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FOOD NICHE RESPONSES IN SOUTHERN TEXAS SMALL MAMMAL COMMUNITIES

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ABSTRACT—Land managers interested in maintaining species diversity often face difficult decisions when managing cattle grazing. Choosing a successful stocking regime and intensity for a particular region can be difficult. Landowners in the southern Texas region face challenges identifying successful stocking regimes or grazing intensity because of high temperatures from April through October and frequent droughts that often last up to or longer than 3 years. Cattle grazing is a major southern Texas agricultural industry that can have profound impacts that alter the diversity and structure of vegetation. Small mammals are an appropriate focal group for understanding ecosystem changes because of their rapid reproductive cycles and successful use in monitoring ecosystem conditions. From 2015 to 2020, we conducted a small mammal mark–recapture study to understand the impacts of grazing, along with variability in temperature and rainfall, on small mammal abundance in southern Texas. Sampling occurred within four different cattle grazing treatments to provide insight on cattle interactions with small mammals. We analyzed changes in small mammal abundance between three groups based on their food preferences: omnivores, granivores, and herbivores. For all three groups, there was a negative influence of temperature, but not precipitation and year, on abundance. With landscapes changing with time, land managers could use these data as a baseline for monitoring small mammal abundance in this region and potentially other similar native rangelands.

RESUMEN—Los administradores de tierras interesados en mantener la diversidad de especies a menudo tienen que tomar decisiones difíciles con relación al manejo del pastoreo para ganado. La elección de la carga animal y la intensidad de uso para una región en particular pueden ser especialmente complejas. Los administradores de tierras de la región sur de Texas enfrentan desafíos identificando exitosos regímenes de carga animal o intensidad de pastoreo debido a las altas temperaturas de abril hasta octubre y las frecuentes sequías que a menudo duran hasta tres años o más. El pastoreo de ganado es una actividad agrícola de gran importancia en el sur de Texas que puede tener fuertes impactos que alteren la diversidad y estructura vegetal. Los pequeños mamíferos representan un adecuado grupo focal para el entendimiento de cambios a nivel ecosistémico debido a la rapidez de sus ciclos reproductivos y a que han sido utilizados de manera exitosa para monitorear el estado de salud de los ecosistemas. De 2015 a 2020, realizamos un estudio corto de captura y recaptura de pequeños mamíferos para entender los impactos del pastoreo, junto con la variación de la temperatura y la precipitación, en la abundancia de pequeños mamíferos en el sur de Texas. Muestreos se llevaron a cabo dentro de cuatro tratamientos diferentes de pastoreo de ganado para generar información acerca de las interacciones entre el ganado y los pequeños mamíferos. Se analizaron los cambios en la abundancia de tres grupos de pequeños mamíferos, basados en sus preferencias alimenticias: omnívoros, granívoros y herbívoros. La abundancia de los tres grupos varió con relación negativa a la temperatura, pero no en cuanto a la precipitación y el año. Ante cambios en el paisaje con el tiempo, estos datos pueden utilizarse como base para monitorear la abundancia de pequeños mamíferos en esta región y potencialmente en otros pastizales nativos similares.

Natural and human activities cause ecosystems to change over time. These changes can potentially alter species richness and abundance. Some species groups, such as small mammals, fill a particular niche and thus play a role in their

ecosystem; therefore, monitoring their presence and abundance can identify changes in local conditions over time (Baumgardt et al., 2019). Such local conditions could include changes in nutrient cycling, soil conditions, and

energy transfer in the food web, and multispecies monitoring of a group such as small mammals can provide insight into the spatial variability in such conditions (Ryszkowski, 1975; Baumgardt et al., 2019). Cattle grazing is known to influence ecosystems by removing live and dead plant material (Altesor et al., 2006), modifying soil nutrient content (Bakker et al., 2004; Steffens et al., 2008), and suppressing woody encroachment in savanna-type landscapes (Bueno et al., 2011).

Small mammals have rapid reproductive cycles that allow them to quickly respond to environmental change (Bueno et al., 2011; Baumgardt et al., 2019); thus, they are an ideal focal group for understanding changes in ecosystems. In addition, small mammals serve a key role as prey for predators (Baumgardt et al., 2019), impact plant diversity through food selection and burrowing (Ryszkowski, 1975), actively participate in nitrogen cycling (Bakker et al., 2004) and carbon exchange (Liu et al., 2013), and serve as indicators of grassland health (Bueno et al., 2011). Generally, small mammal species fulfill the granivore, herbivore, or omnivore food niches wherein their diet comes from one of these dominant groups. Although herbivorous and granivorous species consume vegetation and the associated seeds, a portion of omnivorous small mammals' diet includes insects such as grasshoppers (suborder Caelifera) or other animal matter (Davis and Schmidly, 1994). This makes small mammal herbivores and granivores particularly sensitive to changes that influence vegetation, whereas omnivorous species may be sensitive to changes that influence insect abundance and diversity.

