THE EFFECT OF PRESCRIBED BURNING AND GRAZING ON THE THREATENED TEXAS HORNED LIZARD (*PHRYNOSOMA CORNUTUM*) IN THE WESTERN RIO GRANDE PLAINS

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CHAPTER I

CONSERVATION ECOLOGY OF THE TEXAS HORNED LIZARD: THE EFFECTS OF BURNING AND GRAZING IN A THORNSCRUB ECOSYSTEM

ABSTRACT

The effects of land-use practices on sensitive species, such as endangered or threatened species, is of considerable conservation and political interest. However, little information is available to evaluate the ecological effects of management practices on herpetofauna in general, and on the threatened Texas horned lizard in particular. I examined the effects of rotational livestock grazing and prescribed winter burning on the ecology of the state-threatened Texas horned lizard (*Phrynosoma cornutum*) during the summers of 1998-2000. Five study sites, each with a different burning and grazing treatment, were selected on the Chaparral Wildlife Management Area (CWMA) in southern Texas. Adult lizards caught in the study sites were fitted with backpacks carrying radio transmitters and relocated daily. Summer was divided into 2 seasons, active and inactive, corresponding to relative activity of horned lizards. Canopy cover of herbaceous vegetation data were collected with Daubenmire frames and woody canopy cover with the line intercept method. Harvester ant (*Pogonomyrmex rugosus*) abundance and activity were measured with bait stations. Forbs increased with increasing disturbance. Burning and grazing also reduced litter and increased bare ground. Burning and grazing did not affect woody vegetation. Ant abundance and activity were greater in burned pastures, and these effects varied with season and year. Home ranges of lizards in burned pastures were smaller than in unburned pastures in the active season. All home ranges decreased in size in the inactive season. Level of grazing (heavy vs. moderate) did not affect home range size. Summer (15 Apr - 15 Aug) survival rates (S) of horned lizards were greater ($P = 0.05$) in the moderately grazed sites ($S = 0.54$) than the heavily grazed sites ($S = 0.29$). Survival rates tended to be higher ($P = 0.19$) in burned sites ($S = 0.52$) than unburned sites ($S = 0.38$). Lizards in the moderately grazed, burned site were smaller in length and mass, but supporting data were inconsistent. 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. The effect of grazing was more complex. Survival was decreased in heavily grazed pastures, but range size did not differ among grazing levels. Ant activity was generally higher in the heavily grazed pastures, especially when coupled with burning. Burning appeared to improve lizard resources (e.g., vegetation, ants) and performance (e.g., range size, survival) relative to the control.

INTRODUCTION

The effect of land-use practices on sensitive species, such as endangered or threatened 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 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.

Direct impacts of burning and grazing on horned lizards are not clear. Reynolds (1979) found an increase in numbers of short-horned lizards (*Phrynosoma douglassi)* in grazed (vs. ungrazed) areas due to increased basking sites. Conversely, Jones (1981) found that when grazing altered the vegetational structure of a site, lizard numbers decreased. Many species of agamid lizards seem to prefer burnt areas (Griffiths and Christian 1996). In a study on Texas horned lizards, > 80% of the lizards studied were found in burned and grazed areas. However, search effort within each of the management regimes was not quantified (Fair and Henke 1997).

Indirect effects of burning and grazing on horned lizards, such as those on prey and habitat, are better understood. Ants, the main prey of horned lizards (Milne and Milne 1950, Pianka and Parker 1975), are not deleteriously affected by fire or grazing. Ants can seek refuge inside their mounds during fire events (Fox et al. 1996) and can adjust their activity accordingly after a fire (McCoy and Kaiser 1990). Fire generally reduces ground cover, enabling ants to cover more ground in a shorter period and increase foraging distance (Fox et al. 1996). Immediately after a burn, the number of foraging ants generally increases as the ants take advantage of seeds that fell to the ground during the fire (Fox et al. 1996). Livestock grazing appears to have no effect on ant numbers in desert ecosystems (Heske and Campbell 1991, McClaran and Van Devender 1995:165).

Fire can play a critical role in determining plant species composition (Tyler 1995), and therefore, horned lizard habitat. Many species of plants are dependent upon fire for reproduction (Turner et al. 1994, Tyler 1995), or may be favored due to a decrease in competition with other plants or to an altered organic soil layer following fire (Pyne et al. 1996:189). Fire can cause an initial burst of seedling development as seeds are released from parent plants, as has been found in California chaparral (Tyler 1995). Fire can also change nutrient cycling (McClaran and Van Devender 1995:134). Because harvester ants (*Pogonomyrmex* spp.) are granivorous, this increase in food supply following fire would enable the establishment of more ant colonies. This, in turn, may increase the number of horned lizards in the area.

The habitat of horned lizards can potentially improve or worsen with fire and grazing. Fire reduces shrub canopy cover (Dunne et al. 1991), whereas grazing can decrease the effectiveness of fire by reducing fuel loads (Scifres and Hamilton 1993:16-17). Ruthven et al. (2000) found that forbs increased on southern Texas rangelands in the first year after a winter burn and grazing did not affect forb abundance. Bunting and Wright (1977) also found that forb and grass cover increased by 650%, but shrubs were reduced by 72% following fire in a desert mountain shrub ecosystem of Texas. Grass production may be reduced immediately following a burn, but is enhanced in the long-term because of reduced competition with woody plants (Florence and Florence 1988, Scifres and Hamilton 1993:16-17, McClaran and Van Devender 1995:134). An increase in herbaceous vegetation due to reduced shrub canopy cover provides more seeds for harvester ants. However, shrub canopy cover is important to horned lizards for shade and refuge from predators. Therefore, a large reduction in canopy cover could be detrimental.

Grazing can also potentially alter the microclimate of an area by increasing soil temperatures and wind speeds (Archer and Smeins 1991). Microclimate is probably a more important climatic factor than macroclimate to horned lizards. Grazing can change the species composition of an area (Collins and Wallace 1990:142-145). Other effects of grazing include a decrease in the amount of live biomass (Kelting 1954), increased selection for short, prostrate, growth forms, increased erosion (Milchunas and Lauenroth 1993), increased soil compaction (Kelting 1954, Penfound 1964), increase in noxious species, increase in bare soil, increased run-off, increase in litter (Penfound 1964), and a decrease in flowering, which can reduce plant fitness (Collins and Wallace 1990). All of the effects have the potential to either improve or worsen the habitat of horned lizards.

Specific objectives of my research were to: characterize vegetation in burning and grazing treatments; 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, survival rates, mass and lengths of Texas horned lizards among different burning and grazing treatments. Based on available literature, I made several testable predictions. Bare ground and herbaceous vegetation would increase in burned and grazed sites whereas litter would decrease. Harvester ant activity and abundance would be greatest in the burned and moderately grazed site because of an increase in seeds coupled with an open, sparsely vegetated habitat, which is selected by harvester ants (DeMers 1993). Horned lizards would be less selective of foraging habitat in the moderately grazed and burned site due to an increase in abundance of harvester ants and better habitat characteristics.

Therefore, range size of Texas horned lizards would be smaller and survival rates higher in the moderately grazed and burned sites than in other treatments.

STUDY AREA

The study was conducted on the 6,150-ha Chaparral Wildlife Management Area (CWMA) 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 follow Hatch et al. (1990).

Five study sites (50-60 ha)were selected on the CWMA, each with a different burning and grazing treatment (Figure I.1). Sites were chosen based on similarities in dominant woody species and woody canopy cover. Treatments were: control (ungrazed/unburned), moderately grazed/burned, heavily grazed/burned, moderately grazed/unburned, and heavily grazed/unburned. The control site has not been burned or grazed since 1976 and was considered the least disturbed site. The heavily grazed, burned site was considered the most disturbed site. There was not an ungrazed, burned site available during the course of this study because the management regime on the study area did not entail the burning of ungrazed pastures.

Historical grazing occurred on CWMA, but after TPWD began managing the land, grazing steadily declined and temporarily stopped in 1984. During this time, the grazing system was changed from continuous grazing to different rotation systems. Grazing resumed in 1991 with a 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}. I defined one AU as 2 steers.

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.

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. Employees of the CWMA have been capturing horned lizards from road cruising, drift fences and other random encounters since 1991. This information supplemented data collected for this study.

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% of the total mass of the lizard). Receiving range of the transmitters was around 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, Universal Transverse Mercator (UTM) coordinates, weather, and micro-habitat data. Once lizards began hibernating, a Phrynosoma Includer Device (PID, Figure III.1) was used to keep the lizard from leaving the area upon awakening.

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 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 $\alpha = 0.10$. Actual P-values are reported.

Vegetation

Woody canopy cover by species in each of the 5 study sites was estimated with 12, randomly placed, 30-m transects using the line-intercept method in summer 1999. Herbaceous cover was estimated in quadrat frames (20 x 50 cm^2) in each site during summers 1999 and 2000 (Daubenmire 1959). Frames ($n = 30$) were randomly distributed around each drift fence in the study sites. Cover of bare ground, grass, forbs, litter and woody species in the frame, as well as woody canopy cover over the frame were recorded.

Comparisons of woody vegetation were made with a 2-way ANOVA including burning (burned, unburned) and grazing (moderate, heavy) as main effects and the interaction. Four random woody transects were measured for each of the 3 drift fences per study area. Values from these transects were averaged for each species and for total cover, providing 3 replicates per species per treatment. Because of a small sample of lizards in the control site (ungrazed, unburned), and the lack of an ungrazed, burned site, comparisons to the control were made with pre-planned contrasts. The following contrasts were examined: control vs. grazed sites, control vs. the grazed, unburned sites, and control vs. the heavily grazed, burned site (the most disturbed site). The dominant 5 woody species in the study sites were analyzed for differences across the treatments and the same contrasts were made to the control. Bonferonni adjustments for multiple comparisons were used because the samples were not independent.

Comparisons of differences in herbaceous vegetation were made among the burning and grazing treatments with a 3-way ANOVA including burning, grazing and year (1999, 2000) as main effects and all interactions. Thirty Daubenmire frames were used at each of the 3 drift fences per study area. Values from the 30 frames were averaged for each variable, providing 3 replicates per treatment in the analysis. Contrasts to the control were calculated the same as described above in the woody vegetation analysis.

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 conducted 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 (*Pogonomyrmex rugosus*) were counted. The bait stations were baited again in the evening to assure that ants would keep visiting the dishes. Bait stations were conducted 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 distinguish 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, grazing, season, and year as main effects and all interactions. The treatments creating the repeated measurements were season and year. The number of bait stations visited by ants in each transect was analyzed using a categorical model (PROC CATMOD, SAS Institute, Inc. 1996). Contrasts to the control for all ant analyses were calculated in the same manner as described above in the vegetation analysis.

Home Ranges

Range size of lizards were calculated using 95% minimum convex polygons (MCP; Mohr 1947) and 95% adaptive kernels (AK; Larkin and Halkin 1994) using the Animal Movement Analysis Program (Hooge et al. 1999). Daily distance traveled by lizards was also calculated using the Animal Movement Analysis Program. I included lizards tracked for ≥ 20 locations to ensure a reliable representation of the home range. Because the home range data were not normally distributed, home range size was log-transformed. Individual lizards were used as the experimental unit, although this is pseudoreplication, because the treatments were not replicated (Hurlbert 1984). Therefore, inferences made from these data should be used with caution beyond the study area.

Comparisons of range size and daily distance traveled were made with a 3-way ANOVA including burning, grazing, and season as main effects and all interactions. Preliminary analysis indicated that there were no gender differences in range size and distance traveled. Therefore, data were pooled across sex. Contrasts to the control were calculated in the same manner as described above in the vegetation analysis. Site fidelity tests were performed on the 95% MCP home ranges using the Animal Movement Analysis Program (Hooge et al. 1999). The site fidelity test compared the actual lizard movement paths to equidistant paths with randomized angles to determine if movement was random or more constrained than random. I interpreted a path that tested more constrained than random to exhibit site fidelity.

Survival

Survival rates were estimated using the Kaplan-Meier procedure (Pollock et al. 1989) on lizards tracked for ≥ 10 days. Because the fate of many lizards was unknown, four different survival rate estimates, termed categories, were measured using different assumptions (Munger 1986). Possible reasons for an unknown fate included transmitter failure, removal by a predator, lizard migration, and discovery of a backpack (without a lizard). In all categories, if the fate of the lizard was known (e.g., the carcass of the lizard was found, the lizard was released, etc.), the fate remained as such in the analyses. Lizards with an unknown fate were termed censored in the analyses. Category 1 assumed all censored lizards were alive. In category 2, I estimated the fate for censored lizards based on knowledge of that lizard. Lizards for which a fate could not be estimated were considered alive. In category 3, I estimated the fate for censored lizards based on knowledge of that lizard. Lizards for which a fate could not be estimated were considered dead. In category 4, all censored lizards were considered dead. In 2 cases, the backpacks of the lizards became tangled with a stick leading to the death of the lizard. For these research mortalities, the lizards were considered to be alive in all categories and the last live location was given as the end date for that lizard. 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 summer monitoring (August 15; Pollock et al. 1989).

Lizard Length and Mass

Horned lizards captured on the CWMA in each of the study sites for 1996-1997 (pre-treatment), and 1998-2000 (post-treatment) were used in the analysis for lizard length and mass. Comparisons of total length, SVL, and mass of lizards caught in the study sites before burning was implemented on the CWMA to those caught after burning were made using a 3-way ANOVA including burning, grazing, and time (pre-treatment, post-treatment) as main effects and all interactions. Because horned lizards are sexually dimorphic, males and females were analyzed separately. Contrasts to the control were calculated in the same manner as described above in the vegetation analysis. Comparisons of body condition (size specific mass) among the different treatments were made using Analysis of Covariance with SVL as the covariate.

RESULTS

Vegetation

Bare ground varied by burning, grazing, and year (3-way interaction, $F_{1,16} = 3.32$, $P = 0.08$, Tables I.1, I.2). In 1999, the amount of bare ground in each site was similar. However, in the year 2000, more bare ground was found in the heavily grazed sites compared to the moderately grazed sites ($F_{1,8} = 6.38$, $P = 0.03$) and more bare ground was found in the burned sites compared to unburned sites ($F_{1,8} = 2.41$, $P = 0.08$). None of the contrasts to the control for bare ground were significant. Burning affected litter, but this effect varied by year ($F_{1,16} = 6.48$, $P = 0.02$, Tables I.1, I.2). In 1999, the amount of litter in each site was similar. In 2000, more litter was found in the unburned sites. Percent litter was greater in the control than the 4 grazed sites ($F_{1,25} = 3.47$, $P = 0.07$) and the heavily grazed, burned site ($F_{1,25} = 3.67$, $P = 0.06$).

Burning had an effect on forb cover, but this effect varied by year ($F_{1,16} = 4.35$, $P = 0.05$, Tables I.1, I.2). Grazing also had an effect on forb cover, and this effect varied by year ($F_{1,16} = 13.33$, $P = 0.002$, Tables I.1, I.2). The burned sites had greater forb cover than the unburned sites, but this was especially true for the year 2000. In 1999, the heavily grazed sites contained greater forb cover than the moderately grazed sites. However, in the year 2000, this effect was reversed. Forb cover was lower in the control than the 4 treated sites ($F_{1,25} = 4.44$, $P = 0.04$) and the heavily grazed, burned site ($F_{1,25} = 5.00$, $P = 0.03$). Burning affected grass cover, but this effect varied by year ($F_{1,16} = 5.90$, $P = 0.02$, Tables I.1, I.2). In the year 1999, more grass was found in the burned sites compared to unburned sites. In 2000, the effect was reversed. Grass cover in the control did not differ from the treated sites. Woody stem cover in the Daubenmire frame was consistently low and did not vary ($F_{1,16} = 0.24$, $P = 0.63$, Tables I.1, I.2).

Burning and grazing interacted for the total canopy of woody species over the line transect ($F_{1,8} = 6.07$, $P = 0.03$, Table I.3). The moderately grazed, burned site had less canopy cover than the heavily grazed, burned site ($P = 0.08$) and the moderately grazed, unburned site ($P = 0.01$). None of the contrasts to the control were different for woody canopy cover. Of the five dominant woody species tested, only tasajillo differed among burn treatments ($F_{1,8} = 11.54$, $P < 0.01$, Table I.3). More tasajillo was found in unburned than burned sites. More tasajillo was also found in the control than in the 4 grazed sites ($F_{1,10} = 17.66$, $P = 0.001$) and the grazed, unburned sites ($F_{1,10} = 5.49$, $P = 0.04$). None of the other contrasts to the control were significant.

Ant Abundance and Activity

More harvester ants were found at the bait stations in the burned pastures, but this effect varied by season and level of grazing (3-way interaction, $F_{1,36} = 5.00$, $P = 0.03$, Figure I.2, Table I.4). 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, approximately the same number of ants were found in each burned site. 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 I.3).

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, $F_{1,36} = 3.30$, $P = 0.07$, Figure I.4, Table I.5). 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, $F_{1,36} = 7.55$, $P < 0.01$, Figure I.5, Table I.5). In the active season in both years, 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 site 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 I.3). 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). Fewer ants were found in the control than the burned, grazed sites, though this contrast was not tested (Figure I.3).

Burning and grazing affected the number of bait stations visited by ants, but this effect varied by season (3-way interaction, χ_1^2 = 3.86, P = 0.04, Figure I.6, Table I.6). Bait stations in the burned sites were visited more often by ants than those in the unburned sites, but this effect was greater in the inactive season and on moderately grazed sites. The fewest number of bait stations were visited in the moderately grazed, unburned site. Burning (3-way interaction, χ_1^2 = 4.52, P = 0.03, Figure I.7) and grazing (3-way interaction, χ_1^2 = 2.79, P = 0.09, Figure I.8) also interacted with season and year. In both years, more bait stations were visited in the inactive season and in burned sites. This effect was relatively greater in 1999 (Figure I.7). For the grazing interaction, more bait stations were visited in the inactive season and on heavily grazed sites, but this was especially true in 2000 (Figure I.8). The control had fewer bait stations visited by ants than the heavily grazed, burned site ($F_{1,155}$ = 7.15, $P < 0.01$). Other contrasts to the control were not significant.

Home Ranges

A total of 78 seasonal home ranges from 57 lizards were used in home range analyses (Figure I.9 - I.16). Total area used by horned lizards across both seasons ranged from 0.02 to 11.05 ha for 95 % MCP (Table I.7) and 0.02 to 14.63 ha for 95 % adaptive kernels (Table I.8). The effect of burning on home range size interacted with season for

95 % MCP ($F_{1,14} = 3.49$, $P = 0.08$). In the active season, home ranges in the burned sites ($\bar{x} \pm SE = 1.14 \pm 0.27$ ha, $n = 18$) were smaller than those in the unburned sites (2.01 ± 0.06, $n = 19$), but were smaller and similar in size during the inactive season. All other interactions and main effects were not significant. Grazing did not have an effect on either index of 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. Burning and grazing did not affect 95 % AK, but home ranges were smaller in the inactive season than the active season ($F_{1,14} = 28.10$, $P < 0.01$, Appendix A). None of the contrasts to the control were different.

Burning interacted weakly with grazing in affecting mean daily distance traveled by lizards ($F_{1,46} = 3.17$, $P = 0.08$, Table I.9). Lizards traveled the shortest distance in the moderately grazed, burned site and the longest distance in the heavily grazed, burned site. Lizards also traveled smaller distances each day in the inactive season when compared to the active season ($F_{1,14} = 21.02$, $P = 0.0004$, $\bar{x} = 33.85$ for active season, $\bar{x} = 15.73$ for inactive season). Daily distance traveled by male and female horned lizards was not different ($F_{1,18} = 2.15$, $P = 0.15$). Of the 78 home ranges in the analyses, 43 were considered more constrained than random and the remaining 35 were considered random using the site fidelity tests.

Survival

Summer (15 Apr - 15 Aug) survival rates (S) ranged from 0.25 to 0.62. Category 1 survival rates (S_1) of lizards in the different burning and grazing treatments were not different ($P > 0.14$). Grazing influenced survival rate of lizards in categories 2, 3, and 4 ($P \leq 0.06$ for all comparisons, Figure I.17). Survival rates of lizards in the moderately grazed sites (S_2 = 0.60, S_3 = 0.54, S_4 = 0.46, respectively) were higher than those in the heavily grazed sites (S_2 = 0.36, S_3 = 0.29, S_4 = 0.25, respectively). Burning did not affect summer survival rates ($P \geq 0.19$ for all comparisons, Figure I.18). Male vs. female survival rates did not differ ($P \geq 0.16$ for all comparisons, Figure I.19). Because of a small sample size, lizards from the control site were not used in these analyses, but summer survival rate in the control site was 1.00. However, 2 of 4 lizards in the control pasture died in the September-October period.

Lizard Mass and Length

Lizard length and mass before and after burning was implemented on CWMA were not different ($P \geq 0.36$ for all comparisons). Mass of female lizards were smaller in the moderately grazed sites than heavily grazed sites ($F_{1,82} = 3.32$, $P = 0.07$, Table I.10). Mass of male lizards differed by the burning by grazing interaction ($F_{1,65} = 3.53$, $P = 0.06$). Males in the moderately grazed, burned site had less mass than those in the moderately grazed, unburned site ($P = 0.05$), and the heavily grazed, burned site ($P = 0.09$). Total lengths of female lizards also differed by the burning by grazing interaction ($F_{1,90} = 5.58$, $P = 0.02$, Table I.11). Females in the heavily grazed, burned site were longer than those in the moderately grazed, burned site ($P = 0.04$) and the heavily grazed, unburned site ($P = 0.03$). However, there were no differences in the SVL of females in different treatments. Snout-vent length of male lizards differed by the burning by grazing interaction ($F_{1,74} = 4.48$, $P = 0.09$). Males in the moderately grazed, burned site were shorter than those in the heavily grazed, burned site ($P = 0.03$) and the heavily grazed, unburned site ($P = 0.07$). However, there were no differences in the total length of male lizards in different treatments. None of the contrasts to the control for lizard length and mass were different. Comparisons of body condition across the treatments were not different for male ($F_{4,101} = 1.21$, $P = 0.31$) or female ($F_{4,82} = 0.70$, $P = 0.59$) horned lizards.

DISCUSSION

Vegetation

Burning and grazing can drastically alter vegetation composition and structure. Effects of burning and grazing on horned lizards were probably not due to changes in woody vegetation as sites had similar woody canopy cover and species composition across treatments. On my study sites, burning affected herbaceous variables more than grazing. Grazing is less likely to have an impact on vegetation in semi-arid areas with a long grazing history (Milchunas and Lauenroth 1993), such as the CWMA. Burning effects on herbaceous variables usually interacted with year, indicating a strong influence of time since burning associated with the alternate-year burning regime on the CWMA. Responses of herbaceous variables measured in 1999 to the most recent burn (18 months previously) were muted. Contrary to my prediction, bare ground and litter did not differ between burning treatments in 1999. However, in 2000, the most recent burn was 6 months before the herbaceous vegetation was sampled and the effects of burning on herbaceous canopy (i.e., bare ground, litter, forbs) were more obvious. My findings of increased forb cover after recent burning were consistent with previous work on the CWMA (Ruthven et al. 2000) and other papers showing a positive forb response to fire disturbance (Bunting and Wright 1977, Collins and Wallace 1990:87). The decrease in tasajillo in burned pastures was due to the short stature and burning vulnerability of tasajillo (Bunting et al. 1990).

The interaction of burning and year was complicated by grazing treatments. Grazing also removes litter and increases bare ground, which was supported by lower litter and greater amounts of bare ground on heavily grazed sites in 2000. I conclude from the contrasts that because forb cover was lower and litter accumulation was greater on the control than all 4 grazed sites and the heavily grazed, burned site but not than the 2 grazed, unburned sites, that burning has a greater effect on forbs and litter than grazing.

Ant Abundance and Activity

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% 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 benefited harvester ants, as predicted. 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 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 also 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 in the inactive season 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 enabled 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 could also 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, I did not collect 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 Ven Devender 1995:165). Grazing had a variable effect on harvester ant numbers, and appeared beneficial to ants when coupled with burning (Figure I.3). 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). Though many of the bait stations were visited by relatively few ants, the fact that ants were visiting more bait stations in the heavily grazed and burned sites suggests a larger number of ant mounds in those sites. Therefore, it appears that heavy grazing was beneficial to harvester ants, especially when coupled with burning.

