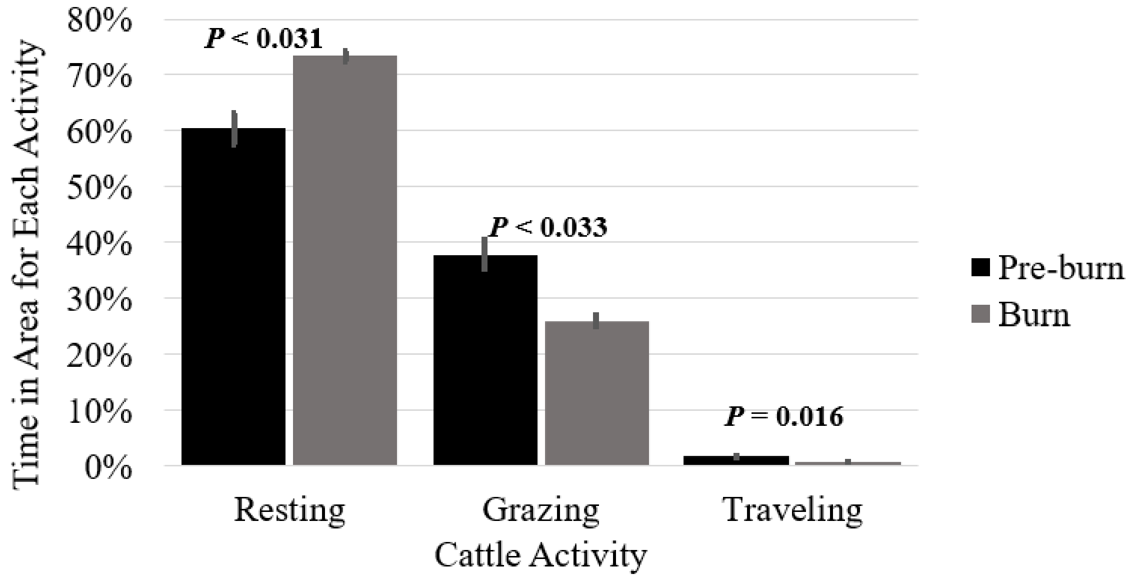


Figure 2.7. Cattle activity in riparian zones pre-burn and burning. Resting points were classified from speeds less than 138 meters per hour. Speeds of 138 to 1,500 meters per hour were classed as grazing points. If the speeds of greater than 1,500 meters per hour, points were designated as travelling. Cattle spent less time grazing and more time resting in the riparian areas during the post-burn summer.

TABLES

	Spring Burn		Unburned
	Tallgrass	**Shortgrass**	
	Increase in Use		
Cold to Hot	46.05 ± 23.05	22.76 ± 19.9	0.92 ± 0.46
Cold to Neutral	11.77 ± 10.58	43.15 ± 26.66	12.61 ± 6.57
Neutral to Hot	32.36 ± 20.94	6.42 ± 6.42	5.4 ± 2.68
	Decrease in Use		
Hot to Cold	-	-	1.27 ± 0.65
Hot to Neutral	-	-	7.17 ± 3.15
Neutral to Cold	-	3.14 ± 3.14	22.59 ± 10.74
	Same Use		
Hot to Hot	-	-	7.61 ± 1.75
Neutral to Neutral	9.83 ± 9.32	23.77 ± 23.77	24.87 ± 8.19
Cold to Cold	-	0.75 ± 0.75	17.56 ± 9.56

Table 2.1. Grazing period one mean probability of each cattle use transitions by burn treatment across all three pastures with standard errors given for variance. Transitions obtained from hot spot analysis of pre-burn GPS points compared to each grazing period hot spot analysis in each pasture. Dashes indicate the lack of occurrence for that transition in the burn treatment.

	Spring Burn		Summer Burn		Unburned
	Tallgrass	Shortgrass	Tallgrass	Shortgrass	
			Increase in Use		
Cold to Hot	1.95 ± 1.95	-	49.43 ± 26.43	32.93 ± 30.42	1.58 ± 1.32
Cold to Neutral	41.46 ± 20.82	30.5 ± 28.93	6.25 ± 6.25	33.61 ± 30.52	7.12 ± 3.69
Neutral to Hot	0.8 ± 0.8	-	37.82 ± 21.69	-	5.89 ± 0.24
			Decrease in Use		
Hot to Cold	-	-	-	-	1.78 ± 0.99
Hot to Neutral	-	-	-	-	7.86 ± 2.02
Neutral to Cold	0.57 ± 0.57	0.96 ± 0.96	-	-	14.57 ± 1.24
			Same Use		
Hot to Hot	-	-	-	-	7.71 ± 3.3
Neutral to Neutral	40.8 ± 30.3	32.38 ± 32.38	6.51 ± 6.51	33.33 ± 33.33	33.33 ± 19.75
Cold to Cold	14.4 ± 10.39	36.17 ± 30.52	-	0.12 ± 0.12	20.17 ± 10.2

Table 2.2. Grazing period two mean probability of each cattle use transitions by burn treatment across all three pastures with standard errors given for variance. Transitions obtained from hot spot analysis of pre-burn GPS points compared to each grazing period hot spot analysis in each pasture. Dashes indicate the lack of occurrence for that transition in the burn treatment.

	Pre-burn	Post-burn	*P*-value
Number of Cows	15	15	-
Number of Pastures	3	3	-
Daily Distance Traveled (m)	3,821 ± 29	3,578 ± 17	<0.001
Rate of Travel in Riparian areas (m/hr.)	201 ± 2	145 ± 1	<0.001
Rate of Travel in Upland areas (m/hr.)	208 ± 1	187 ± 1	<0.001
Sunrise-Sunset Distance Traveled (m)	2,618 ± 19	2,496 ± 15	<0.001
Sunset-Midnight Distance Traveled (m)	595 ± 11	550 ± 6	0.006
Midnight-Sunrise Distance Traveled (m)	636 ± 14	555 ± 5	<0.001
Daily Area Explored (m^2)	287,108.3 ± 3941.6	233,0140.1 ± 2,003.6	<0.001
Daily Spatial Search Pattern (%)	1.7 ± <0.0	2.3 ± 0.3	0.1014
Daily Area Explored of the Pasture (%)	49.9 ± 0.6	42.0 ± 0.4	<0.001

Table 2.3. Pre-burn and burn movement and distance travelled variables of cattle by day for both field seasons with p-values indicating level of differences between years obtained from a two independent sample t-test. Mean and standard erro given across all three pastures, 15 cows, 78 days for days for pre-burn data collection, and 205 days for post-burn season. Rate of travel calculated by multiplying the calculated distance between each point in meters by six to know the distance travelled per hour with 10-minute fixation intervals. Points were classified as being in riparian or upland areas by location in RStudio using shapefiles created in ArcMap. Sunrise and sunset times were obtained for each day in the R package "suncalc", and GPS points were classified into each time of day by the fixation time. Area explored was calculated in ArcMap using the Minimum Bounding Geometry tool by day and cow and calculating the area of each polygon. Daily Spatial Search Pattern calculated by dividing the grazable area - (daily distance travelled)^2 - by Area Explored. Daily Area Explored of Pasture determined by dividing the Daily Area Explored by each respective pasture area. Differences between years were tested with a two independent sample t test in RStudio. All variables except Daily Spatial Search Pattern were significantly less post-burning compared to before burning (p <0.05).

