

# Benefits of Protective Fencing to Plant and Rodent Communities of the Western Mojave Desert, California

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**ABSTRACT** / Human disturbance in the western Mojave Desert takes many forms. The most pervasive are livestock grazing and off-highway vehicle use. Over the past few decades several areas within this region have been fenced to preclude human disturbance. These areas provide opportunities to study the impact of human activities in a desert ecosystem. This paper documents the response of plant and small mammal populations to fencing constructed between 1978 and 1979 at the Desert Tortoise Research Natural Area, Kern County, California.

Aboveground live annual plant biomass was generally greater inside than outside the fenced plots during April 1990, 1991, and 1992. The alien grass *Schismus barbatus* was a notable exception, producing more biomass in the

unprotected area. Forb biomass was greater than that of alien annual grasses inside the fence during all three years of the study. Outside the fence, forb biomass was significantly higher than that of alien grasses only during spring 1992. Percent cover of perennial shrubs was higher inside the fence than outside, while no significant trend was detected in density. There was also more seed biomass inside the fence; this may have contributed to the greater diversity and density of Merriam's kangaroo rats (*Dipodomys merriami*), long-tailed pocket mice (*Chaetodipus formosus*), and southern grasshopper mice (*Onychomys torridus*) in the protected area.

These results show that protection from human disturbance has many benefits, including greater overall community biomass and diversity. The significance and generality of these results can be further tested by studying other exclosures of varying age and configurations in different desert regions of the southwestern United States.

Several sources of human disturbance are widespread throughout North American deserts. One major form is livestock grazing, which can reduce diversity, cover, and biomass of native annual and perennial vegetation (Gardner 1950, Blydenstein and others 1957, Pearson 1965, Potter and Krenetsky 1967, Waser and Price 1981, Belsky 1986). Webb and Stielstra (1979) showed that sheep grazing reduced annual plant density and biomass and perennial plant cover and volume in the western Mojave Desert. Extended overgrazing can lead to community degradation as diverse native plant communities become displaced by less diverse communities (Waser and Price 1981) dominated by exotic grazing-adapted plants (Mack 1981, 1986, D'Antonio and Vitousek 1992). Another source of human disturbance is off-highway vehicle (OHV) use (Stebbins 1974a,b, Luckenbach 1975, Webb and Wilshire 1983), which has steadily increased since the 1960s (Adams and others 1982).

**KEY WORDS:** Sheep grazing; Mojave Desert; Off-highway vehicles; Rodents; *Schismus barbatus*; Succession

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Significantly less Mojave Desert plant cover (Davidson and Fox 1974) and density (Vollmer and others 1976) appear in areas frequented by OHVs compared to control plots.

Grazing and OHVs not only destroy plants directly but also impair seedling establishment by altering the soil (Klemmedson 1956, Wilshire and Nakata 1976, Webb and Stielstra 1979, Adams and others 1982). The time required for recovery is closely tied to changes in soil characteristics, such as bulk density and water retention (Anderson and Holte 1981, West and others 1984, Daddy and others 1981). Soil compaction increased by OHV use and livestock trampling can increase bulk density, making it difficult for seedling roots to penetrate (Grimes and others 1975, 1978) and reduce the infiltration rate of water (Dadkhah and Gifford 1980, Weltz and others 1989).

As producers, plants are important to other organisms higher up the trophic pyramid. Their relationship with desert rodents is a good example. Rodent population densities are correlated positively with yearly variations in primary plant productivity (Hafner 1977, Munger and others 1983, Brown 1987, Brown and Zeng 1989). Species composition also varies with plant density, diversity, and cover (Rosenz-

weig and Winakur 1969, Rosenzweig 1973, Beatley 1976, Price 1978, Munger and others 1983, Price and Waser 1984). Rodents are heavily dependent upon plant seed production for food (Reynolds 1958, French and other 1974, Price and Jenkins 1986) and metabolic water (Vaughan 1986), and densities respond positively to seed bank augmentation (Brown and Munger 1985). The abundance of green vegetation also affects desert rodent fitness (Bradley and Mauer 1971, Van De Graaff and Balda 1973, Reichman and Van De Graaff 1973, French and others 1974, Grant and others 1982). Even if human disturbance has no direct impact, changes in the availability of green vegetation and seeds should affect rodent populations.

