SEASON OF BURN EFFECTS ON MORTALITY, FORAGE PRODUCTION AND PLANT FUNCTIONAL GROUP COMPOSITION IN GULF CORDGRASS VEGETATION COMMUNITIES

A Thesis

by

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ABSTRACT

Season of Burn Effects on Mortality, Forage Production and Plant Functional Group Composition in Gulf Cordgrass Vegetation Communities.

(December 2019)

Jose Silverio Avila Sanchez, B.S., Texas A&M University-Kingsville

Gulf cordgrass (*Spartina spartinae* [Trin.] Merr. ex Hitchc.) is a productive, warm season, perennial bunchgrass. It can provide valuable forage for livestock when young, particularly when other forage may be scarce. However, a problem arises when Gulf cordgrass becomes mature: leaves and stems are very coarse and low in palatability and nutritive value for livestock and wildlife. Removing mature growth encourages production of tender, palatable shoots, and improves overall nutritive value. Fire is the most economical management tool to meet these objectives and is the natural process that kept these Gulf cordgrass communities in prime condition historically. In this study I applied prescribed burning at the pasture scale in grassland communities of coastal prairies and marshes dominated by either Gulf cordgrass or seacoast bluestem (*Schizachyrium scoparium* var. *littorale* [Nash] Bickn.). I burned two 200-ha pastures each winter and summer beginning in winter 2016 for a total of 8 burn and 2 control (no burn) pastures. My main objective was to determine the optimal season of burning by comparing winter and summer season burns in Gulf cordgrass communities of the Gulf Prairies and Marshes ecoregion of Texas. There was no difference in fire temperature between summer and winter burns. Gulf cordgrass plant mortality was higher in burn treatments compared to control treatments. However, there was no difference in Gulf cordgrass plant mortality between winter or summer burn treatments. There was a strong positive relationship between plant mortality and peak fire temperature, and between plant mortality and duration of heat over 65°C. Forage standing crop growth models were unique for each season; estimated regression coefficients were positive in each model in Gulf cordgrass vegetative groups, indicating that forage standing crop increased as days after burning progressed. Forage regrowth showed similar patterns following winter and summer burning for Gulf cordgrass, grasses other than Gulf cordgrass, or total forage standing crop. Forage production for approximately 90 days following burning did not differ between the four burns regardless of season, or between winter and summer burning. The removal of litter and excess growth of mature Gulf cordgrass by prescribed burning allowed native warm season forbs and native sub-shrubs to increase in their relative abundance of forage standing crop compared to control patches. A Non-metric multidimensional scaling ordination (NMDS) analyses showed there was more variation in functional group composition of burned Gulf cordgrass communities than non-burned communities when functional group composition was based on forage standing crop than when it was based on plant density. Burning Gulf cordgrass communities, regardless of season, enhanced production of palatable forage for livestock and created changes in functional group composition. This resulted in greater structural and species heterogeneity, additionally, creating more varied winter and summer habitat for a variety of wildlife species.

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INTRODUCTION AND LITERATURE REVIEW

Gulf cordgrass (*Spartina spartinae* [Trin.] Merr. ex Hitchc.) is a productive, warm season, perennial bunchgrass. It has potential to provide valuable forage for livestock and wildlife when young, particularly when other forage may be scarce (Garza 1980). However, when Gulf cordgrass becomes mature leaves and stems are very coarse and low in palatability and nutritive value for livestock and other wildlife (Hanselka 1981). Removing mature growth encourages production of tender, palatable shoots, and improves overall forage quality (Stubbendieck *et al.* 2007). Prescribed burning is a method to remove old growth and rejuvenate aged stands of Gulf cordgrass. Fire is the most economical management tool to obtain these objectives and is the natural process that kept these grass stands in prime condition historically. Effects of prescribed burning on a plant depend upon several variables, including the timing of the fire in the plant's seasonal life cycle, available soil moisture, and possibly the amount of heat the plant receives (Holechek *et al.* 2011). I conducted this study by applying prescribed burns in different seasons (Winter and Summer) to come up with information that will aid landowners and managers in decisions for meeting specific vegetation community objectives.

Gulf Cordgrass

The genus *Spartina* is represented in Texas by Gulf cordgrass [*Spartina spartinae* (Trin.) Merr. ex Hitchc,], smooth cordgrass (*S. alterniflora* Loisel), marshhay cordgrass [*S. patens* (Ait.) Muhl], big cordgrass [*S. cynosuroides* (L.) Roth.], and prairie cordgrass (*S. pectinata* Link) (Scifres *et al.* 1980). Gulf cordgrass is a highly productive warm-season (C4) bunchgrass that is able to tolerate a large range of climatic conditions in both hemispheres (McAtee *et al.* 1979; Ainouche *et al.* 2003), from high summer temperatures to cold snowfall conditions.

Gulf cordgrass, also known as “sacahuista” (from Nahuatl, an Uto-Aztecan language indigenous to Central Mexico: “zacahuitztli,” from “zacatl” grass or hay, and “huitztli” meaning thorn; (Academic 2017), grows 1 to 1.5 m tall, with short subrhizomes toward the outside, but true rhizomes are absent. Culms are numerous, 5-20 dm. long, and 2.4 mm. thick. Blades are 2-7 dm long, broad at the base, and closely involute essentially the entire length. Ten to 75 spikes per panicle, closely appressed and overlapping (Correll and Johnston 1979).

In Texas Gulf cordgrass can be found distributed along the Gulf of Mexico coast forming extensive meadows along the coastal salt flats, along waterways and other lowland areas (Scifres *et al.* 1980) (Figure 1). It grows in soils that are occasionally submerged, but which most of the time are above sea level (Gould 1975). Oefinger and Scifres (1977) reported that cordgrass occurs on soils relatively high in sodium in the coastal prairies from sandy loam to clay soils.

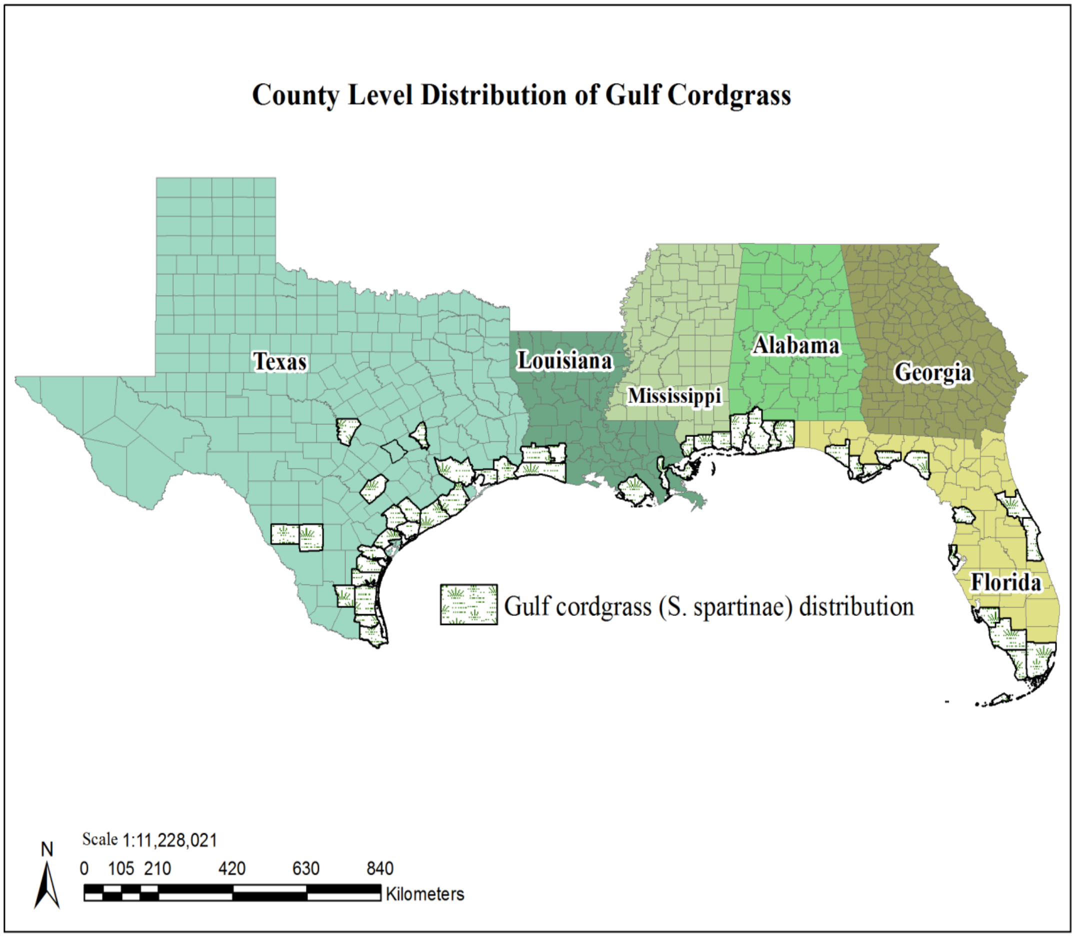

Figure 1. County-level distribution of Gulf cordgrass (*Spartina spartinae* [Trin.] Hitchc.) in the United States. Figure from Haynes *et al.* 2018. Based on NRCS (https://plants.usda.gov). Retrieved January 12, 2018.

Importance of Gulf Coast Prairies and Marshes Ecoregion

Gulf cordgrass is frequently considered an important habitat component for both wildlife and domesticated animals in the Gulf Coast Prairies and Marshes ecoregion. Garza (1980) indicated Gulf cordgrass has been an important range forage species in the region since the beginning of cattle raising in Texas. Aransas National Wildlife Refuge (ANWR), located in the Gulf coast of Texas, has one of the three self-sustaining known wintering wild populations of the endangered whooping crane (*Grus americana*). Managers of the ANWR conduct prescribed burns in three-year rotations to benefit whooping cranes, reducing height of grasses, top-killing brush, and modifying plant composition, making the refuge more attractive habitat for the endangered crane and other wildlife species as well (TPWD 2018).

Gulf cordgrass can be a good grazing resource for cattle. The problem occurs when it grows to a mature stage; its leaves and stems become coarse and low in palatability and nutritive value (low crude protein levels and high fiber content) making it less attractive to foraging animals (Hanselka 1981). This forces animals to spend more time and energy searching for quality forage, sometimes locally overgrazing on adjacent sites where Gulf cordgrass does not grow. It has been found that Gulf cordgrass is utilized by cattle following burning, a study done by Haynes (2018) in Willacy and Kenedy Counties, Texas, found that Gulf cordgrass utilization is around 69% (± 5.3%) in burned patches following both winter and summer burning, but only 10% (± 7.5%) on non-burned patches. A study done in San Patricio County, Texas, showed that after burning Gulf cordgrass-dominated stands the diet of steers consisted of 21-76% Gulf cordgrass, however, in the same study stands dominated by Texas wintergrass (*Nassella leucotricha* Trin. & Rupr. Pohl), steer diets consisted of only 13-36% Texas wintergrass (Angell *et al.* 1986).

Providing sufficient forage following burning is not the only benefit to Gulf cordgrass; several studies have evaluated nutritive content of Gulf cordgrass. A study by Garza *et al.* (1994) in San Patricio County, Texas, found that crude protein levels varied from 8 to 10% throughout the year following clipping Gulf cordgrass plants at 10 and 20 cm. Additionally, a 2018 (Haynes) study from Willacy and Kenedy Counties, Texas, found that CP levels of Gulf cordgrass plants met the nutritive requirements to maintain lactating cows (9-12 % crude protein, Holechek *et al.* 2011) for at least 90 days following burning. In a study of Gulf cordgrass top removal McAtee *et al.* (1979) concluded that burning or shredding resulted in higher nutritional values where digestible energy and crude protein were significantly increased for 30 to 90 days after burning.

Management Issues

Gulf cordgrass tends to be a dominant bunchgrass occurring in almost pure stands. It is categorized as a halophyte, because of its high tolerance to saline soils and resistance to inundation. This bunchgrass is an excellent competitor against other plant species to the extent of exclusion in some cases. If cattle are allowed to graze pastures dominated by Gulf cordgrass localized overgrazing can occur on adjacent sites when more palatable species are found nearby (Oefinger and Scifres 1977).

Fire as a management tool

Bond and Keeley (2005) portrayed fire as an "herbivore." They described fire as a top-down driver that converts organic materials into inorganic products, alters the community structure, and acts as an evolutionary agent. Unlike herbivores that consume tender and palatable stands of forage, fire's "combustive consumption" depends on available fuels and proper weather conditions (Spasojevic *et al.* 2010). Historically burning was used as a common land management tool by Native Americans. Various tribes used fire for making travel easier by turning brushy or woody areas into more visible plains with short vegetation, to corner animals or drive them off cliffs for hunting, to make unwanted guests flee or to burn enemy villages during warfare, to prepare lands for agriculture, or to simply avoid catastrophic wildfires that would occur after drought years (Nyman and Chabreck 1995).

In grasslands, prescribed burning can improve nutritional content, palatability, forage availability, and yield (Stubbendieck *et al.* 2007). According to White and Hanselka (1994), different fire and weather conditions lead to different plant responses. Plant response (including mortality and recruitment) after fire is influenced by the intensity of the fire, condition of the plants, growing stage and weather conditions.

The amount of forage produced depends mainly on the ability of the plant to photosynthesize (Sosebee *et al.* 2003). Factors and conditions that either positively or negatively affect a plant's photosynthetic processes are water supply, the amount of carbon dioxide in the air, intensity and quality of sun light, leaf surface area, soil nutrients, temperature, season of the burn, and physiological efficiency of the plant (Scifres and Drawe 1980, Hulbert 1984, Holechek *et al.* 2011). After burning, plants are left without leaf surface area for photosynthesis. Therefore carbohydrate reserves, or total nonstructural carbohydrates (TNC), are used as an energy source to initiate new growth until there is leaf surface area sufficient for photosynthesis to sustain plant respiration, normally staying low for 2 to 7 days after herbage removal (Butler and Bailey 1973; White 1973; Garza 1980). Once plants have completed the reproductive stage, energy produced by leaves is directed toward storage, followed by a period of dormancy (Sosebee *et al.* 2003).

Carbohydrate reserves are the readily metabolizable source of energy needed for growth, respiration, reproduction and survival of plants. They are stored in roots, rhizomes, stolons, stem bases, and haplocorms of grasses. The major constituents in TNC reserves are glucose, fructose, sucrose, fructosans and starches. Predominant reserves stored by temperate-origin or cool season grasses (C3 plants) are sucrose and fructosans; those from subtropical-tropical or warm season grasses (C4 plants) are sucrose and starches (White 1973). The degree or intensity of water stress and nutrient availability will variably affect the seasonal variation in carbohydrate reserves (White 1973).

Fire-adapted species like Gulf cordgrass are rarely negatively affected in forage production potential by burning. Several studies have indicated that removal of the insulating layer of standing dead vegetation, by either burning or clipping, results in more rapid growth or greater production of leaves in warm-season grasses than those in areas without management treatment (Ehrenreich and Aikman 1963, Hanselka 1981, Garza *et al.* 1994). Tender shoots that emerge after mature leaves have been burned, shredded, or otherwise removed are relished by livestock (Scifres *et al.* 1980). Traditionally, cordgrass has been burned at the convenience of the land manager for use as a reserve forage during cool months, dry summers, or any time forage is limited (McAtee *et al.* 1979). Stubbendieck *et al.* (2007) concluded that when burning is performed at the right time and soil moisture is adequate, grass production yield will increase due to ashes darkening the soil surface, additionally, sunlight is allowed to make contact with the soil, causing it to warm up quickly stimulating earlier growth of grasses suppressing competition from forbs (Halloran 1943).

Season of burn effects

If fire is present year after year in a vegetation type that does not support constant foliage removal, the metabolic reserves of the plants will be depleted, shrinking their root systems and causing them to die (Holechek *et al.* 2011). To have sustained growth, grasses must have a rest period at the appropriate physiological stage to restore their energy resources for growth during the subsequent growing season (Sosebee *et al.* 2003). Therefore, it is important to consider the time of year or growth stage before burning. During floral initiation through seed development, carbohydrate reserves are utilized for reproduction purposes; this is the most critical period for foliage removal. The least critical period is when plants are in their dormant phase, because plants are photosynthetically inactive (Holechek *et al.* 2011). Fire can also damage plants during extreme drought or before flooding (Nyman and Chabreck 1995).

McAtee *et al.* (1979) concluded that season of burning would not be critical as long as moisture content is adequate for maximized regrowth. A study by Hanselka (1981) indicated prescribed burning should be conducted during fall in order to provide palatable, nutritious winter forage for livestock grazing.

Patch-burn Grazing

Previous studies suggest that entire marshes or properties should not be burned simultaneously. Instead, they recommended using a systematic burning plan on a deferred rotation grazing system and burning various pastures each year separated by time such that different units would be in various stages of regrowth, providing quality forage on an annual basis (Hanselka 1981, Nyman and Chabreck 1995). With this in mind, patch-burn grazing (PBG) is a method that applies fire to portions of a pasture at different intervals and times of year, allowing the pasture to have different seral stages making herbivores move spatially from patch to patch as they are continuously burned throughout time (Scasta *et al.* 2015, Weir *et al.* 2013, Fuhlendorf *et al.* 2008, Vermeire *et al.* 2004). This method provides a greater heterogeneity in vegetation stature, plant composition, plant density and forage standing crop (Fuhlendorf and Engle 2001), which are some of the results we are looking for to improve Gulf cordgrass communities.

Main Objective

The objective in this study was to determine the optimal season of burning by comparing winter and summer burns in Gulf cordgrass communities of the Gulf Coast Prairies and Marshes ecoregion along the southern Texas coast. Results from each burning season will aid land managers and owners in season of burning decisions to meet specific objectives.

Specific Objectives

My specific research objectives were to compare effects of winter and summer prescribed burns on the following variables:

1) Fire intensity: Prescribed fire temperatures, fuel moisture, and peak temperature.
2) Gulf cordgrass density, mortality and recruitment.
3) Forage production: Above-ground forage standing crop by species.
4) Functional group composition: Species richness, density and forage standing crop.

Hypotheses

1) Fire intensity: Summer burn treatments will produce higher fire intensities than winter burn treatments. Higher intensity will result in greater percent mortality regardless of season.
2) Gulf cordgrass mortality: Burn treatments will produce higher cordgrass mortality than control treatments. However, summer burning will result in higher cordgrass mortality than winter burning.
3) Forage standing crop and production: Burn treatments will produce greater forage standing crop and production than control treatments. Summer burns will produce greater forage standing crop and production than winter treatments. Winter burning will result in greater perennial grass production than summer burning.
4) Functional group composition: Burn treatments will result in a change in relative abundance of plant functional group than control treatments regardless of season.

However, functional group diversity will be higher in summer burn patches than winter burn patches.

MATERIALS AND METHODS

Study Area

The East Foundation is an Agricultural Research Organization (ARO) whose mission is to promote the advancement of land stewardship through ranching, science and education. East Foundation's lands are in six separate ranches across 4 ecoregions in South Texas (East Foundation 2007). My research took place on the East Foundation's El Sauz Ranch (26.5577° N / 97.4263° W) with its 11,082 hectares (27,385 acres). It is part of the Gulf Coast Prairies and Marshes Texas Ecoregion (Figure 2) (East Foundation 2007).

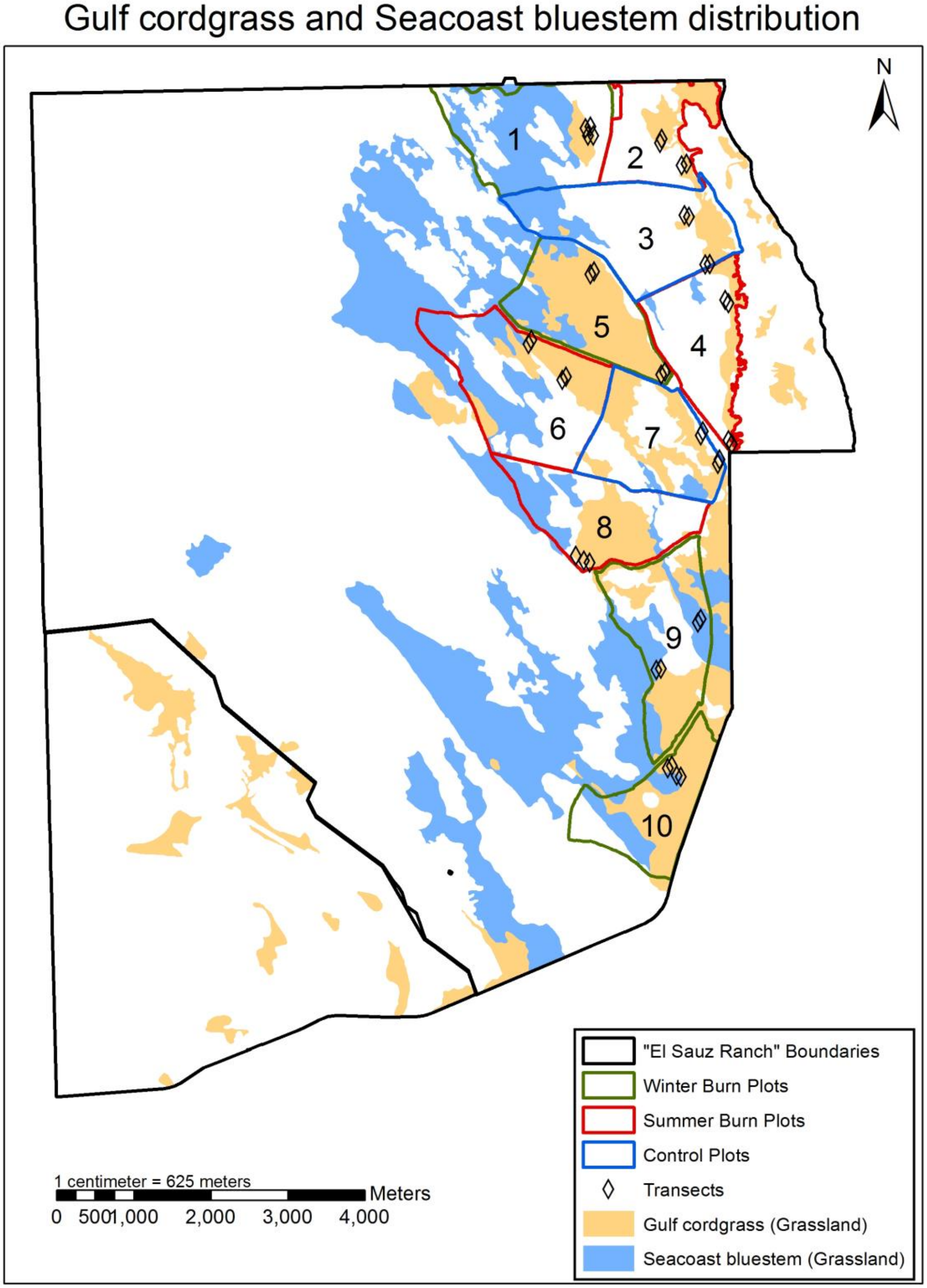

Figure 2. East Foundation's El Sauz Ranch in Willacy and Kenedy Counties, Texas, showing distribution of Gulf cordgrass on the ranch as well as numbered treatment patches (Adapted from *Spartina* spp. map created by KS2 Ecological Field Services).

Area Description

Ecological Site

There are several different ecological sites within the perimeters of the property. Those most dominant are Low Coastal Sand with ~53%; Sandy Loam and Sandy Hill with ~18.6%; Sandy Flat with ~7.7%; Wind Tidal Flat at 3.2%; and Salt Flat at 2.6% (Figure 3 and Table 1) (SSS 2017).

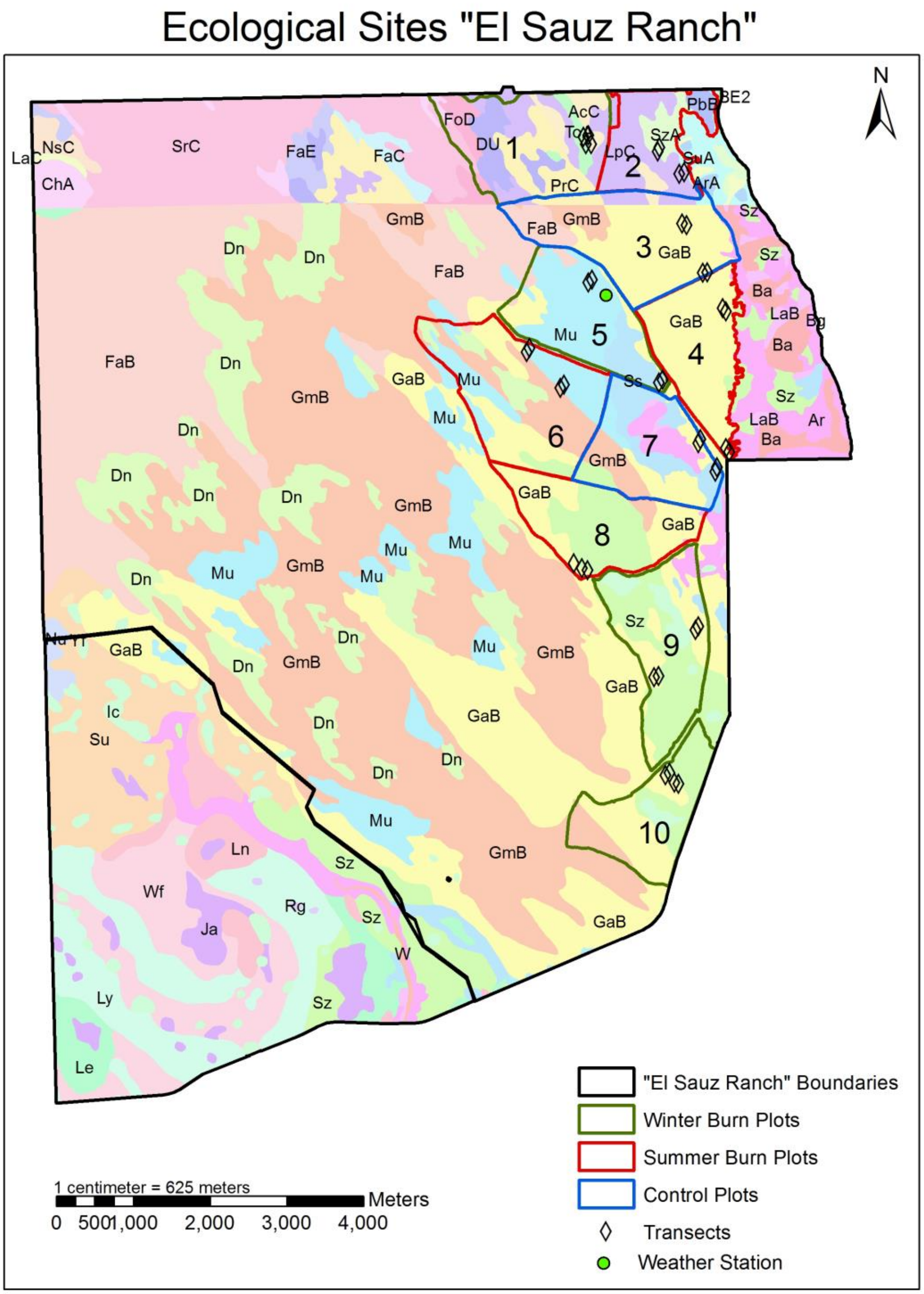

Figure 3. Delineated soil types and vegetation communities of East Foundation’s El Sauz Ranch in Willacy and Kenedy Counties, TX (Soil Survey Staff 2017), Background colors correspond to ecological site (FaB).

Table 1. Legend of soil types from Figure 3 (Soil Survey Staff 2017).

Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent (%) in AOI**
GmB	Galveston- Mustang complex, gently undulating	5720.5	21.095
GaB	Galveston fine sand, gently undulating	4390.1	16.189
FaB	Falfurrias fine sand, 0 to 5% slopes	2881.4	10.626
Dn	Dune land, 5 to 15% slopes, occasionally flooded	1666.8	6.147
Mu	Mustang fine sand, 0 to 1% slopes, occasionally flooded, frequently ponded	1487.8	5.487
SrC	Sarita-Cayo complex, 0 to 5% slopes	1243.4	4.585
SzA	Sauz loamy fine sand	1184.8	4.369
Ly	Lyford sandy clay loam	1062	3.916
Su	Sauz fine sand, 0 to 1% slopes, rarely flooded	924.6	3.410
Wf	Willamar fine sandy loam, 0 to 1% slopes	899.6	3.317
Ar	Arrada sandy clay loam, 0 to 1% slopes, very frequently flooded, frequently ponded	881.2	3.250
LpC	Lopeno-Potrero-Arenisco complex, 0 to 5% slopes, very rarely flooded	490.7	1.810
Ss	Saucel sandy loam	424.6	1.566
Sz	Sauz loamy fine sand	405	1.494
lc	Incell clay	394	1.453
Ln	Lozano fine sandy loam	368.6	1.359
PrC	Potrero-Lopeno-Noria complex, 0 to 5% slopes, very rarely flooded, frequently ponded	341	1.258
Le	Latina sandy clay loam, 0 to 1% slopes, ocasionally ponded	337.7	1.245
Ja	Jarron sandy clay loam	324.6	1.197

Ba	Barrada clay, 0 to 1% slopes, very frequently flooded, occasionally ponded	249.6	0.920
DU	Dune land, 5 to 15% slopes, occasionally flooded	163.4	0.603
ChA	Cayo fine sandy loam, 0 to 1 % slopes	162.2	0.598
SuA	Saucel fine sandy loam, 0 to 1% slope, rarely flooded, occasionally ponded	125.6	0.463
FaE	Falfurrias fine sand, 5 to 15 percent slopes	108.3	0.399
SzA	Sauz-Saucel complex, 0 to 1% slopes, occasionally flooded, occasionally ponded	103.1	0.380
FoD	Falfurrias-Cayo complex, 0 to 8% slopes	102.1	0.377
AcC	Arenisco fine sand, 1 to 5% slopes, very rarely flooded	99	0.365
LaB	Lalinda sandy clay loam, 1 to 5% slopes	94.1	0.347
SuA	Sauz fine sand, 0 to 1% slopes, rarely flooded	81.1	0.299
FaC	Falfurrias fine sand, 0 to 5 percent slopes	73.9	0.273
NsC	Nueces-Sarita association, 0 to 3% slopes	67.8	0.250
Nu	Nueces fine sand, 0 to 3% slopes	63	0.232
ToA	Topo fine sandy loam, 0 to 1% slopes, rarely flooded, frequently ponded	46.8	0.173
LaC	Lalinda fine sandy loam, 1 to 5% slopes, very rarely flooded	38	0.140
PbB	Palobia loamy fine sand, 1 to 3% slopes	32.1	0.118
W	Water	28.3	0.104
AsA	Arrada sandy clay loam, 0 to 1 % slopes	19.4	0.072
Yf	Yturria fine sandy loam	11.5	0.042
BE2	Beaches, gravelly, very frequently flooded	9.4	0.035

Rg	Rio sandy clay loam	8.2	0.030
Bg	Beaches, gravelly, very frequently flooded	1.3	0.005
YtC	Yturria fine sandy loam, 1 to 5% slopes	0.6	0.002
	Total acres AOI	**27117.2**	**100%**

Vegetation

This section will discuss the ecological sites and vegetation communities inside my area of interest (AOI) of East Foundation's El Sauz Ranch. The Gulf cordgrass vegetation community was the main focus of my research study. Where it is found in almost pure stands, the Soil Survey Staff describes this ecological site as Sandy Flat Cordgrass Prairie community. Its most representative graminoid species are: Gulf cordgrass, purple dropseed (*Sporobolus purpurascens* (Sw.) Ham.), brownseed paspalum (*Paspalum plicatum* Michx.), Hartweg's paspalum (*P. hartwegianum* Fourn.), fringed signalgrass (*Urochloa ciliatissima* (Buckley) R. Webster) and red lovegrass (*Eragostris secundiflora* J. Presl) (SSS 2017).

The predominant vegetation community in low coastal sands is the midgrass prairie community. The grasses and grasslike plants in this community include gulfdune paspalum (*P. monostachyum* Vasey), marshhay cordgrass (*Spartina patens* (Aiton) Muhl.), bushy bluestem (*Andropogon glomeratus* (Walter) Britton, Sterns & Poggenb. var. *hirsutior* (Hack.) C. Mohr), slimleaf panicgrass (*Dichanthelium linearifolium* (Scribn. ex Nash) Gould), seacoast bluestem or coastal little bluestem (*Andropogon scoparius* var. *littorale* (Nash) Gould), common threesquare (*Schoenoplectus pungens* (Vahl) Palla), saltgrass (*Distichlis spicata* (L.) Green) and seashore dropseed (*Sporobolus virginicus* (L.) Kunth). Forbs include lanceleaf frogfruit (*Phyla lanceolate* (Michx.) Greene), blue mistflower (*Conoclinium coelestinum* (L.) DC.), Carolina sea-lavender (*Limonium carolinianum* (Walter) Britton), American snoutbean (*Rhynchosia americana* (Houst.

ex. Mill.) M.C. Metz), Texas baccharis (*Baccharis texana* (Torr. & A. Gray) A. Gray), sea oxalis (*Borrichia frutescens* (L.) DC.), Corpus Christi fleabane (*Erigeron procumbens* Kunth), cardinal feather (*Acalypha radians* Torr.), false ragweed (*Ambrosia psilostachya* DC.) and toothed croton (*Croton glandulosus* L.). Woody and shrub species include honey mesquite (*Prosopis glandulosa* Torr.), live oak (*Quercus virginiana* Mill.) and huisache (*Acacia farnesiana* (L.) Wight & Arn.) (Figure 3) (SSS 2017).

Soils

Common soils within the study area include: Galveston-mustang complex (GmB), Mustang fine sand (Mu), Lopeno-Potrero-Arenisco complex (LpC), Potrero-Lopeno-Noria complex (PrC), Sarita-Cayo complex (SrC), Arrada sandy clay loam (Ar), Dune land (Dn), Galveston fine sand (GaB), Falfurrias fine sand (FaB), Saucel sandy loam (Ss), Sauz loamy fine sand (Sz), Jarron sandy clay (Ja), Lyford sandy clay loam (Ly), Sauz fine sand (Su) and Willamar fine sand (Wf) (Figure 3) (SSS 2017).

Climate and Precipitation

My study site represents a semi-arid climate; it receives an annual mean rainfall of 629 mm (24.7 in), and average temperature during the year fluctuates between 18.5° C (65.3° F) and 27.2° C (80.96° F) (PRISM 2018).

East Foundation's El Sauz cattle operation

It is important to mention that East Foundation's El Sauz Ranch carries a continuous grazing system during the length of the study. The main pasture which for this study I will refer to as the 10 patches, was not divided into sub-pastures, and cattle were free to access all patches equally. In table 2 and 3, are the number of cows and bulls present by the end of the fiscal years

2015, 2016 and 2017, and Head count of wildlife species found by the end of the fiscal years of 2016 and 2017.

Table 2. Number of cows and bulls counted by the end of the fiscal years of 2015, 2016 and 2017 at East Foundation's El Sauz Ranch.

Fiscal Year	Cows	Bulls	Total
2015	655	20	675
2016	727	32	759
2017	663	31	694

Table 3. Head count of wildlife species through helicopter surveys found by the end of the fiscal years of 2016 and 2017 at East Foundation's El Sauz Ranch.

Fiscal Year	Deer	Nilgai	Feral pig/ Collared peccary	Total
2016	893	1278	678	2849
2017	770	1410	407	2587

Experimental Design and Treatments

A map created from a previous survey conducted by KS2 Ecological Field Services LLC consulting was used to locate potential Gulf cordgrass patches on El Sauz Ranch. My study design is a completely randomized design with repeated measures. I used 10 patches (experimental units) of at least 150 hectares each with true replication of treatments, ensuring that each patch contained a significant amount of Gulf cordgrass. Treatments of winter and summer burning and controls were randomly assigned to patches. Treatments were: 1) Winter 2016 burn; 2) Summer 2016 burn; 3) Winter 2017 burn; 4) Summer 2017 burn; and 5) Control (no burn); W16, S16, W17, S17, and C, respectively. Assigned treatments and patch sizes in table 4, and distribution of patches and treatments on figure 4. Patches were laid out using existing roads as firelines whenever possible to reduce unnecessary disturbance to the soil. In areas where no roads were present, heavy machinery was used to create mineral lines between treatment patches. Two permanent transects were placed within each patch for repeated vegetation sampling at permanent locations. Each transect was marked with two t-posts placed 60 m apart. One t-post was located within the Gulf cordgrass community, and the other was in the neighboring community which was commonly dominated by seacoast bluestem and gulfdune paspalum patches. The center of each transect was at the approximate boundary between the two communities, thus approximately 30 m of the transect is within each community. The vegetation at the two ends of the transects are referred to as the "Gulf cordgrass" community and the "other" community.

Table 4. Assigned treatments to patches and area in hectares of study area at East Foundation's El Sauz Ranch.

Patch	Treatment	Year burned	Abbreviation	Area (hectares)
9	Winter	2016	W16	234.3
10	Winter	2016	W16	182.6
2	Summer	2016	S16	150.2
6	Summer	2016	S16	304.6
1	Winter	2017	W17	258.39
5	Winter	2017	W17	212.6
4	Summer	2017	S17	191.7
8	Summer	2017	S17	219.8
3	Control		C	279.1
7	Control		C	208.2

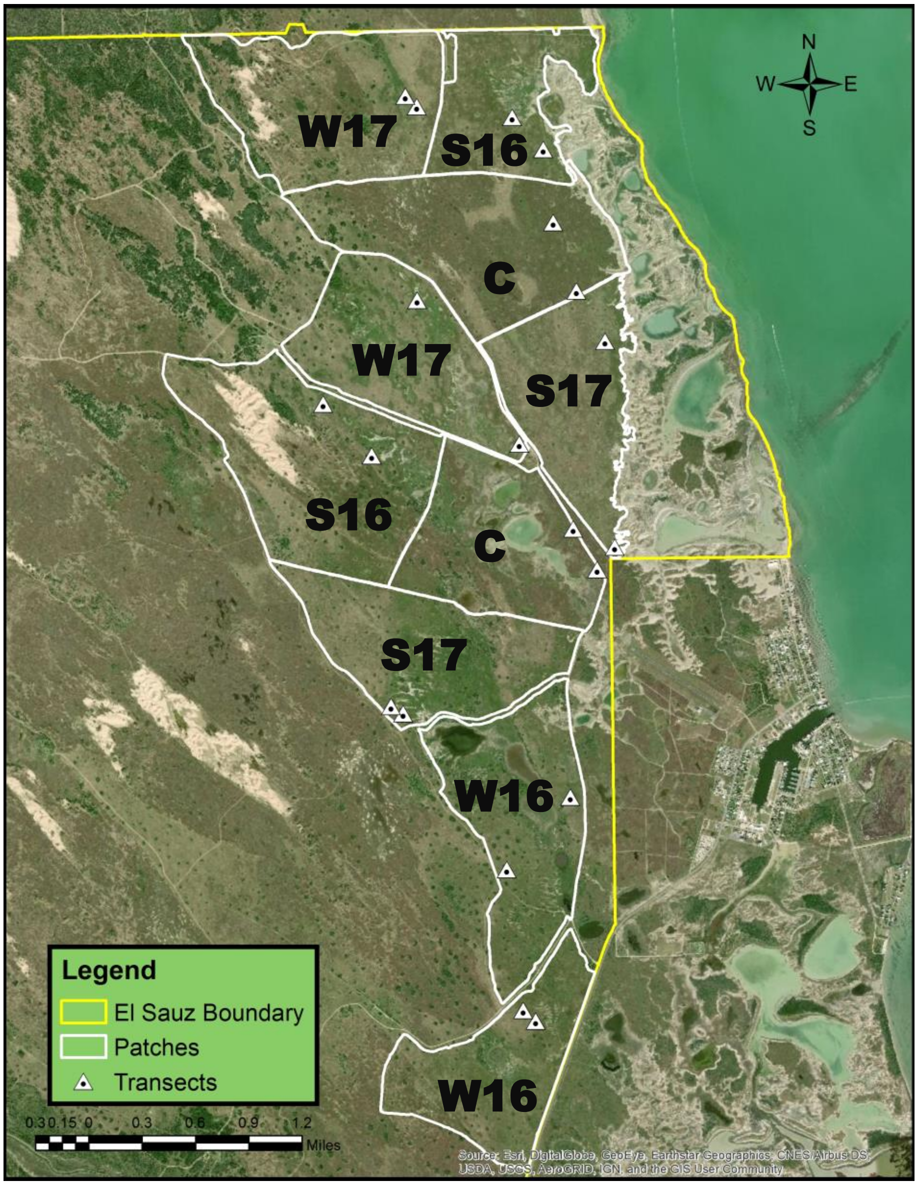

Figure 4. Distribution map of treatment patches and transects on East Foundation's El Sauz Ranch in Willacy and Kenedy Counties, Texas, USA.

Data Collection

Burning and weather conditions

A weather station, HOBO U30/RX3000 (Onset® Computer Corporation, Bourne, MA), was installed in a control patch El Sauz Ranch. The weather station was placed near the center of my study area. This weather station recorded weather conditions each minute (temperature, wind speed and direction and relative humidity) of the general area for the duration of the study.

Burning weather conditions (air temperature, wind speed and direction, and relative humidity) were recorded roughly every 30 minutes before and during burning using a Kestrel® 4500 weather meter. Fire temperatures were recorded with HOBO® U12 J, K, S, T Data Loggers (Onset Computer Corporation, Bourne, Massachusetts, USA). A 3.05 m (10') High Temperature Ceramic Insulation with Inconel Over braid thermocouple (Omega™ Engineering, Inc., Norwalk, CT, USA) was attached to each data logger. Loggers were set to record temperatures every second during the prescribed burn. They were placed inside small sections of 15.24 cm (6") PVC pipe with caps on both ends with the thermocouple protruding through a slit in the PVC. The PVC with data logger was buried in the soil before each burn with the thermocouple left lying on the ground near vegetation. Four data loggers were positioned within each patch adjacent to vegetation sampling transects (two near each transect). Locations of individual data loggers were recorded, to allow me to correlate fire temperatures with plant effects. I ran a paired t-test to find a difference or correlation between fuel loads and temperature during burns, with an alpha level of 0.05.

Soil moisture

Soil moisture was not recorded for burn treatments of 2016, it was later added for the winter and summer 2017 burn treatments. Beginning one week after each W17 and S17 burning treatments, soil moisture samples were collected every 14 days for a period of 90 days after each burn. Using a bucket auger, I collected 8 samples per burned patch, 2 from each vegetative community (Gulf cordgrass and other) near each transect. After collection, samples were placed immediately into Ziploc® bags or sealed aluminum containers to prevent evaporation of moisture. Samples were transported to the lab, placed in crucibles and weighed before being stored inside a drying oven at 105° C (221° F). After 48-72 hours, or when no further weight loss occurred, samples were weighed again. Percent soil moisture was determined using the following formula:

$$\%\ Soil\ Moisture = \left(\frac{Wet\ Weight\ - Dry\ Weight}{Dry\ Weight}\right) \times 100$$

A t-test was used to compare soil water content between W17 and S17.

Fuel loads

For fuel load and moisture calculations, I clipped and collected two 0.25 m^2 forage standing crop samples from each vegetative community (Gulf cordgrass and other) near each sampling transect prior to a burning treatment. Plants were clipped to ~2.5 cm height. Samples were separated into Gulf cordgrass, other grasses, and standing dead herbaceous material. They were placed into paper bags and weighed in the field, then transported and kept inside a drying oven at ~45° C, until no more weight loss occurred. Wet and dry weights were recorded.
Fuel loads were obtained by converting dry weights from gr 0.25 m^{-2} to kg ha^{-1} as follows:

$$gr/0.25m^2 \times \left(\frac{4 \times 10{,}000m^2}{1{,}000m^2}\right) = Kg/ha$$

Or:

$$gr/0.25m^2 \times 40 = Kg/ha$$

Fuel moisture was calculated using Texas Department of Agriculture (TDA) (2002) formula:

$$\%\ \text{Fuel Moisture} = \left(\frac{Wet\ Weight - Dry\ Weight}{Dry\ Weight}\right) \times 100$$

I used correlation analysis to look for a linear relationship between fuel load and fire temperature, this analysis relied on Microsoft Excel.

Forage standing crop

Throughout this thesis, the term forage standing crop will be referred as the herbage or browse that was accessible as food for grazing and browsing animals at a given time. Forage standing crop should not be confused with forage production which was the accumulation of forage standing crop over a period of time. Forage standing crop growth curve models are statistical tools for estimating growth rates, and allow one to estimate growth that could be expected after similar treatments in similar environments. Forage standing crop samples were collected by species every 7^{th} day for 90 days after burning beginning one week after each burn treatment. Each sampling time is called a "period." In addition to the weekly period sampling in the most recently burned patches, at 45 and 90 days after burning those patches I also collected forage standing crop samples from the control patches and patches that had been burned during previous treatments.

During each sampling period, eight 1 m^2 quadrats were randomly located adjacent to each transect, alternating between the two sides of the line each period to evenly represent the transect. Four of these quadrats were located in the Gulf cordgrass community and four in the other community. Aboveground vegetation within the 1 m^2 quadrat was clipped at the height of the plant crowns and collected by species; samples were placed in individual species-specific paper bags with identifying information (date, patch, transect, quadrant, and species). After collection, bagged samples were placed inside a drying oven at ~45° C, and dried until a constant dry weight occurred. Dry samples were weighed without the bag with an error range of 0.01 g. Forage standing crop data were grouped into three categories of interest. The first category was

Gulf cordgrass, second was all other grasses, forbs, vines and shrubs, and third was total forage standing crop. I conducted a regression analysis to predict the forage regrowth of each of the three categories of Gulf cordgrass, other grasses, forbs, vines and shrubs and total forage standing crop after burning.

I developed polynomial models (up to the 5^{th} degree) using data on the observed scales and on natural log-transformed scales. Model selection was based on the coefficient of determination. When candidate models had similar predictive or explanatory power, I chose the simplest model to be the best fit, choosing linear over quadratic, quadratic over cubic, natural data over natural logarithm, *etc*. Each best fit model was tested for heteroskedasticity HCCMETHOD, HC_3 (White 1980). Models of burn treatments that were similar in order/degree and/or had log transformation in each variable or no variables, were compared within each other to see which burn produced more forage standing crop.

Forage standing crop (kg/ha) was also analyzed for composition. Individual species were placed into functional groups to compare with the density functional group composition data. Species were grouped into their native status (native to Texas or introduced species), growth form (grass like form, forb, vines, shrubs and subshrubs) and growth and seeding season (warm season or cool season) according (Clendenin 2016, Hatch and Pluhar 1992, Richardson and King 2011 and Shaw 2012). The total of each functional group was divided by the sum total of all functional groups to determine relative abundance (%) of each functional group on each sampling date.

Forage production

Forage production is the result of calculating the actual accumulation of forage standing crop for a certain period of time. It is an important parameters for ranch managers. Data collected for forage standing crop were used to estimate forage production and, likewise, correct stocking rate for the available forage in the burn units. Forage production was calculated only for Gulf cordgrass in the Gulf cordgrass community by summing the positive differences of forage standing crop available at every sampling date from the first date after burning until the last day of sampling. I also paired and compared W16, S16 and control patches with the longest data set of an average of 15.5 months following burn to compare their forage production. The two transects were averaged for every patch, and forage production was estimated as such:

$$(Forage\ Production = Forage\ standing\ crop\ date\ 1\ + (FSC\ date\ 2 - FSC\ date1) + (FSC\ date\ 3 - FSC\ date\ 2) + (FSC\ date4 - FSC\ date3) + \cdots).$$

To estimate forage dissapearance by grazing I utilized results from Haynes (2018) from a joint experiment in the same burns as in this experiment. In this project, dry weights of Gulf cordgrass (kg/ha) were obtained from paired samples inside and outside exclosures. Forage disapearance was estimated as such:

$$\%\ Forage\ Disapearance = \left(\frac{Outside\ Exclosure - Inside\ Exclosure}{Inside\ Exclosure}\right) \times 100$$

The average utilization percentage used for this analysis for burned patches in winter and summer was 69% (± 5.30%), where the average utilization of control patches was 10% (± 7.5%). It is important to mention that in the absence of exclosures and presence of foraging cattle and wildlife it is generally considered incorrect to calculate forage production to later estimate a correct stocking rate, as these calculations do not take into account forage disappearance from livestock and wildlife grazers during the sampling period. However, it allows for an estimate of forage production after disappearance to estimate growth rate of forage standing crop under these conditions.

Correct stocking rate (CSR) was estimated for each specific burn treatment. Considering 1 animal unit consumes 12 kilograms a day, forage intake was then multiplied by the number of days each burn treatment was sampled, *e.g.* patch 9 for 89 days, patch 10 for 92 days, patch 4 for 79 days, *etc*. Forage intake kg/ha/days was then divided by the amount of utilizable forage (69%) in each specific burn treatment, *e.g.*:

$$CSR\ (ha\ \cdot AU) = \frac{Forage\ Intake\ (kg \cdot ha \cdot\ days)}{Forage\ Production\ (kg \cdot ha) \times utilizable\ forage\ (69\%)}$$

Data management and statistical analysis were conducted in program R (2013) (R Core Team, Vienna, Austria) or Statistical Analysis Software (SAS) (SAS® Institute Inc., Cary, North Carolina).

Gulf cordgrass density mortality and recruitment

Approximately two to three weeks before a scheduled burn treatment I recorded pre-burn plant species density and Gulf cordgrass mortality and recruitment. I recorded the same post-burn data at roughly 45 and 90 days after each burning treatment using the same procedure and collected data at the same time within the control patches and all patches burned in prior treatments.

Using a random number generator, I selected eight permanent sampling locations for 1 m^2 quadrats along the 60 m transect in each patch When an odd number was generated the quadrat was placed on the left side of the transect looking toward the 60 m end from the 0 end. Quadrats were placed on the right of the transect when an even number was generated. Four 2 m^2 quadrats were placed in the cordgrass community and four in the other community.

There were two levels of sampling with one nested inside the other. An area of 1 x 2 m^2 was surveyed by placing a 1 x 1 m^2 PVC frame in the chosen point on the transect for sampling, and then flipping it along the transect for the second 1 m^2. Variables recorded in the 1 x 2 m^2 quadrats were: number of mature living Gulf cordgrass and seacoast bluestem plants to determine density, and number of dead Gulf cordgrass and seacoast bluestem crowns to determine density of dead plants.

Plants were considered mature when there was ample evidence of prior year growth, such as dry or dead leaves, or signs of previous inflorescence. Crowns were considered deceased if no green tillering or sign of green plant parts was visible 45 days and 90 days after a burning treatment. The process to count individual plants for Gulf cordgrass and seacoast bluestem was different. For a mature Gulf cordgrass plant, I would visualize the plant in a “donut” shape because Gulf cordgrass grows outwards from its original growing point as it matures, leaving behind dead space with old stems and leaves in the center. If any part of the plant was inside a sampling quadrat, I counted it as one plant. However, seacoast bluestem is a rhizomatous grass. To determine individual plants, I would manually search for rhizomes underneath the soil surface around plants. I counted a plant as an individual if I found no connection in rhizomatous tissue between it and other aboveground growth sections.

A 0.5 m^2 area was surveyed for total grasses and forbs. A 0.25 m^2 PVC frame was placed inside the 1 m^2 quadrat at the corner nearest the transect and on the side the quadrat would be flipped. This smaller quadrat was flipped at the corner along with the larger quadrat to create the 0.5 m^2 area. Variables recorded in the 0.5 m^2 quadrats were: 1) number of individual plants by species (with the exceptions of Gulf cordgrass and seacoast bluestem because those plants were recorded in the 1 x 2 m^2 quadrats); and 2) recruitment of Gulf cordgrass and seacoast bluestem plants. To be counted as a recruit, plants had to show no signs of regrowth from an existing crown, neighboring crown, or below-ground bud banks or rhizomes. If a plant was too young to identify to species, it was recorded by genus or family. I also created a quadrat map with the locations of recruits and dead crowns for assistance in locating and evaluating them in future sampling periods.

I used analysis of variance (ANOVA) to compare differences of Gulf cordgrass percent mortality between seasons, treatments and years. Subsequently, a logistic regression was used to test for a linear relationship between plant mortality and peak fire temperature, and plant mortality and duration of heat over 65°C (149° F). Odds ratio was calculated using the slope of the logistic regression outcome [exp(c*β̂-1]*100, where c = coefficient (units that represent the change or increase) and β̂= slope. I used 100°F intervals for peak fire temperature and 10 minutes for duration of heat.

For composition, individual species were placed into functional groups to facilitate analysis. Species were grouped into their native status (native to Texas or introduced species), growth form (grass and grass-likes, forbs, vines, shrubs and subshrubs) and growth and seeding season (warm season or cool season), grouping was selected according to Clendenin (2016), Hatch and Pluhar (1992), Richardson and King (2011), and Shaw (2012). Species were assigned into 9 functional groups: introduced forbs cool season (IFC), introduced forbs warm season (IFW), introduced graminoids warm season (IGW), native forbs cool season (NFC), native forbs warm season (NFW), native graminoids cool season (NGC), native graminoids warm season (NGW), native sub-shrubs and shrubs (NSS) and native vines warm season (NVW) (Appendix Table 1). Then total of each functional group was divided by the sum of the total of all functional groups to estimate relative abundance (%) of each functional group from each sampling date. I used PRIMER v6 for a permutational multivariate analysis of variance (PERMANOVA) to compare differences between treatments and seasons over time, and a non-metric multidimensional scaling ordination (NMDS), was used to display changes in plant functional group composition following burning. The Bray-Curtis similarity index was used.

RESULTS

Burning and weather conditions

Burn day temperatures in winter treatments ranged from 20 to 34° C with a mean of 26° C, and in summer treatments from 34 to 38° C with a mean of 35° C (Table 5). Relative humidity ranged from 28 – 65% with a mean of 50.7% during winter treatments, while summer treatment relative humidity ranged from 51 – 78% with a mean of 62.1%. Average wind speeds ranged from 7.3 to 12.2 km/h (4.6 to 7.6 mph), winter wind speeds averaged 10.5 km/h (6.5 mph) while summer wind speeds were 9.5 km/h (5.9 mph). Wind direction during summer burns was consistently South to Southeast. However, during winter burns, wind directions varied from south to southeast and north to northwest if a recent cold front had passed.

I compared the fire temperatures between winter and summer burning and did not find a difference between seasons ($F_{1,12}$ = 0.27, p = 0.61). However, I used a correlation to see if there was a relationship between fuel loads kg/ha and fire temperatures, two recordings were exluded from analysis because two HOBO® thermocouple data loggers failed during the fire. I found that there was a positive relationship between these two variables (r^2 = 0.31, df = 8, p = 0.04).

Table 5. Environmental conditions and fuel characteristics in the Gulf cordgrass vegetation areas during prescribed burn treatments in winter and summer 2016 and 2017 at East Foundation's El Sauz Ranch in Willacy and Kenedy Counties, Texas.

Burn date	**Season of Burn**	**Air temperature °C**	**Relative humidity (%)**	**Wind speed km · hr^{-1}**	**Fuel load kg · ha^{-1}**	**Mean max fire temperature °C**	**Fuel moisture (%)**
Feb 2016	Winter	20-27	28-50	6.5-19.4	14,544	726	35.72
July 2016	Summer	34-38	51-61	4.7-19.8	12,775	838	31.87
Feb 2017	Winter	27-34	48-65	6.5-14.4	27,757	805	26.84
Aug 2017	Summer	31-36	57-78	3.2-16.2	17,946	599	*

Precipitation

The weather station at the ranch recorded 452.11 mm of rainfall during 2016 and 450.80 mm during 2017 (Table 6). In 2016 64% of the total rainfall was received in the first 6 months of the year leaving 36% for the second half of the year, while in 2017 there was a more even distribution of rainfall throughout the year with 50% for the first 6 months and 50% in the second half of the year. Ten years of rainfall records were obtained from the nearest weather station, located in Harlingen, Texas, approximately 47 km from the study site (NCDC 2017). They showed an annual average amount of 620.23 mm. This indicates that rainfall received during the study period was 168.13 and 169.43 mm less than the 10-year average in 2016 and 2017, respectively. In general, summer burn treatments received higher precipitation following burning than did winter burn treatments (Figure 5).

Table 6. Rainfall accumulation and duration of sampling period for each season of burn, as well as accumulation of rainfall 30 days prior to burning and 30 days after burning at East Foundation's El Sauz Ranch in Willacy and Kenedy Counties, Texas.

Season of Burn	Average duration of sampling period (days)	Rainfall received during sampling period (mm)	Rainfall received 30 days prior to burning (mm)	Rainfall received 30 days after burning (mm)
Winter 2016	91	50.4	7.4	17.0
Summer 2016	86	121.8	0.4	25.3
Winter 2017	87	107.2	38.0	44.4
Summer 2017	79	123.9	48.1	64.0

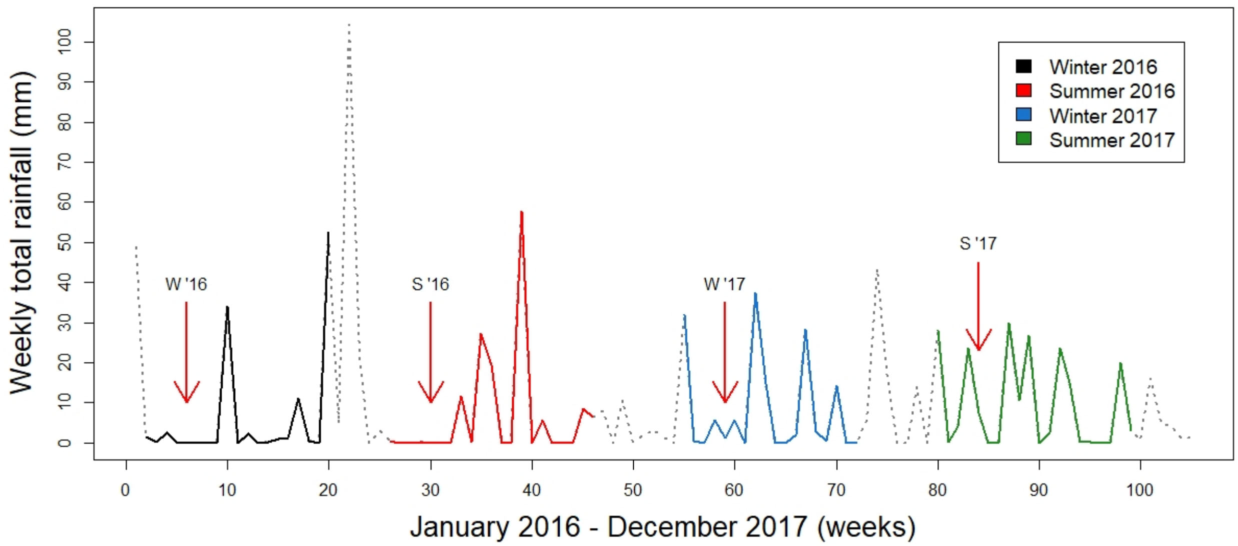

Figure 5. Mean weekly rainfall recorded at East Foundation's El Sauz Ranch in Willacy and Kenedy Counties, Texas from January 2016 to December 2017. Arrows indicate the weeks of each burn treatment, and colored segments include 10 days before to 90 days after a burn treatment.

