The Impact of Off-road Vehicles on a Desert Ecosystem

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ABSTRACT/The effects of operating a 4-wheel drive truck in a 9-ha area of the Mojave Desert were evaluated. A truck was driven over the same 0.9-km track 21 times between November 1973 and May 1974. The vehicle was also driven randomly around the area (1.3 to 3.4 km) 17 times between December 1973 and May 1974.

Spring densities of annual plants in ruts of the regular track (8/m^2) were less than those in control areas (46-112/m^2), but densities in randomly driven plots (39/m^2) did not differ significantly from controls. Severity of damage to shrubs was directly related to intensity of driving in the area. About 58% of shrubs growing in the regular track sustained estimated damage ranging from 81 to 100%. In randomly driven areas only 6% of shrubs were damaged to this extent, while about 61% sustained damage from 0 to 20%. Numbers and kinds of rodents in control and driven areas were similar before and after the experiment. More young rodents were trapped in the experimental plot than in the control area during July 1974, and this may have been promoted by basal sprouting of new growth by damaged shrubs. Estimates of numbers of side-blotched lizards indicated similar densities before, during, and after the experiment. Counts of whiptail lizards in control and experimental areas were the same after the experiment, but counts of gridiron-tailed lizards were much lower in the driven area.

INTRODUCTION

Continued exposure of desert areas to off-road vehicles (ORVs) results in clearly observable damage to vegetation and less conspicuous effects on soil characteristics and populations of animals (see Berry 1973, Stebbins 1974, Busack and Bury 1974, Luckenbach 1975). If usage is sufficiently intense, lasting damage may be done to the desert within a few hours. Carter (1974) described the results of a motorcycle race in Kern County, California, where—in the course of one day—700 cyclists devastated all vegetation in an area approximately 1-2 m wide and 5 km long. Such destruction is particularly serious in desert areas because of the fragility of these ecosystems.

Management of public lands in the western United States has traditionally been based on the concept of multiple use. As a result, many desert areas are used for ORV recreation and some of these areas are exposed to intensive use. How can such recreational practices be reconciled with the equally legitimate concerns of those dedicated to the preservation of these sensitive ecosystems? This question has been addressed by the Desert Management Plan of the Bureau of Land Management (Carter 1974). The agency's plan has been sharply criticized by some scientists, who perceive it as far too generous to the users of ORVs (Stebbins 1974, Luckenbach 1975).

Much of the information available on environmental impacts of ORVs is qualitative. The destructive effects of large races or rallies involving hundreds of vehicles are grossly obvious. Luckenbach (1975) described effects on soils (changes in compaction and permeability), destruction of immature insects, impairment of productivity by annual plants, destruction of bird nests and rodent burrows, and killing of reptiles. It is more difficult to gauge the impact of less intensive usage and to correlate specific ecological effects with various patterns of vehicular operation.

In this study we examined some biological consequences of operating 4-wheel drive trucks in a 9-ha desert area over a period of six months. Growth of annual plants, damage to shrubs, and selected features of populations of lizards and rodents were evaluated in this area. When appropriate, these measurements were compared with similar data acquired in adjoining control areas.

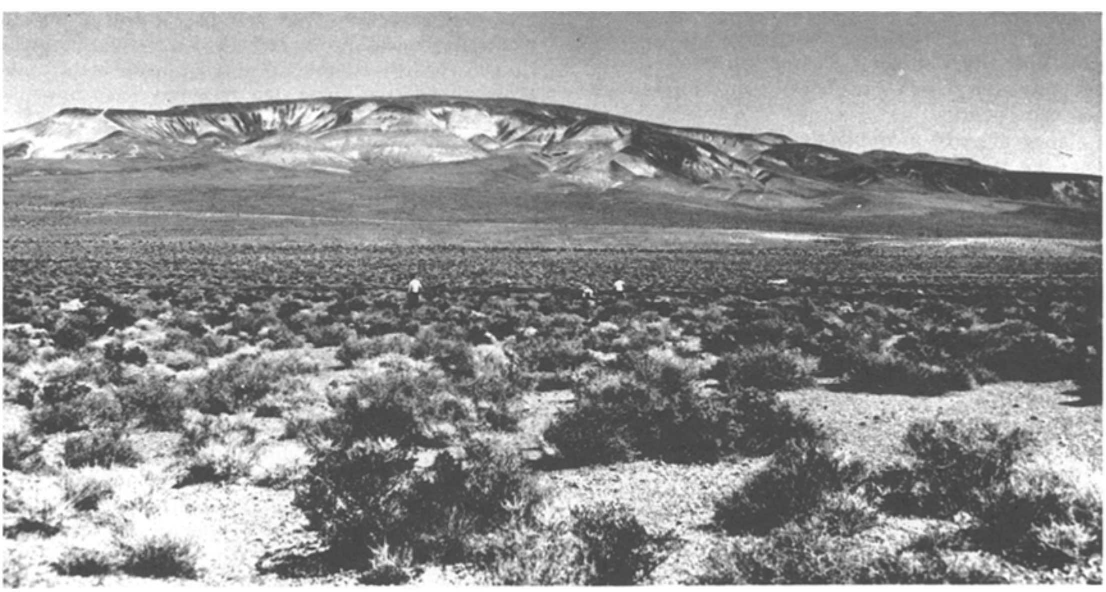
While we did not attempt to evaluate the impact of vehicles on the soil, we recognize that desert soils are particularly vulnerable to this type of disruption (Wilshire and Nakata 1976, Webb 1976, Eckert et al. 1976). The full extent of damage to soils may not be evident until years or even decades after the original disturbance.