The Desert Tortoise Research Natural Area (DTRNA) was originally created to protect the local population of desert tortoises (*Gopherus agassizii*) from human disturbance. I was specifically interested in determining the effects of protective fencing upon the biomass and diversity of the plant community and its associated seed bank. I hypothesized that fencing could affect plants either positively or negatively since some weedy species may benefit from the disturbed condition of the unfenced area. In addition, I predicted that rodent densities and diversity would correlate positively with seedbank production and annual plant biomass.

## Methods

### Study Site

The study area is in the western Mojave Desert at the DTRNA, located adjacent to California City, Kern County, California. Sheep have grazed in the western Mojave Desert, including the area of the DTRNA, since the mid 1800s (US Bureau of Land Management 1980). The land bordering the DTRNA also experiences continued off-highway vehicle (OHV) use (Campbell 1981, 1982, Uptain 1987). Although initiated in 1972, the DTRNA did not receive formal designation until 1980, and perimeter fencing was not constructed until 1978–1979. Trespass onto the reserve has been infrequent near the study plots since fencing (Kristin Berry personal communication). I observed sheep grazing outside the DTRNA during early April 1991, but not during 1990 or 1992, and OHVs were seen periodically throughout the course of the study.

The DTRNA lies within climatic zone I1 (Hickman 1993). Encompassing most of the medium to high deserts of California, this zone is typified by wide swings in seasonal temperature and a predominance

of winter rain. The rainfall year is defined here as being July through June since 75% of the local annual rainfall occurs from November through March, and reproduction and growth in this plant community are keyed to these winter rains. Precipitation measured 20 km from the study site at the Ricardo Ranger Station, Red Rock Canyon State Park, averaged 166 mm/yr with a range of 30–381 from 1971/1972 through 1991/1992. This study began during the second year of a 2-yr dry period during which time average rainfall was only 60 mm/yr. Midsummer maximum temperatures typically exceed 40°C, while minimum temperatures near 0°C predominate from November through February.

The terrain slopes downward to the southwest and is characterized by low rolling hills comprised of shallow (<30-cm-deep) alluvial and residual soils overlying a granitic pediment (Valverde and Hill 1981). Vegetation is typical creosote bush scrub (Munz 1974), dominated by *Larrea tridentata* and *Ambrosia dumosa*.

Two pairs of matched plots were established along the eastern boundary of the reserve at 832–893 m above sea level. Each pair consisted of a 65-ha plot outside and inside the reserve each containing a permanent 0.64-ha small-mammal trapping grid. The plots and the trapping grids within them were matched to control for elevation, slope, aspect, and substrate composition.

### Sampling Methods

Aboveground live biomass of annual vegetation was sampled at ten random points within each plot during April of 1990, 1991, and 1992. All living annual vegetation exposed above the surface of the soil within a 1-m-diameter (0.79-m<sup>2</sup>) circular plot was severed at ground level and collected (see Van Dyne and others 1963). Each sample was sorted by species, dried at 40°C for 48 h, and weighed to the nearest 0.1 mg. Nomenclature for all plants follows Hickman (1993).

The modified point-quarter method (Greig-Smith 1964) was used to estimate density and percent cover of shrubs. Ten random 100-m transects were established within each plot and sampled during June 1990. At ten random points along each transect I took compass bearings to the north, south, east, and west and measured the maximum canopy diameter of the closest shrub within each quadrat and the distance of its root axis from the sample point along the transect.

To estimate seed density, ten soil samples were taken at random points within each trapping grid during either January or February of each year. This was done by pressing a 6-cm-diameter vial into the soil

to a depth of 2 cm and sliding a cap over its open end (Brown and others 1979). The top 2 cm of desert soils have been shown to contain 89% of the total seed bank density (Childs and Goodall 1973). Organic material in each sample was separated by flotation (Reichman 1976, 1984, Nelson and Chew 1977), then seeds were sorted from other organic material under a dissecting microscope and weighed.

Trapping grids consisted of  $8 \times 8$  arrays of sampling stations placed 10 m apart, with one Sherman live trap per station. Rodents were sampled during the new moon on five occasions ranging from four to six nights in length: March 1992, May 1990, April 1991, November 1991, and February 1992 (6144 total trap nights). Toe clipping was used to permanently mark pocket mice (*Chaetodipus* and *Perognathus* sp.) and numbered, metal fingerling tags were attached to an ear for other species. Each individual captured was identified, weighed, sexed, noted for reproductive condition, and released at the point of capture. Population densities were estimated as the minimum number of distinct individuals known to be living during each trapping period (total number of marked animals).

