The Effects of Burning and Grazing on Survival, Home Range, and Prey Dynamics of the Texas Horned Lizard in a Thornscrub Ecosystem

Anna L. Burrow[1], *Richard T. Kazmaier*[1], *Eric C. Hellgren*[1], *and Donald C. Ruthven, III*[2]

Abstract.—We examined the effects of rotational livestock grazing and prescribed winter burning on the state threatened Texas horned lizard, *Phrynosoma cornutum*, by comparing home range sizes, survival estimates and prey abundance across burning and grazing treatments in southern Texas. Adult lizards were fitted with backpacks carrying radio transmitters and relocated daily. Prey abundance (harvester ants, *Pogonomyrmex rugosus*) and activity were greater in burned pastures, but grazing had a variable effect depending on the timing since the last burn. Home ranges in burned pastures were smaller than in unburned pastures in the active season. Level of grazing (heavy vs. moderate) did not affect home range size. Summer survival rates of horned lizards were higher in the moderately grazed sites than the heavily grazed sites. The smaller home ranges, lack of effect on survival rates, and greater prey abundance in burned pastures suggested a positive effect of fire on Texas horned lizards.

Introduction

The effect of land-use practices on sensitive species, such as threatened or endangered species, is of considerable conservation and political interest. However, little information is available to evaluate the ecological effects of management practices such as burning or grazing on herpetofauna in general (Russell et al. 1999), and on the threatened Texas horned lizard, *Phrynosoma cornutum*, in particular. The Texas horned lizard is the official state reptile of Texas (Donaldson et al. 1994), and is a species of special concern in the conservation community. Although the Texas horned lizard was protected by Texas legislative mandate in 1967, it has declined throughout its range, especially in Texas (Price 1990). Suggested reasons for this decline include habitat alteration for land uses such as agriculture or development, the introduction of the red imported fire ant (*Solenopsis invicta*), and the use of insecticides (Price 1990; Donaldson et al. 1994). Such declines can decrease genetic variability and hinder the lizard's ability to adjust to changes in environmental conditions caused by land-use practices.

The habitat and prey of horned lizards can potentially improve or worsen with fire and grazing. Fire reduces shrub canopy cover (Dunne et al. 1991) where grazing can increase the amount of woody vegetation (Archer and Smeins 1991). Ruthven et al. (2000) found that forbs increased on southern Texas rangelands in the first year after a winter burn, but were not affected by grazing. Bunting and Wright (1977) also found that forbs and grass cover increased following fire. Ants, the main prey of horned lizards, are not deleteriously affected by fire or grazing (McCoy and Kaiser 1990; Heske and Campbell 1991; McClaran and Van Devender 1995:165 Fox et al. 1996).

Specific objectives of our research were to: compare the relative abundance and activity of harvester ants, *Pogonomyrmex rugosus*, the main food source of the Texas horned lizard, among different burning and grazing treatments; and compare home range size and survival rates of Texas horned lizards among different burning and grazing treatments. Based on available literature, we made several testable predictions. Harvester ant activity and abundance should be greatest in the moderately grazed/burned site because of an increase in seed production coupled with an open, sparsely vegetated habitat, selected by harvester ants (DeMers 1993). Horned lizards will be less selective of foraging habitat in the moderately grazed and burned site due to greater prey abundance and better habitat interspersion. Therefore, we predicted range size of Texas horned lizards would be smaller and survival rates higher in the moderately grazed/burned sites than in other treatments.

Study Area

The 6,150-ha Chaparral Wildlife Management Area (CWMA) occurs in Dimmit and La Salle Counties, Texas. The CWMA was purchased by the state in 1969 and management authority was given to the Texas Parks and Wildlife Department (TPWD). Average annual rainfall on CWMA is 63 cm with a primary peak in May and a secondary peak in late September/early October (TPWD, unpublished data). The dominant vegetation types on the CWMA are honey mesquite (*Prosopis glandulosa*) woodlands or parklands, with prickly pear cactus (*Opuntia engelmannii*), tasajillo (*Opuntia leptocaulis*), brasil (*Condalia hookeri*), spiny hackberry (*Celtis pallida*), blackbrush acacia (*Acacia rigidula*), twisted acacia (*Acacia schaffneri*), hogplum (*Colubrina texenis*), and Texas persimmon (*Diospyros texana*) as common subdominants. Common and scientific names for vegetation follows Hatch et al. (1990).

Five study sites (50-60 ha) were selected on the CWMA, each with a different burning and grazing treatment.

[1]Department of Zoology, Oklahoma State University, Stillwater, OK 74078

[2]Texas Parks and Wildlife Department, Artesia Wells, TX 78001

Sites were chosen based on similarities in dominant woody species and canopy coverages. Treatments were: control (non-burned/non-grazed), moderately grazed/ burned, heavily grazed/burned, moderately grazed/non-burned, and heavily grazed/ burned. The control site has not been burned or grazed since 1976.