Soil moisture

Soil moisture in 2017 was higher after the winter burn treatment than the summer burn treatment (t_{26}=-5.59, $p < 0.001$). During the 15 weeks of sampling after each burn treatment, soil moisture in winter burn treatment patches averaged 20% while following the summer burn treatment patches averaged 9% soil moisture (Figure 6).

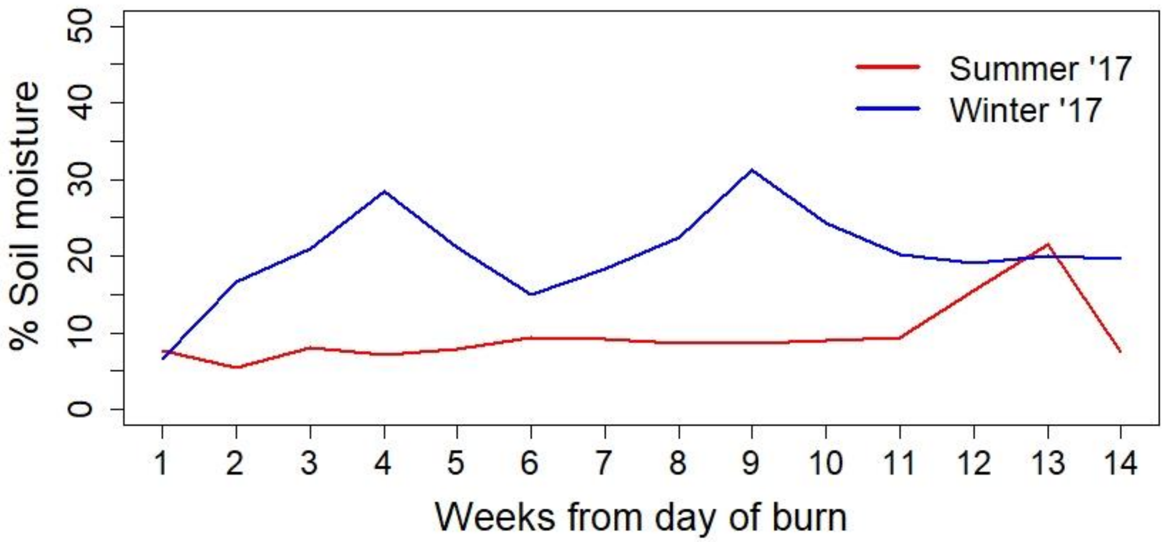

Figure 6. Soil moisture following winter and summer prescribed burn treatments in 2017 at East Foundation's El Sauz Ranch in Willacy and Kenedy Counties, Texas. Solid lines represent weekly mean soil moisture (%) from two patches of each season of burn while dotted lines represent overall mean soil moisture per season.

Gulf cordgrass density and mortality

The mean number of Gulf cordgrass plants in 16m^2 ranged from 54.5 (± 15.5) in W17 to 92 (± 22.5) in W16 during pre-burn sampling in the burn patches and 57 (± 9) in control of summer 2017 to 122.5 (± 11.5) in control of winter 2016 (table 6), no difference was found when comparing mean number of Gulf cordgrass plants at pre-burn between winter and summer patches (t_2 = 0.64, p = 0.29). I compared the burn patches and non-burned patches mean plant density before the burn and found no difference (t_6 = -0.98, p = 0.18).

Mean number of dead Gulf cordgrass plants in 16m^2 at approximately 90 days after each burn ranged from 2 (± 0) in W17 to 14.25 (± 1.25) in S16 (table 7), no differences were found when comparing winter and summer patches (t_2 = -0.73, p = 0.27). However, I found a difference when I compared mean number of dead Gulf cordgrass between burned and non-burned patches (t_6 = 1.94, p = 0.05).

Recruitment of Gulf cordgrass plants were almost absent for the length of the study, mean number of recruitments found in 16m^2 ranged from 0 (± 0) in S17 to 1(± 0.75) in S16, I compared winter and summer patches and found no difference (t_2 = -0.5, p = 0.33).

I compared percent mortality of Gulf cordgrass plants from 90 days following burning between winter and summer burning seasons, found that season of burn is not a determining factor for Gulf cordgrass plant survival (t_2=-0.87, p = 0.24). However, when I compared mortality across all four burn treatments (W16, S16, W17 and S17), there was a difference between burn treatments ($F_{3,4}$ = 7.19, p = 0.43) with S16 having roughly twice as much mortality as the other burn treatments.

Table 7. Means of live, dead, recruits and percent mortality of Gulf cordgrass plants in $16m^2$ and standard errors for each burn patch and non-burned patch in 2016 and 2017 at East Foundation's El Sauz Ranch in Willacy and Kenedy Counties, Texas.

Sampling Period	**Treatment (N=2)**	**Soil water content (%)**	**Mean live plants**	**Mean dead plants**	**Mean recruits**	**Plant mortality (%)**
Winter 2016	Burn	*	92 (± 22.5)	5 (± 1.5)	0.25 (± 0.25)	9.5
Control at W16	No-burn	*	122.5 (± 11.5)	0.75 (± 0.75)	0 (± 0)	1.1
Summer 2016	Burn	*	65 (± 3)	14.25 (± 1.25)	1 (± 0.75)	30.6
Control at S16	No-burn	*	83 (± 10)	0 (± 0)	0 (± 0)	0
Winter 2017	Burn	20.3	54.5 (± 15.5)	2 (± 0)	0.25 (± 0.25)	8.6
Control at W17	No-burn	*	70.5 (± 7.5)	0 (± 0)	0.25 (± 0.25)	0
Summer 2017	Burn	9.2	57 (± 14)	2 (± 1.75)	0 (± 0)	7.3
Control at S17	No-burn	*	57 (± 9)	0 (± 0)	0 (± 0)	0.7

Plant mortality and peak fire temperature and duration

Peak fire temperatures ranged from 446.86° C to 949.42° C. A logistic regression of plant mortality and peak fire temperature indicated a positive relationship between mortality and peak fire temperature regardless of season of burn treatment (t_{12} = 5.09, p = 0.0003); odds of mortality increased 71.43% for each 100° C increase (Figure 7).

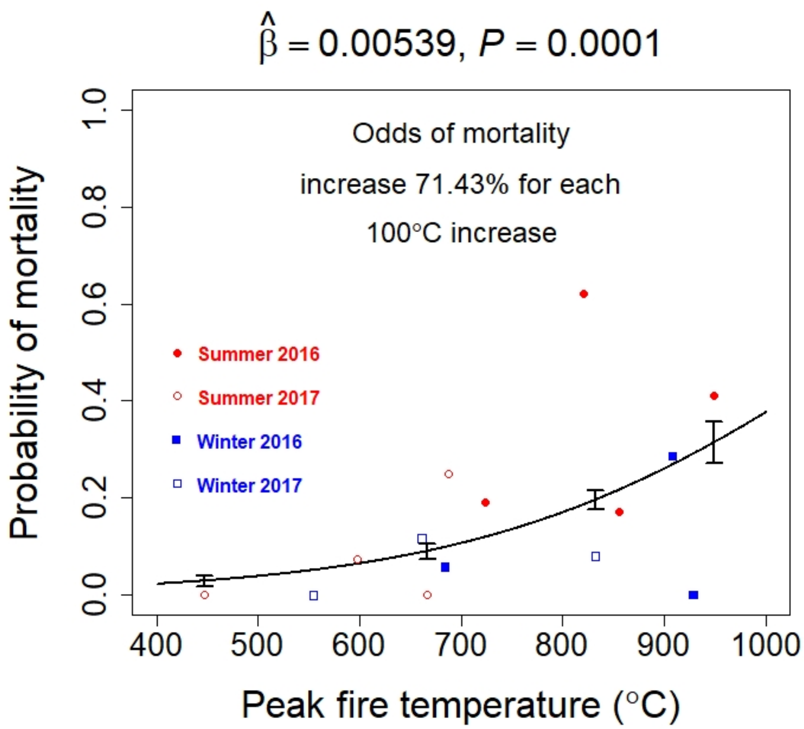

Figure 7. Probability of mortality of Gulf cordgrass plants after prescribed burning in 2016 and 2017 at East Foundation's El Sauz Ranch in Willacy and Kenedy Counties, Texas, graphed in function of peak fire temperature. Filled shapes are burn treatments from 2016 and empty shapes are burn treatments from 2017. Circles are summer burn treatments and squares are winter burn treatments.

The logistic regression of probability of mortality on duration in minutes of heat over 65° C indicated a positive relationship between the probability of mortality in function of the duration of heat over 65° C (t_{12} = 6.94, p = 0.0001). Odds of mortality increase 59.0% for every

10-minute increase in time spent over 65° C, meaning that the longer the plants were under continuous heat over 65° C the higher the odds of mortality (Figure 8).

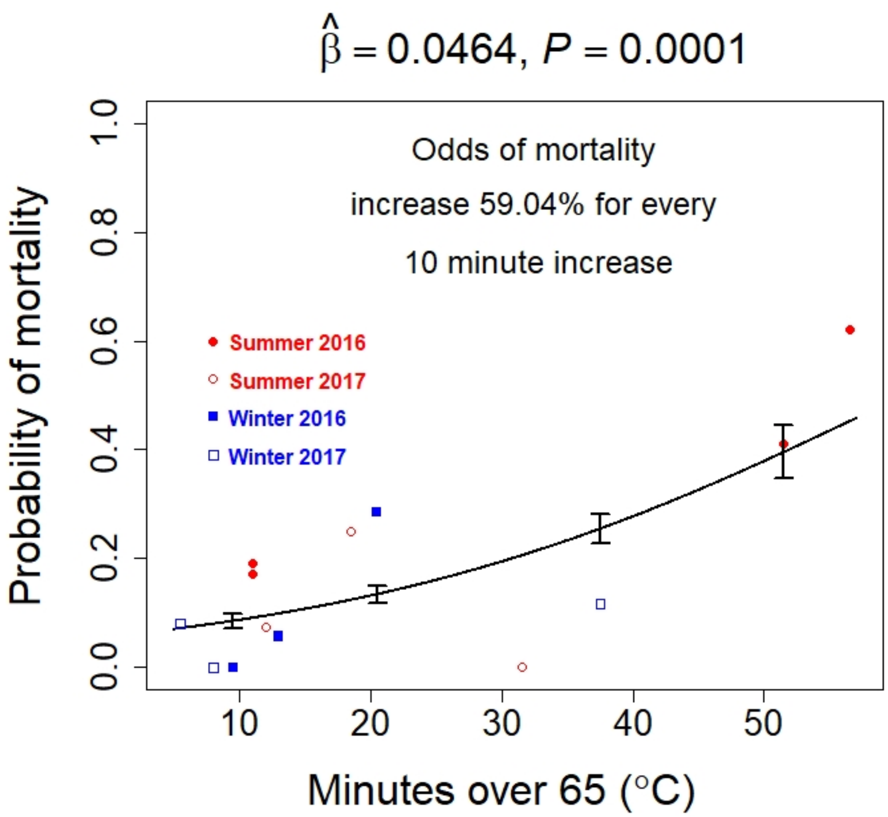

Figure 8. Probability of mortality of Gulf cordgrass plants graphed in function of time spent over 65° C during prescribed burns in 2016 and 2017 at East Foundation's El Sauz Ranch in Willacy and Kenedy Counties, Texas. Filled shapes are burn treatments from 2016 and empty shapes are burn treatments from 2017. Circles are summer burn treatments and squares are winter burn treatments.

Forage standing crop

Cordgrass forage standing crop regrowth models following fire depended on season of burning (Table 8). Estimated regression coefficients were positive in each model and in each vegetation group (Gulf cordgrass, other, and total forage standing crop), indicating that forage standing crop increases as days after burning increase. Best fit models varied depending on season and year of burning. For example, in Gulf cordgrass forage standing crop (Figure 8) for both summer burns, a simple log-linear model with days after burning was selected, whereas for W16 a multiple log-linear model with a quadratic term was selected, and a simple log-log model was appropriate for W17.

Because both summer burns were best fit with a simple log-linear growth curve model, it allowed a comparison of the summer burn models. The S16 model estimated a forage value increase of 1.43 times for every 10 unit increase. In other words, in S16 Gulf cordgrass forage standing crop at day 5 increased from 1.20 kg/ha to 1.74 kg/ha at day 15, and it continued to increase at that rate. The S17 forage value model increased 1.47 times for every 10 units increase, indicating increases in both models were similar.

Regarding forage standing crop (Figure 9) in plant species other than Gulf cordgrass, best fit models were different for each season and year. For winter burns quadratic terms were selected, while simple linear models were appropriate for summer burns. A quadratic linear-linear model was selected for W16, but for W17 a log-log quadratic model was appropiate. Even though S16 and S17 burn treatments had simple linear terms, a log-linear model was more appropiate for S16 and a linear-linear for S17. Comparison among seasons of burn was not possible because of model dissimilarity.

When all types of forage were combined a quadratic log-log model was selected for both summer burn treatments. For W16, a multiple linear-linear model with a quadratic term was selected; in contrast, a simple log-linear model was appropriate for W17.

Table 8. Chosen candidate models for regressing Gulf cordgrass forage standing crop, other forage standing crop and total forage standing crop in the Gulf cordgrass community after prescribed burning in either winter or summer of 2016 or 2017 at East Foundation's El Sauz Ranch in Kenedy and Willacy Counties, TX.

Crop	Season	Model	Order	Intercept	Slope
G. Cordgrass	W16	LY-X	Quadratic	3.41	0.01
	S16	LY-X	Linear	2.37	0.04
	W17	LY-LX	Linear	1.42	0.82
	S17	LY-X	Linear	2.82	0.04
Other forage	W16	Y-X	Quadratic	5.43	0.04
	S16	LY-X	Linear	1.26	0.05
	W17	LY-LX	Quadratic	7.27	0.70
	S17	Y-X	Linear	-28.01	4.88
All forage	W16	Y-X	Quadratic	81.38	0.11
	S16	LY-LX	Quadratic	4.32	0.46
	W17	LY-X	Linear	3.58	0.03
	S17	LY-LX	Quadratic	5.22	0.35

Data were back-transformed to natural data and graphed by type of forage with forage standing crop as the dependent variable and days after burning as the independent variable (Figures 8, 9, and 10). Gulf cordgrass regrowth lagged during the first 40 days after burning with little variation between seasons, with the exception of W17 which had regrowth that increased at a steady rate throughout the first 40 days. Variability of forage standing crop increased as time since burning increased across all seasons of burning (Figure 8). Forage standing crop other than Gulf cordgrass regrowth lagged during the first 60 days after burning following S16 and W17 treatments with increasing variability over time. W16 and S17 displayed more even growth rates with regrowth also greater than the other two treatments at every sampling period after 10 days (Figure 9). Total forage standing crop regrowth (Figure 10) rates are very similar to Gulf cordgrass rates because Gulf cordgrass is the dominant forage type and is driving the results. Time since burning explained the majority of variation in regrowth of all forage types in each season. It explained 94%, 88%, and 84% of the variability in total forage standing crop regrowth following S17, W16, and S16 treatments, respectively, while it was a somewhat weaker estimater for W17 at 72% (Figure 10).

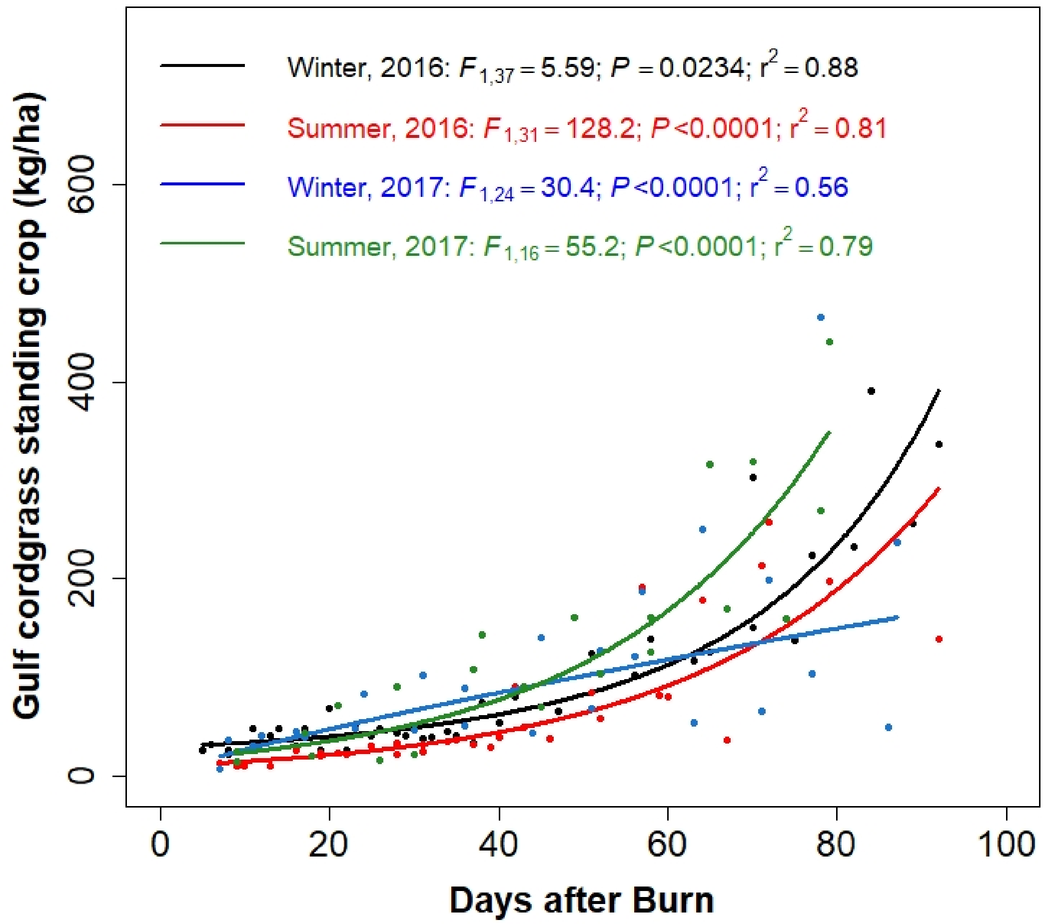

Figure 9. Gulf cordgrass forage standing crop (kg/ha) by season in function of days since prescribed burning in winter and summer 2016 and 2017 at East Foundation's El Sauz Ranch in Willacy and Kenedy Counties, TX.

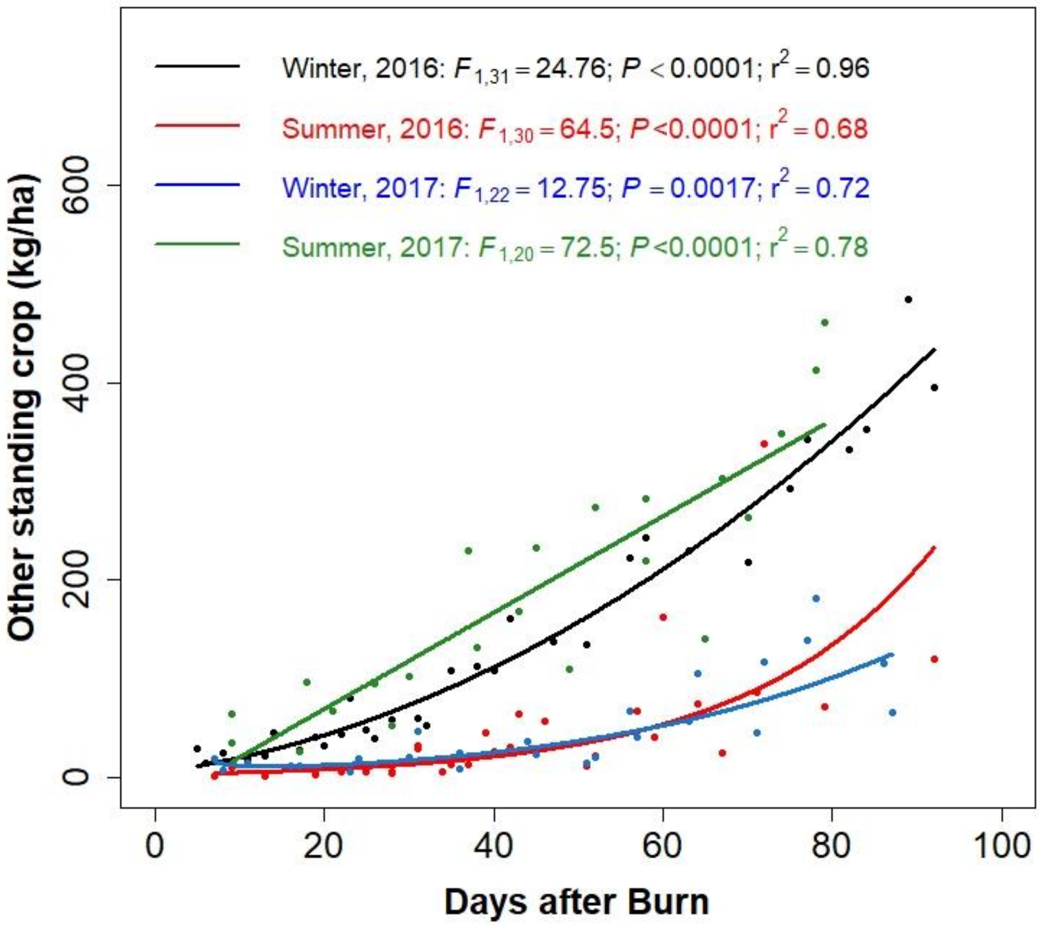

Figure 10. Forage standing crop (kg/ha) other than Gulf cordgrass by season in function of days since prescribed burning in winter and summer 2016 and 2017 at East Foundation's El Sauz Ranch in Willacy and Kenedy Counties, TX.

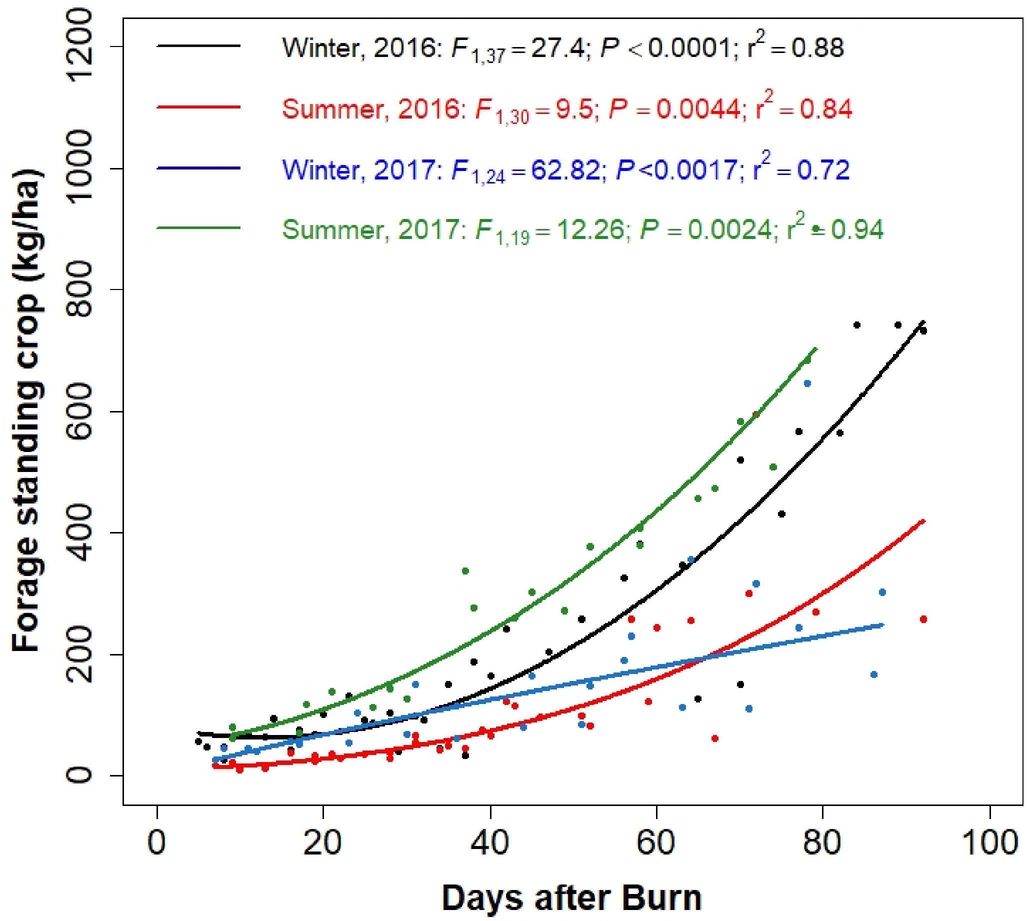

Figure 11. Total forage standing crop (kg/ha) by season in function of days since prescribed burning in winter and summer 2016 and 2017 at East Foundation's El Sauz Ranch in Willacy and Kenedy Counties, TX.

Forage production and carrying capacity

Variability in forage production (kg/ha) in Gulf cordgrass was high across treatments, years, and sites (Table 9). The highest forage production per patch occurred in patches 9 (W16) and 4 (S17), with 1359.6 kg/ha in 89 days and 2069.3 kg/ha in 79 days, respectively. Conversely, the lowest forage production values occurred in patches 5 (W17) and 6 (S16) with 180.4 kg/ha in 87 days and 252.9 kg/ha in 92 days, respectively. Mean forage production across all seasons of burn treatment at 85 days since burning was 697.9 kg/ha. Mean forage production for W16, S16, W17, and S17 was 941.1 kg/ha, 268.6 kg/ha, 361.4 kg/ha, and 1220.8 kg/ha, respectively. I failed to reject the null hypothesis that forage production among burn treatments was similar. There was no significant difference in mean forage production between the four burn treatments ($F_{3,4} = 0.905$, $p = 0.51$). When I compared mean forage production by season of burn only (combining years), winter burn treatment means were 651.2 kg/ha and summer burn treatment means were 744.7 kg/ha. There was no significant difference in mean forage production between summer and winter seasons of burning ($F_{1,6} = 0.034$, $p = 0.86$). Mean forage production following 2016 burn treatments with seasons combined was 604.8 kg/ha, and 791.1 kg/ha in 2017. In addition, the difference between years of burn treatment was not statistically significant ($F_{1,6} = 0.137$, $p = 0.72$).

There was no difference in calculated correct stocking rate between seasons of burn treatment approximately 90 days following treatment. Average correct stocking rate in winter burn patches was 3.82 hectares per animal unit, while in summer burn patches it was 3.86 hectares per animal unit.

Table 9. Gulf cordgrass forage production following prescribed burning treatments at East Foundation's El Sauz Ranch in Willacy and Kenedy Counties, Texas.

Season	**Length of sampling period (days)**	**Hectares per animal unit**	**Forage production (kg/ha/day)**	**Forage production for length of sampling period (kg/ha)**
Winter 2016	91	2.1	10.48	941.06
Summer 2016	86	5.58	3.17	268.55
Winter 2017	87	5.54	4.19	361.40
Summer 2017	79	2.15	15.48	1,220.75

Gulf cordgrass winter and summer forage standing crop and forage production

Pre-burn Gulf cordgrass forage standing crop means were statistically different between W16 and S16 treatments ($F_{1,10.2} = 3.87$, $p = 0.07$) (Figure 12), being higher in W16 patches with 6,889.6 kg/ha (UL: 9,200.6 kg/ha, LL: 5,159 kg/ha) than in S16 patches with 3081.9 kg/ha (UL:

4,115.7 kg/ha, LL: 2,307.8 kg/ha). For the first 90 days after burning, there was no difference between winter and summer forage standing crop. Around 215 and 300 days after burning forage standing crop in winter patches increased significantly and was higher than following summer burning at those points ($F_{1,10.2}$ = 29.2, p = 0.001 and $F_{1,10.2}$ = 11.12, p = 0.007, respectively). At 405 and 470 days after burning forage standing crop in summer burn patches caught up to winter patch, and there were no longer differences ($F_{1,10.2}$ = 0.67, p = 0.431 and $F_{1,10.2}$ = 1.06, p = 0.327, respectively). Gulf cordgrass forage standing crop at 470 days after W16 burns was 1,486.1 kg/ha (UL: 1,984.5 kg/ha, LL: 1,112.8 kg/ha), and was 2,263.4 kg/ha (UL: 3,022.69 kg/ha, LL: 1,694.9 kg/ha) following S16 burning.

