EFFECTS OF SEASONAL PATCH BURNING IN GULF CORDGRASS RANGELANDS ON LIVESTOCK PREFERENCE AND UTILIZATION

A Thesis

by

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ABSTRACT

Effects of Seasonal Patch Burning in Gulf Cordgrass Rangelands on Livestock Preference and Utilization

(May 2018)

Victoria Lynn Haynes, B.S., Texas A&M University-Kingsville

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Mature gulf cordgrass (*Spartina spartinae* [Trin.] Merr. ex Hitchc.) forage value is inadequate for animal consumption. Historically fire has been effective in improving utilization of gulf cordgrass by livestock and promoting higher quality gulf cordgrass regrowth. In this study, I compared season of patch burning on the attraction of livestock to burned patches, utilization of gulf cordgrass following burning, and on the nutritive value of gulf cordgrass following burning. The study design consisted of 10 patches (> 200 ha each) with two patches burned each winter and summer seasons for a 2-y period. I monitored the location of cattle (n = 30) using GPS collars to determine their locations and estimate their attraction to burned areas. Grazing exclosures were used to estimate percent utilization by ungulates and forage disappearance 90 d following burns. Throughout the first year of treatments, forage samples were collected every 3 d for 40 d and then on a weekly basis for 50 d following each burn to determine fiber and crude protein. Regardless of season of burning, proportion a collared cow's locations within the burn patches during prime grazing hours went from 17% before burning to 41% following burn treatments. Utilization and forage disappearance of gulf cordgrass by herbivores throughout 90 d did not differ between seasons of burning. Forage disappearance in the control patches was 407 kg · ha^{-1} · 90 d while forage disappearance in the burn patches was

1,172 kg · ha^{-1} · 90 d. Following both seasons of burning, 1 ha of gulf cordgrass was needed to maintain 1 AU for 90 d. Crude protein values were >9% (the minimum threshold for maintenance of a lactating cow) for 90 d following both Winter and Summer burn treatments. Regardless of winter or summer burning, cattle utilized burned gulf cordgrass rangeland to a greater extent than non-burned patches and nutritive value was ideal for 90 d post burn. This study supports that prescribed fire is an effective method to improve nutritive value and livestock utilization and distribution in gulf cordgrass rangelands.

Keywords: Cattle distribution, gulf cordgrass, home range, patch-burning, season of burning

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INTRODUCTION

Gulf cordgrass (*Spartina spartinae* [Trin.] Hitchc.) is a native, perennial bunchgrass that is commonly found along the Gulf Coast Prairies and Marshes ecoregion stretching along the coast of Texas to Florida. Mature stands of gulf cordgrass exhibit stiff leaf blades that are underutilized by livestock in regards to consumption and are low in nutritive value. Prescribed fire has been applied to gulf cordgrass rangelands to remove senescent mature growth of gulf cordgrass and stimulate regrowth to improve the utilization and nutritive content within gulf cordgrass which in turn improves the diets of livestock during winter dormancy or periods of drought when regrowth is consumed. While several published studies have validated the use of fire in different seasons as a management tool to temporarily improve utilization by cattle and nutritive value of gulf cordgrass (Angell et al. 1986; Oefinger and Scifres 1977; McAtee et al. 1979b), GPS technology has not been used to evaluate spatial distribution of cattle in gulf cordgrass rangelands under a patch burn grazing scenario. Advancements in GPS have made it possible to record animal movements concurrently with landscape conditions; this technology can improve landowners' understanding of animal utilization of the landscape (Handcock et al. 2009). In addition, closely monitoring forage nutritive content following fire with no grazing deferment would determine longevity of heightened gulf cordgrass nutritive content with continuous grazing; fiber content within gulf cordgrass after burning in summer and winter treatments has yet to be investigated. The goal of this project was to produce prescribed fire recommendations to improve utilization and nutritive value of gulf cordgrass rangelands using a patch burn grazing design.

This thesis follows the style of the journal *Rangeland Ecology and Management*.

LITERATURE REVIEW

Cattle Ranching in the Gulf Coast Prairies

Stretching along the gulf coast of South Texas, the Gulf Coast Prairies and Marshes ecoregion consists of productive rangelands supporting wildlife and livestock with cover and forage (Hatch et al. 1990). The ecoregion produces a fairly continuous supply of grasses as the winters are relatively mild and the growing season is extensive with 289 to 300 days of growth (McAtee et al. 1979a; Everitt et al. 1981). In the early 1800s, large-scale fires and native herbivores were commonly reported in these grasslands by European settlers. Historically fires along the Texas Gulf Coastal Prairies originated from lightning strikes and spontaneous combustions while Native Americans and early European pioneers practiced burning for various purposes (Samson and Knopf 1996).

The potential for cattle ranching in the semi-arid southernmost coastal region was evident as numerous settlers and travelers would often describe the wide vastness of the coastal prairie as an ocean, covered in "'a dense mat of grass,' decorated in the spring by 'wild flowers'" (Jordan 1969). As the increase in Texas' human population brought immense herds of cattle (*Bos* spp.) to the coastal prairies, extensive herbivory reduced the probability of wildfire because the occurrence of fire largely depends upon fuel accumulation (Leonard et al. 2010). Fire suppression efforts progressed following the 1940s, and prairies protected from periodic fires began experiencing brush encroachment, invasion by non-native species, slower nutrient cycling, and a loss in biodiversity (Drawe 1980). The ecological value of fire became more evident after decades of suppression, and managers began to reintroduce fire to these landscapes with intentions of integrating fire into their livestock grazing operations (Hanselka 1980).

Traditionally, livestock enterprises in South Texas were mainly cow-calf operations with a few stocker operations (Paschal 1998). The majority of the South Texas cattle industry relies on rangeland forage to supply crude protein (CP) and energy needed to meet cattle nutrient requirements (McCuistion et al. 2014). To survive on rangelands, cattle rely on microorganisms found within their rumens to effectively break down forage structural carbohydrates and supply them with energy; this process requires an adequate supply of nitrogen commonly referred to as protein (Mathis 2003). When forage CP falls below 7%, microbial activity in the rumen is hampered which is followed by a reduction in microbial protein production, forage digestion, and intake (Mathis 2003). Reported CP maintenance requirements for a dry beef cow are 6 to 8%, and for a lactating cow the requirement is 9 to 12% (Hanselka 1981; Holechek 1995). Digestibility of forage can also be affected by the amount of structural carbohydrates or fibrous carbohydrates within the forage. Neutral detergent fiber (NDF) is an indicator of the primary bulk of plant cell wall fibrous components (hemicellulose, cellulose, and lignin) within the forage while acid detergent fiber (ADF) is a measurement of the least digestible fiber components (cellulose and lignin) within the forage. The lower the NDF and ADF, the better quality the forage beef cattle (Rayburn 2014).

Many large herbivores in semi-arid and arid rangelands are selective grazers, meaning they do not graze evenly across the landscape because of biotic and abiotic factors (Teague et al. 2013). Traditional rangeland techniques to improve livestock production and utilization of forages have consisted of annual burning, cross-fencing of pastures, strategic placement of water, and use of herbicides to eliminate forbs. This traditional rangeland management is based on a paradigm of managing for uniform grazing distributions and homogeneous grass-dominated habitats suitable for both cattle production and a narrow range of wildlife species (Churchwell et al. 2008). In the last several decades, landowners have had a growing interest in wildlife recreation for economical purposes, and practices to adjust homogeneous landscapes towards biodiversity for both domestic and wildlife species are on the rise (Hanselka 1998).

Patch-Burn Grazing

A strategy that has been used in other areas to promote extensive biodiversity throughout rangelands, support sustainable livestock production, reduce herbivore impact on intensively grazed areas, and maintain or recover grass-dominated ecosystems is patch-burn grazing (Teague et al. 2008; Fuhlendorf and Engle 2004; Scasta et al. 2015;). The practice of patch-burn grazing exposes sections of a rangeland to prescribed fire and free-roaming herbivores at various times to create a mosaic of vegetation containing different seral stages ranging from recently-burned patches to patches that have not burned for over 2 yr (Fuhlendorf and Engle 2004). Both domestic and wildlife herbivores have been observed heavily utilizing recently-burned areas to proportionately greater extents than previously-burned and non-burned areas (Fuhlendorf and Engle 2001, 2004). The primary reason for the “magnet effect” or attraction to burned areas following a fire is that there is an improvement in the nutritional status and availability of emerging herbaceous plants (Archibald et al. 2005). The preference for recently-burned areas, however, is only temporary because forage quality decreases as plant species mature (Coppedge and Shaw 1998).

Several studies on wild herbivores in Africa have observed negative relationships between preference for recently-burned areas and body size (Wilsey 1996; Sensenig et al. 2010; Eby et al. 2014). Smaller-bodied herbivores (< 100 kg) were more commonly found utilizing recently-burned areas while larger-bodied herbivores (> 100 kg) spent more of their time in non-burned patches. Researchers concluded that because recently-burned areas contained less forage, larger ungulate species spent more time in the non-burned areas to maximize intake. Yet small ungulates fed in burned sites that provided higher-quality forage to fulfil their high metabolic requirements (Wilsey 1996; Sensenig et al. 2010). Eby et al. (2014) reported that by four months after burning, preference for the burned areas by the herbivore community ceased, confirming that time since fire influences how animals distribute themselves on the landscape (Allred et al. 2011). Eby et al. (2014) also suggested that large-bodied herbivores may be more attracted at a larger landscape scale to areas where burning occurred while at a smaller, local scale they select for non-burned areas. Although one might expect an increase in the use of burned areas by smaller herbivores, Meek et al. (2008) reported that drought conditions inhibited use of burned areas by white-tailed deer (*Odocoileus virginianus*) because of low vegetation regrowth.

The marginal value theorem (MVT), proposed by Eric Charnov (1976), suggested that the optimal time a herbivore will forage within an area before moving on to the next depends on foraging efficiency which is influenced by resource uptake (value) and investment (cost) in resource acquisition. In theory, when the intake rate in any area drops to the average rate for the habitat, the animal should leave that area and travel to another to maximize rate of resource intake because more energy would be spent than gained by remaining (Charnov 1976). As an environment becomes richer, the forager's efficiency should increase wherein foraging time is minimized while higher fitness gains are achieved (Winterhalder 1983). With the development of new technologies such as global positioning systems (GPS), spatial analysis of free-ranging animals has made it feasible to study behavior, movement, and home ranges of different species.

Global positioning systems (GPS)

Previous studies report that large herbivore distribution patterns are influenced by many factors, primarily slope, thermal cover, and distance to water (Bailey et al. 1996; Allred et al.

2011). Free-roaming herbivores in heterogeneous landscapes are often selective because their preferred resources vary spatially and temporally on the landscape. To obtain a better understanding of the distribution of free-ranging animals on rangelands, researchers are using GPS to acquire location data. GPS technology has been used to monitor cattle distribution when nutritional value varied on the landscape (Ganskopp and Bohnert 2006; Clark et al. 2017). Ganskopp and Bohnert (2006) reported that nutritional variation in pastures does affect the distribution of cattle as GPS-collared cattle were found in senescent materials 41% of the time while they were found 59% of the time in areas that provided higher quality forage.

Using GPS collars to monitor distribution patterns of large herbivores on different landscapes, as well as monitor distribution following management treatments, assists biologists in providing optimal recommendations to landowners to improve management strategies. Clark et al. (2017) used GPS collars to record beef cattle distribution following prescribed fire in southwestern Idaho. The distribution of livestock tended to focus on foraging patches containing high nutritional quality, which were few in number prior to prescribed burning. Following September burning, there was an increase in the number and density of high-quality foraging patches relative to pre-fire. In response, cattle exhibited longer foraging durations in burned sites because density of high-quality patches increased and foraging activity was interrupted less frequently by traveling between patches (Clark et al. 2017). As the size of the area to be burned increases, one can expect the number and density of high-quality foraging patches to rise (Fuhlendorf and Engle 2004).

Gulf Cordgrass

Gulf cordgrass (*Spartina spartinae* [Trin.] Hitchc.), commonly referenced as “sacahuista” by many ranchers, is a highly-productive perennial bunchgrass that covers thousands of hectares along the Gulf Coast Prairies and Marshes of South Texas (Oefinger and Scifres 1977). This bunchgrass often grows at elevations intermediate between lowland marshes and upland plant communities in large colonies of dense clumps with inclusions along lowlands and fresh waterways inland in Burnet, Dimmit, Frio, La Salle, and Gonzales counties of Texas (Oefinger and Scifres 1977; Scifres and Drawe 1980; Shaw 2011). An individual clump of gulf cordgrass can maintain green tissue year-round and have 15 to 75 coarse blades that are long, involute, and firm in structure (Shaw 2011); its stout stalks can reach from 1 to 2 m tall with sharp tips (Shaw 2011). Gulf cordgrass is well-adapted to soils high in salinity; it also thrives in a variety of soil textures ranging from sandy loam to clays (Scifres et al. 1980). Because gulf cordgrass can remain green year-round, it can be an important source of forage in dormant and dry seasons. The greatest herbage yield for gulf cordgrass occurs during the rainy months of spring and during September and October, with its greatest standing crop yield occurring in fertile clay loams and clays because these soil textures have higher moisture-holding capabilities (Scifres and Drawe 1980; Garza et al. 1994). Although gulf cordgrass is highly productive and can maintain green tissue year-round, livestock do not graze the mature foliage to an appreciable extent if other forages are available (Oefinger and Scifres 1977). Mature growth produces stiff and spine-like leaf blades with low nutritional quality (McAtee et al. 1979a; Scifres and Drawe 1980).

Management of Gulf Cordgrass for Livestock

Management techniques used by ranchers to improve palatability of gulf cordgrass have revolved around the concept of removing the coarse top-growth to allow for new growth to occur (McAtee et al. 1979a). When applying either prescribed fire or mechanical shredding treatments to gulf cordgrass, nutritional value of gulf cordgrass is also enhanced, and production of inflorescences and live standing crop is augmented (Oefinger and Scifres 1977; McAtee et al. 1979a; McAtee et al. 1979b; Angell et al. 1986). McAtee et al. (1979a) on the Rob and Bessie Welder Wildlife Refuge (WWR) and the Aransas National Wildlife Refuge (ANWR) reported that shredding and burning treatments conducted in April resulted in higher live standing crops of green gulf cordgrass within 90 days than treatments conducted in July, September, or December because of greater rainfall following spring treatments. Between the two methods of treatments, gulf cordgrass regrowth in burned patches had higher CP and digestible energy (DE) than in shredding treatments after April, June, September, and December treatments (McAtee et al. 1979b). However, a higher regrowth yield was reported following shredding treatments on both saline fine sand and clay sites presumably because the mulch layer prevented evaporation and conserved moisture content in topsoil (McAtee et al. 1979a). Soil texture proved an important factor also; McAtee et al. (1979a) reported that both burning and shredding in saline fine sand texture resulted in less favorable responses than in the clay sites.

Both studies by McAtee et al. (1979 a and b) indicated shredding is effective in improving gulf cordgrass value; however, economic considerations such as equipment, labor, and fuel costs should be considered when mechanical techniques such as shredding are applied. Prescribed fire may be more favorable than mechanical methods for managing gulf cordgrass rangelands because of its economic advantage, its effectiveness at improving forage quality, and its historic presence on the landscape as a natural disturbance (McAtee et al. 1979 a and b; Drawe 1980; Grace et al. 2005). Prior to burning gulf cordgrass patches on the WWR and ANWR, the total fine fuel load including live plants (gulf cordgrass and other species), standing dead, and mulch ranged from 10,942 to 15,928 $kg \cdot ha^{-1}$ (McAtee et al. 1979a).

Improving Gulf Cordgrass with Fire

Mature, senescent gulf cordgrass foliage on the WWR and ANWR contained CP levels ranging from 4 to 5% (McAtee et al. 1979b; Scifres and Drawe 1980). Following burning in April, June, July, September, or December, gulf cordgrass CP increased and persisted for 30 to 90 days with no grazing (McAtee et al. 1979b). CP levels in new shoots reached 9.3 to 11.8% within a month of regrowth after these burns (McAtee et al. 1979b). However, the highest percentage of CP was also only maintained in the first 30 days on both locations with no grazing (McAtee et al. 1979b). By five months after burning, heightened CP levels were roughly only 2% higher than non-treated gulf cordgrass (McAtee et al. 1979b).

Oefinger and Scifres (1977) suggested that continuous grazing could effectively maintain high CP levels for four to five months after burning because it promotes young available tissue which in turn increases the volume of high-quality forage. In a study conducted on the WWR, CP levels were higher in plants continuously clipped monthly at 10 cm than those clipped at 20 cm for 18 months (Garza et al. 1994). Without constant periodic defoliation, CP levels dropped, ranging from 7.4 to 8.9% at 90 days following a burn (Scifres and Drawe 1980). Garza et al. (1994) suggested gulf cordgrass could withstand removal of herbage at a height of 10 cm on a monthly basis without adverse effects as long as sufficient moisture is received.