Historical grazing occurred on CWMA, but after TPWD began managing the land, grazing steadily declined and temporarily stopped in 1984 because of poor range condition. During this time, the grazing system was changed from continuous grazing to different rotation systems. Grazing resumed in 1991 with a high-intensity, low-frequency rest-rotational system from 1 October to 30 April. Moderately grazed areas were stocked at 25 animal-unit days (AUD) • ha^{-1} • yr^{-1} and heavily grazed areas were stocked at 37.5 - 50 AUD • ha^{-1} • yr^{-1}. We defined one AUD as 2 steers for one day.

A prescribed burning program was initiated on the CWMA in 1997. Burns were conducted using head fires ignited with a drip torch and covered 40 to 80 ha. The study areas used in this research project were burned in February 1998 and November 1999 during dry conditions.

Methods

Field Methods

Lizards were captured in each of the study areas through road cruising, fortuitous encounters, and drift fence arrays. Each study site (*n=5*) on the study area had 3, Y-shaped drift fence arrays that were open for 14 days in either May or June. Upon capture, snout-vent length (SVL), total length, mass, sex, and location of the lizards were recorded. Lizards were marked with an intra-abdominal passive integrated transponder (PIT; AVID, Norco, California, USA) tag. The fifth toe on the front right foot was also clipped to recognize if the lizard had been previously caught. Lizards that were too small to receive a PIT tag, approximately < 50 mm SVL, were given a unique toe clipping sequence.

Adult lizards captured within the five study sites were fitted with custom-made backpacks that carried transmitters (150-151 MHz, L and L Electronics, Mahomet, Illinois, USA). Backpacks were composed of a beige muslin material and elastic straps dyed to match the natural substrate color of the CWMA. The backpack was attached to the lizard by placing an upper strap around the neck and one front leg, and placing an additional strap around the back legs. A drop of cyanoacrelate gel adhesive was used to attach the straps to the lizard's chest and lower abdomen to further secure the backpack. The total mass of the transmitter and backpack bundle was approximately 3 g (< 8 percent of lizard mass). Receiving range of the transmitters was approximately 100 m. An antenna attached to the end of a 5-m PVC pole increased transmitter detectability to approximately 200 m.

Radio-fitted lizards were initially relocated twice daily with a handheld two-element Yagi antenna until lizards resumed normal ranging behavior. Monitoring was then reduced to once daily until hibernation. Every six weeks, lizards were recaptured and given a new transmitter in the field. Once refitted with a backpack, the lizard was released. Data recorded at each relocation included lizard activity and behavior, date, time of day, pasture, burn treatment, UTM coordinates, weather, and micro-habitat data.

Data were collected during the summers of 1998-2000. The summer was divided into 2 seasons, active and inactive, corresponding to the relative activity of horned lizards. The season encompassing 15 April - 30 June was the time of greatest lizard activity and was considered the active season. Lizards are considerably more sedentary during 1 July - 15 August, which was termed the inactive season.

Locations of lizards were estimated by pacing from the position of the lizard in a cardinal direction to a road and then to a permanent landmark with known Universal Transverse Mercator (UTM) coordinates. Coordinates were entered into a Geographical Information System (GIS) to aid in range and habitat analyses. Only lizards with a radiotransmitter were used in home range and survival rate analyses (Munger 1986). All statistical analyses were considered significant at a = 0.10.

Ant Abundance and Activity

Ant abundance and activity were measured with bait stations composed of six petri dishes placed 15-m apart along a transect. Transects were randomly located and followed a compass bearing. Each bait station was baited with millet and was anchored to the ground with a nail to prevent rodents from removing the dishes. Four transects from the same study area were run simultaneously. Petri dishes were baited in the morning and checked between 0800 and 1100 for ant activity to encompass the peak activity of ants (Whitford and Bryant 1979). Number of ants foraging at the station and the number of ants visiting the station within one minute were recorded. Though other species of ants were noted if present, only harvester ants were counted. The bait stations were baited again in the evening to assure that ants would keep visiting the dishes. Bait stations were run for 4 days at a time using the same transects once in the active season and once in the inactive season in all five study areas in the summers of 1999 and 2000. Systematic searches for ant mounds (Whiting et al. 1993; Fair and Henke 1997) were not used in this study because it was difficult to determine harvester ant mounds from other ant mounds, and to

distinguish active ant mounds from inactive ant mounds.

Harvester ant abundance was averaged across the 4 days for each transect, providing 4 replicates for each study site. Differences in ant activity and abundance were compared across the different burning and grazing treatments using a repeated measures, 4-way ANOVA including burning (burn, unburn), grazing (moderate, heavy), year (1999, 2000), and season (active, inactive) as main effects and all interactions. The treatments creating the repeated measurements were season and year. Because of a small sample of lizards in the control site (ungrazed, unburned), and the lack of an ungrazed, burned site, the control site was not used in the ANOVA. Instead, we examined the following contrasts: control vs. grazed sites, control vs. the grazed, unburned sites, and control vs. the heavily grazed, burned site (the most disturbed site).