REFERENCES

Allred, B. W., Fuhlendorf, S. D., Engle, D. M., & Elmore, R. D. (2011). Ungulate preference for burned patches reveals strength of fire-grazing interaction. *Ecol Evol*, *1*(2), 132-144. https://doi.org/10.1002/ece3.12

Allred, B. W., Scasta, J. D., Hovick, T. J., Fuhlendorf, S. D., & Hamilton, R. G. (2014). Spatial heterogeneity stabilizes livestock productivity in a changing climate. *Agriculture, Ecosystems & Environment*, *193*, 37-41. https://doi.org/10.1016/j.agee.2014.04.020

ANKOM. (2020a). *ADF Method 14 - Acid Detergent Fiber in Feeds - Filter Bag Technique (for DELTA)*.

ANKOM. (2020b). *Method15 - Method Neutral Detergent Fiber in Feeds - Filter Bag Technique (for DELTA)*.

Ansley, R. J., W. E. Pinchak, & Ueckert, D. N. (1995). Changes in Redberry Juniper Distribution in Northwest Texas (1948 to 1982). *Rangelands*, *17*(2), 49-53.

AOAC. (2005). 18th Ed., AOAC Official Methods of Analysis. INTERNATIONAL, Gaithersburg, MD, Method 973.18.

Allred, B. W., Fuhlendorf, S. D., Engle, D. M., & Elmore, R. D. (2011). Ungulate preference for burned patches reveals strength of fire-grazing interaction. *Ecol Evol*, *1*(2), 132-144. https://doi.org/10.1002/ece3.12

Allred, B. W., Scasta, J. D., Hovick, T. J., Fuhlendorf, S. D., & Hamilton, R. G. (2014). Spatial heterogeneity stabilizes livestock productivity in a changing climate. *Agriculture, Ecosystems & Environment*, *193*, 37-41. https://doi.org/10.1016/j.agee.2014.04.020

Anderson, R. C. (2006). Evolution and Origin of the Central Grassland of North America: Climate, Fire, and Mammalian Grazers. *The Journal of the Torrey Botanical Society*, *133*(4), 626-647.

ANKOM. (2020a). *ADF Method 14 - Acid Detergent Fiber in Feeds - Filter Bag Technique (for DELTA)*.

ANKOM. (2020b). *Method15 - Method Neutral Detergent Fiber in Feeds - Filter Bag Technique (for DELTA)*.

Ansley, R. J., W. E. Pinchak, & Ueckert, D. N. (1995). Changes in Redberry Juniper Distribution in Northwest Texas (1948 to 1982). *Rangelands*, *17*(2), 49-53.

AOAC. (2005). 18th Ed., AOAC Official Methods of Analysis. INTERNATIONAL, Gaithersburg, MD, Method 973.18.

AOAC. (2006). Official Method 990.03, Protein (Crude) in Animal Feed, Combustion Method, in Official Methods of Analysis of AOAC International, 18th edition Revision 1, 2006. Chapter 4, pp. 30-31, AOAC International, Gaithersburg, MD.

Archer, S. R., Erik M. Andersen, Katharine I. Predick, Susanne Schwinning, Robert J. Steidl, & Woods, S. R. (2017). Woody Plant Encroachment: Causes and Consequences. In D. D. Briske (Ed.), *Rangeland Systems*. Springer. https://doi.org/10.1007/978-3-319-46709-2

Axelrod, D. I. (1985). Rise of the Grassland Biome, Central North America. *Botanical Review*, *51*, 163-201.

Belsky, A. J., Matzke, A., & Uselman, S. (1999). Survey of livestock influences on stream and riparian ecosystems in the western United States. *Journal of Soil and Water Conservation*, *54*(1), 419-431. https://www.jswconline.org/content/jswc/54/1/419.full.pdf

Bidwell, T. G., Masters, R. E., Elmore, R. D., & Weir, J. R. (2007). Oklahoma's Native Vegetation Types. In *Natural Resource Ecology and Management, Oklahoma Cooperative Extension Service, and Oklahoma State University*.

Bolker, B., & R Development Core Team. (2022). *_bbmle: Tools for General Maximum Likelihood Estimation_. R package version 1.0.25,* . https://CRAN.R-project.org/package=bbmle

Bond, W. J., G. F. Midgley, & Woodward, F. I. (2003). The importance of low atmospheric CO2 and Fire in Promoting the Spread of Grasslands and Savannas. *Globoal Change Biology*, *9*, 973-982.

Briske, D. D. (1991). Developmental morphology and physiology of grasses. In R. K. H. a. J. W. Stuth (Ed.), *Grazing Management: An Ecological Perspective*. Timber Press.

Clark, P. E., Lee, J., Ko, K., Nielson, R. M., Johnson, D. E., Ganskopp, D. C., Chigbrow, J., Pierson, F. B., & Hardegree, S. P. (2014). Prescribed fire effects on resource selection by cattle in mesic sagebrush steppe. Part 1: Spring grazing. *Journal of Arid Environments, 100-101*, 78-88. https://doi.org/10.1016/j.jaridenv.2013.10.012

Dairy One. (2021). *Forage Laboratory*. Retrieved March 17 from https://dairyone.com/services/forage-laboratory-services/about-the-forage-laboratory/

ESRI. (2019). ArcGIS Desktop. Release 10.8.0. Redlands, CA: Environmental Systems Research Institute.

Falk, D. A., Miller, C., McKenzie, D., & Black, A. E. (2007). Cross-Scale Analysis of Fire Regimes. *Ecosystems*, *10*(5), 809-823. https://doi.org/10.1007/s10021-007-9070-7

Farney, J. K., Rensink, C. B., Fick, W. H., Shoup, D., & Miliken, G. A. (2017). Patch burning on tall-grass native prairie does not negatively affect stocker performance or pasture composition. *The Professional Animal Scientist, 33*(5), 549-554. https://doi.org/10.15232/pas.2016-01574

Fuhlendorf, S. D., & Engle, D. M. (2001). Restoring Heterogeneity on Rangelands: Ecosystem Management Based on Evolutionary Grazing Patterns. *BioScience*, *51*(8), 625-632.

