

# Effects of Protective Fencing on Birds, Lizards, and Black-Tailed Hares in the Western Mojave Desert

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**ABSTRACT** / Effects of protective fencing on birds, lizards, black-tailed hares (*Lepus californicus*), perennial plant cover, and structural diversity of perennial plants were evaluated from spring 1994 through winter 1995 at the Desert Tortoise Research Natural Area (DTNA), in the Mojave Desert, California. Abundance and species richness of birds were higher inside than outside the DTNA, and effects were larger during breeding than wintering seasons and during a high than a low rainfall year. Ash-throated flycatchers (*Myiarchus cinerascens*), cactus wrens (*Campylorhynchus brunneicapillus*), LeConte's thrashers (*Toxostoma lecontei*), loggerhead shrikes (*Lanius ludovicianus*), sage sparrows (*Amphispiza belli*), and verdins (*Auriparus flaviceps*) were more

abundant inside than outside the DTNA. Nesting activity was also more frequent inside. Total abundance and species richness of lizards and individual abundances of western whiptail lizards (*Cnemidophorus tigris*) and desert spiny lizards (*Sceloporus magister*) were higher inside than outside. In contrast, abundance of black-tailed hares was lower inside.

Structural diversity of the perennial plant community did not differ due to protection, but cover was 50% higher in protected areas. Black-tailed hares generally prefer areas of low perennial plant cover, which may explain why they were more abundant outside than inside the DTNA. Habitat structure may not affect bird and lizard communities as much as availability of food at this desert site, and the greater abundance and species richness of vertebrates inside than outside the DTNA may correlate with abundances of seeds and invertebrate prey.

Livestock grazing can reduce diversity, cover, and biomass of plants (Webb and Stielstra 1979, Waser and Price 1981) and negatively affect rodents (Bock and others 1984, Bich and others 1995) and desert tortoises (Berry 1978, Nicholson and Humphreys 1981) in the Mojave Desert. Off-highway vehicle (OHV) use can also negatively affect plant (Davidson and Fox 1974, Webb and Wilshire 1983) and animal communities (Busack and Bury 1974, Webb and Wilshire 1983). Areas in the Mojave Desert have been fenced to exclude livestock and OHVs to protect plants and animals, but the effects of these enclosures have rarely been evaluated. The Desert Tortoise Research Natural Area (DTNA) was created to protect habitat for what was, during the 1970s, the highest known density of desert tortoises (*Gopherus agassizii*) in the Mojave Desert (US Bureau of Land Management and California Department of Fish and Game 1988). Protection at the DTNA has benefited both plant and nocturnal rodent communities (Brooks 1995) in addition to desert tortoises (Berry and others

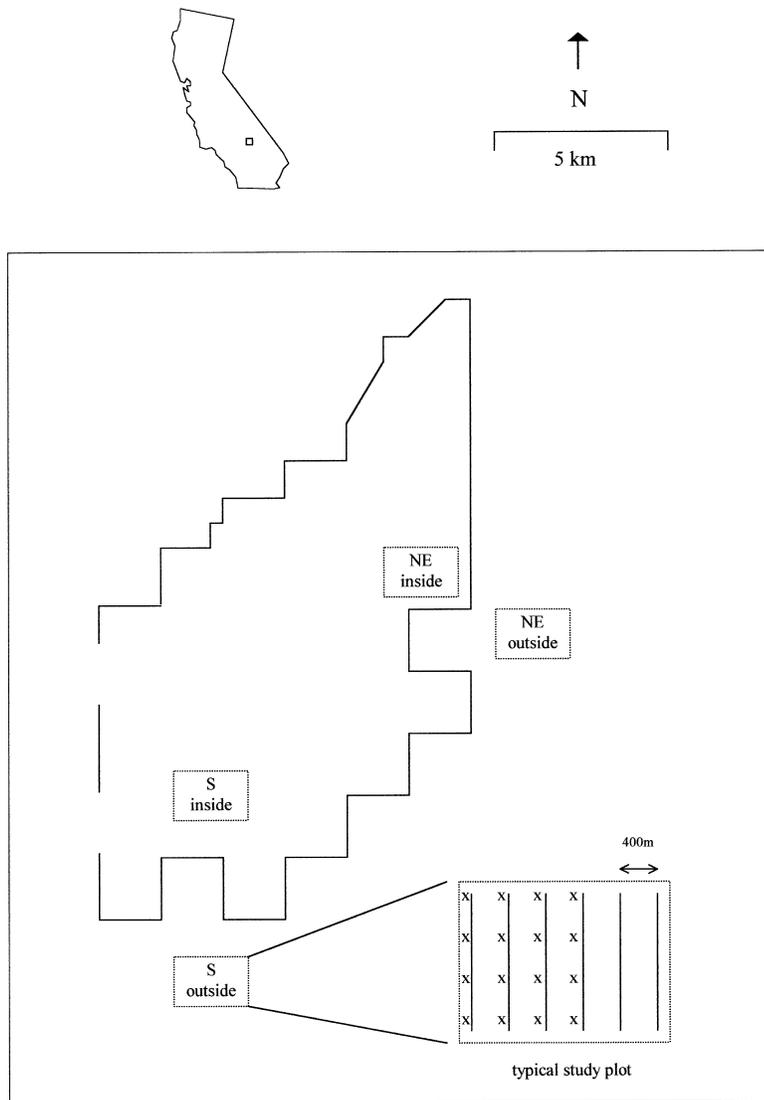
1990), but it is unknown if other taxa are also affected. The current study documents effects of fenced protection on bird and lizard communities, a population of black-tailed hares (*Lepus californicus*), and characteristics of the perennial plant community that may affect these vertebrates.

Abundance and diversity of nocturnal rodents and biomass of seeds are higher inside than outside the DTNA (Brooks 1995). Most rodent species at this site are granivorous and their abundance is likely correlated with abundance of seeds. However, relative abundance of seeds does not explain why grasshopper mice (*Onychomys torridus*) were more abundant inside, because 80% of this species' diet consists of invertebrates (Ingles 1965). These data suggest that invertebrate prey, in addition to seeds, may be more abundant inside the DTNA. Based on the apparent effect of fenced protection on food availability, I predicted that abundances and diversities of bird and lizard communities would also be higher inside than outside the DTNA.

Black-tailed hares do not typically feed on seeds or invertebrates, but graze annual plants during the spring and browse perennial shrubs during the remainder of the year (Jaeger 1961, Sosa Burgos 1991). The lower biomass of annuals and cover of perennial plants outside than inside the DTNA (Brooks 1995) suggest that black-tailed hares may be less abundant outside. However, black-tailed hares are often associated with

**KEY WORDS:** Birds; Fenced protection; *Lepus californicus*; Lizards; Mojave Desert; Off-highway vehicles; Protected area management; Sheep grazing

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**Figure 1.** Approximate location of the Desert Tortoise Research Natural Area in California, showing the northeastern (NE) and southern (S) study plots. The fenceline (solid line) was adopted from US Bureau of Land Management and California Department of Fish and Game (1988, Fig. 2). Arrangements of bird point-count stations (x) and lizard and hare transects (vertical lines) are illustrated in the “typical study plot” insert. Hare transects only included those four that intersect the point-count stations whereas lizard transect included all six.

open habitats (Burt and Grossenheider 1976, Sosa Burgos 1991), suggesting that they may be more abundant outside. It was therefore unclear how fenced protection might affect populations of black-tailed hares.