Utilization of Gulf Cordgrass by Livestock

Oefinger and Scifres (1977) indicated that livestock utilization of mature gulf cordgrass is negligible as there were few leaf tips of unburned plants grazed. Once fire has been applied to a gulf cordgrass pasture and herbaceous recovery commences, young gulf cordgrass regrowth is more palatable and tender to herbivores than old growth because new growth contains more digestible soluble cell content relative to cell wall content (Oefinger and Scifres 1977). Cattle have been reported consuming young regrowth to a greater extent than before burning, and outperforming cattle on non-burned gulf cordgrass rangelands because higher weight gains are achieved in fall burned gulf cordgrass (Angell et al. 1986). Following fall burning on the WWR, gulf cordgrass pastures afforded mature cattle sufficient nutrition during winter to maintain weight. Growing livestock, however, had a difficult time maintaining and gaining weight during midwinter, and supplemental feeding was recommended for growing livestock (Angell et al. 1986). However, when other desirable grasses and forbs become available, recently-burned communities of gulf cordgrass were only utilized by cattle for a short period allowing gulf cordgrass to mature after grazing pressure ceased (Oefinger and Scifres 1977; Scifres and Drawe 1980). In gulf cordgrass patches on the WWR, higher Animal Unit Days (AUD) $\cdot$ ha^{-1} were available 6 months after spring burning than on non-treated mature areas (McAtee et al. 1979b). Oefinger and Scifres (1977) reported cattle consumed an average of 4 kg $\cdot$ ha^{-1} $\cdot$ d^{-1} of gulf cordgrass for 1 year following a January burn while average consumption following an October burn was 3 kg $\cdot$ ha^{-1} $\cdot$ d^{-1}. The stocking rate recommendation by Oefinger and Scifres (1977) for burned gulf cordgrass rangeland was 1 Animal Unit (AU) $\cdot$ ha^{-4} $\cdot$ yr^{-1} following a fall burn.

Season to Burn

Annual burning in gulf cordgrass communities may not allow for sufficient senescent top-growth to carry a fire uniformly (Angell et al. 1986). Thus to achieve a thorough burn, rangelands consisting of gulf cordgrass should be burned every two to three years (Scifres and Drawe 1980). Regarding scale, researchers have advised burning large patches to prevent overgrazing (Oefinger and Scrifres 1977).

Historically, cattle ranchers have burned gulf cordgrass and managed it as a reserve source of forage to alleviate shortages during winter dormancy or droughts when high-quality forage is scarce (Oefinger and Scifres 1977; McAtee et al. 1979a; Scifres and Drawe 1980; Hanselka 1981). Applying fire to gulf cordgrass rangelands in warm, moist periods and prior to seasonal reductions of other available forage is recommended to promote sufficient recovery and higher quality and utilization of gulf cordgrass (Oefinger and Scifres 1977). To obtain higher yields of gulf cordgrass, McAtee et al. (1979a) advised that burning be conducted in the spring when soil moisture is high, providing favorable conditions for growth. Many prairies are managed with spring burning because this season of burning has been documented to increase dominance of C4 grasses which are preferred for livestock forage (Samson and Knopf 1996). However, conducting a burn during early fall has been discussed as the most logical timing, because of the critical need for green forage along the coastal prairies during the late fall to early spring months (Oefinger and Scrifres 1977; McAtee et al. 1979b; Angell et al. 1986). Utilization of gulf cordgrass by livestock is thought to be regulated by both site characteristics (other forages available, soil texture and moisture promoting gulf cordgrass production) and date after fire (Oefinger and Scifres 1977).

Following several seasons of burning on the WWR and ANWR, age of regrowth, rather than season of burning, was recognized as the cause for change in nutritional levels and degree of utilization (McAtee et al. 1979b; Hanselka 1981). If gulf cordgrass is the dominant species in a pasture, a proper grazing management plan is required with stocking rate calculated to prevent damage to stands by overgrazing, yet continue to stimulate succulent, nutritious regrowth through grazing disturbance (Scifres and Drawe 1980). A short deferment between burning and grazing of gulf cordgrass is recommended to allow for vigorous herbaceous recovery but not plant maturity (Scifres and Drawe 1980; Teague et al. 2013). Garza et al. (1994) suggests deferment for 45 to 90 days to allow total nonstructural carbohydrates (TNC) levels to be replenished; however, in a study by Angell et al. (1986), cattle were stocked into pastures 30 days after burning. Management-intensive grazing is deemed essential for maintaining long-term sustained forage quality and utilization of gulf cordgrass by livestock because light grazing allows gulf cordgrass to progress to a mature stage and become less palatable for livestock (Garza et al. 1994). Hanselka (1981) with Texas Agricultural Extension Service supported the idea of using a rotational, naturally-deferred grazing system controlled by burning to provide year-long grazing of gulf cordgrass rangelands by treating sections of a pasture at different times. Thus my goal in this project was to produce prescribed fire recommendations to improve utilization of gulf cordgrass rangelands using a patch-burn grazing design.

Objectives

The specific objectives of this research were to 1) quantify cattle attraction to and use of burned areas following Winter and Summer burning; 2) quantify utilization and forage disappearance of gulf cordgrass in post-Winter and Summer burning; and 3) closely assess changes in gulf cordgrass nutritive values (fiber and CP) following Winter and Summer burn treatments.

I hypothesized that 1) cattle would be attracted to both Winter and Summer burned areas and cattle would be spending more time in the burned areas after treatment; 2) utilization of gulf cordgrass would increase following burning; and 3) nutritive value within gulf cordgrass following Winter and Summer burn treatments would improve following fire and would be higher than what was indicated in previous literature, and would not differ between seasons.

MATERIALS AND METHODS

Study Area

The East Foundation is an Agricultural Research Organization devoted to supporting wildlife conservation and other public benefits of ranching and private land stewardship. The East Foundation's El Sauz Ranch is located primarily in Willacy County with a small portion in Kenedy County (Fig. 1). El Sauz Ranch (26.5577° N / 97.4263° W) is comprised of 11,082 ha (27,385 ac) in the Gulf Coast Prairies Texas Ecoregion. There are numerous ecological sites within my study area including sandy flats, active sandhills, low coastal sands, and coastal sands, with coastal sands being the primary site type on the property (Soil Survey Staff 2015). Soil series within the study area are: Arrada sandy clay loam (Ar), Dune land (Dn), Falfurrias fine sand, 0 to 5% slopes (FaB), Galveston fine sand, (gently undulating) (GaB), Galveston-Mustang complex (GmB), Incell clay (Ic), Lalinda sandy clay loam (LaB), Mustang fine sand (Mu), Sauz-Saucel sandy loam (Ss), and Sauz loamy fine sand (Sz) (Soil Survey Staff 2015). The site has a humid subtropical climate with 658 mm (25.9 in) of annual mean rainfall and an average temperature fluctuation between 18.9 and 26.7° C (66 and 80° F) (NOAA 2015). The growing season of the Coastal Prairies is 289 to 300 days (McAtee et al. 1979a).

Vegetation within the study patches consists of native grasses such as gulf cordgrass, switchgrass (*Panicum virgatum* L.), seacoast bluestem (*Schizachyrium littorale* [Nash] E.P. Bicknell), hooded windmill grass (*Chloris cucullata* Bisch.), red lovegrass (*Eragrostis secundiflora* J. Presl.), tumble lovegrass (*E. sessilispica* Buckley*)*, brownseed paspalum (*Paspalum plicatulum* Michx.), coastal sandbur (*Cenchrus spinifex* Cav.), and forbs such as partridge pea (*Chamaecrista fasciculata* (Michx.) Greene), gulf croton (*Croton punctatus* Jacq.), littleleaf sensitive-briar (*Mimosa microphylla* Dryand.), lavender thrift *(Limonium carolinianum*

[Walter] Britton), and American snoutbean (*Rhynchosia americana* [Houst. ex Mill.] M.C. Metz) (Soil Survey Staff 2015, USDA 2015). Mottes of native woody species include honey mesquite (*Prosopis glandulosa* Torr.) and live oak (*Quercus virginiana* Mill.) (Soil Survey Staff 2015; USDA 2015).

El Sauz's cattle operation was run as a continuous grazing system. El Sauz had a moderate stocking density close to 1 AU · ha^{-14}. The cow-calf operation had roughly 660 breeding cows and 27 bulls that are worked twice each year and are not provided any supplemental feed. The breeding cows were a cross between Santa Gertrudis and Beef-masters (*Bos taurus)* breeds (Gilly Riojas pers comm).

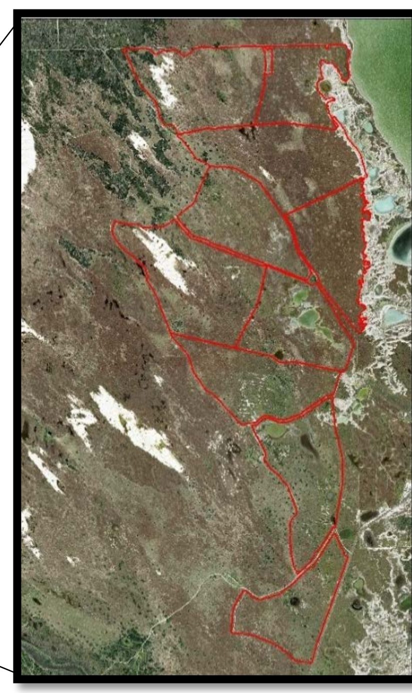

Figure 1. Study Site on the East Foundation's El Sauz ranch near Port Mansfield, Texas, USA. Red outlined areas are individual treatment patches.

Experimental Design

I delineated 10 study patches, at least 202 ha (500 ac) each, in June 2015. Totaling approximately 2,333 ha along the eastern portion of the El Sauz property. I used a completely randomized study design, with three treatments (non-burn Control, Winter burn, and Summer burn) which I randomly assigned to each patch with 2, 4, and 4 replications, respectively. I defined Winter treatments as any burn conducted in February, while Summer treatments were defined as any burn conducted in July, or August. For two consecutive years, each winter and summer season, I burned two discrete patches to create a mosaic of treated patches differing in season and time since burning. Each patch had two 60 m transects that traversed a gulf cordgrass community and an adjacent "other" vegetative community with roughly half of each transect in each vegetative community. I collected vegetation data along these transects (Fig. 2).

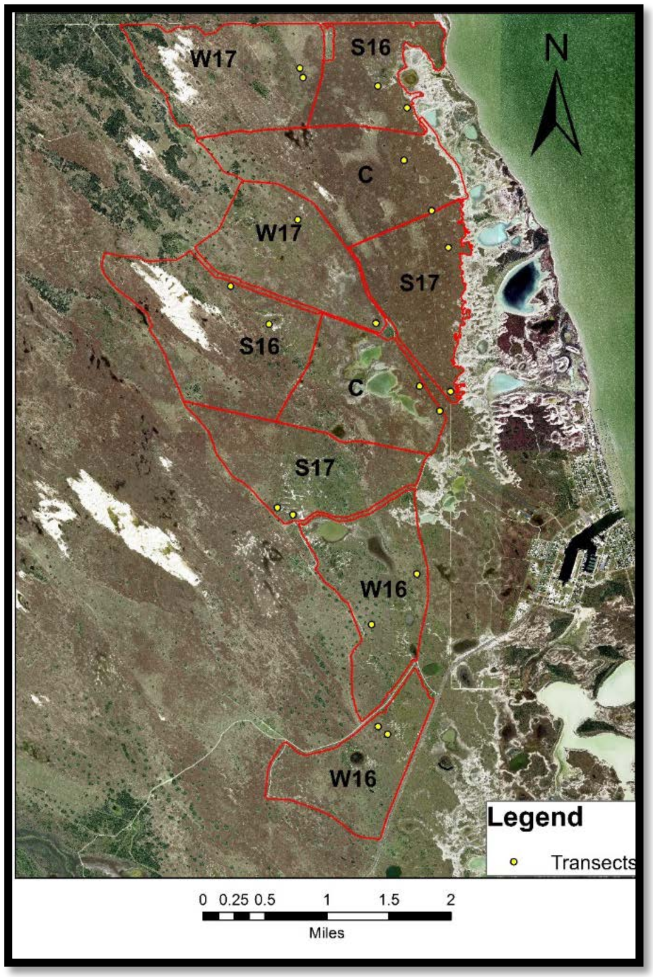

Figure 2. Assigned 2016 and 2017 treatments and transect locations on East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA. Patches labeled W16 were Winter 2016 burn treatments; patches labeled S16 were Summer 2016 burn treatments; patches labeled W17 were Winter 2017 burn treatments; patches labeled S17 were Summer 2017 burn treatments; patches labeled C were Control (no-burn) treatments. Yellow dots represent transects located within the patches.

Burning, Weather, and Fuel Data

I placed A HOBO U30/RX3000 (Onset® Computer Corporation, Bourne, MA) weather station in the center of the study area in July 2015 to acquire daily rainfall (mm) data for the duration of the study. Prior to burning, mineral lines (approximately 3 to 4.5 m [10 to 15 ft] wide) were dozed and/or disked by the East Foundation Ranches personnel on all sides of the study patches with double mineral lines approximately 30 m (100 ft) apart on the west and north sides for blacklining. I applied burning treatments February 5 and 10, 2016; July 22 and August 3, 2016; February 7 and 8, 2017; and August 2 and 11, 2017. On burn days, I recorded weather variables of air temperature (°C), wind speed (mps), wind direction, and relative humidity (%) near the burn patch every 30 min during the burn (Kestrel® 4500 Weather Meter, Nielsen-Kellerman, Boothwyn, PA, USA). I measured fine fuel load ($kg \cdot ha^{-1}$), fuel moisture (%), and fire temperature (°C) in the treatment patch. I recorded fire temperatures by HOBO Type J, K, T, E, R, S, B, N Thermocouple Data Loggers (Onset Computer Corporation, Bourne, MA) with OMEGA® High Temperature Inconel Overbraided Ceramic Fiber Insulated Thermocouples (XCIB-K-1-2-10, OMEGA Engineering, Norwalk, CT). I placed each data logger inside a PVC pipe section capped at both ends with the thermocouple extended through a slot in the pipe. I buried the PVC with the data logger in the ground immediately prior to burning for protection from extreme heat. I used two data loggers near each vegetation transect in each burn patch, one near the gulf cordgrass section and one near the other section of the transect. I left the thermocouple aboveground near the base of a gulf cordgrass plant on that end of the transect and near other perennial grass fuels (typically seacoast bluestem) on the other plant community end. I estimated fuel load ($kg \cdot ha^{-1}$) and fuel moisture (%) by gathering all aboveground biomass (standing live, standing dead, and litter) to the ground level in two, $0.25\ m^{-2}$ frames randomly placed on the ground within both communities near each transect. I placed fuel load samples in paper bags, measured with a scale while wet, transported to a drying trailer and dried at 40° C until all moisture was lost, and re-weighed to determine percent fuel moisture and fuel load. Fuel moisture was calculated using TDA (2002) formula:

$$\% \text{ Fuel Moisture} = \left[\frac{\text{wet weight-dry weight}}{\text{dry weight}} \right] \times 100 \qquad \textbf{[1]}$$

With a predominant southeast wind, the lighting strategy of each patch began with blacklining occurring on the downwind west and north sides inside the double mineral lines with 4 or 5 torchmen spread across the width of the area walking and lighting into the wind in areas where no cordgrass occurred. In areas with thick cordgrass blacklining was completed using a backfire. Once blacklining was completed, head fires or flanking fires were used depending on the shape of the patch and wind direction, to burn the main patch area.

Data Collection using GPS Collars

In July 2015, seven months prior to the first burning treatments, East Foundation personnel captured several herds of cattle within water traps (a fenced-in area around water troughs) throughout the eastern portion of the property (IACUC exemption #1331.). Of those, I fitted 20 adult cows with body condition scores from 4 to 6 with Lotek LifeCycle® GPS neck collars (Lotek Wireless, Inc., Newmarket, Ontario, Canada). I programmed collars to collect GPS locations every 13 h, and record locations throughout the 2-y study. The 13-h programming allowed for a longer battery life, making it possible to keep the collars on the same individuals throughout the 2-y period. This programming also allowed me to obtain cattle locations at different times of the day during the months before and after each treatment to obtain monthly utilization of burned patches.

In October 2015, I deployed an additional 10 Lotek LifeCycle GPS neck collars with the same data collection schedule on cows with similar physical condition to the first group of cattle. Collared cattle had access to the entire property throughout the experiment. Calving occurred year-round. Throughout the study, the cattle were only restricted in their movements during biennial working days; these working days plus the day immediately following were removed from data analyses. Future mention of fixes/locations recorded by the GPS collars were based on remaining days. Collars that malfunctioned were also removed from analyses.

This thesis will only cover the GPS collar data collected in 2016 Winter and Summer treatments (with 2 replications each treatment) because of complications. GPS collar data obtained in 2017 were not used in before and after analyses because of the confounding effect of treatments being located adjacent to each other on the landscape. E.g., "before" locations for Winter 2017 burn treatments were "after" locations of Summer 2016, thus treatment effects were not independent. This was not a factor for Winter and Summer 2016 treatments because they were not adjacent to each other on the landscape. In addition, following the Summer 2017 treatment, only three collars were still operational and collecting data and those three individuals were only near one of the two treated patches.