Cattle grazing has been a major Texas industry for most of the past two centuries (Richardson and Hinton, 2010). Southern Texas in particular is a semiarid region that experiences frequent droughts and has an extended growing season of approximately 300 days (Montalvo et al., 2020). This region is dominated by plant species such as honey mesquite (*Prosopis glandulosa*), seacoast bluestem (*Schizachyrium scoparium* var. *littorale*), purple threeawn (*Aristida purpurea*), and prickly pear (*Opuntia* species; Montalvo et al., 2020). Grazing generally occurs on the various herbaceous species of the region but also on shrubs and cacti.

Using mark–recapture data collected from 2015 to 2020 in southern Texas, we examined how grazing treatments and environmental changes—temperature and precipitation—influenced small mammal abundance within food niches. We examined four grazing treatments: continuous-high, continuous-moderate, rotational-high, and rotational-moderate (see below). We compared treatments to reference sites that followed a traditional grazing management approach, described in further detail in the Methods. We also analyzed temperature and precipitation data along with grazing treatments to identify the influences of these abiotic factors on species of small mammals. Because cattle grazing targets vegetation, we hypothesized that cattle grazing would directly impact herbivorous and

granivorous species of small mammals, whereas impact on omnivorous species would be both direct by cattle grazing and indirect by environmental factors, such as temperature and precipitation, that might drive changes in insect abundances (Altesor et al., 2006; Palmer, 2010; Kwok et al., 2016; Souther et al., 2019).

MATERIALS AND METHODS—Study Area—Our study was conducted as part of a long-term monitoring project on the East Foundation's San Antonio Viejo Ranch, located within Jim Hogg and Starr counties, Texas. The ranch is 61,000 ha and functions as a living laboratory to promote the advancement of land stewardship through ranching, science, and education. This project focused on the Coloraditas Grazing Research and Demonstration Area (CGRDA) on San Antonio Viejo, established in 2014 (Fig. 1). The mean annual temperature for this region is 22°C, ranging from 7 to 35°C, and the mean annual rainfall for this region is 50.3 cm. This area consists of two main ecoregions: Texas-Tamaulipan Thornscrub and Coastal Sand Plain (Omernik, 1987).

Grazing Treatment—The CGRDA includes 7,502 ha on the northern portion of the San Antonio Viejo Ranch, divided into 10 pastures of 1,875 ha each. These 10 pastures in the CGRDA are part of an experimental grazing study that uses different stocking rates and grazing methods. During our study, pastures had one of two stocking rates: a rate based on the average forage growth expectation for this region (35 acres per animal unit [ac/AU], hereafter referred to as a high stocking rate) and a more conservative rate (50 ac/AU, hereafter referred to as a moderate stocking rate). We combined each stocking rate with either rotational or continuous grazing methods, equating to a total of four grazing treatments: continuous-high, continuous-moderate, rotational-high, and rotational-moderate. Herein, we refer to the combination of a stocking rate with a grazing method as a grazing treatment. Continuously grazed treatments had a single replicate, whereas the rotational treatments did not have replicates due to pasture constraints, assuming year could stand as the rotational replication (Fig. 2). Using year as a rotational replication is a limitation of this study because it is a rather large assumption. To mitigate the impact of this assumption on our results, we assigned the treatment pastures randomly so there was no bias in selecting the vegetation makeup of each treatment. The stocking rates in the CGRDA were rigid during this study. The only flexible element was the timing of the rotation and the duration in which cattle grazed one of the three pastures for the rotational treatments. In this study, we also included reference pastures located outside of the CGRDA within the San Antonio Viejo Ranch property as a baseline condition to compare with the four grazing treatments. The East Foundation managed the reference pastures that used traditional grazing methods for this region, where stocking rate is flexible and often includes a combination of rotational and continuous grazing depending on animal and forage conditions (Kohler, 2020). The reference pastures served to compare small mammal abundance in rangeland that uses traditional grazing methods for the region to the experimental grazing methods of the pastures in the CGRDA.