Home Ranges

Range size of lizards were calculated using 95 percent minimum convex polygons (MCP; Mohr 1947) with the Animal Movement Analysis Program (Hooge et al. 1999). We included lizards tracked for ³ 20 locations to ensure a reliable representation of the home range. Because the home range data were not normally distributed, home range sizes were log-transformed. Individual lizards were used as the experimental unit, although this represents pseudoreplication, because the treatments were not replicated (Hurlbert 1984). Therefore, any inferences made from these data should be used with caution beyond the study area.

Comparisons of range size were made with a 3-way ANOVA including burning, grazing, and season as main effects and all interactions. Preliminary analysis indicated no gender differences in range size. Therefore, data were pooled across sex. Contrasts to the control were calculated in the same manner as described above in the ant analyses.

Survival

Survival rates were estimated using the Kaplan-Meier procedure (Pollock et al. 1989). Only lizards tracked for ³ 10 days were used in these analyses. The fate of many lizards was unknown due to transmitter failure, removal by a predator, lizard migration, and discovery of a backpack (without a lizard). Lizards with an unknown fate were termed censored in the analyses. To determine survival, we estimated the fate for censored lizards based on knowledge of that lizard. Lizards for which a fate could not be estimated were considered alive. To test for differences in the survival function (shape of the curve) between treatments, a log-rank test was used (Pollock et al. 1989). A Z-test statistic was also used to compare the survival curves on the last day of the summer (August 15; Pollock et al. 1989).

Table 1.—Number of ants at the bait station upon arrival (n = 4 in each treatment) for the active and inactive seasons on the Chaparral Wildlife Management Area, summers 1999 and 2000. The treatments are designated as U-U (control), Mg-B (Moderately grazed, burned), Mg-U (Moderately grazed, unburned, Hg-B (Heavily grazed, burned), and Hg-U (Heavily grazed, unburned)

	Active Season		Inactive Season	
Treatment	$\bar{x}$	SE	$\bar{x}$	SE
U-U	8.3	4.5	5.3	1.6
Mg-B	5.8	2.4	28.6	3.9
Mg-U	1.8	1.3	5.2	2.1
Hg-B	9.6	3.0	16.6	3.0
Hg-U	2.8	1.2	4.8	1.4

Results

Ant Abundance and Activity

More harvester ants were found at the bait station in the burned pastures, but this effect varied by season and level of grazing (3-way interaction, $F_{1,36} = 5.00$, $P = 0.03$, Table 1.). In both seasons, more ants were found in the burned pastures than the unburned pastures; however, this was especially true in the inactive season. More ants were found in all sites in the inactive season. In the active season, similar numbers of ants were found in the burned sites. In the inactive season, more ants were found in the moderately grazed/burned site than the heavily grazed, burned site ($P < 0.01$). In both seasons, the number of ants at the bait station was similar in the unburned sites. More ants were found in the control than the unburned, grazed sites ($F_{1,75} = 7.66$, $P < 0.01$). Fewer ants were found in the control than the 4 grazed sites ($F_{1,75} = 15.72$, $P < 0.01$) and the heavily grazed, burned site ($F_{1,75} = 12.24$, $P < 0.01$, Figure 1).

Burning affected the number of ants that arrived at the bait stations in one minute, but this effect varied by season and year (3-way interaction, $F_{1,36} = 3.30$, $P = 0.07$, Table 2). More ants were found in the burned sites in both seasons and both years than the unburned sites ($P < 0.04$ for all comparisons), except for the active season of 1999 ($P = 0.47$). In both years, more ants were found in the inactive season than active season for burned sites ($P < 0.01$ for both comparisons). More ants were also found in the burned sites in 2000 when compared to 1999 for both seasons ($P < 0.01$ for both comparisons). Finally, the number of ants that visited the bait stations was similar in the unburned sites for both seasons and both years.

Grazing also affected the number of ants that arrived at the bait station, but this effect varied by season and year (3-way interaction, $F_{1,36} = 7.55$, $P < 0.01$, Table 1). In the