Our study was done in Rock Valley, Nye County, Nevada, in the northern Mojave Desert (Fig. 1). This area, at an elevation of about 1040 m, is 130 km NW of Las Vegas and is part of the U.S. Energy Research and Development Administration's Nevada Test Site. Our study area was on a compound alluvial fan surface (bajada) sloping 4% to the northwest. Soils were well drained, with moderate permeability, and exhibited moderate erosion. Some areas were weakly developed desert pavement with about 50% of the surface covered by rock and gravel. Soil beneath shrubs was fine sand to

KEY WORDS: Off-Road Vehicles, Desert Ecosystems, Human Impact, Mojave Desert
Environmental Management, Vol. 1, No. 2. pp. 115–129

depths of around 15 cm, gravelly loamy sand to 33 cm, and cemented gravel between 33 and 57 cm. Soils in bare areas were gravelly sandy loam to around 43 cm, and cemented gravel below 43 cm (Romney et al. 1973). Air temperatures in Rock Valley range from −15°C to 45° C. Rainfall is highly variable in timing and amount, but the most predictable period of rainfall is between November and March. Mean annual precipitation in Rock Valley between 1963 and 1974 was 12.75 cm. The vegetation is composed primarily of perennial shrubs with an aggregate density of about 8900/ha and coverage of around 20%. Six shrub species make up roughly 85% of the perennial above-ground standing crop: *Ambrosia dumosa* (Gray) Payne, *Ephedra nevadensis* Wats., *Krameria parvifolia* Benth., *Larrea divaricata* Cav., *Lycium andersonii* Gray, and *L. pallidum* Miers. Rock Valley contains one of the study sites sponsored by the Desert Biome, U.S. International Biological Program (IBP), and more detailed descriptions of edaphic and biotic features may be found in IBP reports (Turner 1972, 1973) and some of the chapters in Wallace and Romney (1972).

Figure 1. View of Rock Valley, Nye County, Nevada.



Procedures

Establishment of test area

The 9-ha test area, a 300-m square, was located 100 m east of the northeastern corner of the IBP site, so that measurements made in the latter area could be used as control observations (Fig. 2). A grid with 100-m intervals was established within this square.

In October 1973 a preliminary survey was made of vegetative and topographic features of the test area. Six 2 × 400-m belt transects were laid out across the area; three ran north-south and three ran east-west. The parallel transects were 100 m apart and extended 50 m beyond the boundaries of the test area. All shrubs within transects were recorded. These data were used to map the test area and to establish boundaries of different zones of vegetation. The plan of vehicular use insured that all vegetative zones were involved.

Control areas and pre-test measurements

The IBP control site was a 46-ha area lying west of the test area (Fig. 2). Observations of plants and animals in the test area were compared with similar data acquired on the IBP site.

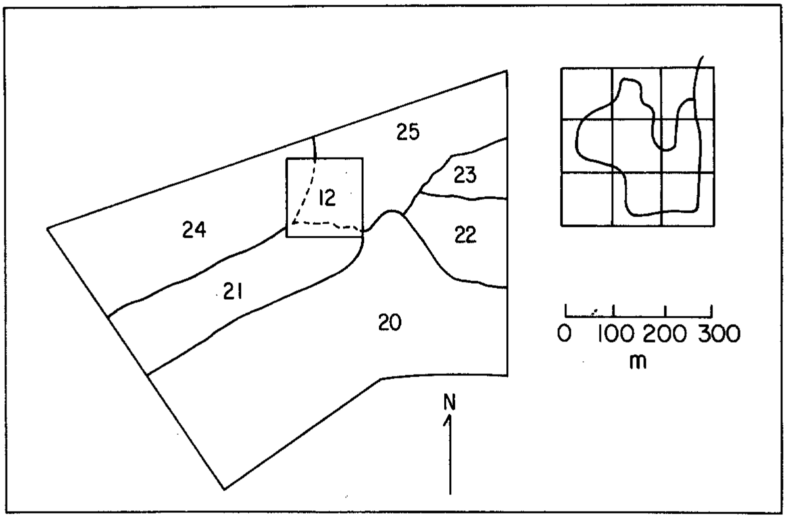


Figure 2. Test area of 9 ha (right) and 46-ha IBP site (left) in Rock Valley, Nevada. The map indicates the course of the regularly driven track in the test area and portions of the IBP site which were used as control areas (vegetation Zones 22, 23, and 25, and Plot 12).

During October 1973, before any driving began, censuses of several species of small rodents and of one species of lizard (*Uta stansburiana*) were made in the test area and on the IBP site. The latter work was done in Plot 12, a 165 × 165-m plot of about 2.7 ha (Fig. 2).

Pre-test censuses of rodents. Trap stations were laid out along two parallel lines 105 m apart in Plot 12. Each line was 165 m long and included 12 stations at 15-m intervals. In the test area trap stations were laid out along two lines 100 m apart. Each line was 300 m long and contained 21 stations 15 m apart. Two traps (French 1964) were used at every station. Traps were activated around sunset and inspected before midnight. Animals were marked and released at point of capture. The simultaneous censuses of both areas were taken on four consecutive nights of trapping in October 1973. Total numbers of different individuals of each species registered during the censuses were taken as measures of abundance. We estimated densities in the two areas by computing effective areas trapped for each of five species in question. Effective trapping areas were calculated from estimates of sigma (σ) for each species given by Maza et al. (1973). This parameter is related to extent of home ranges and is a measure of relative vagility. We used 3 σ as an estimate of species' range and trapping areas were adjusted accordingly. Values of σ and estimated effective trapping areas for each species are given in Table 1. Depending on the species involved, traps in the test area provided a census of an area from 20 to 50% greater than the area trapped in Plot 12.

Pre-test censuses of Uta stansburiana. Censuses of *Uta* were carried out in the test area and the northwest portion of Plot 12 between 1 and 10 October 1973. One ha in the test area and 0.8 ha in Plot 12 were evaluated. Five collections of *Uta* were made in each area. Animals were noosed, marked with quick-drying paints, and released at point of capture. The sequences of five consecutive samples taken in each area were analyzed as suggested by Schumacher and Eschmeyer (1943). Densities were computed by adjusting population estimates for the size of the areas evaluated.