GPS Collar Data Collection

Raw data files, containing collar location information retrieved via satellite, were downloaded from Lotek's Wireless GPS WEB Service® and were imported into Microsoft® Excel (Microsoft, Inc., Redmond, WA). Dilution of precision (DOP) 7 or above were excluded from data files to use only more accurate GPS locations (Bjørneraas et al. 2010). Files were then imported into a geographic information system (GIS) ArcMap 10.3® (ESRI, The Redlands, CA) to display, store and analyze spatial data. Data were projected in Universal Transverse Mercator (UTM) zone 14 with the North American 1983 datum.

Proportion of Locations within Treated Patches

To determine proportion of locations of collared cows within a treatment area on a monthly basis prior to and following burning, I used the 'selection by location' tool in ArcMap 10.3. The number of locations of each cow that fell within a treatment patch each month out of the total number of locations recorded for that cow that month was converted to percent. Monthly percent of GPS locations of each collared individual within the patches was calculated 3 mo before patches were treated and 5 mo following treatment.

Distance from Burned Patches

After each burn I delineated the perimeter of the burned area by driving around the burned patch and collecting perimeter data using a Trimble® Juno 5 Series (Trimble Inc., Sunnyvale, California**)** GPS unit with an accuracy of 2 m. To determine whether cattle were attracted to the patches following Winter and Summer 2016 burning treatments, I calculated distance from each recorded location to the perimeter of the two burn patches treated in each season (two distances were recorded per fix; i.e., the distance to each of the two burn patches) before and after burning using the distance tool (ArcMap 10.3). The distance of each collared individual from the patches was calculated 3 mo before patches were treated and 5 mo following treatment.

Estimation of Core Area (50%) and Home Range (95%) Sizes

I estimated sizes of core areas (50% probability contour) and home ranges (95% probability contour) (ha) for each cow on a monthly basis using the Adaptive Kernel estimator in the Ecological Software Solutions LLC Biotas® program (Ecological Software Solutions LLC, Hegymagas, Hungary). The adaptive kernel estimate was used because of its flexibility in assigning bandwidths to observations excluding bias towards a fixed bandwidth (Seaman and

Powell 1996). I used the least-square cross-validation method to calculate the bandwidths (Silverman 1986; Worton 1989). This method produces estimates with small variances and bias (Bowman 1985; Powell 2000). I calculated the sizes of monthly core areas and home ranges 3 mo before patches were treated and 5 mo following treatment. Polygons of core areas and home range areas created within Biotas were saved as shapefiles and further managed within ArcMap 10.3.

Overlap with Burned Patches

To investigate shifts/movements in the locations of core areas and home range areas following burning, I used core area and home range area polygons obtained from Biotas for each cow to assess monthly overlap of these ranges with the burned areas. The union analysis tool in ArcMap 10.3 was used to calculate area of overlap between two polygons (the core area or home range polygon and the treated patch's polygon). The core area or home range area that overlapped with the burned patches was converted to percent overlap by dividing the area of overlap (m^2) by the true size of the cow's core area or home range area, and multiplying by 100 (Webb et al. 2011).

Ungulate Vehicular Count Survey

To further monitor ungulate utilization, ground-based visual ungulate counts were conducted on a weekly basis for two w before and 90 d after each burn treatment. Counts were performed of adult cattle, calves (< approximately 226 kg (500 lbs.) as judged visually), white-tailed deer, and nilgai (*Boselaphus tragocamelus*) within each patch. Throughout the first year of treatments, counts of animals within each patch were acquired by driving an ATV slowly (2.2 to 4.5 $m \cdot s^{-1}$ or 5 to 10 mph) on the main ranch road. These weekly ATV-driven ungulate recordings were conducted during prime grazing hours either in the morning (07:00 to 09:30 h) or in the evening (16:00 to 18:30 h) alternating each week (Howery et al. 1996; Wilsey 1996). After analyzing the first year of counts following Winter and Summer 2016 burns, I found too much variation (coefficient of variation [CV] = 243.5% in 2016) thus the sampling strategy was changed for 2017 treatments. The new count strategy involved driving the ATV slowly (2.2 to 4.5 $m \cdot s^{-1}$ or 5 to 10 mph) on the mineral lines around the entire perimeter of each recently-burned patch and each control patch before and for 90 d after burning treatments on a weekly basis and during prime grazing hours noted above. Using this new sampling strategy, my CV = 63.9% in 2017.

To calculate total visibility within each study patch following treatment, I followed the spotlight survey method proposed by Texas Parks and Wildlife (Jester undated). To measure the farthest distance I could see an animal in each patch from the survey road, an assistant on an ATV drove inside the patch, perpendicular from the survey line. Once the ATV was at the farthest visible distance, the distance was measured with a Nikon® ProStaff 550 range-finder (Nikon, Melville, NY). This method was repeated every 0.16 km (0.10 mile). I obtained these visibility measurements in recently-treated patches near the end of the 90-d sampling period to mitigate negative impacts on plants recovering from fire.

Vegetative Collection for Utilization and Nutritional Analyses

Exclosures

Two to three days after both patches were burned four cattle panels, 5 m long × 1.27 m high (16 ft × 4 ft) were wrapped into a circular grazing exclosure supported by two t-posts in each recently-burned patch. Two exclosures were established around randomly-chosen gulf cordgrass plants near each sampling transect. Exclosures were used to evaluate two variables: 1) nutritive content of gulf cordgrass without grazing pressure; and 2) utilization and forage disappearance of gulf cordgrass by herbivores following each season of burning. Utilization is expressed as a percentage (%) while forage disappearance of gulf cordgrass will be expressed as kg · ha^{-1}. A paired-plot method similar to the method described by Scifres et al. (1977) was used to estimate utilization and forage disappearance of gulf cordgrass as influenced by burning treatments. At ~ 30-d after establishment (~ 30-d post-burn), a 1 m^2 frame was placed inside each exclosure, and gulf cordgrass within the frame was clipped to stubble height of ~ 2.5 cm (1 in). During each exclosure harvest, samples of the same size were harvested from the grazed area (outside the exclosures) for nutrition analysis. The two closest 1 m^2 frames from the nutrition collections (n = 4) at each transect to the exclosures were used for comparisons. Exclosures were then randomly relocated to new areas of gulf cordgrass in the exposed area. Gulf cordgrass was clipped again in the same manner after roughly another 30 d (~ 60-d post-burn). The relocation procedure was conducted once more, and gulf cordgrass inside exclosures was clipped near the 30-d mark again (~ 90-d post-burn). Gulf cordgrass samples collected for exclosure nutritional analyses and utilization were kept in a drying trailer at 40° C until no further weight loss occurred, and then weighed. After weighing, gulf cordgrass from each exclosure was ground in a THOMAS Wiley mill (Thomas Scientific, Swedesboro, NJ). Ground material was mixed and placed into a labeled 113 g (4 oz) WHIRL-PAK bag (Nasco, Fort Atkinson, WI) for nutritional analysis.

Similar exclosures (n = 12) were placed inside Control patches immediately after Summer 2017 treatments. These exclosures were randomly placed inside Control patches. Gulf cordgrass inside and outside exclosures in Control patches were clipped ~ 90 d after exclosure placement (~ 90 d following Summer 2017 treatment) using the same method mentioned above;

however, gulf cordgrass in the exposed area (outside) (*n* = 12) was obtained by randomly tossing 1 m^2 quadrats within the gulf cordgrass community near each exclosure.

Utilization Estimates of Gulf Cordgrass

For each of the four seasons of burning treatments (Winter 2016, Summer 2016, Winter 2017, and Summer 2017), differences between dry weights of gulf cordgrass ($kg \cdot ha^{-1}$) collected inside each exclosure and that collected in the closest 1 m^2 frame (from the nutrition collection) to each exclosure was determined, divided by the inside exclosure weight, and multiplied by 100 to estimate percent utilization (Oefinger and Scifres 1977; Scifres et al. 1977). Utilization estimates of gulf cordgrass were averaged per patch and then by season (e.g., Winter 2016 and 2017 patch utilization estimates together). Utilization estimates of gulf cordgrass in the Control patches were obtained in Summer 2017 using the same method described above (i.e., differences between dry weights of gulf cordgrass ($kg \cdot ha^{-1}$) collected inside each exclosure and in the 1 m^2 frame outside each exclosure was determined), divided by the inside exclosure weight, and multiplied by 100 to estimate percent utilization.

Gulf Cordgrass Forage Disappearance Estimates

Although a portion of disappearance of forage can be attributed to factors (e.g., trampling) other than consumption, a larger portion of forage disappearance was more likely to be because of consumption by herbivores (Ortega-S., pers comm). Forage disappearance estimates of gulf cordgrass throughout the 90 d following both treatments were obtained by adding the estimated forage removed ($kg \cdot ha^{-1}$) obtained from the every 30 d exclosure and exposed harvests (i.e., I added the differences between dry weights of gulf cordgrass collected inside and outside exclosures and averaged the amount for each treatment). Forage disappearance estimates of gulf cordgrass throughout the 90 d in the Control patches were obtained by simply averaging the differences between dry weights of gulf cordgrass collected inside and outside exclosures on d 90.

Nutritional Analyses

Fuel load samples were kept for pre-burn nutritional analysis after dry weights were obtained. To evaluate influence of days since burning on gulf cordgrass' nutritional value after Winter 2016 and Summer 2016 burning treatments, forage samples were collected in recently burned patches every third d for 40 d, and then once weekly for another 50 d. Post-burned gulf cordgrass forage samples were obtained by randomly tossing four 1 m^2 quadrats within the gulf cordgrass community near each transect, and hand-clipping all cordgrass within each quadrat to a stubble height of ~ 2.5 cm (1 in). All gulf cordgrass forage clipped from a quadrat was placed into a labeled paper bag resulting in four separate bags taken from each of the two transects in each of the two recently-burned patches. Nearing the 45^{th} and 90^{th} d following each burn, gulf cordgrass in non-burned (Control) patches was clipped in the same method described above to compare nutritive value between non-burned and recently-burned areas. Gulf cordgrass samples collected for nutritional analyses were kept in a drying trailer at 40° C until no further weight loss occurred, and were weighed for utilization estimation prior to nutritional analysis. After weighing, the four samples from each transect were combined into one bag to create a composite sample representative of that transect. Composite samples were then ground in a THOMAS® Wiley mill (Thomas Scientific, Swedesboro, NJ). Ground material was mixed and placed into a labeled 113 g (4 oz) WHIRL-PAK® bag (Nasco, Fort Atkinson, WI) for nutritional analysis.

Forage Chemical Analysis

Gulf cordgrass samples were analyzed in the Lehmann Lab at Texas A&M University-Kingsville for CP and sequential detergent fiber analyses. Van Soest et al. (1991) detergent fiber analysis of neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were determined with an ANKOM ^{200} Fiber Analyzer (ANKOM® Technology Corp., Macedon, New York). Total nitrogen (N) for the CP analysis (N × 6.25) was calculated using a vario MACRO analyzer in the carbon-nitrogen (CN) mode (Elementar Analysensysteme GmBH, Hanau, Germany).

STATISTICAL ANALYSIS

A complication I came across was the lack of true control groups of cattle for distribution analysis because Control patches (no burning) were neighbored by the Burn treatment patches (Fig. 2), and cattle were not restrained in their movements. Thus, the same individual collared cattle used both Control and Burn treatment patches. This is problematic because the cow is the statistical patch for these analyses; thus, using the same cow in two different treatments is akin to treating one plant in a study with pesticide to determine pesticide’s effect on growth, and then treating the same plant with fertilizer to determine fertilizer’s effect on growth.

Proportion of Locations within Treated Patches

To test the hypothesis that proportion of GPS locations within burned patches did not differ before and after treatment, a generalized linear mixed model was used with time (before or after), season (Winter or Summer), and their interaction (time × season) as fixed effects; random effects included patch nested within season, and the interaction between time and patch nested within season. For this analysis, I chose the collared cattle nearest the patches (individuals within 1,000 m) based on distance results. I analyzed data from within 3 mo before and 5 mo after 2016 burning treatments. There were 7 individual cows included in Winter 2016 analysis (n = 21 before; n = 35 after); there were 12 individual cows within 1,000 m to Summer 2016 burn treatment patches to be included in analysis (n = 36 before; n = 60 after). Each response variable was modeled with the Satterthwaite's (1946) approximation. To account for repeated measurements on the same cow over time, I modeled several variance-covariance structures [vc, ar(1), arh(1), cs, csh, toep, toeph, un, arma(1,1)] and used Akaike theoretic criteria (AICc) to select the "best" structure.

Distance from Burned Patches

I obtained the average distance of each cow to a 2016 burn patch before and after burn treatments by measuring the distance from each fix to the perimeter of each patch. I then averaged the distances on a weekly basis before as well as after each fire for all cattle. Because of the spatial arrangement of the Winter 2016 patches and because they were burned a few days apart, I combined the two Winter 2016 patches into one large patch. Summer 2016 patches were analyzed separately because they were not adjacent and they were burned 2 weeks apart. When a fix was located within a burn patch it's distance to the patch was recorded as 0. When all collared cattle were included in analysis regardless of location before treatment I found no shortened distance to burned treatments because cattle that were too far away to be influenced by burning masked the movements made by individuals who were closer.   Thus I created distance categories for the collared cattle; e.g., one category consisted of cattle whose mean distance to a treatment patch before treatment was < 1,000 m; the second category consisted of cattle whose mean distance to a treatment patch before treatment was between 1,000 and 2,000 m, etc.

Distance categories were: 1) < 1000 m; 2) 1,000 – 2,000 m; 3) 2,000 – 3,000 m; 4) 3,000 – 4,000 m; 5) 4,000 – 5,000 m; and 6) > 5,000 m. When all times since burning were included in analysis, distances that were recorded too long after burning masked differences that were recorded in the first several months following burning treatments. Therefore, datasets used for the analysis contained only distances obtained within 12 w prior to treatment and 20 w following treatment. Because of bimodal distribution of residuals and the fact that not all of the distance categories contained collared cattle, a linear mixed model was not appropriate. Therefore, for each cow I assigned a "plus" to a cow if average distance after the burn was closer than average distance before the burn and a "minus" otherwise. An upper 1-tailed (nonparametric) sign test (Conover 1999) was used to test the null hypothesis that burning had no effect on cattle movement against the alternative hypothesis that cattle were more likely to move toward the burn patches (i.e., the probability of a "plus" was greater than the probability of a "minus"). Both treatments lacked collared cattle in some categories (i.e., Winter 2016 treatments only had cattle in categories 1, 2, 4, and 6 while Summer 2016 treatments only had cattle in categories 1,3, and 4), and thus analysis was conducted on cattle within 1,000 m and cattle beyond 1,000 m separately).

Core Area and Home Range Size

Change in the mean size of core areas and home range areas was analyzed using a linear mixed model to test the hypotheses that average core area and home range sizes did not differ between times (before or after burning). Time (before and after burning), season of treatment (Winter or Summer), and their interaction (time × season) were fixed effects in the model; random effects included individual collared cows nested within season. Each response variable was modeled with the Satterthwaite's (1946) approximation. For this analysis, I chose the collared cattle nearest the patches (individuals within 1,000 m) based on distance results. Because cattle movements are so variable monthly, I included 3 mo before and 5 mo after 2016 burning treatments. There were 7 individual cows included in Winter 2016 analysis. Because cattle movements are so variable monthly, I included 3 mo before (n = 21) and 5 mo after (n = 35) Winter 2016 burning treatments. There were 12 individual cows within 1,000 m to a Summer burn treatment patch to be included in analysis (n = 36 before; n = 60 after). The Shapiro-Wilk (1965) test was performed to test for normality. All 95% and 50% home range data were not normally distributed. However, when testing for normality on a logarithmic scale, normality was satisfied. Therefore, the natural log transformation home range size data were used for statistical analyses while log transformed means were back-transformed for data presentation (Jager and Looman 1987). With a log transformation, back transformation means are estimates of the median on the observed scale. Furthermore, standard errors (± se) are asymmetrical around the median. Therefore, presenting a median (± se) is equivalent to presenting a 32% confidence interval (CI). In the results section, I will present median (± se) as median (CI). To account for repeated measurements on the same cow over time I modeled several variance-covariance structures [vc, ar(1), arh(1), cs, csh, toep, toeph, un, arma(1,1)], and used Akaike theoretic criteria (AICc) to select the "best" structure (Burnham and Anderson 2002).

Core Area and Home Range Overlapping Burn Patches

To test the hypothesis that average percent overlap of core areas and 95% home ranges with burn patches did not differ between time (before or after burning), a linear mixed model was performed with time (before or after burning), season of treatment (Winter or Summer), and their interaction (time × season) as fixed effects; random effects included individual collared cows nested within season. For this analysis, I chose the collared cattle nearest the patches (individuals within 1,000 m) based on distance results. There were 7 individual cows included in Winter 2016 analysis; I analyzed data from within 3 mo before (n = 21) and 5 mo after (n = 35) treatments. There were 12 individual cows within 1,000 m to the Summer 2016 burn treatment patches to be included in analysis; I analyzed data from within 3 mo before (n = 36) and 5 mo after (n = 60) Summer 2016 burning treatments. Each response variable was modeled with the Satterthwaite's (1946) approximation. The Shapiro-Wilk (1965) test was performed to test for normality. Percent overlap data were normally distributed so no transformations were necessary. To account for repeated measurements on the same cow over time, I modeled several variance-covariance structures [vc, ar(1), arh(1), cs, csh, toep, toeph, un, arma(1,1)] and used Akaike theoretic criteria (AICc) to select the "best" structure.