#### Data Analysis

For plant data, the average of the ten subsamples taken within each of the two plots outside the fence were compared with the average of their matched plot inside by a two-tailed paired Student's *t* test (1 *df*; Sokal and Rohlf 1981). Mammal density and diversity were calculated during each of the five trapping periods. The difference between the average of the two plots inside and that of the two plots outside was taken as a single sample. A two-tailed *t*-test was again used (4 *df*). Independence of samples was assumed in this repeated measures design since recaptures between sampling periods averaged only 5%.

Three measures of ecological diversity were utilized: species richness, evenness, and the Shannon-Wiener index (Pielou 1975). General trends in the data were measured using a nonparametric sign test (Sokal and Rohlf 1981). The significance level used for all statistical tests was  $P \leq 0.05$ .

## Results

### Annual Plants

Aboveground live plant biomass differed between the fenced and unfenced plots. During the spring of 1990, five of the six species sampled possessed greater biomass inside than outside the fence (sign test,  $P =$

0.11; Table 1). The one species with more biomass outside was the exotic grass *Schismus barbatus*. Individually, the biomass of *Lasthenia californica* was significantly greater inside the fence (Table 1).

Scant precipitation during the 1989/1990 rainfall year coupled with high precipitation during that of 1990/1991 resulted in an order of magnitude increase in the total aboveground annual plant biomass. Inside, it increased from 12,325 to 199,460 g/ha, and outside from 4,740 to 57,770 g/ha (Table 1). Seventeen of 18 species sampled in 1991 produced more biomass inside than outside of the fence (sign test,  $P = 0.00$ ; Table 1). Again, the one species with greater biomass outside the protected area was *Schismus barbatus*. *Lasthenia californica* produced significantly more biomass inside the fence, while *Schismus barbatus* produced significantly more outside.

Moderate precipitation during 1991/1992 produced significantly different spring annual biomass levels of 94,920 g/ha inside and 39,610 g/ha outside the fence. Fifteen of 17 species sampled possessed higher biomasses inside than outside the fence (sign test,  $P = 0.00$ ; Table 1). The anomalous species, *Bromus madritensis rubens* and *Schismus barbatus*, are both aliens. The biomasses of *Amsinckia tessellata* and *Camissonia campestris* were both significantly greater inside the fence.

Although species richness was not significantly different, it was consistently higher inside the fence during each of the three years of this study (Table 1). The biomass of forbs was significantly greater than that of exotic annual grasses inside the fence during each of the three years, whereas it was significantly higher outside only during 1992 (Table 2).

### Perennial Shrubs

Percent cover of *Ambrosia dumosa*, and *Lycium andersonii* were both significantly greater inside than outside the fence (Table 3). Eleven of 13 species (sign test,  $P = 0.01$ ) possessed greater cover, and seven of 13 (sign test,  $P = 0.50$ ) had higher densities inside the fence. No individual species had a significantly higher density inside, whereas one species, *Psoralea montii*, was significantly higher outside the fence. Diversity indices demonstrated a trend toward higher values inside, although differences were not significant (Table 4).

### Soil Seed Content

Seed biomass was significantly higher inside the fence during 1991 (Table 5). Biomass estimates inside ranged from two to four times greater than those outside.

Table 1. Aboveground live biomass (g dry weight/ha) and species richness ( $N$  of species/0.79-m<sup>2</sup> sample) of annual vegetation, April 1990–1992