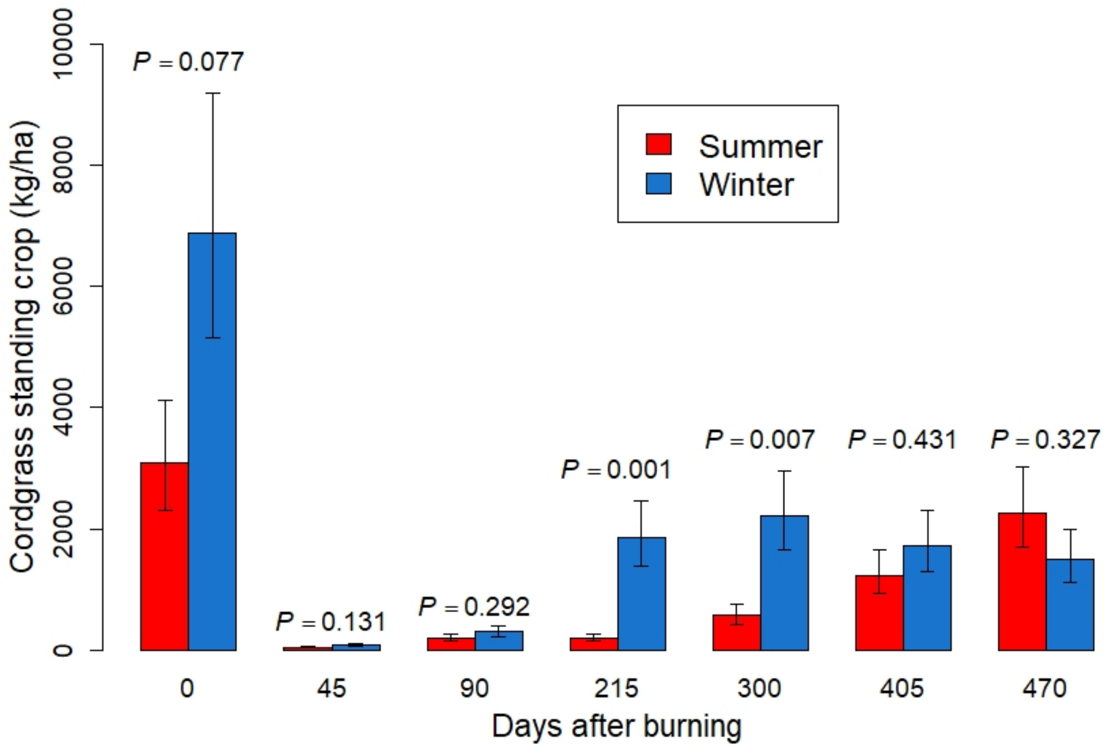

Figure 12. Gulf cordgrass forage standing crop (kg/ha) long-term comparison from pre-burn (0 days) to 470 days of growth for winter and summer 2016 burn treatments. (For 0, 45, 90, 215, 300, 405, and 470 days after burning, *F* values are 3.87, 2.70, 1.23, 29.2, 11.12, 0.67 and 1.06, respectively, with *P* values of 0.077, 0.131, 0.292, 0.0003, 0.0073, 0.4312, and 0.3274, respectively, all with 1 and 10.2 *df*).

During 15.5 months of grazing following W16 burning forage production was 6,899.8 kg/ha while it was 9,462.4 kg/ha for 15.5 months following S16. Control patches had a production of 39,460 kg/ha during the same time frame.

Gulf cordgrass forage standing crop in control patches varied greatly, displaying wide swings throughout the 650 days of the study. Forage standing crop of Gulf cordgrass ranged from 2,773.1 kg/ha to 11,909.4 kg/ha (Figure 11) in control patches. Seasonal growth distribution patterns are noticeable but different for each patch and time of year.

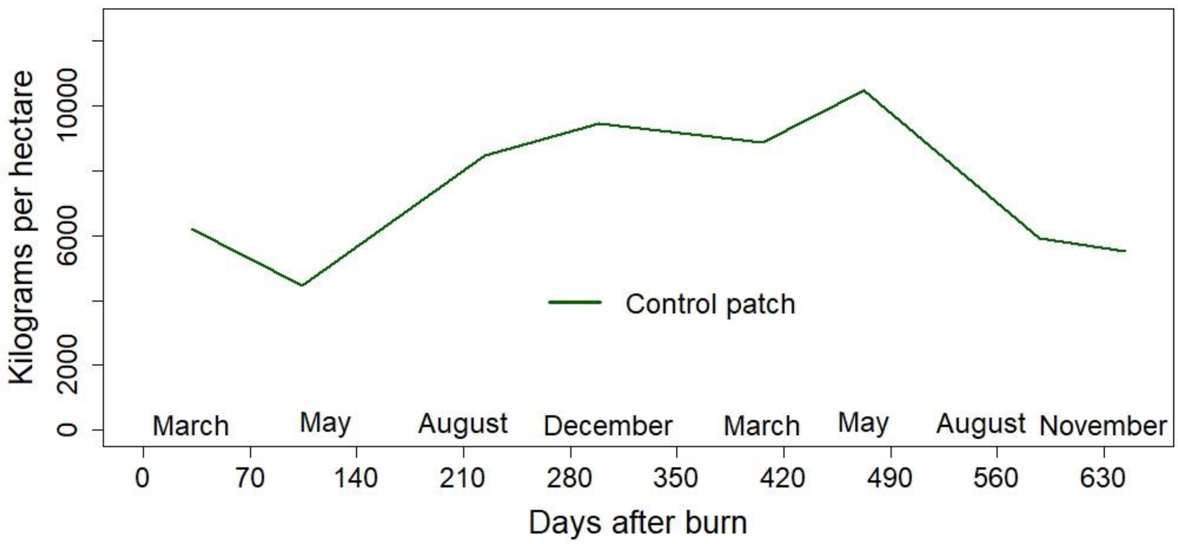

Figure 13. Gulf cordgrass forage standing crop averages in control patches in kilograms per hectare for approximately 650 days throughout the study at East Foundation's El Sauz Ranch in Kenedy and Willacy Counties, TX. Green line represents Gulf cordgrass forage standing crop of control patch.

Functional Group Composition

Plant species richness

For the first 90 days following burning, season of burn (winter vs. summer) was not a determining factor for species richness ($F_{1,6} = 0.12$, $p = 0.72$). Number of species did not differ significantly between winter and summer treatments (Table 10).

Table 10. Species richness index estimates (standard errors) for Winter and Summer burning at East Foundation's El Sauz ranch in Willacy and Kenedy Counties from pre-burn to 90 days following burning.

Season	**Preburn**	**45 Days Post-burn**	**90 Days Post-burn**	**All Sampling Periods**
Winter	7.75 (± 2.49)	17.75 (± 2.54)	25.00 (± 0.95)	16.83 (± 1.47)
Summer	20.75 (± 3.51)	16.75 (± 3.54)	17.75 (± 2.65)	18.42 (± 2.88)

NMDS ordination of plant density composition

For the following NMDS ordinations numbers on graphs represent sampling periods, 0 = pre-burn sampling, date 1 = 45 days after burning (DAB), 2 = 90 DAB, 3 = 215 DAB, 4 = 300 DAB, 5 = 405 DAB, 6 = 470 DAB, 7= 595 DAB, and 8= 635 DAB. For W16 burn treatments there were unfortunately no density sampling conducted prior to burning (Figure 14). In successive sampling dates, there appears to be no obvious trend in plant functional group composition changes that would indicate directional change in either the control patches or burn patch plant density functional group composition. Permutational multivariate analysis of variance (PERMANOVA) on burn and control treatment comparisons following W16 burn treatments indicated no interaction between treatment and days since burn ($F_{7,14}$ = 0.403 p = 0.974), no effect of treatment ($F_{1,2}$ = 0.45, p = 0.717), and no effect of days since burning ($F_{7,14}$ =1.16, p = 0.316).

S16 date 0 indicates pre-burn data collected (Figure 15). Burn and control functional group composition at sampling date 0 are much closer on the graph indicating more similarity than sampling dates in the first 300 days following burning (dates 1-4). In sampling dates 5 and 6 functional group composition has become more similar between burn and control patches again as the distance between them has decreased. PERMANOVA comparisons of S16 burn and control patches showed no interaction between treatment and days after burn ($F_{6,12}$ = 1.37, p = 0.204) and no effect of treatment ($F_{1,2}$ = 2.11, p = 0.172). However, composition changed ($F_{6,12}$ = 2.42, p = 0.005) over time.

W17 burn patches density functional group composition was close to density composition from the control patches at sampling date 0 also (Figure 16). However, they remain separated, indicating density functional group composition differences from patch to patch. The burned patches tend to be located around NGC and NVW.

For S17 burn treatments there are only two sampling dates following burning (Figure 17). Their movement over time is similar to the control treatments.

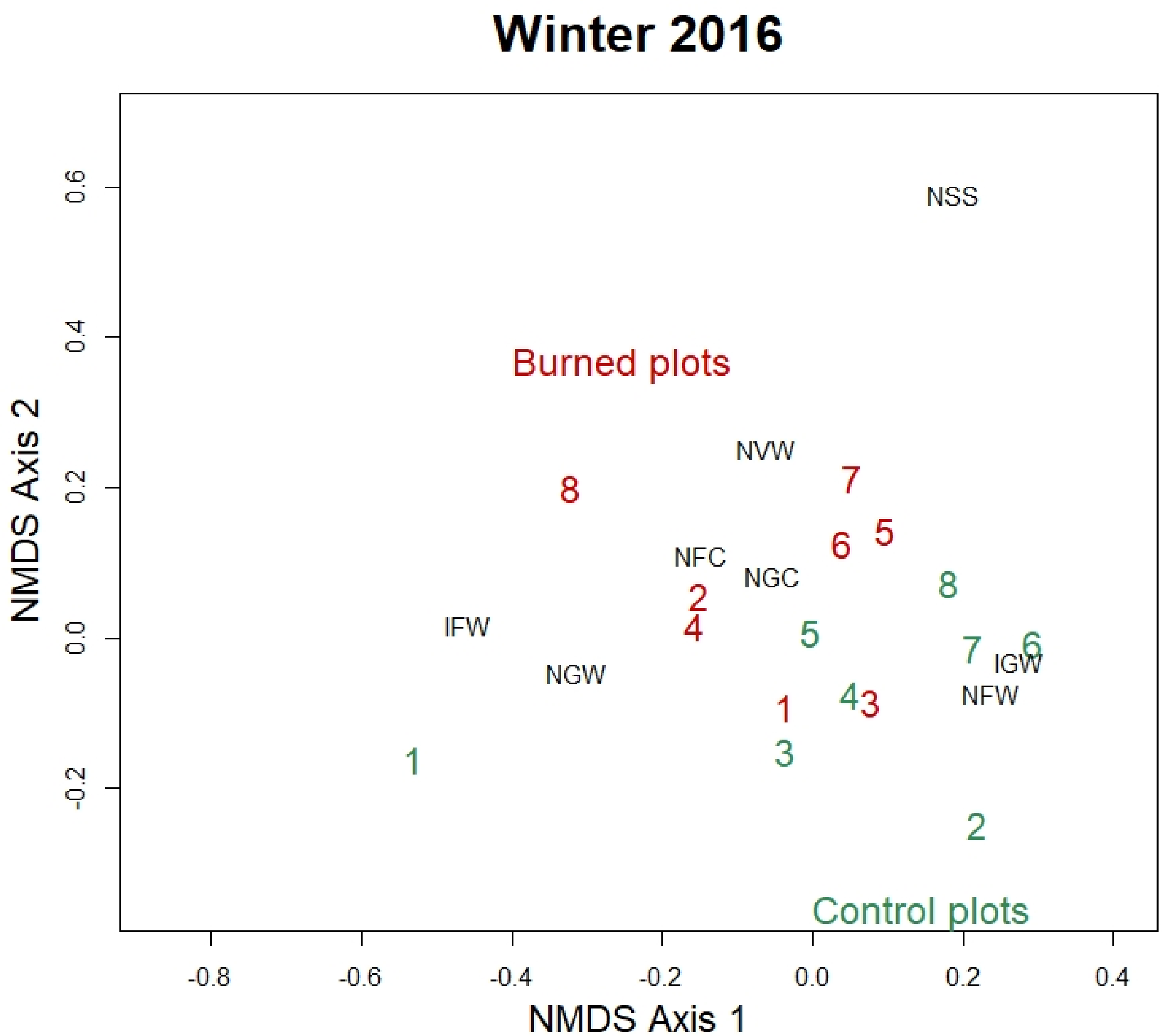

Figure 14.Winter 2016 burn treatment NMDS ordination using the Bray-Curtis similarity index of functional groups as a resemblance matrix, show plant density functional group composition over time following burn treatment. Burned patches are the numbers in red (Patches 9 and 10 for W16) and control patches are in green (Patches 3 and 7). Numbers indicate sampling periods 1 = 45 days after burning (DAB), 2 = 90 DAB, 3 = 215 DAB, 4 = 300 DAB, 5 = 405 DAB, 6 = 470 DAB, 7= 595 DAB, and 8= 635 DAB.

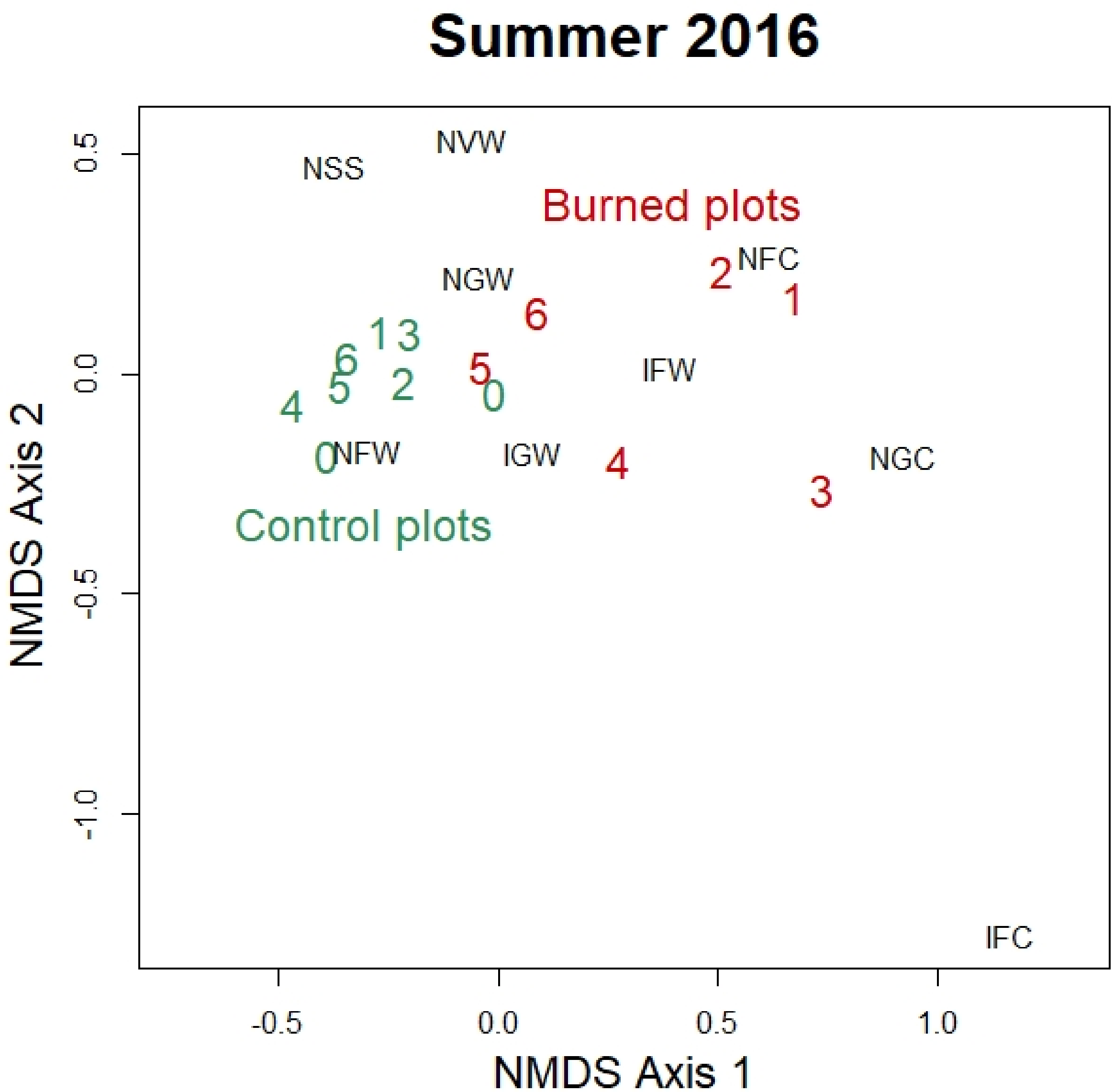

Figure 15. Summer 2016 burn treatment NMDS ordination using the Bray-Curtis similarity index as the resemblance matrix, show plant density functional group composition over time following burn treatment. Burned patches are in red (Patches 2 and 6 for S16) and control patches in green (Patches 3 and 7). Numbers indicate the sampling periods 0 = pre-burn sampling, date 1 = 45 days after burning (DAB), 2 = 90 DAB, 3 = 215 DAB, 4 = 300 DAB, 5 = 405 DAB, and 6 = 470 DAB.

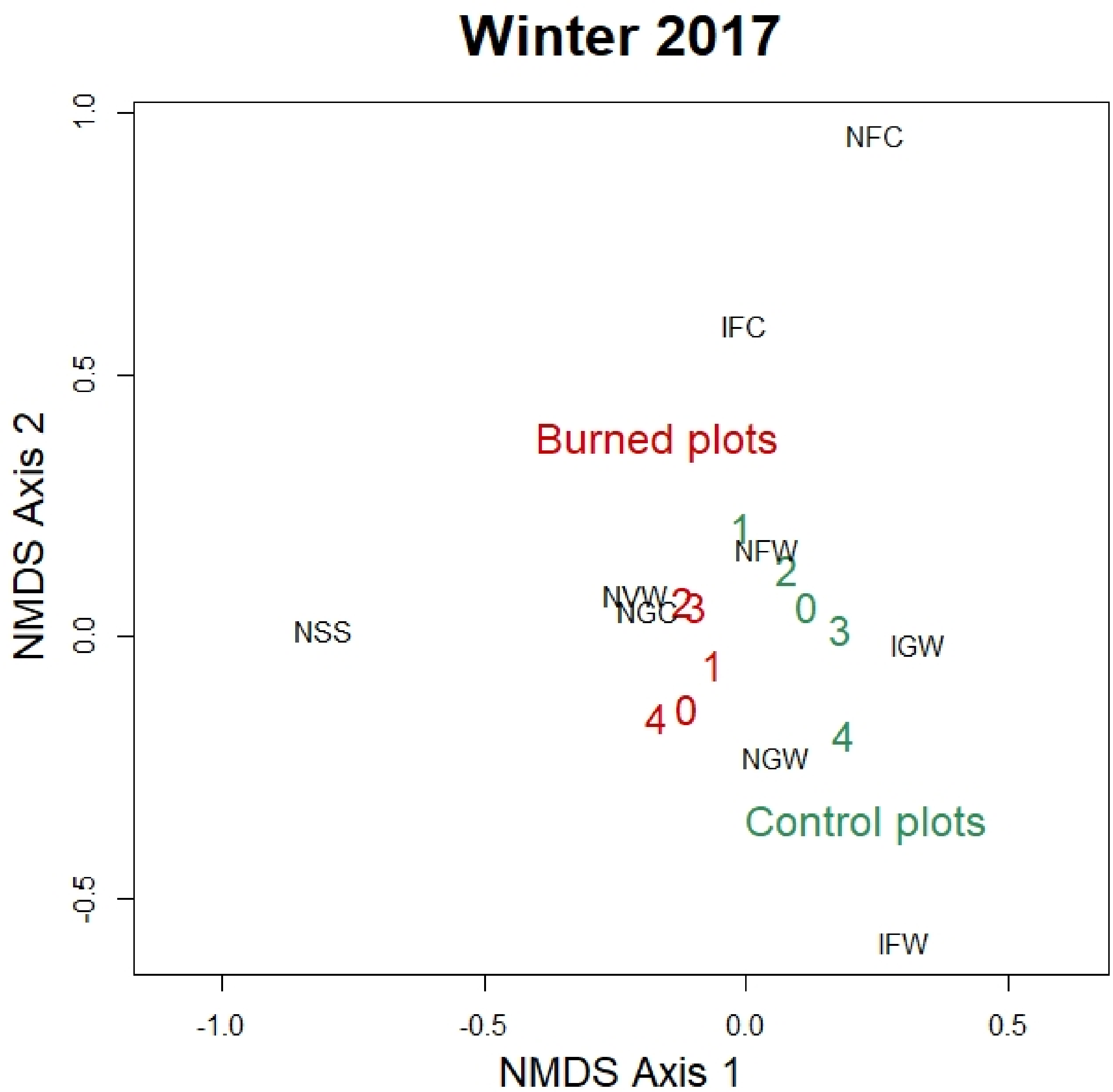

Figure 16. Winter 2017 burn treatment NMDS ordination using the Bray-Curtis similarity index of functional groups as a resemblance matrix, show plant density functional group composition over time following burn treatment. Burned patches are in red (Patches 1 and 5 for W17) and control patches in green (Patches 3 and 7). Numbers indicate sampling periods 0 = pre-burn sampling, date 1 = 45 days after burning (DAB), 2 = 90 DAB, 3 = 215 DAB, and 4 = 300 DAB.

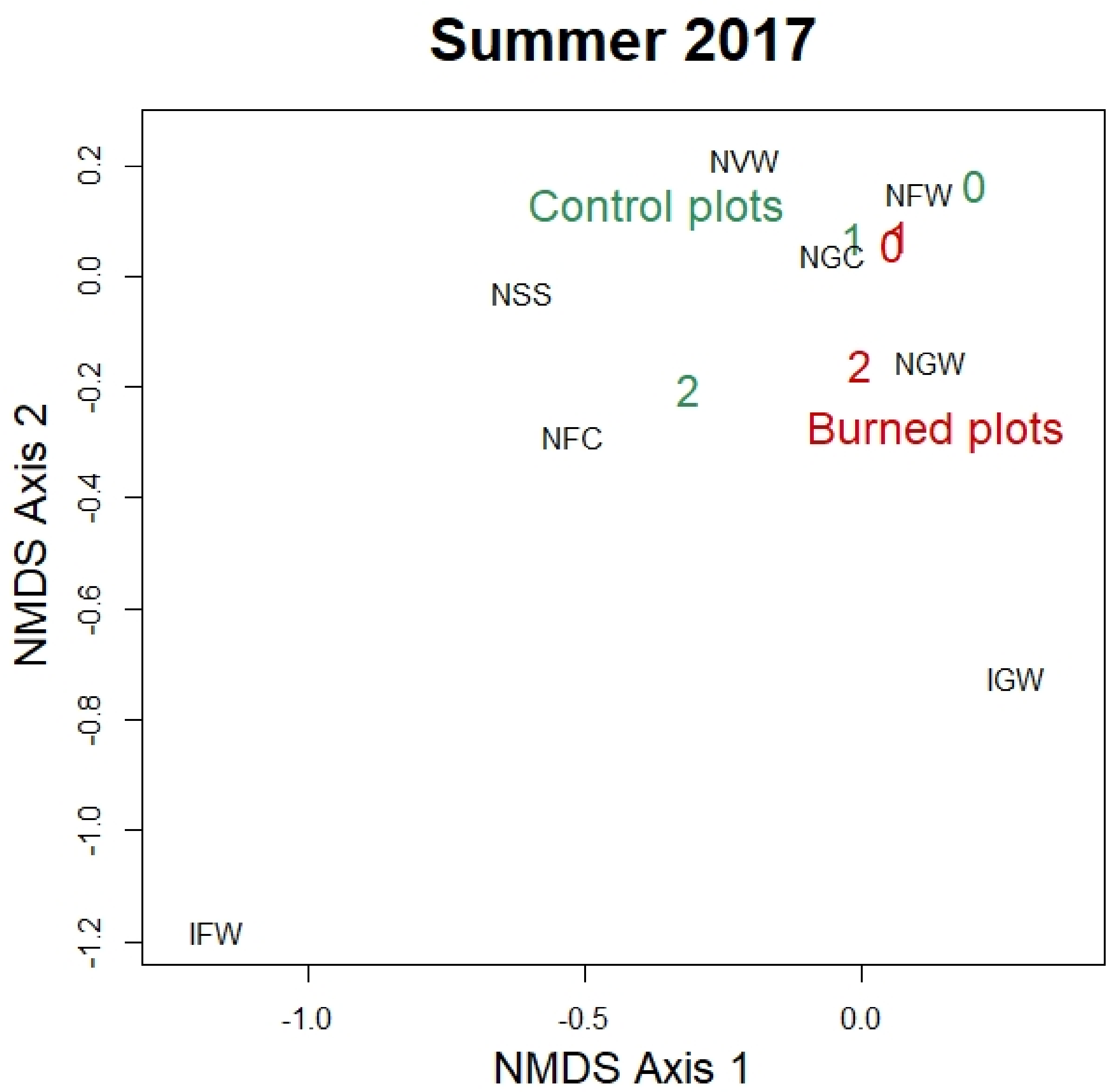

Figure 17. Summer 2017 burn treatment NMDS ordination using the Bray-Curtis similarity index of functional groups as a resemblance matrix, show plant density functional group composition over time following burn treatment. Burned patches are in red (Patches 4 and 8 for S17) and control patches in green (Patches 3 and 7). Numbers indicate sampling period 0 = pre-burn sampling, date 1 = 45 days after burning (DAB), and 2 = 90 DAB.

NMDS ordination of forage standing crop composition

Ordination of forage standing crop functional group composition in burn treatment indicates greater variation after burn and over time according to the density functional group composition ordination. All pre-burn points (0) are close to the group of control patch points, and all are close to NGW group. After treatments, burned patches shifted away from the control patches. In W16 (Figure 18) after separating from control patches, functional group composition shifted towards pre-burn functional group composition by sampling period 4 and stabilized by periods 5,6,7, and 8.

S16 functional group composition of forage standing crop changed after burning, and moved away from the control patch group (Figure 19). It stayed in the same area, with the exception of sampling period 2 that had a spike of NGW. S16 functional group comparisons of forage standing crop indicate a different outcome than W16. W17 and S17 burn patches (Figures 20 and 21) indicate movement similar to W16 data until sampling periods 4 and 2 respectively, starting close to the control group at 0 (pre-burn), and then moving away after burning.

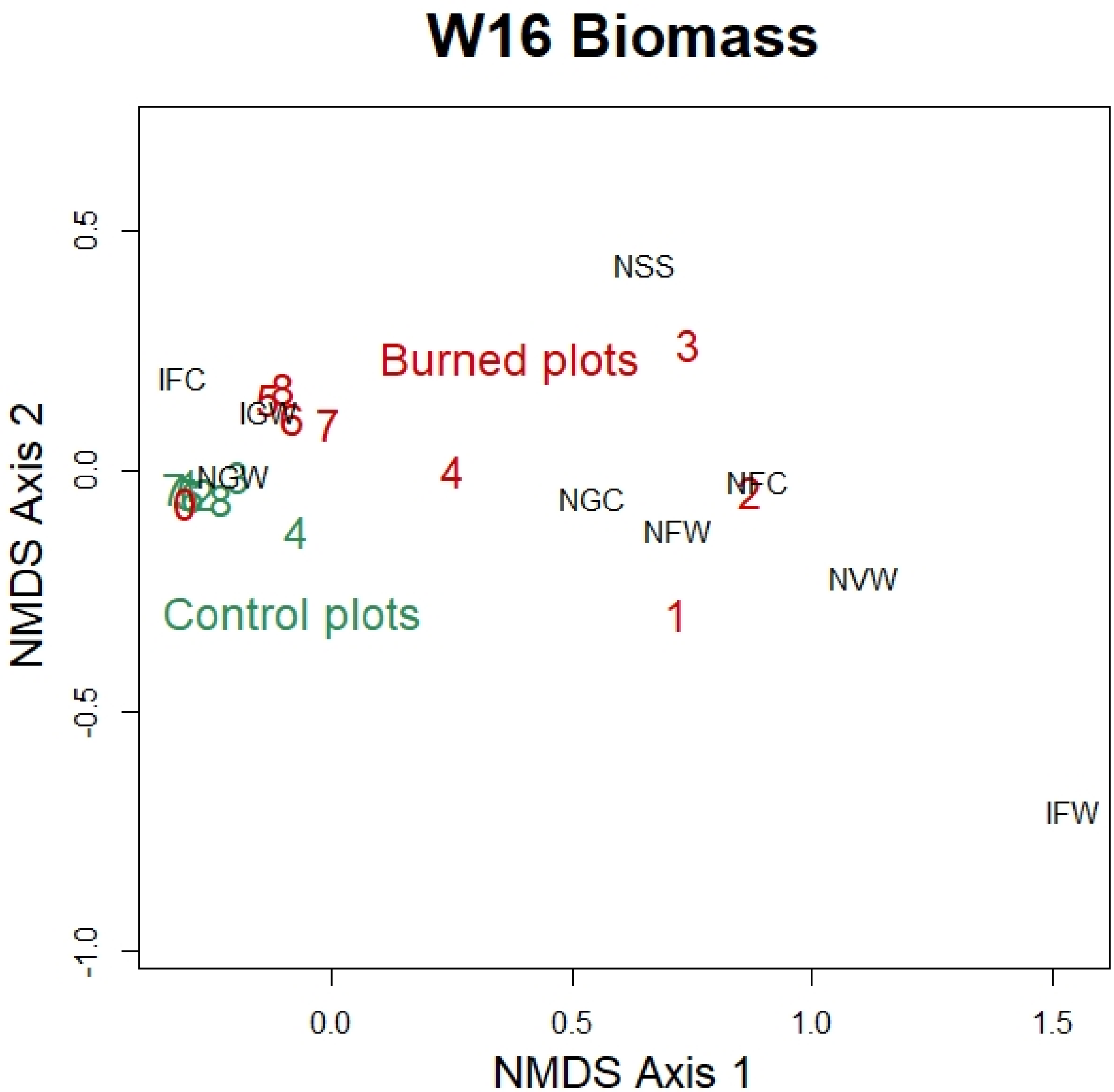

Figure 18. Winter 2016 burn treatment NMDS ordination using the Bray-Curtis similarity index of functional groups as a resemblance matrix, show forage standing crop functional group composition over time following burn treatment. Burned patches are in red (Patches 9 and 10 for W16) and control patches in green (Patches 3 and 7). Numbers indicate sampling periods 0 = Pre-burn data, 1 = 45 days after burning (DAB), 2 = 90 DAB, 3 = 215 DAB, 4 = 300 DAB, 5 = 405 DAB, 6 = 470 DAB, 7= 595 DAB, and 8= 635 DAB.