Ungulate Vehicular Count Surveys

Total number of animals (total number of adult cattle, calves, deer, and nilgai) counted in the Summer 2017 burn patches and Control patches before and following the Summer 2017 treatments were analyzed with a generalized linear mixed model with treatment (burn or control), and time (before or after burning), and their interaction (treatment × time) as fixed effects; random effects included patch nested within treatment and the interaction between patch and time nested within treatment. Each response variable was modeled assuming a negative binomial distribution and Satterthwaite's (1946) approximation. Because total visibility within each patch varied and treatments were conducted on large areas, the analysis was based on animals counted · ha^{-100}.

Data obtained in 2017 were not used in before and after analyses because of the confounding effect of treatments being located adjacent to each other on the landscape. E.g., "before" locations for Winter 2017 burn treatments were "after" locations of Summer 2016, thus treatment effects were not independent. Data obtained in 2016 could not be presented due to extensive variation among weekly sampling when I used the original technique. Results from the new count strategy following Summer 2017 treatments are in Appendix B.

Utilization, Forage Disappearance, and Carrying Capacity

I tested the hypothesis that average utilization, carrying capacity, and gulf cordgrass forage disappearance did not differ between treatment (Winter burn, Summer burn, and Control) with a general linear model. Bartlett's test (Kirk 2013) was used to test the assumption of homoscedasticity; variances of residuals were homogeneous for each response variable.

Forage Nutritive Content (CP, NDF, ADF, ADL)

Mean changes in gulf cordgrass CP, NDF, ADF and ADL as a function of days since burning were modeled using piecewise linear regression (Neter et al. 1996) for both seasons of burning in 2016 to test the hypothesis that average nutritive content within gulf cordgrass following burning did not differ between seasons of burning. The NLIN procedure of Statistical Analysis Software (SAS; SAS ® Institute Inc., Cary, North Carolina) was used to improve (through iteration) initial estimates of break points and slopes that were based on graphical inspection. The statistical model for responses with one break point was:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 (X_{i1} - C_1) X_{i2} + \varepsilon_i \quad \textbf{[2]}$$

The statistical model with two break points was:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 (X_{i1} - C_1) X_{i2} + \beta_3 (X_{i1} - C_2) X_{i3} + \varepsilon_i \quad \textbf{[3]}$$

where Y_i is forage nutritive content parameter; X_{i1} is days since burn; X_{i2} = 1 if $X_{i1} > C_1$ and 0 otherwise; and X_{i3} = 1 if $X_{i1} > C_2$ and 0 otherwise; C_1 and C_2 are break points; and ε_i is the residual error. (Neter et al. 1996). A simple linear regression without break points was adequate for ADL in Winter 2016 and a second-order polynomial in days since burning was used for Summer 2016 data.

RESULTS

Burn Conditions

Each burn patch was > 200 ha and took the majority of a day to burn. Air temperature ranged from 20 to 34° C (68 to 93 °F) during Winter burning and 34 to 38° C (93 to 100 °F) during Summer burning treatments (Table 1). Wind speeds were 1.8 to 5.4 m · s^{-1} (4 to 12 mph) during Winter burns and 1.3 to 5.5 m · s^{-1} (3 to 12 mph) during Summer burns. Relative humidity ranged from 28 to 65% during Winter burns and 51 to 78% during Summer burn treatments. The mean high fire temperature and fine fuels recorded and collected in the gulf cordgrass community and in the other plant community are provided in Table 1 below.

Table 1. Weather and fuel conditions averaged by season of treatment at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, in 2016 and 2017.

Burn Day Conditions	Winter 2016	Summer 2016	Winter 2017	Summer 2017
Temperature range °C (°F)	20-27 (68-80)	34-38 (93-100)	27-34 (81-93)	31-36 (88-97)
Relative humidity range %	28-50	51-61	48-65	57-78
Wind speed range m · s^{-1} (mph)	1.8-5.4 (4-12)	1.3-5.5 (3-12)	1.8-4.0 (4-9)	0.9-4.5 (2-10)
Gulf cordgrass fuel load kg · ha^{-1} (lbs/ac)	14,544 (12,976)	12,775 (11,398)	27,757 (24,737)	17,946 (16,011)
Seacoast bluestem fuel load kg · ha^{-1} (lbs/ac)	8,898 (7,938)	9,437 (8,419)	14,696 (13,095)	9,674 (8,631)
Cordgrass mean high fire temperature °C (°F)	726 (1,339)	838 (1,540)	805 (1,481)	599 (1,111)
Seacoast bluestem mean high fire temperature °C (°F)	512 (954)	532 (989)	277 (530)	319 (607)

Precipitation

Rainfall received on the property throughout the 90 d following the Winter 2016 burns was 50.29 mm (1.98 in.), 116.33 mm (4.58 in.) following Summer 2016 burn treatments, and 100.84 mm (3.97 in.) following Winter 2017 burn treatments (Fig. 3). The property received 48.26 mm (1.9 in.) in the month prior to Winter 2016 burn treatment, 2.54 mm (0.1 in.) prior to Summer 2016 burn treatments, and 15.24 (0.6 in.) prior to Winter burn treatments.

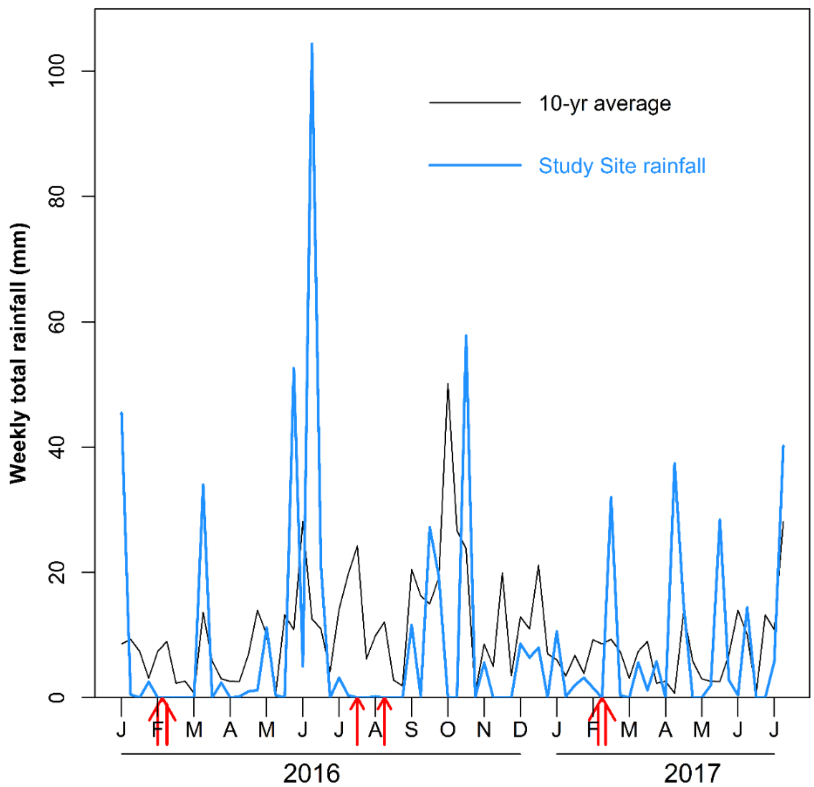

Figure 3. Weekly precipitation recorded at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA from January 2016 to July 2017 compared to the 10-yr average. Blue line indicates weekly precipitation (mm) recorded on site by a HOBO weather station. Black line indicates the 10-yr average in the area obtained from NOAA. Red arrows indicate weeks of Winter 2016, Summer 2016, and Winter 2017 burn treatments.

Proportion of Locations within Treated Patches

All Locations

There was no season effect ($F_{1,1.8}$ = 6.07, P = 0.1460) or season × time interaction ($F_{1,2.3}$ = 2.46, P = 0.2401) for proportion a collared cow's locations within burn treatment areas; there was a significant effect of time ($F_{1, 2.3}$ = 32.54, P = 0.0208) on proportion of presence (Fig. 4). Average proportion a collared cow's locations within the burn patches during the 3 mo before burning treatments was 13% (± 4%). During the 5 mo after burning, proportion a collared cow's locations within the burn patches increased to 49% (± 6%, Fig. 4).

Although effect of time did not differ between seasons, there was an appearance of a season effect (Winter 2016, P = 0.0197 and Summer 2016, P = 0.0972). In Winter 2016 burn patches, mean proportion a collared cow's locations within the burn patches during the 3 mo before burning was 6% (± 3%); that increased to 41% (± 8%) during the 5 mo following treatment. In Summer 2016 treatment areas, mean proportion a collared cow's locations within the burn patches during the 3 mo before burning was 26% (± 8%) and was 58% (± 8%) during the 5 mo following treatment.

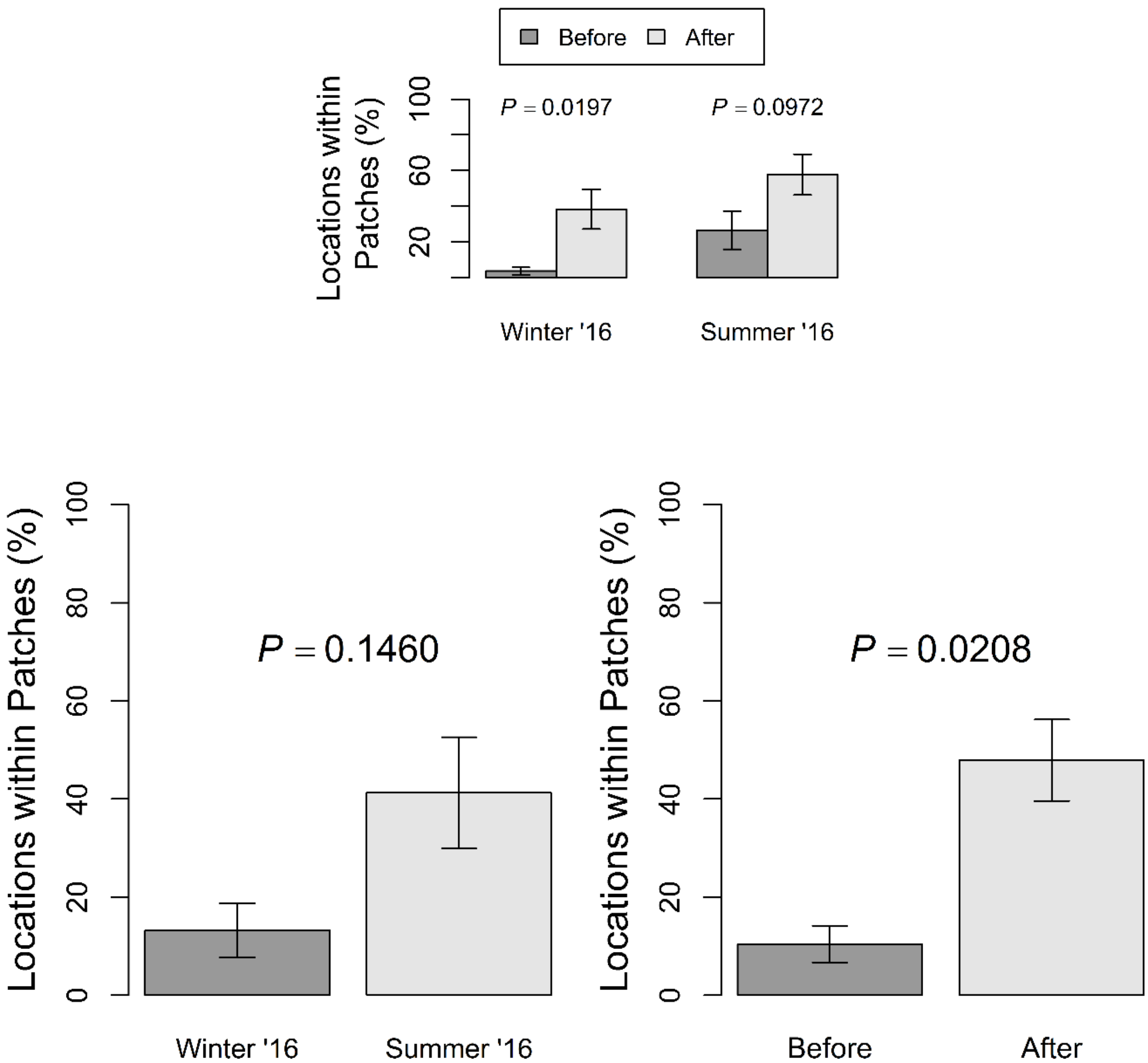

Figure 4. Average GPS locations (%) of collared cattle being present in a burned treatment patches before (*n* = 3 mo) and after (*n* = 5 mo) treatments (Winter 2016, *n* = *7* cows; Summer 2016, *n* = 12 cows) on East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA. Proportion a collared cow's locations within the burn patches based on the season × time interaction holding season constant is at top. Proportion a collared cow's locations within the burn patches based on season is at bottom left. Proportion a collared cow's locations within the burn patches based on time is at bottom right.

Prime Grazing Hours Locations

When considering only prime grazing hours (7:00 to 10:30 h and 17:00 to 20:30 h), there was no statistically significant season effect ($F_{1,1.9}$ = 3.38, P = 0.2081) or season × time interaction ($F_{1,1.7}$ = 5.36, P = 0.1714). There was a time effect ($F_{1, 1.6}$ = 38.85, P = 0.0379) for proportion a collared cow's locations within the burn patches (Fig. 5). Average proportion a collared cow's locations within the burn patches during the 3 mo before burning treatments was 17% (± 6%). During the 5 mo after burning, proportion a collared cow's locations within the burn patches increased to 41% (± 12%, Fig. 5).

Although effect of time did not differ between seasons, there was an appearance of a season effect (Winter 2016, P = 0.0237 and Summer 2016, P = 0.1715). In Winter 2016 burn patches, mean proportion a collared cow's locations within the burn patches during the 3 mo before burning was 5% (± 3%); that increased to 43% (± 11%) during the 5 mo following treatment. In Summer 2016 treatment areas, mean proportion a collared cow's locations within the burn patches during the 3 mo before burning was 28% (± 11%) and was 56% (± 12%) during the 5 mo following treatment.

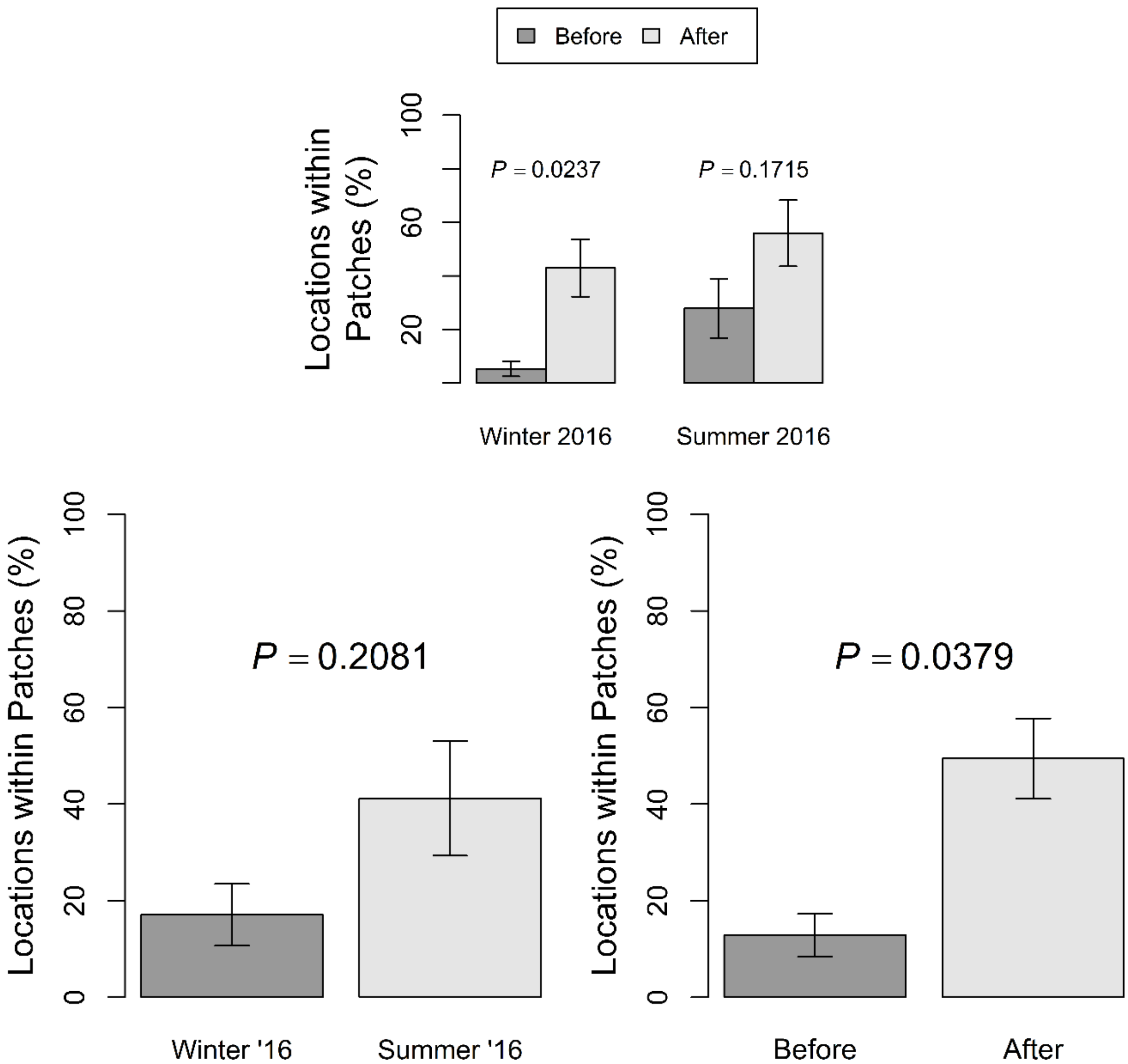

Figure 5. Average percent of GPS locations of collared cattle present in a burned patch before (*n* = 3 mo) and after (*n* = 5 mo) treatments (Winter 2016, *n* = 8 cows; Summer 2016, *n* = 12 cows**)** during prime grazing hours (7:00 to 10:30 h and 17:00 to 20:30 h), on East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA. Proportion a collared cow's locations within the burn patches based on the season × time interaction holding season constant is at top. Proportion a collared cow's locations within the burn patches based on season is at bottom left. Proportion a collared cow's locations within the burn patches based on time is at bottom right.