Fuhlendorf, S. D., & Engle, D. M. (2004). Application of the Fire: Grazing Interaction to Restore a Shifting Mosaic on Tallgrass Prairie. *Journal of Applied Ecology*, *41*(4), 604-614.

Fuhlendorf, S. D., Engle, D. M., Elmore, R. D., Limb, R. F., & Bidwell, T. G. (2012). Conservation of Pattern and Process: Developing an Alternative Paradigm of Rangeland Management. *Rangeland Ecology & Management, 65*(6), 579-589. https://doi.org/10.2111/rem-d-11-00109.1

Fuhlendorf, S. D., Engle, D. M., Kerby, J., & Hamilton, R. (2009). Pyric herbivory: rewilding landscapes through the recoupling of fire and grazing. *Conserv Biol*, *23*(3), 588-598. https://doi.org/10.1111/j.1523-1739.2008.01139.x

Fuhlendorf, S. D., Harrell, W. C., Engle, D. M., Hamilton, R. G., Davis, C. A., & Jr., D. M. L. (2006). Should Heterogeneity Be the Basis for Conservation? Grassland Bird Response to Fire and Grazing. *Ecological Applications, 16*(5), 1706-1716.

Fuhlendorf, S. D., Richard W. S. Fynn, Devan Allen McGranahan, & Twidwell, D. (2017). Heterogeneity as the Basis for Rangeland Management. In D. D. Briske (Ed.), *Rangeland Systems* (pp. 169–196). Springer.

Fuhlendorf, S. D., Townsend, D. E. I., Elmore, R. D., & Engle, D. M. (2010). Pyric-Herbivory to Promote Rangeland Heterogeneity: Evidence From Small Mammal Communities. *The Southwestern Naturalist*, *18*, 443-451.

Goering, H. K., & Van Soest, P. J. (1970). ARS/USDA Handbook

In *Forage Fiber Analyses (apparatus, reagents, procedures, and some applications)* (pp. P13-14). Washington, D.C. 20402: Superintendent of Documents, US Government Printing Office.

Guyette, R. P., Stambaugh, M. C., Dey, D. C., & Muzika, R.-M. (2012). Predicting Fire Frequency with Chemistry and Climate. *Ecosystems*, *15*(2), 322-335. https://doi.org/10.1007/s10021-011-9512-0

Haines, T. K., & Busby, R. L. (2001). Prescribed Burning in the South: Trends, Purpose, and Barriers. *Southern Journal of Applied Forestry*, *25*(4), 149-153.

Hemphill, C. H. (2020). *The Effect of Rotational Grazing on the Performance and Grazing Behavior of Cow-Calf Pairs, and the Effectiveness of Frequent Human Interaction in Altering the Temperament of Mature Beef Cows* Oklahoma State University].

Hobbs, N. T., & Swift, D. M. (1985). Estimates of Habitat Carrying Capacity Incorporating Explicit Nutritional Constraints. *The Journal of Wildlife Management*, *49*(3). https://doi.org/10.2307/3801716

Holechek, J. L. (1984). Comparative contribution of grasses, forbs, and shrubs to the nutrition of range ungulates. *Rangelands Archives*, *6*(6), 261-263.

Hutjens, M. F. (2002). Dry Lot ± Dairy Cow Breeds. *Dairy Farm Management Systems*, 693-699.

Kay, C. E. (1998). Are ecosystems structured from the top-down or bottom-up? A new look at an old debate. *Wildlife Society Bulletin*, *26*, 484–498.

Kerby, J. D., Fuhlendorf, S. D., & Engle, D. M. (2006). Landscape heterogeneity and fire behavior: scale-dependent feedback between fire and grazing processes. *Landscape Ecology*, *22*(4), 507-516. https://doi.org/10.1007/s10980-006-9039-5

Knight, C. W., Bailey, D. W., & Faulkner, D. (2018). Low-Cost Global Positioning System Tracking Collars for Use on Cattle. *Rangeland Ecology & Management*, *71*(4), 506-508. https://doi.org/10.1016/j.rama.2018.04.003

Larson, D. M., Dodds, W. K., Whiles, M. R., Fulgoni, J. N., & Thompson, T. R. (2016). A before-and-after assessment of patch-burn grazing and riparian fencing along headwater streams. *Journal of Applied Ecology*, *53*(5), 1543-1553. http://www.jstor.org/stable/44133908

Lechowicz, M. J. (1982). The Sampling Characteristics of Electivity Indices. *Oecologia*, *52*, 22-30.

Lee, M. A. (2018). A global comparison of the nutritive values of forage plants grown in contrasting environments. *J Plant Res*, *131*(4), 641-654. https://doi.org/10.1007/s10265-018-1024-y

Limb, R. F., Fuhlendorf, S. D., Engle, D. M., & Miller, R. F. (2016). Synthesis Paper: Assessment of Research on Rangeland Fire as a Management Practice. *Rangeland Ecology & Management*, *69*(6), 415-422. https://doi.org/10.1016/j.rama.2016.07.013

Limb, R. F., Fuhlendorf, S. D., Engle, D. M., Weir, J. R., Elmore, R. D., & Bidwell, T. G. (2011). Pyric-Herbivory and Cattle Performance in Grassland Ecosystems. *Rangeland Ecology & Management*, *64*(6), 659-663.

Maguire, L. A., & Albright, E. A. (2005). Can behavioral decision theory explain risk-averse fire management decisions? *Forest Ecology and Management*, *211*(1-2), 47-58. https://doi.org/10.1016/j.foreco.2005.01.027

Mbatha, K. R., & Ward, D. (2010). The effects of grazing, fire, nitrogen and water availability on nutritional quality of grass in semi-arid savanna, South Africa. *Journal of Arid Environments*, *74*(10), 1294-1301. https://doi.org/10.1016/j.jaridenv.2010.06.004

McDowell, L. R. (2003). *Minerals in Animal and Human Nutrition* (2 ed.). Elsevier.

McGranahan, D. A., Henderson, C. B., Hill, J. S., Raicovich, G. M., Wilson, W. N., & Smith, C. K. (2014). Patch Burning Improves Forage Quality and Creates Grass-Bank in Old-Field Pasture: Results of a Demonstration Trial. *Southeastern Naturalist*, *13*(2), 200-207. https://doi.org/10.1656/058.013.0203

Melvin, M. A. (2018). *2018 National Prescribed Fire Use Survey Report*.