Species	1990					1991					1992				
	Inside	Outside	Diff.	$t^a$	$P$	Inside	Outside	Diff.	$t$	$P$	Inside	Outside	Diff.	$t$	$P$
<i>Amsinckia tessellata</i>	4,635	1,350	3,285	3.17	0.20	91,025	22,735	68,290	3.16	0.20	25,940	7,110	18,830	69.74 <sup>c</sup>	0.01
<i>Bromus madritensis rubens</i>	0	0	0			0	0	0			1,320	165	1,155	2.78	0.23
<i>Calycoseris parryi</i>	0	0	0			1,810	30	1,780	1.00	0.50	1,830	361	1,469	12.35 <sup>c</sup>	0.05
<i>Comissonia campestris</i>	0	0	0			7,025	0	7,025	1.00	0.50	0	0	0		
<i>Caulanthus inflatus</i>	0	0	0			0	0	0			610	95	1,309	0.98	>0.50
<i>Chaenactis fremontii</i>	0	0	0			625	0	625	1.00	0.50	200	0	200	1.00	0.50
<i>Corropis bigelovii</i>	0	0	0			945	0	945	1.00	0.50	2,130	145	1,985	0.89	>0.50
<i>Cryptantha spp.</i>	0	0	0			790	0	790	1.00	0.50	0	0	0		
<i>Dithyrea californica</i>	4,105	3,365	740	0.67	>0.50	25,295	25,130	165	0.01	>0.50	15,035	12,750	2,285	2.21	0.28
<i>Erodium cicutarium</i>	0	0	0			18,700	25	18,675	7.49	0.09	0	0	0		
<i>Eschscholzia minutiflora</i>	0	0	0			7,300	890	6,410	2.06	0.30	1,650	165	1,485	1.02	0.49
<i>Gilia latiflora</i>	0	0	0			8,125	1,115	7,010	0.84	>0.50	3,595	640	2,955	1.86	0.32
<i>Gilia spp.</i>	0	0	0			4,260	565	3,695	12.12 <sup>c</sup>	0.05	9,475	645	8,830	1.67	0.38
<i>Lasthenia californica</i>	3,155	0	3,155	42.09 <sup>c</sup>	0.02	2,210	0	2,210	2.87	0.22	0	0	0		
<i>Linanthus dichotomus</i>	0	0	0			0	0	0			1,305	0	1,305	1.00	0.50
<i>Lotus humistratus</i>	0	0	0			785	0	785	1.00	0.50	0	0	0		
<i>Lupinus odoratus</i>	0	0	0			0	0	0			4,700	2,170	2,530	0.84	>0.50
<i>Malacothrix coulteri</i>	0	0	0			1,170	0	1,170	1.00	0.50	220	0	220	1.00	0.50
<i>Pectocarya setosa</i>	42	3	39	10.90	0.06	11,745	3,220	9,715	2.34	0.27	9,500	3,870	5,630	3.80	0.17
<i>Pectocarya spp.</i>	0	0	0			5,100	0	5,100	1.00	0.50	0	0	0		
<i>Phacelia fremontii</i>	385	0	385	1.12	0.47	9,715	0	9,715	1.00	0.50	12,495	2,640	9,855	10.43	0.06
<i>Phacelia tanacetifolia</i>	10	22	-12	7.44	0.09	2,835	4,060	-1,225	49.50 <sup>c</sup>	0.02	4,915	7,840	-2,925	8.73	0.07
<i>Schismus barbatus</i>															
Sign Test <sup>b</sup>			$P = 0.11$					$P = 0.00c$					$P = 0.00c$		
Total	12,325	4,740	7,585	2.91	0.22	199,460	57,770	141,690	3.83	0.17	94,920	39,610	55,310	61.11 <sup>c</sup>	0.01
Species richness	3.5	1.5	2.0	4.59	0.15	4.3	2.2	2.1	3.50	0.19	4.3	3.7	0.6	4.34	1.15

<sup>a</sup>Two-tailed paired  $t$  test (1  $df$ ).

<sup>b</sup>Two-tailed sign test  $P$  value of greater overall biomass inside of the reserve ( $N = 18$ ).

<sup>c</sup> $P \leq 0.05$ .

Table 2. Aboveground live biomass (g dry weight/ha) of forbs and alien grass species (*Schismus* and *Bromus* spp.)

Year	Inside						Outside					
	Forbs	Grasses	F/G	D <sup>a</sup>	$t^b$	$P$	Forbs	Grasses	F/G	D	$t$	$P$
1990	12,315	10	1,232	12,305	35.98	0.02 <sup>c</sup>	4,716	23	259	4,693	2.09	0.29
1991	196,673	2,835	34	193,838	27.36	0.02 <sup>c</sup>	53,710	4,060	13	49,650	1.17	0.45
1992	89,998	4,919	18	85,079	20.98	0.03 <sup>c</sup>	30,756	8,855	4	21,901	12.68	0.05 <sup>c</sup>

<sup>a</sup>Difference between the forb and grass biomass.

<sup>b</sup>Two-tailed paired  $t$  test (1  $df$ ).

<sup>c</sup> $P \leq 0.05$ .