Patterns and schedule of driving

Two vehicles were used to drive over the test area. One was a 4-wheel drive Ford Crewcab (F250) weighing 2,544 kg, including driver and full gas tank. The other

Table 1 Estimates of Sigma (σ) for Six Species of Rodents in Rock Valley. Effective Trapping Areas for Two Grids of Traps were Based on Values of 3σ.

Species	σ	Effective trapping areas (ha) Plot 12	Test area
Perognathus formosus	15.4	4.75	7.24
P. longimembris	19.0	6.10	8.84
Dipodomys merriami	37.3	12.78	16.95
D. microps	26.5	8.55	11.88
Onychomys torridus	61.6	25.35	31.42
Ammospermophilus leucurus	71.9	32.00	38.87

was a 4-wheel drive International Travelall (1100D) weighing 2,274 kg similarly loaded. The Ford truck was equipped with size 700-16 tires and had a wheelbase of 3.78 m; the Travelall had size 700-15 tires and had a wheelbase of 3.02 m. The test area was driven on 21 occasions between November 1973 and May 1974; the Travelall was used all but five times.

Driving in the test area was done in two ways. Beginning on November 19, 1973, the Ford truck was driven twice over a fixed course of about 0.9 km (Fig. 2). This procedure was repeated on the following 2 days to establish the track clearly for subsequent use. The track was later driven 18 times between November 28, 1973 and May 3, 1974. The track was always circled twice. The vehicle was never operated faster than 20 kph. Starting on December 6, 1973 and continuing until May 3, 1974 the driving schedule was expanded to include not only two circuits of the track, but also a period of random driving over the test area. Drivers crossed the regular track from time to time but generally avoided driving closely parallel to it. Seventeen random excursions ranged from 1.3 to 3.4 km (average of 2.5 km). During the experiment the regular track was driven 38 km in about 4 hours, while 42.5 km of random driving were logged in just over 5 hours.

SAMPLES IN THE TEST AREA

Post-test measurements

Annual Plants. During May 1974 annual plants were sampled at various locations throughout the test area. Sampling locations were established in areas exposed to sporadic use and in the regularly driven track. Twenty points were randomly selected in irregularly driven areas. Each point was assigned a cardinal compass direction (north, east, south or west). Lines originating from these reference points were extended 50 m in assigned directions. If a line extended beyond the study area the direction taken from the starting point was reversed. Five starting points were also selected on the regularly driven track at 0.18-km intervals. At each point a 50-m line was marked off down the center of the track.

Along each 50-m line, 10 points were randomly selected. The same intervals were used for all transects. At each of these points, two 0.25-m^2 quadrats were sampled and all annual plants counted. In the regularly driven track one of the quadrats was placed on the hump between the tire ruts and the other placed in a rut (alternating between left and right rut).

SAMPLES IN CONTROL AREAS

Portions of the adjoining IBP site were used as control areas for comparison with observations in the test area. Analysis of perennial vegetation of the IBP site in 1971 showed that the area was not homogeneous in terms of kinds and relative abundances of shrubs. Six vegetative zones were recognized (see Turner 1972). The three zones closest to the test area are zones 22, 23, and 25 (Fig. 2). Densities of annual plants in these zones were estimated from counts in 0.10-m^2 quadrats during April 1974. Fifty-two quadrats were counted in Zone 22, 36 in Zone 23, and 136 in Zone 25. Details regarding the location of these quadrats are given in Turner (1972), and further information regarding 1974 sampling is given by Ackerman et al. (1975).

Shrubs. During June 1974, shrubs were examined in randomly driven areas and in the regular track. Ten points were established at 0.09-km intervals along the regular track. From each of these points a 2 × 50-m belt transect was laid out along the track. All shrubs that fell within the quadrat were recorded by species. This count included any shrub whose canopy was 75% within the quadrat. Estimates of the percentages of these shrubs destroyed by driving were made. We also estimated portions of remaining shrubs composed of new growth.

Ten pairs of points were established in randomly driven areas adjoining the ten points in the regular track. Members of each pair were located on opposite sides of the track at a distance of 15 m from the track. Five other points were positioned in other parts of the test area exposed to random driving. From each point a 2 × 50-m belt transect was laid out. Information similar to that taken in the regular track was collected along each of these 25 transects.

CENSUSES OF UTA

Censuses of Uta stansburiana and other lizards. During the spring of 1974 this work was carried out between March 6 and 15 in the control plot (12) and March 13 and April 4 in the test area. Areas evaluated were, as before, 0.8 and 1.0 ha. Six censuses were made in Plot 12 and seven in the test area. During the fall of 1974, after the period of summer reproduction, the two areas were inspected again. Six censuses were conducted in Plot 12 between September 16 and 23 and six in the test area between September 25 and October 4. At this time, a few lizards about 3 months old were taken from each area and weighed before being released.

COUNTS OF OTHER LIZARDS

In the spring of 1974 counts of whiptail lizards (*Cnemidophorus tigris*) and gridiron-tailed lizards (*Callisaurus draconoides*) were made in a 3.6-ha plot in the test area and in a 9-ha area on the IBP site. Three counts were made in both test area and IBP site on alternating days during mid-May. On each occasion, four people, separated by 7.5 m, walked through the area and recorded lizards observed. Such counts are not enumerations of total populations. Past work in Rock Valley with fenced populations of whiptail lizards (Turner et al. 1969) showed that incomplete counts of this species may be converted to estimates of absolute density by multiplying the average number observed by 3.3 (Medica et al. 1971). However, counts made during this experiment were used only as relative measures of abundance in test and control areas.

CENSUSES OF RODENTS

Heteromyids and cricetids. These rodents were counted for four nights in both April and July 1974 using the same procedures described previously. Trapping in test and control areas was carried out simultaneously from April 22 to 26 and again from July 8 to 11. Live body weights of animals from both areas were determined in the field with a Pesola spring balance.