Microsoft Corporation. (2018). *Microsoft Excel*. https://office.microsoft.com/excel

Morris, G., & Conner, L. M. (2017). Assessment of accuracy, fix success rate, and use of estimated horizontal position error (EHPE) to filter inaccurate data collected by a common commercially available GPS logger. *PLoS One*, *12*(11), e0189020. https://doi.org/10.1371/journal.pone.0189020

National Academies of Sciences Engineering Medicine. (2016). *Nutrient Requirements of Beef Cattle: Eighth Revised Edition*. The National Academies Press. https://doi.org/doi:10.17226/19014

NEON. (2022). *National Ecological Observatory Network - Data Portal*. Retrieved June 6 from https://www.neonscience.org

NWCG. (2021). S-290 Unit 10: Fuel Moisture. National Wildfire Coordinating Group. Available at: http://stream1.cmatc.cn/pub/comet/FireWeather/S290Unit10Fuel Moisture/comet/fire/s290/unit10/navmenu.php_tab_1_page_4.1.1.htm. Accessed 06 February 2021.

Nyamuryekung'e, S., Cibils, A. F., Estell, R. E., VanLeeuwen, D., Steele, C., Octavio Roacho Estrada Rodríguez Almeida, F., González, A. L., & Spiegal, S. (2020). Do Young Calves Influence Movement Patterns of Nursing Raramuri Criollo Cows on Rangeland? *Rangeland Ecology and Management*, *73*(1), 84-92.

Polito, V. J., Baum, K. A., Payton, M. E., Little, S. E., Fuhlendorf, S. D., & Reichard, M. V. (2013). Tick Abundance and Levels of Infestation on Cattle in Response to Patch Burning. *Rangeland Ecology and Management*, *66*(5), 545-552, 548. https://doi.org/10.2111/REM-D-12-00172.1

Powell, J., Martin, B., Dreitz, V. J., & Allred, B. W. (2018). Grazing Preferences and Vegetation Feedbacks of the Fire-Grazing Interaction in the Northern Great Plains. *Rangeland Ecology & Management*, *71*(1), 45-52. https://doi.org/10.1016/j.rama.2017.09.003

PRISM Climate Group. (2020). *Time Series Values for Individual Locations - Bessie, OK*. Oregon State University. Retrieved June 8 from http://prism.oregonstate.edu

Quintans, D. (2019). _electivity: Algorithms for Electivity Indices_. R package version 1.0.2 https://CRAN.R-project.org/package=electivity

R Core Team. (2022). *R: A language and environment for statistical computing. R Foundation for Statistical Computing*. https://www.R-project.org/

RStudio Team. (2022). *RStudio: Integrated Development Environment for R. Retrieved from RStudio, Inc.* http://www.rstudio.com/

Spiess, J. W., McGranahan, D. A., Geaumont, B., Sedivec, K., Lakey, M., Berti, M., Hovick, T. J., & Limb, R. F. (2020). Patch-Burning Buffers Forage Resources and Livestock Performance to Mitigate Drought in the Northern Great Plains. *Rangeland Ecology & Management*, *73*(4), 473-481. https://doi.org/10.1016/j.rama.2020.03.003

Stambaugh, M. C., Richard P. Guyette, Ralph Godfrey, E.R. McMurry, & Marschall, J. M. (2009). Fire, Drought, and Human History near the Western Terminus of the Cross Timbers, Wichita Mountains, Oklahoma, USA. *Fire Ecology*, *5*(2), 51-65. https://doi.org/10.4996/fireecology.0502051

Teague, W. R., Duke, S. E., Waggoner, J. A., Dowhower, S. L., & Gerrard, S. A. (2008). Rangeland Vegetation and Soil Response to Summer Patch Fires Under Continuous Grazing. *Arid Land Research and Management*, *22*(3), 228-241. https://doi.org/10.1080/15324980802183210

Thapa, S. K., de Jong, J. F., Hof, A. R., Subedi, N., Joshi, L. R., & Prins, H. H. T. (2022). Fire and forage quality: Postfire regrowth quality and pyric herbivory in subtropical grasslands of Nepal. *Ecol Evol*, *12*(4), e8794. https://doi.org/10.1002/ece3.8794

Thapa, S. K., de Jong, J. F., Subedi, N., Hof, A. R., Corradini, G., Basnet, S., & Prins, H. H. T. (2021). Forage quality in grazing lawns and tall grasslands in the subtropical region of Nepal and implications for wild herbivores. *Global Ecology and Conservation*, *30*. https://doi.org/10.1016/j.gecco.2021.e01747

Thieurmel, B., & Elmarhraoui, A. (2019). _suncalc: Compute Sun Position, Sunlight Phases, Moon Position and Lunar Phase_. R package version 0.5.0. https://CRAN.R-project.org/package=suncalc

Van Liew, D., J. Richard Conner, Urs P. Kreuter, & Teague, R. (2012). An Economic Comparison of Prescribed Extreme Fire and Alternative Methods for Managing Invasive Brush Species in Texas: a Modeling Approach. *The Open Agriculture Journal*, *6*, 17-26.

Van Soest, P. J., Robertson, J. B., & Lewis, B. A. (1991). Methods for Dietary Fiber, Neutral Detergent Fiber, and Nonstarch Polysaccharides in Relation to Animal Nutrition. *Journal of Dairy Science*, *74*, 3583-3597.

Vermeire, L. T., Mitchell, R. B., Fuhlendorf, S. D., & Gillen, R. L. (2004). Patch burning effects on grazing distribution. *Rangeland Ecology & Management*, *57*(3), 248-252. https://doi.org/10.2111/1551-5028(2004)057[0248:Pbeogd]2.0.Co;2

Wanchuk, M. R., McGranahan, D. A., Sedivec, K. K., Swanson, K. C., Hovick, T. J., & Limb, R. F. (2021). Contrasts in forage mineral concentration with patch-burn grazing: a preliminary analysis. *Translational Animal Science*, *5*(Supplement_S1), S75-S79. https://doi.org/10.1093/tas/txab173

Web Soil Survey. (2021). *Web Soil Survey*. Natural Resources Conservation Service, United States Department of Agriculture. Retrieved August 14 from http://websoilsurvey.sc.egov.usda.gov

Weir, J. (2009). *Conducting Prescribed Fires: A comprehensive manual*.