Fire and grazing can improve conditions for harvester ants in several ways. As previously mentioned, fire increased forb and grass cover and available bare ground, and decreased litter accumulation. Grazing also increased forb abundance and decreased litter accumulation, and the moderately grazed, burned site contained the least amount of woody canopy. Because harvester ants are granivores, most activity occurs in areas interspersed with 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 ant abundance associated with burning could result in a subsequent increase in Texas horned lizard density or a decrease in ranging behavior.

Home Ranges

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 for closely related species (Lowe and Stebbins 1954, Baharav 1975, Turner and Medica 1982). Range size for male and female flat-tailed horned lizards (*Phrynosoma m'callii*) in Arizona were 1287 m^2 and 509 m^2, respectively (Turner and Medica 1982). The regal horned lizard (*Phrynosoma solare*) was found to be restricted to ranges averaging 181 m^2 for males and 125 m^2 for females (Lowe and Stebbins 1954). 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 based on limited sampling.

I propose that the smaller home ranges of horned lizards in burned pastures resulted from improved habitat of horned lizards, such that ecological requirements (i.e., food, cover) were found in a smaller area. This was consistent with my prediction. Ant indices indicated more prey abundance in burned sites. Habitat selection analyses

(Chapter 2) indicated that lizard selection of microsites was similar across treatments. 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. These findings were further supported by the data on mean daily distance traveled. Lizards moved the shortest distances in the moderately grazed, burned site, again suggesting that all requirements were found in a smaller area, thereby decreasing ranging behavior.

The mechanism by which burning and grazing may improve horned lizard resource distribution, and thus reduce home range size, is by creating a mix of open habitats and vegetation cover. The reduction in litter coupled with an increase in bare ground in burned and grazed sites created suitable habitat for horned lizards. 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. 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.

Home range sizes and daily distance traveled were smaller in the inactive season than the active season. This effect was expected based on our observations of horned lizard activity. As previously mentioned, horned lizards were most active between 15 April and 30 June. 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 (> 50° C; Forrester et al. 1998) to points that could be lethal to horned lizards; 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 enable lizards to move shorter distances to find food, thereby reducing the ranging behavior of the lizards.

Reproductive activities may explain the lack of differences in home range size and daily distance traveled by male and female horned lizards. Though previous studies on other *Phrynosoma* species suggest that males move farther than females and thus have larger home ranges (Lowe and Stebbins 1954, Baharav 1975, Turner and Medica 1982), few studies on Texas horned lizards have discussed gender differences in male and female home range size. As previously mentioned, Munger (1984*c*) found that male horned lizards had larger home ranges than female horned lizards in Arizona. Both male and female Texas horned lizards in my study traveled great distances presumably for reproductive purposes. Males traveled to search for females; females traveled to search for suitable nest sites (Chapter III). Therefore, behavior between male and female horned lizards was similar and there were no differences in home range size and mean daily distance traveled.

Munger (1984*c*) found that although most Texas horned lizards have a home range, some individuals are apparently nomadic. My data were consistent with this finding. Over half of the lizards in this study exhibited high site fidelity. Sometimes female horned lizards would leave their home range for several days to lay a nest, but returned to their original home range. Site fidelity in horned lizards could be explained by the desire to return to permanent locations of ant mounds (Pianka and Parker 1975) or cover. However, many horned lizards seemed to continuously wander. Nomadic horned lizards may have been displaced juveniles or were still searching for mates or nest sites. It is also likely that some lizards had such extensive home ranges that site fidelity was hard to distinguish. A long-term study could address this question.

Survival

Estimates on survival rates of horned lizards are imprecise and contentious due to the large number of censored lizards. Pianka and Parker (1975) suggested adult Texas horned lizards have comparatively high survival rates. Munger (1986) found that Texas horned lizards in southeastern Arizona had annual survival rates between 35.0 and 86.0%, whereas Fair and Henke (1999) estimated 8-month survival rates (Mar-Oct) in southern Texas to be lower (8.9 -54.0%). Estimates by Fair and Henke (1999) were 8-month estimates and assumed constant daily survival over time, whereas my estimates were summer (Apr-Aug) survival rates. However, when daily survival rates provided by

Fair and Henke (1999) are converted to summer survival rates (28-68%), they are similar to my estimates (25 - 62%).

I suggest that survival estimates in categories 1 and 4 are biased, as some lizards considered dead were probably alive and vice versa. I consider survival rates from categories 2 and 3 to be least biased. Contrary to my prediction, burning did not affect summer survival rates of horned lizards, though survival rates were higher in burned than unburned sites during the inactive season ($P = 0.03$). 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. 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, ant, and vegetation data. Because male and female horned lizards had similar movement behavior, both may have been equally susceptible to depredation. Therefore, it was not surprising that the survival rates of male and female lizards did not differ.

Lizard Length and Mass

Lizards in the moderately grazed, burned site were smaller in both length and mass. Although statistical effects were inconsistent, directions of non-significant comparisons were consistent with significant effects. Lizards may be smaller in the moderately grazed, burned site because greater resource abundance (e.g. ants) and better habitat (e.g. smaller home ranges, more bare ground and forbs) in the moderately grazed, burned site enabled lizards to more successfully reproduce. Therefore, more young lizards were caught in this site, producing smaller length and mass distributions. On the other hand, it is possible that resource abundance and distribution are of poorer quality than other sites and therefore, growth of the lizards in this site were stunted. Under this scenario, the smaller mass of lizards in the moderately grazed, burned site could be the reason those lizards had smaller home ranges. This phenomenon has been well documented in other species (McNab 1963, Harestad and Bunnell 1979). However, other ecological data suggests that this hypothesis is not likely. Because lizard lengths and mass were not different before and after the burning treatment was implemented, it is likely that burning was not the cause of the smaller lizards. It is my opinion that differences in length and mass across treatments were largely a sampling artifact.

Conclusions

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 on horned lizards was more complex. Survival was less in heavily grazed pastures than other treatments, but range size did not differ among grazing levels. Also, ant activity was generally higher in the heavily grazed pastures, especially when coupled with burning. My comparisons to an ungrazed, unburned control were limited by a small sample in the control pasture. Burning appeared to improve lizard resources (e.g., vegetation, ants) and performance (e.g., range size, survival) relative to the control. It appeared that an alternate-year burning regime and stocking rates of livestock such as that implemented by CWMA created suitable habitat for Texas horned lizards in southern Texas.

My study provides a framework to address the effects of burning and grazing on Texas horned lizards. Unfortunately, this study was unable to completely separate the effects of burning and grazing due to the lack of an ungrazed, burned site on the study area. Because most of southern Texas is currently being grazed, and because grazing by domestic livestock has occurred in southern Texas since the 1800's (McClaran and Van Devender 1995:131-132, 230-231), assessing the effects of grazing vs. not grazing is largely a moot point. From a conservation standpoint, it is unlikely that large tracts of land will be ungrazed in the future. Even if possible, it is unlikely that removing grazing would significantly impact horned lizard populations. The belief that the decline of horned lizards has only occurred in recent decades, long after widespread grazing became a common practice, suggests that grazing alone is not the key factor in the decline.

The results of the study could have been affected by the low sample size of horned lizards in the control site. It was impossible to find all lizards in the area, although diligent efforts was made to do so. Had I been able to locate more lizards in the control, thus increasing the sample size, I would have been better able to address the effects of burning and grazing on horned lizards. Future studies of this sort should attempt to estimate density and population growth rates in each study site. Studies on the effects of land management practices on ants should also measure seed production to better address seasonal and yearly effects on foraging behavior of ants, as foraging effort of ants is directly correlated with seed production (Whitford and Ettershank 1975).

This research also exemplifies the need for long-term studies. Several variables that I measured interacted with year (i.e., herbaceous vegetation, ants). Therefore, it is important to study those variables over several years to determine the level of those interactions. Because I sampled over 2 years, more definitive conclusions could be drawn than would have been possible in a shorter study.

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Table I.1. Herbaceous canopy cover (%) measured by Daubenmire frames in each treatment on the Chaparral Wildlife Management Area, summer 1999. 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).

	Treatment									
Herbaceous	U-U		Mg-B		Mg-U		Hg-B		Hg-U	
Variable	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Bare ground	28.21	10.65	34.98	10.99	46.66	5.40	32.82	6.36	34.11	6.79
Litter	25.83	3.84	17.61	4.50	17.64	4.23	18.50	7.52	17.00	0.88
Grass	44.99	10.55	42.77	3.33	36.88	6.37	43.22	3.58	41.72	7.29
Forb	12.83	1.61	14.72	5.64	10.49	2.61	19.58	1.93	16.55	1.68
Woody spp.	0.77	0.77	0.22	0.39	0.88	0.96	1.88	2.11	1.00	1.73

Table I.2. Herbaceous canopy coverages (%) measured by Daubenmire frames in each treatment on the Chaparral Wildlife Management Area, summer 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).

Herbaceous	Treatment									
	U-U		Mg-B		Mg-U		Hg-B		Hg-U	
Variable	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Bare ground	31.94	4.72	46.00	2.74	36.05	2.82	48.77	2.57	47.66	3.20
Litter	27.94	2.37	19.66	1.17	29.61	1.20	17.84	2.46	24.22	2.53
Grass	39.38	4.54	17.55	0.81	29.89	2.47	20.77	4.47	22.61	3.47
Forb	4.72	0.22	24.50	1.62	12.05	2.02	16.05	4.49	7.66	0.58
Woody spp.	4.66	0.19	1.83	0.82	5.72	3.48	1.17	0.28	1.55	0.58

Table I.3. Canopy cover (cm; mean ± standard deviation) for the five dominant woody species and total canopy cover (%) over the 30-m line transects (n = 12 in each treatment) on the Chaparral Wildlife Management Area, summer 1999. 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).

	Treatment									
	U-U		Mg-B		Mg-U		Hg-B		Hg-U	
Species	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Brasil	95.5	119.2	110.1	135.1	178.9	35.5	204.1	24.8	144.8	124.1
Granjeno	56.4	89.2	19.8	31.7	70.0	34.7	80.83	46.4	65.2	109.7
Hogplum	10.9	18.9	147.9	52.6	110.1	95.1	111.4	49.3	94.9	140.6
Mesquite	138.8	133.5	58.0	48.9	327.8	141.8	196.3	179.0	78.3	69.7
Tasajillo	231.2	101.8	13.3	21.5	38.8	8.1	23.1	12.4	124.4	58.
Canopy Cover (%)	46.56	12.4	20.18	0.03	37.77	0.02	31.06	0.05	29.38	0.03

Table I.4. 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

Table I.5. 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 I.6. Number of bait stations visited by ants (*n* = 96 possible for each treatment) for the active and inactive seasons, years 1999 and 2000 on the Chaparral Wildlife Management Area. 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	
Treatment	Active Season	Inactive Season	Active Season	Inactive Season
U-U	5	18	45	42
Mg-B	14	55	41	79
Mg-U	2	5	25	21
Hg-B	24	45	42	76
Hg-U	10	28	36	54

Table I.7. Home range sizes (ha) of Texas horned lizards 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

Table I.8. Home range sizes (ha) of Texas horned lizards using 95% Adaptive Kernels (AK) 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	0.82	0.30	0.11	1.79	4	1.18	0.74	0.04	3.18
Mg-B	8	1.96	0.85	0.03	6.95	10	0.54	0.17	0.02	1.41
Mg-U	9	1.95	0.32	0.29	3.21	5	0.32	0.10	0.03	0.63
Hg-B	10	2.35	0.63	0.34	7.57	6	1.56	1.03	0.21	6.69
Hg-U	10	2.01	0.80	0.11	6.48	10	2.71	1.43	0.07	14.63

Table I.9. Mean daily distances traveled by Texas horned lizards (m) 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).

Treatment	n[a]	$\bar{x}$	SE
U-U	10	20.2	4.5
Mg-B	18	19.6	3.3
Mg-U	14	27.8	3.4
Hg-B	16	34.0	6.3
Hg-U	20	22.5	3.0

[a] Experimental unit is mean daily distance traveled by a single lizard in a season (active or inactive).

Table I.10. Mass (g) of male and female horned lizards on the Chaparral Wildlife Management Area from 1996 to 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).

	Male			Female		
Treatment	n	$\bar{x}$	SE	n	$\bar{x}$	SE
U-U	16	41.1	2.4	17	43.8	4.2
Mg-B	12	27.2	2.1	8	33.6	3.9
Mg-U	23	39.4	3.0	39	45.1	2.4
Hg-B	16	40.0	2.1	15	48.7	3.0
Hg-U	21	38.8	2.9	27	47.5	2.1

Table I.11. Total length (mm) and snout-vent length (mm) of male and female horned lizards on the Chaparral Wildlife Management Area from 1996 to 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).

	Male					Female				
		Total length		Snout-vent length			Total Length		Snout-vent length	
Treatment	n	$\bar{x}$	SE	$\bar{x}$	SE	n	$\bar{x}$	SE	$\bar{x}$	SE
U-U	21	131.9	4.2	82.8	2.4	25	130.7	3.7	88.3	2.4
Mg-B	12	118.0	3.4	75.7	2.0	8	126.0	6.1	85.1	4.1
Mg-U	29	130.1	3.0	82.4	1.8	43	135.9	2.4	92.2	1.6
Hg-B	16	134.1	3.2	85.2	1.6	16	140.6	3.0	95.0	1.8
Hg-U	24	130.2	3.4	83.7	2.1	30	131.4	2.1	92.6	2.1

Figure I.1. Study sites for examining the effects of burning and grazing on Texas horned lizards at Chaparral Wildlife Management Area, Dimmit and La Salle Counties, Texas.

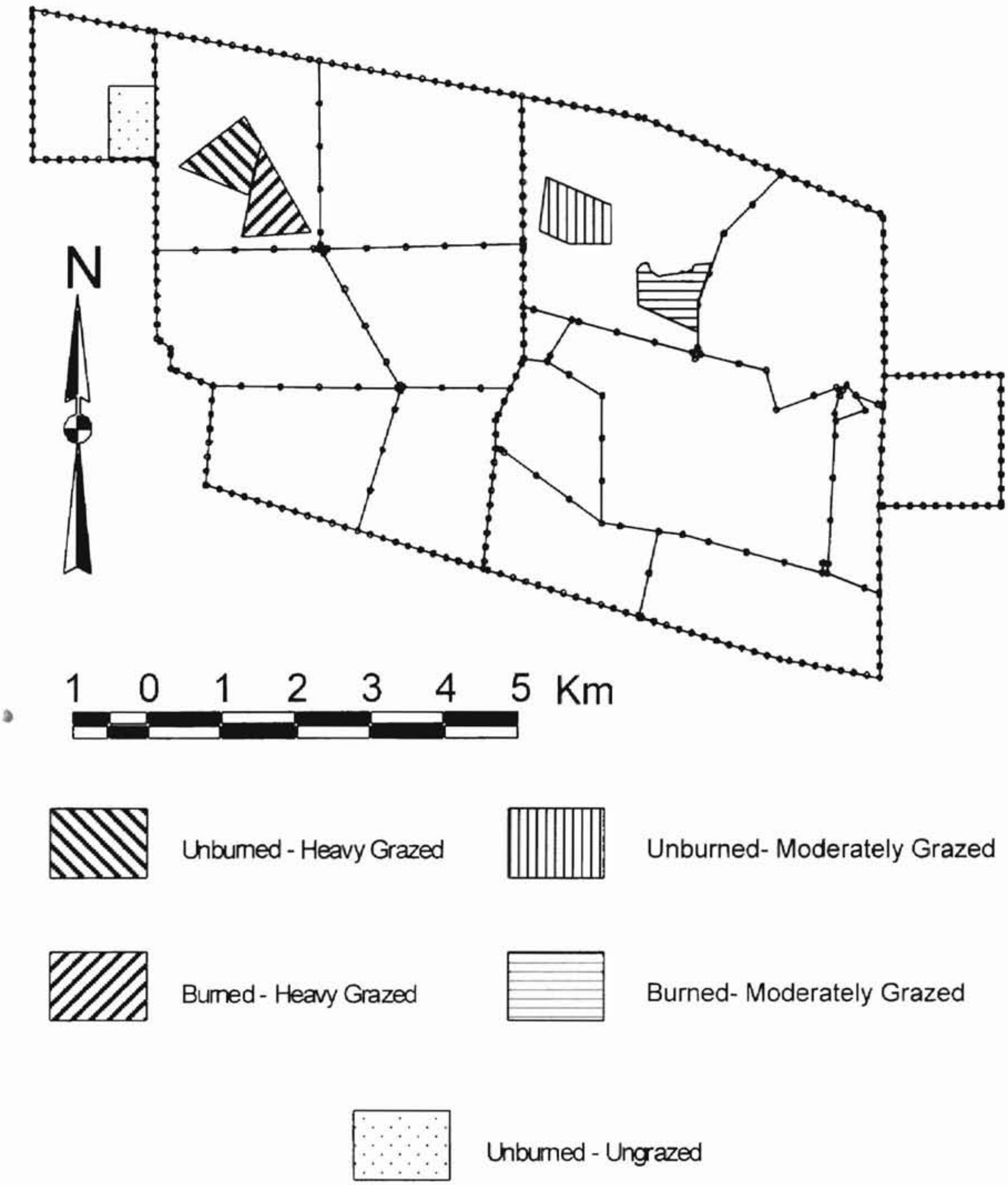

N
1 0 1 2 3 4 5 Km
Unburned - Heavy Grazed
Unburned- Moderately Grazed
Burned - Heavy Grazed
Burned- Moderately Grazed
Unburned - Ungrazed

Figure I.2. Treatment (burning and grazing) by season (active, inactive) interaction for the number of ants at the ant bait station upon arrival at the Chaparral Wildlife Management Area, summers 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).

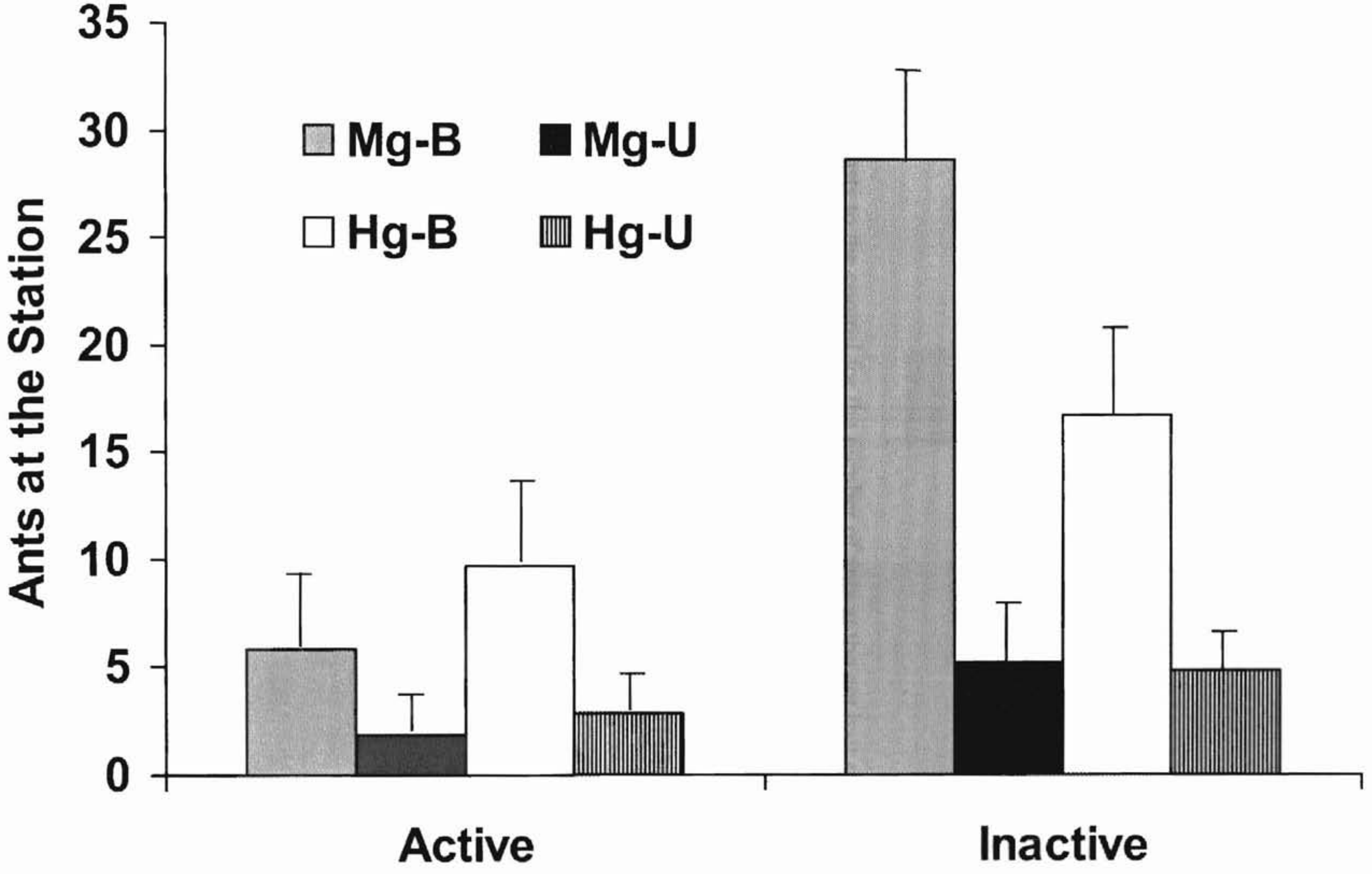

Ants at the Station
35
30
25
20
15
10
5
0
Mg-B
Mg-U
Hg-B
Hg-U
Active
Inactive

Figure I.3. 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).

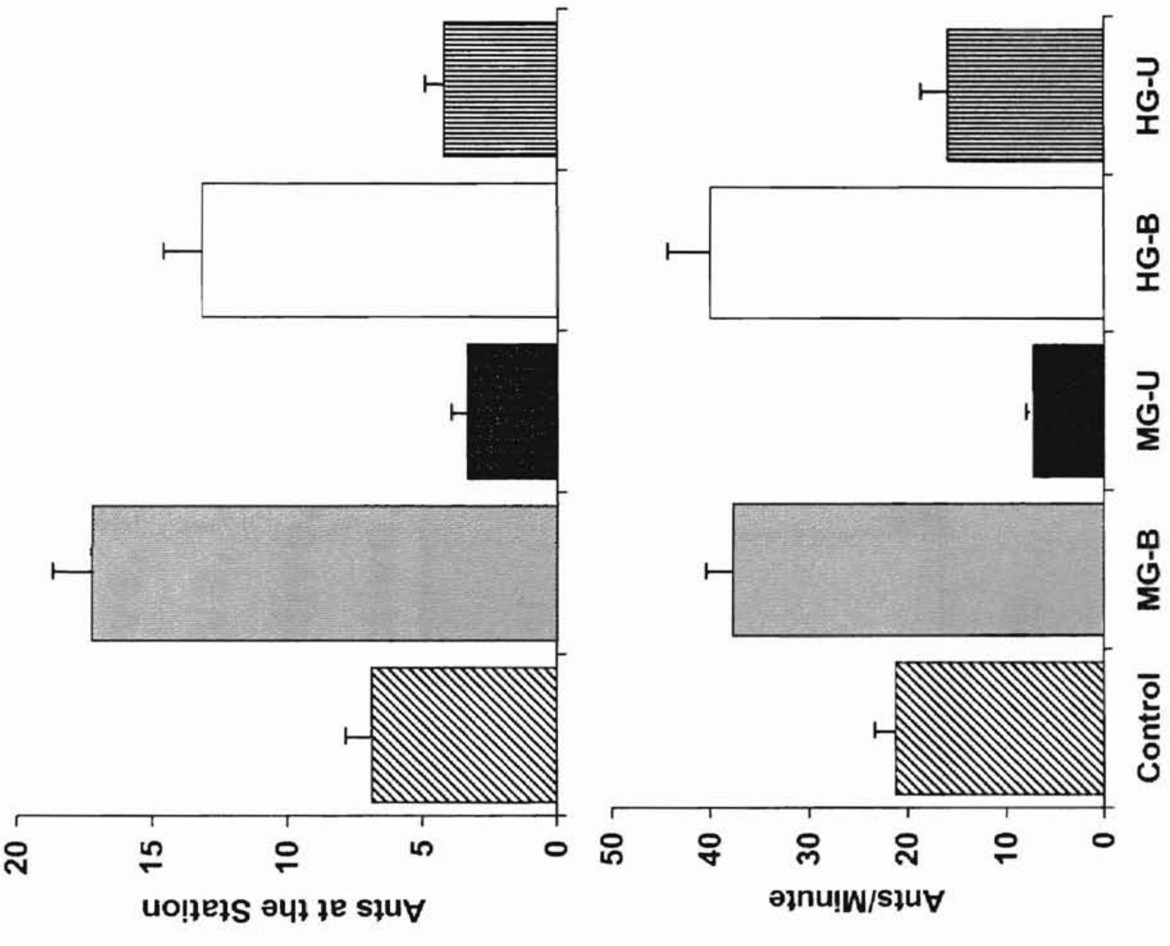

Ants at the Station
20
15
10
5
0
Ants/Minute
50
40
30
20
10
0
Control
MG-B
MG-U
HG-B
HG-U

Figure I.4. Burning by season (active, inactive) by year (1999, 2000) interaction for the number of ants that visited the ant bait stations within one minute at the Chaparral Wildlife Management Area.