Sciuromorphs. Ground squirrels (*Ammospermophilus leucurus* and *Spermophilus tereticaudus*) were trapped from May 6 to 9 and from August 5 to 8 in both areas. Two wire fabric live traps (Tomahawk Live Trap Co. #102) were placed at each station. Each trap was equipped with an aluminum bait tray wired to the back panel. A masonite sheet was used as a heat shield. These traps were open from 0800 hours to 1800 hours and were checked at 2-h intervals. Live body weights were obtained as above.

Estimates of the abundance of pocket gophers (*Thomomys bottae*) were based on inspections and mapping of mounding activity in the test area and in Plot 12. Burrow system locations were inferred from maps and numbers of gophers estimated by assuming one animal per system. Procedures were similar to those used by Dingman and Byers (1974). These inspections were carried out during the spring of 1974 and again in August 1974. Approximate densities were computed assuming an area of 9 ha for the test area and 2.7 ha for Plot 12.

Table 2 Numbers of Annuals Counted in 0.25-m^2 Quadrats in Regularly and Randomly Driven Areas.

Randomly driven area (20 quadrats/site)		Regularly driven track (10 quadrats/site)	
Site	Annuals	Site	Annuals
1	156	Middle of track (hump)	
2	455		
3	96	1	132
4	119	2	58
5	246	3	25
6	227	4	9
7	147	5	79
8	111		
9	245	Totals	303
10	250		
11	5		
12	15	Tire tracks (ruts)	
13	148		
14	75	1	38
15	277	2	22
16	154	3	1
17	135	4	5
18	174	5	29
19	233		
20	624	Totals	95
Totals	3912		

Results

Annual plants

In areas exposed to random driving. Table 2 summarizes combined numbers of annual plants at 20 sites exposed to random vehicular use. Each group of 20 quadrats comprised an aggregate area of 5 m^2, so the total area sampled was 100 m^2. Overall density of annuals was, then, about 39/m^2.

In the regularly driven track. Table 2 also gives numbers of annual plants counted at five sites in the regularly driven track. Density of annuals in ruts was about 8/m^2 and in the hump between ruts about 24/m^2.

In control areas. As mentioned previously, we used observations of annual plants made during April and May 1974 in Zones 22, 23, and 25 on the IBP site as measures of normal abundance. Estimated densities of annuals in these three zones were 112, 80, and 46/m^2, respectively (Ackerman et al. 1975).

Comparisons between situations. Table 3 summarizes foregoing estimates of annual densities in three parts of the IBP site (control areas) and in three situations in the

Table 3 Estimated Densities of Annual Plants in Control and Test Areas in Rock Valley.

Area	Number of Quadrats	Size of Quadrats (m^2)	Estimated Density of Annual Plants (n/m^2)
Control areas			
Zone 22	52	0.10	112
Zone 23	36	0.10	80
Zone 25	136	0.10	46
Test areas			
Ruts of regular track	50	0.25	8
Hump of regular track	50	0.25	24
Randomly driven areas	400	0.25	39

test area. A first impression is that driving affected numbers of annual plants, and that reductions in density were correlated with intensity of use. In examining this possibility in more detail we face the insurmountable problem that numbers of annuals in control and test areas were not compared before the experiment. Hence, we can argue only on grounds of geographic proximity and general similarities in perennial vegetation, that observations in the control areas are appropriate measures of what would normally have been expected in the test area.

Counts of annuals in individual quadrats were not normally distributed. Many quadrats examined were either devoid of annuals or had only a few plants. This was particularly true of quadrats located in the regularly driven track (Fig. 3). However, even control sites exhibited similar distributions. Of 136 quadrats examined in Zone 25, 44 were devoid of annuals and 57 others had from one to four plants. None of these distributions was normalized by transformations of counts to logarithms or square roots. The distributions were clearly of the "rare event" form, but did not fit expectations computed for Poisson distributions. We compared these distributions by means of two non-parametric procedures: the median test (Siegel 1956) and the Wilcoxon two-sample test (Sokal and Rohlf 1969).

We first made comparisons between quadrats in the test area. We used data from 50 of the 400 quadrats in the randomly driven areas—20 from site 5, 20 from site 13, and 10 from site 9. The mean number of plants in these 50 quadrats (10.7) differed from the overall mean (9.75), but we considered the subset representative of the total assemblage.

We also compared quadrats in randomly driven areas with 50 quadrats in Zone 22 and 100 quadrats in Zone 25 of the IBP site. Because quadrats in the IBP site were 0.1 m^2, we multiplied counts by 2.5 to make them comparable to counts made in 0.25 m^2 quadrats in the test area. For comparisons of randomly driven areas with Zone 25 we used a subset of 100 quadrats from the test area (sites 1, 5, 9, 13, and 17). The mean number of

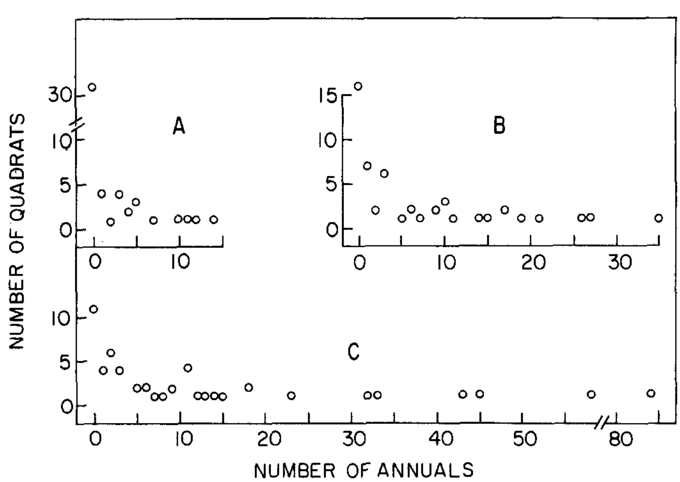


Figure 3. Numbers of annuals counted in fifty 0.25-m^2 quadrats located in ruts of the regularly driven track (a), on the hump between the ruts of the track (b), and in randomly driven portions of the test area (c).