In addition to affecting the abundance of food, fenced protection may influence vertebrate communities by affecting cover, structural diversity, and species diversity of perennial plants (Pianka 1966, Roth 1976, Mills and others 1991). Habitat structure is particularly important in defining the ecological niches of birds (Wiens 1969), and human disturbances such as grazing seem to affect birds (Wiens 1973) and lizards (Jones 1981) through changes in vegetation structure. Reduced cover of perennial plants may expose vertebrates to greater rates of predation outside than inside the DTNA, and reduced structural and species diversity outside may provide fewer microhabitats and ecological niches (Pianka 1966). I therefore measured perennial

plant cover and structural diversity inside and outside the DTNA to evaluate the relationship between these factors and patterns of vertebrate abundance.

## Methods

### Site Description

The 10,100-ha DTNA is located in the Fremont Valley and Rand Mountains of the western Mojave Desert, near California City, Kern County, California, USA (Figure 1). Average annual rainfall in this region is 157 mm, 83% of which occurs between November and April. Mid-summer temperatures range from an average low of 19°C to a high of 34°C, and mid-winter temperatures range from an average low of 0°C to a high of 7°C (US National Oceanic and Atmospheric Administration 1994). The western Mojave Desert con-

Table 1. Repeated-measures ANOVA of total bird abundance at the Desert Tortoise Research Natural Area

	Source of variation							
	Breeding season				Wintering season			
	<i>df</i>	MS	<i>F</i> <sup>a</sup>	<i>P</i> <sup>b</sup>	<i>df</i>	MS	<i>F</i>	<i>P</i>
NE site								
Between subject								
Protection <sup>c</sup>	1	8.6493	<b>22.61</b>	<b>0.0001</b>	1	3.572	2.21	0.1477
Error	30	0.3825			30	1.6171		
Within subject								
Sample period	3	7.4433	<b>17.57</b>	<b>0.0001</b>	1	16.654	<b>10.28</b>	<b>0.0032</b>
Sample								
period × protection	3	1.4919	<b>3.52</b>	<b>0.0296</b>	1	0.4329	0.29	0.5930
Error	90	0.4236			30	1.6202		
S site								
Between subject								
Protection	1	4.0042	<b>11.38</b>	<b>0.0021</b>	1	3.6706	<b>4.42</b>	<b>0.0440</b>
Error	30	0.3518			30	0.8306		
Within subject								
Sample period	3	9.6172	<b>17.98</b>	<b>0.0001</b>	1	0.3965	0.46	0.5022
Sample								
period × protection	3	0.3133	0.59	0.7141	1	0.6895	0.80	0.3775
Error	90	0.5348			30	0.8593		

<sup>a</sup>Type III sums of squares were used to determine *F* values and significant effects are in bold type ( $P \leq 0.05$ ).

<sup>b</sup>Within-subjects *P* values for the breeding season were Huynh-Feldt corrected.

<sup>c</sup>Protection was a fixed factor with two levels, inside and outside the DNTA.

tains very little habitat that has not been significantly altered by human disturbances, and the DTNA contains some of the least disturbed land in the region (US Fish and Wildlife Service 1994).

*Types of human disturbance.* Although many forms of human disturbance are present at the DTNA, sheep grazing and OHV use are the most widespread and enduring. This area was one of the first and most intensely used rangelands in the California deserts. Grazing began in the mid-1800s, peaked around 1910 at 500,000 to 1,000,000 sheep per year, and currently 20,000 sheep graze 120,000 ha from March through May (US Bureau of Land Management 1980, 1993). Reduction in total sheep grazing was accompanied by decreased rangeland used, so the intensity of grazing may not have decreased as much as the reduction in absolute numbers of sheep suggests. Range condition is considered "fair," which means that soil erosion is more extensive, plant cover and production are lower, plants sensitive to grazing are less common, and weedy species of plants are more common relative to the natural condition of the rangeland (US Bureau of Land Management 1980).

Recreational use of OHVs has been prevalent near the DTNA since the 1960s (US Bureau of Land Management 1973) and has been particularly intense in this area compared to others in the Mojave Desert (US Bureau of Land Management 1980). Between 1979 and 1985 the amount of habitat lost to OHV use increased

23% due to campsites and 130%–157% due to additional OHV trails near the southeast corner of the DTNA (Berry and others 1990). Loss of habitat generally equates to destruction of perennial plants and alterations of the soil that make the landscape unusable for many animals.

*Protection from human disturbances.* In 1973 an informal agreement restricted sheep grazing within the DTNA, and in 1978 grazing was officially prohibited (US Bureau of Land Management and California Department of Fish and Game 1988). The DTNA was open to unlimited OHV travel until 1973 when recreational OHV use was prohibited (US Bureau of Land Management 1973). Roads within the DTNA are periodically used to gain access to private land inholdings, but the natural reinvasion of perennial shrubs and bunch grasses onto these roads suggests that use is infrequent. In 1980 the DTNA was withdrawn from mining for 20 years, firearm use was prohibited in most areas, and the removal of plants and vertebrates was restricted to approved scientific studies (US Bureau of Land Management and California Department of Fish and Game 1988). A 1-m tall fence of 15- × 15-cm welded wire surrounds the DTNA perimeter (Figure 1). Most of this fence was constructed by 1980, including sections that protect the sites described in this study.

Sheep grazing continued on the public land outside the DTNA until 1994, when much of it was designated as critical habitat for the desert tortoise and closed to

sheep grazing (US Fish and Wildlife Service 1994). Unrestricted recreational OHV use also continued on public land outside the DTNA until 1980, when it was restricted to designated roads and trails (US Bureau of Land Management 1980). Approximately 80% of the land adjacent to the DTNA, including the area studied in this paper, is privately owned. In contrast to public land, recreational OHV use on private land is widespread and essentially unrestricted. Sheep graze these private lands in all but the driest years, often during years when public land is not grazed due to excessively low annual plant biomass. Visitors to the DTNA are largely confined to the interpretive center, which is located more than 3 km from the study areas (US Bureau of Land Management and California Department of Fish and Game 1988).