The East Foundation deferred cattle from the CGRDA from March 2014 to December 2015; thus, data collected in 2015 represented pretreatment periods. In December 2015, East Foundation introduced 435 same-aged Santa Gertrudis cross heifers

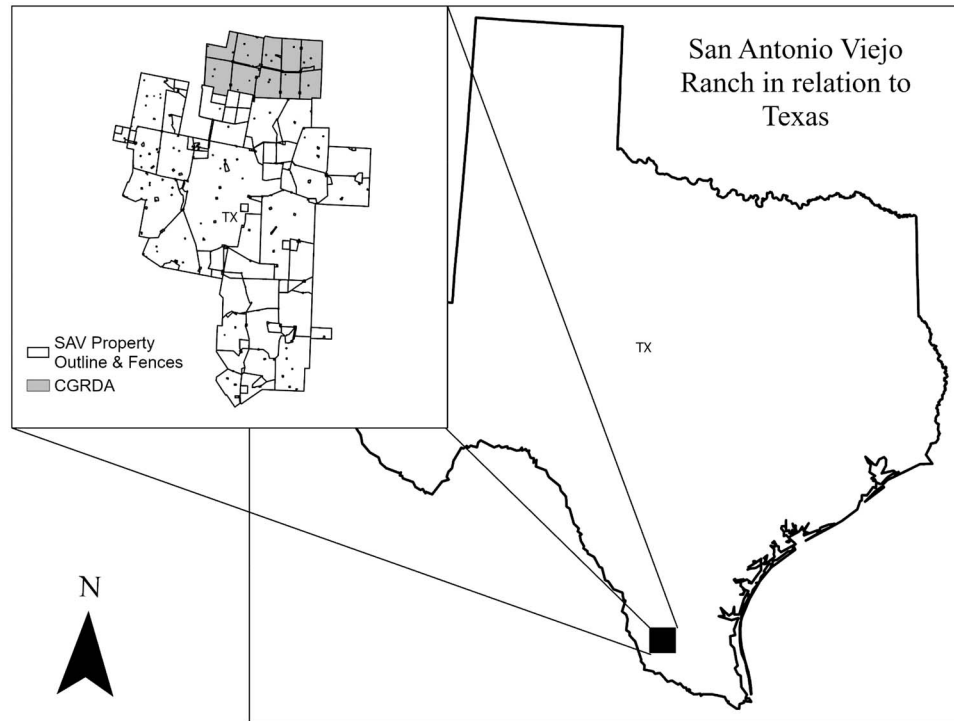


FIG. 1—Location and pastures of the San Antonio Viejo Ranch in southern Texas. Small mammal trapping for this study took place in the CGRDA pastures (shaded in gray) from 2015 to 2020. Trapping for the reference treatments occurred in random locations across the San Antonio Viejo Ranch outside of the CGRDA.

to the study system. They rotated the herds within the rotational treatments based on our assessment of the body condition of cattle and forage standing crop. The data collected from 2016 to 2018 represent the treatment period of this project. In May 2018, immediately following the small mammal

trapping season, the East Foundation deferred the cattle from the CGRDA due to a prolonged drought period in 2017. They removed the cattle with the purpose of allowing the vegetation to grow and recover free from grazing pressure as well as to reduce the economic loss on cattle. In 2019 and 2020, we conducted sampling after we removed the cattle, which represents posttreatment information.

Small Mammal Sampling—We trapped small mammals at 30 grids by using square (11×11) trapping configurations with an intertrap spacing of 20 m. Trapping occurred each year from February to April (Texas A&M University Institutional Animal Care and Use Committee permit 2016-0296). For trapping, we used large ($7.6 \times 9.5 \times 30.5$ cm, model XLK) and extra-large ($10.2 \times 11.4 \times 38$ cm, model XLF15) Sherman live traps (H. B. Sherman Traps, Inc., Tallahassee, Florida). We placed traps unopened and without bait 3 nights before trapping to allow individuals to become accustomed to the traps (Baumgardt et al., 2019). We baited and opened traps in the late afternoon before the first trap night with 1 teaspoon (4.9 mL) of a mixture of peanut butter and rolled oats. We placed a Nestlet square (Ancare, Bellmore, New York) in each trap for bedding material. The following morning, we checked and closed traps and then we processed the captured animals. We trapped for four to six consecutive trap nights unless there was a forecast for overnight temperatures below 4°C or a high probability of precipitation ($\geq 80\%$). At processing, we color marked each animal captured with a unique color combination on the ventral surface below the neck by using permanent markers (Baumgardt et al., 2019). We also weighed and examined every individual for sex, age, and reproductive status. We then released each animal at the capture location. When we recaptured individuals, we identified them by their marking on