Table 4 Densities of Annuals in Control and Test Areas. Values for Zones 22 and 25 Adjusted to Quadrat Size of 0.25 m^2.

Situation	Number of Quadrats	Number of Plants	Mean Number of Annuals Per Quadrat
(1) Ruts of regular track	50	95	1.90
(2) Hump of regular track	50	303	6.06
(3) Randomly driven area	50*	535	10.70
(4) Randomly driven area	100**	930	9.30
(5) Zone 25	100	1200	12.00
(6) Zone 22	50	1432	28.65

*sites 5, 13, half of site 9

**sites 1, 5, 9, 13, 17

Table 5 Comparisons of Densities of Annual Plants in Control and Test areas in Rock Valley.

Comparisons of Situations in Table 5	x^2 (Median Test)	t_s (Wilcoxon Two-sample Test)
1 and 2	9.04*	3.37*
1 and 3	16.00**	4.61**
2 and 3	0.65	1.44
3 and 6	0.64	1.26
4 and 5	3.39	0.74

*$p < 0.01$

**$p < 0.001$

plants per quadrat in this subset (9.3) was only slightly less than the mean for 400 quadrats (9.75).

Table 4 gives densities of annuals in both control and test situations in terms of 0.25 m^2 quadrats. Table 5 gives statistical comparisons of selected situations. The tests show clear differences between numbers of annuals in ruts of the track and in other parts of the test area. We judge this to be an unequivocal experimental effect. The other distributions compared did not differ significantly. The tests employed are not particularly sensitive to differences in distribution means and we believe that Zone 22 actually supported more annuals than the other areas. Between 1971 and 1974 estimates of annual densities in Zone 22 were consistently higher than those for other zones. However, because we do not know the normal relationship between Zone 22 and the test area, we cannot be sure that the post-test density of annuals in portions of the test area exposed to random driving was reduced by vehicular traffic.

Table 6 Estimated Damage to Shrubs Exposed to Two Test Situations in Rock Valley, Nevada.

Estimated Damage (%)	Number of Shrubs: Randomly Driven Areas	Number of Shrubs: Regularly Driven Track
0-20	298	17
21-40	52	8
41-60	59	11
61-80	49	26
81-100	29	85

Shrubs

Table 6 summarizes estimates of damage to 487 shrubs in areas subjected to random driving and 147 shrubs in the regular track. Average estimated damage in the first situation was about 38%; in the latter 76%. As would be expected, shrubs exposed to repeated driving were severly damaged. Both live and dead stems were broken and pressed to the ground. Stems still standing exhibited broken twigs or shoots. Leaves were dislodged. Damage to about 30% of all shrubs examined in the track was scored as 100%, i.e., all of the original above-ground parts were broken off. About 54% of the shrubs in the track sustained $\geq$ 90% damage. On the other hand, in areas subjected to random use about 43% of the shrubs inspected were undamaged and about 56% received damage estimated at $\leq$ 10%.

Table 7 gives estimates of damage to 11 common perennial species examined in the track and randomly driven area. Were different species of shrubs more or less susceptible to damage? We examined this question with χ^2 tests. Table 8 gives degrees of estimated damage (by quartiles) for 403 shrubs of seven species examined in randomly driven portions of the test area. Total χ^2 was about 20, and with 18 degrees of freedom there is no reason to conclude that shrub species differed in their vulnerability to random driving.

Table 9 presents similar data for shrubs examined in the regular track. Here it was necessary to combine the first two quartiles so that expected values would not be too small. The total χ^2 was about 15. With 6 degrees of freedom the probability of the observed distributions reflecting uniform susceptibility to damage is only about 2%. Slightly over half the total χ^2 was contributed by *Acamptopappus shockleyi*. We suggest that this shrub is more resistant to repeated abuse by vehicles than the

Table 7 Estimated Damage Sustained by Eleven Species of Shrubs Exposed to Two Test Situations in Rock Valley, Nevada.

Species	Regular Track n	Regular Track Estimated Destruction (%) (x̄ ± SE)	Randomly Driven Areas n	Randomly Driven Areas Estimated Destruction (%) (x̄ ± SE)
Acamptopappus shockleyi	22	58.6 ± 8.4	40	17.0 ± 4.4
Ambrosia dumosa	38	76.4 ± 4.9	162	22.6 ± 2.4
Ceratoides lanata	7	81.6 ± 9.3	33	25.2 ± 6.4
Coleogyne ramossisima	1	97.0	14	45.7 ± 7.8
Ephedra nevadensis	11	75.0 ± 8.7	43	24.8 ± 4.8
Grayia spinosa	6	61.7 ± 15.6	28	19.8 ± 5.6
Krameria parvifolia	1	90.0	20	15.3 ± 6.0
Larrea divaricata	27	85.2 ± 3.7	43	27.7 ± 4.6
Lycium andersonii	9	68.2 ± 10.3	47	30.4 ± 4.2
L. pallidum	18	91.3 ± 2.1	35	35.5 ± 5.8
Salazaria mexicana	4	54.0 ± 25.4	11	27.3 ± 7.3

Table 8 Estimated Damage to 403 Shrubs of Seven Species in Randomly Driven Portions of the Test Area. Number in Parentheses are Expected Values Assuming Uniform Susceptibility to Damage.