### Nocturnal Rodents

The densities of *Chaetodipus formosus*, *Dipodomys merriami*, and *Onychomys torridus* were significantly higher inside the fence (Table 6). Species richness, evenness, and Shannon-Wiener index were all significantly higher in the protected area as well (Table 7).

### Discussion

Mojave Desert perennial shrubs require a relatively long recovery period to return to predisturbance condition (Wells 1961, Vasek and others 1975a,b, Webb

and Wilshire 1979, 1983, Lathrop and Archibald 1980a,b, Webb and Newman 1982). Creosote bush scrub within this region has been estimated to take anywhere from 46 years (Webb and others 1987) to "a few centuries" (Vasek 1979/1980) for regeneration following disturbance. It is not surprising, therefore, that the number of shrub species and the overall shrub density were not affected by only 11 years of fencing at the Desert Tortoise Research Natural Area (DTRNA). Shrub cover and, to a lesser degree, evenness, however, were greater inside the fence. In various locations 10–50 km from the DTRNA, the per-

Table 3. Cover (%) and absolute density (plants/ha) of shrub vegetation, June 1990

	Cover					Density				
	In	Out	Difference	<i>t</i>	<i>P</i> <sup>a</sup>	In	Out	Difference	<i>t</i>	<i>P</i> <sup>a</sup>
<i>Acamptopappus sphaerocephalus</i>	0.57	0.65	-0.08	0.27	0.27	85	333	-248	11.14	0.06
<i>Ambrosia dumosa</i>	2.79	1.45	1.34	17.40	0.04*	482	361	121	1.22	0.44
<i>Chrysothamnus nauseosus</i>	0.01	0.00	0.01	1.00	0.50	0	1	-1	1.00	0.50
<i>Ephedra nevadensis</i>	0.38	0.00	0.38	3.59	0.18	45	0	45	2.80	0.23
<i>Ericameria cooperi</i>	0.05	0.08	-0.03	0.49	>0.50	7	14	-7	0.68	>0.50
<i>Eriogonum fasciculatum</i>	0.53	0.06	0.47	7.74	0.08	145	14	131	2.85	0.22
<i>Hymenoclea salsola</i>	0.49	0.09	0.40	1.42	0.39	34	20	14	0.34	>0.50
<i>Krascheninnikovia lanata</i>	0.01	0.00	0.01	1.00	0.50	1	0	1	1.00	0.50
<i>Larrea tridentata</i>	21.21	16.28	4.93	1.86	0.32	393	515	-122	6.00	0.11
<i>Lycium andersonii</i>	0.86	0.09	0.77	11.67	0.05 <sup>c</sup>	53	18	35	2.80	0.23
<i>Psoralea fremontii</i>	0.87	0.46	0.41	10.95	0.06	32	64	-32	32.01	0.02 <sup>c</sup>
<i>Tetradymia stenolepis</i>	0.33	0.22	0.11	1.79	0.33	30	38	-8	0.29	>0.50
<i>Xylorhiza tortifolia</i>	1.22	0.03	1.19	2.36	0.26	220	19	201	2.76	0.23
Sign test <sup>b</sup>			<i>P</i> = 0.01 <sup>c</sup>					<i>P</i> = 0.50		
Total	29.30	19.40	9.90	3.64	0.18	1,527	1,397	130	0.57	>0.50

<sup>a</sup>Two-tailed paired *t* test (1 *df*).

<sup>b</sup>Two-tailed sign test *P* value of greater cover and density inside of the reserve (*N* = 13).

<sup>c</sup>*P* ≤ 0.05.

Table 4. Diversity indices of shrub vegetation, June 1990

Index <sup>a</sup>	Inside	Outside	Difference	<i>t</i> <sup>b</sup>	<i>P</i>
S	7.00	5.85	1.15	1.46	0.39
E	0.57	0.35	0.22	6.50	0.10
H	1.45	0.91	0.54	7.27	0.09

<sup>a</sup>S = species number/transect; E = evenness; H = Shannon-Wiener index.

<sup>b</sup>Two-tailed paired *t* test (1 *df*).

Table 5. Soil seed bank biomass (kg dry weight/ha)

Year	Inside	Outside	Difference	<i>t</i> <sup>a</sup>	<i>P</i>
1990	107	50	57	3.65	0.18
1991	121	54	67	47.38	0.02 <sup>b</sup>
1992	193	56	137	8.42	0.08

<sup>a</sup>Two-tailed paired *t* test (1 *df*).