Weir, J. R., & Scasta, J. D. (2017). Vegetation Responses to Season of Fire in Tallgrass Prairie: A 13-Year Case Study. *Fire Ecology*, *13*(2), 137-142. https://doi.org/10.4996/fireecology.130290241

Welti, E. A. R., Roeder, K. A., de Beurs, K. M., Joern, A., & Kaspari, M. (2020). Nutrient dilution and climate cycles underlie declines in a dominant insect herbivore. *Proc Natl Acad Sci U S A*, *117*(13), 7271-7275. https://doi.org/10.1073/pnas.1920012117

Wesley, R. L., Cibils, A. F., Mulliniks, J. T., Pollak, E. R., Petersen, M. K., & Fredrickson, E. L. (2012). An assessment of behavioural syndromes in rangeland-raised beef cattle. *Applied Animal Behaviour Science*, *139*(3-4), 183-194. https://doi.org/10.1016/j.applanim.2012.04.005

West, A. L., Zou, C. B., Stebler, E., Fuhlendorf, S. D., & Allred, B. (2016). Pyric-herbivory and Hydrological Responses in Tallgrass Prairie. *Rangeland Ecology & Management*, *69*(1), 20-27. https://doi.org/10.1016/j.rama.2015.10.004

Winter, S. L., Fuhlendorf, S. D., & Goes, M. (2014). Patch-Burn Grazing Effects on Cattle Performance: Research Conducted in a Working Landscape. *Rangelands*, *36*(3), 2-7. https://doi.org/10.2111/Rangelands-D-13-00079.1

Woods, A. J., Omernik, J. M., Butler, D. R., Ford, J. G., Henley, J. E., Hoagland, B. W., Arndt, D. S., & Moran, B. C. (2005). Ecoregions of Oklahoma. In (Vol. map scale 1:1,250,000, pp. color poster with map, descriptive text, summary tables, and photographs). Reston, Virginia: U.S. Geological Survey.

APPENDICES

Appendix A. To create the hot spot analysis transition maps, we completed a hotspot analysis in ArcMap on the pre-burn and burn GPS points by pasture and grazing period. To select the cells from the hotspot analysis in different burn units and in unburned areas, we used the tool "Select Layer By Location" with the "Relationship" option set to "HAVE_THEIR_CENTER_IN" and the "Selecting Features" as the individual burn unit. For unburned areas, we followed the same steps to add each burn unit selection to the previous selection and use the "Switch Selection" to select everything outside the burn units. We exported each selection by right clicking the layer, hovering over "Data", and clicking "Export Data…", and followed steps to save the selected features in the proper location as a CSV file. Using RStudio, for grazing period two, we imported all files, combined them, and calculated transitions based on the Gi_Bin column from each year's attribute table using the function and code below. For grazing period one, we used the same methods just different files and considering the summer burn units as unburned. We exported the created data frame as a CSV file, imported it back into ArcMap, and joined it to a copy of a hotspot analysis layer for all three pastures which was saved as a transition layer. We used the transition column as the labeling feature to create a transition map for each pasture.

```
tran_matrix_S2 <- function(pasture, burn_unit){
  HS_2020 <-
read_excel(str_c("D:/OSU/Project/CowData/HotSpot_AttributteTable/Summer_2020/",
pasture, "_", "2020", "_", burn_unit, ".xlsx")) %>%
    transform(yr_2020 = Gi_Bin) %>%
    select(FID, yr_2020)

  HS_2021_2 <-
read_excel(str_c("D:/OSU/Project/CowData/HotSpot_AttributteTable/Summer_2/",
pasture, "_", "Summer2", "_", burn_unit, ".xlsx")) %>%
    transform(yr_2021 = Gi_Bin) %>%
    select(yr_2021)

trans_join <- cbind(HS_2020, HS_2021_2) %>%
  mutate(trans = str_c(yr_2020, yr_2021),
         transition_level = ifelse(trans == "-3-3", "CC",
                          ifelse(trans == "-30", "CN",
                                ifelse(trans == "-33", "CH",
                                      ifelse(trans == "0-3", "NC",
                                            ifelse(trans == "00", "NN",
                                                  ifelse(trans == "03", "NH",
                                                        ifelse(trans == "3-3", "HC",
                                                          ifelse(trans == "30", "HN",
                                                            ifelse(trans == "33", "HH", "NA"))))))))))
return(trans_join)}
trans_matrix_S2 <- do.call("rbind", list(tran_matrix_S2("8", "HD"),
                                  tran_matrix_S2("8", "HG"),
                                  tran_matrix_S2("8", "LD"),
                                  tran_matrix_S2("8", "LG"),
                                  tran_matrix_S2("8", "unburned2"),
                                  tran_matrix_S2("NB", "HD"),
                                  tran_matrix_S2("NB", "HG"),
                                  tran_matrix_S2("NB", "LD"),
                                  tran_matrix_S2("NB", "LG"),
                                  tran_matrix_S2("NB", "unburned2"),
                                  tran_matrix_S2("7", "HD"),
                                  tran_matrix_S2("7", "HG"),
                                  tran_matrix_S2("7", "LD"),
                                  tran_matrix_S2("7", "LG"),
                                  tran_matrix_S2("7", "unburned2")))
```

Appendix B. Formula for Calculating the Distance Between Points in Excel

- Full pasture data was sorted by cow, date, and time
- Formulas were copy and pasted into excel, beginning on the second row
- The correct latitude and longitude value cells were inserted into the formula
- The formula was pulled down the entire data
- The numbers were copied to adjacent cells as values to preserve numbers
- Zeros were inserted where there was a change of cow or GPS unit
- The files are now ready to be imported into R for further analysis

Kilometers:
=ACOS(COS(RADIANS(90-Lat1)) * COS(RADIANS(90-Lat2)) + SIN(RADIANS(90-Lat1)) * SIN(RADIANS(90-Lat2)) * COS(RADIANS(Long1-Long2))) * 6371

Miles:
=ACOS(COS(RADIANS(90-Lat1)) * COS(RADIANS(90-Lat2)) + SIN(RADIANS(90-Lat1)) * SIN(RADIANS(90-Lat2)) * COS(RADIANS(Long1-Long2))) * 3959