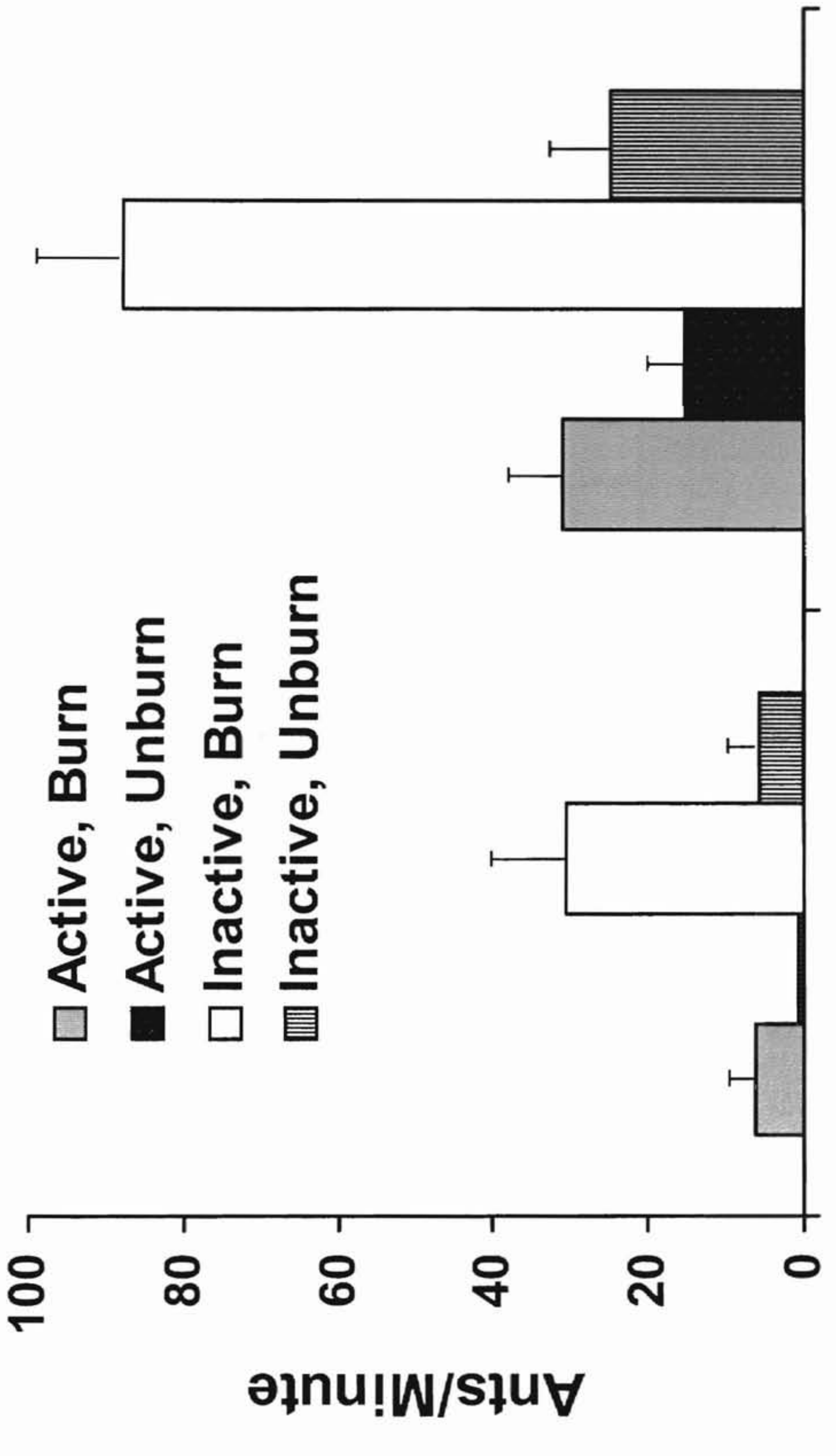

Ants/Minute
100
80
60
40
20
0
1999
2000
▨ Active, Burn
■ Active, Unburn
☐ Inactive, Burn
▤ Inactive, Unburn

Figure I.5. Grazing by season (active, inactive) by year (1999, 2000) interaction for the number of ants that visited the ant bait stations within one minute at the Chaparral Wildlife Management Area.

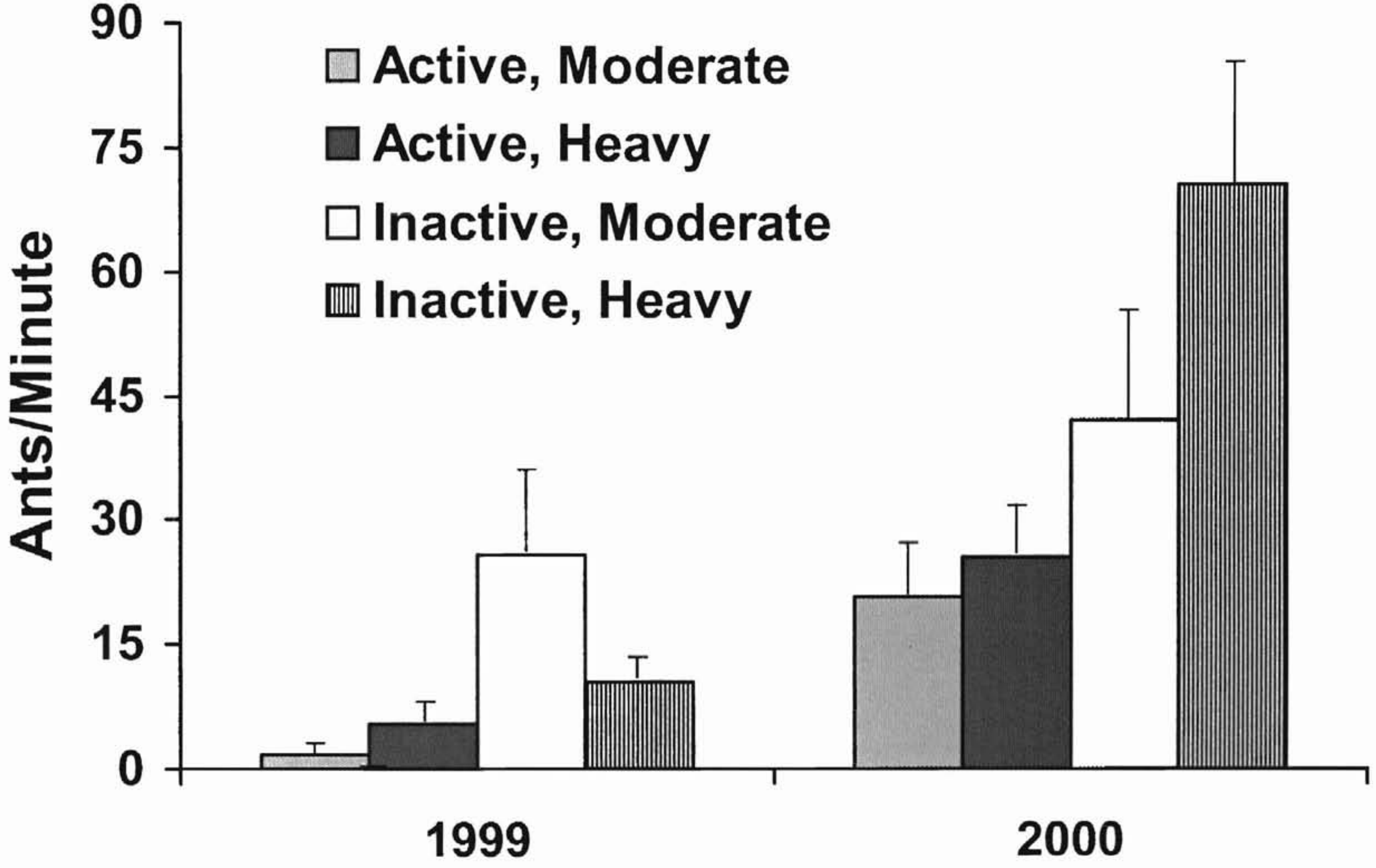

Ants/Minute
90
75
60
45
30
15
0
▨ Active, Moderate
■ Active, Heavy
☐ Inactive, Moderate
▥ Inactive, Heavy
1999
2000

Figure I.6. Number of ant bait stations visited at the Chaparral Wildlife Management Area as affected by treatment (burning, grazing) and season (active, inactive), summers 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).

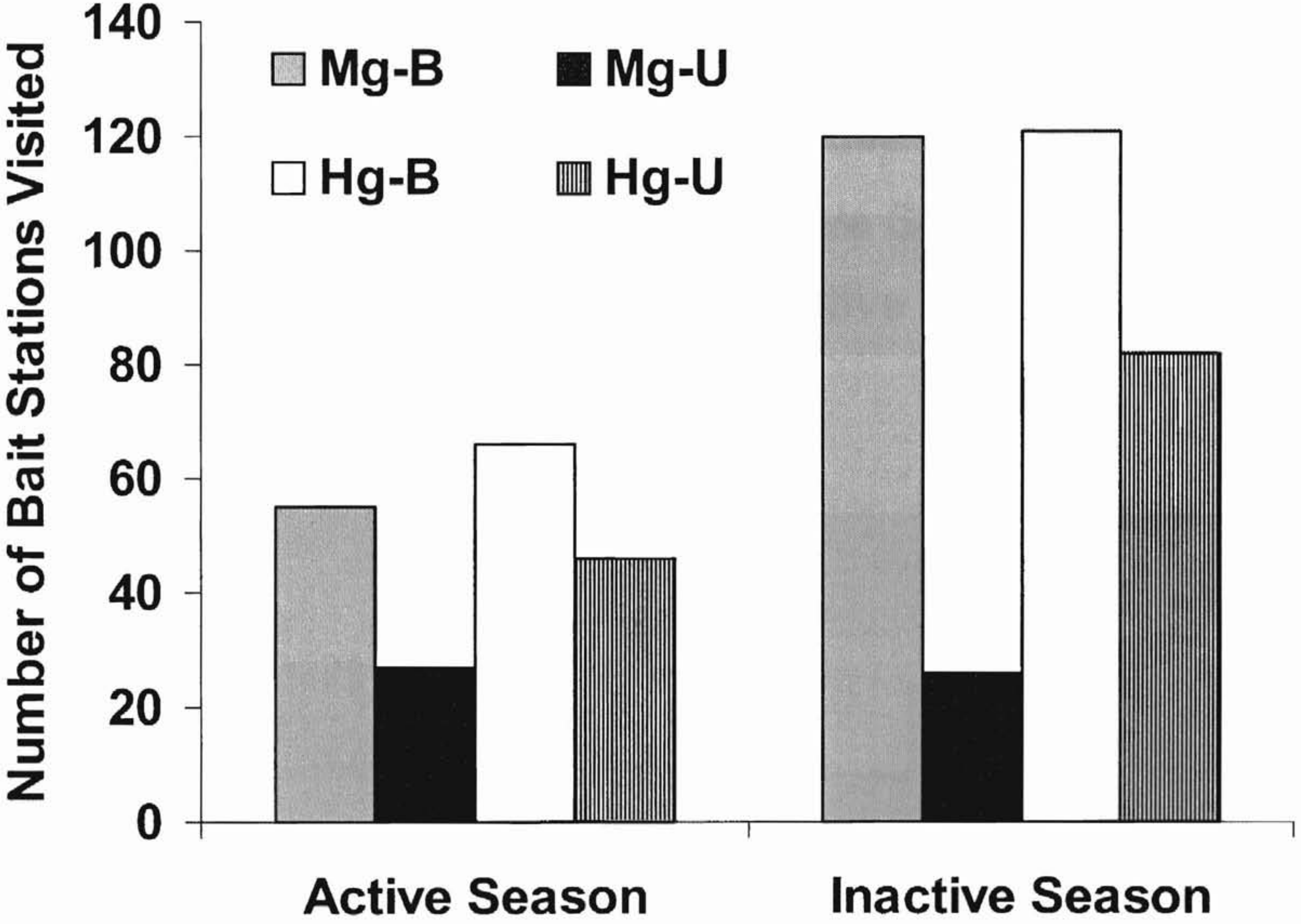

140
120
100
80
60
40
20
0
Number of Bait Stations Visited
Mg-B
Mg-U
Hg-B
Hg-U
Active Season
Inactive Season

Figure I.7. Burning by season by year interaction for the number of ant bait stations visited at the Chaparral Wildlife Management Area as affected by treatment (burning, grazing) and season (active, inactive), summers 1999-2000.

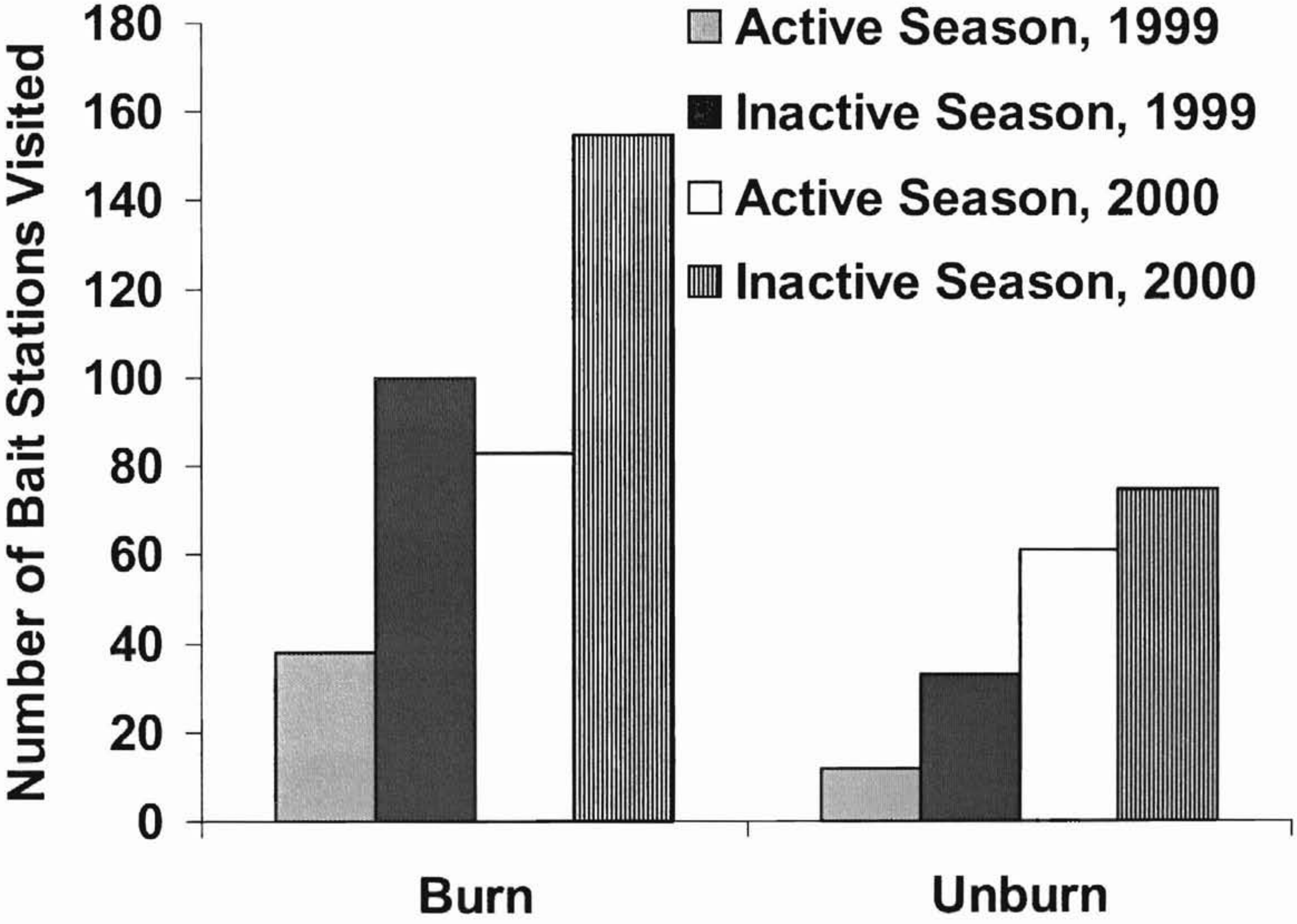

Number of Bait Stations Visited
180
160
140
120
100
80
60
40
20
0
Burn
Unburn
▨ Active Season, 1999
■ Inactive Season, 1999
☐ Active Season, 2000
▥ Inactive Season, 2000

Figure I.8. Grazing by season by year interaction for the number of ant bait stations visited at the Chaparral Wildlife Management Area as affected by burning, season (active, inactive) and year (1999, 2000), summers 1999 and 2000.

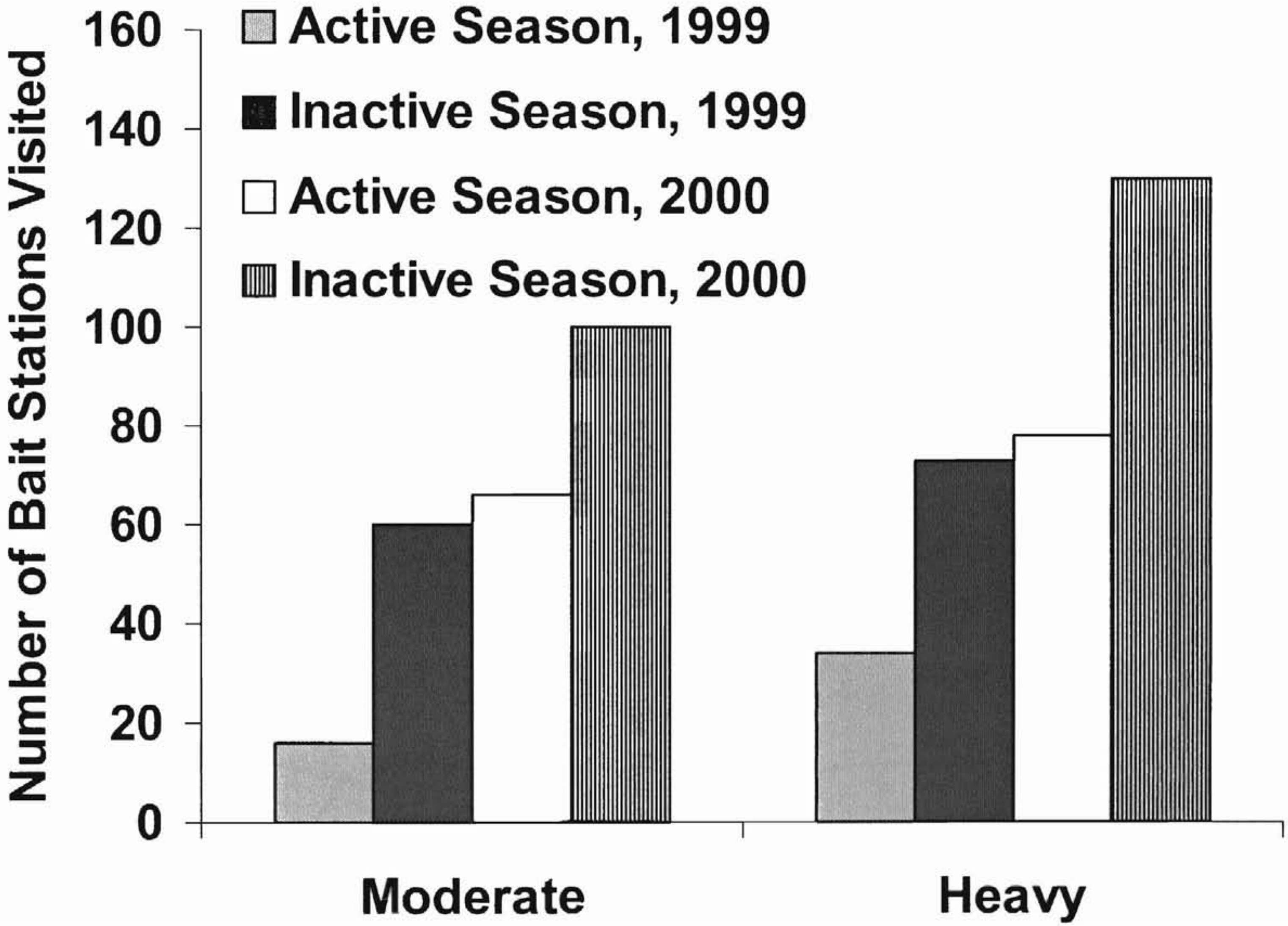
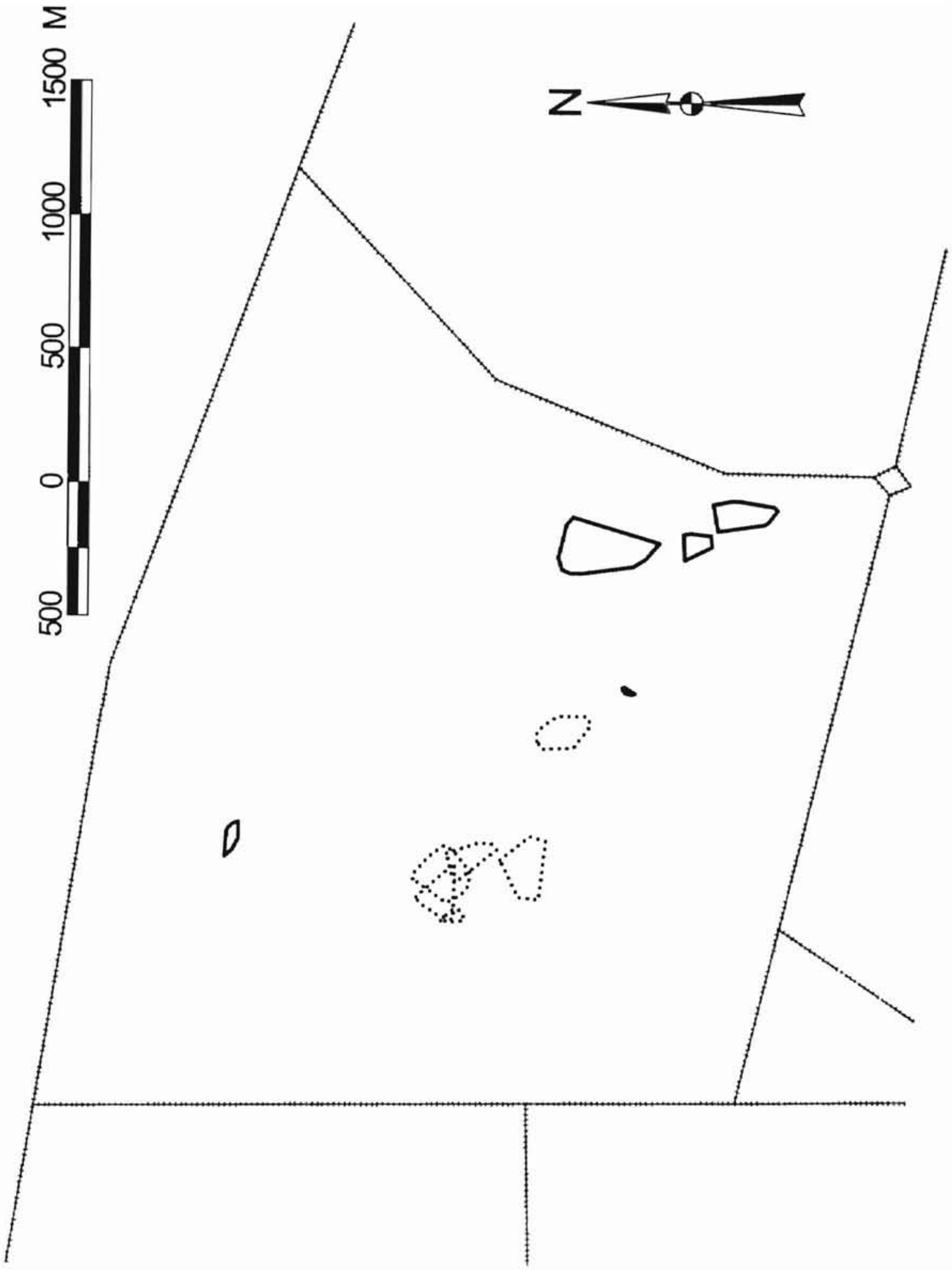

Number of Bait Stations Visited
160
140
120
100
80
60
40
20
0
Active Season, 1999
Inactive Season, 1999
Active Season, 2000
Inactive Season, 2000
Moderate
Heavy

Figure I.9. Home ranges (95% MCP) in the active season of male horned lizards in the moderately grazed pasture of the Chaparral Wildlife Management Area, summers 1998-2000. Home ranges in the burned site are designated with a solid line. Home ranges in the unburned site are designated with a dashed line.