Species	0–25%	26%–50%	51–75%	76 100%
Acamptopappus shockleyi	30 (24.81)	4 (7.05)	4 (3.77)	2 (4.37)
Ambrosia dumosa	106 (100.50)	28 (28.54)	11 (15.27)	17 (17.69)
Ceratoides lanata	22 (20.47)	2 (5.81)	4 (3.11)	5 (3.60)
Ephedra nevadensis	27 (26.67)	7 (7.58)	3 (4.05)	6 (4.69)
Larrea divaricata	26 (26.67)	9 (7.58)	4 (4.05)	4 (4.69)
Lycium andersonii	23 (29.16)	12 (8.28)	8 (4.43)	4 (5.13)
L. pallidum	16 (21.71)	9 (6.17)	4 (3.30)	6 (3.82)

Table 9 Estimated Damage to 105 Shrubs of Four Species in the Regularly Driven Track in Test Area. Numbers in Parentheses are Expected Values Assuming Uniform Susceptibility to Damage.

Species	0–50%	51–75%	76–100%
Acamptopappus shockleyi	8 (3.35)	2 (2.72)	12 (15.92)
Ambrosia dumosa	7 (5.79)	4 (4.71)	27 (27.51)
Larrea divaricata	1 (4.11)	5 (3.34)	21 (19.54)
Lycium andersonii	0 (2.75)	2 (2.23)	16 (13.02)

other three species. Other investigators have reported that the closely related species *A. sphaerocephalus* is also less susceptible to damage by ORVs (Davidson. 1973, Keefe and Berry 1973). The small size of these shrubs may contribute to their "resistance." It is also possible that stems of these two species are less brittle than those of other species studied.

Rodents

Table 10 gives numbers of five species of rodents trapped in the test area and Plot 12 at three times between October 1973 and July 1974 as well as numbers of antelope ground squirrels trapped during 1974. Other rodents trapped in Plot 12 included one *Dipodomys deserti* (April), four *Spermophilus tereticaudus* (two in April and two in June), and one *Peromyscus crinitus* (October). Other species trapped in the test area included three *Neotoma lepida* (two in October and one in June), four *Peromyscus crinitus* (October), and one *Spermophilus tereticaudus* (April). Table 10 also gives density estimates of various species in the two areas and combined densities for five or six species. Highest densities were consistently exhibited by *Perognathus longimembris* and this pocket mouse usually accounted for about half the aggregate density of all species considered in Table 10. Table 11 gives information about pocket gophers in the two areas after the driving had concluded. Pocket

Table 10 Numbers (and Estimated Densities Per ha) of Rodents Trapped in Test and Control Areas in Rock Valley. Asterisks Indicate Juveniles Included in the Count.

Species	October 1973 Plot 12	October 1973 Test Area	April 1974 Plot 12	April 1974 Test Area	July 1974 Plot 12	July 1974 Test Area
Perognathus formosus	12 (2.5)	29 (4.0)	5 (1.1)	13 (1.8)	0 (0.0)	8 (1.1)
P. longimembris	32 (5.3)	38 (4.3)	37 (6.1)	24 (2.7)	16 (2.6)	24 (2.7)
Dipodomys merriami	3 (0.2)	10 (0.6)	5 (0.4)	25* (1.5)	4 (0.3)	11* (0.6)
D. microps	9 (1.0)	12 (1.0)	8 (0.9)	9 (0.8)	6 (0.7)	6 (0.5)
Ammospermophilus leucurus	—	—	12* (0.4)	27* (0.7)	26 (0.8)	31* (0.8)
Onychomys torridus	4 (0.2)	5 (0.2)	1 (0.04)	4 (0.1)	1 (0.04)	3* (0.09)
Total numbers (including other species)	61	100	71[1]	103[2]	55	84[3]
Combined densities of 5 or 6 species (n/ha)	9.2	10.1	8.9	7.6	4.4	5.8

[1] includes 1 juvenile

[2] includes 12 juveniles

[3] includes 11 juveniles

gopher densities did not differ between plots during either spring or summer censuses.

What do the data in Table 10 show about control and test areas? First, we emphasize that two lines of traps 100 m apart yield only approximate measures of species' densities. Certainly some *Perognathus formosus* occurred in Plot 12 during July 1974, but none was taken in the course of four nights of trapping. Then, too, adjustments for effective areas trapped introduced another source of error. We do not attach particular significance to the apparent difference in numbers of *Perognathus longimembris* in the two areas in April, because parity was evidently restored over the next three months. It is conceivable that the continued operation of a vehicle in the test area temporarily reduced numbers of this pocket mouse. Why only this particular species would be affected is not clear. Failure of populations to increase between April and July reflected poor reproduction in Rock Valley in 1974. Our general conclusion, based on over a decade of experience with populations of rodents in Rock Valley, is that observed numbers and trends in the two areas were essentially similar—whether considered in terms of individual species' densities or aggregate numbers.

Mean live body weights for five species of adult rodents trapped in the two areas during April and July 1974 were used in a factorial analysis of variance. Aside from obvious differences between species. The analysis showed a significant decline in body weights between April and July ($F = 54.5, F_{.01} = 4.66$) but no difference between areas ($F = 0.64$).

Reproduction by rodents occupying Plot 12 was poor in 1974. This area was trapped in mid-April and again in mid-July for the IBP census (see Maza and Turner 1975). These authors reported: "No young-of-the-year were recorded for either species of pocket mouse and only minimal signs of reproductive activity (in terms of external morphology) were observed. Reproduction by kangaroo rats and a few other species of ground squirrels and grasshopper mice occurred, but at minimal levels." These findings are in accord with a later trapping done with 24 traps during April and June of 1974, when a single juvenile ground squirrel was trapped (Table 10). On the other hand, trapping the test area in April and July 1974 revealed the presence of 23 juvenile rodents—15 ground squirrels, six heteromyids and two grasshopper mice. Here again it is hard to evaluate the observed difference between the areas in terms of possible effects of driving in the test area. The available evidence shows no indication that driving interfered with reproduction by rodents in the test area. Rather the pos-

Table 11 Estimated Numbers and Densities of Pocket Gophers (*Thomomys bottae*) in Test and Control Areas in Rock Valley During 1974.