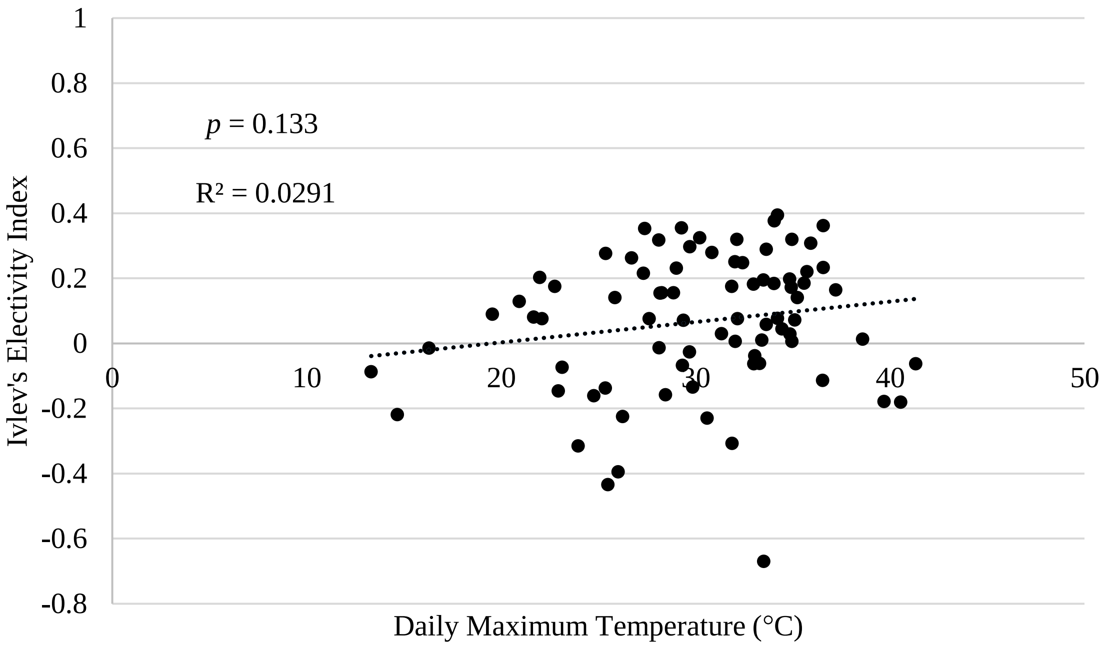
Source: https://stackoverflow.com/questions/11879053/driving-distance-between-two-coordinates

Alternatively, this one could be used but it gives nearly the same numbers

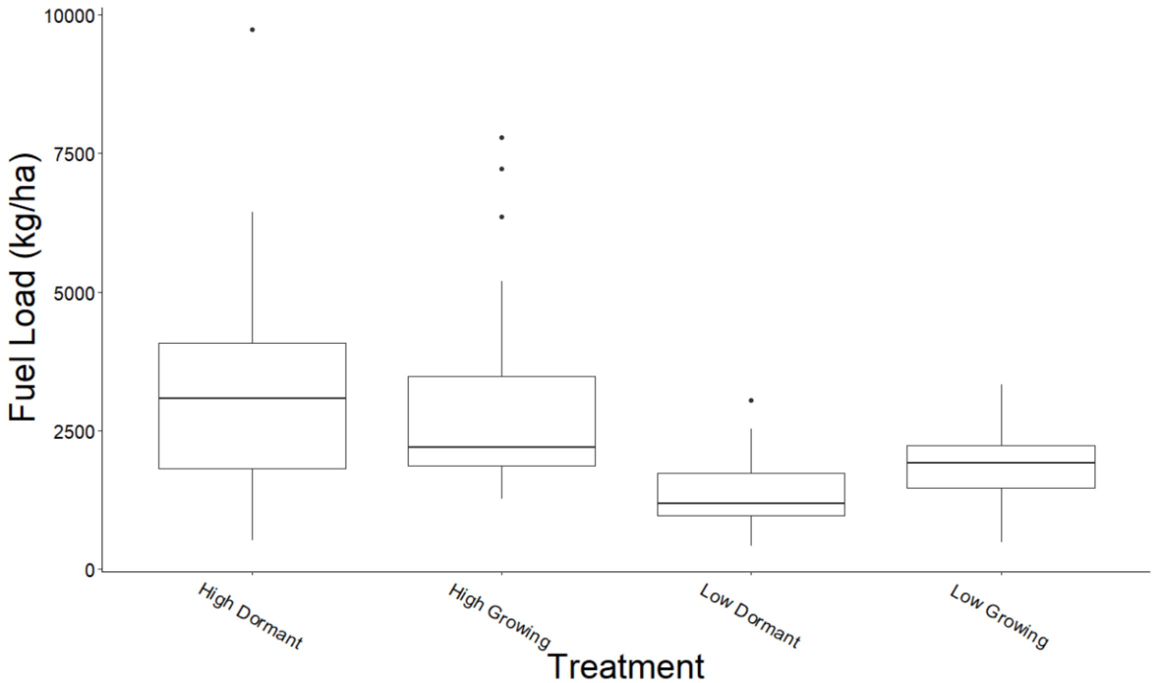
=2*ATAN2(SQRT(1-SIN(ABS(H3-H2)*PI()/180/2)^2+COS(H2*PI()/180)*COS(H3*PI()/180)*SIN(ABS(I3-I2)*PI()/180/2)^2),SQRT(SIN(ABS(H3-H2)*PI()/180/2)^2+COS(H2*PI()/180)*COS(H3*PI()/180)*SIN(ABS(I3-I2)*PI()/180/2)^2))*6371

Source: https://www.mrexcel.com/board/threads/calculating-distance-between-two-latitude-longitude-points.202255/

Appendix C. Effect of daily maximum temperature on cattle selectivity of riparian areas using Ivlev's Electivity Index for pre-burn field season. P-value calculated from linear model fitted to data. Daily maximum temperature did have a significant, positive effect on cattle selection for riparian areas ($R^2 = 0.0291$) during the pre-burn summer.



Appendix D. Fuel loads for each burning treatment. Includes samples taken just prior to burning in each patch across all three pastures and multiplied from grams per ¼ m^2 to kilograms per hectare.



Appendix E. Linear regression models tested using time since fire (TSF), Biomass, and/or Shannon's species diversity index (Diversity) to predict levels of each different variable. Each variable was fitted for each of the 15 different models which include linear, quadratic, and exponential models. The matric is the dependent or response variable. The model equation is given in the model column showing which independent or predicting variables were used for each model. The log(matric) models denote exponential type models, and independent variables with ^2 after them indicate the model was quadratic. All other models were linear relationships. The Akaike Information Criterion (AICc), shows how well each model explains the variability within the data. The model with the lowest AIC is considered to be the best fit. The best fit model then sets the basis and the rest of the models are compared to it using the Difference in AIC (dAICc). All subsequent model AIC values are subtracted from the top model AIC to show how far away from the top model each lower ranking model is. K is the number of parameters in each model. Models with higher K values are more complex and less useful because while they may explain more variability, they can add to much complexity, make it impractical, and result in a higher AIC. The model weight, or wi, is a value between 0 and 1 indicating to what extent the model in question is really a good fit for the data, with values closer to being more likely to be the best fitting model and values closer to zero being less suitable. The Log Likelihood, or LL, given in the table is the model residual sum of squares, which also helps determine how well each model fits the data.