500
0
500
1000
1500 M
N

Figure I.10. Home ranges (95% MCP) in the inactive season of male horned lizards in the moderately grazed pasture of the Chaparral Wildlife Management Area, summers 1998-2000. Home ranges in the burned site are designated with a solid line. Home ranges in the unburned site are designated with a dashed line.

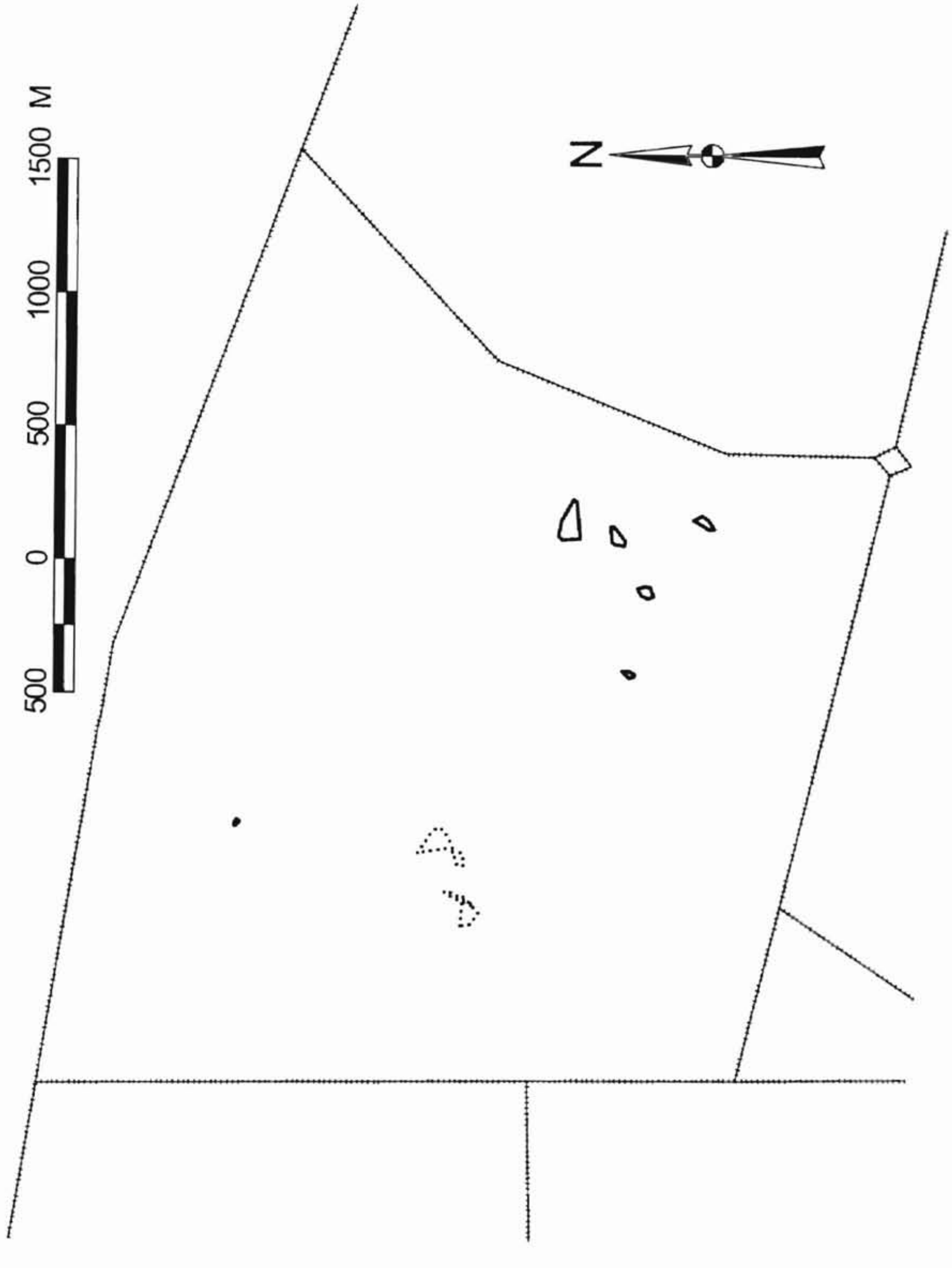

500
0
500
1000
1500 M
N

Figure I.11. Home ranges (95% MCP) in the active season of female horned lizards in the moderately grazed pasture of the Chaparral Wildlife Management Area, summers 1998-2000. Home ranges in the burned site are designated with a solid line. Home ranges in the unburned site are designated with a dashed line.

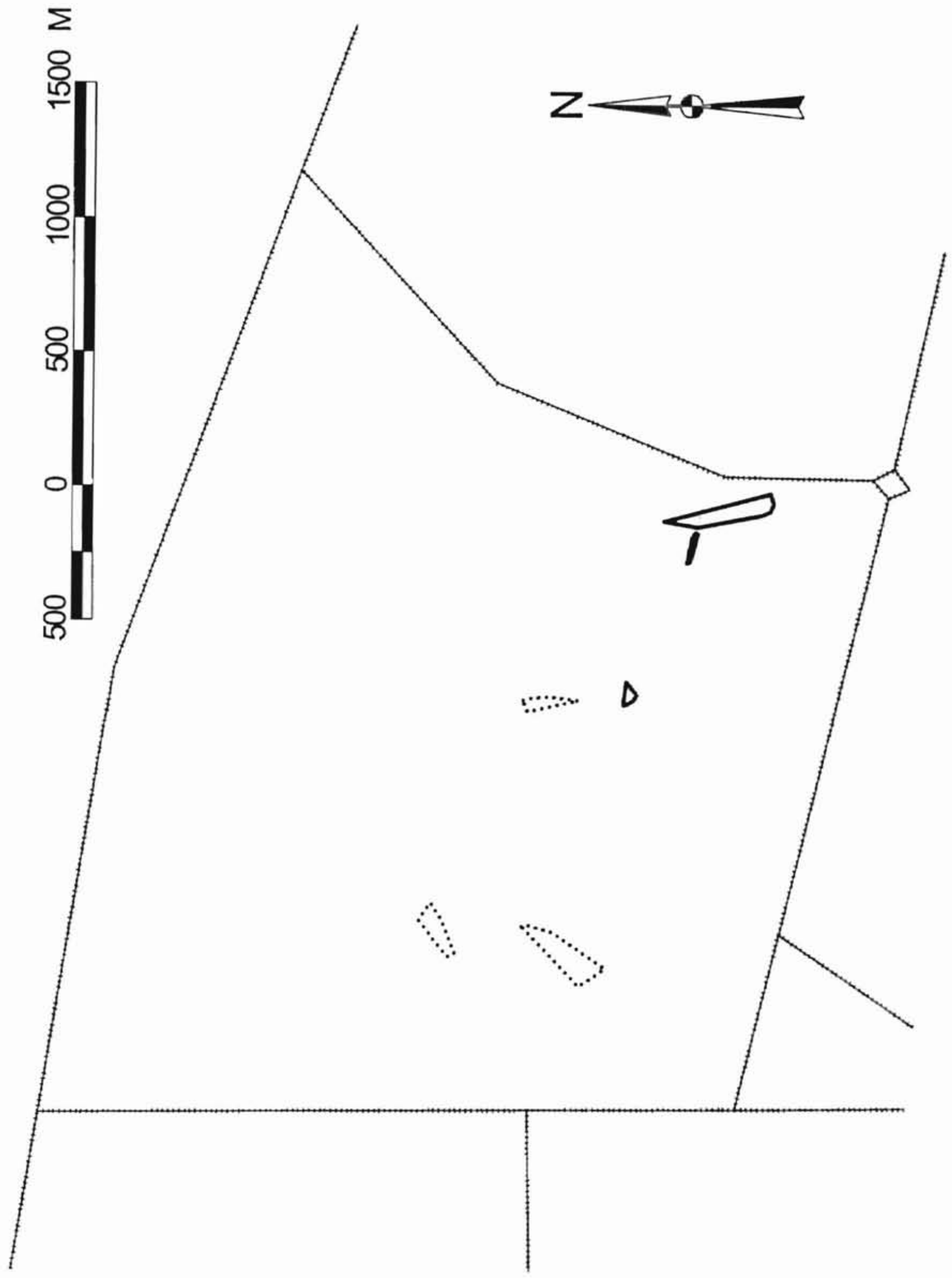

500
0
500
1000
1500 M
N

Figure I.12. Home ranges (95% MCP) in the inactive season of female horned lizards in the moderately grazed pasture of the Chaparral Wildlife Management Area, summers 1998-2000. Home ranges in the burned site are designated with a solid line. Home ranges in the unburned site are designated with a dashed line.

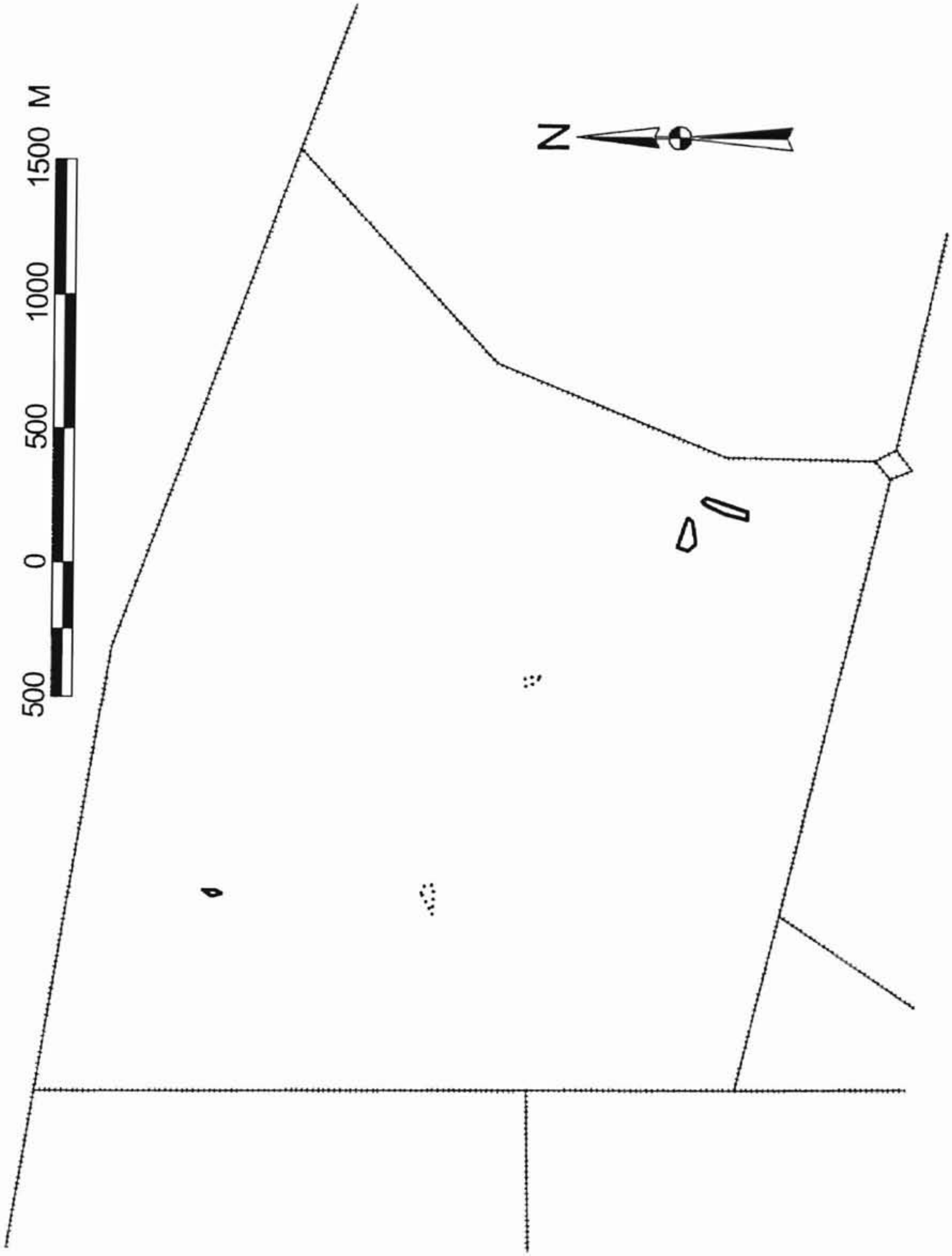

1500 M
1000
500
0
500
N

Figure I.13. Home ranges (95% MCP) in the active season of male horned lizards in the heavily grazed and ungrazed pastures of the Chaparral Wildlife Management Area, summers 1998-2000. Home ranges in the burned site are designated with a solid line. Home ranges in the unburned sites are designated with a dashed line.

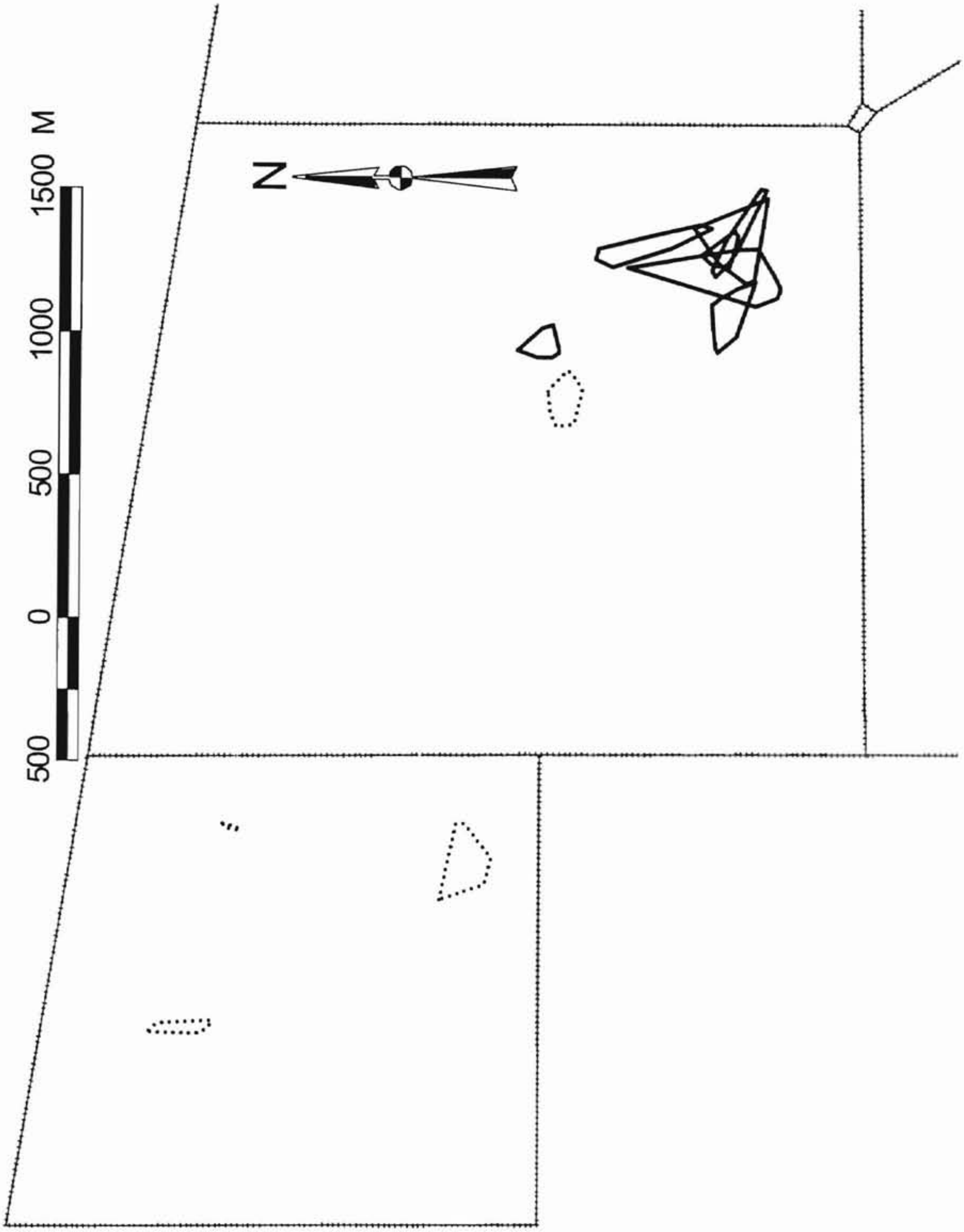

500
0
500
1000
1500 M
N

Figure I.14. Home ranges (95% MCP) in the inactive season of male horned lizards in the heavily grazed and ungrazed pastures of the Chaparral Wildlife Management Area, summers 1998-2000. Home ranges in the burned site are designated with a solid line. Home ranges in the unburned site are designated with a dashed line.

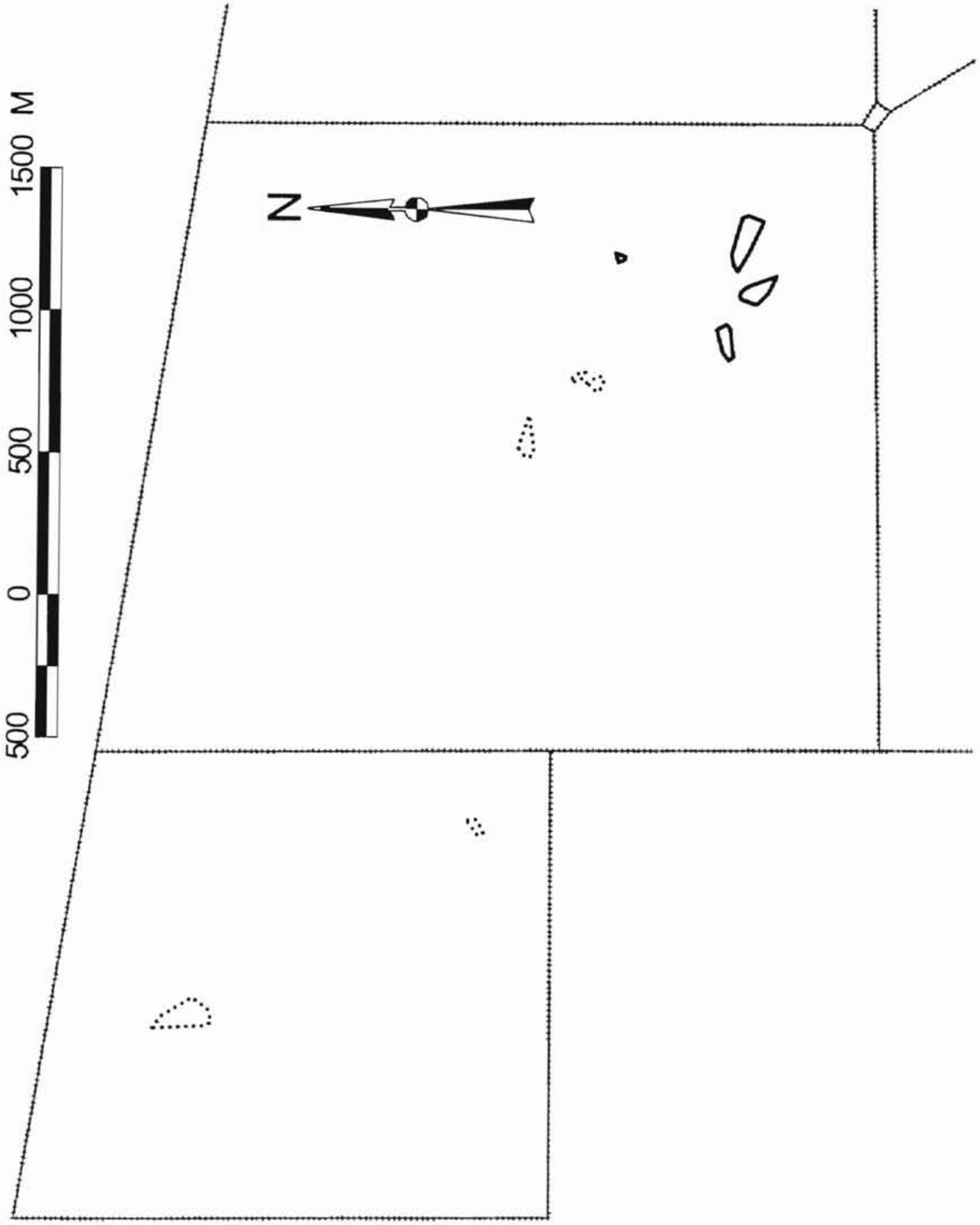

500
0
500
1000
1500 M
N

Figure I.15. Home ranges (95% MCP) in the active season of female horned lizards in the heavily grazed and ungrazed pastures of the Chaparral Wildlife Management Area, summers 1998-2000. Home ranges in the burned site are designated with a solid line. Home ranges in the unburned site are designated with a dashed line.

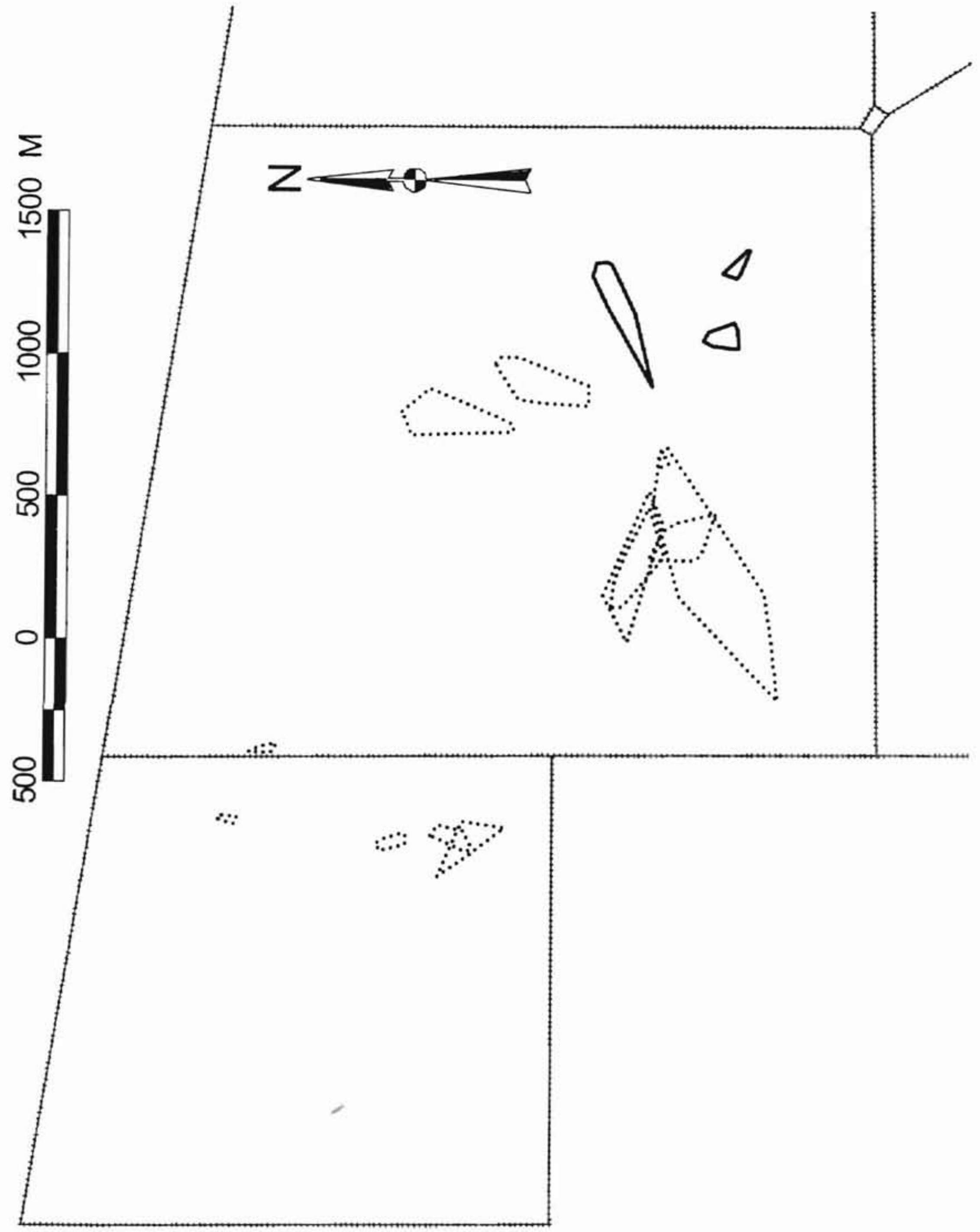

500
0
500
1000
1500 M
N

Figure I.16. Home ranges (95% MCP) in the inactive season of female horned lizards in the heavily grazed and ungrazed pastures of the Chaparral Wildlife Management Area, summers 1998-2000. Home ranges in the burned site are designated with a solid line. Home ranges in the unburned site are designated with a dashed line.