Date	Area	Estimated Number of Gophers	Approximate Density (n/ha)
March-April 1974	Test area	19	2.1
	Plot 12	5	1.9
August 1974	Test area	7	0.8
	Plot 12	2	0.7

Table 12 Numbers of *Uta stansburiana* Enumerated and Estimated Densities in Test and Control Areas in Rock Valley.

Date	Area	Individuals Enumerated	Estimated Density (n/ha)
October 1973	Test	59	93.0
	Plot 12	73	107.3
March-April 1974	Test	73	77.8
	Plot 12	63	80.0
September-October 1974	Test	50	59.6
	Plot 12	34	49.0

sibility should be considered that the greater number of young rodents in the test area was in some way associated with the use of vehicles.

Lizards

Table 12 summarizes capture-recapture estimates and total numbers of *Uta stansburiana* registered in the test area and in Plot 12 at three times during 1973 and 1974. The data indicate a decline in numbers of lizards present (or captured) between October 1973 and September 1974. It is certainly logical that numbers should decline between the fall of 1973 and the ensuing spring. Fall densities of *Uta* are high because of recruitment of young during the summer. Furthermore, in October these lizards are big enough to be conspicuous and easily collected by hand. We cannot explain the low numbers of lizards (relative to March) present in both areas during late September 1974. It is possible that hatchling lizards were still too small to be readily observed and taken by hand. This is true during August (Turner and Gist 1965), and might have been true in 1974 if hatchling lizards emerged later than usual. The main point to be made in connection with the present experiment is that estimates of abundance in test and control areas followed similar trends.

The age distributions of the 1974 samples were essentially identical during March, with 89% of the *Uta* registered in the test area and 90% of the *Uta* in Plot 12 about 8 months of age. In September 1974 collections, 76% of *Uta* from the test area were hatchlings, but only 59% of those from Plot 12 were juveniles. It is not clear whether this difference in meaningful, but reproduction by *Uta* in the test area was apparently not impaired. During September 1974, 37 young lizards hatched during the summer were taken in the two areas. The mean weight of 20 lizards from the test area (1.61 g) did not differ from the mean weight (1.39 g) of 17 lizards from Plot 12 ($t = 1.56$).

Table 13 gives counts of two other species of lizards made in the test area and on the IBP site during May and June 1974. We computed expected counts of *Cnemidophorus tigris* and *Callisaurus draconoides* in the two areas assuming expectations to be proportional to areas. Total χ^2 for *Callisaurus* in May (8.6) indicated a highly significant departure from expectations ($p \cong 0.01$). Tests for *Cnemidophorus* revealed no significant differences in relative numbers in the two areas ($\chi^2 \cong 3.8$, $p = 0.1\text{-}0.2$).

Discussion

The exposure of portions of our study area—over a period of 6 months—to a total of 4 to 5 hours of driving by trucks affected both annual and perennial vegetation. Numbers of annuals growing in regularly driven ruts were lower than in other areas and mean densities of annuals in other driven situations were lower than in control areas (although the latter differences were not statistically significant). Shrubs in the regular track were heavily damaged, although few were killed. Some changes in apparent densities of vertebrates were not clearly interpretable, but trends of animal populations in the experimental plot were generally matched by those in control areas.

Table 13 Actual Counts (and Area-Adjusted Counts) of two Species of Lizards in Test and Control Areas in Rock Valley During 1974.

Date	*Cnemidophorus tigris* Test Area (3.6 ha)	*Cnemidophorus tigris* IBP Site (9.0 ha)	*Callisaurus draconoides* Test Area	*Callisaurus draconoides* IBP Site
May 13-14	13 (3.6)	21 (2.3)	1 (0.3)	14 (1.6)
May 15-16	6 (1.7)	26 (2.9)	2 (0.6)	16 (1.8)
May 23-24	4 (1.1)	16 (1.8)	1 (0.3)	11 (1.2)
May Means	7.7 (2.1)	21.0 (2.3)	1.3 (0.4)	13.7 (1.5)

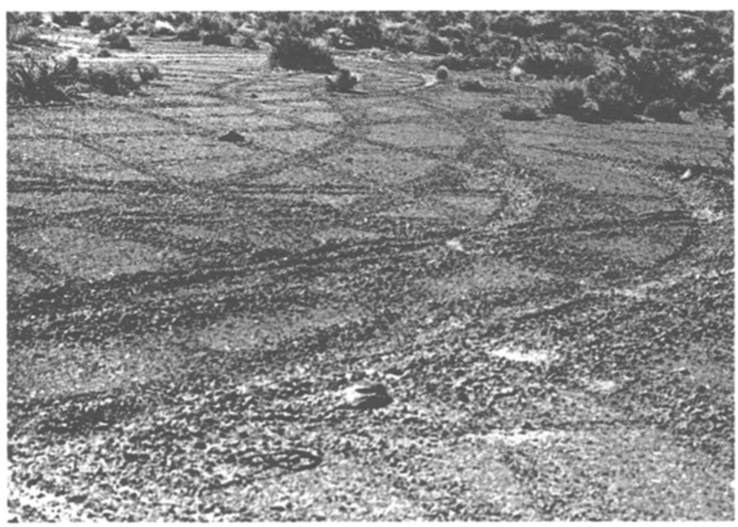
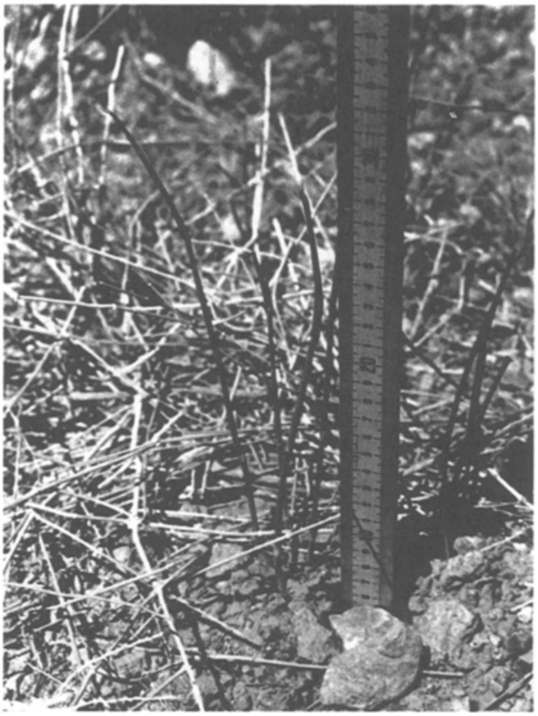


Figure 4. Truck tracks in the experimental plot: (a) Regularly driven track. (b) Disturbance of desert pavement by random driving.