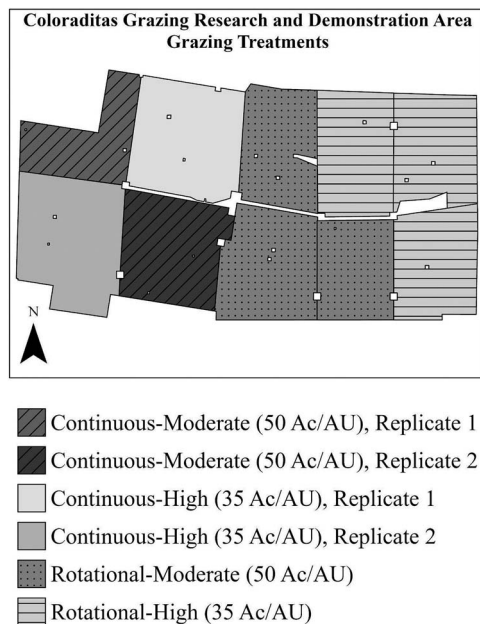


FIG. 2—Map depicts the grazing treatments within the CGRDA during the study period from 2015 to 2020. The legend shows the assignment of each grazing treatment in pastures, with stocking rate measured as acres per animal unit (ac/AU).

TABLE 1—Small mammal species caught in and around the CGRDA on San Antonio Viejo property in southern Texas from 2015 to 2020, grouped into appropriate food niche groups based on dietary preferences (Young and Jones, 1982; Davis and Schmidly, 1994).

Granivores	Herbivores	Omnivores
<i>Dipodomys ordii</i>	<i>Neotoma micropus</i>	<i>Peromyscus leucopus</i>
<i>Perognathus merriami</i>	<i>Baiomys taylori</i>	<i>Ictidomys mexicanus</i>
<i>Chaetodipus hispidus</i>	<i>Sigmodon hispidus</i>	<i>Onychomys leucogaster</i>
<i>Reithrodontomys fulvescens</i>		
<i>Liomys irroratus</i>		

the ventral surface and processed them as described earlier. We did not record them as new individuals or assign new markings.

We grouped species into food niches based on known predominant food sources (Table 1; Young and Jones, 1982; Davis and Schmidly, 1994). We classified species with a majority of their food source coming from grains as granivores, species with a majority of their food source coming from vegetation as herbivores, and species with a portion of their food source coming from meat as omnivores.

Data Analysis—We calculated small mammal abundances for each food niche with Program MARK by using Huggin's p&c, a closed population model (White and Burnham, 1999). We used Shapiro's test (Shapiro and Wilk, 1965) to test for normality and Levene's test (Levene, 1960) to evaluate homoscedasticity among the food niche abundances. A $(Y + 1)$ transformation of the data was necessary to meet the assumptions of a parametric regression. We used a factorial analysis of covariance (ANCOVA; stats package; R) to test for differences in abundance estimates. We tested four covariates by which abundances could potentially differ: food niche (three groups), grazing treatment (five levels: one reference and four treatments), temperature (deviation from 100-year average; National Oceanic and Atmospheric Administration, <https://www.ncdc.noaa.gov/cag/>), year (2015–2020), precipitation

(deviation from 100-year average; National Oceanic and Atmospheric Administration, 2020), and the interaction between grazing and year. To have a treatment effect, there must be a significant difference of abundances in the interaction between year and grazing covariate because year is representative of the experiment timeline (pretreatment, during treatment, and posttreatment). For each small mammal food niche abundance (granivore, herbivore, and omnivore), we also ran a linear regression with the temperature and precipitation covariates to identify whether these weather parameters had an influence on abundance.

RESULTS—Average abundance estimates of each species of small mammal by year and food niche varied widely (Fig. 3). From 2016 to 2017, omnivore abundance decreased by 82%, granivore abundance decreased by 50%, and herbivore abundance decreased by 70%. Abundances in 2017 and 2018 were lowest for all small mammal groups. All groups began to recover in 2019, and by 2020, granivore and herbivore abundances recovered to numbers above the original 2015 estimate. Their abundances increased by 83% and 209%, respectively, compared with those of 2015. Omnivore numbers remained relatively low by 2020, 70% lower than the original 2015 estimate.