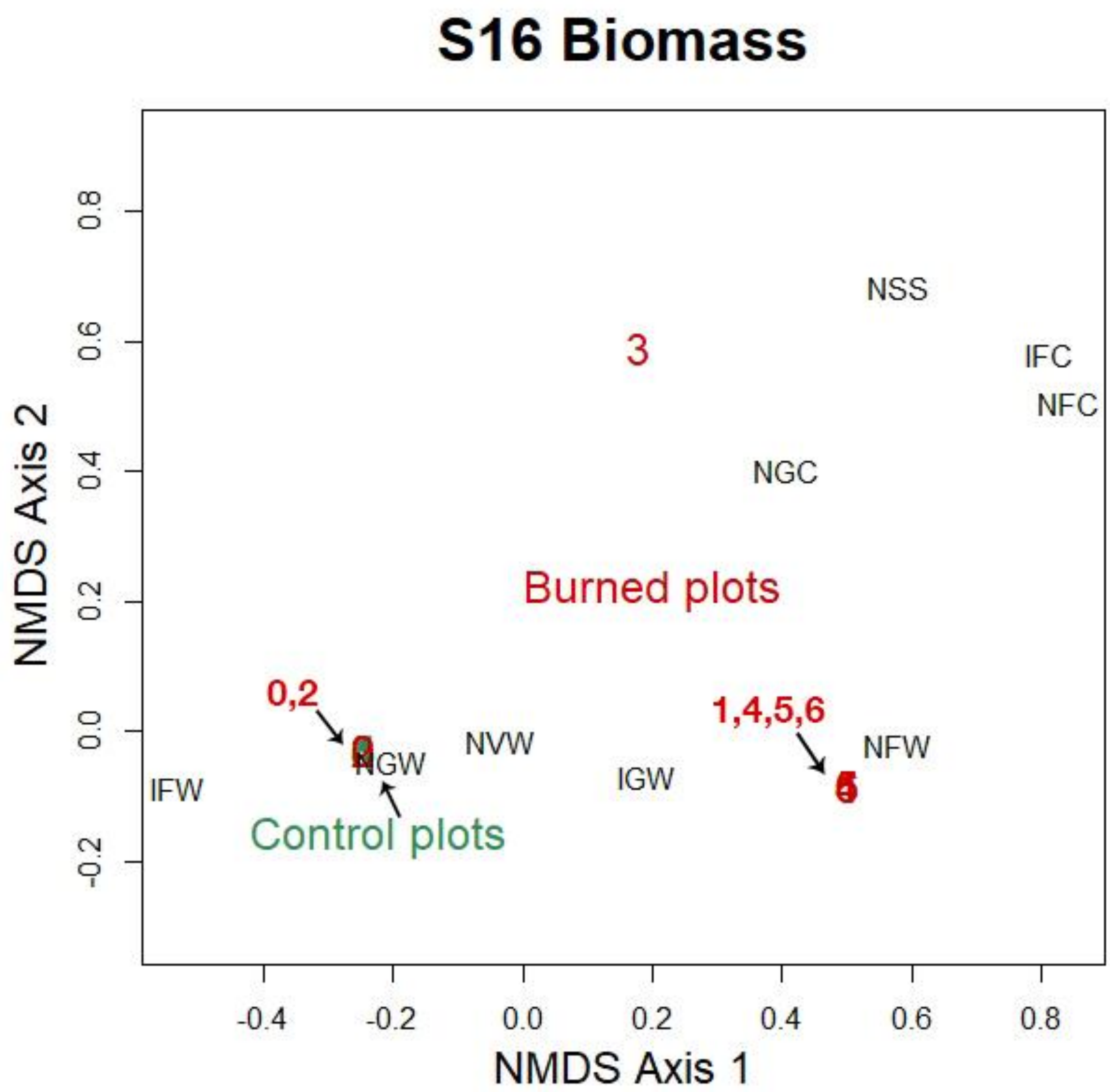

Figure 19. Summer 2016 burn treatment NMDS ordination using the Bray-Curtis similarity index as the resemblance matrix, show forage standing crop functional group composition over time following burn treatment. Burned patches are in red (Patches 2 and 6 for S16) and control patches in green (Patches 3 and 7). Numbers indicate sampling periods 0 = Pre-burn data, 1 = 45 days after burning (DAB), 2 = 90 DAB, 3 = 215 DAB, 4 = 300 DAB, 5 = 405 DAB, and 6 = 470 DAB.

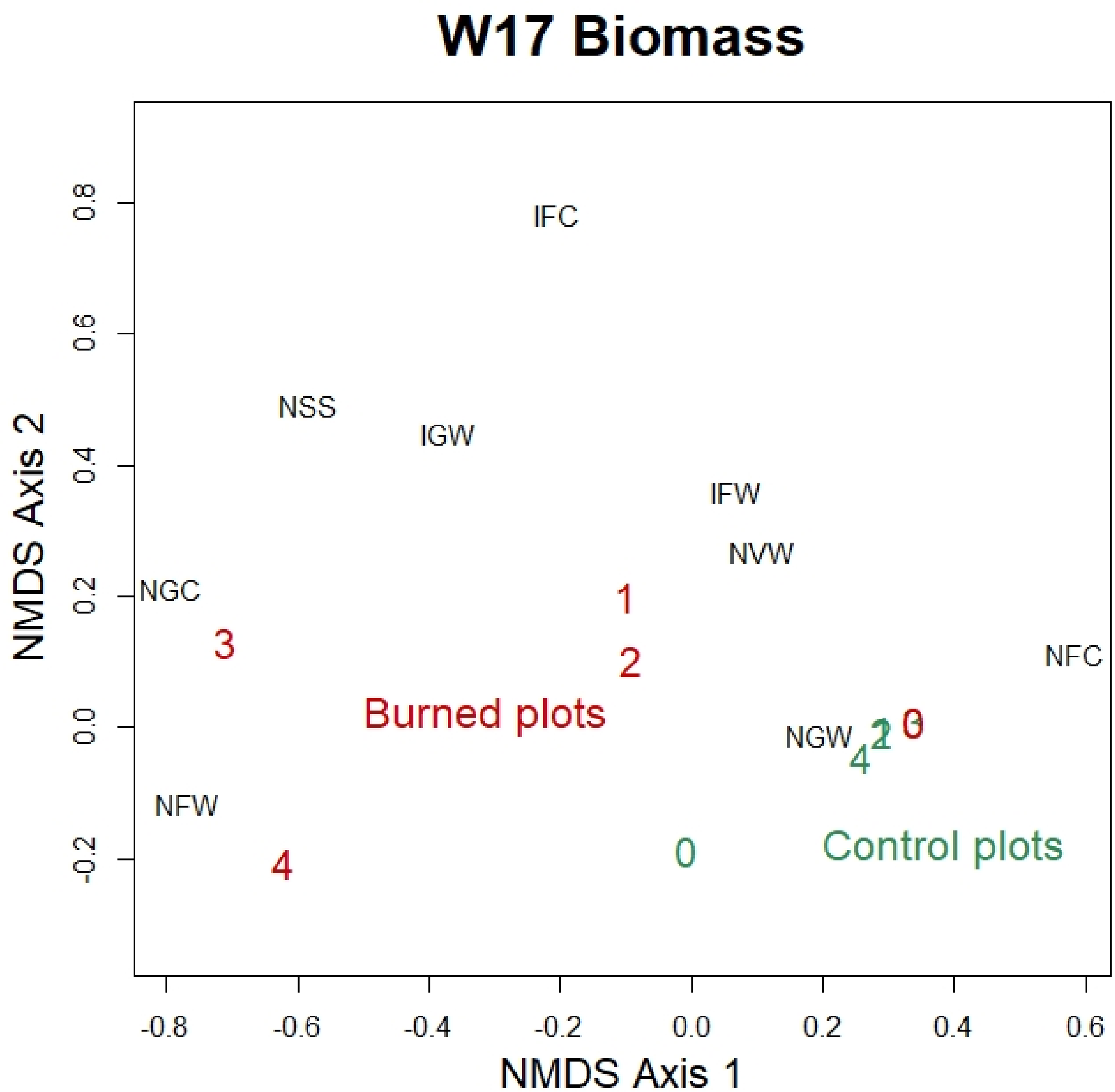

Figure 20. Winter 2017 burn treatment NMDS ordination using the Bray-Curtis similarity index of functional groups as a resemblance matrix, show forage standing crop functional group composition over time following burn treatment. Burned patches are in red (Patches 1 and 5 for W17) and control patches in green (Patches 3 and 7). Numbers indicate sampling periods periods 0 = Pre-burn data, 1 = 45 days after burning (DAB), 2 = 90 DAB, 3 = 215 DAB, and 4 = 300 DAB.

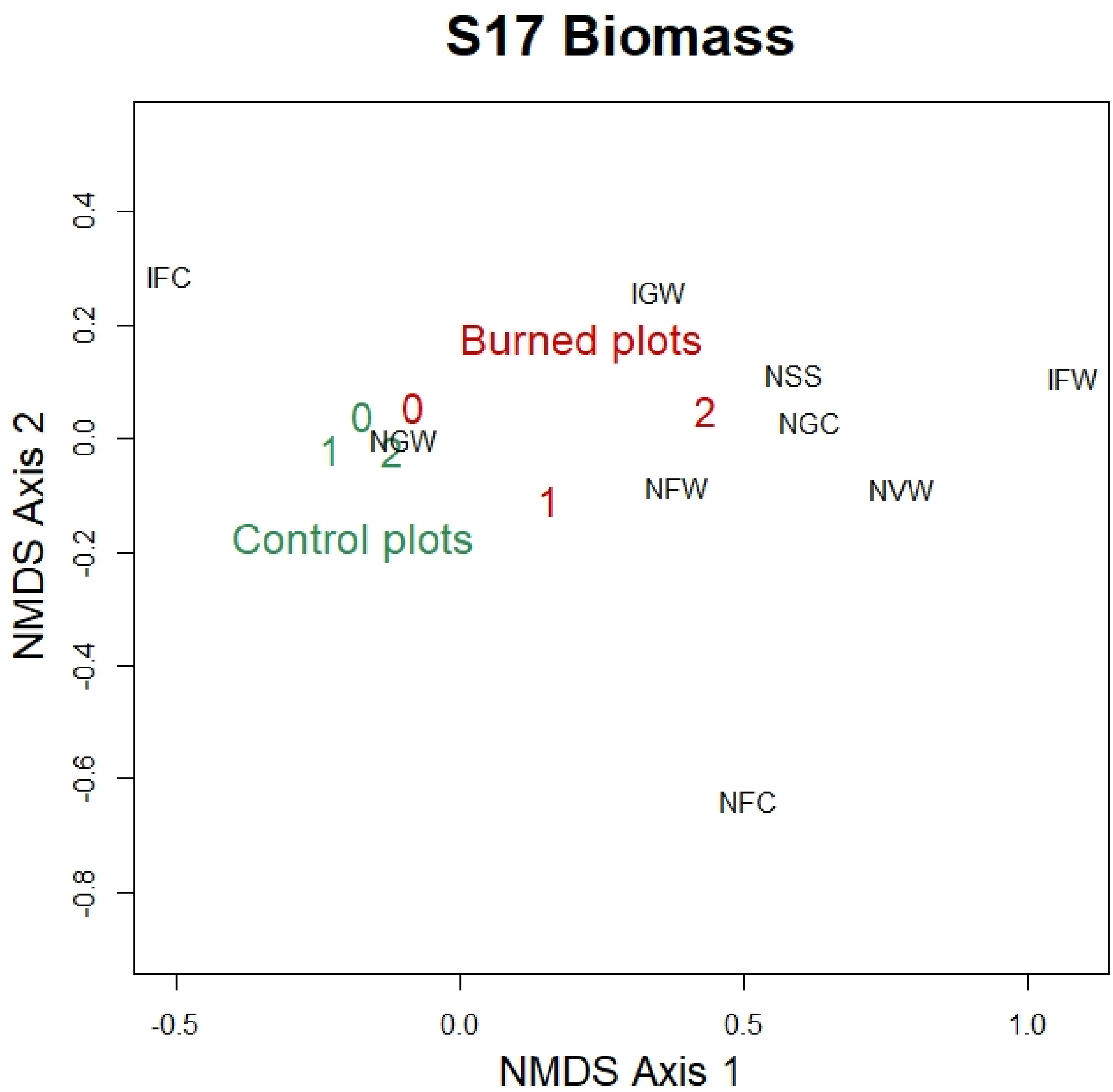

Figure 21. Summer 2017 burn treatment NMDS ordination using the Bray-Curtis similarity index of functional groups as a resemblance matrix, show forage standing crop functional group composition over time following burn treatment. Burned patches are in red (Patches 4 and 8 for S17) and control patches in green (Patches 3 and 7). Numbers indicate sampling 0 = Pre-burn data, 1 = 45 days after burning (DAB), and 2 = 90 DAB.

Plant density and forage standing crop composition

Density and forage standing crop composition data can only be descriptively compared between treatments (burn vs. non-burn) because of the difference in the two variables (Figures 22-25). A total of 162 taxa were recorded while conducting density counts and forage standing crop clipping in burn and control treatment patches for both 2016 and 2017. These species were arranged into nine functional groups. The order of species per group from greatest to fewest were NFW (74), NCW (41), NFC (17), IGW (10), NVW (6), NGC and NSS (5), IFW (3) and IFC (1). Relative density of functional groups fluctuated as expected through the seasons, i.e., cool season species were denser in winter and spring, and warm season species in summer and autumn. On average, the functional groups with the highest relative density for all seasons and treatments (burned and control) were NFW (37.4%), NGW (34.5%, which includes Gulf cordgrass), NGC (12.6%) and NSS (6.1%).

Relative density of winter patches and summer patches before burning was more similar to each other than to control patches (Figures 21-24). After winter burning relative density in winter patches (Figures 21 and 23) was more similar to control patches than to summer burn patches after burning (Figures 22 and 24). Changes in relative density after winter burning include the appearance of a small percentage (<3%) of IFW after W16 treatments, while IFC made a brief appearance following W17 burns. Following W17 burn treatments NSS was not recorded in density quadrats.

Summer burn treatments had greater relative density of NGC (21.87%) following burning compared to winter treatments (8.03%). Additionally, S16 treatments created an increase in density of NGC and a slight increase in density of NFC during the first year. S16 treatments also increased forage standing crop of NFW. While S17 burn treatments were followed for a shorter time after burning, they appear to have had less impact on NGC than S16 treatments had.

Relative forage standing crop was similar across all treatment patches before applying burn treatments. However, as with relative density, burning created more room and resources for some less common functional groups to increase in relative forage standing crop. Again, there was a brief appearance of IFW (<5%) in the first 6 months after W16 burning. After burning, both winters and S16 treatments increased in relative forage standing crop of NFW over control treatments and pre-burn conditions; this trend is more difficult to identify following S17 burning treatments because of the short time they were followed. Functional groups with the highest relative forage standing crop were NGW (69.9%), NFW (18.2%) and NSS (5.8%).

I compared forage standing crop functional group composition between season of burn from pre-burn to 90 days following burning (W16 and W17 vs. S16 and S17) and found there was no season effect ($F_{1,6}$ = 0.47, p = 0.67). No statistical difference was found when comparing within season, *i.e.*, between winter burns of 2016 and 2017 ($F_{1,2}$ = 3.17, p = 0.16) and between summer burns of 2016 and 2017 ($F_{1,2}$ = 0.40, p = 0.71), to account for variation between years of burning during the same season. This indicates no significant variation between the two years from pre-burn to 90 days following burning. A pair-wise comparison of relative forage standing crop between sampling dates regardless of season or year, indicated a difference between pre-burn and post-burn, between pre-burn and 45 days after burning ($t_{1,4}$ = 2.77, p = 0.04) and pre-burn and 90 days after burning ($t_{1,4}$ = 3.78, p = 0.01), but no difference between 45 and 90 day sampling dates ($t_{1,4}$ = 1.06, p = 0.37). I compared composition of forage standing crop in each season of burn to the control patches by pairing sampling dates from the burned treatments to control treatments. For the W16 burn comparison (winter 2016 burn vs. control over 8 sampling dates) and W17 burn comparison (winter 2017 burn vs. control over 5 sampling dates) there was an interaction of treatment x date ($F_{7,14}$ = 3.44, p = 0.01) and ($F_{4,8}$ = 4.39, p = 0.02) respectively, indicating there was a difference between treatments, and that difference varies over time. For S16 forage standing crop composition comparisons (summer 2016 burn vs. control with 7 sampling dates) there was a hint of an interaction of treatment x date ($F_{6,12}$ = 2.02, p = 0.05). Regarding S17 forage standing crop composition changes (summer 2017 burn vs. control with 3 sampling dates) there was no effect of treatment ($F_{1,2}$ = 4.46, p = 0.13), sampling date ($F_{2,4}$ = 2.45, p = 0.16), or their interaction. Non-burned patch forage standing crop composition did not change over time ($F_{7,7}$ = 1.18, p = 0.37) across 8 sampling dates.

I also compared forage standing crop composition in W16 and S16 burn patches (treatments with the longest sets of paired sampling dates since burning) over 6 sampling dates. I found an interaction of treatment x date ($F_{6,12}$ = 2.53, p = 0.04) between W16 and S16 between 45 and 470 days since burning. When analyzed separately, W16 forage standing crop composition had a greater probability of being significantly different over time ($F_{6,6}$ = 5.51, p = 0.01) than S16 burn treatment ($F_{6,6}$ = 2.15, p = 0.07).

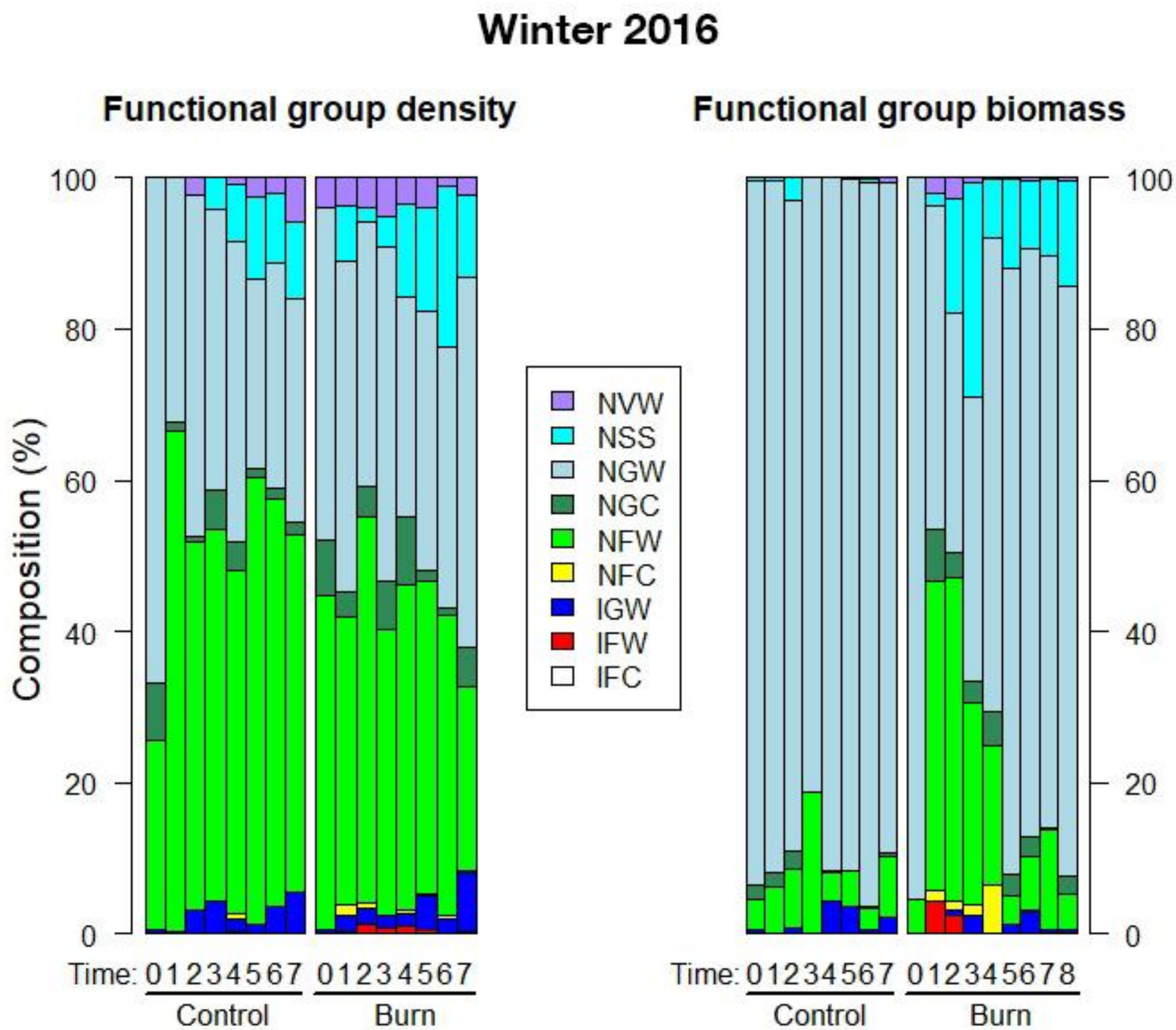

Figure 22. Composition of functional groups in control patches (3 and 7) and W16 burn (9 and 10). Represented is percentage of functional groups at each sampling period from period 1 (approximately 45 days after the burn) to period 8 (approximately 635 days after the burn).

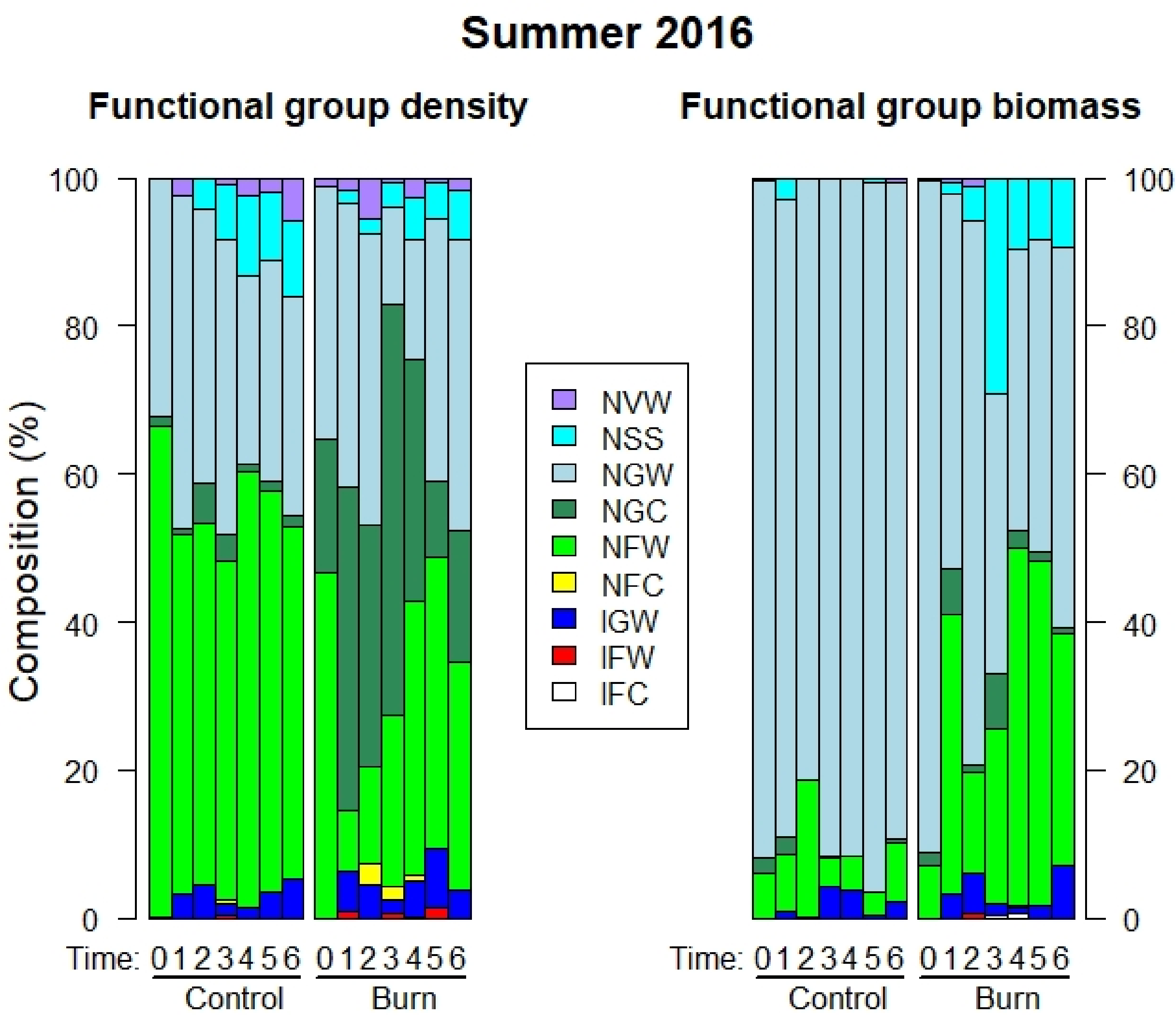

Figure 23. Composition of functional groups in control patches (3 and 7) and S16 burn (2 and 6). Represented is percentage of functional groups at each sampling period from pre-burn to period 6 (approximately 470 days after the burn).

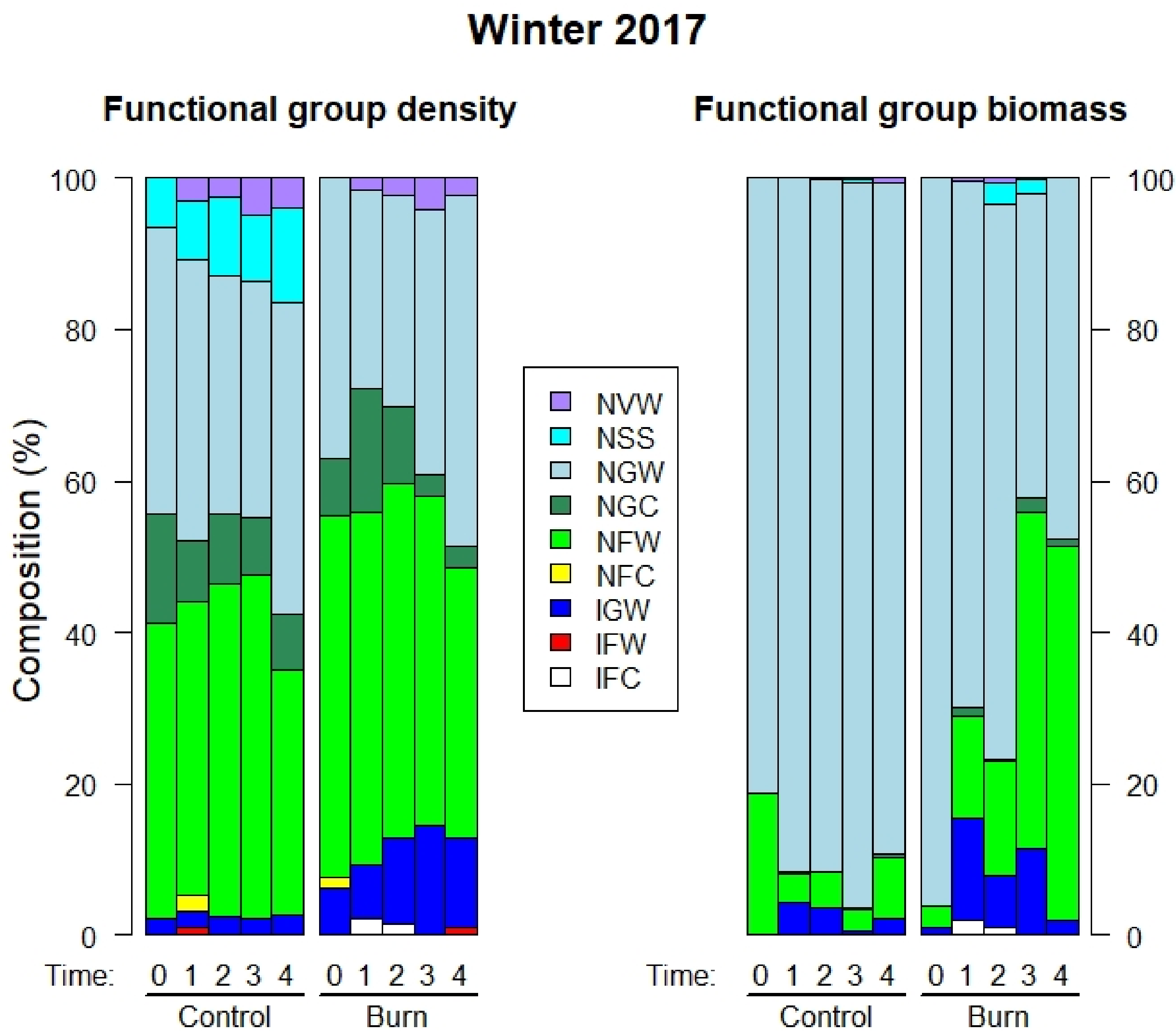

Figure 24. Composition of functional groups in control patches (3 and 7) and W17 burn (1 and 5). Represented is percentage of functional groups at each sampling period from pre-burn to period 4 (approximately 300 days after the burn).