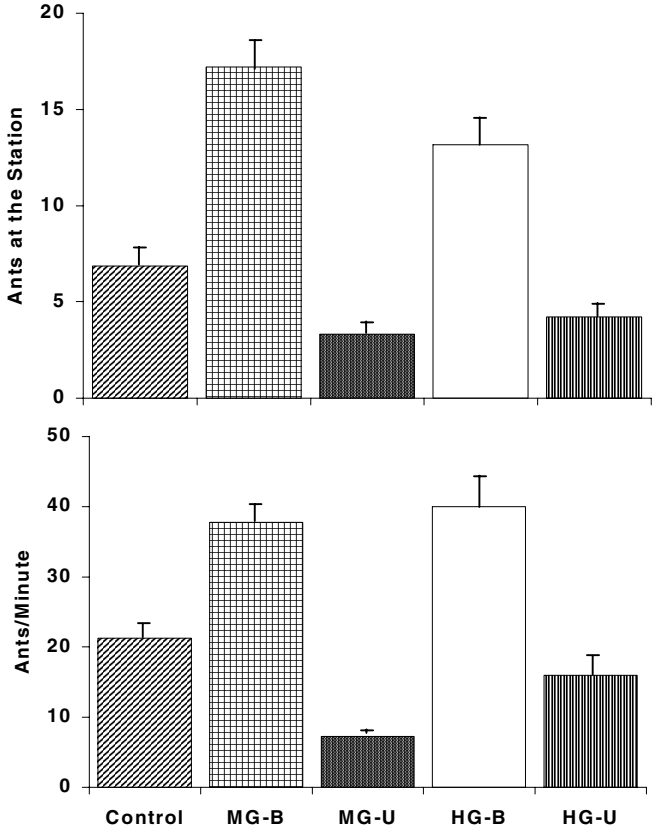

Figure 1.—Contrasts to the control for the number of ants at the ant bait stations upon arrival and the number of ants that visited the station within one minute at the Chaparral Wildlife Management Area, summer 1999-2000. The treatments are designated as Mg-B (moderately grazed, burned), Mg-U (Moderately grazed, unburned), Hg-B (Heavily grazed, burned), and Hg-U (Heavily grazed, unburned).

active season, the number of ants that visited the bait stations was similar in the moderately and heavily grazed sites. However, in the inactive season of 1999, more ants were found in the moderately grazed sites than the heavily grazed sites ($P = 0.05$); whereas in 2000 during the inactive season, more ants were found in the heavily grazed sites than the moderately grazed sites ($P < 0.01$). In both years, more ants were found in the inactive season than the active season for all sites ($P < 0.01$ for all comparisons) except for the heavily grazed sites in 1999 ($P = 0.51$). More ants were found in 2000 than 1999 for both seasons and levels of grazing ($P < 0.04$ for all comparisons).

More ants arrived at the station in the control than for the 4 grazed sites ($F_{1,75} = 3.52$, $P = 0.06$), but fewer than in the heavily grazed, burned site ($F_{1,75} = 5.86$, $P = 0.01$, Figure 1). More ants were found in the control than the unburned, grazed sites, but this difference was not significant ($F_{1,75} = 1.23$, $P = 0.27$). Though this comparison was not tested, fewer ants were found in the control than the burned, grazed sites (Figure 1).

Home Ranges

A total of 78 seasonal home ranges from 57 lizards were used in home range analyses. Total area used by horned lizards across both seasons ranged from 0.02 ha to 11.05 ha for 95 percent MCP (Table 3). The effect of burning on home range size interacted with season for 95 percent MCP ($F_{1,14} = 3.49$, $P = 0.08$). In the active season, home ranges in the burned sites ('x ± SE = 1.14 ± 0.27 ha, $n = 18$) were smaller than those in the unburned sites (2.01 ± .06, $n = 19$), but were smaller and similar in size in both sites during the inactive season. All other interactions and main effects were not significant. Grazing did not have an effect on home range size ($P = 0.15$). Average (± SE) home range size for lizards in the control was 0.66 (± 0.22) in the active season and 0.80 (± 0.28) in the inactive season. None of the contrasts to the control were different.

Survival

Summer (15 Apr - 15 Aug) survival rates (S) ranged from 0.25 to 0.62. Grazing influenced survival rate of lizards ($P = 0.05$, Figure 2). Survival rates of lizards in the moderately grazed sites ($S = 0.60$) were higher than those in the heavily grazed sites ($S = 0.36$). Burning did not affect summer survival rates ($P = 0.19$, Figure 3). Because of a small sample size in the control, lizards from the control were not used in these analyses, but summer survival rate in the control was 1.00. However, 2 of 4 lizards died in the September - October period.

Discussion

The diet of the horned lizard consists primarily of ants (Burt 1928; Milne and Milne 1950; Pianka and Parker 1975; Whitford and Bryant 1979; Rissing 1981; Munger 1984*a*; Munger 1984*b*; Schmidt et al. 1989). Pianka and Parker (1975) found that 69 percent of the diet of Texas horned lizards was composed of harvester ants, with beetles composing the remainder. Numbers of harvester ants, therefore, could be one of the main components determining optimal habitat for a horned lizard. Previous studies on the effects of burning and grazing on ants showed that ants are not deleteriously affected by fire or grazing (McCoy and Kaiser 1990; Fox et al. 1996). The large increase in ant numbers for all ant indices in burned sites compared to unburned sites implies that on the CWMA, burning was beneficial to harvester ants. This conclusion was supported by the contrasts to the control. Ant numbers in the ungrazed, unburned control were intermediate to low values on the grazed, unburned sites, and high values on the grazed, burned sites.