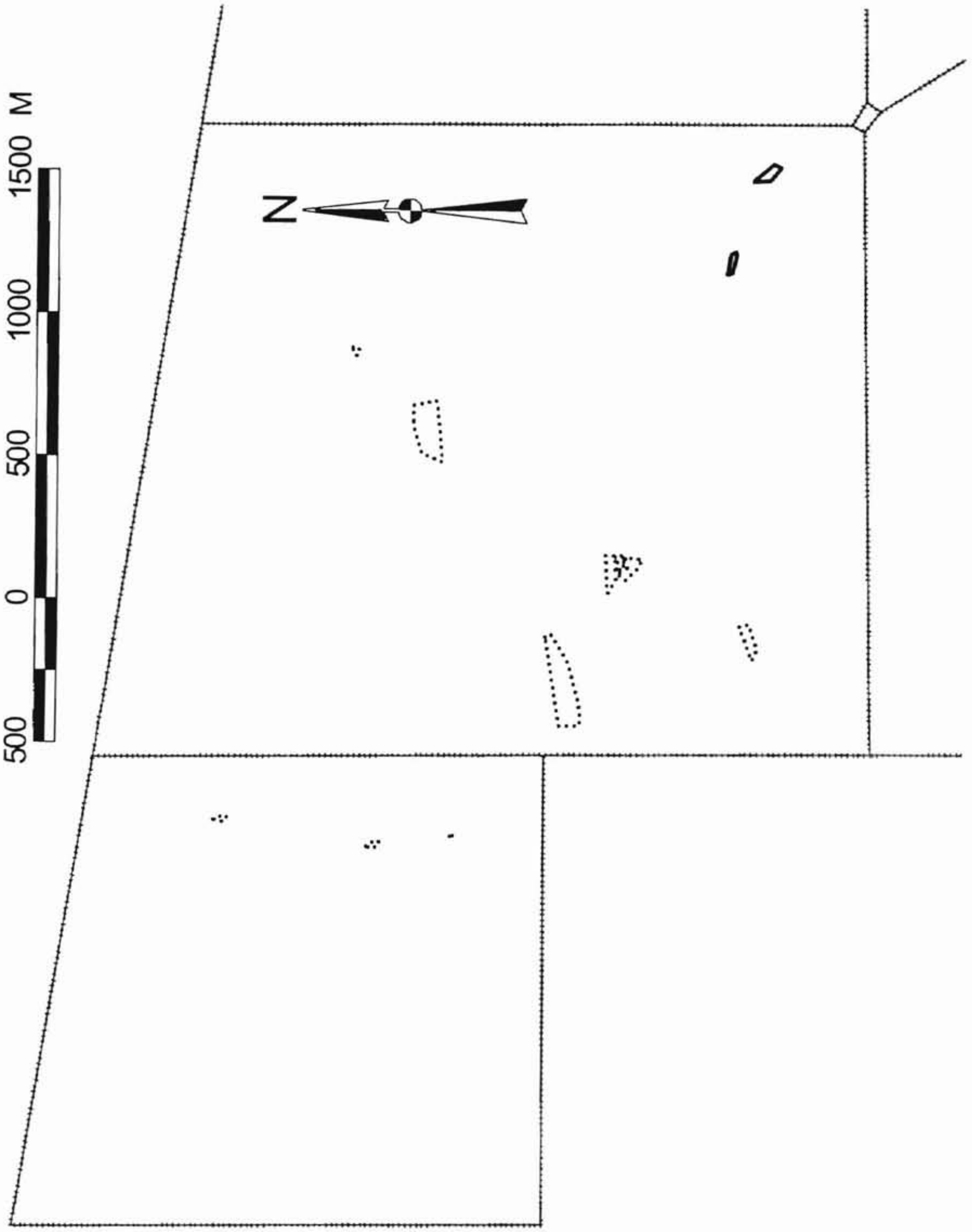

500
0
500
1000
1500 M
N

Figure I.17. Survival rates (category 2) of 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.

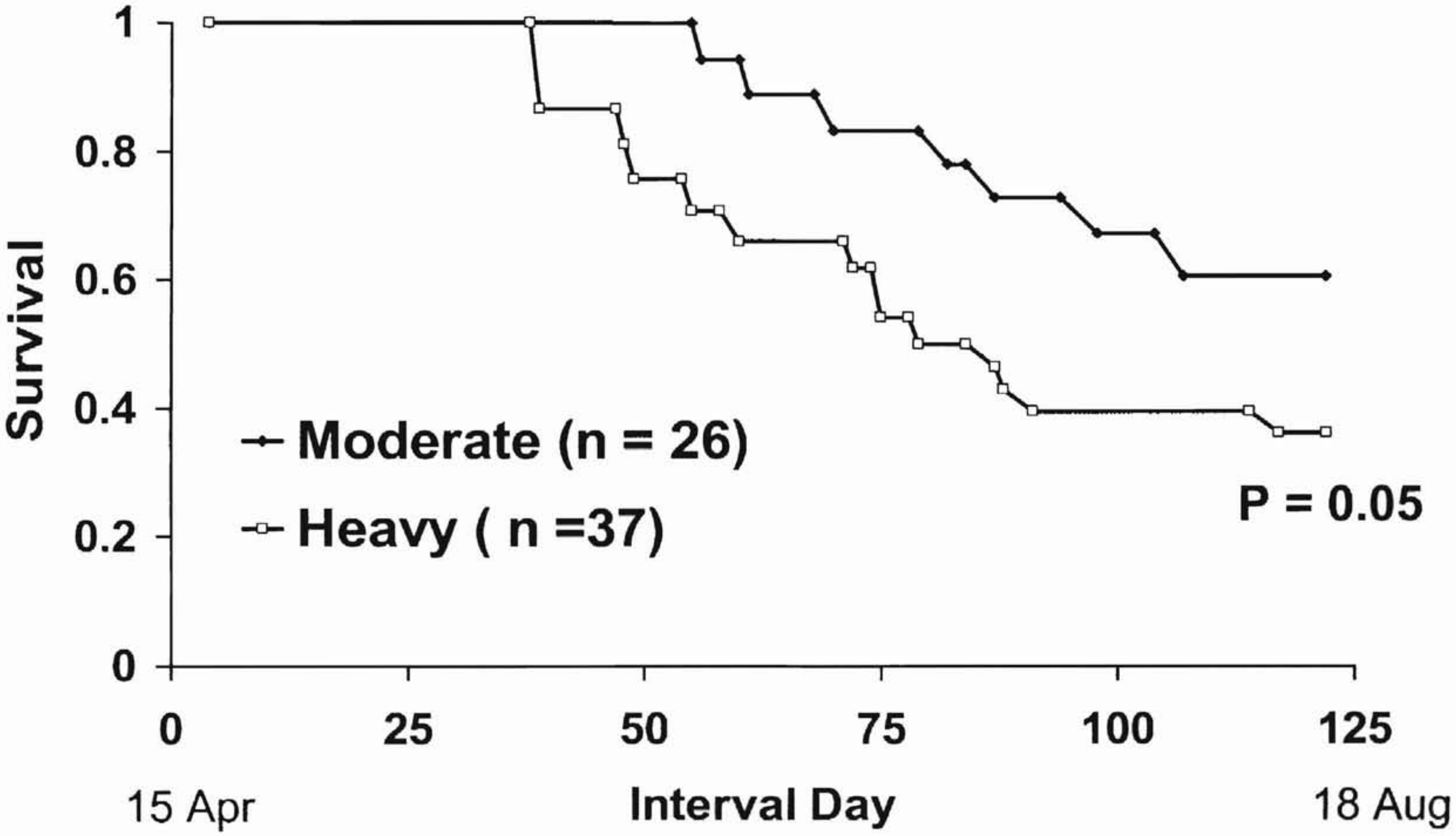

1
0.8
0.6
0.4
0.2
0
Survival
Moderate (n = 26)
Heavy (n =37)
P = 0.05
0
25
50
75
100
125
15 Apr
Interval Day
18 Aug

Figure I.18. Survival rates (category 2) of 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.

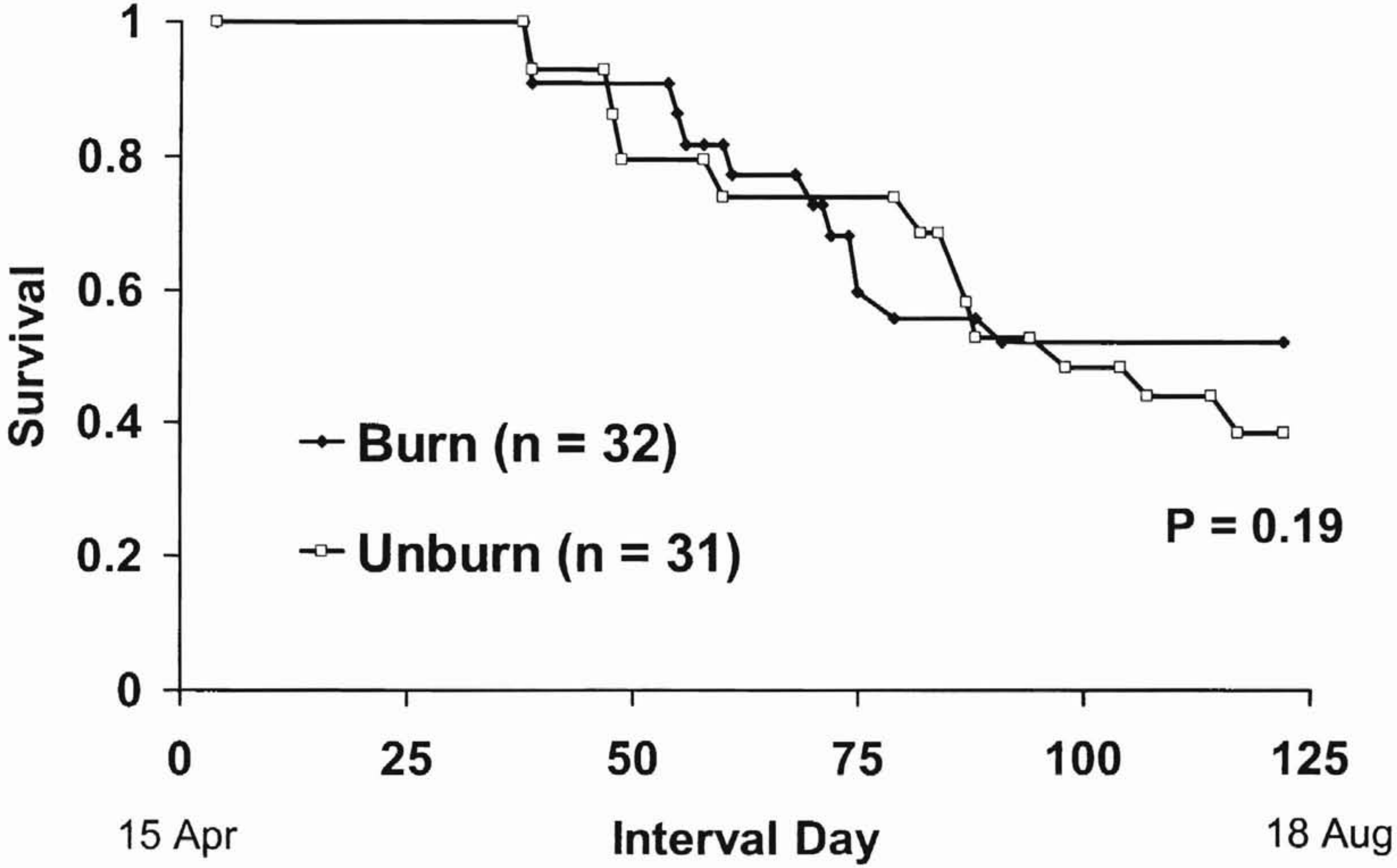
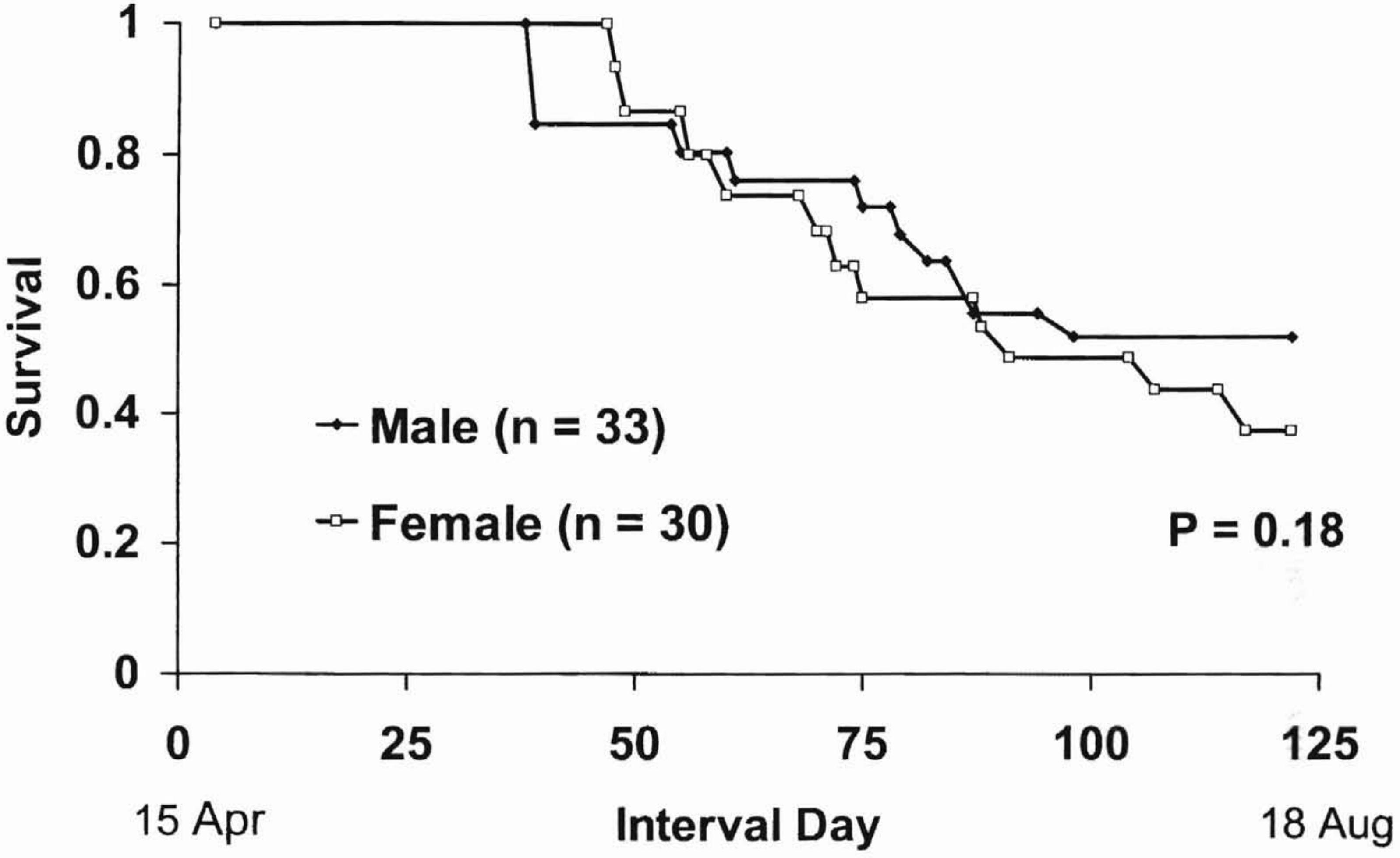

1
0.8
0.6
0.4
0.2
0
Survival
Burn (n = 32)
Unburn (n = 31)
P = 0.19
0
25
50
75
100
125
15 Apr
Interval Day
18 Aug

Figure I.19. Survival rates (category 2) of male ($S = 0.51$, 95% CI = 0.30-0.73) and female ($S = 0.37$, 95% CI = 0.15-0.60) horned lizards at the Chaparral Wildlife Management Area, summers 1998-2000.


1
0.8
0.6
0.4
0.2
0
Survival
Male (n = 33)
Female (n = 30)
P = 0.18
0
25
50
75
100
125
15 Apr
Interval Day
18 Aug

CHAPTER II

HABITAT SELECTION OF TEXAS HORNED LIZARDS IN SOUTHERN TEXAS

ABSTRACT

The Texas horned lizard (*Phrynosoma cornutum*) has declined throughout its range, especially in Texas. By understanding habitat selection by the Texas horned lizard, recommendations can be made to restore and maintain viable populations in southern Texas. I examined the daily and seasonal habitat requirements of Texas horned lizards, and determined if habitat selection differed among land management treatments in southern Texas. Five study sites were used, each with a different burning and grazing treatment. Adult horned lizards caught in the study sites were fitted with backpacks carrying radio transmitters and relocated daily. Habitats at radio locations and random points 10 m from the lizard were assessed using a Daubenmire frame. Relocations were made during 3 time intervals (morning, afternoon, evening) and two seasons (active, inactive). Horned lizards used bare ground and herbaceous vegetation as much as their availability in the morning and evening for thermoregulation and foraging purposes, but avoided bare ground in the afternoon. In the afternoons, lizards selected woody vegetation and litter as a thermal refuge and to escape predators. Lizards also appeared less dependent on herbaceous vegetation and more dependent on woody vegetation and litter in the inactive season compared to the active season due to increased temperatures. I did not detect differences in habitat selection among land management treatments. Habitat management focused on Texas horned lizards should focus on creating a mosaic of bare ground, herbaceous vegetation and woody vegetation in close proximity.

INTRODUCTION

The Texas horned lizard occurs throughout Texas and Oklahoma, as well as parts of Kansas, Missouri, New Mexico, Arizona, and Mexico (Munger 1986, Price 1990). It has recently declined throughout its range, especially in Texas (Price 1990). Habitat destruction, introduction of the red imported fire ant (*Solenopsis invicta*), and use of insecticides are putative causes of this decline (Price 1990, Donaldson et al. 1994).

Habitat use by Texas horned lizards has been studied in the past (Whiting et al. 1993, Sheffield and Carter 1994, Fair and Henke 1997, Fair and Henke 1998). However, these studies offer inadequate information on specific habitat requirements and selection. For example, Fair and Henke (1998) sampled habitat selection on a small number of lizards, but did not consider the effects that land management practices implemented on their study site had on that selection. Whiting et al. (1993) studied habitat selection only when horned lizards were most active.

Texas horned lizards use a variety of habitats including open deserts and grasslands, usually with sparse vegetation (Ballinger 1974, Price 1990, Whiting et al. 1993, Sheffield and Carter 1994, Fair and Henke 1997). They are thought to prefer open, frequently disturbed areas due to increased ease of mobility (Whiting et al. 1993). 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 directly exposing lizards to solar radiation (Heath 1964). Conversely, open habitats could be detrimental to horned lizards if there is insufficient thermal cover during the hottest parts of the day, and inadequate cover to escape from predators.

Habitat selection by Texas horned lizards varies with time of day and season. They are generally active in the morning and early evening (Creusere and Whitford 1982, Fair 1995, Henke and Montemayor 1998) for thermoregulation and foraging. However, peak activity periods change throughout the year depending on temperature fluctuations. During late spring and early summer, lizards often remain active for the entire day. As temperatures rise in the summer, activity patterns shift to mornings and evenings (Pianka and Parker 1975). Throughout the hottest part of the day, horned lizards remain cool by burying themselves in soil (Arnold 1995), retiring to burrows, seeking shade under shrub clumps (Whitford and Bryant 1979, Fair 1995), or climbing into shrub canopies (Whitford and Bryant 1979). Some species of *Phrynosoma* (including *P. cornutum*) hibernate (Potter and Glass 1931; Mayhew 1965) from late October to late March or early April (Potter and Glass 1931).

I was interested in the effects of land management practices on habitat selection by Texas horned lizards. My objectives were to: 1) examine daily and seasonal patterns in habitat selection of the Texas horned lizard; and 2) determine if habitat selection differed among land management treatments (i.e., burning and grazing) in southern Texas. Both burning and grazing can drastically alter a landscape. In brief, fire can reduce shrub canopy cover (Dunne et al. 1991) and increase forb and grass cover (Bunting and Wright 1977). Grazing can induce brush invasion, thereby increasing woody vegetation (Scifres and Hamilton 1993), and can decrease live biomass (Kelting 1954). Nevertheless, I predicted no difference in microhabitat features selected by horned lizards among treatments, though lizards may be more selective in treatments with less suitable habitat. By understanding links between management and lizard behavior, recommendations can be made for restoration and maintenance of viable populations.

METHODS

Study Area

The study was conducted on the 6,150-ha Chaparral Wildlife Management Area (CWMA) in Dimmit and La Salle Counties, Texas. The CWMA was purchased by the state of Texas in 1969 and management authority was given to the Texas Parks and Wildlife Department (TPWD). The CWMA has an average rainfall of 63 cm with two peaks in May and late September/early October (TPWD, unpublished data). The dominant vegetation type on the CWMA is 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 texensis*), and Texas persimmon (*Diospyros texana*) as common subdominant woody species. Common and scientific names for vegetation follow Hatch et al. (1990).

Five study sites (50 - 60 ha) were selected on the CWMA, each with a different burning and grazing treatment (Figure I.1). Sites were chosen based on similarities in dominant woody species and canopy coverages. Treatments were: control (unburned/ungrazed), moderately grazed/burned, heavily grazed/burned, moderately grazed/unburned, and heavily grazed/unburned. The control site had not been burned or grazed since 1976. No ungrazed, burned sites were available.

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}. I 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.

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. Adult lizards caught within the five study sites were fitted with backpacks that carry radio transmitters (150-151 MHz, L and L Electronics, Mahomet, Illinois, USA). Backpacks were composed of a beige cotton muslin with elastic straps and were dyed to match the natural substrate color of the CWMA to avoid disrupting the cryptic coloration of the horned lizards. I attached the backpack by placing an upper strap around the neck and one front leg and placing an additional strap anterior to the back legs. A drop of cyanoacrelate gel adhesive attached 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% of the total mass of the lizard). Following release, lizards were relocated daily. At each relocation, I recorded lizard activity and behavior, date, time of day, pasture, treatment, weather, and micro-habitat data.

Habitat selection data were collected during the summers of 1999 and 2000. I recorded habitat selection at 2 levels: the frame level and the point level. The scale of selection at the frame level was a quadrat frame (20 x 50 cm; Daubenmire 1959) centered on lizard relocations and paired with a random location 10 m from the lizard. Direction was randomized by walking in the direction of the second hand of a watch. Measurements estimated in the frame were percent cover by forbs, grasses, bare ground, litter, and woody stems, and woody canopy over the frame. It should be noted that measurements made for woody stems in the frame were different than woody canopy over the frame. Woody vegetation found in the frame were woody plants that had an actual ground component in the frame. Woody canopy measurements were those that had a canopy component over the frame, but no ground component rooted in the frame. Both measures of woody vegetation were used to gauge arboreal sites for thermoregulation by lizards.