Small mammal abundance varied by food niche ($F_{2,70} = 8.81$, $P \leq 0.001$, $r^2 = 0.19$), with omnivore abundance (average N-Hat = 8.51) being approximately 30% lower than herbivore abundance (average N-Hat = 12.22) and approximately 50% lower than granivore abundance (average N-Hat = 16.94; Table 2). Overall abundance (Table 3) varied by grazing treatment ($F_{4,70} = 5.06$, $P \leq 0.001$, $r^2 = 0.21$), precipitation ($F_{1,70} = 4.38$, $P = 0.040$, $r^2 = 0.05$), and temperature ($F_{1,70} = 54.18$, $P \leq 0.001$, $r^2 = 0.42$), but did not vary by year ($F_{5,70} = 0.02$, $P = 0.88$, $r^2 < 0.001$). Temperature, grazing treatment, and food niche had the largest relative effect sizes and therefore the greatest impact

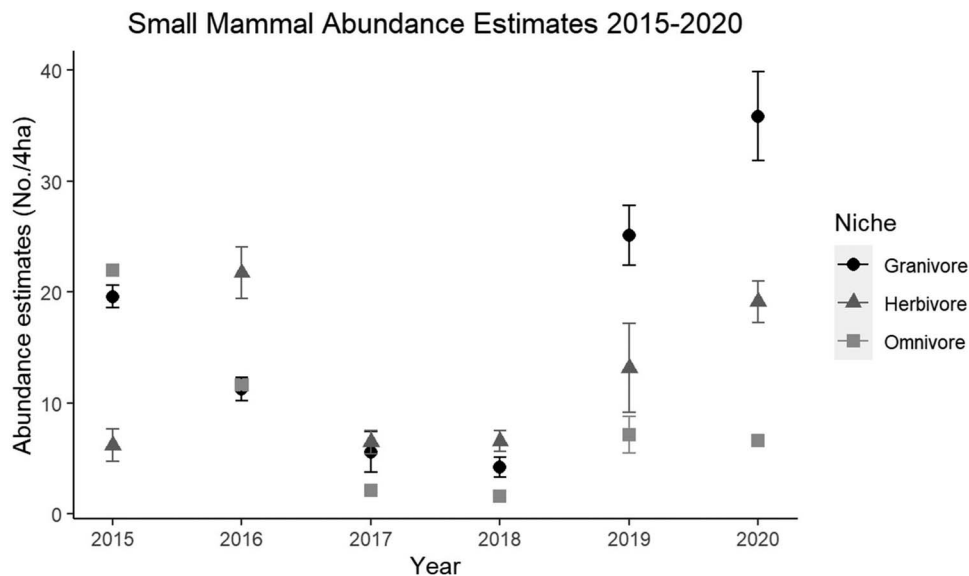


FIG. 3—Average abundance estimates (N-Hat) per trapping grid (4 ha each) and associated SE (represented by error bars) for food niche groups of small mammals (omnivore, granivore, or herbivore) captured from 2015 to 2020.

TABLE 2—Average abundance estimates (N-Hat) per trapping grid (4 ha each) and associated SE for food niche groups of small mammals (omnivore, granivore, or herbivore) captured from 2015 to 2020 in and around the pastures of the CGRDA on San Antonio Viejo property in southern Texas.

Food niche	2015	2016	2017	2018	2019	2020
Omnivore						
N-Hat	21.95	11.64	2.12	1.61	7.13	6.61
SE	0.28	0.43	0.37	0.14	1.65	0.36
Granivore						
N-Hat	19.61	11.26	5.61	4.24	25.11	35.83
SE	1.04	1.03	1.83	0.88	2.71	4.01
Herbivore						
N-Hat	6.19	21.73	6.49	6.60	13.18	19.14
SE	1.46	2.34	1.03	0.94	4.00	1.89

on abundances. Precipitation, although also significant, had a relatively low effect size. There was no variation in the interaction between grazing and year ($F_{20,70} = 0.33, P = 0.86, r^2 = 0.02$), implying there was no true treatment effect on overall abundance (Table 3). In general, small mammal abundance showed a negative correlation with temperature ($r^2 = 0.27, F_{2,87} = 16.34, P \leq 0.001$); however, the r^2 value was relatively low. Small mammal abundance showed no correlation with precipitation ($r^2 = 0.27, F_{2,87} = 16.34, P = 0.16$).