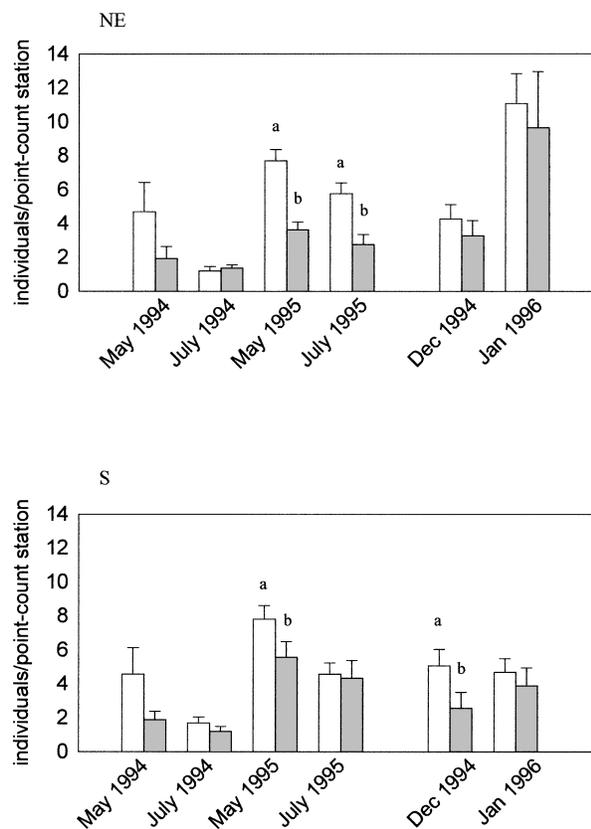
**Study plots.** I established study sites near the northeastern and southern boundaries to encompass the two extremes in elevation and perennial plant community composition at the DTNA (Figure 1). One 2.25-ha plot was established in an area protected from human disturbance (inside) and one in an unprotected area adjacent to the DTNA (outside) at each site. I matched the two plots at each site for slope, aspect, elevation, dominant perennial plant species, proportion of sandy wash to gravelly hill topography, and other soil characteristics. Each of the plots was located at least 400 m from the DTNA fence.

The northeastern site ranged in elevation from 870 m to 915 m, was southwest-facing with 0–15% slope, and was primarily composed of gravelly residual soils less than 30 cm deep over a granitic pediment (Valverde and Hill 1981). It was dominated by creosote bush (*Larrea tridentata*) and white bursage (*Ambrosia dumosa*). Cheese bush (*Hymenoclea salsola*), desert needlegrass (*Achnatherum speciosum*), and Indian ricegrass (*Achnatherum hymenoides*) were also common where soils were deeper near washes.

The southern site ranged from 470 m to 740 m, was southwest-facing with 0–3% slope, and was primarily composed of sandy alluvial soils less than 30 cm deep over a granitic pediment (Valverde and Hill 1981). The perennial plant community at the southern site was similar to the northeastern site except that washes were wider and were dominated by allscale (*Atriplex polycarpa*) and cheese bush.

#### Field Methods

I established permanent survey areas within the outside and inside plots at each of the two study sites. After randomly determining which of the four plots to survey first, the matched plot was visited on the next sampling day. Censuses were conducted on consecutive days of relatively calm and clear weather to minimize



**Figure 2.** Average number of birds per point-count station ( $+1$  SE) inside (unshaded) and outside (shaded) the NE and S sites at the Desert Tortoise Research Natural Area. Dissimilar letters only appear above bars that are significantly different within sample periods ( $P \leq 0.05$ ; ANOVA, type III sums of squares).

variation within sample periods due to environmental conditions (David 1981, Dawson 1981a). Each bird survey area contained a  $4 \times 4$  array of 16 point-count stations, separated by 400 m from adjacent stations (Figure 1). Because birds in this habitat are rarely seen beyond 50 m, or heard beyond 100 m, the probability of counting the same individual at different stations was minimized by spacing the stations 400 m apart. Bird were surveyed 9–16 May and 5–8 July 1994, and 20–23 May and 1–4 July 1995. The dates roughly correspond to the beginning and end of the breeding season during each year. Surveys were also conducted in the winter on 4–11 December 1994 and 2–5 January 1996. Surveys began when the morning sun first appeared on the horizon, and continued for approximately 2.5 h. Each point-count station was sampled for 5 min, during which time the number of birds that were either heard or seen occupying the surrounding area were recorded. Birds in flight were not recorded unless they landed within visual range. Morning censuses provide the most accurate estimates of bird abundance and diversity

Table 2. Repeated-measures ANOVA of bird species at the Desert Tortoise Research Natural Area

	Source of variation							
	Breeding season				Wintering season			
	<i>df</i>	MS	<i>F</i> <sup>a</sup>	<i>P</i> <sup>b</sup>	<i>df</i>	MS	<i>F</i>	<i>P</i>
NE site								
Between subject								
Protection <sup>c</sup>	1	1.3644	<b>14.31</b>	<b>0.0007</b>	1	0.0065	0.09	0.7707
Error	30	2.8551			30	0.0752		
Within subject								
Sample period	3	1.4930	<b>14.28</b>	<b>0.0001</b>	1	0.2201	2.37	0.1341
Sample period × protection	3	0.5954	<b>5.69</b>	<b>0.0014</b>	1	0.0079	0.09	0.7719
Error	90	0.1046			30	0.0928		
S site								
Between subject								
Protection	1	1.2218	<b>18.76</b>	<b>0.0002</b>	1	0.4242	<b>5.17</b>	<b>0.0303</b>
Error	30	0.0651			30	0.0821		
Within subject								
Sample period	3	1.9443	<b>15.02</b>	<b>0.0001</b>	1	0.4353	<b>4.31</b>	<b>0.0465</b>
Sample period × protection	3	0.0383	<b>0.30</b>	<b>0.0014</b>	1	0.0179	0.18	0.6771
Error	90	0.1294			30	0.1010		

<sup>a</sup>Type III sums of squares were used to determine *F* values and significant effects are in bold type ( $P \leq 0.05$ ).

<sup>b</sup>Within-subjects *P* values for the breeding season were Huynh-Feldt corrected.

<sup>c</sup>Protection was a fixed factor with two levels, inside and outside the DNTA.

within desert-scrub habitat, and most species present in the morning are also present in the evening (Grue and others 1981). Active nesting activity was recorded and bird nomenclature followed Scott (1987).

Lizard survey areas each contained six 1200-m transects partially overlapping the bird survey areas (Figure 1). Transects were oriented parallel to the elevation contour and separated from adjacent transects by 400 m within each study plot. Lizards were surveyed 9–12 July 1994, and 20–24 May and 1–4 July 1995. Surveys began at 09:00 h PST and continued until approximately 11:00 h. Lizard nomenclature followed Stebbins (1985).