The scale of habitat selection at the point level was the lizard itself, and dominant woody and herbaceous species providing cover at that point. Woody species were categorized as tall (typically > 2 m tall), mid-sized (1-2 m tall), and small (typically < 1 m tall; Table II.1). Lizard locations with no woody canopy present were classified as none. Dominant herbaceous vegetation covering the lizard was categorized by grouping species as native grasses, introduced grasses, and forbs (Table II.2). Lizard locations with no herbaceous canopy were also classified as none. This information was also recorded at the random point using a horned lizard model.

Habitat selection data were recorded during three time intervals and two seasons. The time intervals were morning (0700 - 1100), afternoon (1100 - 1800), and evening (1800 - 2100). Each lizard had an equal number of observations in all three time intervals. The season encompassing 15 April - 30 June was the time of greatest lizard activity and was considered the active season. Lizards were more sedentary from 1 July - 15 August, and this was considered the inactive season. A total of 89 lizards were used to collect 1,700 habitat selection data points, with approximately 850 locations in each season. I only used habitat selection data for one time period per day per lizard to decrease dependency of the samples.

Statistical Analyses

Frame Level.–I analyzed data at the frame level with multivariate analysis of variance in SAS (MANOVA, SAS Institute, Inc. 1996). I chose MANOVA to isolate which independent variables were important in explaining habitat selection by horned lizards. Dependent variables included percent bare ground, litter, forbs, grass, woody plants, and woody canopy. Independent variables included type of location (lizard vs. random), time of day, season, and treatment. Bonferroni adjustments were used for multiple comparisons and were considered significant at $\alpha = 0.007$ (Tabachnick and Fidell 1989). If a habitat feature was used more than its availability, it was considered selected. If a feature was used less than its availability, it was considered avoided.

Point Level.–The effect of season and time of day on the use of dominant woody and herbaceous species by horned lizards were analyzed using log-linear modeling in SAS (SAS Institute, Inc. 1996). Log-linear modeling was used because both dependent and independent variables were categorical. I removed non-significant higher-level interactions from the model to produce the simplest model with a significant fit ($P < 0.05$). Pairwise comparisons using SAS (SAS Institute, Inc. 1996) were performed to test for independence at the varying times of day and seasons. All statistical comparisons, unless stated otherwise, were considered significant at $\alpha = 0.05$.

RESULTS

Frame Level

Selection or avoidance of vegetation characteristics by horned lizards did not vary by treatments at the frame scale. However, vegetation characteristics at random and lizard locations were different, and this difference interacted with time of day (Wilk's $\lambda = 0.93$, $F_{12,3300} = 9.47$, $P < 0.01$, Table II.3). Of the habitat variables measured, bare ground ($P = 0.0001$), litter ($P = 0.0001$) woody vegetation ($P = 0.0001$), and woody canopy ($P = 0.0001$) varied between lizard and random locations after the Bonferroni adjustment. Bare ground was avoided by lizards in the afternoon, but used according to its availability in the mornings and evenings. Litter and woody stems were selected by lizards in the afternoon, but use was similar to availability in the mornings and evenings. Lizards selected woody canopy at all times of day, but this effect was greatest in the afternoon.

Vegetation characteristics varied between random and lizard locations, but this difference also interacted with season (Wilk's $\lambda = 0.98$, $F_{6,1650} = 5.30$, $P < 0.01$, Table II.4). Of the habitat variables measured, litter ($P = 0.0001$) and woody canopy ($P = 0.0001$) varied between lizard and random locations after the Bonferroni adjustment. Litter and woody canopy were selected by lizards, and this selection was stronger in the inactive season.

Vegetation characteristics varied by the treatment by season interaction (Wilk's λ = 0.99, $F_{24,5757} = 2.78$, $P = 0.01$), but only for grass ($P = 0.001$, Table II.5) after the Bonferonni adjustment. The interpretation of this interaction is that season differences in grass cover in all frames (random and lizard sites) varied across treatments. Selection or avoidance of grass cover did not vary by treatment or season.

Point Level

Selection or avoidance of woody or herbaceous categories by horned lizards did not vary by treatment at the point scale. Frequencies of dominant woody categories at random and lizard locations were different, but this difference varied by time of day (χ_6 = 40.15, $P < 0.001$, Figure II.1). Shrubs were selected throughout the day, but this effect was greatest in the afternoon. Lizards selected all types of shrubs and avoided sites with no woody shrubs ($\chi_3^2 < 124.66$ for all comparisons, $P < 0.01$ for all comparisons).

Selection of woody categories was not consistent across seasons ($\chi_3^2 = 14.94$, $P <$ 0.01, Figure II.2). Lizards selected all types of woody plants and avoided sites with no woody vegetation in both seasons, but this effect was greatest in the inactive season (χ_3^2 < 124.73 for both comparisons, $P < 0.01$ for both comparisons). The distribution of dominant woody categories across all locations varied by treatment and season (χ_{11}^2 = 21.75, $P = 0.04$).

Frequency of herbaceous categories at random and lizard locations were different, but this difference varied by time of day ($\chi_6^2 = 18.91$, $P < 0.01$, Figure II.3). In the morning, lizards selected introduced grasses and forbs and avoided areas with no herbaceous canopy ($\chi_3^2 = 7.44$, $P = 0.05$). In the afternoon, lizards selected fewer grasses and forbs and more areas with no herbaceous canopy than what was available (χ_3^2 =

13.82, $P < 0.01$). In the evening, lizard and random locations did not differ ($\chi_3^2 = 0.81$, $P = 0.84$).

Selection of herbaceous categories interacted with season ($\chi_3^2 = 10.82$, $P = 0.01$, Figure II.4). In the active season, lizard and random locations contained the same categories of herbaceous canopy ($\chi_3^2 = 4.54$, $P = 0.20$). In the inactive season, lizards selected less native grass and more areas lacking herbaceous canopy than what was available ($\chi_3^2 = 8.56$, $P = 0.03$). The distribution of herbaceous categories across all locations varied by treatment and season ($\chi_{11}^2 = 21.79$, $P = 0.02$).

DISCUSSION

Lizards are found in areas of bare ground and herbaceous vegetation in the mornings and evenings for several reasons. First, lizards are ectotherms, and therefore dependent on the external environment to maintain optimal body temperatures. By exploiting different microhabitat types, horned lizards can regulate body temperatures to affect performance (Cowles and Bogert 1944, Prieto and Whitford 1971, Guyer and Linder 1985). For this reason, habitat selection by horned lizards is of vital importance. When a lizard is at its optimal body temperature, its ability to perform important functions such as foraging, predator avoidance, and reproduction increases (Huey 1991, Bauwens et al. 1996, Diaz 1997). However, to achieve optimal body temperature, a lizard may have to forfeit its chances to forage and reproduce (Huey 1991). Areas of bare ground and little herbaceous canopy enable horned lizards to maximize sun exposure in the cooler parts of the day, specifically the morning and evening. At these times, lizards can thermoregulate less and invest more energy into other important functions (Bauwens et al. 1996). My findings were consistent with Fair and Henke (1998).

Second, daily activity patterns of horned lizards match those of their main prey, the harvester ant (*Pogonomyrmex* spp.) (Pianka and Parker 1975). Harvester ants typically exhibit a bimodal daily activity pattern, with peak activity occurring in the morning and late afternoon (Holldobler and Wilson 1990). Because harvester ants are granivores, most activity occurs in areas with bare ground and sparse herbaceous vegetation. Ants forage on forb and grass seed heads, and sparse vegetation facilitates foraging (Holldobler and Wilson 1990). This foraging strategy may explain why lizards selected sites containing forbs in the morning. Bare ground is also important to harvester ants for thermoregulatory reasons because they are strongly thermophilic (Holldobler and Wilson 1990). DeMers (1993) noted that ants may prefer more open areas to build mounds. Because harvester ants are available, horned lizards can effectively forage in open areas in the morning and evening. Finally, because of the dorso-ventrally flattened body shape of the horned lizard, open areas facilitate movement (Whiting et al. 1993, Fair 1995).

Texas horned lizard behavior in the afternoon differs from that of the mornings and evenings. In the afternoon, which is the hottest part of the day, horned lizards are more dependent on woody vegetation and litter as thermal refuges (Heath 1965, Guyer and Linder 1985, Fair and Henke 1998) and less dependent on bare ground and herbaceous vegetation. In the afternoon, air temperatures in southern Texas often exceed 38°C, with operative and substrate temperatures often surpassing 45°C (Forrester et al. 1998). Because of their flattened body shape, horned lizards are more affected by substrate temperatures than air temperatures (T. Russell, Oklahoma State University, unpublished data). In the afternoon, lizards escape from the heat by burying in the litter or substrate, seeking shade under shrub clumps, or climbing into shrub canopies (Whitford and Bryant 1979, Shaffer and Whitford 1981, Arnold 1995, Fair 1995). Russell (Oklahoma State University, unpublished data) also found that horned lizards on the CWMA used sunny habitats in the morning and shady habitats in the afternoon. Shrub clumps may also offer protection from predators (Fair 1995). My data at the frame and point scales were consistent with these previous observations of lizard selection for woody canopy cover and litter in the heat of the day. Diel changes in microhabitat use also have been seen in other lizards such as *Eremias lineo-ocellata* (Huey and Pianka 1977), *Sceloporus merriami* (Grant and Dunham 1988, Grant 1990), and *Podarcis hispanica* (Bauwens et al. 1996, Diaz et al. 1996).

Horned lizards do not usually forage in the open during the afternoons because harvester ants are typically not active at that time (Shaffer and Whitford 1981). The peak activity of ants occurs between air temperatures of 20 and 40° C (Whitford et al. 1980) and temperatures on the CWMA commonly exceed 40° C in the afternoons (TPWD, unpublished data). Because harvester ant mounds are typically found in somewhat barren areas, little protection is offered from a hot sun and harvester ants generally seek refuge in their mounds and cease activity at these times (Holldobler and Wilson 1990). Because harvester ants are not available, horned lizards may be utilizing shrubs to continue foraging on other prey during this time (Heath 1965, Shaffer and Whitford 1981). Other species of ants and food sources of the horned lizard, such as beetles and termites, remain active under shrubs during the hottest times of the day.

Daily selection patterns were intensified in the inactive season, when average daily and maximum temperatures increase (TPWD, unpublished data). Seasonal variation in activity due to varying temperatures also have been found in lizards such as *Phrynosoma solare* (Baharav 1975), *Agama hispida* (Huey and Pianka 1977), *Conolophus pallidus* (Christian et al. 1983), and *Lacerta vivipara* (Van Damme et al. 1987). Fair and Henke (1998) found that Texas horned lizards buried themselves more often after July. Horned lizards could remain alert and forage for longer periods of time during the active season without having to find a thermal refuge (Pianka and Parker 1975) such litter and soil (Fair and Henke 1998). Also, the peak activity of ants is likely longer in the active season of May and June, when temperatures are not as high as in July and August. Ant activity is depressed when temperatures reach the upper lethal limit (Whitford and Ettershank 1975). Because of these factors, horned lizards are more dependent on cover provided by litter and woody vegetation in the inactive season.

The burning and grazing treatments implemented by the CWMA did not have an effect on habitat selection by horned lizards, as predicted. Though season by treatment interactions existed for the distribution of woody and herbaceous categories, lizard selection did not vary with these interactions. Although lizards may have been using areas categorized by different distributions of woody and herbaceous vegetation in different seasons by treatment, these areas were large enough that characteristics of random frames and frames at the lizard did not differ. Therefore, although burning and grazing may have altered the habitat available to lizards, lizards were still selecting the same microhabitat features.

Vegetation characteristics of lizard locations were different than random locations, suggesting that lizards were selecting specific habitat features. Interactions of independent variables revealed that this was particularly true in the afternoon and the hotter inactive season, when lizards were more dependent on woody canopy for thermoregulation. Horned lizards need a variety of habitat features as temperatures and food availability change throughout the day and year. I believe habitat favored by Texas horned lizards includes a mosaic of bare ground, herbaceous vegetation and woody vegetation in close proximity. Burning and grazing in southern Texas at intensities studied herein did not affect microhabitat selection by Texas horned lizards. However, management practices that maximize the availability of the suitable mosaic for Texas horned lizards should lead to higher lizard densities.

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Table II.1. Categorization of woody species utilized by Texas horned lizards and identified at random locations at the Chaparral Wildlife Management Area, summer 1999. Common and scientific names for vegetation follow Hatch et al. (1990).

Woody Category	Scientific Name	Common Name
Tall	Acacia berlandieri	Guajillo
(Typically > 2 m tall)	Acacia minuta	Huisache
	Acacia schaffneri	Twisted acacia
	Bumelia celastrina	Coma
	Celtis pallida	Spiny hackberry
	Condalia hookeri	Brasil
	Diospyros texana	Texas persimmon
	Prosopis glandulosa	Honey mesquite
	Zanthoxylum fagara	Lime pricklyash
Mid-sized	Acacia rigidula	Blackbrush
(1 - 2 m tall)	Aloysia gratissima	Whitebrush
	Colubrina texensis	Hogplum
	Forestiera angustifolia	Narrowleaf foresteria
	Guayacum angustifolium	Guayacan
	Karwinskia humboldtiana	Coyotillo
	Salvia ballotiflora	Shrubby blue sage
	Schaefferia cuneifolia	Desert yaupon
	Ziziphus obtusifolia	Lotebush
Small	Echinocereus enneacanthus	Strawberry cactus
(Typically < 1 m tall)	Jatropha dioica	Leatherstem
	Koeberlinia spinosa	Allthorn
	Lantana horrida	Common lantana
	Lantana macropoda	Veinyleaf lantana

Table II.1 cont.

	Opuntia engelmannii	Prickly pear
	Opuntia leptocaulis	Tasajillo
	Parkinsonia texana	Paloverde
		Logs

Table II.2. Categorization of herbaceous species utilized by Texas horned lizards and identified at random locations at the Chaparral Wildlife Management Area, summer 1999. Common and scientific names for vegetation follow Hatch et al. (1990).

Herbaceous Category	Scientific Name	Common Name
Native Grasses	Aristida spp.	Threeawn
	Bouteloua spp.	Grama
	Brachiaria ciliatissima	Fringed signal grass
	Cenchrus incertus.	Common sandbur
	Chloris cucullata	Hooded windmillgrass
	Eragrostis secundiflora	Red lovegrass
	Eragrastis sessilispica	Tumble lovegrass
	Heteropogon contortus	Tanglehead
	Panicum spp.	Panicum
	Paspalum spp.	Paspalum
	Setaria spp.	Bristlegrass
Introduced Grasses	Cenchrus ciliaris	Buffelgrass
	Eragrostis lehmanniana	Lehmann lovegrass
Forbs	Amphiachyris dracunculoides	Broomweed
	Aphanostephus spp.	Lazy daisy
	Argemone albiflora	Pricklypoppy
	Chamaecrista fasciculata	Partridge pea
	Croton spp.	Croton
	Dalea spp.	Dalea
	Diodia teres	Buttonweed
	Evolvulus alsinoides	Slender evolvulus
	Gaillardia pulchella	Indian blanket
	Hedyotis greenmanii	Bluets

Table II.2 cont.

Krameria lanceolata	Trailing ratany
Lesquerella argyraea	Silvery bladderpod
Melampodium cinereum	Plains blackfoot
Monarda punctata	Spotted horsemint
Nama hispidium	Gray nama
Palafoxia texana	Texas palafoxia
Sida spp.	Sida
Simsia calva	Bush sunflower
Thelesperma burridgeanum	Burridge greenthread
Thymophylla pentachaeta	Dogweed
Verbesina encelioides	Cowpen daisy

Table II.3. Average % bare ground, litter, woody stem, and woody canopy used by horned lizards and at random locations across 3 times of day measured in Daubenmire frames at the Chaparral Wildlife Management Area, summer of 1999 and 2000.

	Time of Day											
	Morning				Afternoon				Evening			
Herbaceous	Lizard		Random		Lizard		Random		Lizard		Random	
variable (%)	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Bare ground	38.7	1.5	44.9	1.7	24.1	1.6	47.3	1.7	39.3	1.7	47.8	1.8
Litter	24.1	1.6	20.7	1.3	47.8	2.3	22.7	1.5	29.9	2.0	22.4	2.4
Woody stem	4.7	0.8	2.6	0.7	14.7	1.6	2.7	0.6	5.2	0.9	1.8	0.5
Woody canopy	11.9	1.4	8.1	1.2	42.6	2.2	10.2	1.3	23.4	1.9	7.3	1.0

Table II.4. Average % litter and woody canopy used by lizards and at random locations across 2 seasons measured in Daubenmire frames at the Chaparral Wildlife Management Area, summers of 1999 and 2000.

	Season							
	Active				Inactive			
Herbaceous	Lizard		Random		Lizard		Random	
variable	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Litter	24.5	1.3	20.3	1.1	43.3	1.8	23.6	1.7
Woody Canopy	20.4	1.5	8.6	1.0	31.0	1.7	8.5	1.0

Table II.5. Average % grass cover at sites used by Texas horned lizards and random sites measured in Daubenmire frames at the Chaparral Wildlife Management Area, summers of 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	*n* Lizards	*n* Frames	$\bar{x}$	SE	*n* Lizards	*n* Frames	$\bar{x}$	SE
U-U	4	68	36.9	4.3	3	114	17.8	2.4
Mg-B	12	202	23.1	1.7	6	176	23.0	2.4
Mg-U	11	230	21.9	1.4	8	187	22.4	1.7
Hg-B	12	206	25.8	1.5	10	156	19.4	1.7
Hg-U	10	166	24.7	1.6	9	203	24.2	1.8

Figure II.1. Frequency of occurrence of shrub categories at Texas horned lizard and paired random locations at three times of day at the Chaparral Wildlife Management Area, summers 1999-2000. Tall shrubs were those species generally > 2 m in height. Mid-sized shrubs were those generally 1-2 m in height and small shrubs were < 1 m in height. Lizard locations with no woody species present were classified as none.

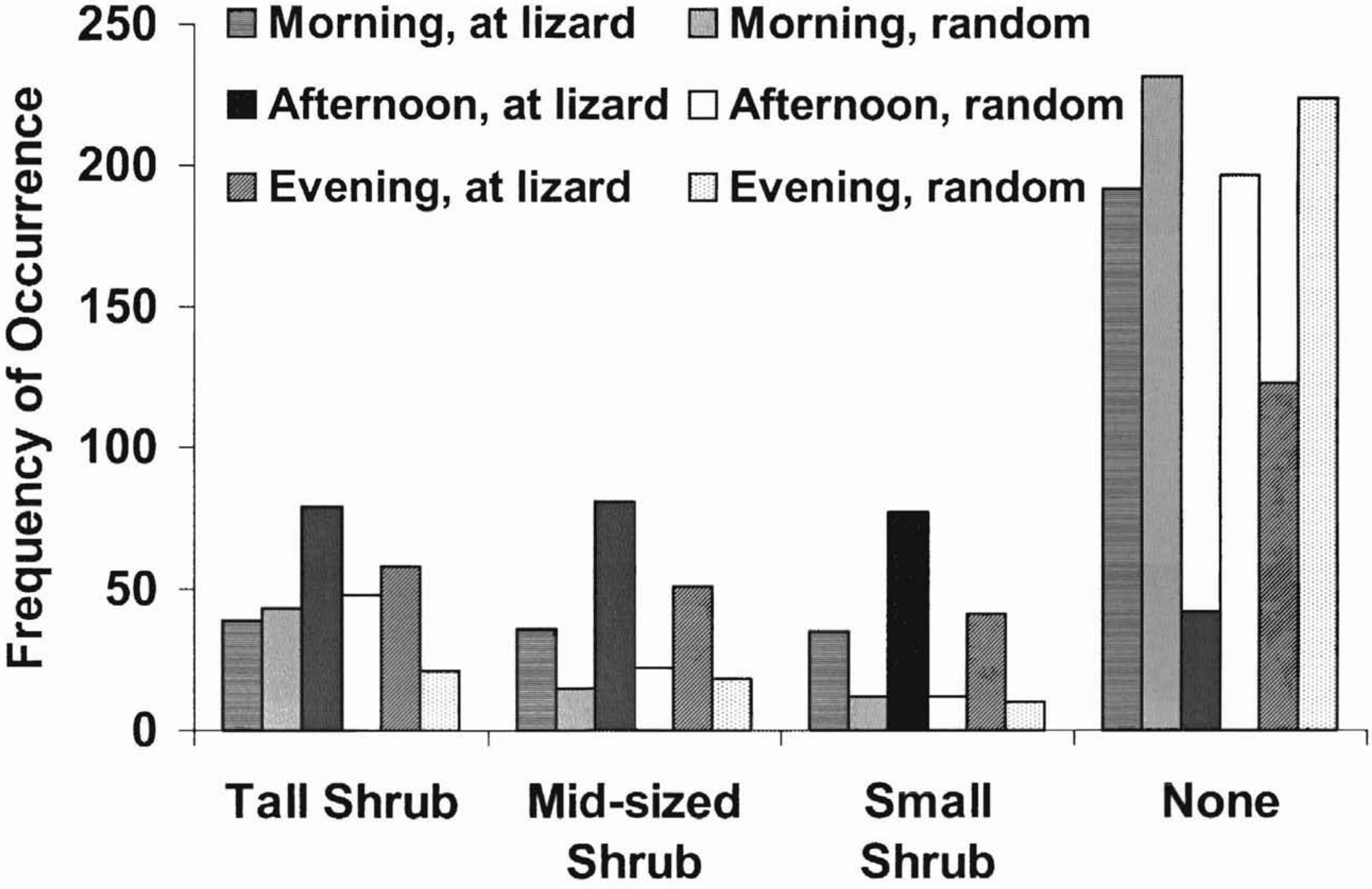
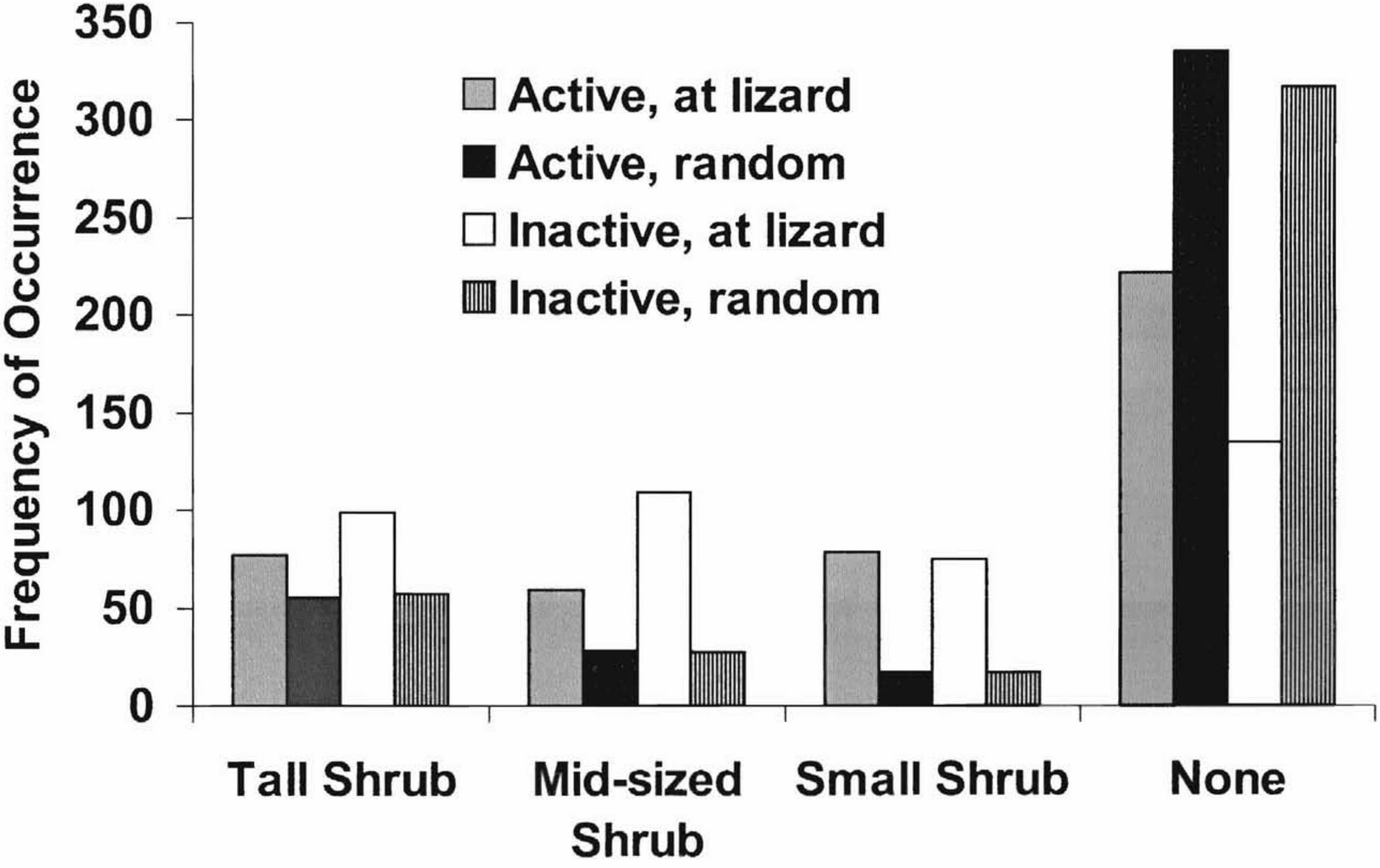

Frequency of Occurrence
250
200
150
100
50
0
▤ Morning, at lizard
▒ Morning, random
■ Afternoon, at lizard
☐ Afternoon, random
▨ Evening, at lizard
░ Evening, random
Tall Shrub
Mid-sized Shrub
Small Shrub
None

Figure II.2. Frequency of occurrence of shrub categories at Texas horned lizard and paired random locations for the active and inactive seasons at the Chaparral Wildlife Management Area, summers 1999-2000. Tall shrubs were those species generally > 2 m in height. Mid-sized shrubs were those generally between 1-2 m in height and small shrubs were < 1 m in height. Lizard locations with no woody species present were classified as none.