Proportions within Controls

When all hours were included in the proportion a collared cow's locations within control areas (including any non-burned areas but excluding that season's patches to be treated and previous treated patches), there was no statistically significant season effect ($F_{1,1.8}$ = 6.07, P = 0.1460) or season × time interaction ($F_{1,2.3}$ = 2.46, P = 0.2401). There was a significant time effect ($F_{1, 2.3}$ = 32.54, P = 0.0208). The average proportion a collared cow's (n = 7 Winter, n = 12 Summer) locations within control areas in 2016 during the 3 mo before burning treatments was 87% (± 4%). During the 5 mo after burning, proportion a collared cow's locations within control areas decreased to 51% (± 6%).

When considering prime grazing hours (7:00 to 10:30 h and 17:00 to 20:30 h) in the proportion a collared cow's locations within control areas, there was a statistically significant season effect ($F_{1,14.1}$ = 9.05, P = 0.0093), time effect ($F_{1, 15.2}$ = 76.04, P = < 0.0001), and season × time interaction ($F_{1,15.2}$ = 12.52, P = 0.0029). While holding season constant, the difference in the proportion a collared cow's locations within control areas was in the before proportions ($F_{1, 12.9}$ = 12.64, P = 0.0036), not in the after treatment proportions ($F_{1, 15.3}$ = 0.67, P = 0.4246). The proportion of collared cattle in control areas before the Winter 2016 treatments was 92% (± 3%) while it was 69% (± 6%) before the Summer 2016 treatments. The average proportion of collared cattle in control areas following 2016 burn treatments was 47% (± 3%).

While cattle within 1,000 m of the Winter 2016 patches did not fall into the true control patches 3 mo before or 5 mo after treatments, cattle within 1,000 m of the Summer 2016 patches did. I found no difference in the average proportion of collared cattle in the true control patches following Summer 2016 burn treatments whether analyzing all hours ($F_{1, 2.3}$ = 0.56, P = 0.5223) or only prime grazing hours ($F_{1, 1}$ = 0.44, P = 0.6279). When including all hours of the day, the average proportion was 0.14% (± 0.3%) before the Summer 2016 treatment and was 0.42% (± 0.8%) following the Summer 2016 treatment, indicating little use of the true control patches.

Distance from Burned Patches

Cattle (*n* = 7) whose average distance from Winter 2016 patches were within 1,000 m pre-treatment were not closer to patches following treatment (*P* = 0.063; Table 2). Cattle (*n* = 4; *n* = 8) within 1,000 m of either Summer 2016 patches pre-treatment moved closer to the patches following treatment (*P* = 0.063 for patch 2; *P* = 0.035 for patch 6). Cattle whose average distance from the Winter or Summer 2016 patches were farther than 1,000 m pre-treatment were not closer to the patches following treatments (*P* > 0.5).

During the grazing hours, cattle (*n* = 8) whose average distance from Winter 2016 patches were within 1,000 m pre-treatment were closer to patches following treatment (*P* = 0.035; Table 3). Cattle (*n* = 4; *n* = 8) within 1,000 m of either Summer 2016 patches pre-treatment were closer to the patches following treatment (*P* = 0.063 for patch 2; *P* = 0.035 for patch 6). Cattle whose average distance from the Winter and Summer 2016 patches were farther than 1,000 m pre-treatment were not closer to the patches following treatments (*P* > 0.5).

Table 2. Effect of seasons of burning on cattle movement towards burned patches at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA following winter and summer burning in 2016. Winter 2016 patches were analyzed as one analysis while the summer 2016 patches were analyzed as two separate analyses because Winter patches were burned a few days apart while there was a 2 week hiatus between the two Summer patches for treatment. *n* represents the number of cattle within a category for a season, and *y* represents the number of cattle who were closer to a patch following treatment.

Category	Season											
	Winter 2016				Summer 2016				Summer 2016			
Average Distance Before Fire (m)	*n, y*	Average Distance Before (m)	Average Distance After (m)	*P*	*n, y*	Average Distanc e Before (m)	Average Distance After (m)	*P*	*n, y*	Average Distance Before (m)	Average Distance After (m)	*P*
< 1,000	7,6	557.2	435.5	0.063	4,4	385.2	167.3	0.063	8,7	153.7	95.0	0.035
> 1,000	20,7	3,673.5	3,702.4	0.942	21,9	5,037.8	4,962.4	0.808	18,9	3,071.4	3,009.2	0.593

P values are for a one-sided test of the null hypothesis that burning had no effect on cattle movement against the alternative hypothesis that cattle were more likely to move toward the burn patches (i.e., the probability of a "plus" was greater than the probability of a "minus").

Table 3. Effect of seasons of burning on cattle movement towards burned patches at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA following winter and summer burning in 2016 during prime grazing hours (7:00 to 10:30 h and 17:00 to 20:30 h). Winter 2016 patches were analyzed as one analyses while the summer 2016 patches were analyzed as two separate analysis because Winter patches were burned a few days apart while there was a 2 week hiatus between the two Summer patches for treatment. *n* represents the number of cattle within a category for a season, and *y* represents the number of cattle who were closer to a patch following treatment.

Category	Season											
	Winter 2016				Summer 2016				Summer 2016			
Average Distance Before Fire (m)	*n, y*	Average Distance Before (m)	Average Distance After (m)	*P*	*n, y*	Average Distance Before (m)	Average Distance After (m)	*P*	*n, y*	Average Distance Before (m)	Average Distance After (m)	*P*
< 1,000	8,7	590.0	425.3	0.035	4,4	398.4	168.0	0.063	8,7	146.0	94.8	0.035
> 1,000	19,5	3,809.5	3,880.9	0.990	21,8	5,047.2	4,962.1	0.905	18,9	3,093.8	3,034.0	0.593

P values are for a one-sided test of the null hypothesis that burning had no effect on cattle movement during prime grazing hours against the alternative hypothesis that cattle were more likely to move toward the burn patches (i.e., the probability of a "plus" was greater than the probability of a "minus").

Core Area and Home Range Size

Core area size (50%) of cattle within 1,000 m of a treated patch was analyzed for 8 time periods (3 mo prior to burning and 5 mo post burning) for Winter (n = 7) and Summer (n = 12) 2016 treatments. While month and season did interact ($F_{7,61.8}$ = 2.48, P = 0.0260), time (before or after burning) and season did not interact ($F_{1,32.7}$ = 2.72, P = 0.1088) in their effects on core area and core area did not differ ($F_{1,32.7}$ = 0.45, P = 0.5067) before (estimated median core area = 8.8 ha, CI: 6.1, 12.4) and after (estimated median core area = 11.3 ha, CI: 8.3, 15.3; Fig. 6).

Similar results were found when home range size (95%) was analyzed. The home range size (95%) of cattle within 1,000 m of a burn patch before treatment was analyzed for 8 time periods (3 mo prior to burning and 5 mo post-burning) for the Winter (n = 7) and Summer (n = 12) 2016 treatments. Time period (month to month) and season of burning interacted ($F_{7, 63.3}$ = 3.99, P = 0.0011) in their effects on home range size (see Appendix A). Effects of time (before or after burning) did not interact ($F_{1,45.9}$ = 1.89, P = 0.1754) with season of burning; furthermore, the main effect of time was not significant ($F_{1,45.9}$ = 0.06, P = 0.8021; median home range size before burning = 169.2 ha; CI: 140.1, 204.2; and median home range size after burning = 178.4 ha; CI: 151.3, 210.4; Fig. 6).

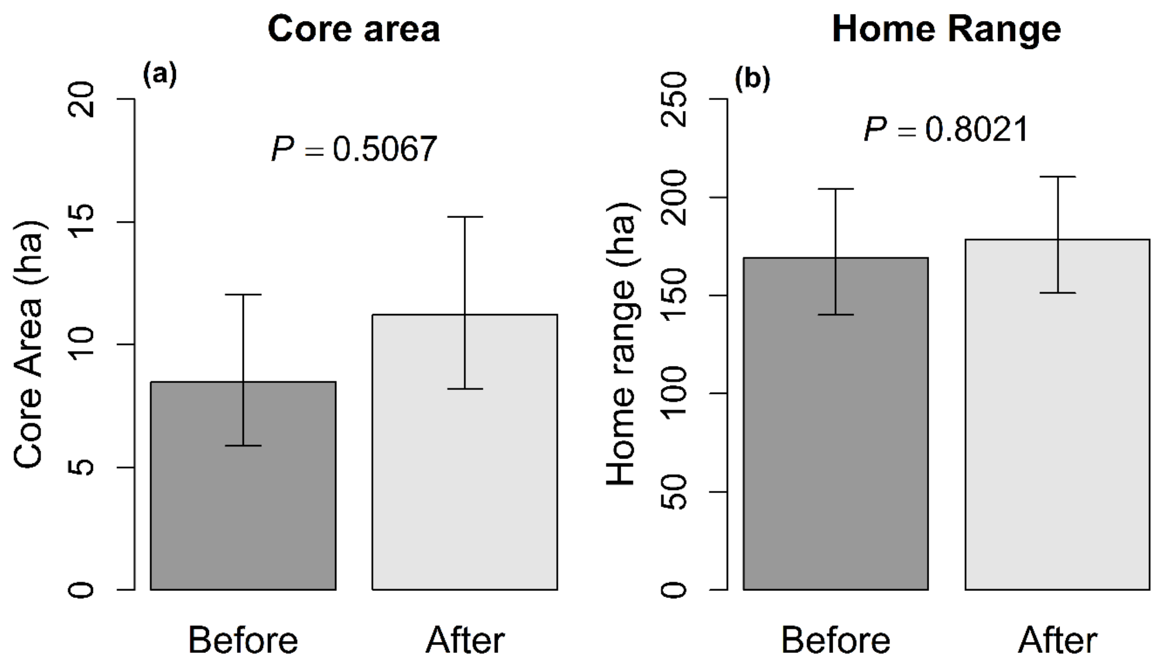

Figure 6. Size of core area and home range of collard cattle at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA following 2016 treatments. The median size (ha) of (a) core areas and (b) 95% home ranges of collared cattle 3 mo before and 5 mo after Winter 2016 (n = 7 cows) and Summer 2016 (n = 12 cows) burn treatments at El Sauz ranch in Willacy and Kenedy Counties, TX. Core and home range size were estimated using Adaptive Kernel estimation. Note different scales between the size of core area (50%) and 95% home range.

Core Area and Home Range Overlapping Burn Patches

Percent overlap of core area after burning (46.6% ± 3.8%) was greater ($F_{1,56.1}$ = 45.35, P < 0.0001) than percent overlap before burning (13.4% ± 3.6%); furthermore, this effect did not depend ($F_{1,56.1}$ = 0.18, P = 0.6738) on season of burning (Fig. 7).

Percent overlap of 95% home range after burning (43.6% ± 2.8%) was greater ($F_{1,30.3}$ = 51.35, P < 0.0001) than percent overlap before burning (23.7 ± 2.9%); furthermore, this effect did not depend ($F_{1,30.3}$ = 0.71, P = 0.4056) on season of burning (Fig. 7).

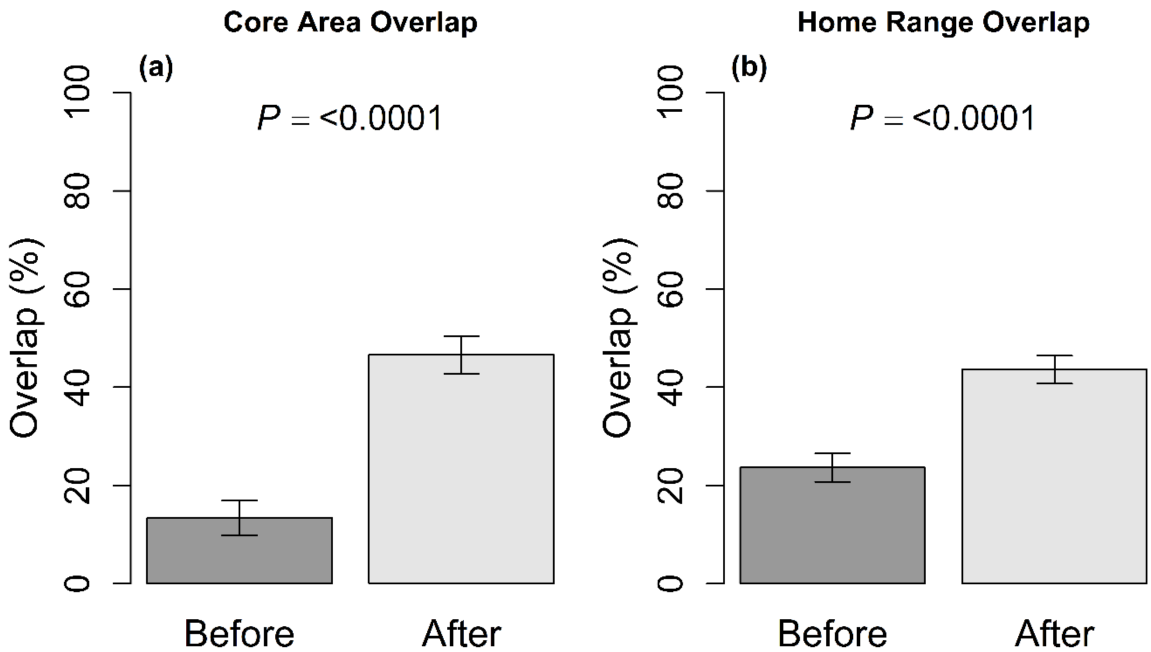

Figure 7. Extent of core areas and home ranges of collard cattle within burn patches at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA following 2016 treatments. Average overlap (%) of (a) core area and (b) 95% home range area within burn patches 3 mo prior to and 5 mo following Winter 2016 (*n* = 7 cows) and Summer 2016 (*n* = 12 cows) burn treatments.

Utilization Estimates of Gulf Cordgrass

For 90 d following burn treatments, there was a difference in utilization of gulf cordgrass among treatments (Winter, Summer, and Control) ($F_{2,3} = 20.75$, $P = 0.0175$). While there was no difference between Winter and Summer burn treatments ($F_{1,3} = 0.02$, $P = 0.8967$), there was a difference in utilization between Control and combined Burn treatments ($F_{1,3} = 41.48$, $P = 0.0076$). Average utilization in Control patches was 10% (± 7.5) while average utilization within

Winter and Summer patches was 69% (± 5.3). As time progressed after burning, there was a decline in monthly utilization estimates of gulf cordgrass (%).

Gulf Cordgrass Forage Disappearance Estimates

For 90 d following burn treatments, there was a difference in forage disappearance of gulf cordgrass among treatments (Winter, Summer, and Control) ($F_{2,3}$ = 10.65, P = 0.0434) following burn treatments. While there was no difference between Winter and Summer burn treatments ($F_{1,3}$ = 4.99, P = 0.1117), there was a difference in gulf cordgrass disappearance between Control and combined Burn treatments ($F_{1,3}$ = 16.32, P = 0.0273). Average gulf cordgrass forage disappearance in Control patches was 407 (± 154) kg · ha^{-1} while average gulf cordgrass forage disappearance within Winter and Summer patches was 1,172 (±109) kg · ha^{-1}.

Carrying Capacity Estimates within Gulf Cordgrass

For 90 d following burn treatments, there was a difference in carrying capacity among treatments (Winter, Summer, and Control) ($F_{2,3}$ = 10.89, P = 0.0421) following burn treatments. While there was no difference between Winter and Summer burn treatments ($F_{1,3}$ = 5.04, P = 0.1104), there was a difference in carrying capacity between Control and combined Burn treatments ($F_{1,3}$ = 16.74, P = 0.0264). Average carrying capacity in Control patches was 0.38 AU · ha^{-1} · 90 d (± 0.14) while carrying capacity in Winter and Summer patches was 1.08 AU · ha-1 · 90 d (± 0.10).