Abundance of black-tailed hares was estimated by two methods. One estimate involved counting the total number of hares seen along the four 1250-m lizard transects that directly overlapped the bird survey grids (Figure 1). Hares were surveyed 9–16 May and 5–8 July 1994. Data from a December 1994 survey were not included in the analyses because no hares were sighted. A second estimate was derived from counts of fecal pellets made at the northeastern site during a separate study of annual plants (M. Brooks unpublished data). After all annual plants were clipped at the surface of the soil and removed, I counted the number of intact fecal pellets within a 40 × 50-cm sampling frame, 120 frames inside and 120 outside the DTNA. Broken fragments of pellets were not counted. This method assumed that the number of fecal pellets correlated positively with the

time spent by black-tailed hares in a particular area. I recorded fecal pellet counts 15–25 April 1994 and 18–26 April 1995. I also evaluated the relative abundance of black-tailed hares qualitatively by recording the frequency of signs of their presence from 1989 through 1995. These signs included: (1) clipped and trampled dead annual plant stalks (forms) accompanied by piles of fecal droppings beneath creosote bush shrubs, (2) trails or runs (~13 cm wide) crossing intershrub spaces, (3) depressions filled with fine dust used as resting sites and for dusting off parasites, and (4) clipped ends from creosote bush shrubs lying on the ground beneath the outer edge of shrub canopies (Jaeger 1961).

I used the point-quarter technique to determine cover, height, volume, and diversity of the perennial plant community in June 1995 (Greig-Smith 1964), recording measurements at each station in the 4 × 4 grid of bird sampling points (Figure 1). Plant nomenclature followed Hickman (1993).

Rainfall data were obtained from two US National Oceanic and Atmospheric Administration weather stations, one 21 km northwest of the study site in Randsburg (60 years of data) and the other 40 km southwest in Mojave (95 years of data) (US National Oceanic and Atmospheric Administration 1994). I used linear distance-weighted averages of monthly precipitation at each station to approximate long-term average conditions at the DTNA.

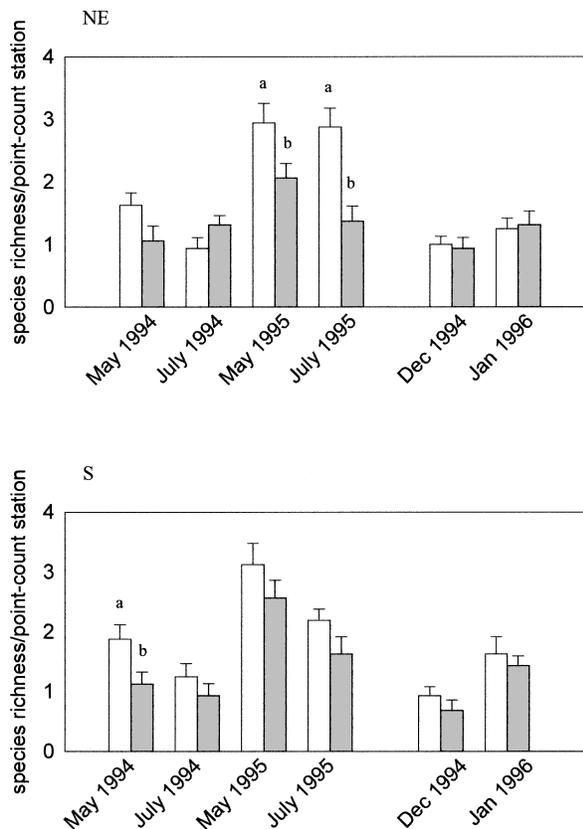
### Data Analyses

Average numbers of individuals and species were used as indices of vertebrate abundance and species richness. Indices such as these, rather than absolute values, are sufficient for determining relative differences between areas (Bull 1981, Dawson 1981b). However, the probability of detection may have been affected by the amount of perennial plant cover (Dawson 1981a), and because cover was lower outside than inside the DTNA (Brooks 1995), vertebrates may have been easier to detect outside. Although this potential bias may reduce confidence in results that indicate higher abundance and species richness outside, it can only increase confidence in results that show higher values inside the DTNA.

Raw data from bird point-counts, lizard transects, and black-tailed hare transects were nonnormal and heteroscedastic, so each datum was increased by 0.5 and square-root transformed before using parametric statistics (Sokal and Rohlf 1995). The frequency distribution of the data better approximated a normal distribution and became less heteroscedastic following transformation. Total abundance and species richness of birds and lizards were analyzed by repeated-measure analysis of variance (rmANOVA) with one fixed effect, protection, analyzed over repeated sample periods (Sokal and Rohlf 1995). Individual bird and lizard species were also analyzed by rmANOVA. Within-sample-period *P* values of all rmANOVA analyses were Huyhn-Feldt corrected (Huyhn and Feldt 1976). I analyzed fecal pellet data using the nonparametric Mann-Whitney rank sum test because they were highly skewed and heteroscedastic and transformation did not change these characteristics.

Perennial plant cover was calculated assuming circular canopies ( $A = \pi r^2$ ) where *r* was the average canopy radius of the major axis and the axis 90° apart from it. I calculated volume using the formula for a spheroid ( $V = 4/3\pi ab^2$ ) where *a* was the average canopy diameter of the major axis and the axis 90° apart from it and *b* was the height, which in all cases was less than the cover diameter. Height, cover, and volume classes of perennial plants were determined by inspection of their frequency distributions, and corresponded to clumping of the data around points along the continuum. Structural and species diversities of perennial plants were calculated using the Shannon-Weiner index ( $H = -\sum p_i \ln p_i$ ) (Magurran 1988). Effects of protection on shrub diversity and cover were analyzed using the Mann-Whitney rank sum test (Sokal and Rohlf 1995).

Abundances of individual bird and lizard species were reported in the text when the one-tailed signifi-



**Figure 3.** Average bird species richness per point-count station (+1 SE) inside (unshaded) and outside (shaded) the NE and S sites at the Desert Tortoise Research Natural Area. Dissimilar letters only appear above bars that are significantly different within sample periods ( $P \leq 0.05$ ; ANOVA, type III sums of squares).

cance level of the difference due to protection was  $P \leq 0.10$ , but the general level of statistical significance for all tests was  $P \leq 0.05$ . Analyses were performed using SAS/STAT statistical software (SAS Institute 1988). Untransformed means and standard errors were reported in the text, tables, and figures.

### Results

During the first year of this study, winter rainfall was 50% of average from November 1993 through April 1994. During the second year, rainfall was 200% of average from November 1994 through April 1995 (US National Oceanic and Atmospheric Administration 1993, 1994, 1995).

#### Birds

Twenty-two bird species were observed, one that was only found inside at the northeastern site, six that were only found inside at the southern site, and two that were

Table 3. Repeated-measures ANOVA of lizard abundance and species richness at the Desert Tortoise Research Natural Area

	Source of variation						
	Total abundance				Species richness		
	<i>df</i>	MS	<i>F</i> <sup>a</sup>	<i>P</i> <sup>b</sup>	MS	<i>F</i>	<i>P</i>
NE site							
Between subject							
Protection <sup>c</sup>	1	3.3203	<b>20.98</b>	<b>0.0010</b>	0.3785	4.66	0.0563
Error	10	0.1583			0.0813		
Within subject							
Sample period	2	5.4932	<b>27.86</b>	<b>0.0001</b>	0.0954	1.90	0.1763
Sample period × protection	2	0.4039	2.05	0.1551	0.0223	0.44	0.6479
Error	20	0.1971			0.0503		
S site							
Between subject							
Protection	1	3.2210	<b>23.77</b>	<b>0.0006</b>	0.2129	2.68	0.1329
Error	10	1.3550			0.7952		
Within subject							
Sample period	2	2.2158	<b>9.25</b>	<b>0.0022</b>	0.5722	<b>14.66</b>	<b>0.0001</b>
Sample period × protection	2	0.6695	2.79	0.0918	0.0274	0.70	0.5076
Error	20	0.2396			0.0390		

<sup>a</sup>Type III sums of squares were used to determine *F* values and significant effects are in bold type ( $P \leq 0.05$ ).