Frequency of Occurrence
350
300
250
200
150
100
50
0
▨ Active, at lizard
■ Active, random
☐ Inactive, at lizard
▥ Inactive, random
Tall Shrub
Mid-sized Shrub
Small Shrub
None

Figure II.3. Frequency of occurrence of herbaceous vegetation categories at Texas horned lizard and paired random locations at three times of day at the Chaparral Wildlife Management Area, summers 1999-2000. Lizard locations with no herbaceous species present were classified as none.

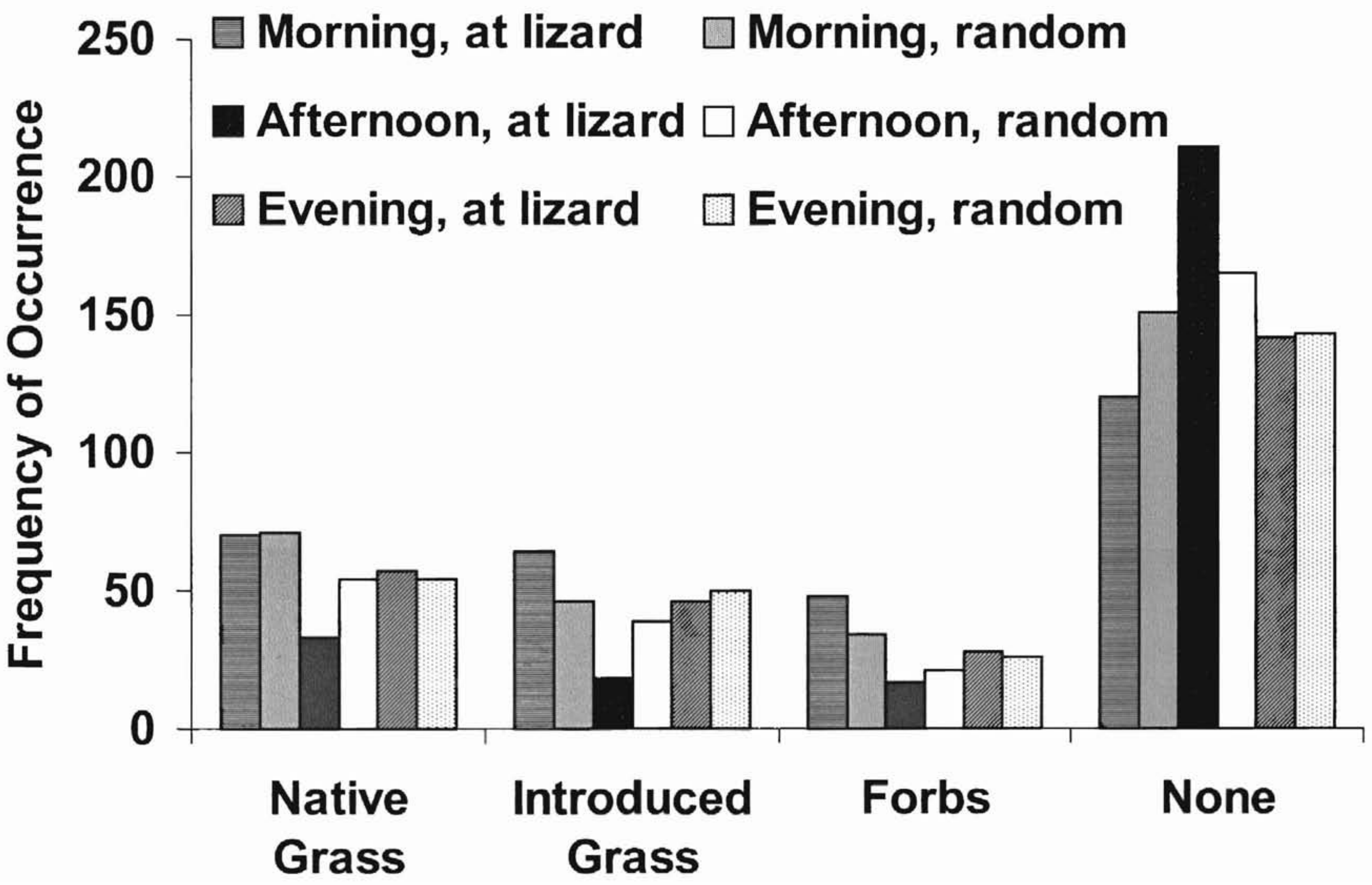
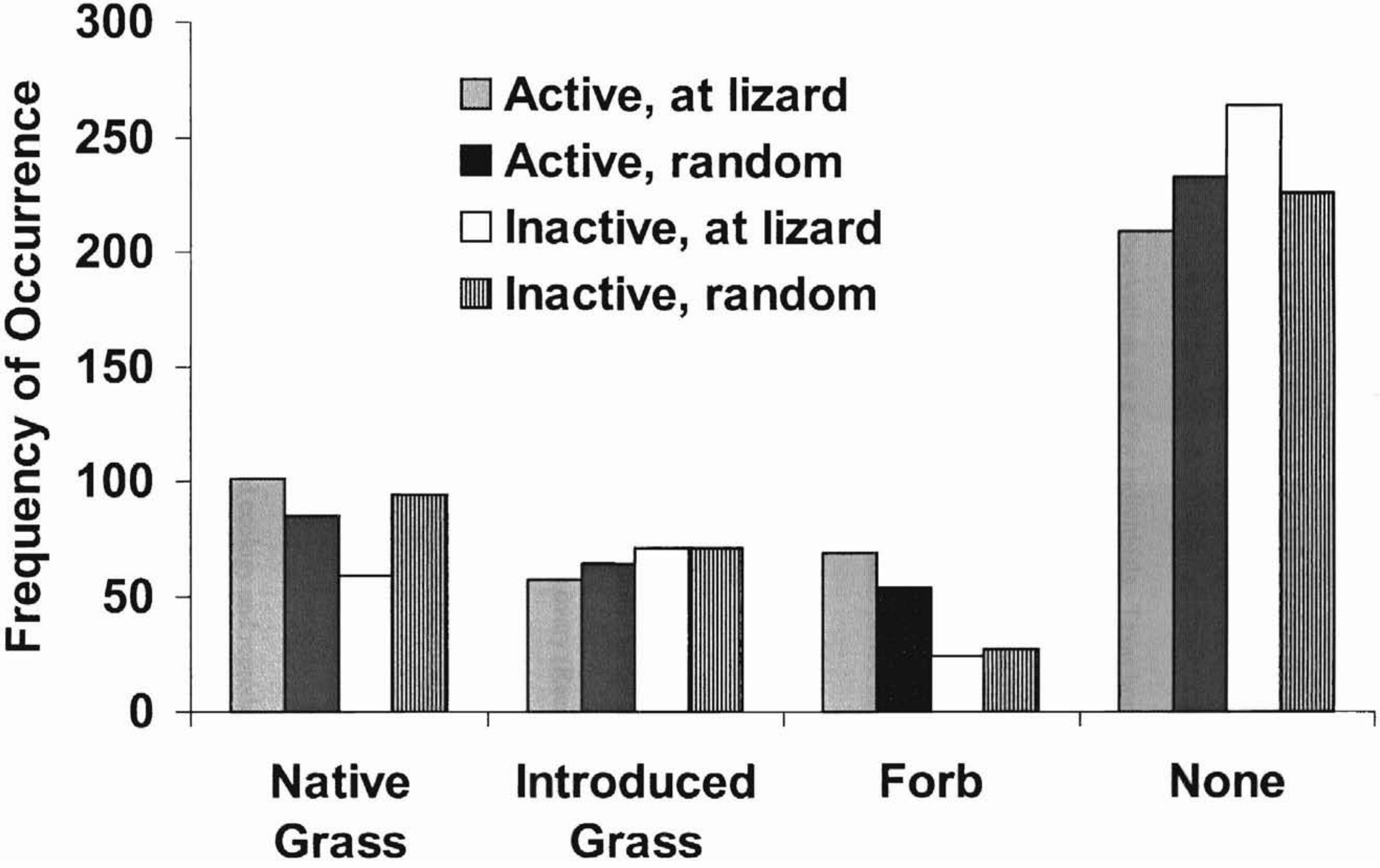

Morning, at lizard
Morning, random
Afternoon, at lizard
Afternoon, random
Evening, at lizard
Evening, random
Frequency of Occurrence
250
200
150
100
50
0
Native Grass
Introduced Grass
Forbs
None

Figure II.4. Frequency of occurrence of herbaceous vegetation categories at Texas horned lizard and paired random locations for the active and inactive seasons at the Chaparral Wildlife Management Area, summers 1999-2000. Lizard locations with no herbaceous species present were classified as none.


300
250
200
150
100
50
0
Frequency of Occurrence
Active, at lizard
Active, random
Inactive, at lizard
Inactive, random
Native Grass
Introduced Grass
Forb
None

CHAPTER III

NOTES ON TEXAS HORNED LIZARD REPRODUCTION

Considerable information exists on reproduction in horned lizards. Most information is based on observations for a few individuals. Texas horned lizards are thought to reach sexual maturity at 22 months (Pianka and Parker 1975). They generally reproduce between the months of April and July (Milne and Milne 1950). Givler (1922) believed that because males usually emerge from hibernation before females, females were inseminated shortly after emergence. After a gestation period of about 40 days, eggs are laid between late May and mid-July (Milne and Milne 1950). Several studies (Cahn 1926, Wood 1936, Hewatt 1937) have reported finding individual horned lizard nests with 27, 28, and 14 eggs laid per nest. Two other studies (Ballinger 1974, *n* = 152; Pianka and Parker 1975, *n* = 73;) reported the average number of oviducal eggs as 26.5 and 23.7, with one report of 34 unlaid eggs in the female's ovary (Reese 1922). Once the nest is laid, the female covers the nest with debris so that the nest cannot be detected (Ramsey 1956). After an incubation period of 5 to 9 weeks (Ramsey 1956, Peslak 1985), the hatchlings emerge from the nest fully developed and are approximately 23 mm in length (Fair 1995).

I made daily observations on horned lizard ecology and reproduction in the summers of 1999 and 2000 with radio-telemetry at the Chaparral Wildlife Management Area (CWMA) in Dimmit and La Salle Counties of Texas. Horned lizards generally emerged from hibernation throughout March and early April. By late March and early

April, both male and female horned lizards were moving long distances daily (up to 452 m), probably in search of mates (Chapter 1).

Once a lizard was observed building a nest, I marked the location and checked it frequently. When the nest was completed and covered, and the female was no longer present, I placed a Phrynosoma Includer Device (PID, Figure III.1) over the nest to observe the hatchlings when they emerged. I checked on the nest periodically until 40 days after the nest was laid, at which time I began checking the nest daily.

I observed 9 different gravid females over the course of the summers. Of those 9 lizards, 4 lizards built only test nests before they died or moved the nest to a new, unknown location. One lizard that moved the nest to a new, unknown location re-nested later in the summer. One of the remaining 5 lizards also laid 2 nests in a given summer, with suspicion of a possible third nest for one lizard. One lizard with a previously unsuccessful nest was also observed mating again on 29 June.

Nests (*n* = 7) were built between 24 April and 20 July. Nests were usually built under a shrub clump in an area nearly devoid of herbaceous vegetation. Several nests were dug straight down and then made a 90-degree turn. Lizards either dug nests using their back legs while facing the entrance to the nest or with their front legs while facing the inside of the nest. Unlike Cahn's (1926) observations that nests were laid at night, all nests I observed were dug in the morning and concealed by that evening or the next morning. However, I did not make observations at night.

Once a female was inseminated, she would leave her home range ($\bar{x}$ = 208.5 m away) to lay a nest. The female stayed with the nest 1 to 2 days and then returned to her original home range. These movements may reduce competition between the female and her offspring. Successful nests (*n* = 4) were laid between 24 April and 27 June. The number of eggs in each nest and hatchling success rate varied greatly between nests (Table III.1). The length of time between nest-laying and hatchling emergence were 42, 49 and 50 days. Unfortunately, I did not observe hatchling emergence from one successful nest, but it was believed to have hatched between 7 and 13 days after the nest was laid. In all nests, the hatchlings emerged following a rain event or just before a rain event. All hatchlings weighed < 0.5 g. Total lengths of hatchlings ranged from 26 to 33 mm ($\bar{x} = 30.9$) and snout-vent lengths ranged from 17 to 23 mm ($\bar{x} = 20.0$).

One nest was unsuccessful because it was depredated by a coyote before I covered the nest with a PID. The remaining unsuccessful nests contained 26 and 28 eggs, respectively, that were shriveled and hard. The eggs probably did not hatch due to desiccation, as these nests were laid late in the summer.

Reproduction of horned lizards has been widely documented in the past; however, most studies took place in the early 1900's. Since then, much habitat of horned lizards has been drastically altered and it is important to document how that change affects reproduction. All nests that I located were laid in unburned sites and, with one exception, in a heavily grazed pasture. To my knowledge, this is the first report of re-nesting in horned lizards. It also appears that hatchling success was linked to the time of year that the nest was laid and recent rain events at the time of hatchling emergence.

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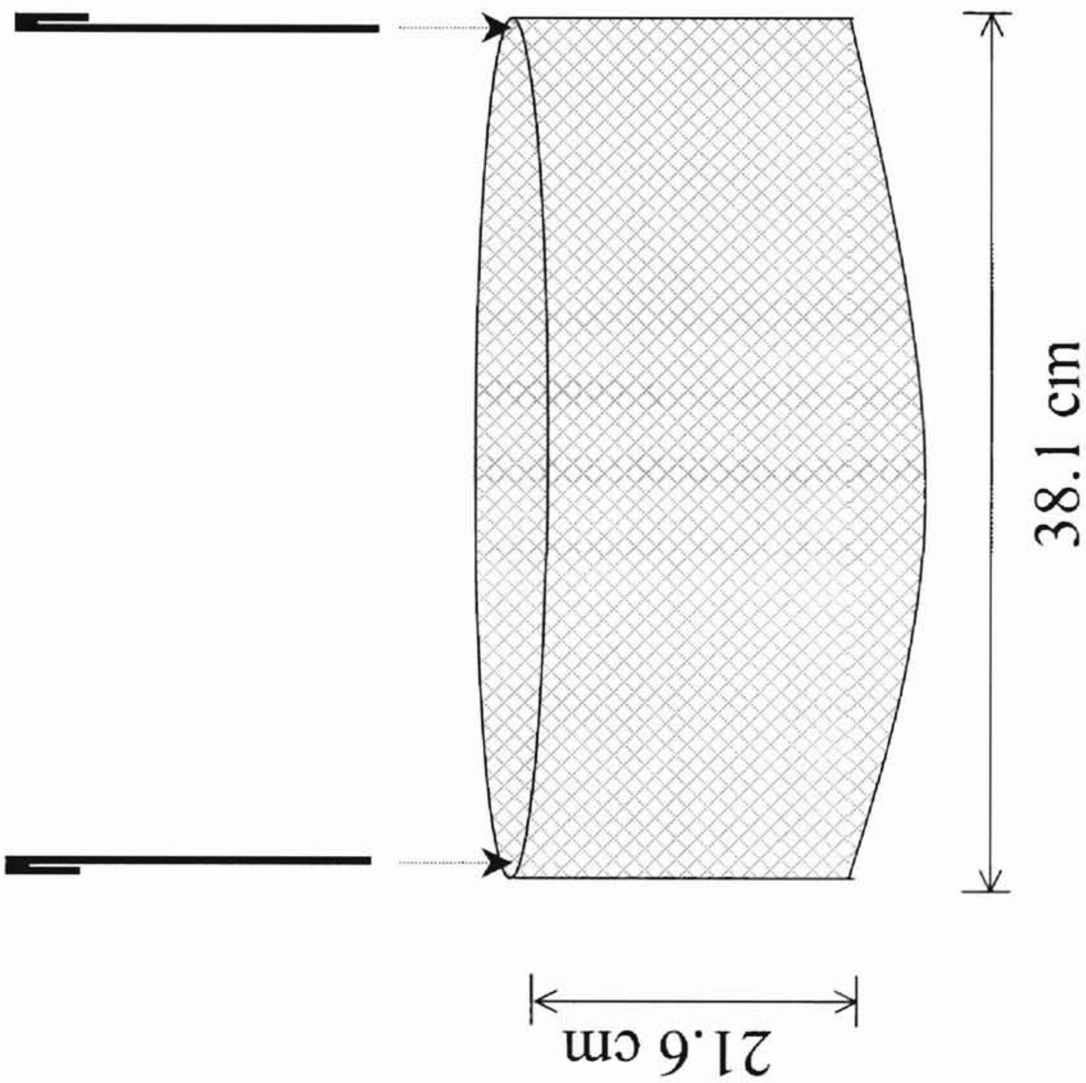
Table III.1. Nest and hatching success rate for female lizards found on the Chaparral Wildlife Management Area, summers of 1999 and 2000.

Lizard	Date nest laid	Date nest hatched	# of hatchlings	# of eggs
37[a]	16 May 1999	4 July 1999	19	20
79	24 April 1999	13 June 1999	4	6
51	9 June 1999		0	28
33	20 July 1999		0	26
48	22 May 2000	29 May - 6 June 2000[c]	20	21
89[ab]	26 May 2000			
89[a]	27 June 2000	8 August 2000	19	29

[a] Lizard re-nested within same summer.
[b] Nest depredated by coyote.
[c] Range given because exact hatching date was unknown.

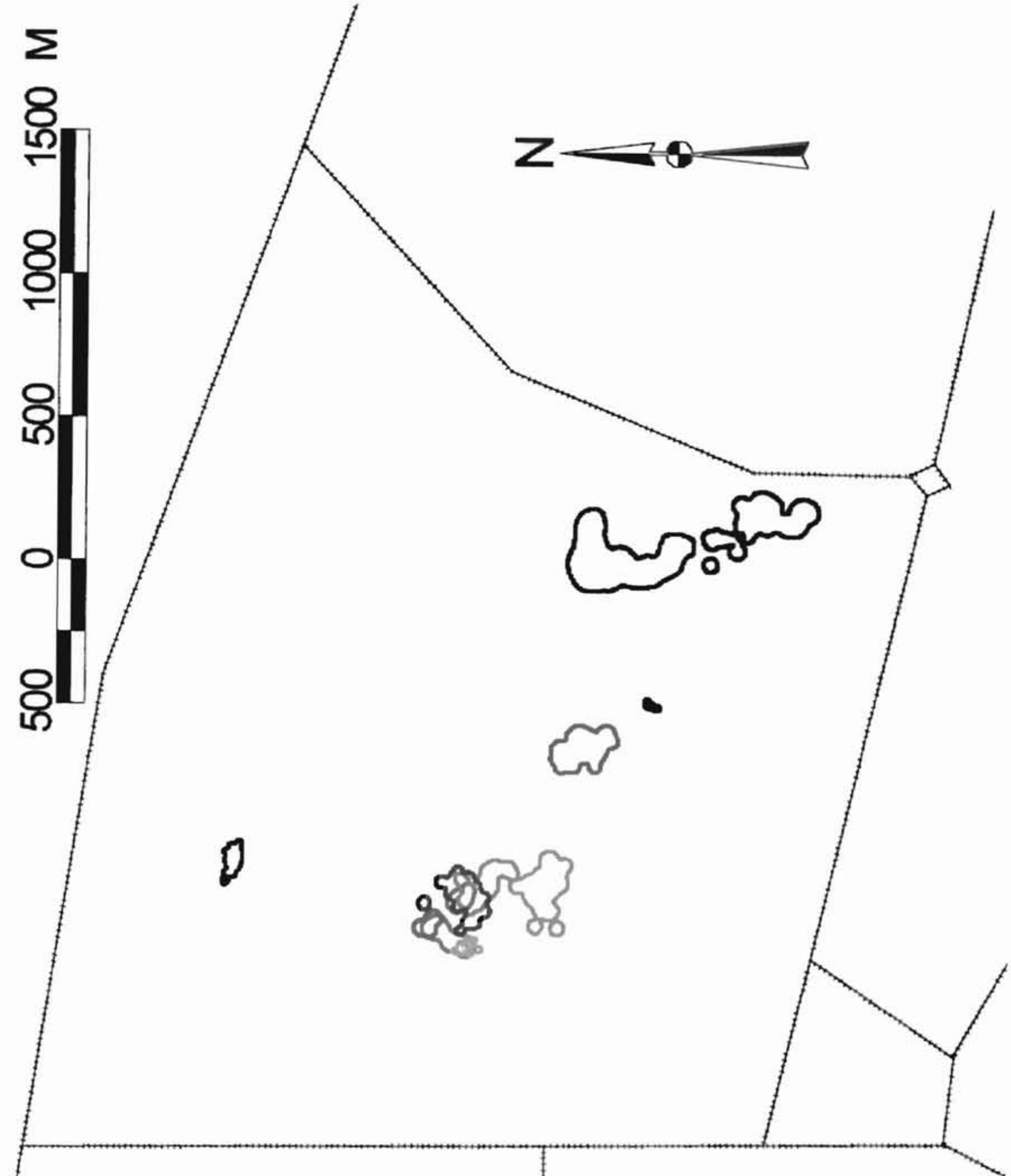
Figure III.1. Phrynosoma Includer Device (PID). The lining of the PID was constructed of wire. The sides and top of each PID was lined with 0.32 to 0.64 cm (0.128 to 0.25 inches) hardware cloth. Rebar stakes with nails attached were used to hold the wire and PID in place.


38.1 cm
21.6 cm

APPENDIX A

HOME RANGES OF HORNED LIZARDS USING 95% ADAPTIVE KERNELS

Figure A.1. Home ranges (95% adaptive kernel) in the active season of male horned lizards in the moderately grazed pasture of the Chaparral Wildlife Management Area, summers 1998-2000. Home ranges in the burned site are designated with a black line. Home ranges in the unburned site are designated with a colored line.