Time Since Fire

Metric	K	AICc	dAICc	wi	LL
	3	-42.25	0	1	24.27
	3	395.39	437.64	0	-194.6
Crude Protein	4	396.17	438.42	0	-193.9
	3	-119.5	0	1	62.91
	4	523.4	642.94	0	-257.5
ADF	3	525.04	644.58	0	-259.4
	3	-63.66	0	1	34.97
	4	633.87	697.53	0	-312.7
aNDF	3	640.77	704.43	0	-317.2
	3	-340.6	0	1	173.43
	4	391.68	732.27	0	-191.6
TDN	3	399.3	739.88	0	-196.5
	4	142.75	0	0.97	-67.14
	3	150.57	7.82	0.02	-72.15
Calcium_DM	3	151.59	8.83	0.01	-72.65
Phosphorus	3	-332.5	0	0.69	169.37

	4	-330.9	1.62	0.31	169.66
	3	-8.33	324.13	0	7.31
	4	-109.9	0	0.87	59.17
	3	-106.1	3.73	0.13	56.21
Magnesium	3	88.53	198.39	0	-41.12
	3	62.01	0	1	-27.87
	4	122.64	60.63	0	-57.08
Potassium	3	126.77	64.76	0	-60.25
	3	135.76	0	1	-64.74
	4	1300.4	1164.7	0	-646
Iron_ppm	3	1302.9	1167.1	0	-648.3
	3	75.25	0	1	-34.48
	4	751.6	676.36	0	-371.6
Zinc_ppm	3	753.13	677.88	0	-373.4
	3	7.42	0	1	-0.57
	3	390.73	383.31	0	-192.2
Copper_ppm	4	391.86	384.44	0	-191.7
	3	89.67	0	1	-41.69
	3	859.5	769.84	0	-426.6
Manganese_ppm	4	861.7	772.03	0	-426.6
	3	89.06	0	1	-41.39
	4	100.42	11.36	0	-45.97
Molybdenum_ppm	3	104.35	15.29	0	-49.04

Grass Cover

Metric	K	AICc	dAICc	wi	LL
	3	-6.59	0	1	6.36
	4	863.58	870.17	0	-427.7
Crude Protein	3	876.57	883.16	0	-435.2
	3	-329	0	1	167.54
	3	1120.3	1449.3	0	-557.1
ADF	4	1122.1	1451.1	0	-557
	3	-285.3	0	1	145.73
	3	1294.5	1579.8	0	-644.2
aNDF	4	1296.6	1581.9	0	-644.2
	3	-875.6	0	1	440.86
	3	756.93	1632.5	0	-375.4
TDN	4	758.87	1634.5	0	-375.3
	3	227.41	0	0.5	-110.6
Calcium_DM	4	227.43	0.02	0.5	-109.6

	3	263.63	36.22	0	-128.8
	4	-742.4	0	1	375.28
	3	-717.6	24.71	0	361.88
Phosphorus	3	79.71	822.06	0	-36.79
	3	-368.4	0	0.67	187.27
	4	-367	1.42	0.33	187.6
Magnesium	3	148.92	517.32	0	-71.4
	3	158.21	0	1	-76.04
	4	199.09	40.88	0	-95.44
Potassium	3	207.62	49.41	0	-100.8
	3	352.92	0	1	-173.4
	3	2896.8	2543.9	0	-1445
Iron_ppm	4	2897	2544.1	0	-1444
	3	244.69	0	1	-119.3
	3	2223	1978.3	0	-1108
Zinc_ppm	4	2224.8	1980.1	0	-1108
	3	45.38	0	1	-19.63
	4	818.14	772.76	0	-405
Copper_ppm	3	818.53	773.15	0	-406.2
	3	221.37	0	1	-107.6
	3	1868.3	1646.9	0	-931.1
Manganese_ppm	4	1869.3	1647.9	0	-930.5
	3	179.86	0	1	-86.87
	3	212.34	32.47	0	-103.1
Molybdenum_ppm	4	213.74	33.88	0	-102.8

Biomass

Metric	K	AICc	dAICc	wi	LL
	3	43.75	0	1	-18.81
	4	894.01	850.26	0	-442.9
Crude Protein	3	948.54	904.79	0	-471.2
	3	-285.1	0	1	145.62
	4	1145.6	1430.8	0	-568.7
ADF	3	1162.7	1447.8	0	-578.3
	3	-210.1	0	1	108.1
	3	1371.9	1582	0	-682.9
aNDF	4	1372.1	1582.2	0	-681.9
	3	-802.4	0	1	404.26
	4	830.18	1632.6	0	-411
TDN	3	830.24	1632.6	0	-412.1

	3	266.36	0	0.66	-130.1
	4	267.72	1.36	0.34	-129.8
Calcium_DM	3	299.48	33.12	0	-146.7
	4	-655	0	1	331.63
	3	-612.9	42.2	0	309.49
Phosphorus	3	174.77	829.81	0	-84.32
	3	-295	0	0.51	150.55
	4	-294.9	0.05	0.49	151.57
Magnesium	3	236.77	531.75	0	-115.3
	3	251.21	0	1	-122.5
	4	281.76	30.56	0	-136.8
Potassium	3	300.54	49.33	0	-147.2
	3	291.98	0	1	-142.9
	4	2861.8	2569.8	0	-1427
Iron_ppm	3	2876.9	2584.9	0	-1435
	3	252.56	0	1	-123.2
	3	2222.5	1970	0	-1108
Zinc_ppm	4	2224.5	1972	0	-1108
	3	136.08	0	1	-64.98
	4	871.22	735.14	0	-431.5
Copper_ppm	3	899.6	763.52	0	-446.7
	3	242.4	0	1	-118.1
	4	1876.5	1634.1	0	-934.1
Manganese_ppm	3	1888.7	1646.3	0	-941.3
	3	176.36	0	1	-85.12
	3	210.02	33.66	0	-102
Molybdenum_ppm	4	212.1	35.74	0	-102

Species Richness

Metric	K	AICc	dAICc	wi	LL
	3	158.15	0	1	-76.02
	4	1025.2	867.07	0	-508.5
Crude Protein	3	1035.7	877.58	0	-514.8
	3	-254.8	0	1	130.46
	3	1195.4	1450.2	0	-594.6
ADF	4	1196.6	1451.4	0	-594.2
	3	-192.9	0	1	99.5
	3	1392.1	1585	0	-693
aNDF	4	1394.1	1587	0	-692.9
TDN	3	-779.6	0	1	392.84