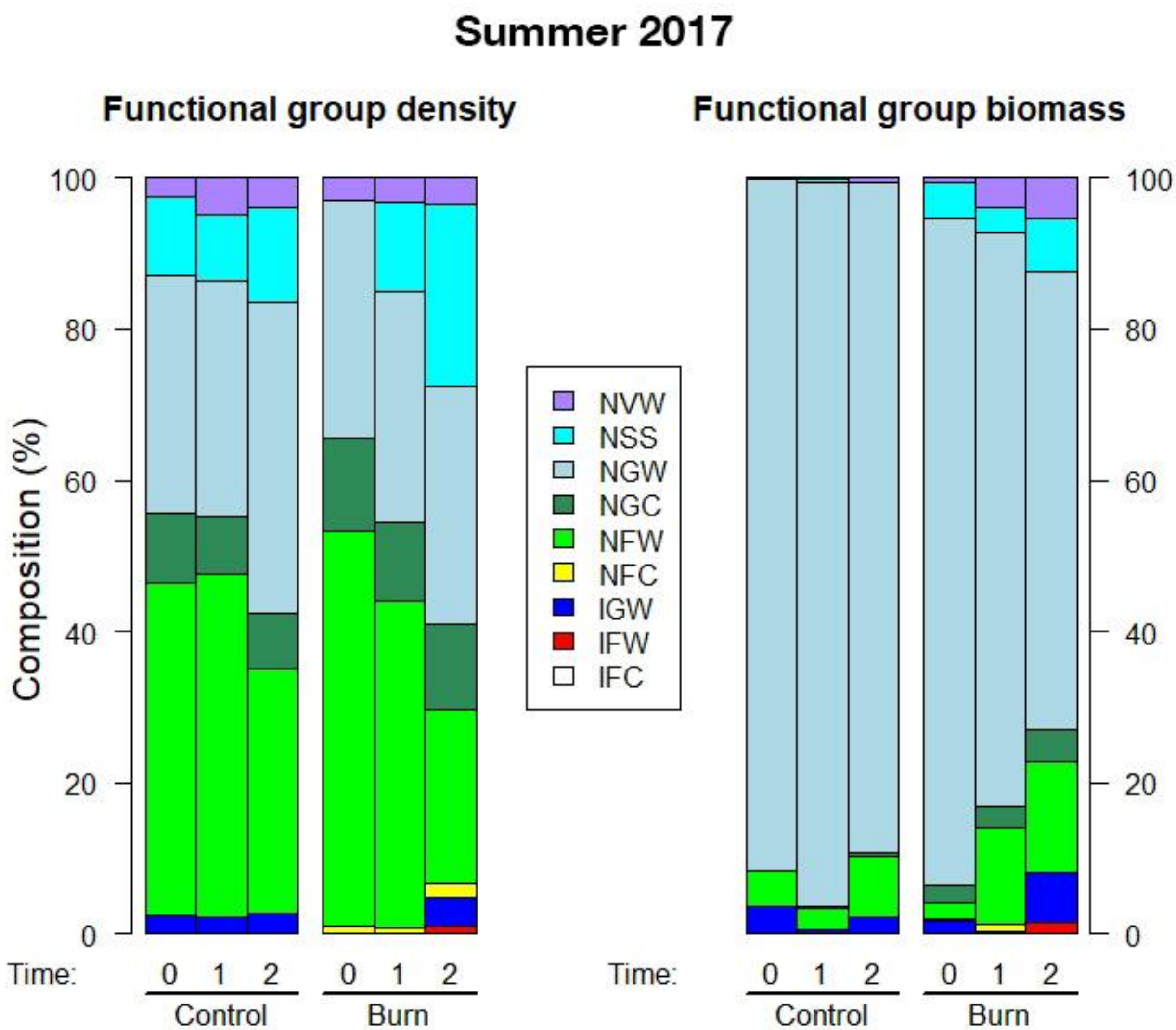

Figure 25. Composition of functional groups in control patches (3 and 7) and S17 burn (4 and 8). Represented is percentage of functional groups at each sampling period from pre-burn to period 2 (approximately 90 days after the burn).

DISCUSSION

Burning and Weather Conditions

Precipitation

Precipitation received during years 2016 and 2017 was similar in amount, but distribution throughout the year was different. In 2016 there were more intense, short rainfall periods, while in 2017 rains were distributed more evenly throughout the various seasons and months. On average for both years, precipitation received was approximately 73% of the 10-year average, meaning that the study was conducted during a moderate drought (55 – 86 % of the average rainfall) according to Norwine and Bingham (1986).

Soil moisture

Soil moisture content was considerably higher for winter burns than summer burns in 2017. This coincides with findings of several other studies of Gulf cordgrass in San Patricio County, Texas, that also found soil moisture in Gulf cordgrass stands was higher during fall and winter than summer (Angell *et al.* 1986, Garza *et al.* 1994 and Britton *et al.* 2010). However, a study on Gulf cordgrass in Kenedy County, Texas, reported the opposite, where soil moisture was higher during summer rather than winter (Oefinger and Scifres 1977).

The burn patches of Gulf cordgrass in this study were primarily located in sandy loam soils. According to Oefinger and Scifres (1977), soil moisture content depends highly on soil type; they reported higher soil moisture on alkali sandy loam sites (14 and 12.5%) compared to loamy sand sites (10%) in burns that took place during October and November. Water holding capacity in these types of soils ranges from 0.75 inches of water per foot of soil in fine sand to

1.40 in sandy loam soils, drying up or percolating through soils rather quickly. This is why it is important to study recent rainfall closely before deciding to conduct a prescribed burn.

Sharrow and Wright (1977) studied on tobosagrass (*Pleuraphis mutica* Buckl.) production in Mitchell County, Texas. They found that soil moisture decreased by transpiration of faster growing plants, rather than evaporation because litter and plant top growth are removed by burning. This finding is similar to Hulbert (1969), who studied fire and litter effects on bluestem prairies in Morris and Dickinson Counties, Kansas. Additionally, soil moisture is lower in burned patches compared to non-burned patches, because litter slows evaporation of water from the soil and plants are not as active as when they are regrowing after having been recently defoliated.

Fire temperatures

In this study, fire temperatures were not different from season of burn between winter and summer burning. This tells us that summer burns are not "cooler" or "hotter" than a winter burn, despite having higher air temperatures and relative humidity in summer than winter.

Density, Recruitment and Mortality

Gulf cordgrass plant density and recruitment

Gulf cordgrass density ranged from 34,063 plants per hectare in W17 burn patches to 57,500 plants per hectare in W16 burn patches before burning. This density is high compared to Scifres and Drawe (1980) who reported ranges averaging from 2,500 to 7,000 plants per hectare of Gulf cordgrass plants in Kenedy County, Texas.

Seedlings of Gulf cordgrass plants were almost absent for the length of the study. Oefinger and Scifres (1977) discovered wet and saturated soils were often necessary for full development of a Gulf cordgrass community in Kenedy County, Texas. My annual rainfall for the two years of this study was roughly 73% of the average rainfall, which could explain the absence of Gulf cordgrass seedlings in both burned and non-burned patches.

Gulf cordgrass plant mortality

Findings of my study show that season of burn does not significantly affect Gulf cordgrass mortality for the first burn conducted in many years. Past studies have indicated summer burning would be expected to result in higher mortality, possibly because of higher daily temperatures and lower soil moisture to support regrowth of the plants after fire (Fulbright and Ortega 2013, Hernandez and Guthery 2012, and Wright and Bailey 1982).

Gulf cordgrass mortality on non-burned patches was low, with presence of dead plants only occurring in winter 2016 (1.1 %) and summer 2017 (0.7 %). A study by Zimmerman *et al.* (2010) of silky bushman grass (*Stipagrostis uniplumis* (Licht.) De Winter var. *uniplumis)* in Namibia, showed that even in the absence of fire there was high mortality in grasses (31%) due to a high amount of dead forage standing crop and litter that created competitive pressure. Chamrad and Box (1965), in San Patricio County, Texas, reported a mortality of 76.8% for seacoast bluestem and 63.8% for brownseed paspalum following a drought on similar soils as in my study (sandy loam).

Little research has been done on Gulf cordgrass plant survival and mortality dynamics. Gulf cordgrass mortality following burning in this study was relatively low compared to other species and studies. Scifres and Duncan (1982), studied brownseed paspalum response to season of burning near Brazos County, Texas. They reported much higher plant mortality during summer (93%), fall (50%), spring (8%), and early spring burning (24%) than in control areas.

Sanders (2000) reported that June and July burning caused more damage to bunchgrasses compared to spring and fall burns in sagebrush-grasslands in the Intermountain Region. My study did not show any overall differences in Gulf cordgrass plant mortality between seasons. However, the summer 2016 burn treatments did produce significantly higher Gulf cordgrass mortality than the other three burn treatments when compared individually. I also compared fire temperatures of each burn and did not find the summer 2016 burn treatment to be significantly higher than the other burn treatments. However, rainfall during the 30 days prior to burning was only 0.4 mm before the summer 2016 burn treatments, which was much less than rainfall prior to the other burn treatments. This indicates adequate rainfall before burning is crucial for Gulf cordgrass plant survival along the southern Gulf coast of Texas.

My results did show a positive relationship between peak fire temperature and Gulf cordgrass plant mortality, as well as duration of heat over 65°C and Gulf cordgrass plant mortality, regardless of season of burn. Permanent damage to vascular plant tissue and plant mortality depend on many factors such as species, fuel moisture, fire temperature, duration of heat, physiological stage and form, tolerance to fire, *etc*., (Wright 1971, Wright and Bailey 1982). Several authors have reported that a temperature of 60°C from a 2 to 60 minute period is a thermal death point for most plant tissues (Hare 1961, Kayll 1966, Wright 1970). Mean peak fire temperatures recorded in this study regardless of season of burn were 446.9° C and higher; and 86% of transects burned (14 transects with temperature data) received from 10-57 minutes of heat over 65°C, enough heat and time to cause permanent damage to vascular plant tissue.

I also used logistic regression with duration of heat in minutes over 65°C and percent mortality of Gulf cordgrass. I found that odds of mortality of Gulf cordgrass plants dying was more directly correlated to duration of heat over 65°C than peak fire temperature. Odds of mortality increased 59% for every 10-minute increase in time over 65°C, while odds of mortality increased 5.5% for every 10°C increase in temperature. A study of squirreltail (*Sitanion hystrix* (Nutt.) J. G. Smith) and needle-and-thread (*Stipa comata* Trin. and Ruper.) by Wright (1970), explained that mortality of plant tissue also depended on plant morphology and fuel moisture content, and was a function of temperature and duration or time.

Forage Production

Forage production depends on many factors including plant competition, season, precipitation, soil moisture, forage disappearance, *etc*., (Holecheck *et al.* 1995). Forage production of Gulf cordgrass varied from patch to patch regardless of season and year. The lowest forage production was 2.1 kilograms per hectare per day while the highest was 26.2 kilograms per hectare per day over 3 months following burning. Scifres *et al.* (1980) in Kenedy County, Texas, reported a low average of 6 kilograms per hectare per day and a high of 46 kilograms per hectare per day over a span of 13 months. A study of Gulf cordgrass nutritive content following winter and summer burning on the same study site as mine, indicated crude protein decreased and fiber content increased for approximately 20-40 days following a burn, causing ungulates to select for higher quality and more palatable forage (Haynes 2018). A justification for increased forage production after the initial 40 days post-burning could be reduced use of Gulf cordgrass by grazers as it becomes coarser and lower in nutritive content over time. The differences in my mortality results following winter 2016 (9.5%) and summer 2016 (30.6%) burning may partially explain the increased forage production following winter 2016 (10.5 kg/ha/day) burning compared to summer 2016 (3.2 kg/ha/day) burning also. Lower mortality following winter burning in 2016 may have allowed Gulf cordgrass plants to grow more forage because a smaller percent of plants were killed, although this is contradictory to a finding by Rideout-Hanzak *et al.* (2011) in the Southern High Plains of Texas when they found perennial grass mortality was not linked to biomass following severe wildfire.

Gulf cordgrass forage standing crop long-term comparison for 2016 winter and summer burn treatments

I will refer to the comparison between the two first burn treatments in 2016 (winter and summer 2016) as “long-term,” because these two burn treatments were the patches with the longest sampling period (up to 470 days following burning), allowing me to compare differences in forage production for more than 90 days following burning. There was great deal of variation in pre-burn forage standing crop, but no significant difference between winter and summer 2016 burn patches. Following burning, winter patches had a faster recovery in forage standing crop growth than summer 2016. The increased growth of Gulf cordgrass at 215 and 300 days after burning in winter 2016 can be supported by Garza *et al.* (1994) who reported Gulf cordgrass clipped at 10 cm had increased growth from spring to the end of summer. However, other findings from McAtee *et al.* (1979) indicated the opposite trend. They found that Gulf cordgrass reached its pretreatment forage standing crop levels after 5 months (95% of pretreatment forage standing crop) following a burn in July compared to a December burn that regrew 89% of pretreatment forage standing crop levels after 6 months. In my study Gulf cordgrass forage standing crop did not reach pretreatment levels for at least 635 days following burning.

Although long-term Gulf cordgrass forage standing crop in control patches was higher than the 2016 burn treatments over a span of 15.5 months (39,459.82 kg/ha non-burned compared to 9,462.44 kg/ha and 6,899.75 kg/ha for summer and winter, respectively), utilization in burn patches (69%) was higher than in non-burned patches (10%) at the same study site over the same period according to Haynes (2018). Oefinger and Scifres (1980) reported forage standing crop of Gulf cordgrass of 21,500 kg/ha in a span of 13 months in Kenedy County, Texas. Therefore, burning Gulf cordgrass in either season after many years of no burning, should enhance production and utilization of more nutritious and palatable forage by grazing ungulates.

Functional Group Composition

Percentage of functional groups for density composition depended partially on the amount of species that were included in each group; there was higher density in groups with a higher number of species. Additionally, smaller plants that occurred often increased the percent density of a group. In contrast, forage standing crop composition indicated a relative amount of forage standing crop available from each functional group. In this comparison large plants such as Gulf cordgrass created a majority of the forage standing crop changing the relative amounts of the functional groups. This is a result of low-density plants with high weights, and high-density plants with low weights (such as forbs). Both comparisons give important insights into changes that occur after burning, as different plant types exert their dominance or presence at various times following burning.

The temporary removal of litter and excess growth of mature Gulf cordgrass allowed other species and functional groups to increase in relative density and forage standing crop. It also allowed for increased production of seedlings of suppressed grass species and forbs. These findings are supported by Shay *et al.* (2001) who found that burning in consecutive years in Manitoba mixed prairies reduced litter and allowed increases in species relative abundance. West and Hassan (1985) reported that after a wildfire in a sagebrush-grass, perennial bunchgrass production nearly returned to pre-burn amounts within two years. Wright (1974) found that two bunchgrasses, side-oats grama (*Bouteloua curtipendula* (Michx.) Torr.) and Texas wintergrass

(*Nassella leucotricha* (Trin. & Rupr.) Pohl.), took at least 2 years to fully recover following fire in the High Plains and Rolling Plains of Texas. Brockway *et al.* (2001) indicated herbaceous plant species richness increased following a dormant season burn compared to a decrease following a growing season burn, which was possibly even detrimental to the plant community, in northeastern New Mexico.

When forage standing crop in the two treatments with the longest time since burning were compared (W16 and S16 with 6 total sampling dates including pre-burn [470 days]), I noticed a difference both statistically and biologically. Winter and summer 2016 responded similarly for the first 90 days since burning, but by day 405 after winter 2016 burning forage standing crop composition shifted back to pre-burn levels. Meanwhile in summer 2016 patches NFW and NSS relative forage standing crop were still high compared to pre-burn conditions for the next winter-spring, and summer-autumn growing seasons. Variation between the two treatments may be caused by several factors, 1) winter burning did not negatively affect Gulf cordgrass. Therefore, after winter burning Gulf cordgrass gained a competitive advantage over other species suppressing other herbaceous plants. 2) if Gulf cordgrass was not suppressing other vegetation following summer burning, other species gained competitive abilities to grow and reproduce long enough to be detectable for the rest of the sampling period. Winter and summer 2017 treatments did not have enough post-burn data sampling dates to be compared to 2016 burn treatments.

CONCLUSIONS

There was no difference in fire temperatures between winter and summer burning despite having higher ambient temperatures and relative humidity in summer than in winter. Ambient conditions do not necessarily affect fire temperatures. Rainfall received during the length of the study (two years) was approximately only 73% of the annual average rainfall, indicating a moderate drought. Rainfall patterns were different between the two years, however, which illuminated effects of fire during different rainfall patterns before and after burning on this vegetation community.

There was no statistical difference in Gulf cordgrass plant mortality between winter and summer burn treatments overall. However, the burn treatments with the highest percent mortality were summer 2016 treatments, and that corresponded to almost absent rainfall 30 days prior to burning. There was a strong positive relationship between plant mortality and peak fire temperature, and plant mortality and duration of heat over 65°C, regardless of season of burning. Gulf cordgrass plant mortality was higher in burned patches compared to non-burned patches, thus fire did cause some mortality.

Forage standing crop growth models indicated that forage standing crop increased as days after burning progressed. Growth did not depend upon season of burn for Gulf cordgrass, herbaceous vegetation other than Gulf cordgrass, or total forage standing crop. Forage production for approximately 90 days following burning was similar between burn treatments. However, forage production was different between seasons in the two long-term data sets (>90 days after burning to 470 days after burning). Gulf cordgrass forage regrew faster from 215 to 300 days following burning in winter patches, but by 405 days following burning there was no difference between winter and summer 2016 burning treatments.

The combination of removal of both litter and excess growth of mature Gulf cordgrass, resulting increase in space, and possible increases in available water and nutrients to remaining plants after prescribed burning is likely what allowed other functional groups to increase in their relative density and forage standing crop, compared to the pre-burn sampling date and non-burned treatment patches. NMDS ordination of forage standing crop functional group composition showed greater fluctuation and movement following burning than in density of functional group composition. Regardless of season, forage standing crop functional groups of NFW and NSS increased in their relative abundance following burning. There was no difference between season of burn in forage standing crop functional group composition, and plant species richness for at least 90 days following burning. At 405 days after burning functional group composition of winter patches transitioned back to be similar to functional group composition of non-burned patches, while summer patches held their post-burn functional group composition for the length of the study (to 470 days following burning).

MANAGEMENT IMPLICATIONS

I used prescribed burning in the South Texas Gulf prairies and Marshes ecoregion in both winter and summer months as a range improvement. Historically, summer burns may have been conducted for insect control, and winter burns for foraging cattle and wildlife (Scifres and Drawe 1980). Determining which season to burn depends on each land manager's objectives.

Native Americans and early settlers burned pastures at high frequencies possibly as short as 1-2 years for various specific reasons mentioned in literature review (Scifres and Drawe 1980). However, frequency of fire cannot be set by time alone. Factors such as precipitation or drought, wildlife presence, and livestock stocking density must be considered. Failing to make these considerations could cause stress to vegetation and fauna present and may reduce usable forage of native grassland species.

Environmental conditions during summer burn treatments included higher ambient temperatures and relative humidity than winter burns. However, these environmental differences do not equate to different burn intensities between seasons. Regarding manpower and ease of burning large patches (*e.g.*, 200 to 300 hectare patches), it is less physically demanding and fatiguing to burn during late fall or winter because ambient temperatures are lower, compared to summer burning when temperatures are higher and the wind is hot and humid. Cool season burning could allow for large patches to be burned with smaller crews, fewer breaks, and less risk of injury or illness to crew members compared to summer burning. Burning during winter with lower relative humidity also may allow for more even and complete burns compared to summer burns that may burn in a patchy pattern.

From the results of this study, I found that rainfall prior to burning is essential for plant survival, accumulated rainfall of at least 38 mm for 30 days before burning will increase Gulf cordgrass plant survival after burning, by ensuring ample water in the soil for plants to initiate and sustain rapid growth. This will allow plants to recover faster following burning, gaining ground cover rapidly to aid with erosion control, and protecting the soil from being blown or washed away by constant south coastal winds or heavy rains.

A patch-burn grazing system is appropriate for Gulf cordgrass communities. Haynes (2018) results showed that Gulf cordgrass utilization was higher following burning of 69% (± 5.3) regardless of season, compared to non-burned patches 10% (± 7.5). Forage production for at least 90 days following burning was adequate, and correct stocking rate was not different between winter (3.82 ha/AU) and summer (3.86 ha/AU) for the first 90 days following burning. Thus burning in either season will provide enough Gulf cordgrass forage following the first burn after many years of no burning. Nutritionally, winter and summer burning both increased Gulf cordgrass nutritive content. Crude protein increased to roughly 15% at 30 days after burning in both winter and summer, later decreasing to 10% by 90 days after burning in both seasons (Haynes 2018). In conclusion, burning at least 150 hectares in Gulf Prairies and Marshes vegetation (Gulf cordgrass, seacoast bluestem, gulfdune paspalum, *etc*.) in either winter or summer after many years of no burning, will provide enough forage and nutritive content to sustain a healthy herd with lactating or non-lactating cows for at least 90 days following burning.

In a patch-burn grazing system cattle should theoretically move away from previously-burned patches onto newly burned patches allowing pastures to rest and increase fuels for future burns. If this does not occur, pasture deferral from grazing should be considered if planning to conduct a prescribed burn with short return intervals (≤ 3 years) in Gulf cordgrass grasslands. Allowing patches of Gulf cordgrass forage standing crop to increase and accumulate fuels and litter will provide fuel continuity and successful prescribed burns.

After a long period of no burning, prescribed burning in either winter or summer will increase valuable and nutritious forage of native, warm-season grasses (NGW, Gulf cordgrass dominated group) and important browse plants in the native, warm-season forbs (NFW) and native sub-shrubs (NSS) groups also. However, differences between the two seasons becomes more apparent following 405 days after burning, when patches burned in winter become more similar in functional group composition to non-burned patches, yet patches burned in summer maintain their post-burn functional group composition differences for a longer period (up to 470 days). This gives landowners options when choosing a specific season to burn or if patch-burn grazing is not their initial management strategy. Burning in winter will allow Gulf cordgrass to recover faster and maintain growing rapidly and producing sufficient forage for cattle up to 405 days after burning. Burning in summer will ~~produce~~ also provide enough forage for cattle, however, it will maintain post-burn functional group composition with important browse species for wildlife such as deer, nilgai and avian species for a longer time. It is important to note that these results can be expected with the first burn after a long period of no burning, but results may vary with continued burning over many years while holding season constant.

This mosaic type of disturbances (prescribed burning in this case) with varying seasons of burn, age classes of pastures, and numbers of livestock present results in increased structural heterogeneity. This, in turn, increases suitable winter and summer habitat for a wider variety of wildlife species, particularly bird species including grassland, shore, wading, waterfowl, migrating and resident birds (Hovick *et al.* 2014, Gabrey *et al.* 1999 and Baldwin *et al.* 2007). A Tews *et al.* (2004) review found a positive correlation between habitat heterogeneity and animal species diversity. In a patch-burning and grazing design such as this, cattle grazing following burning prolongs and intensifies the effects of the fire disturbance. Livestock move into newly burned areas (Haynes 2018) allowing non-burned areas to rest and allowing birds and other wildlife to nest or find cover in them.

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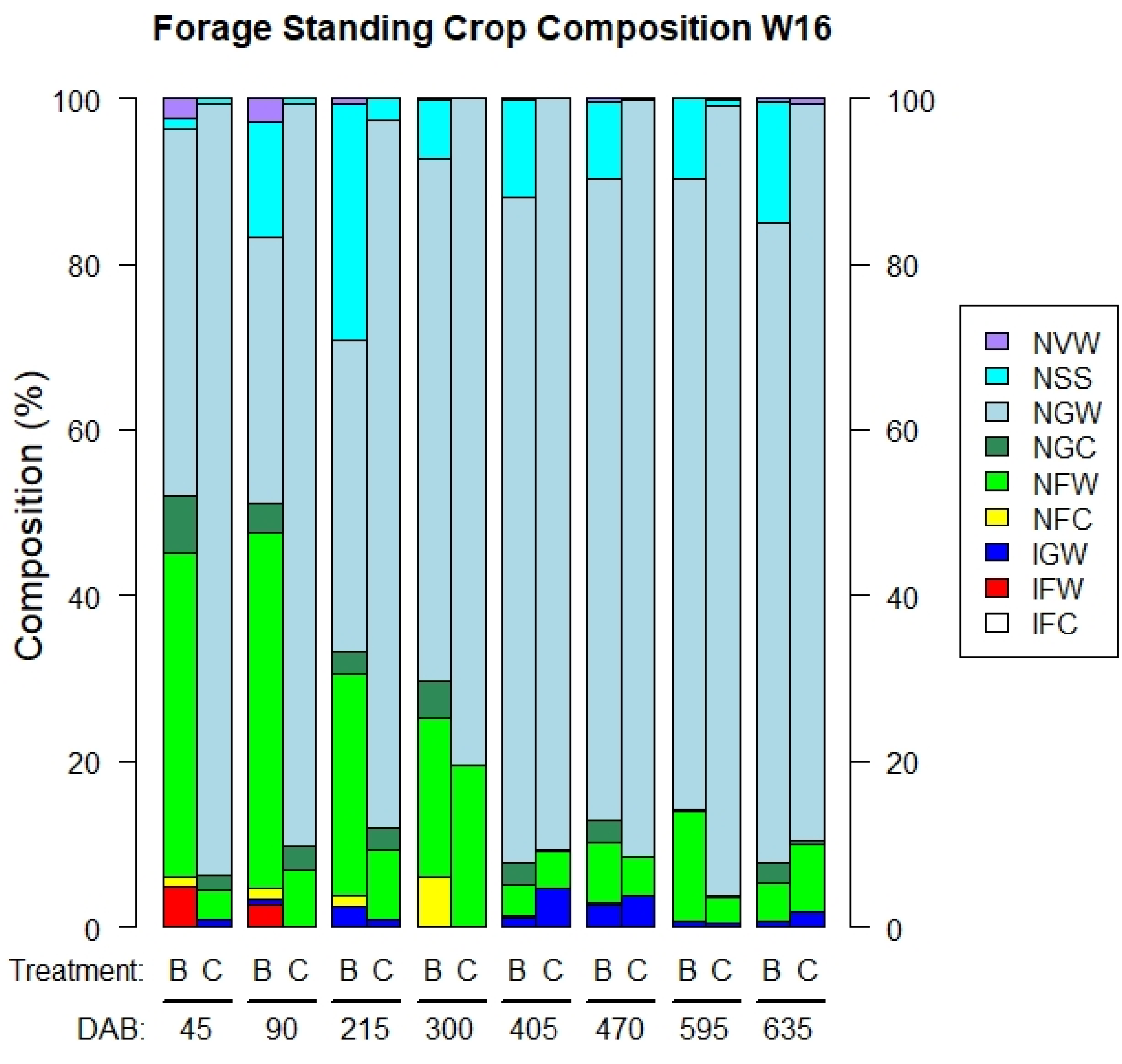
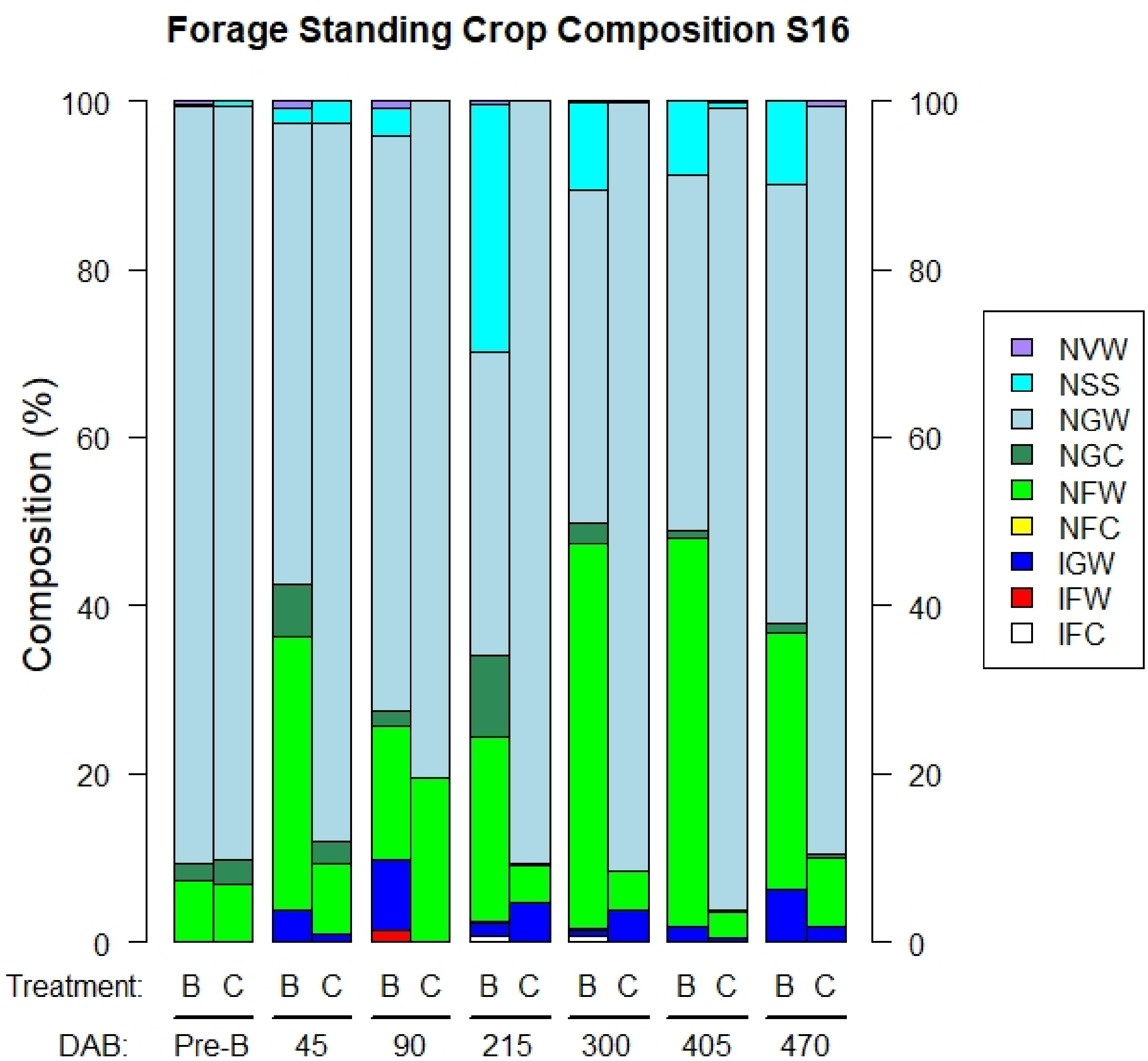
APPENDICES