500
0
500
1000
1500 M
N

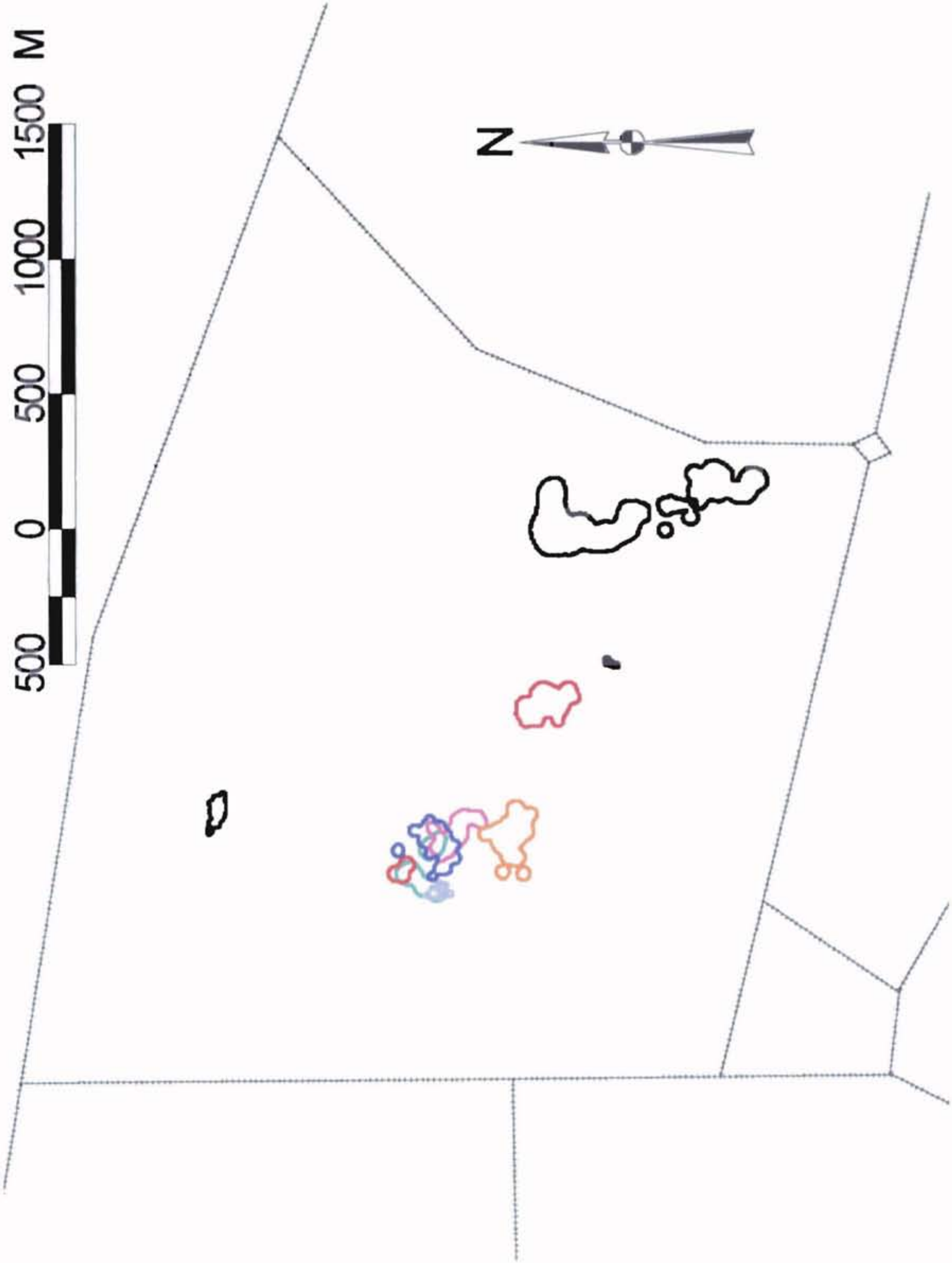

500
0
500
1000
1500 M
N

Figure A.2. Home ranges (95% adaptive kernel) in the inactive season of male horned lizards in the moderately grazed pasture of the Chaparral Wildlife Management Area, summers 1998-2000. Home ranges in the burned site are designated with a black line. Home ranges in the unburned site are designated with a colored line.

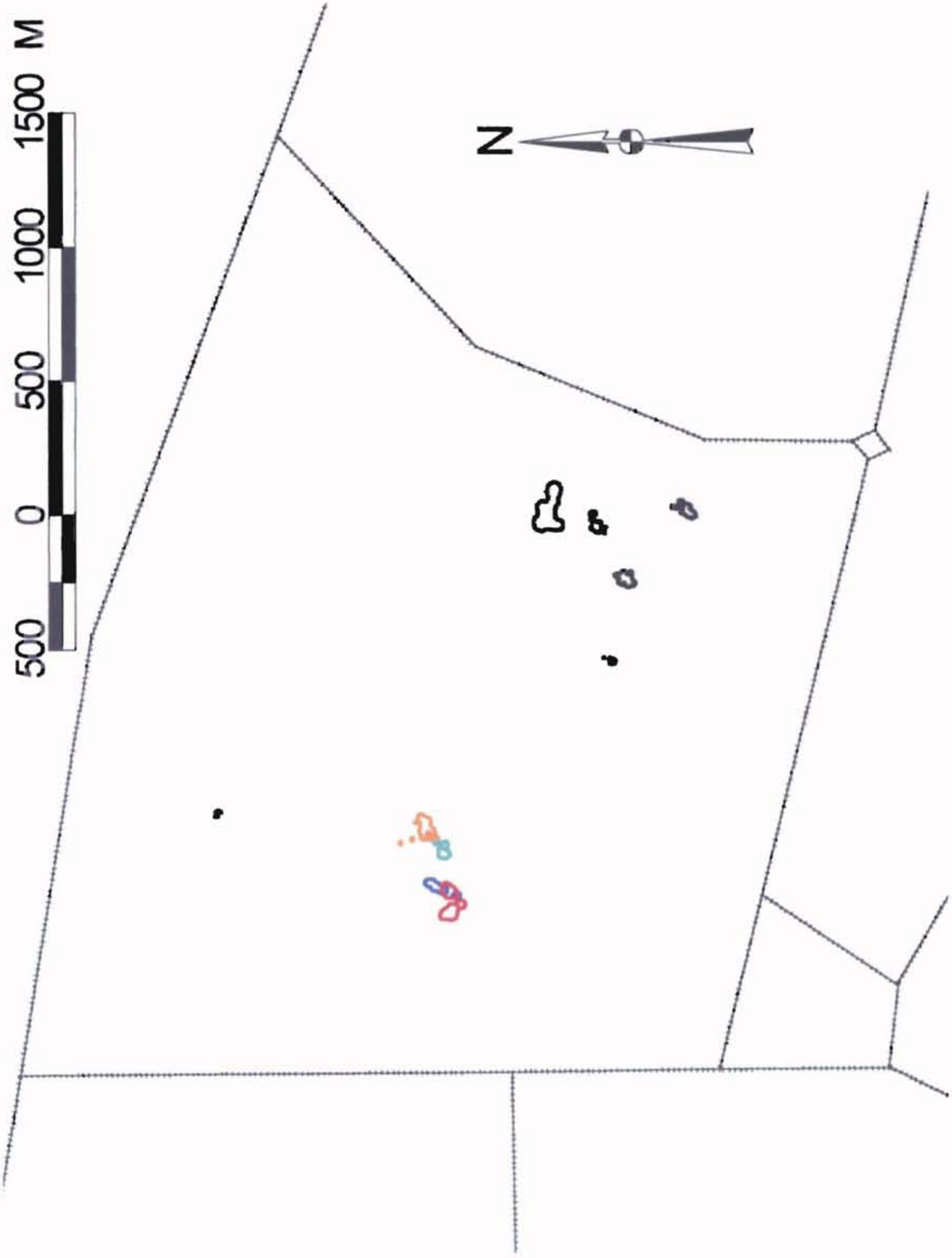

500
0
500
1000
1500 M
N

Figure A.3. Home ranges (95% adaptive kernel) in the active season home ranges of female horned lizards in the moderately grazed pasture of the Chaparral Wildlife Management Area, summers 1998-2000. Home ranges in the burned site are designated with a colored line. Home ranges in the unburned site are designated with a black line.


500
0
500
1000
1500 M
N

Figure A.4. Home ranges (95% adaptive kernel) in the inactive season of female horned lizards in the moderately grazed pasture of the Chaparral Wildlife Management Area, summers 1998-2000. Home ranges in the burned site are designated with a colored line. Home ranges in the unburned site are designated with a black line.


500
0
500
1000
1500 M
N

Figure A.5. Home ranges (95% adaptive kernel) in the active season of male horned lizards in the heavily grazed and ungrazed pastures of the Chaparral Wildlife Management Area, summers 1998-2000. Home ranges in the burned site are designated with a black line. Home ranges in the unburned sites are designated with a colored line.

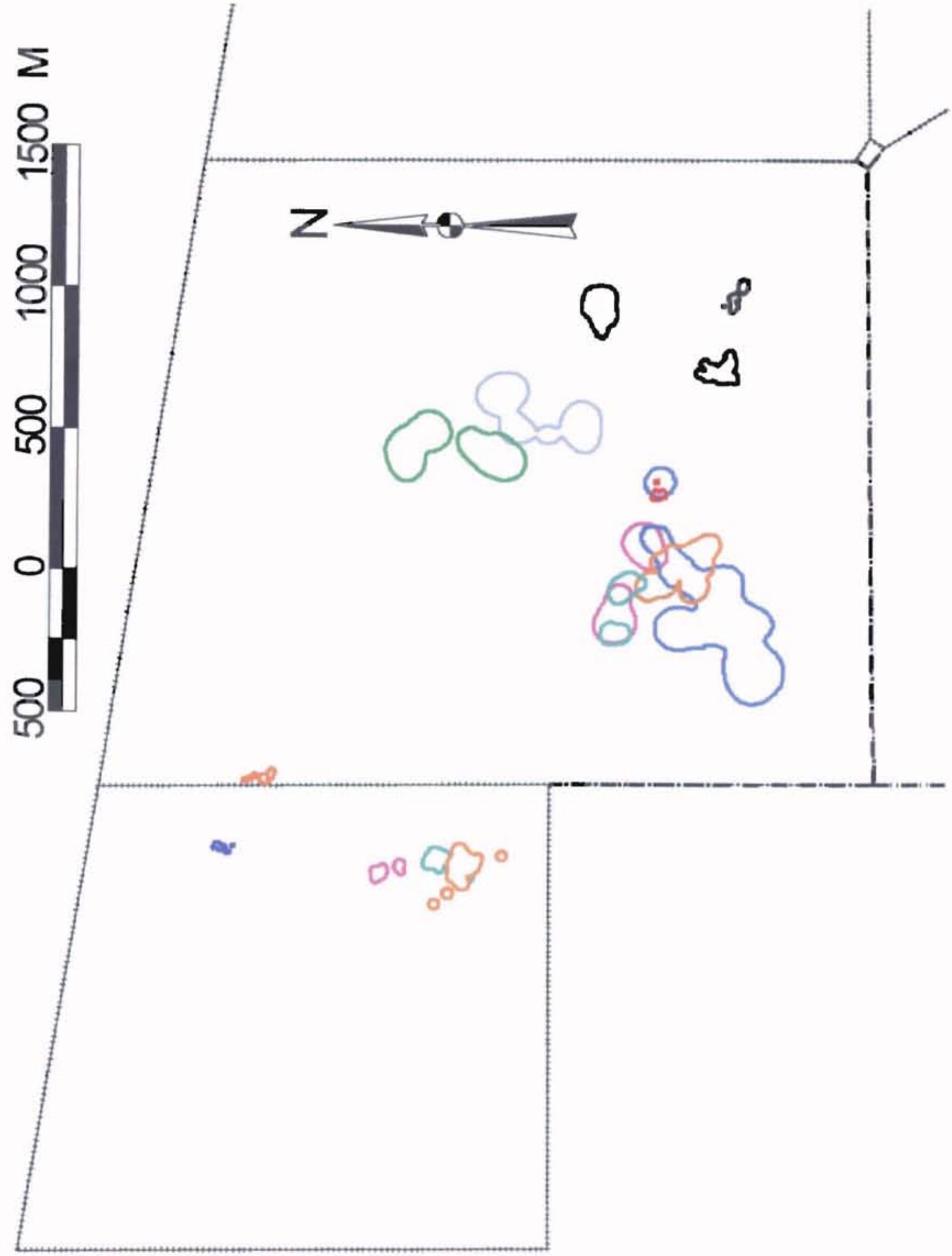

500
0
500
1000
1500 M
N

Figure A.6. Home ranges (95% adaptive kernel) in the inactive season of male horned lizards in the heavily grazed and ungrazed pastures of the Chaparral Wildlife Management Area, summers 1998-2000. Home ranges in the burned site are designated with a black line. Home ranges in the unburned site are designated with a colored line.

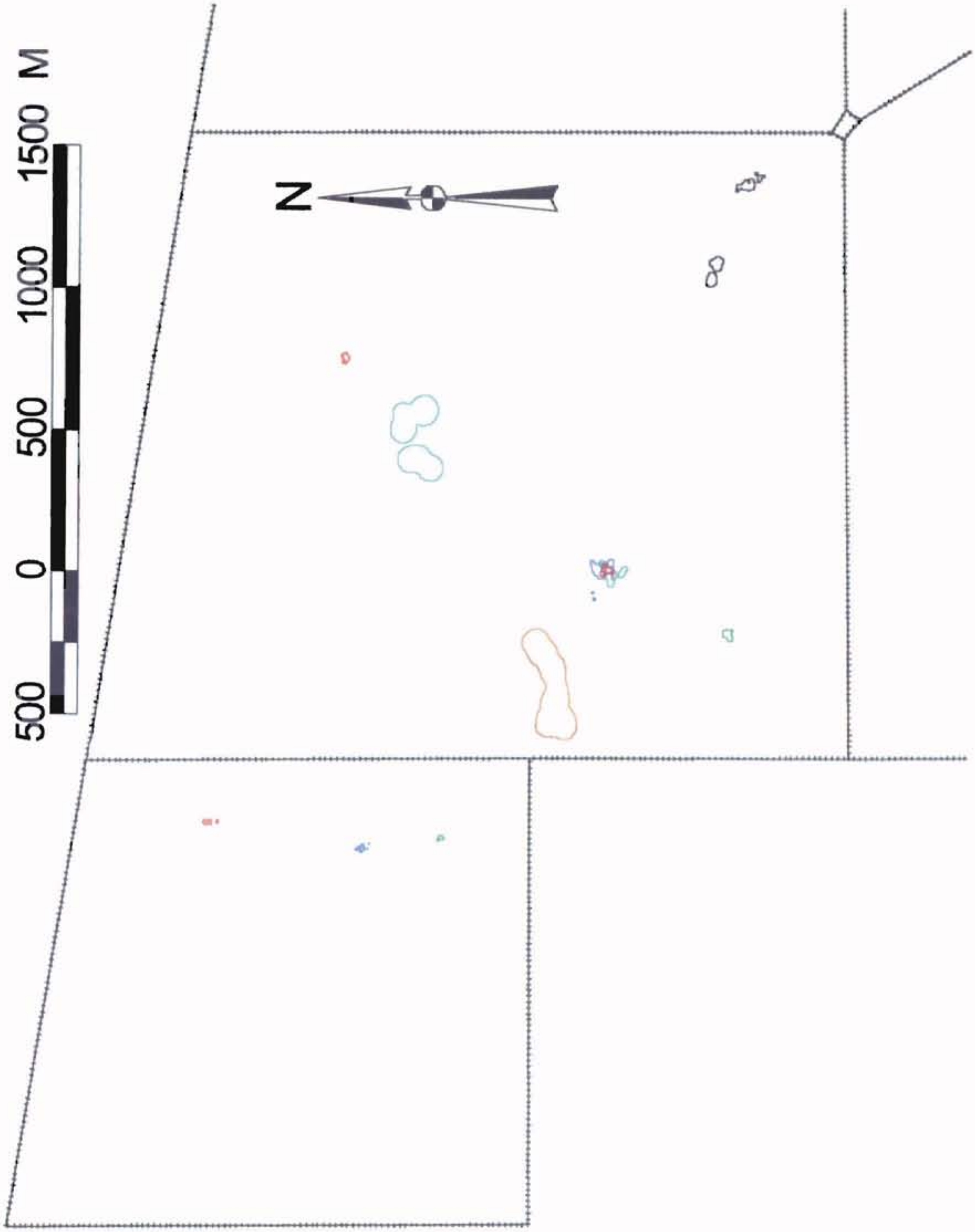

500
0
500
1000
1500 M
N

Figure A.7. Home ranges (95% adaptive kernel) in the active season of female horned lizards in the heavily grazed and ungrazed pastures of the Chaparral Wildlife Management Area, summers 1998-2000. Home ranges in the burned site are designated with a colored line. Home ranges in the unburned site are designated with a black line.

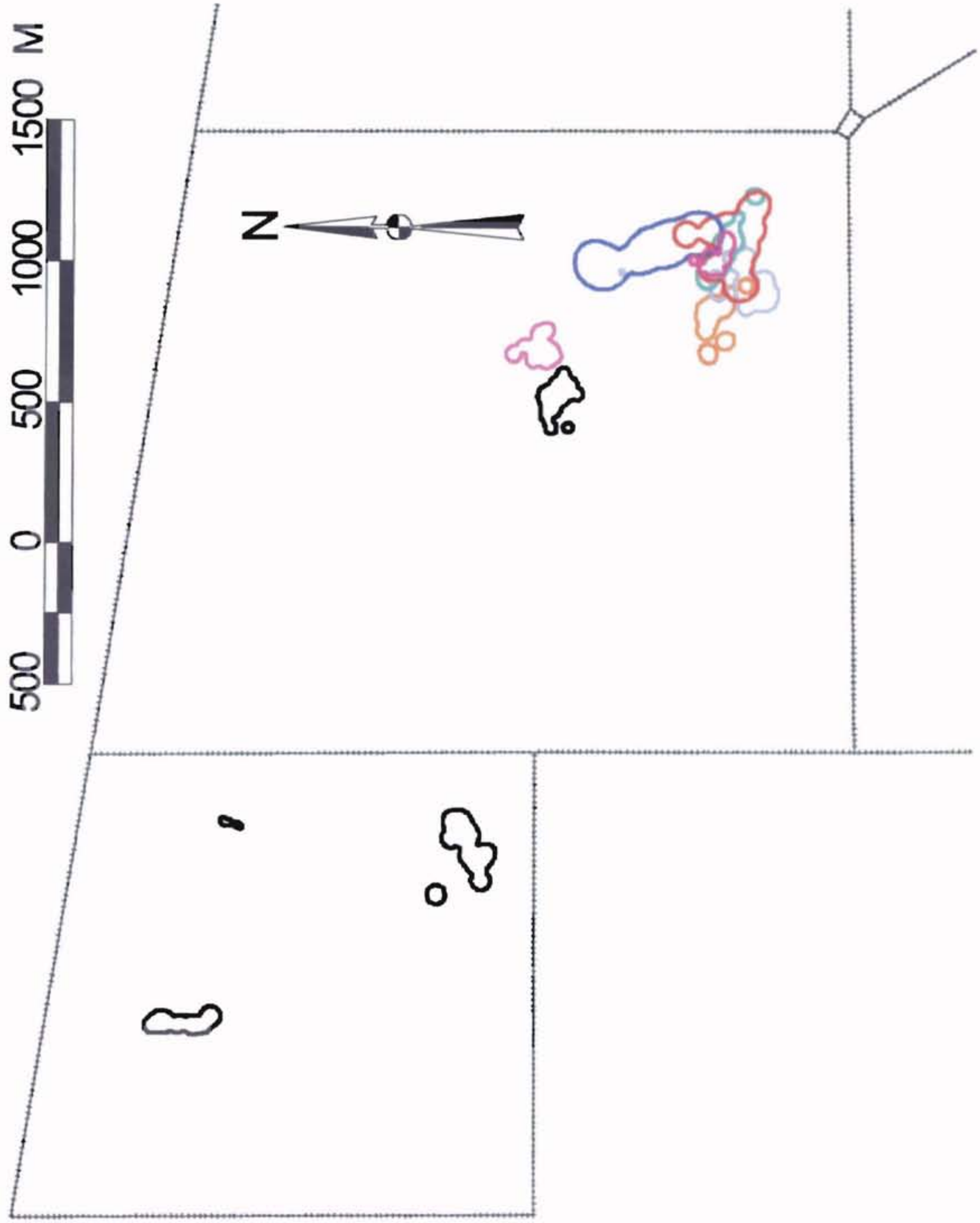
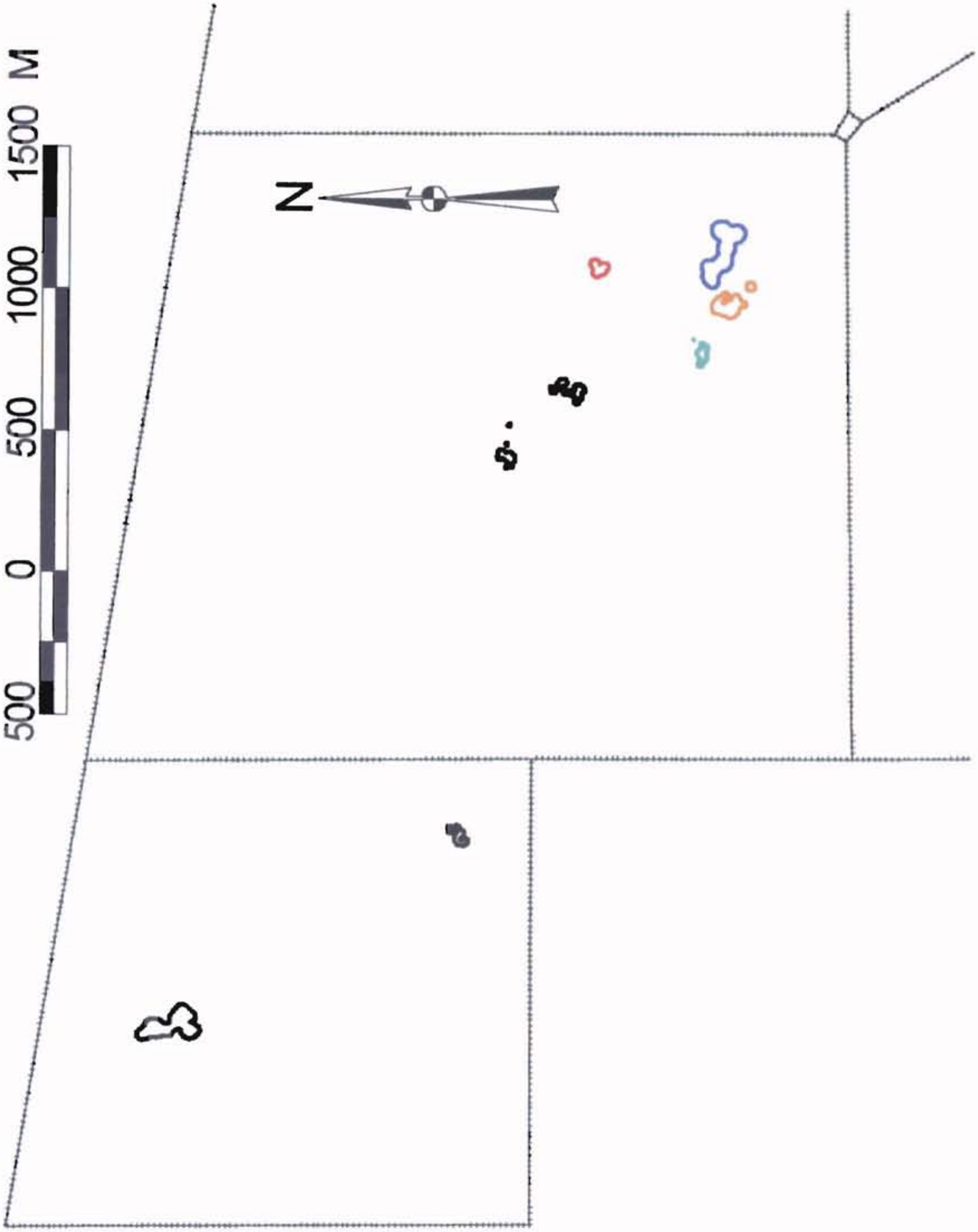

500
0
500
1000
1500 M
N

Figure A.8. Home ranges (95% adaptive kernel) in the inactive season of female horned lizards in the heavily grazed and ungrazed pastures of the Chaparral Wildlife Management Area, summers 1998-2000. Home ranges in the burned site are designated with a colored line. Home ranges in the unburned site are designated with a black line.


500
0
500
1000
1500 M
N

VITA

Anna L. Burrow

Candidate for the Degree of

Master of Science

Thesis: THE EFFECT OF PRESCRIBED BURNING AND GRAZING ON THE THREATENED TEXAS HORNED LIZARD (*PHRYNOSOMA CORNUTUM*) IN THE WESTERN RIO GRANDE PLAINS

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