<sup>b</sup>*P* ≤ 0.05.

cent cover of *Ambrosia dumosa*, which was shown to benefit from protection in this study, decreased 16–19% under grazing pressure (Webb and Stielstra 1979). Off-highway vehicle (OHV) use has also been implicated in the reduction of plant cover (Davidson and Fox 1974). Interestingly, the density of *Psoralea fremontii* was greater outside the fence, while its percent cover was higher inside (*P* = 0.06). This may be due to repeated browsing, which keeps these plants small without killing them. Fencing prevents biomass

removal and trampling by livestock and mechanical destruction of plants by OHVs. Cessation of these activities at the DTRNA has affected plant cover after only a decade of protection.

Although no such studies are known from the western Mojave Desert, Chihuahuan and Sonoran desert annual plant communities also demonstrate the ability to recover following protection from grazing (Gardner 1950, Waser and Price 1981). They responded with increased biomass and diversity. Protection afforded by fencing at the DTRNA has similar results, with the primary benefit being greater biomass production by forbs than alien annual grasses. It should be noted that sampling of annuals was confined to April of each year when plant biomass production and local grazing activity were at their peak. This experimental design factor eliminates from analysis many species of annual plants that develop during later phenological periods. It is likely, however, that these plants also benefit from protection since local grazing and OHV activity often continue through the late spring and early summer and much of their impact, such as soil compaction, remains a factor long after the initial disturbance.

In many parts of the Mojave Desert alien annual grasses such as *Bromus madritensis rubens* and *Schismus barbatus* now comprise a substantial fraction of the total annual plant cover and biomass (Kay and others 1988). This invasion has been facilitated by excessive off-road vehicle use (Davidson and Fox 1974) and grazing (Young and Evans 1971, Mack 1991, Barto-

Table 6. Nocturnal small rodent population densities (animals/0.64 ha; inside–outside), 1990–1992

	Inside	Outside	Difference	<i>t</i> <sup>a</sup>	<i>P</i>
<i>Chaetodipus formosus</i>	16.9	3.9	13.0	17.67	0.00 <sup>c</sup>
<i>Dipodomys merriami</i>	19.7	8.3	11.4	2.85	0.05 <sup>c</sup>
<i>Onychomys torridus</i>	2.2	0.0	2.2	2.89	0.05 <sup>c</sup>
<i>Perognathus longimembris</i>	18.8	19.1	-0.3	0.05	>0.50
<i>Peromyscus maniculatus</i>	0.4	0.0	0.4	1.00	0.50
Sign test <sup>b</sup>			<i>P</i> = 0.19		
Total	58.0	31.3	26.7	2.31	0.08

<sup>a</sup>Two-tailed paired *t* test (4 df).

<sup>b</sup>Two-tailed sign test *P* value of higher density inside of the reserve (*N* = 5).

<sup>c</sup>*P* ≤ 0.05.

Table 7. Diversity indices of nocturnal rodent populations

Index <sup>a</sup>	Inside	Outside	Difference	<i>t</i> <sup>b</sup>	<i>P</i>
S	3.70	2.50	1.20	5.69	0.01 <sup>c</sup>
E	0.57	0.42	0.15	5.87	0.01 <sup>c</sup>
H	0.92	0.68	0.24	6.59	0.01 <sup>c</sup>

<sup>a</sup>S = species number/0.49 ha sample; E = evenness; H = Shannon-Wiener index.

<sup>b</sup>Two-tailed paired *t* test (4 df).

<sup>c</sup>*P* ≤ 0.05.

lome and others 1986). Unfortunately, once established, these alien species continue to spread even after disturbance has ceased (Mack 1981, 1986, D'Antonio and Vitousek 1992). This profusion of exotic grasses is a potential threat to the indigenous flora, since they can successfully compete with both herbaceous and woody native plants (Schultz and others 1955; Van Auken and Bush 1988, Cohn and others 1989, Billings 1990) especially in areas of current or past human disturbance (Mack 1986). Specifically, they compete well for limiting resources such as nitrogen (Gutierrez and Whitford 1987a, Elliott and White 1989), water (Schultz and others 1955, Da Silva and Bartolome 1984, Gutierrez and Whitford 1987b, Melgoza and others 1990), and light (Bush and Van Auken 1987, Thompson and Harper 1988, Van Auken and Bush 1990).