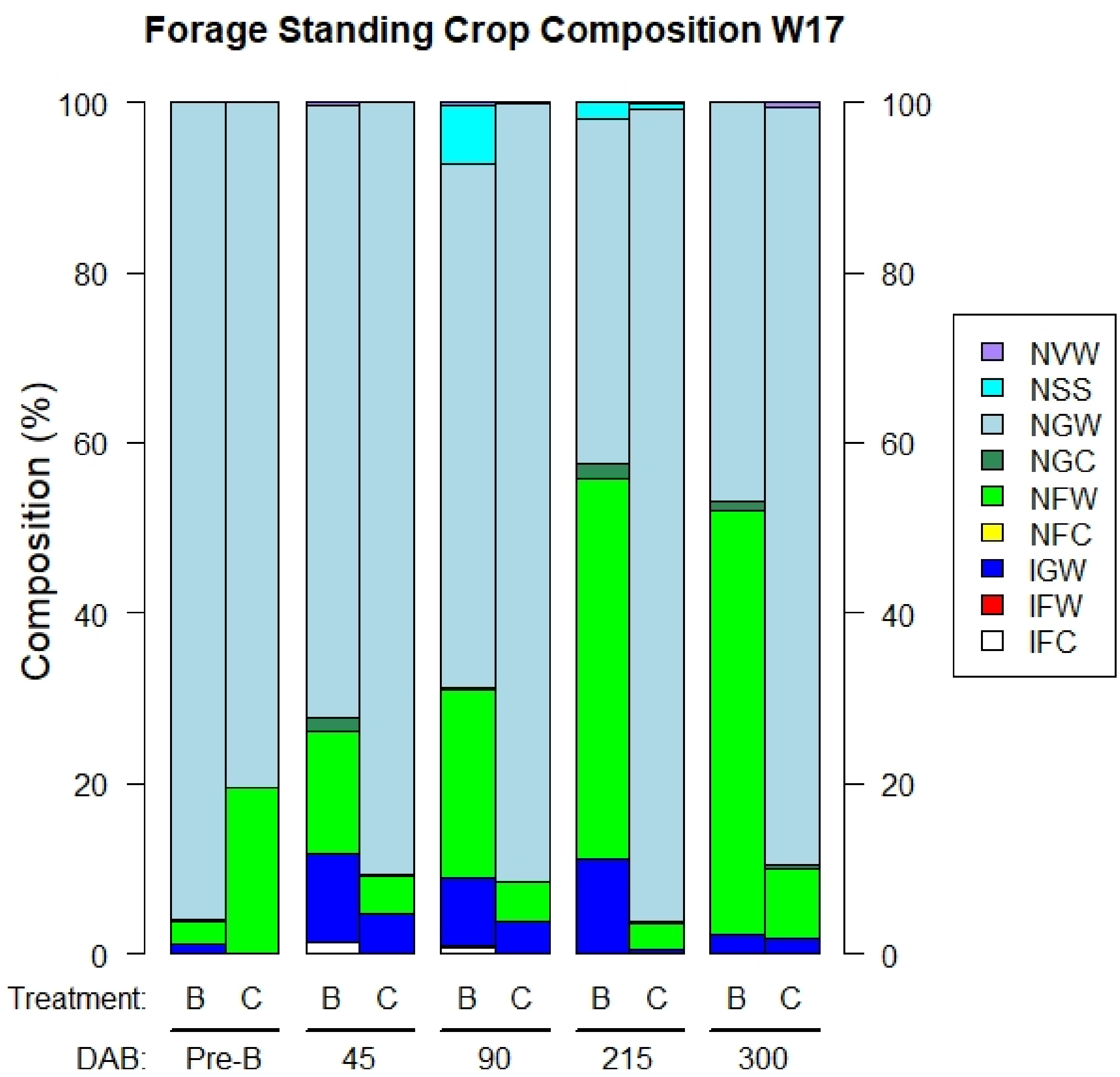
APPENDIX A SUPPLEMENTAL FIGURES



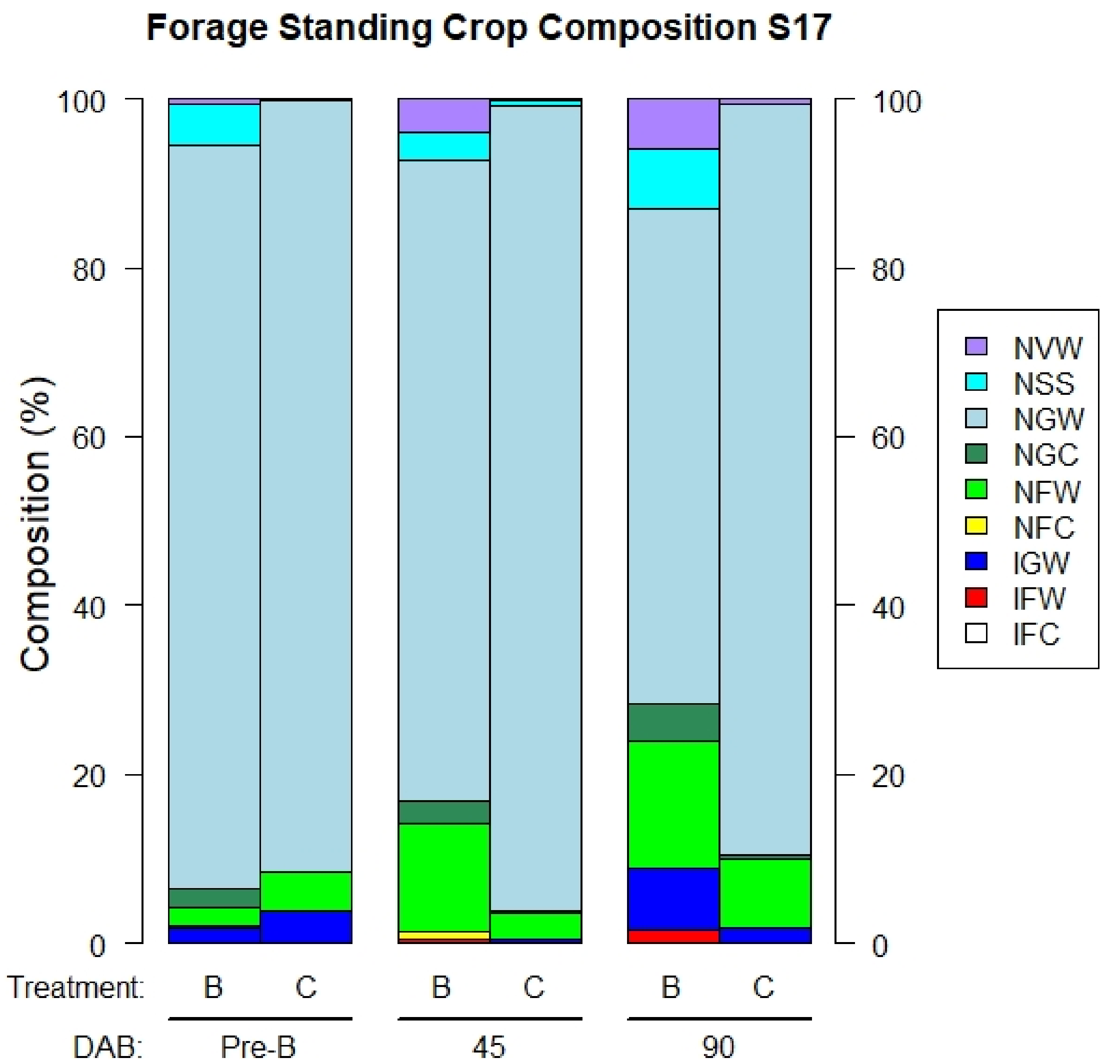
Appendix Figure A 1. Forage standing crop composition of functional groups in (B) W16 burn (9 and 10) and (C) control patches (3 and 7) side by side. Represented is percentage of functional groups at each sampling period and days after burn (DAB).



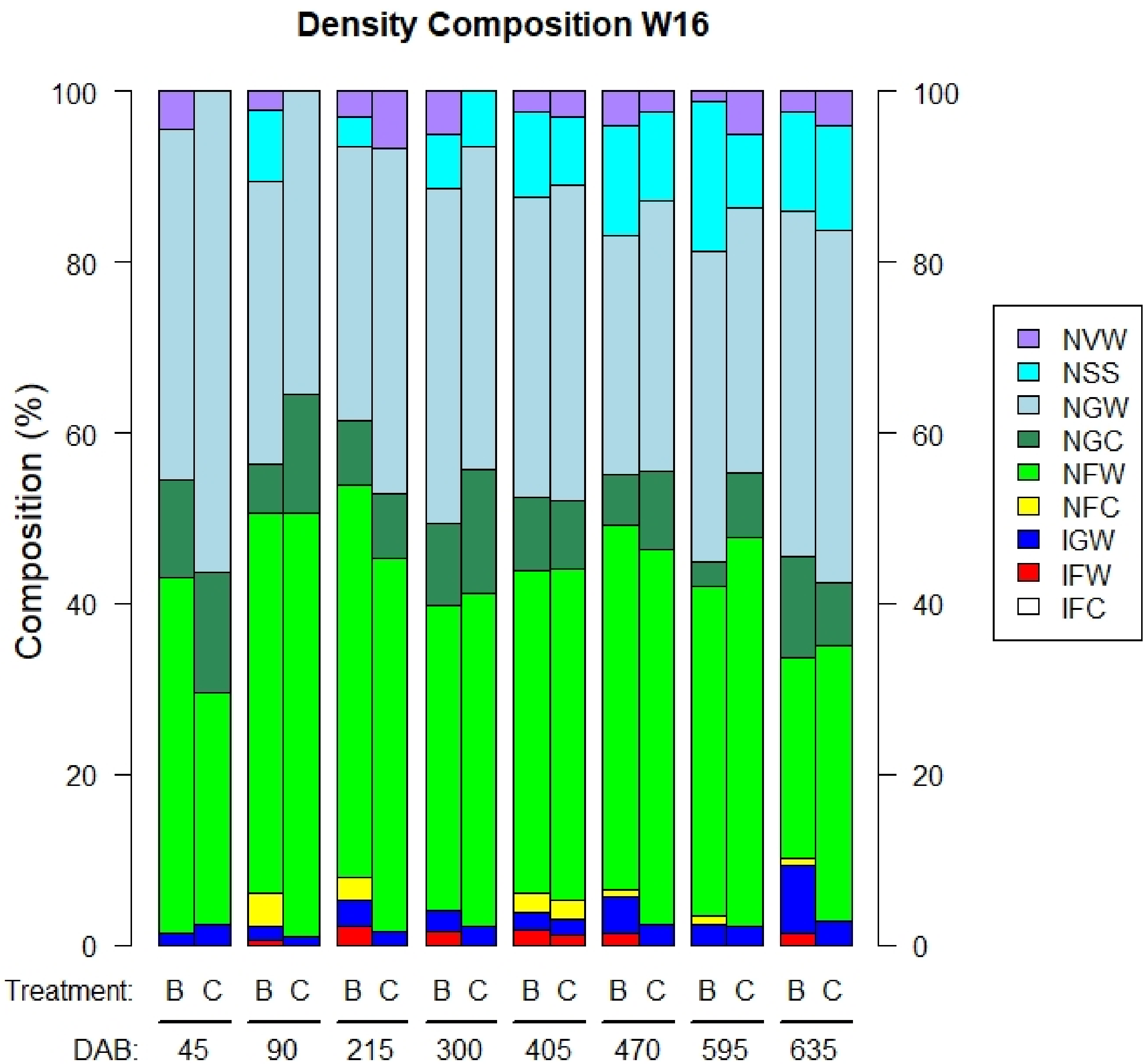
Appendix Figure A 2. Forage standing crop composition of functional groups in (B) S16 burn (2 and 6) and (C) control patches (3 and 7) side by side. Represented is percentage of functional groups at each sampling period and days after burn (DAB).



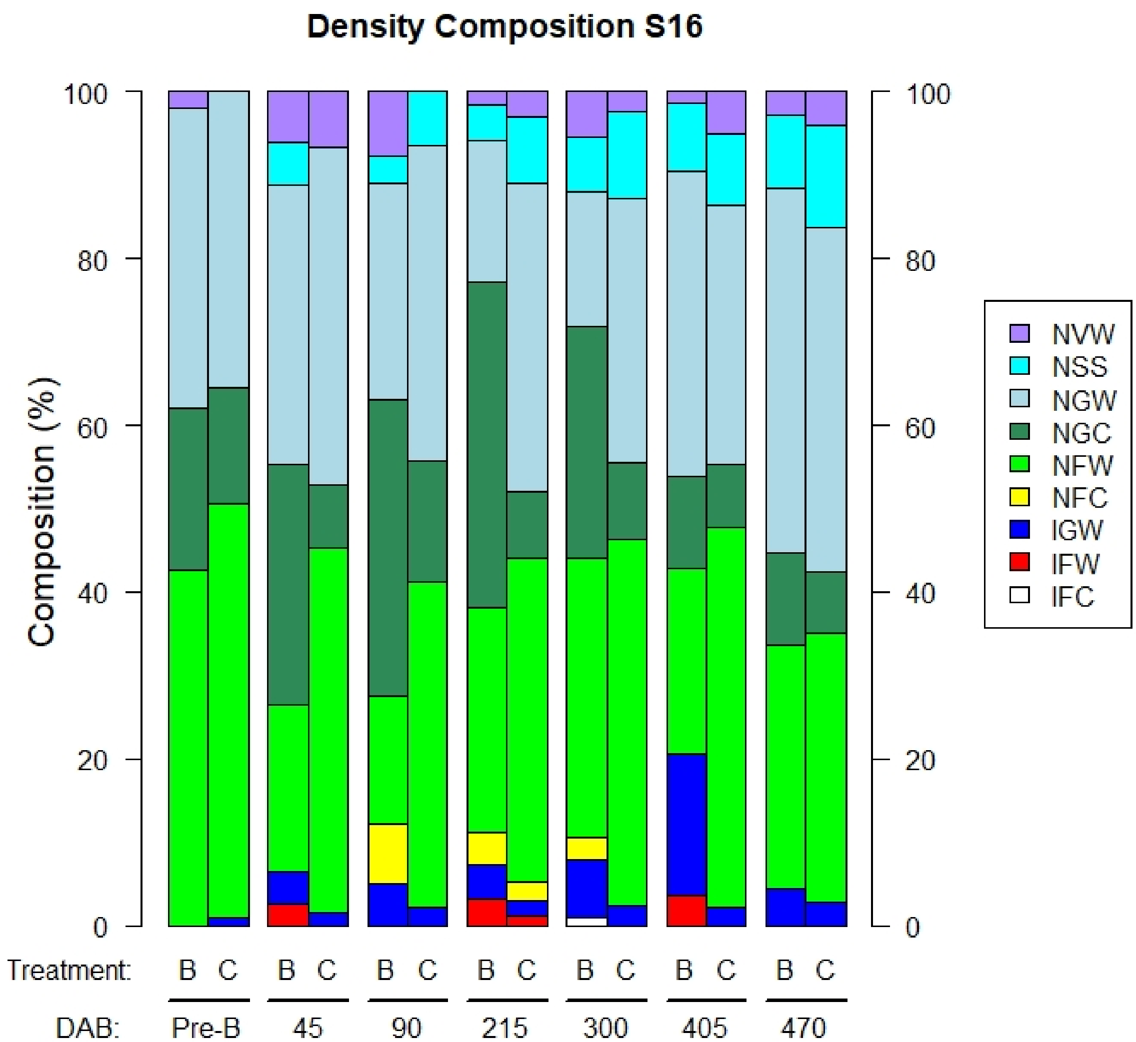
Appendix Figure A 3. Forage standing crop composition of functional groups in (B) W17 burn (1 and 5) and (C) control patches (3 and 7) side by side. Represented is percentage of functional groups at each sampling period and days after burn (DAB).



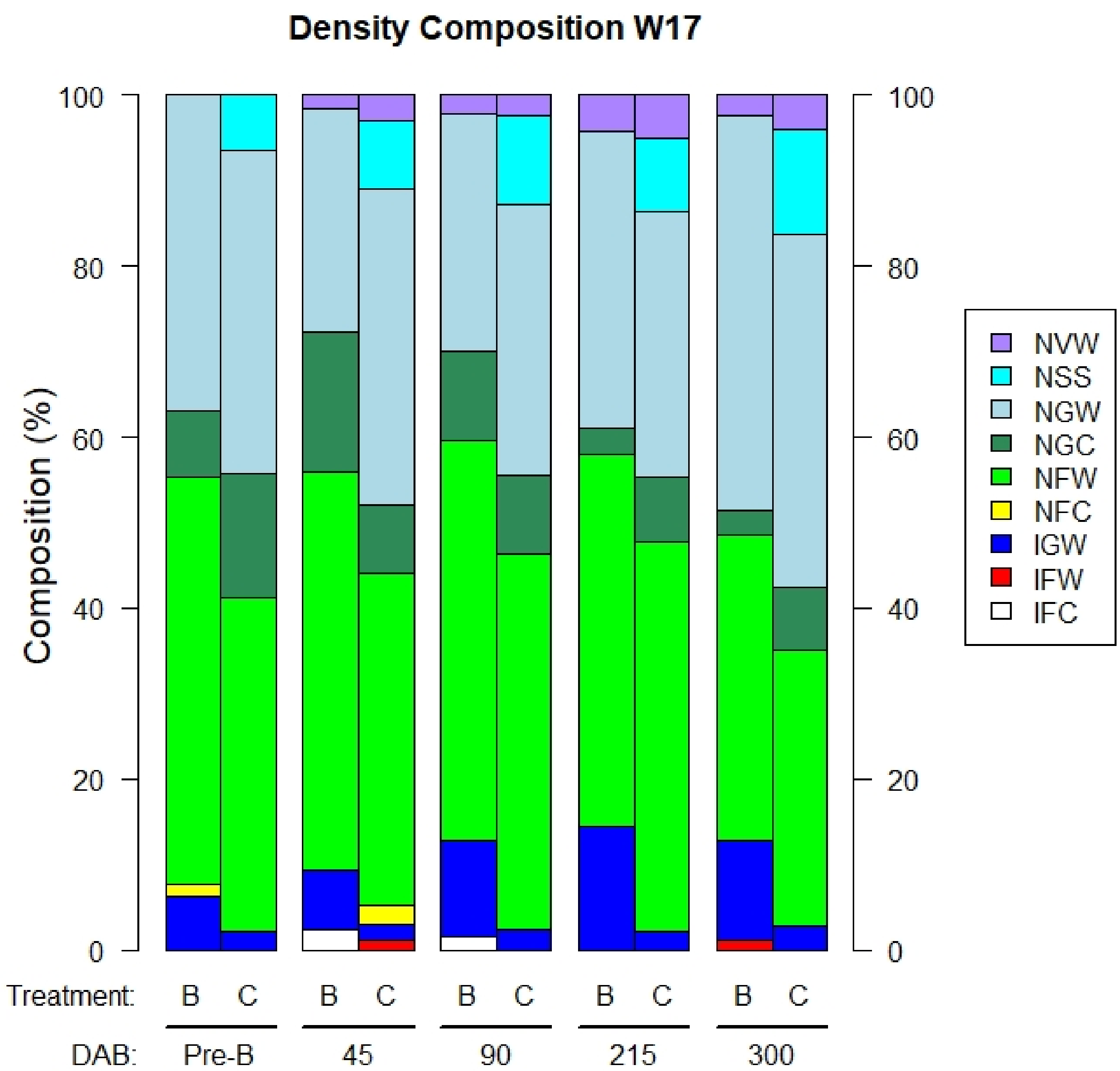
Appendix Figure A 4. Forage standing crop composition of functional groups in (B) S17 burn (4 and 8) and (C) control patches (3 and 7) side by side. Represented is percentage of functional groups at each sampling period and days after burn (DAB).



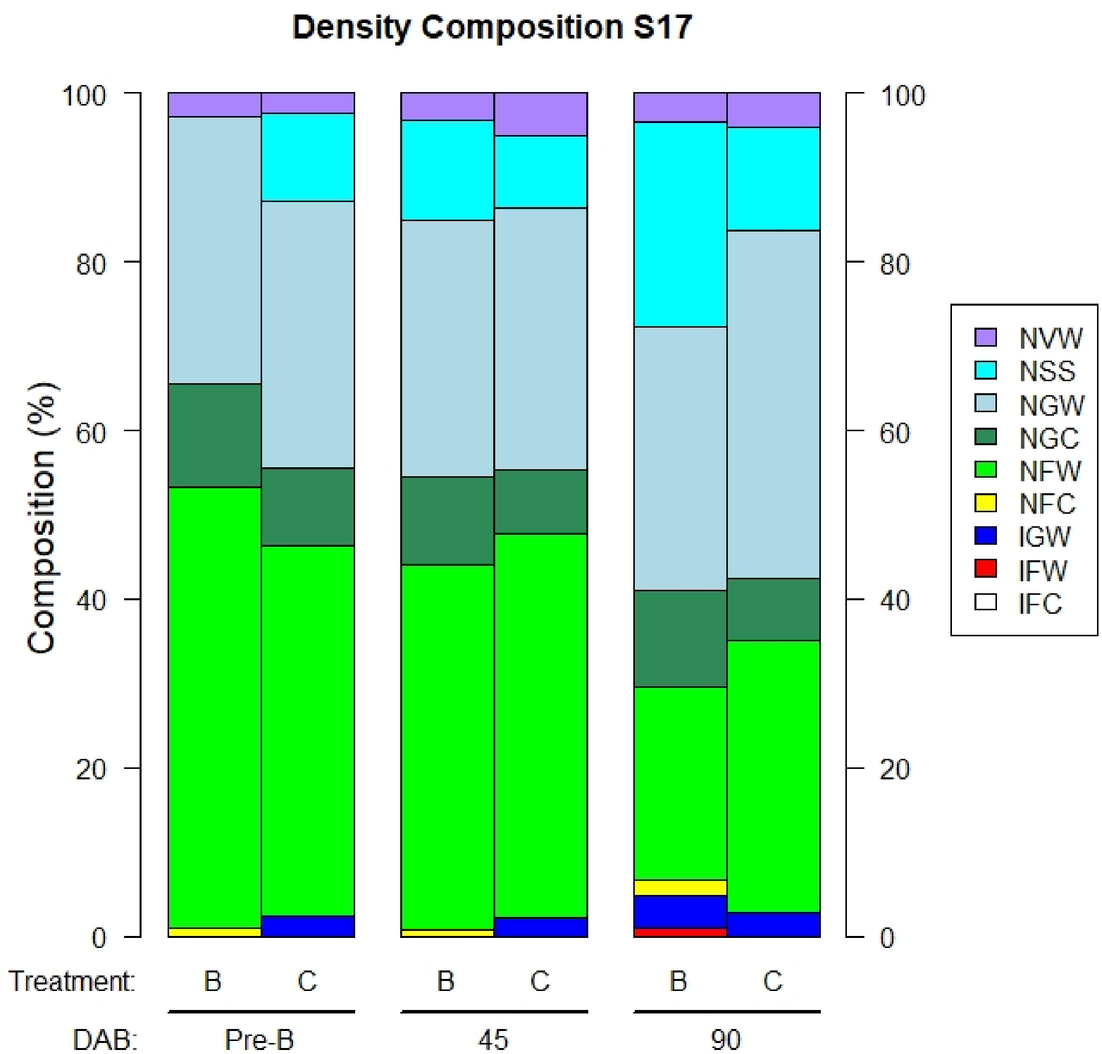
Appendix Figure A 5. Density count composition of functional groups in (B) W16 burn (9 and 10) and (C) control patches (3 and 7) side by side. Represented is percentage of functional groups at each sampling period and days after burn (DAB).



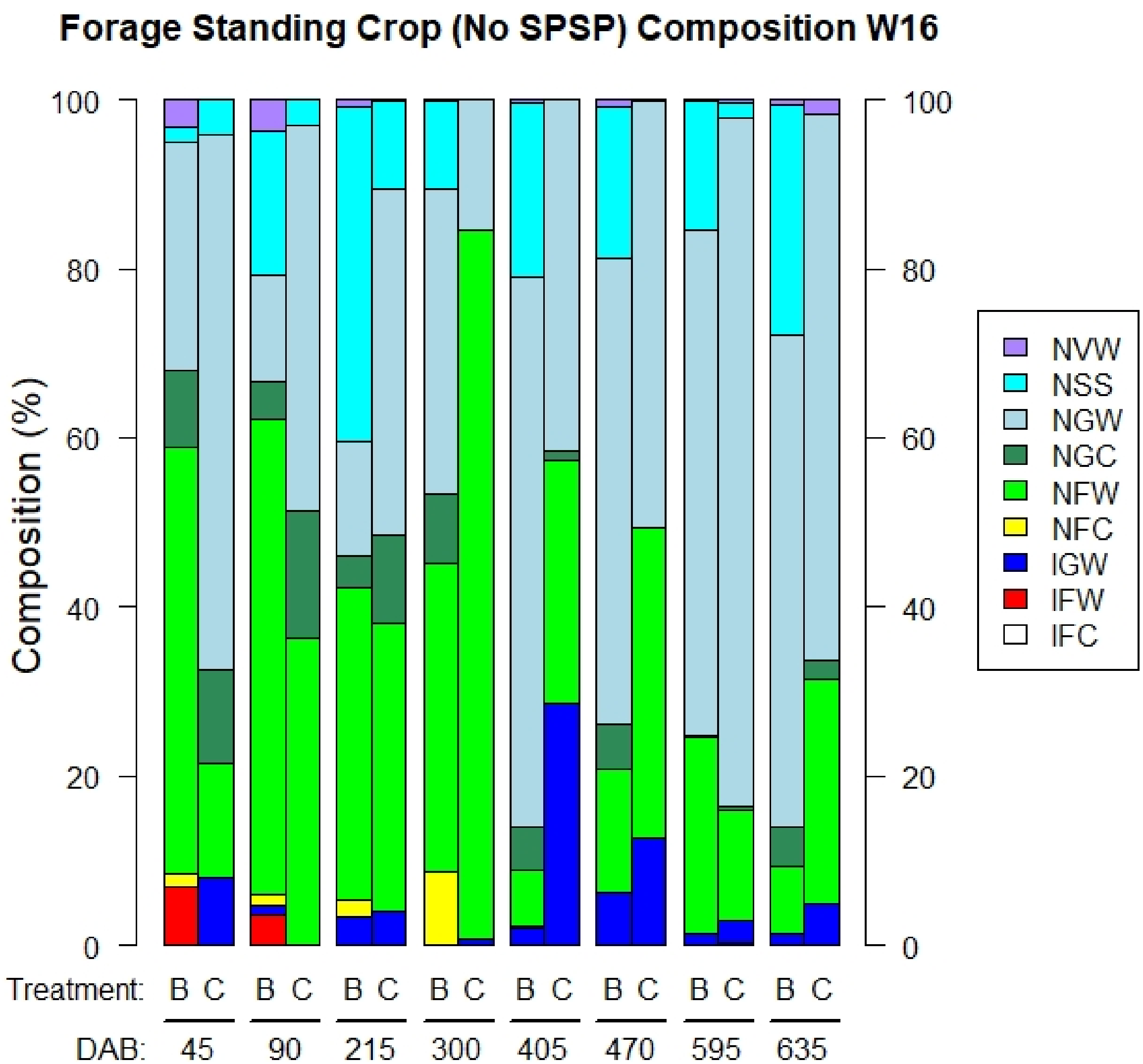
Appendix Figure A 6. Density count composition of functional groups in (B) S16 burn (2 and 6) and (C) control patches (3 and 7) side by side. Represented is percentage of functional groups at each sampling period and days after burn (DAB).