<sup>b</sup>Within-subjects *P* values for the breeding season were Huynh-Feldt corrected.

<sup>c</sup>Protection was a fixed factor with two levels, inside and outside the DTNA.

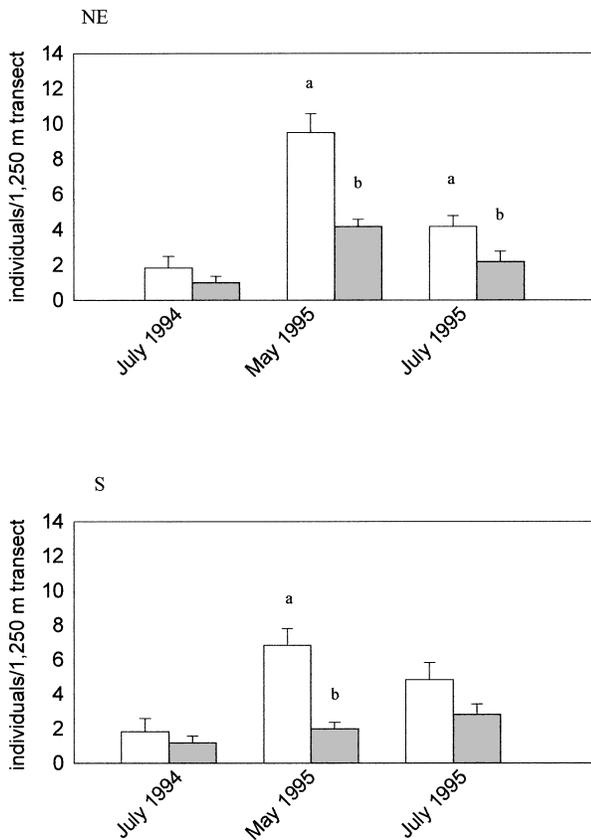
only found outside at the southern site (Appendix 1). Protection and sample period significantly affected total bird abundance at both sites and the level of significance was higher during the breeding than the wintering season (Table 1). Abundance was higher inside than outside the DTNA, particularly during the breeding season at the northeastern site, and during the second compared to the first year of this study (Figure 2). Patterns of bird abundance were similar among sites, and there were no significant interactions between site and protection or site and sample period. Only a few species at each site displayed significant effects of protection, but all were more abundant inside than outside the DTNA. At the northeastern site, sage sparrow (*Amphispiza belli*) abundance was 222% higher inside (inside =  $3.30 \pm 0.71$ , outside =  $1.49 \pm 0.59$ ,  $F_{1,30} = 22.44$ ,  $P < 0.0001$ ), LeConte's thrasher (*Toxostoma lecontei*) abundance was 317% higher inside (inside =  $0.19 \pm 0.07$ , outside =  $0.06 \pm 0.04$ ,  $F_{1,30} = 9.56$ ,  $P < 0.0043$ ), and loggerhead shrike (*Lanius ludovicianus*) abundance was 367% higher inside (inside =  $0.11 \pm 0.07$ , outside =  $0.03 \pm 0.03$ ,  $F_{1,30} = 3.17$ ,  $P < 0.0851$ ). At the southern site, sage sparrow abundance was 163% higher inside (inside =  $3.37 \pm 0.64$ , outside =  $2.07 \pm 0.56$ ,  $F_{1,30} = 7.86$ ,  $P < 0.0119$ ), verdin (*Auriparus flaviceps*) abundance was 200% higher inside (inside =  $0.22 \pm 0.08$ , outside =  $0.11 \pm 0.05$ ,  $F_{1,30} = 4.23$ ,  $P < 0.0486$ ), and ash-

throated flycatcher (*Myiarchus cinerascens*) abundance was 700% higher inside (inside =  $0.07 \pm 0.05$ , outside =  $0.01 \pm 0.01$ ,  $F_{1,30} = 5.06$ ,  $P < 0.0319$ ). Cactus wrens (*Campylorhynchus brunneicapillus*) were only found inside the DTNA at the southern site, but the difference was only marginally significant due to a small sample size (inside =  $0.04 \pm 0.03$ , outside =  $0.00 \pm 0.00$ ,  $F_{1,30} = 3.19$ ,  $P < 0.0843$ ).

Protection and sample period also affected species richness of birds at both study sites, and the level of significance was more significant during the breeding than the wintering season (Table 2). Species richness was generally higher inside than outside the DTNA during the breeding at both sites (Figure 3). The significant sample period × protection interaction during the breeding season (Table 2) reflected 200% higher species richness during 1995 than 1994 (Figure 3). Patterns of bird species richness were similar among sites, and there were no significant interactions between site and protection or site and sample period. Anna's hummingbirds (*Calypte anna*), ash-throated flycatchers, cactus wrens, loggerhead shrikes, and verdins were all observed on at least one occasion nesting inside the DTNA, whereas only verdins were seen nesting outside.

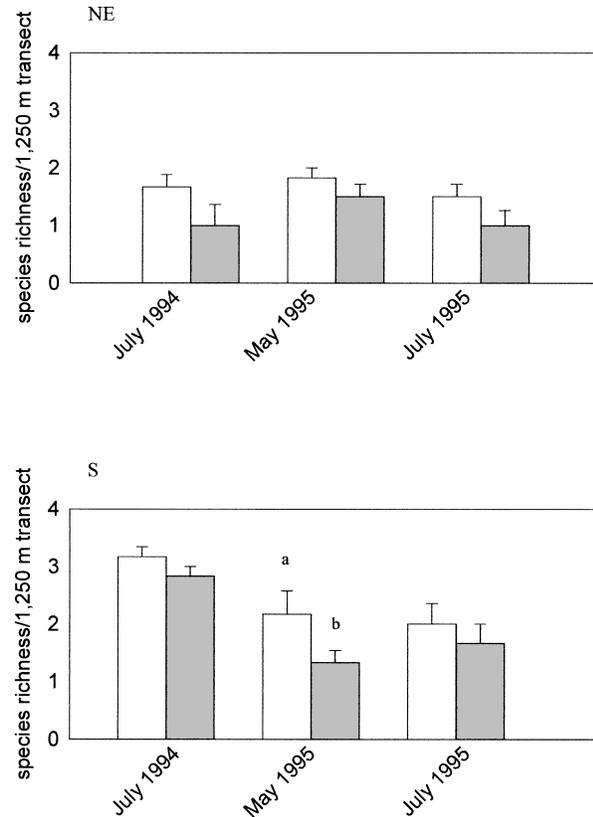
#### Lizards

Six lizard species were observed, one that was only found inside the DTNA (Appendix 2). Protection and