The interpretation that burning had a positive effect on ant activity and distribution was complicated by interacting effects with grazing, season, and year. However, examination of these interactions indicated that, with regard to burning, the treatment effect varied

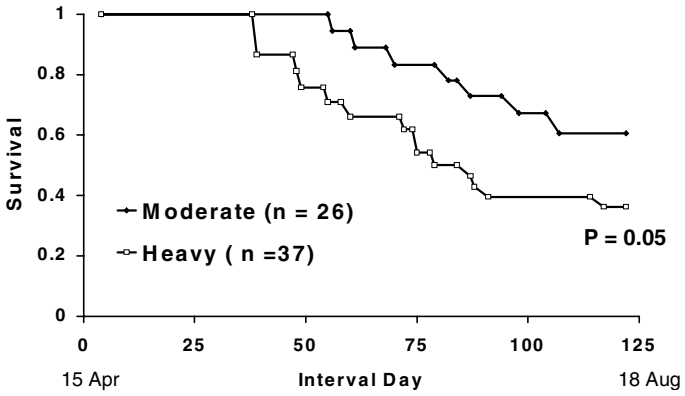

Figure 2.—Survival rates of Texas horned lizards in the moderately grazed (*S* = 0.60, 95% CI = 0.37-0.83) and heavily grazed sites (*S* = 0.36, 95% CI = 0.16-0.55) of the Chaparral Wildlife Management Area, summers 1998-2000.

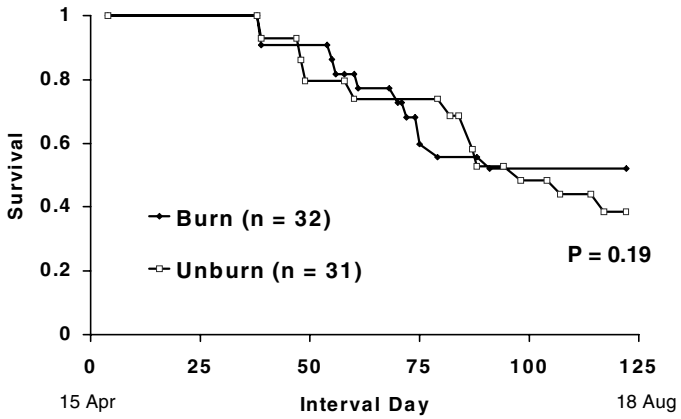

Figure 3.—Survival rates of Texas horned lizards in the burned (*S* = 0.52, 95% CI = 0.30-0.73) and unburned (*S* = 0.38, 95% CI = 0.16-0.60) sites of the Chaparral Wildlife Management Area, summers 1998-2000.

Table 2.—Number of ants that visited the bait stations within one minute (n = 4 in each treatment) for the active and inactive seasons on the Chaparral Wildlife Management Area, summers 1999 and 2000. The treatments are designated as U-U (control), Mg-B (Moderately grazed, burned), Mg-U (Moderately grazed, unburned, Hg-B (Heavily grazed, burned), and Hg-U (Heavily grazed, unburned)

	1999				2000			
	Active Season		Inactive Season		Active Season		Inactive Season	
Treatment	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
U-U	1.3	1.0	7.7	2.9	35.5	10.7	40.4	12.9
Mg-B	3.1	1.5	45.7	12.8	28.4	73.7	73.7	11.3
Mg-U	0.1	< 0.1	5.8	2.5	12.8	6.7	10.2	5.1
Hg-B	9.4	4.9	15.2	5.1	33.4	8.4	101.8	17.3
Hg-U	1.2	0.2	5.6	2.2	17.5	5.4	39.1	7.2

Table 3.—Home range sizes of Texas horned lizards (ha) using 95% Minimum Convex Polygon (MCP) for active and inactive seasons on the Chaparral Wildlife Management Area, summer 1998-2000. The treatments are designated as U-U (control), Mg-B (Moderately grazed, burned), Mg-U (Moderately grazed, unburned), Hg-B (Heavily grazed, burned), Hg-U (Heavily grazed, unburned)

	Active Season					Inactive Season				
Treatment	n	$\bar{x}$	SE	minimum	maximum	n	$\bar{x}$	SE	minimum	maximum
U-U	6	0.66	0.22	0.06	1.28	4	0.80	0.28	0.22	2.11
Mg-B	8	1.04	0.50	0.04	4.26	10	0.32	0.10	0.02	0.96
Mg-U	9	1.33	0.20	0.25	2.11	5	0.23	0.05	0.10	0.35
Hg-B	10	1.22	0.31	0.03	3.13	6	0.80	0.28	0.22	2.11
Hg-U	10	2.62	1.02	0.06	11.05	10	0.49	0.02	0.04	1.93

only in magnitude by season and year. The direction of the burning effect did not vary with time. Foraging activity in Chihuahuan desert harvester ants varied with season and year, with greater numbers of foragers in July and August than May and June (Whitford and Ettershank 1975). The greater number of harvester ants on the CWMA in the inactive season could be a result of increased foraging effort by harvester ants caused by greater seed availability in the inactive season, coupled with an increase in the number of foragers from reproductive efforts in early summer (Whitford and Ettershank 1975). Harvester ants are also thermophilic (Holldobler and Wilson 1990), so it is possible that the hotter temperatures associated with the inactive season enable harvester ants to forage more.