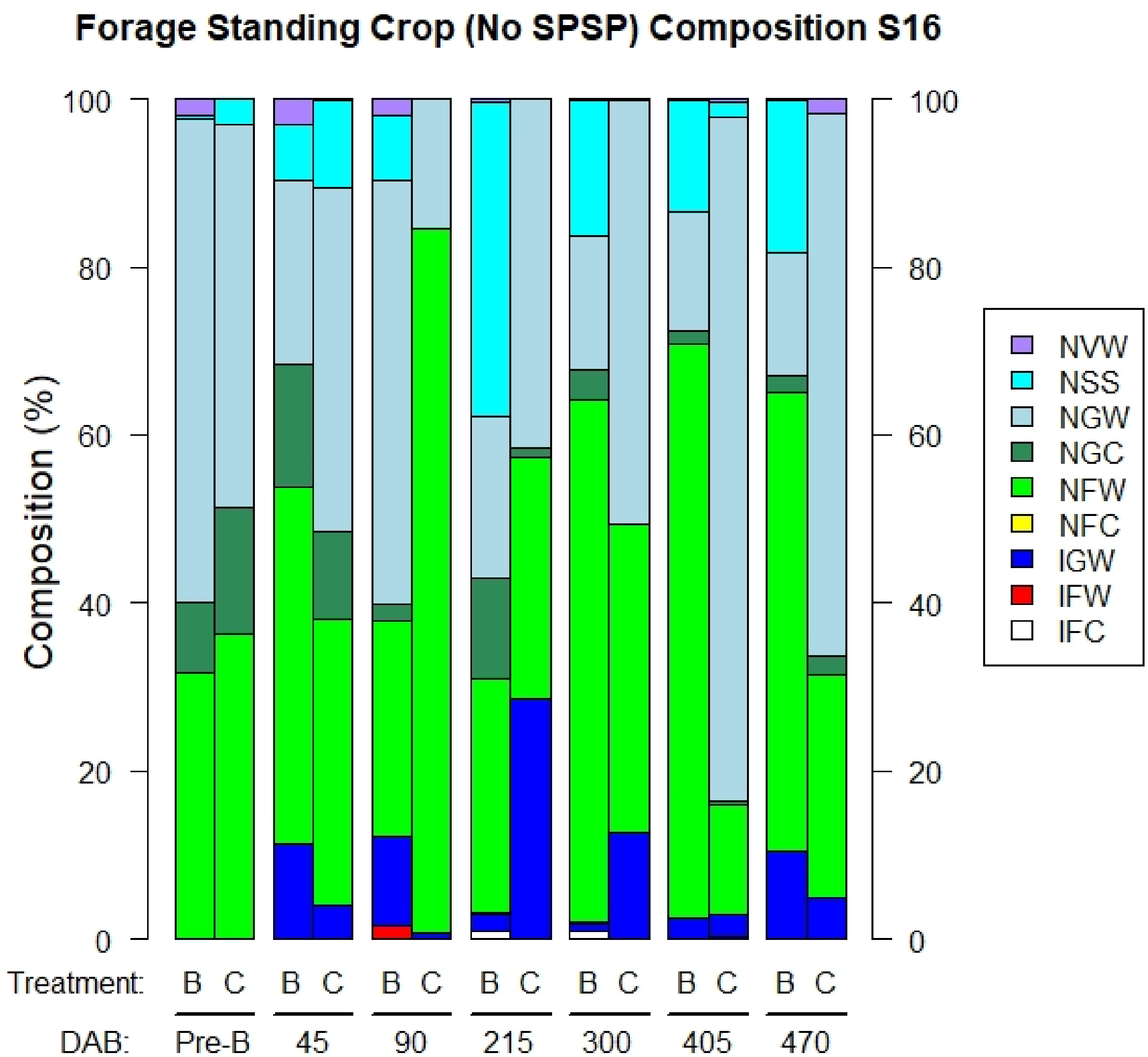
Appendix Figure A 7. Density count composition of functional groups in (B) W17 burn (1 and 5) and (C) control patches (3 and 7) side by side. Represented is percentage of functional groups at each sampling period and days after burn (DAB).



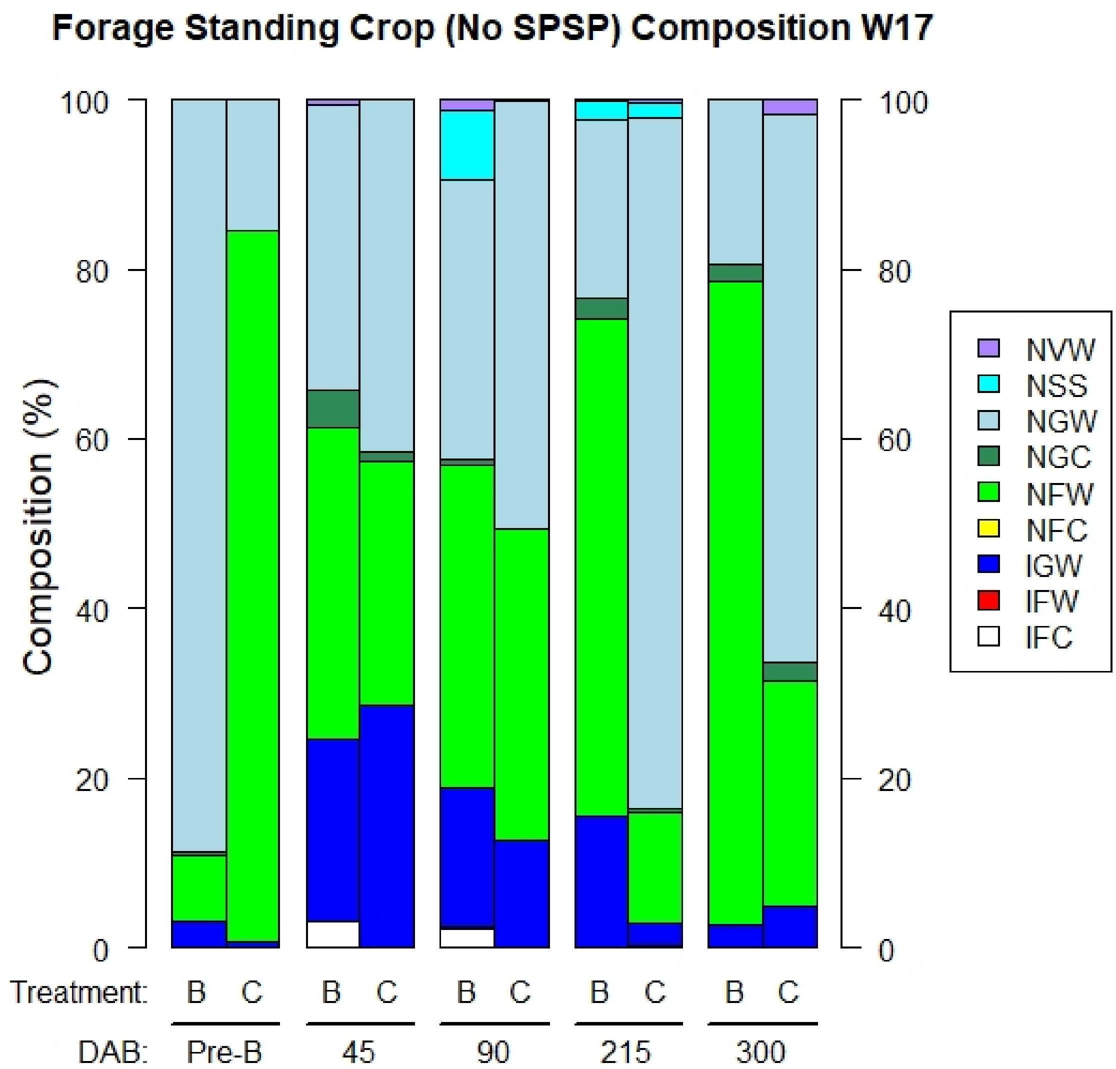
Appendix Figure A 8. Density count composition of functional groups in (B) S17 burn (4 and 8) and (C) control patches (3 and 7) side by side. Represented is percentage of functional groups at each sampling period and days after burn (DAB).



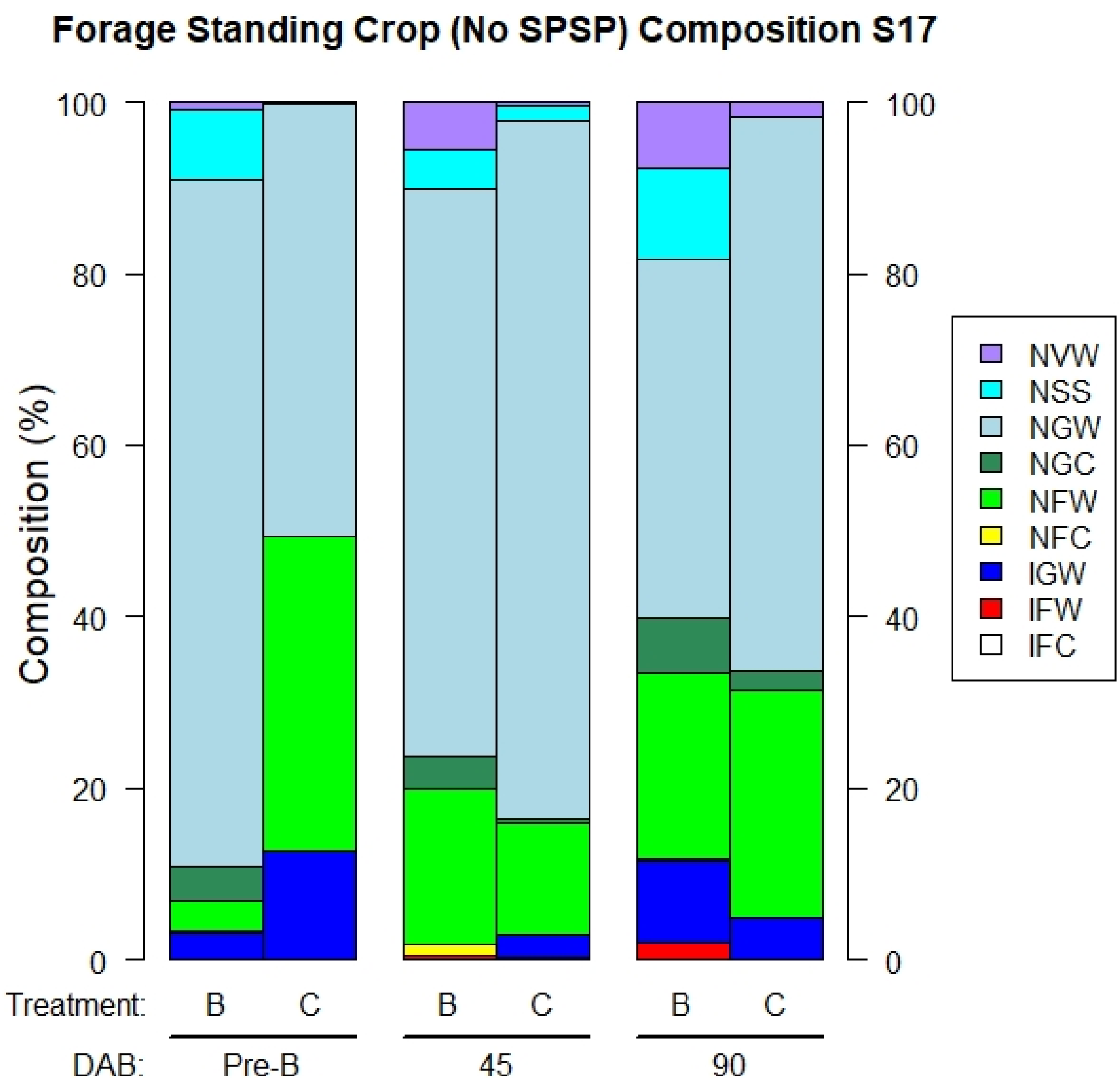
Appendix Figure A 9. Forage standing crop composition of functional groups in (B) W16 burn (9 and 10) and (C) control patches (3 and 7) side by side without Gulf cordgrass present in analysis. Represented is percentage of functional groups at each sampling period and days after burn (DAB).



Appendix Figure A 10. Forage standing crop composition of functional groups in (B) S16 burn (2 and 6) and (C) control patches (3 and 7) side by side without Gulf cordgrass present in analysis. Represented is percentage of functional groups at each sampling period and days after burn (DAB).



Appendix Figure A 11. Forage standing crop composition of functional groups in (B) W17 burn (1 and 5) and (C) control patches (3 and 7) side by side without Gulf cordgrass present in analysis. Represented is percentage of functional groups at each sampling period and days after burn (DAB).



Appendix Figure A 12. Forage standing crop composition of functional groups in (B) S17 burn (4 and 8) and (C) control patches (3 and 7) side by side without Gulf cordgrass present in analysis. Represented is percentage of functional groups at each sampling period and days after burn (DAB).

APPENDIX B SUPPLEMENTAL TABLES

Appendix Table B 1. Functional groups of individual species found in density and forage standing crop quadrats. Species were grouped into their resident status (Native or introduced), growth form (Grass and grass-likes, forbs, shrubs and subshrubs, or vines) and season of growth (Cool or warm season).

Functional Groups

IFC - Introduced Forbs Cool Season

Code	Scientific Name	Common Name
DAPU	*Daucus pusillus* Michx.	Wild carrot

IFW - Introduced Forbs Warm Season

Code	Scientific Name	Common Name
CAPU	*Capsella bursa-pastoris* (L.) Medik.	Shepherds purse
PHTE	*Phyllanthus tenellus* Roxb.	Thender leaf-flower
RIBR	*Richardia brasiliensis* Gomes	Tropical mexican clover

IGW - Introduced Graminoids Warm Season

Code	Scientific Name	Common Name
CYDA	Cynodon dactylon (L.) Pers.	Common bermuda grass
DAAE	*Dactyloctenium aegyptium* (L.) Beauv.	Crowfoot grass
DIAN	*Dicanthium annulatum* (Forssk.) Stapf	Kleberg bluestem
DIAR	*Dichanthium aristatum* (Poir.) C.E. Hubbard	Angleton bluestem
DIBI	*Digitaria bicornis* (Lam.) Roem. & Schult.	Crabgrass
ERLE	*Eragrostis lehmanniana* Nees	Lehmann's love grass
PAAN	*Panicum antidotale* (Retz.)	Blue panicgrass
PAMA	Panicum maximum (Jacq.)	Guinea grass
PECI	*Pennisetum ciliare* (L.) Link	Buffelgrass
SEIT	*Setaria italica* (L.) P. Beauv.	Foxtail millet

NFC - Native Forbs Cool Season

Code	Scientific Name	Common Name
ALDR	*Alophia drummondii* (Graham) R.C. Foster	Purple pleat leaf
ANMI	Anagallis minima (L.) Krause	Chaffweed

BABR	*Baptisia bracteata* Muhl. ex Elliott var. leucophaea (Nutt.) Kartesz & Gandhi	Plains wild indigo
COMI	*Corydalis micrantha* (Engelm. ex A. Gray) A. Gray	Scrambled eggs
CRINR	*Crotalaria incana* L.	Hoary rattle box
GACA	*Galactia canescens* Benth.	Hoary milkpea
LEAU	*Lepidium austrinum* Small	Southern pepperweed
NOBI	*Nothoscordum bivalve* (L.) Britton	Crow poison
PHGL	*Phlox glabriflora* (Brand) Whitehouse ssp. littoralis (Cory) Wherry	Rio grande phlox
PHST	*Phlox stansburyi* (Torr.) A. Heller	Cold-dessert phlox
PLHO	*Plantago hookeriana* Fisch. & C.A. Mey.	Hookers plantain
PLRH	*Plantago rhodosperma* Decne.	Redseed plantain
SCMU	*Scutellaria muriculata* Epling	Rio grande skullcap
STPR	*Stellaria prostrata* Baldw.	Prostrate starwort
STSY	*Stillingia sylvatica* L.	Queen's delight
ZOBR	*Zornia bracteata* Walter ex J.F. Gmel.	Bracted zornia
ZORE	*Zornia reticulata* Sm.	Net leaf rabbit's ears

NFW - Native Forbs Warm Season

Code	Scientific Name	Common Name
ACRA	*Acalypha radians* Torr.	Cardinal's feather
AGHE	*Agalinis heterophylla* (Nutt.) Small ex Britton	Prairie agalinis
AGMA	Agalinis maritima (Raf.) Raf.	Seaside agalinis
AMPS	*Parthenium hysterophorus L.*	False ragweed
APSK	Aphanostephus skirrhobasis (DC.) Trel.	Coastal lazy daisy
BOFR	*Borrichia frutescens* (L.) DC.	Sea ox eye
CEVI	*Centrosema virginianum* (L.) Benth.	Spurred butterfly-pea
CHFA	*Chamaecrista fasciculata* (Michx.) Greene	Partrige pea
CHMA	*Chamaesyce maculata* (L.) Small	Spotted sandmat
CHSE	*Chamaesyce serpens* (Kunth) Small	Hierba de la golondrina
CITE	*Cirsium texanum* Buckley	Texas thistle
COBA	*Coreopsis basalis* (A. Dietr.) S.F. Blake	Coreopsis
COBE	*Conoclinium betonicifolium* (Mill.) R.M. King & H. Rob.	Betony mistflower
CODI	*Commelina diffusa* Burm. f.	Climbing dayflower
CODR	*Cooperia drummondii* Herb.	Rainlily
CONU	*Coreopsis nuecensis* A. Heller	Crown tickseed
CRCA	*Croton capitatus* Michx. var. *lindheimeri* (Engelm. & A. Gray) Mull. Arg.	Wooly croton
CRGL	*Croton glandulosus* L*.*	Tooth croton
CRIN	*Croton incanus* Kunth	Torrey's croton
CRRI	Croptilon rigidifolium (E.B. m.) E.B. Sm.	Scratch daisy
DAPO	*Dalea pogonathera* A. Gray	Bearded dhalia
DITE	*Diodia teres* Walter	Rough buttonweed

ELBR	*Elytraria bromoides Oerst.*	Wheatspike scalystem
ERMU	*Eriogonum multiflorum* Benth.	Heartsepal buckwheat
ERPR	*Erigeron procumbens* (Houst. *ex* Mill.) G.L. Nesom	Corpus christi fleabane
EUCO	*Eupatorium compositifolium* Walter	Yankeeweed
EUEX	*Eustoma exaltatum* (L.) Salisb. Ex G. Don	bluebell gentian
EVAL	*Evolvulus alsinoides* (L.) L.	Slender evolvulus
EVSE	*Evolvulus sericeus* Sw.	Silky evolovulus
FLBR	*Flaveria brownii* A. Powell	Browns flaveria
FRGR	*Froelichia gracilis* (Hook.) Moq.	Slender snakecotton
GAPU	*Gaillardia pulchella* Foug.	Indian blanket
HEAN	*Helianthus annuus* L.	Sunflower
HECU	*Heliotropium curassavicum* L.	Seaside heliotrope
JUPI	*Justicia pilosella* (Nees) Hilsenb.	Gregg's tube tongue
LICA	*Limonium carolinianum* (Walter) Britton	Sea lavendar
LYAL	*Lythrum alatum* Pursh var. *lanceolatum* (Elliott) Torr. & A. Gray ex Rothr.	Lance leaf loosestrife
MAAU	*Malvastrum aurantiacum* (Scheele) Walp.	Wright's false mallow
MADR	*Malvaviscus arboreus* Dill. Ex Cav. var. *drummondii* *(Torr. & A. Gray) Schery*	Wax mallow
MILA	*Mimosa latidens* (Small) B.L. Turner	Sensitive brier
MIST	*Mimosa strigillosa* Torr. & A. Gray	Powder puff
MOCI	*Monarda citriodora* Cerv. ex Lag.	Lemon beebalm
NAJA	*Nama jamaicense* L.	Fiddleleaf
OESP	Oenothera speciosa Nutt.	Primrose
OEXE	*Oenthera xerogaura* W.L. Wagner & Hoch	Drummond's beeblossom
OXFR	*Oxalis frutescens* L.	Shrubby wood sorrel
PAHO	*Palafoxia hookeriana* Torr. & A. Gray	Sand palafoxia
PAHY	*Parthenium hysterophorus* L.	False ragweed
PATE	*Palafoxia texana* DC.	Texas palafoxia
PHCI	*Physalis cinerascens* (Dunal) Hitchc.	Small flower ground cherry
PHHE	*Physalis hederifola* A. Gray	Ivyleaf ground cherry
PHNO	*Phyla nodiflora* (L.) Greene	Texas frogfruit
PHPO	*Phyllanthus polygonoides* Nutt. Ex Spreng.	Leaf flower
PHPU	*Physalis pubescens* L.	Husk tomato
POPI	*Portulaca pilosa* L.	Chisme
PSOB	*Pseudognaphalium obtusifolium* (L.) Hilliard & B.L. Burtt	Rabbit-tobacco
RAPE	*Ratibida peduncularis* (Torr. & A. Gray) Barnhart	Mexican hat
RAPH	*Rayjacksonia phyllocephala* (DC.) R. L. Hart. & M.A. Lane	Gumweed
RHPH	*Rhynchosida physocalyx* (A. Gray) Fryxell	Bladderpod sida
RUNU	*Ruellia nudiflora* (Engelm. & A. Gray) Urb.	Runyon's wild petunia

	var. runyonii (tharp & F.A. Barkley) B.L. Turner	
SABI	*Salicornia bigelovii* Torr.	Glasswort
SAEB	*Samolus ebracteatus* Kunth ssp. *alyssoides* (A. Heller) R. Knuth	Limewater brookweed
SESE	*Sesuvium sessile* Pers.	Sea purslain
SIAB	*Sida abutifolia* Mills	Spreading sida
SICI	*Sida ciliaris* L.	Bracted sida
SICO	*Sida cordifolia* L.	Heart leaf fanpetal
SILI	*Sida lindheimeri* Engelm. & A. Gray	Lindheimers sida
SOEL	*Solanum elaeagnifolium* Cav.	Silverleaf nightshade
SORO	*Solanum rostratum* Dunal	Buffalo bur
SOSE	*Solidago sempervirens* L.	Seaside goldenrod
STLA	*Stemodia lanata* Sesse & Moc. ex Benth.	Gray-wooly twintip
SULI	*Suaeda linearis* (Elliott) Moq.	Sea blite
THTE	*Thymophylla tenuiloba* (DC.) Small	Bristle leaf dogweed
VEHA	*Verbena halei* Small	Texas vervain

NGC - Native Graminoids Cool Season

Code	Scientific Name	Common Name
BOMA	*Bolboschoenus maritimus* (L.) Palla	Alkali bulrush
CAREX	*Carex L*.	Sedge
DIOL	*Dichanthelium oligosanthes* (Schult.) Gould	Scribners rossettegrass
DISP	*Dichanthelium sphaerocarpon* (Ell.) Gould & Clark	Roundseed rosettegrass
ELPA	*Eleocharis parvula* (Roem. & Schult.) Link ex Bluff. Nees & Schauer	Dwarf spike rush

NGW - Native Graminoids Warm Season

Code	Scientific Name	Common Name
ANGL	*Andropogon glomeratus* (Walter) Britton, Sterns & Poggenb.	Bushy bluestem
ARPU	*Aristida purpurea* Nutt.	Purple three awn
BOBA	*Bothriochloa barbinodis* (Lag.) Herter var. barbinis	Cane bluestem
BOHI	*Bouteloua hirsuta* Lag.	Hairy grama
BOLA	*Bothriochloa laguroides* (DC.) Herter	Silver bluestem
CESP	*Cenchrus spinifex* Cav.	Coastal sandbur
CHAN	*Chloris andropogonoides* Fourn.	slimspike windmillgrass
CHCU	*Chloris cucullata* Bisc.	Hooded windmillgrass
CYOD	*Cyperus odoratus L.*	Flat sedge
ELTR	*Elionurus tripsacoides* Humb. & Bonpl. Ex Willd.	Pan american balsumscale
ERSE	*Eragrostis sessilispica* Buckley	Tumble lovegrass

ERSEC	*Eriochloa sericea* (Scheele) Munro ex Vasey	Texas cupgrass
ERSR	*Eragrostis secundiflora* J. Presl	Red lovegrass
FICA	*Fimbristylis castanea* (Michx.) Vahl	Fimbrystilis
FUSI	*Fuirena simplex* Vahl	Umbrella grass
HECO	*Heteropogon contortus* (L.) P. Beauv. ex Roem. & Schult.	Tanglehead
HIBE	*Hilaria belangeri* (Steud.) Nash	Curly mesquite
MOLI	*Monanthochloe littoralis* Engelm	Shore grass
MUCA	Muhlenbergia capillaris (Lam.) Trin.	Gulf coast muhly
PACA	*Panicum capillare* L.	Witchgrass
PAHA	*Panicum hallii* Vasey	Halls panicum
PAMO	*Paspalum monostachyum* Vasey	Gulfdune paspalum
PAPL	*Paspalum plicatulum* Michx.	Brown seed paspalum
PASE	*Paspaplum setaceum* Michx.	Thin paspalum
PAVI	*Panicum virgatum* L.	Switchgrass
RHCO	*Rhynchospora colorata* (L.) H. Pfeiffer	White umbrella sedge
RHPU	*Rhynchospora pusilla* Chapm. ex M.A. Curtis	Fairy beaksedge
SALT	*Distichlis spicata* (L.) Greene	Saltgrass
SCPU	*Schoenoplectus pungens* (Vahl) Palla	American bulrush
SCSC	*Schizachyrium scoparium* (Michx) Nash *var. littorale (Nash) Gould*	Seacoast bluestem
SCSCL	*Schizachyrium scoparium* (Michx.) Nash var. scoparium	Little bluestem
SEPA	*Setaria parviflora* (Poir.) Kerguelen	Knotroot bristlegrass
SEVU	*Setaria vulpiseta*(Lam.) Roem. & Schult.	Plains bristlegrass
SIBI	*Sisyrinchium biforme* E.P. Bicknell	Blue eyed grass
SPAI	*Sporobolus airoides* (Torr.) Torr.	Alkali sacaton
SPCR	*Sporobolus cryptandrus* (Torr.) A. Gray	Sand dropseed
SPPU	*Sporobolus purpurascens* (Sw.) Ham.	Purple dropseed
SPPY	*Sporolobus pyramidatus* (Lam.) Hitchc.	Whorled dropseed
SPSP	*Spartina spartinae* (Trin.) Merr. *ex* Hitchc.	Gulf cordgrass
TRTE	*Tridens texanus* (S. Watson) Nash	Texas tridens
UNPA	*Uniola paniculata* L.	Sea oats

NSS - Native Subshrubs

Code	Scientific Name	Common Name
ABFR	*Abutilon fruticosum* (Guill. & Perr.)	Texas indian mallow
BATE	*Baccharis texana* (Torrr. & A. Gray) A. Gray	Texas baccharis
PTVI	*Pterocaulon virgatum* (L.) DC.	Blackroot
THPE	*Thymophylla pentachaeta* (DC.) Small	Needle dogweed
WAIN	*Waltheria indica* L.	Hierba del soldado

NVW - Native Vines Warm Season

Code	Scientific Name	Common Name
CLDR	*Clematis drummondii* Torr. & A. Gray	Old mans beard
CYBA	*Cynanchum barbigerum* (Scheele) Shinners	Thicket threadvine
FUCL	*Funastrum clausum* (Jacq.) Schltr.	White twine vine
IBLI	*Ibervillea lindheimeri* (A. Gray) Greene	Globe berry
PAFO	*Passiflora foetida* L.	Passion flower
RHAM	*Rhynchosia americana* (Houst. ex Mill.) M.C. Metz	American snoutbean

VITA

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Education

- Elementary school - Brown Elementary (Lubbock, Texas) 1998 – 2003 and Escuela Primaria Profesor Lauro Aguirre (Gonzalez, Tamaulipas, Mexico) 2003 - 2004
- Middle school - Escuela Secundaria Tecnica No. 19 "Lic. Natividad Garza Leal" (Ciudad Madero, Tamaulipas, Mexico) 2004 - 2007
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- Forestry Engineer, Universidad Autónoma Agraria Antonio Narro. Saltillo, Coahuila, México. 2011 - 2016. Bachelor Thesis "The effects of wildfire in the composition and structure of rosaceae shrubs in Sierra Zapalinamé, Coahuila"

Workshops

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- Ranching for Business Lectureship. 2018. Kingsville, Texas.

Work experience

- Laboratorist in livestock nutrition. INIFAP, Campo experimental "Las Huastecas", Cuauhtémoc, Altamira, Tamaulipas, México. 2011 (6 months)
- Technician with graduate students. Monitoring wildlife: desert bighorn sheep, aoudad, scaled quail, gambels quail, Montezuma quail, mule deer, and white-tail deer. "Borderlands Research Institute" Sul Ross State University, Alpine, Texas. 2015 (5 months)
- Professional photographer (Weddings, Events, Social, Landscape and Wildlife)
- Currently, Graduate research assistant (Caesar Kleberg Wildlife Research Institute, Texas A&M University-Kingsville.)
- Leading and participating in prescribed burns of grasslands and shrublands of Tamaulipas, Nuevo Leon and South Texas. >30 events.
- Wildlife Monitoring with telemetry, trap cameras and visual observation. (Whitetail deer, Mule deer, Aoudad, Scaled Quail, Montezumae Quail, Gambels Quail)
- Wildlife captures (Whitetail deer, Mule deer, Aoudad, Scaled Quail, Montezumae Quail, Gambels Quail)
- Vegetation sampling in forest (Piney woods, tropical and semiarid) and rangelands.