Forage Nutritive Content (CP, NDF, ADF, ADL)

Crude Protein (CP)

Prior to burning treatments, CP (%) in gulf cordgrass ranged from 4 to 6% in both Winter and Summer 2016 burn treatments. Winter predicted values at 30 d after burning were estimated at 14.67% (± 0.30%), while Summer values were estimated at 14.88% (± 0.39%; Fig. 8). At 60 d following Winter burning, CP (%) levels were estimated at 12.26% (± 0.28%) while they were estimated at 12.48% (± 0.35%) following Summer burning. At 90 d after Winter burning, protein levels were estimated at 9.84% (± 0.50%) while they were estimated at 10.07% (± 0.64%) following Summer burning.

For the first 19 d following Winter 2016 burn treatments, CP (%) increased 0.39 (± 0.03) patches each day and was estimated to peak at 15.53% (± 0.37) on d 19 post-burn. Crude protein (%) then decreased 0.08 (± 0.01) patches each d until 90 d post-burn. Crude protein levels within Control treatments (non-burned gulf cordgrass) ranged from 5.5 to 6.3% on d 45 and 90 following Winter 2016 treatment. Following Winter 2016 burn treatments, 81.5% of the variation in CP was explained by time since burning.

For the first 12 d following Summer 2016 burn treatments, CP (%) increased 0.78 (± 0.09) patches each d and was estimated to peak at 16.29% (± 0.56) on d 12 post-burn. Crude protein (%) then decreased 0.08 (± 0.01) patches each d until 90 d after Summer 2016 burns. Following Summer 2016 burn treatments, 75.6% of the variation in CP was explained by time since burning. Crude protein levels in Control treatment (non-burned gulf cordgrass) patches ranged from 4.6 to 5.8% on roughly 45 and 90 d following Summer 2016 burn treatments.

The piecewise linear models differed ($F_{3,55} = 26.6$, $P < 0.0001$) between seasons. Furthermore, the initial increase in CP (prior to reaching threshold values for each season) was faster (t_{55} = 4.40, P < 0.0001) in plants burned during Summer 2016 treatments than during Winter 2016 treatments; however, the decline in CP (after threshold values were reached) did not differ (t_{55} = 0.02, P = 0.9880) between seasons.

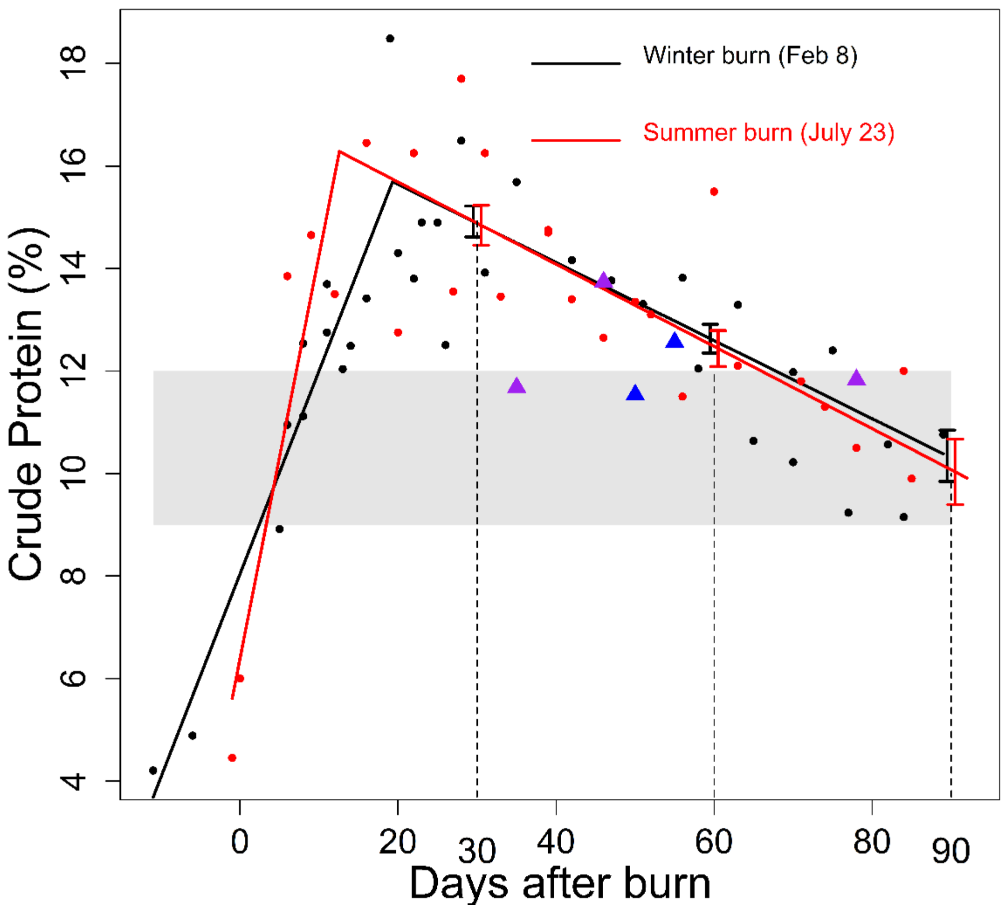

Figure 8. CP levels (%) in gulf cordgrass as a function of time since fire following the 2016 treatments at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA. Each point represents mean CP level in gulf cordgrass in a treated patch (n = 8 quadrats · patch · sampling). Black line represents Winter 2016 treatments while red line represents Summer 2016 treatments. Predicted values (± std error) for 30, 60 and 90 d are indicated by the dashed vertical lines; Winter 2016 standard error bars are shifted 1 d to the left and Summer 2016 standard error bars are shifted 1 d to the right on the figure to reduce overlapping standard error bars. Each blue and magenta triangle represents mean CP level (%) in exclosures in winter (blue) and summer (magenta), respectively (Table 4). Shaded area indicates the maintenance levels for lactating cows (Hanselka 1981).

NDF, ADF, ADL

NDF

Prior to burning treatments, NDF (%) within mature gulf cordgrass ranged from 74 – 76% in Winter and Summer 2016 treatment patches. For the first 32 d following Winter 2016 burn treatments, NDF (%) in gulf cordgrass decreased 0.30 (± 0.04) patches each d and was estimated to reach the lowest value at 66.24% on d 32 post-burn (Fig. 9). NDF (%) then increased 0.15 (± 0.02) patches each following d for 90 d. Time since fire was responsible for 68.4% of the variation in NDF (%) following Winter 2016 burn treatments.

For the first 21 d following Summer 2016 burn treatments, NDF (%) decreased 0.31 (± 0.08) patches each d and was estimated to reach the lowest percentage at 67.13% on d 21 post-burn. NDF (%) then increased 0.13 (± 0.03) patches each d after that until 71 d post-burn, and then decreased 0.2446 patches (± 0.06) each d until 90 d following Summer 2016 burn treatments. Time since fire was responsible for 49.6% of the variation in NDF (%) following Summer 2016 burn treatments. NDF levels in Control (non-burned gulf cordgrass) patches ranged from 73.48 to 80.90% on roughly 45 and 90 d following 2016 burn treatments.

The piecewise linear models differed ($F_{3,58}$ = 7.87, P = 0.0002) between seasons. The initial decrease in NDF (prior to reaching threshold values for each season) did not differ between burning treatments (t_{58} = -0.21, P = 0.8381); the increase in NDF (after threshold values were reached) did not differ either (t_{58} = -0.91, P = 0.3652) between seasons of treatment. The difference in models was because a third slope occurred after Summer 2016 burn treatments but not after Winter 2016.

ADF

Prior to burning treatments, the ADF (%) within mature gulf cordgrass ranged from 41 to 43% in both Winter and Summer 2016 burn patches. For the first 6 d following Winter 2016 burn treatments, ADF (%) decreased 0.94 (± 0.26) patches each d and was estimated to reach the lowest value at 37.64% on d 6 post-burn (Fig. 9). Then ADF (%) increased 0.03 (± 0.01) patches until 90 d post-Winter 2016 burn. Time since fire was responsible for 29.1% of the variation in ADF following Winter 2016 burn treatments

For the first 19 d following Summer 2016 burn treatments, ADF (%) decreased 0.36 (± 0.07) patches each d and was estimated to reach the lowest percentage at 34.47% on d 19 post-burn. ADF (%) then increased 0.04 (± 0.02) patches until 73 d post burn, and then increased 0.24 (± 0.15) patches each d until 90 d after Summer 2016 burn treatments. Time since fire was responsible for 67.3% of the variation in ADF (%) following Summer 2016 burn treatments. ADF in Control (non-burned gulf cordgrass) patches ranged from 37.39 to 45.40% at roughly 45 and 90 d following 2016 burn treatments.

The piecewise linear models differed ($F_{3,57}$ = 3.32, P = 0.0261) between seasons. Furthermore, the initial decrease in ADF (prior to reaching the first threshold values for each season) was faster (t_{57} = 2.18, P = 0.0333) in plants burned during Winter 2016 treatments than during Summer 2016 treatments; however, the increase in ADF (after initial threshold values were reached) did not differ (t_{57} = 0.25, P = 0.8061) between seasons. Additionally, the difference in models was also attributed to a third slope occurring after Summer 2016 burn treatments but not after Winter 2016.

ADL

Prior to burning treatments, ADL (%) within mature gulf cordgrass was 5% in Winter 2016 burn treatment patches and roughly 8% in Summer 2016 burn treatment patches. Throughout the 90 d following Winter 2016 burn treatments, ADL (%) increased 0.0032 patches each d while following Summer 2016 burn treatments, ADL (%) initially declined but began to increase slightly at roughly 70 d (Fig. 9). Time since fire was responsible for only 0.25% of the variation in ADL (%) following Winter 2016 burn treatments. Yet it was responsible for 60.4% of the variation in ADL (%) following the Summer 2016 burn treatments. ADL in Control (non-burned gulf cordgrass) patches ranged from 3.85 to 6.82% at roughly 45 and 90 d following 2016 burn treatments.

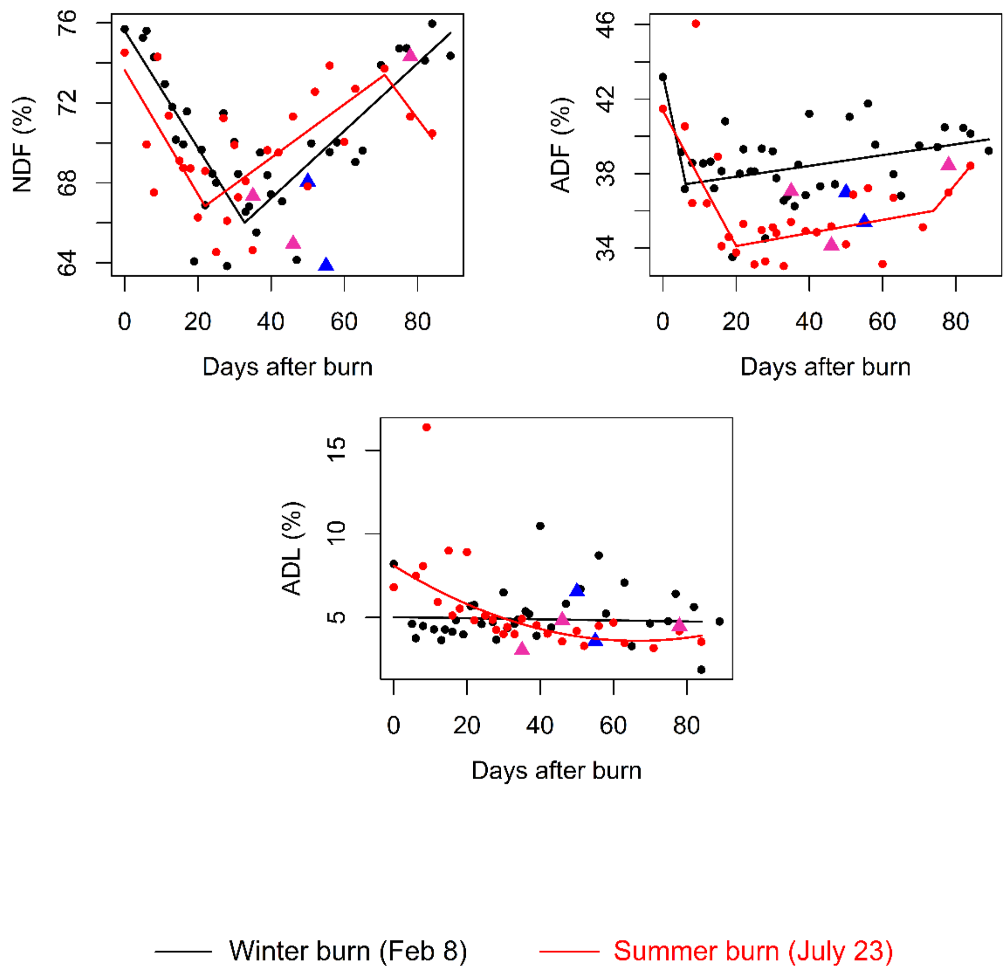

Figure 9. NDF, ADF, and ADL levels (%) in gulf cordgrass as a function of time since fire following the 2016 treatments at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA. Each point represents mean NDF, ADF, or ADL level in gulf cordgrass in a treated patch (*n* = 8 quadrats · patch · sampling). Black lines represent Winter 2016 treatments while red lines represent Summer 2016 treatments. Values of ADF and ADL exceeding 43 and 15, respectively, were removed from the data set for statistical analyses. Blue and magenta triangles represent means (%) in a patch's exclosures in Winter (blue) and Summer (magenta), respectively (Table 4).

Exclosure Nutritive Content

First exclosures (*n = 8*) of the study were established in Winter 2016 burn patches 3 wks following treatment. First exclosure harvest for Winter 2016 treatments occurred ~ 50 d after fire but with ~ 30 d of protection from herbivores. Mean NDF averaged 68.06% (± 0.572%; *n* = 2) and 63.86% (± .; *n* = 1) with 32 days of protection (50 and 55 days post-Winter 2016 treatments). Mean NDF averaged 75.24% (± 1.370%; *n* = 4) and 71.01% (± 1.409%; *n* = 4) with 42 d of protection (92 and 97 d post-Winter 2016 treatments; Table 4).

Table 4. Nutritive content of gulf cordgrass inside exclosures after winter and summer burning treatments in 2016 at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA.

Season 2016	Patch	Days after Fire	Days of Protection	CP (%)	NDF (%)	ADF (%)	ADL (%)	*n*
Winter	9	55	32	12.57 (± .)	63.86 (± .)	35.4 (± .)	3.59 (± .)	1
	10	50	32	11.54 (± 0.170)	68.06 (± 0.572)	36.98 (± 0.428)	6.55 (± 0.498)	2
	9	97	42	11.92 (± 0.625)	71.01 (± 1.409)	35.87 (± 0.538)	3.93 (± 0.204)	4
	10	92	42	11.90 (± 0.421)	75.24 (± 1.370)	38.74 (± 0.762)	4.08 (± 0.160)	4
Summer	2	46	35	13.74 (± 0.441)	64.95 (± 0.721)	34.15 (± 0.875)	4.83 (± 0.489)	4
	6	35	35	11.68 (± 1.785)	67.35 (± 1.400)	37.06 (± 0.502)	3.05 (± 0.066)	4
	2	78	32	11.84 (± 0.810)	74.32 (± 2.678)	38.46 (± 1.283)	4.48 (± 0.194)	4

DISCUSSION

For proportion of locations within treated patches, distance from burned patches, and cattle core area and home range size and overlap, 2017 treatments could not be considered independent from 2016 treatment effects. I.e., as the study progressed "before" and "after" effects for collared cows that were free to move to any area on the ranch became complicated by the fact that any individual fix of a cattle collar could be considered "after" data from on season of burn treatments and, simultaneously, "before" data from another season of burn treatments. Future patch burning-grazing research should carefully consider placement of treatment patches. A study in Oklahoma separated their study sites by at least 1,600 m to avoid possible confounding effects (Vermeire et al. 2004).

Proportion of Locations within Treated Patches

Regardless of whether proportion of locations within patches was analyzed with all locations or based solely on prime grazing hours, there was a significant increase in the proportion following burn treatments. This preference for burned areas agrees with results reported by Fuhlendorf and Engle (2004) and Ramirez-Yanez et al. (2007). Although natural water sources were present in the Winter 2016 burn treatment patches and possibly Summer burn patches during times of average to high precipitation, it should be noted that no water troughs were located in our treated patches (both Winter and Summer 2016 burn patches) which may have inhibited full use of these patches observed in the proportion of locations within patches.

There was still a lack of full utilization following Summer 2016 treatments as average proportion was 58% (all locations) and 56% (prime grazing hours); this was probably because no water troughs were located in the burned patches, but also because of metabolic requirements. Metabolic requirements of large herbivores may lead to tradeoffs between foraging in burned and non-burned areas. While recently-burned areas produce high-nutritive forage, quantity may be limiting for large herbivores. In response, large herbivores will often select patch edges to obtain intermediate levels of vegetation quantity and quality (Allred et al. 2011). This was probably a factor following Winter 2016 burn treatments as well.