Increased seed availability and reproduction can also explain year effects. Whitford and Ettershank (1975) stated that harvester ant activity was regulated by seed availability and colony satiation. Perhaps 2000 was an exceptionally good year for seed production or reproduction resulting in more foraging ants. Increased ant activity in 2000 also could be a result of depleted resources from 1999. If granaries were depleted in 1999 due to a bad seed year, foraging effort would increase in 2000 to attempt to replenish the granaries. Low seed production in 1999 would also result in reduced activity in that year (Whitford and Ettershank 1975), thereby reducing the number of foraging ants at the bait stations. Unfortunately, we do not data on seed production to support these speculations.

Previous studies concluded that livestock grazing did not affect ant numbers in desert ecosystems (Heske and Campbell 1991; McClaran and Van Devender 1995:165). Grazing had a variable effect on harvester ant numbers, and appeared beneficial to ants when coupled with burning (Figure 1.1). As with burning, effects were stronger in the inactive season. The effect of level of grazing on ant activity interacted with year and specific ant index. For example, in the inactive seasons, more ants arrived at the station in moderately grazed sites in 1999, but in heavily grazed sites in 2000. However, more bait stations were consistently visited by ants in heavily grazed sites. In addition, higher ant indices were seen on the heavily grazed/burned site in all contrasts with the control. More bare ground in the heavily grazed site could be responsible for the increase in ants in heavily grazed sites in 2000, because harvester ants prefer areas of sparse vegetation (Holldobler and Wilson 1990). Therefore, it appears that heavy grazing was more beneficial to harvester ants, especially when coupled with burning.

Fire and grazing can improve conditions for harvester ants in several ways. Fire can increase forb and grass cover (McClaran and Van Devender 1995:134; Ruthven et al. 2000) and available bare ground, and decrease litter accumulation. Grazing can also increase forb abundance and decrease litter accumulation (Kelting 1954). Because harvester ants are granivores, most activity occurs in areas with interspersed bare ground and herbaceous vegetation. Forb and grass seeds provide the ants with food, and the sparse vegetation facilitates foraging (Holldobler and Wilson 1990). Finally, DeMers (1993) noted that harvester ant queens prefer to start a new mound in open areas with little vegetation. An increase in prey abundance associated with burning could result in a subsequent increase in Texas horned lizard density or a decrease in ranging behavior.

Home range size is inversely proportional to the distribution and abundance of resources for many species, including several lizards (Mares et al. 1976; Litvaitis et al, 1986; Boutin 1990; Lacher and Mares 1996). Little is known about the size of home ranges for the Texas horned lizard, although information does exist in closely related species (Lowe and Stebbins 1954; Baharav 1975; Turner and Medica 1982). Munger (1984*c*) reported home range sizes of Texas horned lizards in Arizona as averaging 1.35 ha for females (n = 13) and 2.40 ha for males (n = 10). Home ranges in my study were considerably larger than those previously reported by Fair and Henke (1999), who estimated home range size of Texas horned lizards in southern Texas to be between 0.02 to 1.47 ha (n = 16). However, their home range estimates were only the sum of weekly estimates of several months.

We propose that the smaller home ranges of horned lizards in burned pastures resulted from burning improving the habitat of horned lizards to the degree that ecological requirements (i.e., food, cover) were found in a smaller area. Because grazing did not affect home range size, it is possible that grazing at the intensities studied is neither beneficial nor harmful to the habitat of horned lizards. The mechanism by which burning and moderate grazing may improve horned lizard resource distribution, and thus reduce home range size, is by creating open habitats interspersed with vegetation cover. Whiting et al. (1993) found that Texas horned lizards selected disturbed habitats over undisturbed habitats. They suggested that prey abundance and suitable open habitats were major factors related to the spatial occurrence of Texas horned lizards in Texas. Disturbances that create an open, sparsely vegetated habitat appear to benefit horned lizards in several ways. Open areas facilitate movement by this dorso-ventrally flattened species (Whiting et al. 1993). Fair and Henke (1998) also found that Texas horned lizards selected recently burned areas compared to areas with large litter accumulation because of increased mobility. Pianka (1966) found that horned lizards preferred open areas to sit and wait for their prey, thus increasing foraging efficiency. Open habitats also aid in thermoregulation by allowing horned lizards exposure to direct solar radiation (Heath 1965). Finally, horned lizards may select open habitats due to an increase in food abundance, specifically of harvester ants.

Smaller home ranges in the inactive season were expected based on our observations of horned lizard activity. Fair and Henke (1999) also found that home ranges decreased in size as the summer progressed until hibernation. Several reasons could explain seasonal differences in activity and ranging behavior of horned lizards. First, increased mobility of horned lizards during late spring and early summer could be due to mate-searching and nest-building activities. Horned lizards on the CWMA typically emerge from hibernation in early March or April and become highly mobile, often moving > 100 m/day to reproduce, build nests, and lay eggs. Second, as the summer progressed, the temperatures rose to points that could be lethal to horned lizards (Forrester et al. 1998); therefore, horned lizard movements were likely constrained by temperature in the inactive season. Third, the increase in harvester ant abundance and activity in the inactive season may have enabled lizards to move shorter distances to find food, thereby reducing the ranging behavior of the lizards.