**Figure 4.** Average number of lizards per transect (+1 SE) inside (unshaded) and outside (shaded) the NE and S sites at the Desert Tortoise Research Natural Area. Dissimilar letters only appear above bars that are significantly different within sample periods ( $P \leq 0.01$ ; ANOVA, type III sums of squares).

sample period significantly affected total lizard abundance at both sites, whereas species richness was only marginally affected at the northeastern site (Table 3). There were no significant interactions between sample period and protection, site and protection, or site and sample period. Abundance of lizards was higher inside than outside the DTNA at both study sites (Figure 4). At the northeastern site, western whiptail (*Cnemidophorus tigris*) abundance was 200% higher inside (inside =  $4.00 \pm 0.54$ , outside =  $2.00 \pm 0.49$ ,  $F_{1,10} = 18.02$ ,  $P < 0.0017$ ) and desert spiny lizards (*Sceloporus magister*) were only found inside (inside =  $0.22 \pm 0.14$ , outside =  $0.00 \pm 0.00$ ,  $F_{1,10} = 4.00$ ,  $P < 0.0734$ ). At the southern site, western whiptail abundance was 205% higher inside (inside =  $3.18 \pm 0.53$ , outside =  $1.55 \pm 0.40$ ,  $F_{1,10} = 21.83$ ,  $P < 0.0009$ ). Although overall species richness of lizards was generally higher inside than outside the DTNA (Figure 5), levels of significance were weak (Table 3).



**Figure 5.** Average lizard species richness per transect (+1 SE) inside (unshaded) and outside (shaded) the NE and S sites at the Desert Tortoise Research Natural Area. Dissimilar letters only appear above bars that are significantly different within sample periods ( $P \leq 0.01$ ; ANOVA, type III sums of squares).

#### Black-Tailed Hares

Abundance of black-tailed hares estimated from transect surveys (Table 4, Figure 6) and fecal pellet counts (Figure 7) were both significantly higher outside than inside at both study sites. Signs of black-tailed hare presence such as forms, runs, dusting-off sites, and clipped ends of creosote bushes suggested a similar trend.

#### Perennial Plant Community Structure

Height of perennial plants was separated into three classes: (1) less than 60 cm [white bursage, goldenhead (*Acemtopappus sphaerocephalus*), and cheese bush]; (2) between 60 and 140 cm (creosote bush, cheese bush, and allscale); and (3) greater than 140 cm (creosote bush). Cover of perennial plants was also separated into three classes: (1) less than 1000 cm<sup>2</sup> (white bursage and goldenhead); (2) between 1000 and 5000 cm<sup>2</sup> (white bursage, cheese bush, and goldenhead); and (3) greater than 5000 cm<sup>2</sup> (creosote bush, cheese bush, allscale, and white bursage). Volume of perennial plants was

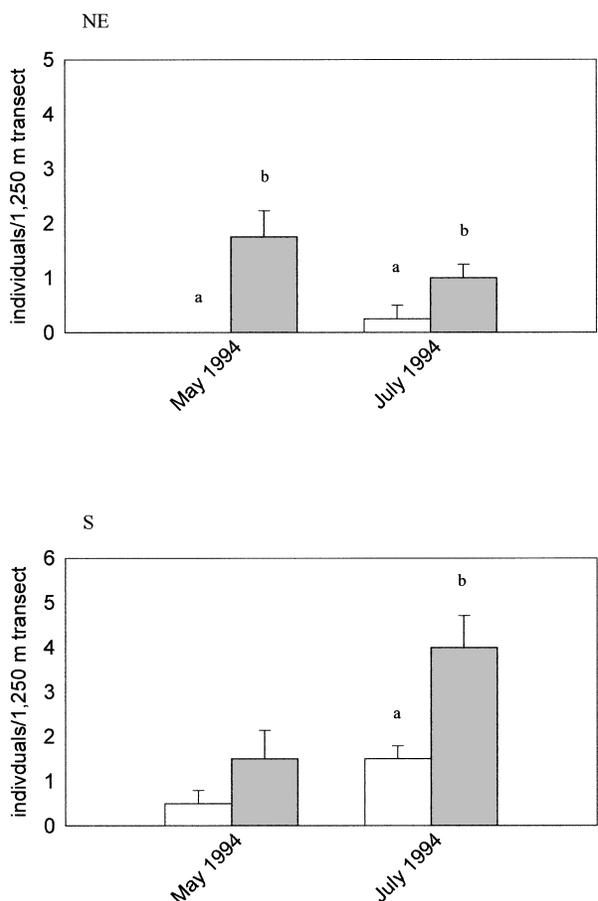
Table 4. Repeated-measures ANOVA of black-tailed hare abundance at the Desert Tortoise Research Natural Area

	<i>df</i>	Source of variation					
		NE site			S site		
		MS	<i>F</i> <sup>a</sup>	<i>P</i> <sup>b</sup>	MS	<i>F</i>	<i>P</i>
Between subject							
Protection	1	1.2459	<b>50.75</b>	<b>0.0004</b>	1.1669	<b>6.64</b>	<b>0.0419</b>
Error	6	0.0246			0.1757		
Within subject							
Sample period	2	0.0261	0.21	0.6608	1.4261	<b>21.27</b>	<b>0.0036</b>
Sample period × protection	2	0.1769	1.44	0.2751	0.1025	1.53	0.2625
Error	6	0.1226			0.0670		

<sup>a</sup>Type III sums of squares were used to determine *F* values and significant effects are in bold type ( $P \leq 0.05$ ).

<sup>b</sup>Within-subjects *P* values for the breeding season were Huynh-Feldt corrected.

<sup>c</sup>Protection was a fixed factor with two levels, inside and outside the DNTA.



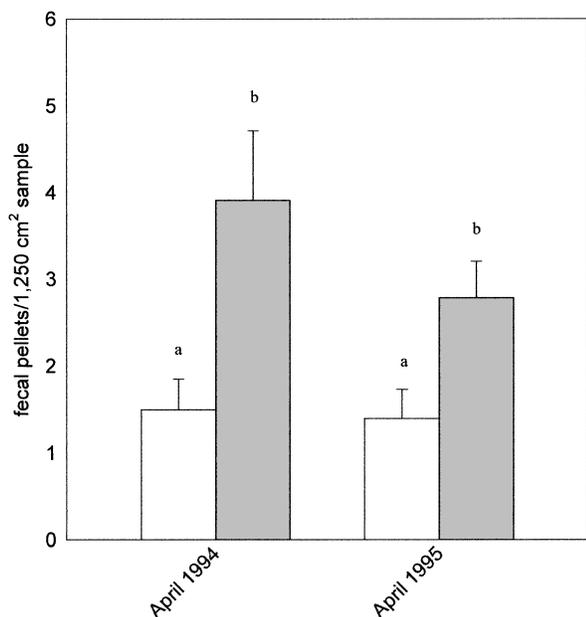
**Figure 6.** Average number of black-tailed hares per 1200-m transect (+1 SE) inside (unshaded) and outside (shaded) the NE and S sites at the Desert Tortoise Research Natural Area. Dissimilar letters only appear above bars that are significantly different within sample periods ( $P \leq 0.01$ ; ANOVA, type III sums of squares).