Distance to Burned Patches

Whether all hours were included in the analysis or only the prime grazing hours, the Summer 2016 treatments shortened the distance of collared cattle to the burn patches if cattle were within 1,000 m from the patches prior to burning. The Winter 2016 treatments shortened the distance of collared cattle during the prime grazing hours that were within 1,000 m from the patches prior to burning. When all hours were included in the analysis the Winter 2016 treatments did not shorten the distance of collared cattle to the burn patches if cattle were within 1,000 m from the patches prior to burning. Although Winter 2016 treatments did not shorten mean distance to burned areas when all hours were included, there were significant increases in the proportion of locations within a burn treatment indicating that Winter treatments did attract cattle to the previously underutilized burned areas. Regardless of time of day, neither 2016 burn treatments (Winter or Summer) shortened the distance of collared cattle from the burn patches if cattle were farther than 1,000 m from the patches prior to burning. These distance from burned patches results can give landowners insight to appropriate distances between burn patches on large land holdings to attract and meet the needs of cattle in different herds. While Ganskopp's (2001) study conducted in Oregon indicated that cattle continuously remained within 1.16 km (1,160 m) from water sources, Vermeire et al. (2004) reported cattle traveling 1.6 km (1,600 m) from water to utilize burned patches following burning in northwestern Oklahoma.

Core Area and Home Range Size and Overlap

Whether burning was conducted during Winter or Summer 2016, the average core area and home range sizes were not altered following treatments. Fire did not have an effect on core area or home range size (Fig. 6). However, fire did have an effect on the extent of core area and home range located within recently-burned patches. The extent of core area and home range overlap with the burn patches did increase following both Winter and Summer 2016 burn treatments. The increased portions of core area and home range falling within the patches following burning signals a shift in the location of both home ranges and core areas, signifying a strong preference for recently-burned patches.

Utilization and Forage Disappearance Estimates of Gulf Cordgrass

The degree of utilization of gulf cordgrass has been suggested as being regulated by both time since burning and arrangement of resources on the landscape. As time since fire progressed in my study, utilization of gulf cordgrass declined as cattle moved onto other forage available in the patches as indicated by Oefinger and Scifres (1977) and Scifres and Drawe (1980). However, utilization of gulf cordgrass did not differ whether it was burned in the late winter or late summer. A previous study conducted in Oklahoma indicated that cattle showed no preference for one burn season (winter or spring) over the other (Vermeire et al. 2004). Britton et al. (2010) indicated that whether burning was conducted during winter or summer, there was no difference in vegetative production on Matagorda Island, along the southern Texas coast; there was only a short-term difference in frequency of certain plant species (Britton et al. 2010).

Because average forage disappearance of gulf cordgrass throughout the 90 d following fire was 1,172 kg $\cdot$ ha^{-1} regardless of season of burning, and the average cow consumes 12 kg $\cdot$ d, I recommend that 1 ha of gulf cordgrass per cow be burned in either winter or late summer to improve forage nutrition and feed 1 cow for a period of 90 d. This recommendation is assuming favorable conditions (precipitation, temperature and soil texture) for growth. When inadequate rainfall precedes and follows burning, perennial grass growth decreases while annual forbs and grasses increase (Teague et al. 2008). Based on the gulf cordgrass forage disappearance estimate of 407.5 kg · ha^{-1} in Control patches, 3 ha of mature, non-treated gulf cordgrass would be required to feed 1 cow for 90 d. Given the resulting high-nutritive content in forage following burning, a landowner leasing recently-burned gulf cordgrass rangeland for grazing may choose to charge $36 · head · 90 d ($12 · head · 30 d; Ortega-S., pers comm).

Forage Nutritive Content (CP, NDF, ADF, ADL)

I analyzed nutritional content of gulf cordgrass and distribution data following only the 2016 Winter and Summer burn treatments for various important reasons. First, for nutritional analyses there would be no need to continue in the second year if no differences between seasons of burning were found in the first year, and nutritional analyses are costly in terms of manpower time expended and laboratory supplies.

Following both seasons of burning CP initially rose sharply (Fig. 8). Then as time progressed CP content steadily decreased in gulf cordgrass while fiber (NDF, ADF, and ADL) increased. At 90 d following both treatments, average CP levels in gulf cordgrass were roughly 10%. There was, however, a faster rise in CP following Summer 2016 burn treatments than Winter 2016 burn treatments. One explanation for this is that warmer soil surface temperatures in the Summer stimulated bacteria to rapidly produce nitrate ions for plant uptake (Sharrow and Wright 1977). Additionally, in the month following the Summer burn treatments there was fully double the amount of precipitation at the ranch (100.84 mm) than in the month following the Winter burn treatments (50.29 mm). Although the rise in CP differed following seasons of burning, the similar CP level decline from d 19 to d 90 suggests that there was no meaningful effect of season on CP value in gulf cordgrass regrowth following fire. The delay in regrowth reaching its highest CP levels and lowest fiber levels following burning treatments in both seasons may be related to the short internodes from the old growth (previously protected from fire within gulf cordgrass crowns) on the tips of the gulf cordgrass regrowth when collected for forage nutritive content. Over time new green growth comprised a higher proportion of the shoot samples collected as the short internodes disappeared. Eventually CP and fiber results reached their thresholds before slowly reverting to pre-burn levels.

Gulf cordgrass CP content in exclosures after 30 d of establishment was similar to CP levels reported by McAtee et al. (1979b) at roughly 30 d with no defoliation. Literature comparisons of fiber levels in gulf cordgrass with no defoliation was not feasible because there is no published study of fiber content in gulf cordgrass. Typically as forage matures, digestibility decreases while fiber (NDF, ADF) increases. However, it appears as though exposed/grazed forage had higher fiber content than gulf cordgrass in the first 30-d exclosure harvests following both seasons of treatment. Fulbright and Ortega (2013) reported increased growth rates (compensatory growth) as a defense mechanism in response to grazing which would lead to higher fiber (cell wall) content in foliage. While time since fire explained a high amount of variation in nutritional content of gulf cordgrass following fires, it did not completely explain variability in nutritional content. Other factors could include soil moisture, degree of defoliation over the 90 d period, and nutrient availability in the soil (Garza et al. 1994; McCuistion et al. 2014).

Further Discussion

Recognizing the influences of time since fire and season of burning on vegetation and animal distribution on rangelands along the southern coastal prairies of Texas is essential for managing these rangelands appropriately. Prescribed fire is an effective and cost-efficient way to manage gulf cordgrass rangelands for livestock and to remove senescent forage. Although my results suggest that season of burning (winter or summer) is insignificant when using fire to improve utilization by livestock and improving nutritive content of gulf cordgrass, other management objectives should be considered as well. Increasing young woody species mortality or promoting forb production are common objectives when using fire that may be better met with a summer burn. Providing habitat for wintering grounds and resting stops for migratory birds along the southern Texas coast is another concern that has steered managers to burn in late summer (Britton et al. 2010). However, the health and safety of the fire crew is also an important consideration because summer temperatures in south Texas easily rise above 35° C. The exertion involved in prescribed burning combined with such extreme temperatures can be dangerous to human health. Animal welfare is another factor. Following burning there is a vast percentage of bare ground which will reflect heat and increase body temperatures of livestock. Vegetative ground cover is essential for cooler surfaces as plants reflect less radiation than bare ground; leaves absorb most of the sun's energy and cool the air by transpiration (Collinson 1988). Shay et al. (2001) found soil surface temperatures in recently burned areas were higher than ambient air temperatures and were also significantly higher ($P \leq 0.0001$) than soil surface temperatures in control (non-burned) areas. Ensuring there is thermal cover for domestic and wildlife species is crucial. For reasons of human health and leaving vegetation for cooling during the extremely hot South Texas summers, winter burning would be favored over summer burning when it meets the vegetative management objectives just as well. However, repeated burning of different patches during winter and summer seasons, holding season constant within a patch over multiple years, will lead to vegetative differences between patches and greater variety in wildlife habitat. Patch burning in a continuous grazing system could be an applicable practice that requires less time and money than mechanical methods when landowners desire even distribution on the landscape, as in a rotational grazing system (Teague et al. 2013). Fire can be used as a tool to alter grazing behavior and shift it from a selective scale to a landscape scale because plants that previously were underutilized by herbivores become increasingly more favorable and available with fire (Coppedge and Shaw 1998; Scasta et al. 2015; Clark et al. 2017.

MANAGEMENT IMPLICATIONS

Prescribed fire in gulf cordgrass rangelands is effective in attracting nearby cattle to previously underutilized areas and improving the utilization of gulf cordgrass. Forage production removed by grazing animals throughout the 90 d following the Winter and Summer burns (2016 & 2017) was 1,172 kg · ha^{-1}. Considering this, with favorable growing conditions, 1 ha of gulf cordgrass can support 1 AU for 90 d following either a winter or summer burn. In addition, crude protein levels in gulf cordgrass throughout the 90 d following the Winter and Summer 2016 burns was appropriate to fulfill the needs of lactating and non-lactating cattle.

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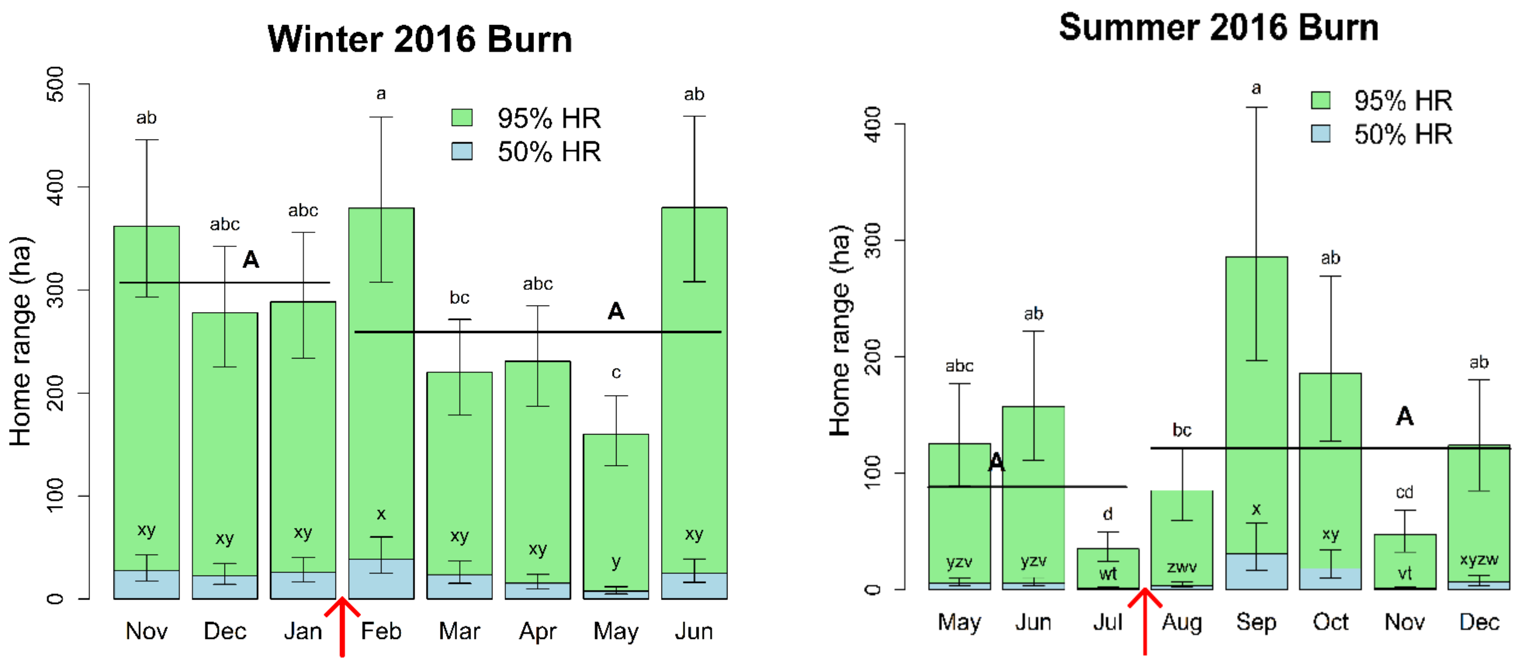
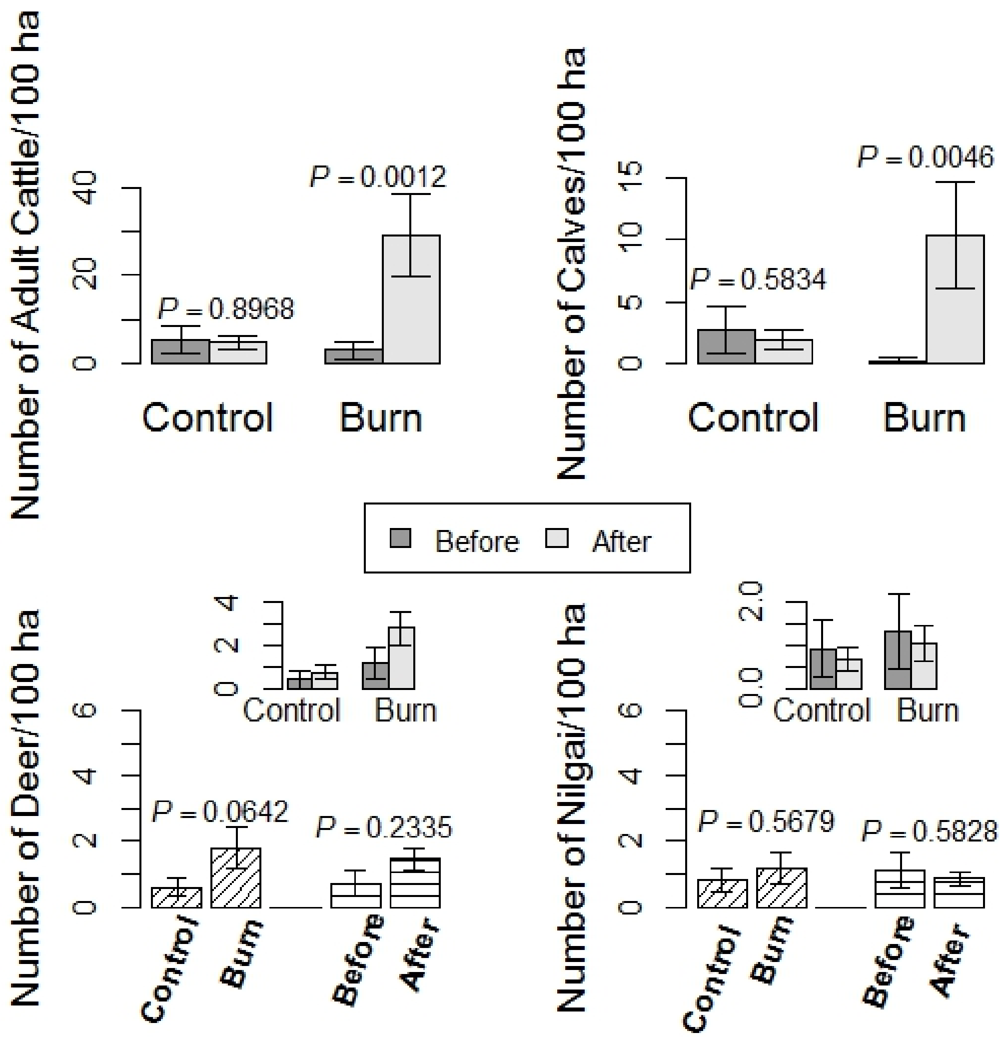
APPENDICES



Appendix Figure A1. Monthly core area and home range size of cattle (Winter *n* = 7 cows; Summer *n* = 12 cows) following the 2016 treatments at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA. Month to month variation did differ between 2016 burn treatments (Winter and Summer) presumably because of climate and spatial variation of resources (shade, water, vegetation) on the landscape over time (Morellet et al. 2013).



Appendix Figure A2. Results from the Summer 2017 ungulate counts at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA. There was an interaction effect between time (before and after) × treatment (burn or control) for the adult cattle and calves following our summer 2017 treatment. When holding treatment constant and looking at time, there was a difference in the number of adult cattle counted in the Summer 2017 patches following burning treatment ($F_{1,44} = 12.00$, $P = 0.0012$) as well as the number of calves counted ($F_{1,44} = 8.90$, $P = 0.0046$). There was no evidence for an interaction effect between time and treatment for white-tailed deer or nilgai. When analyzing the time and treatment effects separately for white-tailed deer (WTD) or nilgai (NIL), we found no treatment [($F_{1,33.05} = 3.67$, $P = 0.0642$ (WTD)), ($F_{1,3.205} = 0.40$, $P = 0.5679$ (NIL))], or time [($F_{1,33.05} = 1.47$, $P = 0.2335$ (WTD)), ($F_{1,36.09} = 0.31$, $P = 0.5828$ (NIL))] effect following Summer 2017 treatments.

APPENDIX B. SUPPLEMENTAL TABLES

Appendix Table B1. Individual cow's core area and home range sizes (ha) at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA during 2016 burn treatments. The * indicates a collar malfunction and variable could not be measured for that individual.