Granivores—Granivore abundance varied with temperature and had the greatest relative effect size ($F_{1,16} = 35.78, P \leq 0.001, r^2 = 0.67$). Abundance was, on average, approximately 83% lower in years during which temperatures were highest compared with years during which temperatures were lower. Abundance did not vary with precipitation ($F_{1,16} = 1.02, P = 0.33, r^2 = 0.05$). There was no variation of abundance with grazing treatment ($F_{4,16} = 0.19, P = 0.94, r^2 = 0.04$), year ($F_{5,16} = 3.84, P = 0.07, r^2 = 0.18$), or grazing \times year ($F_{20,16} = 0.77, P = 0.56, r^2 = 0.15$), implying that there was no treatment effect on granivores (Table 4). From the linear regression, there was a negative correlation of temperature with granivore abundance ($r^2 = 0.33, F_{2,27} = 6.69, P \leq 0.001$); however, the r^2 value was relatively low. There was no correlation with precipitation ($r^2 = 0.33, F_{2,27} = 6.69, P = 0.16$).

TABLE 3—Results of ANCOVA examining the impacts of food niche group, grazing treatment (one reference and four treatments), precipitation, temperature, year, and grazing treatment effect (grazing \times year) on small mammal abundance in and around the CGRDA on San Antonio Viejo property in southern Texas from 2015 to 2020. Statistically significant differences in means are indicated by * ($P < 0.05$) and ** ($P < 0.01$).

Covariate	df	SS	MS	F	P	r^2
Food niche (3)	2	5.88	2.94	8.81	$\leq 0.001^{**}$	0.19
Grazing treatment (5)	4	6.75	1.69	5.06	$\leq 0.001^{**}$	0.21
Precipitation	1	1.46	1.46	4.38	0.04*	0.05
Temperature	1	18.08	18.08	54.18	$\leq 0.001^{**}$	0.42
Year (6)	5	0.01	0.01	0.02	0.88	≤ 0.001
Grazing \times year	20	0.43	0.11	0.33	0.86	0.02

TABLE 4—Results of the factorial ANCOVA examining the impacts of grazing treatment (one reference and four treatments), precipitation, temperature, year, and grazing treatment effect (grazing \times year) on abundance of granivore small mammals in the CGRDA on San Antonio Viejo property in southern Texas from 2015 to 2020. Statistically significant differences in means are indicated by * ($P < 0.05$) and ** ($P < 0.01$).

Covariate	df	SS	MS	F	P	r^2
Grazing treatment (5)	4	0.25	0.06	0.19	0.94	0.04
Precipitation	1	0.33	1.02	1.02	0.33	0.05
Temperature	1	11.58	11.58	35.78	$\leq 0.001^{**}$	0.67
Year (6)	5	1.24	1.24	3.84	0.07	0.18
Grazing \times year	20	0.99	0.25	0.77	0.56	0.15

Herbivores—Herbivore abundance varied by grazing treatment ($F_{4,16} = 4.64, P \leq 0.001, r^2 = 0.51$) where abundances within the continuous-high, rotational-moderate, and continuous-moderate grazing treatments were similar and approximately 200% greater than the abundances within the reference and rotational-high sites, which were also similar. Abundance did not vary by year ($F_{5,16} = 0.96, P = 0.34, r^2 = 0.05$) or grazing \times year ($F_{20,16} = 0.37, P = 0.83, r^2 = 0.08$), indicating that there was not a treatment effect (Table 5). There was variation in herbivore abundance by temperature ($F_{1,16} = 5.24, P = 0.03, r^2 = 0.23$); however, there was no variation in herbivore abundance by precipitation ($F_{1,16} = 0.98, P = 0.34, r^2 = 0.05$). Relatively, midtemperature years produced highest abundances, whereas high temperature years produced an approximately 71% lower abundance. Overall, grazing treatment and temperature had the largest relative effect size, but grazing treatment had more than double the impact on herbivore abundance than temperature. Based on the linear regression, however, neither precipitation ($r^2 = 0.07, F_{2,27} = 1.02, P = 0.91$) nor temperature ($r^2 = 0.07, F_{2,27} = 1.02, P = 0.22$) showed a linear correlation with herbivore abundance.