separated into four classes: (1) less than 0.2 m<sup>3</sup> (white bursage and goldenhead); (2) between 0.2 and 0.5 m<sup>3</sup> (white bursage, cheese bush, and goldenhead); (3) between 0.5 and 1.0 m<sup>3</sup> (white bursage and cheese bush); and (4) greater than 1.0 m<sup>3</sup> (creosote bush, cheese bush, and allscale). Diversity in species composition, height, cover, and volume of perennial plants were not significantly affected by protection (Table 5). Percent cover was the only component of the perennial plant community that was significantly affected by protection, with approximately 50% higher values inside than outside the DTNA.

## Discussion

Protection resulted in higher abundance and species richness of birds and lizards, but lower abundance of black-tailed hares. Two bird species that were more abundant inside than outside the DTNA are listed as Species of Special Concern in California, the LeConte's thrasher and loggerhead shrike (Natural Diversity Database, California Department of Fish and Game 1997). Thus, protection at the DTNA has been of benefit to bird and lizard communities in general and individual Species of Special Concern in particular, but absence of protection has benefited only one species, the black-tailed hare.

Effects of protection were similar during the two years of this study, although rainfall varied greatly. Effects of protection were also similar at the two study sites, although they represented extremes in elevation, physical distance, perennial plant community type, and edaphic conditions typically encountered at the DTNA. Although intermediate levels of rainfall and habitat types were not sampled, I believe the results of this study



**Figure 7.** Average number of fecal pellets from black-tailed hares per 1250 cm<sup>2</sup> (+1 SE) inside (unshaded) and outside (shaded) the NE site at the Desert Tortoise Research Natural Area. Dissimilar letters only appear above bars that are significantly different within sample periods ( $P \leq 0.01$ ; Mann-Whitney U test,  $N = 120$  for each group).

can be generalized to other rainfall years and locations within the DTNA, and possibly elsewhere in the Mojave Desert where similar rainfall, disturbance, and plant community characteristics occur.

Effects of protection on bird abundance and richness were stronger during the breeding than the wintering season and during a year of high compared to low rainfall. Birds were also more abundant inside than outside a livestock enclosure during breeding than wintering seasons in the Chihuahuan Desert (Bock and others 1984, Bock and Webb 1984). Food may become limiting sooner outside than inside these enclosures as density and species richness of birds increase. Simultaneous monitoring of food and bird abundance is needed to test this hypothesis. Alternatively, effects of protection may be more apparent when livestock are present. Breeding seasons and high rainfall years correspond to peaks in ephemeral forage, and livestock grazing is most intense during these times. In either case, effects of protection seem to be strongest when abundance and diversity of birds are highest.

Density, diversity, and breeding activity of most desert bird species decrease in response to livestock grazing (Bock and others 1984, Bock and Webb 1984) and OHV use (Harmata and others 1978, Luckenbach

1978), but the opposite may also occur. In arid grasslands, abundances of horned larks (*Eremophila alpestris*) and mourning doves (*Zenaida aurita*) were higher where livestock grazing reduced plant cover (Bock and others 1984, Bock and Webb 1984). These birds generally prefer open areas for feeding on seeds (Baeppler 1968, Leopold 1972, Terres 1980) and are well adapted for nesting on bare ground (Ryder 1980). Horned larks in particular were more abundant in arid grasslands where livestock grazing had decreased plant cover and increased habitat patchiness (Wiens 1973, Ryder 1980). Horned larks are considered an indicator species for the presence of grazing in arid grasslands (Ryder 1980, Bock and Webb 1984), but this relationship may not occur in arid shrublands where undisturbed plant communities already have low cover and high heterogeneity (Ryder 1980).

Although horned larks and mourning doves were present at the DTNA, their abundance was unaffected by fenced protection. There was much less plant cover at the DTNA compared to arid grasslands, and the higher shrub cover inside (13%–15%) than outside (6%–7%), although statistically significant, may have been ecologically insignificant to some birds. The preference of some birds for open ground may have been counterbalanced by their need for seeds that were more abundant inside (Brooks 1995). The potential trade-off between habitat structure and food availability may also explain the high densities of Merriam's kangaroo rats found inside the DTNA. Like horned larks and mourning doves, Merriam's kangaroo rats prefer open habitat (Reynolds 1958, Price 1978), and feed almost exclusively on seeds (French and others 1974, Price and Jenkins 1986). Seedbank biomass may therefore be a better indicator of habitat quality for granivorous vertebrates than perennial plant cover in the Mojave Desert. These conclusions emphasize the need to conduct community studies that transcend trophic levels when investigating the effects of human disturbances on plants and animals.

Biomass, density, or diversity of desert lizard communities typically decreases (Busack and Bury 1977, Jones 1981, Webb and Wilshire 1983), but can increase (Vitt and Ohmart 1974, Jones 1981) in response to livestock grazing and OHV use. Some lizard species appear to benefit from livestock grazing if the resulting vegetation structure reduces resource competition (Vitt and Ohmart 1974, Jones 1981). However, these potential benefits seem small compared to the variety of ways that anthropogenic disturbances can adversely affect lizard communities. For example, reptiles and their burrows can be

Table 5. Perennial plant community characteristics at the Desert Tortoise Research Natural Area

	Species diversity ( <i>H</i> ) <sup>a</sup>	Height diversity ( <i>H</i> )	Cover diversity ( <i>H</i> )	Volume diversity ( <i>H</i> )	Cover (%)	Dominant species (>50% relative cover)	Codominant species (>10% relative cover)
NE site							
Inside	0.84ab (0.09)	0.34a (0.10)	0.81a (0.06)	0.84a (0.09)	14.46a (2.60)	<i>Larrea tridentata</i>	<i>Ambrosia dumosa</i>
Outside	0.83a (0.07)	0.42a (0.07)	0.78a (0.07)	0.87a (0.10)	6.38b (1.45)	<i>Larrea tridentata</i>	<i>Hymenoclea salsola</i>
S site							
Inside	0.78a (0.08)	0.40a (0.10)	0.60b (0.09)	0.62a (0.09)	12.77a (2.33)	<i>Larrea tridentata</i>	<i>Atriplex polycarpa</i> <i>Hymenoclea salsola</i>
Outside	0.76a (0.10)	0.48a (0.10)	0.62b (0.09)	0.65a (0.10)	7.24b (1.42)	<i>Larrea tridentata</i>	<i>Atriplex polycarpa</i>

<sup>a</sup>Shannon-Weiner diversity index  $H = -\sum p_i \ln p_i$ .