Cow	Winter 2016 50% Core Area Size (ha)		Winter 2016 95% Home Range Size (ha)		Summer 2016 50% Core Area Size (ha)		Summer 2016 95% Home Range Size (ha)	
	Before (3 mo)	After (5 mo)	Before (3 mo)	After (5 mo)	Before (3 mo)	After (5 mo)	Before (3 mo)	After (5 mo)
39009	*	*	*	*	*	*	*	*
39010	51.32	9.53	419.09	215.61	12.47	6.15	269.41	189.01
39011	64.47	9.91	377.85	158.29	2.39	3.43	95.51	81.49
39012	21.05	1.29	197.62	61.92	0.02	6.58	48.87	129.48
39013	67.15	24.96	436.38	244.23	39.16	1.23	400.35	103.73
39014	8.08	8.36	206.20	236.70	*	*	*	*
39015	46.46	14.03	314.53	161.16	3.23	3.56	49.24	93.13
39016	15.47	4.71	222.57	109.70	2.63	9.24	102.25	178.99
39017	32.47	3.11	257.68	87.17	-0.03	11.85	30.10	164.78
39018	29.88	5.53	362.80	212.83	0.51	1.65	56.56	116.73
39019	22.73	16.23	274.40	265.96	14.05	26.22	283.56	440.34
39020	270.56	54.00	993.27	372.61	42.28	84.99	286.50	416.20
39021	44.95	18.95	403.03	238.83	13.58	26.56	208.51	256.05
39022	31.18	7.20	293.15	147.73	*	*	*	*
39023	43.14	35.36	354.05	484.36	78.09	2.62	529.42	90.97
39024	62.69	-0.01	294.18	41.77	-0.86	2.05	10.80	88.26
39025	44.08	18.30	402.81	218.06	8.53	2.77	211.48	85.36
39026	11.30	1.16	260.74	62.38	0.52	0.42	52.41	36.68
39027	33.41	29.85	317.47	269.98	5.08	2.03	131.63	65.59
39028	*	*	*	*	*	*	*	*
39663	73.46	13.99	793.04	326.47	3.69	-0.07	159.05	62.61
39664	47.13	5.91	307.03	189.60	2.17	0.13	88.26	54.41
39665	46.46	12.77	752.06	309.67	2.20	7.24	131.55	282.73
39666	17.95	38.65	231.46	340.54	13.44	8.02	295.84	172.63
39667	18.21	26.15	264.82	250.72	63.02	18.80	420.98	271.69
39668	21.00	12.02	313.38	207.28	37.05	16.05	412.08	321.01
39669	30.25	21.18	282.99	208.47	5.18	4.51	159.54	186.61
39670	*	*	*	*	*	*	*	*
39671	14.16	40.17	286.80	318.71	8.50	8.65	242.38	263.54
39672	16.99	14.87	214.36	286.43	1.23	9.97	77.59	198.91

Appendix Table B2. Individual cow's core area and home range overlap with 2016 prescribed burn patches (%) at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA. The * indicates a collar malfunction and variable could not be measured for that individual.

Cow	Winter 2016 50% Core Area Within Patch (%)		Winter 2016 95% Home Range Within Patch (%)		Summer 2016 50% Core Area Within Patch (%)		Summer 2016 95% Home Range Within Patch (%)	
	Before (3 mo)	After (5 mo)	Before (3 mo)	After (5 mo)	Before (3 mo)	After (5 mo)	Before (3 mo)	After (5 mo)
39009	*	*	*	*	*	*	*	*
39010	0	0	0	0	0	0	0	0
39011	0	0	0	0	20	54.2	56	55.4
39012	0	0	0	0	0	46.4	1.33	31.6
39013	0	0	0	0	0	0	0	0
39014	0	0	0	0	*	*	*	*
39015	0	0	0	0	21	42.6	41.67	59.6
39016	0	0	0	0	26	48.6	40.33	55.2
39017	0	0	0	0	13.33	36.75	33.67	51
39018	0	0	0	0	13.67	69.6	25.33	62.2
39019	0	0	0	0	0	0	0	0
39020	0	0	0	0	48.5	77.2	32.5	71.5
39021	0	0	0	0	42.67	67.8	34.33	47.8
39022	0	0	0	0	*	*	*	*
39023	0	0	0	0	0	0	0	0
39024	0	0	0	0	0	63.33	13	52
39025	0	0	0	0	24.5	53	49.5	59.67
39026	0	0	0	0	0	37.08	31.65	44.79
39027	0	0	0	0	55.33	54	53.33	56.8
39028	*	*	*	*	*	*	*	*
39663	4	39.8	9	27.8	0	0	0	0
39664	0	28.6	2	15.4	0	0	0	0
39665	0	28.2	3	31.2	0	0	0	0
39666	10	36.4	17	30.8	0	0	0	0
39667	11.33	32.6	16	41.4	0	0	0	0
39668	5.33	31	13	35.8	0	0	0	0
39669	5.67	57.6	11.67	48.4	0	0	0	0
39670	*	*	*	*	*	*	*	*
39671	1	58.4	14.33	39.6	0	0	0	0
39672	0	0	0	0	0	0	0	0

Appendix Table B3. Individual cow's distance (m) from 2016 prescribed burn patches before and after treatment at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA. The * indicates a collar malfunction and variable could not be measured for that individual. Highlighted distances are individuals who were within 1,000 m to a patch prior to treatment.

Cow	Winter 2016 Patch 9 & 10		Summer 2016 Patch 2		Summer 2016 Patch 6	
	Before (3 mo)	After (5 mo)	Before (3 mo)	After (5 mo)	Before (3 mo)	After (5 mo)
39009	*	*	*	*	*	*
39010	3,528.78	3,764.13	6,786.02	6,656.41	3,214.69	3,018.96
39011	3,136.55	3,421.75	2,096.24	2,351.87	168.58	73.55
39012	5,757.43	5,882.81	993.26	447.23	2,603.89	2,902.37
39013	3,505.72	3,679.32	6,816.37	6,589.90	3,236.90	2,956.42
39014	5,032.33	5,011.94	*	*	*	*
39015	3,122.07	3,316.85	2,194.53	2,387.88	139.28	88.02
39016	3,346.43	3,370.58	2,127.83	2,253.45	156.54	103.17
39017	3,326.95	3,333.28	2,211.28	2,263.29	156.54	103.17
39018	5,188.49	5,259.35	218.26	97.34	2,812.21	2,987.75
39019	3,018.49	3,566.15	6,806.96	6,534.42	3,204.36	2,892.45
39020	4,883.40	4,809.07	170.47	61.42	2,745.96	3,041.12
39021	5,076.96	5,018.22	158.84	63.31	2,765.91	3,031.80
39022	5,203.21	5,162.76	*	*	*	*
39023	3,363.83	3,630.87	6,498.04	6,964.63	2,958.63	3,292.42
39024	3,380.17	3,449.01	2,023.24	2,174.42	192.27	111.16
39025	3,045.03	3,378.51	2,135.27	2,323.61	152.30	105.23
39026	3,205.09	3,478.70	2,066.20	2,279.39	189.67	84.12
39027	3,178.79	3,170.99	2,281.00	2,349.09	97.34	96.32
39028	*	*	*	*	*	*
39663	453.60	272.56	8,193.25	8,129.40	4,516.97	4,419.97
39664	923.58	749.00	6,971.53	7,332.36	3,281.21	3,622.06
39665	2,128.84	688.20	8,349.41	8,446.87	4,681.76	4,737.59
39666	453.60	287.70	6,314.81	5,926.82	2,762.97	2,292.99
39667	466.04	433.93	6,136.88	5,069.18	2,592.90	1,855.04
39668	483.05	556.80	6,096.35	5,597.02	2,513.72	2,173.70
39669	535.11	174.12	6,369.07	5,532.22	2,845.33	2,178.69
39670	*	*	*	*	*	*
39671	585.38	574.69	6,352.83	5,963.96	2,806.71	2,338.59
39672	1,042.18	655.07	6,967.05	7,084.41	3,269.16	3,367.74

Appendix Table B4. Individual cow's distance (m) from 2016 prescribed burn patches during prime grazing hours before and after treatment at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA. The * indicates a collar malfunction and variable could not be measured for that individual. Yellow highlighted distances are individuals who were within 1,000 m to a patch prior to treatment during prime grazing hours.

Cow	Winter 2016 Patch 9 & 10		Summer 2016 Patch 2		Summer 2016 Patch 6	
	Before (3 mo)	After (5 mo)	Before (3 mo)	After (5 mo)	Before (3 mo)	After (5 mo)
39009	*	*	*	*	*	*
39010	3467.12	3799.29	6677.21	6727.95	3130.65	3100.49
39011	3056.34	3439.36	2111.83	2365.68	142.718	69.312
39012	5813.01	5894.96	1041.88	500.637	2598.51	2870.66
39013	3618.59	3682.15	6695.69	6600.77	3118.08	2974.56
39014	4900.79	5037.53	*	*	*	*
39015	3136.7	3415.88	2185.14	2335.62	130.438	79.763
39016	3404.64	3459.47	2091.03	2241.28	146.853	89.452
39017	3344.09	3378.7	2149.19	2219.06	171.169	140.964
39018	5072.38	5207.77	248.17	71.127	2818.33	3011.12
39019	3005.87	3612.49	6701.58	6532.7	3120.34	2921.85
39020	5042.47	4834.87	182.78	44.492	2672.01	3190.12
39021	5135.81	4979.91	120.75	55.656	2807.36	3058.2
39022	5157.91	5130.45	*	*	*	*
39023	3430.97	3576.6	6326.83	7033.49	2772.41	3371.63
39024	3371.55	3540.62	2002.14	2186.81	186.136	99.832
39025	3075.23	3401.86	2146.56	2347.58	125.405	101.075
39026	3235.78	3525.44	2069.67	2277.22	173.977	78.284
39027	3242.38	3123.4	2270.1	2318.43	91.159	99.343
39028	*	*	*	*	*	*
39663	495.372	399.992	8316.2	8183.16	4653.44	4469.89
39664	831.39	566.52	7112.56	7348.92	3437.44	3650.53
39665	1868.29	696.84	8419.35	8462.28	4762.92	4779.36
39666	495.372	399.992	6352.71	5904.77	2808.8	2291.28
39667	487.094	350.612	6194.29	5059.27	2662	1852.06
39668	443.654	550.089	6210.47	5451.21	2650.61	2101.66
39669	541.687	124.202	6449.43	5506.54	2943.08	2210.53
39670	*	*	*	*	*	*
39671	623.102	531.024	6355.94	5963.87	2816.78	2359.89
39672	802.46	479.75	7153.93	7178.54	3454.88	3472.26

Appendix Table B5. Analysis of Variance table for proportion of cattle collar locations within treated patches at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA in 2016.

Source of Variation	*df*	*F*	*P*
Season	1, 1.807	6.07	0.1460
Time	1, 2.317	32.54	0.0208
Season*Time	1, 2.317	2.46	0.2401

Appendix Table B6. Analysis of Variance table for proportion of cattle collar locations within Treated Patches during prime grazing hours at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA in 2016.

Source of Variation	*df*	*F*	*P*
Season	1, 1.991	3.38	0.2081
Time	1, 1.665	38.85	0.0379
Season*Time	1, 1.665	5.36	0.1714

Appendix Table B7. Analysis of Variance table for cattle core area size at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA in 2016.

Source of Variation	*df*	*F*	*P*
Season	1, 16.3	8.27	0.0108
Time	7, 61.8	3.59	0.0026
Season*Time	7, 61.8	2.48	0.0260
Contrasts:			
Before vs After	1, 32.7	0.45	0.5067
Season x Before vs After	1, 32.7	2.72	0.1088

Appendix Table B8. Analysis of Variance table for collared cattle home range size at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA in 2016.

Source of Variation	*df*	*F*	*P*
Season	1, 16.0	11.18	0.0041
Time	7, 63.3	3.46	0.0033
Season*Time	7, 63.3	3.99	0.0011
Contrasts:			
Before vs After	1, 45.9	0.06	0.8021
Season x Before vs After	1, 45.9	1.89	0.1754

Appendix Table B9. Analysis of Variance table for collared cattle core area overlap of burn patches at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA in 2016.

Source of Variation	*df*	*F*	*P*
Season	1, 31.2	5.75	0.0227
Time	7, 29.4	22.72	<.0001
Season*Time	7, 29.4	0.69	0.676
Contrasts:			
Before vs After	1, 56.1	45.35	<.0001
Season x Before vs After	1, 56.1	0.18	0.6738

Appendix Table B10. Analysis of Variance table for collared cattle home range overlap to burn patches at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA in 2016.

Source of Variation	*df*	*F*	*P*
Season	1, 17.9	16.77	0.0007
Time	7, 17.6	26.36	<.0001
Season*Time	7, 17.6	1.67	0.1817
Contrasts:			
Before vs After	1, 30.3	51.35	<.0001
Season x Before vs After	1, 30.3	0.71	0.4056

Appendix Table B11. Analysis of Variance table for crude protein in gulf cordgrass forage at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA in 2016.

Source of Variation	*df*	*SS*	*MS*	*F*	*P*
date3	1	314.3973	314.3973	167.83	<.0001
x2	1	340.4122	340.4122	181.72	<.0001
season	1	4.92573	4.92573	2.63	0.1106
date3*season	1	36.33923	36.33923	19.4	<.0001
x2*season	1	30.40408	30.40408	16.23	0.0002
Error	55	103.0303	1.873278		
all season models equality test	3	149.447	49.81567	26.59	<.0001

Parameter	*Estimate*	*SE*	*t*	*P*
first slope	0.587138	0.045321	12.96	<.0001
second slope	-0.08037	0.008204	-9.8	<.0001
1st slope 1st model	0.786752	0.083048	9.47	<.0001
1st slope 2st model	0.387525	0.036319	10.67	<.0001
2nd slope 1st model	-0.08025	0.011913	-6.74	<.0001
2nd slope 2st model	-0.08049	0.011282	-7.13	<.0001
1st slope equality between models	0.399226	0.090643	4.4	<.0001
2nd slope equality between models	0.000247	0.016407	0.02	0.988
winter day 30	14.67256	0.326826	44.89	<.0001
summer day 30	13.01816	1.083492	12.02	<.0001

Appendix Table B12. Analysis of Variance table for neutral detergent fiber (NDF) at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA in 2016.

Source of Variation	*df*	*SS*	*MS*	*F*	*P*
date3	1	203.0374	203.0374	48.63	<.0001
x2	1	279.7921	279.7921	67.01	<.0001
x3	1	16.94615	16.94615	4.06	0.0486
season	1	6.097296	6.097296	1.46	0.2318
date3*season	1	0.175869	0.175869	0.04	0.8381
x2*season	1	0.096131	0.096131	0.02	0.8799
Error	58	242.1692	4.175331		
all season models equality test	3	98.57917	32.85972	7.87	0.0002

Parameter	*Estimate*	*SE*	*t*	*P*
first slope	-0.30176	0.043273	-6.97	<.0001
second slope	0.151517	0.018936	8	<.0001
1st slope 1st model	-0.31064	0.076622	-4.05	0.0002
1st slope 2st model	-0.29288	0.040243	-7.28	<.0001
2nd slope 1st model	0.134234	0.030633	4.38	<.0001
2nd slope 2st model	0.1688	0.02227	7.58	<.0001
1st slope equality between models	-0.01776	0.086547	-0.21	0.8381
2nd slope equality between models	-0.03457	0.037873	-0.91	0.3652

Appendix Table B13. Analysis of Variance table for acid detergent fiber (ADF) at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA in 2016.

Source of Variation	*df*	*SS*	*MS*	*F*	*P*
date3	1	56.96197	56.96197	24.2	<.0001
x2	1	59.78267	59.78267	25.4	<.0001
x3	1	2.90405	2.90405	1.23	0.2713
season	1	2.506109	2.506109	1.06	0.3065
date3*season	1	11.20527	11.20527	4.76	0.0333
x2*season	1	10.46495	10.46495	4.45	0.0394
Error	57	134.1546	2.35359		
all season models equality test	3	23.42118	7.807059	3.32	0.0261

Parameter	*Estimate*	*SE*	*t*	*P*
1st slope 1st model	-0.36237	0.066566	-5.44	<.0001
1st slope 2st model	-0.94	0.256226	-3.67	0.0005
2nd slope 1st model	0.034989	0.021516	1.63	0.1094
2nd slope 2st model	0.029043	0.010893	2.67	0.01
1st slope equality between models	0.577632	0.264731	2.18	0.0333
2nd slope equality between models	0.005946	0.024116	0.25	0.8061

Appendix Table B14. Analysis of Variance table for acid detergent lignin (ADL) at East Foundation's El Sauz ranch in Willacy and Kenedy Counties, Texas, USA in 2016.

Source of Variation	*df*	*SS*	*MS*	*F*	*P*
date3	1	18.11319	18.11319	15.75	0.0006
Date3*date3	1	7.53051	7.53051	6.55	0.0172
Error	24	27.60437			

Parameter	*Estimate*	*SE*	*t*	*P*
Intercept	8.09561	0.61410	13.18	<0.0001
Date3	-0.13524	0.03408	-3.97	0.0006
Date3*date3	0.00102	0.00040	2.56	0.0172