Omnivores—Omnivore abundance varied by grazing treatment ($F_{4,16} = 20.59, P \leq 0.001, r^2 = 0.82$; Table 6) where abundances within the continuous-high, rotational-moderate, and continuous-moderate grazing treatments

TABLE 5—Results of the factorial ANCOVA examining the impacts of grazing treatment (one reference and four treatments), precipitation, temperature, year, and grazing treatment effect (grazing × year) on abundance of herbivore small mammals in the CGRDA on San Antonio Viejo property in southern Texas from 2015 to 2020. Statistically significant differences in means are indicated by * ($P < 0.05$) and ** ($P < 0.01$).

Covariate	df	SS	MS	F	P	r ²
Grazing treatment (5)	4	9.11	2.28	4.64	0.01*	0.51
Precipitation	1	0.48	0.48	0.98	0.34	0.05
Temperature	1	2.57	2.57	5.24	0.03*	0.23
Year (6)	5	0.47	0.47	0.96	0.34	0.05
Grazing × year	20	0.73	0.18	0.37	0.83	0.08

were similar and approximately 137% greater than the abundances within the reference and rotational-high sites, which were also similar (Table 7). Abundance varied by year ($F_{5,16} = 50.09$, $P \leq 0.001$, $r^2 = 0.74$); in 2015, abundance decreased by approximately 93% in 2018, when abundance was lowest (Table 2). Omnivore abundance did not vary by the interaction grazing × year ($F_{20,16} = 1.36$, $P = 0.29$, $r^2 = 0.23$). Abundance also varied with temperature ($F_{1,16} = 125.69$, $P \leq 0.001$, $r^2 = 0.87$) and precipitation ($F_{1,16} = 14.34$, $P \leq 0.001$, $r^2 = 0.44$; Table 6). Abundance decreased, on average, approximately 87% during the highest temperature years compared with the lowest temperature years. Abundance was approximately 303% higher than other years when precipitation was closest to the average for the region. Grazing treatment and temperature had the largest relative effect size. However, based on the linear regression, there was no correlation of omnivore abundance with precipitation ($r^2 = 0.64$, $F_{2,27} = 23.96$, $P = 0.20$) and there was a negative correlation with temperature ($r^2 = 0.64$, $F_{2,27} = 23.96$, $P \leq 0.001$).

DISCUSSION—Our results failed to support our hypothesis that there would be a grazing treatment effect on herbivore and granivore abundances. Rather, they exhibited responses to environmental covariates. However, the results did support our hypothesis that omnivore abundance would be driven by environmental factors such as temperature and

TABLE 6—Results of the factorial ANCOVA examining the effects of grazing treatment (one reference and four treatments), precipitation, temperature, year, and grazing treatment effect (grazing × year) on abundance of omnivore small mammals in the CGRDA on San Antonio Viejo property in southern Texas from 2015 to 2020. Statistically significant differences in means are indicated by * ($P < 0.05$) and ** ($P < 0.01$).

Covariate	df	SS	MS	F	P	r ²
Grazing treatment (5)	4	7.55	1.89	20.59	≤ 0.001 **	0.82
Precipitation	1	1.32	1.32	14.34	≤ 0.001 **	0.44
Temperature	1	11.53	11.53	125.69	≤ 0.001 **	0.87
Year (6)	5	4.59	4.59	50.09	≤ 0.001 **	0.74
Grazing × year	20	0.50	0.13	1.36	0.29	0.23

Table 7—Mean small mammal abundance and SD values for each food niche group (omnivore, herbivore, or granivore) across grazing treatment (continuous-high, continuous-moderate, rotational-high, rotational-moderate, or reference sites), and year (2015–2020). Calculation of values was from small mammal trapping data collected in the CGRDA on San Antonio Viejo property in southern Texas from 2015 to 2020 by using 4-ha trapping grids.

Variable	Omnivore		Herbivore		Granivore	
	Mean	SD	Mean	SD	Mean	SD
Continuous-high	13.76	9.11	17.60	9.60	17.18	16.53
Continuous-moderate	9.24	7.84	16.65	9.31	16.65	12.89
Rotational-high	3.69	5.69	5.22	5.41	5.22	14.00
Rotational-moderate	10.59	10.78	14.50	8.55	14.50	10.03
Reference sites	5.25	5.70	7.13	6.52	7.13	19.52
2015	21.95	0.28	6.19	1.46	19.61	1.04
2016	11.64	0.43	21.73	2.34	11.26	1.03
2017	2.12	0.37	6.49	1.03	5.61	1.83
2018	1.61	0.14	6.60	0.94	4.24	0.88
2019	7.13	1.65	13.18	4.00	25.11	2.71
2020	6.61	0.36	19.14	1.89	35.83	4.01