Environmental conditions can also be altered by annual grass invasions (Vitousek 1990, D'Antonio and Vitousek 1992). For example, the insulating effect of increased grass litter reduces soil water loss and temperature fluctuation (Facelli and Pickett 1991), aiding in their establishment at the expense of native species (Evans and Young 1970, Whisenant 1990). Alien grasses are also often associated with increased fire intensity and frequency (Brown and Minnich 1986).

Alteration of the disturbance regime such as this often leads to both population and ecosystem change (Vitousek 1990). Desert shrubs are not adapted to recurrent fire (Wright 1982), and recent outbreaks have led to significant floristic alteration of creosote bush scrub habitat in the California desert (O'Leary and Minnich 1981, Brown and Minnich 1986). Although there is no recent evidence of fire near the DTRNA, the increase in abundance of alien grasses observed during the course of this study suggests that burning may occur there in the future.

This study suggests that protection alone can limit, but not prevent, the proliferation of alien annual grasses once they have colonized an area. As rainfall increased over the three years of this study, annual grasses gradually gained dominance irrespective to protection. However, the forb/grass ratio was consistently higher inside the fence, where the transition towards more grass biomass appeared to lag about one year behind the unprotected area. It seems that annual grasses benefit from periods of increased rainfall when their high reproductive potential can outpace that of native forbs. Further research is needed to determine the effect that exotic grasses have upon ecosystem dynamics in this region.

It has been proposed that grazing may benefit certain rodent species (Phillips 1936, Reynolds 1950, 1958). For example, *Dipodomys* spp. seem to prefer open habitat, and densities may increase with grazing-induced decreases in shrub cover (Reynolds 1958). The present study suggests otherwise, and more recent research supports this contention (Whitaker 1967, Hansen 1965, Turner and others 1973, Bock and others 1984, Hunter 1991). Heske and Campbell (1991) found significantly more rodents inside than outside of an 11-year-old cattle enclosure in the Chihuahuan Desert. Included were two species, *Dipodomys merriami* and *Onychomys torridus*, that were also found in greater numbers inside the DTRNA.

The reduced seed bank biomass found outside of the fence seems to be the key element linking plant community health to that of rodents. Reichman (1991) states that "in North American deserts seed abundance and distribution serve as the cornerstone of community organization among rodents (especially heteromyids)." In addition, since rodents can consume up to 87% of the total yearly seed production (Chew and Chew 1970), the effect of disturbance outside of the fence could potentially have been obscured by increased seed consumption inside where rodent densities were higher. The fact that significant differences in seed biomass were detected in spite of this suggests that human disturbance has a greater impact upon the seed bank than do rodents.

Despite the assumption that *Dipodomys* spp. prefer open habitats (Reynolds 1958), the population density of *Dipodomys merriami* in this study correlated positively with greater shrub cover inside the fence. Perhaps the disparity in the seed bank overshadowed the importance of habitat structure to this species. In addition, densities of *Perognathus longimembris* were virtually identical inside and outside the fence, suggesting that the difference in seed availability did not affect them. This species prefers the relatively small, closely spaced shrubs (Mary Price personal communication) present outside the fence, which may have masked the effect of seed distribution.

Disturbance is beneficial to natural communities under certain conditions. In a review of the subject, Souza (1984) points out that periodic disturbance is effective at keeping competitively superior species from dominating a community. Competition is minimized by keeping the populations of individual species well below their carrying capacities (Noble and Slayter 1980, Souza 1984). For this scenario to occur, however, ecosystems must be allowed to recover before the next disturbance pulse. Otherwise density and diversity will progressively decrease as weedy, disturbance-adapted species, such as Old World annual grasses, gain in dominance (Souza 1984). In order to maintain maximal diversity, disturbance must therefore be intermediate in frequency and intensity (Caswell 1978). The present study suggests that the degree of human disturbance outside of the DTRNA is currently too great. Any future plans designed to foster diversity here should take this into account, in addition to such variable factors as local rates of recruitment, competitive exclusion, and successional status (Huston 1979).

This study shows that the floral and faunal community structure of the western Mojave Desert can profit from fenced protection. These benefits not

only affect individual plant and animal populations, but the overall ecosystem as well. Due to the absence of data before the fence was put up, it is impossible to characterize these positive responses as true recovery from past disturbance or continued degradation outside of the DTRNA since the time it was fenced. In either case, protection has benefitted this desert ecosystem, and fencing seems to be a viable mitigation tool against human disturbance in this area of the Mojave Desert.

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