	3	852.48	1632	0	-423.2
	4	854.45	1634	0	-423.1
	3	268.24	0	0.64	-131.1
	4	269.36	1.12	0.36	-130.6
Calcium_DM	3	303.58	35.34	0	-148.7
	4	-598.4	0	1	303.28
	3	-586.6	11.81	0	296.34
Phosphorus	3	215.8	814.15	0	-104.8
	3	-282.5	0	0.71	144.3
	4	-280.7	1.74	0.29	144.47
Magnesium	3	262.94	545.42	0	-128.4
	3	245.05	0	1	-119.5
	4	294.39	49.34	0	-143.1
Potassium	3	295.42	50.36	0	-144.7
	3	400.13	0	1	-197
	4	2930.8	2530.6	0	-1461
Iron_ppm	3	2937.2	2537	0	-1466
	3	259.61	0	1	-126.7
	3	2222.7	1963.1	0	-1108
Zinc_ppm	4	2224.6	1965	0	-1108
	3	152.25	0	1	-73.06
	4	906.71	754.46	0	-449.3
Copper_ppm	3	910.7	758.45	0	-452.3
	3	266.34	0	1	-130.1
	4	1901	1634.7	0	-946.4
Manganese_ppm	3	1906.1	1639.8	0	-950
	3	179.54	0	1	-86.71
	3	210.7	31.16	0	-102.3
Molybdenum_ppm	4	212.75	33.22	0	-102.3

Shannon's Species Diversity

Metric	K	AICc	dAICc	wi	LL
	3	149.16	0	1	-71.52
	3	998.84	849.68	0	-496.4
Crude Protein	4	1000.7	851.57	0	-496.3
	3	-241	0	1	123.57
	4	1178.5	1419.5	0	-585.1
ADF	3	1179.5	1420.5	0	-586.7
	3	-190.2	0	1	98.17
	3	1361.5	1551.7	0	-677.7
aNDF	4	1363.4	1553.6	0	-677.6

	3	-766.6	0	1	386.35
	3	832.47	1599.1	0	-413.2
TDN	4	834.44	1601	0	-413.1
	3	259.37	0	0.71	-126.6
	4	261.21	1.84	0.29	-126.5
Calcium_DM	3	283.85	24.48	0	-138.9
	3	-576.5	0	0.74	291.3
	4	-574.4	2.07	0.26	291.31
Phosphorus	3	217.22	793.69	0	-105.6
	3	-274.4	0	0.73	140.28
	4	-272.4	2.01	0.27	140.32
Magnesium	3	256.54	530.98	0	-125.2
	3	255.63	0	1	-124.8
	3	305.21	49.58	0	-149.5
Potassium	4	306.8	51.17	0	-149.3
	3	387.32	0	1	-190.6
	3	2874	2486.7	0	-1434
Iron_ppm	4	2875.3	2488	0	-1434
	3	253.4	0	1	-123.6
	3	2177.6	1924.2	0	-1086
Zinc_ppm	4	2178.4	1925	0	-1085
	3	153.04	0	1	-73.46
	3	890.67	737.63	0	-442.3
Copper_ppm	4	892.71	739.67	0	-442.3
	3	262.67	0	1	-128.3
	3	1869.2	1606.5	0	-931.5
Manganese_ppm	4	1870.1	1607.5	0	-931
	3	178.41	0	1	-86.14
	3	208.03	29.62	0	-101
Molybdenum_ppm	4	210.08	31.67	0	-100.9

Forb Cover

Metric	K	AICc	dAICc	wi	LL
	3	-6.59	0	1	6.36
	4	863.58	870.17	0	-427.7
Crude Protein	3	876.57	883.16	0	-435.2
	3	-329	0	1	167.54
	3	1120.3	1449.3	0	-557.1
ADF	4	1122.1	1451.1	0	-557
	3	-285.3	0	1	145.73
aNDF	3	1294.5	1579.8	0	-644.2

	4	1296.6	1581.9	0	-644.2
	3	-875.6	0	1	440.86
	3	756.93	1632.5	0	-375.4
TDN	4	758.87	1634.5	0	-375.3
	3	227.41	0	0.5	-110.6
	4	227.43	0.02	0.5	-109.6
Calcium_DM	3	263.63	36.22	0	-128.8
	4	-742.4	0	1	375.28
	3	-717.6	24.71	0	361.88
Phosphorus	3	79.71	822.06	0	-36.79
	3	-368.4	0	0.67	187.27
	4	-367	1.42	0.33	187.6
Magnesium	3	148.92	517.32	0	-71.4
	3	158.21	0	1	-76.04
	4	199.09	40.88	0	-95.44
Potassium	3	207.62	49.41	0	-100.8
	3	352.92	0	1	-173.4
	3	2896.8	2543.9	0	-1445
Iron_ppm	4	2897	2544.1	0	-1444
	3	244.69	0	1	-119.3
	3	2223	1978.3	0	-1108
Zinc_ppm	4	2224.8	1980.1	0	-1108
	3	45.38	0	1	-19.63
	4	818.14	772.76	0	-405
Copper_ppm	3	818.53	773.15	0	-406.2
	3	221.37	0	1	-107.6
	3	1868.3	1646.9	0	-931.1
Manganese_ppm	4	1869.3	1647.9	0	-930.5
	3	179.86	0	1	-86.87
	3	212.34	32.47	0	-103.1
Molybdenum_ppm	4	213.74	33.88	0	-102.8

VITA

Katherine Elizabeth Haile

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF PYRIC HERBIVORY ON RANGELAND FORAGE QUALITY AND AVOIDED GRAZABLE AREAS

Major Field: Natural Resource Ecology and Management

Biographical:

Education:

Completed the requirements for the Master of Science in Natural Resource Ecology and Management at Oklahoma State University, Stillwater, Oklahoma in December, 2022.

Completed the requirements for the Bachelor of Science in Natural Resource Management at Sul Ross State University, Alpine, Texas in May, 2020.

Experience:

- Graduate Research Assistant 2020-2022
- Oral Presentations: Society for Range Management
  Annual Meeting (Albuquerque, NM), 2022
  Central Ecology and Evolution Conference 2021, 2022
- Teaching Assistant, BIOL 4464 Ornithology 2021
- Teaching Assistant, NREM 3613-
  Principles of Range Management 2021
- Member of planning committees for
  Central Ecology and Evolution Conference 2021, 2022
- Secretary for NREM Graduate Student Organization 2021-2022
- Leader for Blue Thumb water sampling with GSO 2021-2022

Professional Memberships:

- Texas and Southwestern Cattle Raisers Association 2018-2022
- Society for Range Management 2018-2022