precipitation. Herbivorous and granivorous small mammal abundances progressed over time in a similar manner to each other, but differently from those of the omnivorous group. Omnivorous small mammal abundance decreased by more than half, whereas herbivore abundances more than tripled and granivore abundances increased by more than half over the study period. Following the extended drought period from 2017 to 2018 and the removal of cattle in 2018, herbivorous and granivorous groups in 2019 were able to recover to abundances greater than or equal to the levels before the drought, whereas omnivore abundances were not. This indicates that perhaps the increase in precipitation, reduced temperatures, and lack of cattle allowed the vegetation to recover more quickly, thus impacting the species groups that rely on vegetation more directly. This pattern might indicate that cattle exacerbate the negative impacts of drought on small mammal communities because abundance estimates rebounded after cattle removal after the 2018 trapping season. Because small mammal numbers were able to rebound upon deferment of cattle postdrought, it might be beneficial to defer cattle immediately after a drought to encourage recovery of small mammal communities. However, we cannot attribute the increase in abundances in 2019 to postdrought conditions or cattle removal alone because those two events coincided in the study period. Because temperature and drought are often associated (Willhite, 2000; Jeong et al., 2014), this pattern might reflect the relationship between temperature and small mammal communities found in our study.

The recovery of small mammal omnivores might be lagged because of their reliance on insects for food, if vegetation must first recover for insect abundances to recover. We found a highly negative correlation of omnivore

abundance with temperature, so it is probable that temperature influences insect abundance. Some invertebrate taxa exhibit a negative relationship with temperature long term (Kwok et al., 2016). In addition, different invertebrate taxa are more active, and thus available to predators, during different seasons based on temperature, with overall abundance being lower in winter (Palmer, 2010), which accounts for a portion of the small mammal trapping season. This relationship could be further explored by sampling insects and quantifying their abundance during the trapping season.

We did not find any differences in small mammal abundances between high and moderate stocking rates for either the continuous or rotational grazing methods or the traditionally grazed reference pastures. Our lack of a grazing treatment effect contradicts the findings of many other grazing studies (Bowland and Perrin, 1989; Nyako-Lartey and Baxter, 1995; Keesing, 1998; Bueno et al., 2011). This finding, however, is not unique. For example, Yarnell et al. (2007) found a lack of direct grazing impact on a majority of their target small mammal species. We also might not have seen a grazing treatment effect because grazing levels, like those in Yarnell et al. (2007), were different relative to other studies that made similar comparisons due to differences in climatic conditions and other regional factors. In addition, the impact of grazing might not have been evident because of a lack of comparison to areas where grazing was absent for the entire treatment period. However, including areas where grazing was absent was not the objective of the study, and appropriate locations for such comparisons did not exist in the general study area. Cattle grazing is a major industry in Texas (Richardson and Hinton, 2010), so our aim was to inform private landowners of management practices that may better support wildlife while maintaining a working ranch operation. This eliminates the utility of a comparison to areas that are not grazed. It is possible that the stocking rate, grazing method (rotational or continuous), or both were not different enough to produce meaningfully different treatments in this study. Alternatively, it is possible that temperature and precipitation are simply stronger predictors of fluctuations in small mammal abundances than grazing treatment.

These results have implications for management practices within native rangelands. Temperature and its association with drought seem to drive much of the changes we see in the small mammal communities in this region. All three food niche groups of small mammals experienced declines in response to drought and recovered with cattle removal and drought relief. However, omnivores recovered at a much lower rate, potentially due to the combined effects of grazing and drought on both the vegetation and the invertebrate prey communities that account for a portion of their diet (Rambo and Faeth, 1999; Kruess and Tschardtke, 2002; DeBano, 2006; Barnett and Facey, 2016). These data and associated

responses of these small mammal focal groups show that small mammals are sensitive to drought, a typical weather phenomenon in this region, although they show some resiliency in their ability to recover afterward. Cattle grazing, regardless of treatment type, likely exacerbated the effects of the drought on the small mammals studied herein, and their deferment postdrought may enhance small mammal recovery. Because small mammals can be indicators of a changing environment, monitoring their populations is a valuable step in understanding rangeland condition. With projections of increased temperature and decreased rainfall in Texas, resulting in more frequent and severe droughts (Jeong et al., 2014), these responses might become more extreme and potentially influence other taxonomic groups in the future.

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