Estimates on survival rates of horned lizards are contentious due to the large number of censored lizards. Munger (1986) found that Texas horned lizards in southeastern Arizona had annual survival rates between 35.0 and 86.0 percent, whereas Fair and Henke (1999) estimated 8-month survival rates (Mar-Oct) in southern Texas to be lower (8.9 -54.0 percent). However, Pianka and Parker (1975) suggested adult Texas horned lizards have comparatively high survival rates. Our estimates (25 - 62 percent) fall between those of Munger (1986) and Fair and Henke (1999). Lower survival rates in the heavily grazed sites suggested that heavier levels of grazing increase the vulnerability of horned lizards to mortality and may counteract increased prey abundance. Burning did not affect summer survival rates of horned lizards, though survival rates were higher in burned than unburned sites during the inactive season ($P = 0.03$). Higher survival rates in moderately grazed sites and burned sites could be due to better juxtaposition of food and cover, as supported by the home range and ant data.

The smaller home ranges, increased survival rates (at least in the inactive season), and greater prey abundance in burned pastures suggested a positive effect of fire on the ecology of Texas horned lizards. The effect of grazing was more complex. Survival was decreased in heavily grazed pastures, but range size did not differ among grazing level. Also, ant activity was generally higher in the heavily grazed pastures, especially when coupled with burning. Our comparisons to an ungrazed, unburned control were limited by a small sample in the control pasture. However, measures of lizard resources (e.g., vegetation, ants) and performance (e.g., range size, survival) were generally comparable between control and treated pastures. An alternate-year burning regime and stocking rates of livestock such as those implemented by CWMA created suitable habitat for Texas horned lizards in southern Texas.

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Literature Cited

Archer, S. C., and F. E. Smeins. 1991. **Ecosystem-level processes**. *In* R.K. Heitschmidt and J.W. Stuth, eds. Grazing management: an ecological perspective. Timber Press, Portland, Oregon: 109-139.

Baharav, D. 1975. **Movement of the horned lizard, *Phrynosoma solare***. Copeia. 1975: 649-657.

Boutin, S. 1989. **Food supplementation experiments with terrestrial vertebrates: patterns, problems, and the future**. Canadian Journal of Zoology. 68: 203-220.

Bunting, S. C., and H. A. Wright. 1977. **Effects of fire on desert mountain shrub vegetation in Trans-Pecos, Texas**. *In* Research Highlights, Volume 8: Noxious Brush and Weed Control Range and Wildlife Management. Texas Tech University, Lubbock, Texas, USA: 14-15.

Burt, C. E. 1928. **Insect food of Kansas lizards with notes on feeding habits**. Journal of Kansas Entomological Society. 1: 50-68.

Daubenmire, R. 1959. **A canopy coverage method of vegetational analysis**. Northwest Science. 33: 43-64.

DeMers, M. N. 1993. **Roadside ditches as corridors for range expansion of the western harvester ant (*Pogonomyrmex occidentalis*)**. Landscape Ecology. 8: 93-102.

Donaldson, W., A. H. Price, and J. Morse. 1994. **The current status and future prospects of the Texas horned lizard (*Phrynosoma cornutum*) in Texas**. Texas Journal of Science. 46: 97-113.

Dunne, J., A. Dennis, J. W. Bartolome, and R. H. Barrett. 1991. **Chaparral response to a prescribed fire in the Mount Hamilton Range, Santa Clara County, California**. Madrono. 38: 21-29.

Fair, S. E., and S. E. Henke. 1997. **Effects of habitat manipulations on Texas horned lizards and their prey**. Journal of Wildlife Management. 61: 1366-1370.

Fair, S. E., and S. E. Henke. 1998. **Habitat use of Texas horned lizards in Southern Texas**. Texas Journal of Agriculture and Natural Resources. 11: 73-86.

Fair, S. E., and S. E. Henke. 1999. **Movements, home ranges, and survival of Texas horned lizards (Phrynosoma cornutum)**. Journal of Herpetology. 33: 517-525.

Forrester, D. N., F. S. Guthery, S. D. Kopp, and W. E. Cohen. 1998. **Operative temperature reduces habitat space for northern bobwhites**. Journal of Wildlife Management. 62: 1506-1511.

Fox, B. J., M. D. Fox, J. E. Taylor, G. P. Jackson, J. Simpson, P. Higgs, L. Rebec, and R. Avery. 1996. **Comparison of regeneration following burning, clearing, or mineral sand mining at Tomago, NSW: II. Succession of ant assemblages in a coastal forest**. Australian Journal of Ecology. 21: 184-199.

Hatch, S. L., K. N. Gandhi, and L. E. Brown. 1990. **Checklist of the Vascular Plants of Texas**. Texas A&M University system, College Station, TX, USA.

Heath, J. E. 1965. **Temperature regulation and diurnal activity in horned lizards**. University of California Publications in Zoology. 64: 97-136.

Heske, E. J., and M. Campbell. 1991. **Effects of an 11-year exclosure on rodent and ant numbers in the Chihuahuan Desert, southeastern Arizona**. The Southwestern Naturalist. 36: 89-93.