<sup>b</sup>Dissimilar letters indicate significant ( $P \leq 0.05$ ) Mann-Whitney rank sum test between pairwise combinations of the four cells within each column. Standard errors are in parentheses.

crushed by OHVs (Wilshire 1983) and livestock (Nicholson and Humphreys 1981, Berry and others 1990), and the presence of vehicles typically results in lower reptile densities caused by disruption of their behavioral patterns and by direct mortalities (Berry and others 1990, Boarman and others 1993, Rosen and Lowe 1994).

Western whiptail lizards were significantly more abundant in ungrazed than grazed Sonoran desert-scrub (Jones 1981) and inside than outside the DTNA. The vast majority of this species' diet consists of invertebrates, and western whiptails spend most of their time in areas where invertebrates are abundant (Vitt and Ohmart 1977), suggesting that their higher abundance inside the DTNA may be in response to availability of prey. Although invertebrate abundance was not quantified at the DTNA, arthropods were 24 times less abundant in areas of OHV use compared to controls in the Sonoran Desert (Luckenbach and Bury 1983), and their abundance and species diversity were significantly reduced by livestock grazing in other ecosystems (Morris 1968, Gibson and others 1992). Shade provided by perennial plants benefit desert invertebrates by protecting them from solar radiation (Larmuth 1979, Smith and others 1987), and the 50% higher perennial plant cover found inside the DTNA may be associated with higher abundance of invertebrates. Invertebrates often use the burrows of other animals to aid their reentry into the soil (Crawford 1991), and damage to these burrows by livestock and OHVs may decrease abundance of invertebrates outside the DTNA. Western whiptail lizards use a significant portion of their energy foraging across large areas, and if more energy is used searching for food, then less remains for reproduction (Jones 1981). If this is true, then abundance of western whiptail lizards may be a good indicator of invertebrate abundance in the Mojave Desert.

In contrast to bird and lizard communities, abundance of black-tailed hares was lower inside than outside the DTNA, and this pattern is consistent with other studies in North America. Black-tailed hares were more abundant in grazed than ungrazed grasslands in Oklahoma (Phillips 1936), and the number of fecal pellets from hares was 200% higher in grazed than ungrazed desert grassland in Arizona (Vorhies and Taylor 1933). Areas grazed by livestock in the Arizona study had lower cover of perennial shrubs and grasses than ungrazed areas, similar to the DTNA. Black-tailed hares are often found close to human habitations and they preferentially feed on early successional plants (Vorhies and Taylor 1933) that are generally more abundant outside the DTNA (Brooks 1995). Black-tailed hares may have also benefited from the more open habitat present outside the DTNA, allowing them to detect predators from a distance and more easily elude them.

I found no significant effects of protection on diversities of perennial plant height, cover, or volume. Bird and lizard communities may be less affected by structural diversity of woody plants in deserts than in more mesic ecosystems (Jones 1981, Krebs 1985, Wiens 1991). Fifteen years of fenced protection at the DTNA seems to have been insufficient to exhibit differences in structural diversity of perennial plants but apparently was sufficient to affect abundance and species richness of bird and lizard communities. However, another aspect of perennial plant structure may have contributed to the effects of fencing on vertebrate communities. As creosote bush branches die, they create piles of dead branches on the ground beneath them that create additional shade from high mid-day temperatures and provide additional perching and foraging areas. This habitat structure may be particularly important for

arboreal lizards such as desert spiny lizards (Vitt and Ohmart 1974), sit-and-wait predators such as side-blotched lizards (*Uta stansburiana*) that often survey their foraging area from elevated perches (Rundel and Gibson 1996), and widely foraging species such as western whiptail lizards that often climb into the lower branches of woody shrubs during the summer in search of prey (Vitt and Ohmart 1977). Dead branches are much less common beneath creosote bushes outside than inside the DTNA (M. Brooks personal observation), and this may be caused by sheep that excavate pits beneath creosote bushes and OHVs that drive through and destroy shrub branches (Berry and others 1990).

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### Appendix 1. Birds observed at NE and S study sites<sup>a</sup>

	NE	S		NE	S
Alaudidae			Parulidae		
Horned lark ( <i>Eremophila alpestris</i> )	x	x	Orange-crowned warbler ( <i>Vermivora celata</i> )		x <sup>1</sup>
Columbidae			Townsend's warbler ( <i>Dendroica occidentalis</i> )		x <sup>1</sup>
Mourning dove ( <i>Zenaidura macroura</i> )	x	x	Verdin ( <i>Auriparus flaviceps</i> )	x	x
Cuculidae			Wilson's warbler ( <i>Wilsonia pusilla</i> )	x	
Greater roadrunner ( <i>Geococcyx californicus</i> )		x <sup>O</sup>	Strigidae		
Fringillidae			Burrowing owl ( <i>Athene cunicularia</i> )	x	x
Black-throated sparrow ( <i>Amphispiza</i> <i>quinquestrata</i> )	x	x	Sylviidae		
Brewer's sparrow ( <i>Spizella breweri</i> )		x <sup>1</sup>	Blue-gray gnatcatcher ( <i>Poliophtila caerulea</i> )		x <sup>1</sup>
House finch ( <i>Carpodacus mexicanus</i> )	x	x <sup>O</sup>	Trochilidae		
Sage sparrow ( <i>Amphispiza belli</i> )	x	x	Anna's hummingbird ( <i>Calypte anna</i> )	x <sup>1</sup>	x <sup>1</sup>
White-crowned sparrow ( <i>Zonotrichia leucophrys</i> )	x	x	Costa's hummingbird ( <i>Calypte costae</i> )		x <sup>1</sup>
Icteridae			Troglodytidae		
Hooded oriole ( <i>Icterus pustulatus</i> )		x	Cactus wren ( <i>Campylorhynchus bunneicapillus</i> )		x
Western meadowlark ( <i>Sturnella neglecta</i> )		x	Tyrannidae		
Laniidae			Ash-throated flycatcher ( <i>Myiarchus</i> <i>cinerascens</i> )	x	x
Loggerhead shrike ( <i>Lanius ludovicianus</i> )	x	x			
Mimidae					
LeConte's thrasher ( <i>Toxostoma redivivum</i> )	x	x			

<sup>a</sup>Superscripts indicate species that were only found inside (I) or outside (O) the DTNA at each study site.

### Appendix 2. Lizards observed at the north-eastern NE and S study sites

	NE	S
Iguanidae		
Desert horned lizard ( <i>Phrynosoma platyrhinos</i> )	x	x
Desert spiny lizard ( <i>Sceloporus magister</i> )	x <sup>a</sup>	
Long-nosed leopard lizard ( <i>Gambelia wislizenii</i> )	x	x
Side-blotched lizard ( <i>Uta stansburiana</i> )	x	x
Zebra-tailed lizard ( <i>Callisaurus draconoides</i> )	x	x
Teiidae		
Western whiptail lizard ( <i>Cnemidophorus tigris</i> )	x	x

<sup>a</sup>Species was found only inside the DTNA.

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