Holldobler, B., and E. O. Wilson. 1990. **The Ants**. The Belknap Press, Cambridge, MA, USA.

Hooge, P. N., W. Eichenlaub, and E. Solomon. 1999. **The animal movement program**. USGS, Alaska Biological Service Center.

Hurlbert, S. H. 1984. **Pseudoreplication and the design of ecological field experiments**. Ecological Monographs. 54: 187-211.

Lacher, T. E., Jr., and M. A. Mares. 1996. **Availability of resources and use of space in eastern chipmunks, *Tamias striatus***. Journal of Mammalogy. 77: 833-849.

Litvaitis, J. A., J. A. Sherburne, and J. A. Bissonette. 1986. **Bobcat habitat use and home range size in relation to prey density**. Journal of Wildlife Management. 50: 110-117.

Lowe, C. H., Jr., and R. C. Stebbins. 1954. **Normal field movements and growth rates of marked regal horned lizards (*Phrynosoma solare*)**. Ecology. 35: 420-421.

Mares, M. A., M. D. Watson, and T. E. Lacher, Jr. 1976. **Home range perturbations in *Tamias striatus***. Oecologia. 25: 1-12.

McClaran, M. P., and T. R. Van Devender. 1995. **The desert grassland**. University of Arizona Press, Tuscon, Arizona, USA.

McCoy, E. D., and B. W. Kaiser. 1990. **Changes in foraging activity of the southern harvester ant *Pogonomyrmex badius* (Latreille) in response to fire**. American Midland Naturalist. 123: 112-123.

Milne, L. J., and M. J. Milne. 1950. **Notes on the behavior of horned toads**. American Midland Naturalist. 44: 720-741.

Mohr, C. O. 1947. **Table of equivalent populations of North American mammals**. American Midland Naturalist. 37: 223-249.

Munger, J. C. 1984*a*. **Long-term yield from harvester ant colonies: implications for horned foraging strategy**. Ecology. 65: 1077-1086.

Munger, J. C. 1984*b*. **Optimal foraging? patch use by horned lizards (Iguanidae:*Phrynosoma*)**. The American Naturalist. 123: 654-680.

Munger, J. C. 1984*c*. **Home ranges of horned lizards (*Phrynosoma*): circumscribed and exclusive?** Oecologia. 62: 351-360.

Munger, J. C. 1986. **Rate of death due to predation for two species of horned lizard, *Phrynosoma cornutum* and *P. modestum***. Copeia. 1986: 820-824.

Pianka, E. R. 1966. **Convexity, desert lizards, and spatial heterogeneity**. Ecolgy. 47: 1055-1059.

Pianka, E. R., and W. S. Parker. 1975. **Ecology of horned lizards: a review with special reference to *Phrynosoma platyrhinos***. Copeia. 1975: 141-162.

Pollock, K. H., S. R. Winterstein, C. M. Bunck, P. D. Curtis. 1989. **Survival analysis in telemetry studies: the staggered entry design**. Journal of Wildlife Management. 53: 7-15.

Price, A. H. 1990. ***Phrynosoma cornutum***. Catalogue of American Amphibians and Reptiles. 469: 1-7.

Rissing, S. W. 1981. **Prey preferences in the desert horned lizard: influence of prey foraging method and aggressive behavior**. Ecology. 62:v1031-1040.

Russell, K. R., D. H. Van Lear, and D. C. Guynn, Jr. 1999. **Prescribed fire effects on herpetofauna: review and management implications**. Wildlife Society Bulletin. 27: 374-384.

Ruthven, D. C., J. F. Gallagher, and D. R. Synatzske. 2000. **Effects of fire and grazing on forbs in the western south Texas plains**. The Southwestern Naturalist. 45: 89-94.

SAS Institute Inc. 1996. **SAS/STAT User's Guide: Statistics, Version 6, Fourth ed., Vol. 1, 2**. SAS Institute Inc., Cary, North Carolina.

Schmidt, P. J., W. C. Sherbrooke, and J. O. Schmidt. 1989. **The detoxification of ant (*Pogonomrymex*) venom by a blood factor in horned lizards (*Phrynosoma*)**. Copeia. 1989: 603-607.

Turner, F. B. and P. A. Medica. 1982. **The distribution and abundance of the flat-tailed horned lizard (*Phrynosoma m'calli*)**. Copeia. 1982: 815-823.

Whitford, W. B., and W. G. Whitford. 1973. **Combat in the horned lizard, *Phrynosoma cornutum***. Herpetologica. 29: 191-192.

Whitford, W. G. and M. Bryant. 1979. **Behavior of a predator and its prey: the horned lizard (*Phrynosoma cornutum*) and harvester ants (*Pogonomrymex* spp.)**. Ecology. 60: 686-694.

Whiting, M. J., J. R. Dixon, and R.C. Murray. 1993. **Spatial distribution of a population of Texas horned lizards (*Phrynosoma cornutum*: Phrynosomatidea) relative to habitat and prey**. The Southwestern Naturalist. 38: 150-154.