When the test area was inspected in November 1975—18 months after driving ceased—little damage to shrubs was apparent from a distance. Vegetation obscured many old tracks, but when viewed from nearby both the regular track and random tracks were clearly discernible (Fig. 4). Observers agreed that the most esthetically displeasing features of the test area were open areas of desert pavement where tracks were still conspicuous. From 15 years of experience in Rock Valley we know that truck tracks can persist at least 10 to 12 years, depending on the substrate.

Damage to the soil surface is not limited to esthetics. Desert pavement, along with vegetation, shields the soft, friable soil underneath from erosion by wind and water. While the vegetation may eventually recover, the protection afforded the desert pavement is for all practical



purposes destroyed due to its slow rate of formation (Wilshire and Nakata 1976). Compaction of subsurface soil by ORVs can result in decreased soil permeability and water-holding capacity (Davidson and Fox 1974, Wilshire and Nakata 1976).

In our experiment we imposed only modest stresses and our results are not applicable to situations involving the concerted operation of large numbers of vehicles—whether for a few hours or days or longer. Our trucks were driven slowly (<20 km/hr), but ORVs are often operated at significantly higher speeds. Furthermore, our measurements extended only over a period of about a year, and we do not know what, if any, further consequences may develop in the future. Damage resulting from disruption of soils may not be fully expressed until years after the original impact (Wilshire and Nakata 1976).

The complexity of ecosystem function may make the interpretation of superficially simple effects difficult. Responses may be influenced by conditions existing just before or during the experiment. For example, our experiment began in the fall of 1973 and continued through the 1974 growing season, which was generally typical of drier years. Previous work has shown that under these conditions from 60 to 80% of new production is invested in leaves and less energy is devoted to new shoots and reproduction (Bamberg et al. 1976).

Figure 5. Basal sprouting by damaged shrubs: (a) *Ephedra nevadensis*, (b) *Larrea divaricata* (foreground) and *Lycium andersonii* (center).

There is also more variability between shrubs of the same species during a poor year. Conversely, during a year of high primary productivity relatively more energy is invested in reproductive structures and less in new leaves. Even though comparative measurements are made in control areas, these kinds of differences may influence the interpretation of experimental results.

One evident response of shrubs damaged by our vehicles was sprouting from the base (Fig. 5). This was not observed among shrubs in the control area nor in undriven parts of the test area. The amount of sprouting varied depending on severity of damage, which was related to the number of times the shrub was driven over. Some shrubs in the regular track were so damaged that sprouting was prevented. Sprouting by damaged shrubs may be greatly influenced by the time at which damage is imposed and the root carbohydrate reserves. If root carbohydrate reserves are low when stems are broken, regrowth is retarded (Donart and Cook 1970). Root reserves are low following early spring growth, and a plant damaged at this time will respond less vigorously than one damaged prior to breaking dormancy. Carbohydrate reserves are replenished if sufficient time is allowed for regrowth (Donart and Cook 1970, Bóo and Pettit 1975). Hence, repeated damage inflicted by driving a regular track could exhaust root reserves and prevent or inhibit regrowth. Shrubs in the regular track exhibited less regrowth than those in randomly driven areas.

Our study extended over a period of about a year and it is natural to inquire as to possible longer-term consequences of the driving. Are some influences only expressed after several months or years? Are some apparently minor effects intensified with passage of time? Although we cannot give precise answers to these questions, we will discuss some ideas relating to these problems. Above-ground shrub biomass decreased conspicuously in the test area as a result of the driving but few plants were killed. Hence, density and diversity (calculated from relative abundances of species) remained essentially unaltered. Resprouting from bases, the process that eventually leads to repair of damage, was evident during the spring of 1974. Beatley (1974) found that when almost all above-ground parts of creosotebush, *Larrea divaricata*, were destroyed, natural regrowth led to recovery. After 10 years the damaged plants were scarcely distinguishable from nearby plants that had not been damaged. If other desert shrubs respond with similar vigor, areas with limited damage may reestablish shrub cover within a couple of decades if there is no further damage. Vasek et al. (1975b) concluded that species of the creosotebush community ". . .are probably adapted in varying degree to continual, but relatively slight disturbance." These observations are encouraging, but they do not negate the original damage, nor the time required for repair. Then, too, neither our experiment nor Beatley's observations have much bearing on the fate of areas subjected to heavier use (e.g., see Duck 1976). In a study of effects of power line construction, Vasek et al. (1975a) observed that severely disturbed creosotebush scrub vegetation recovered significantly, but not completely, after 33 years. However the degree of recovery at different sites varied considerably. The authors concluded that the recovery rates of these desert shrub ecosystems could not be accurately predicted. After 33 years, Wells (1961) found considerable revegetation on streets of a Nevada ghost town. However, species composition differed considerably from that of an adjacent, less disturbed site. The abandoned street showed ". . .a large increase in bunchgrass and an invasion by pioneer shrubs (e.g., *Hymenoclea salsola* and *Salazaria mexicana*) which ordinarily are chiefly confined to dry washes." Vasek et al. (1975a, b) also noted pioneer shrub invasions of more heavily disturbed sites. Productivity, diversity (Johnson et al. 1975), and cover (Vasek et al. 1975a) of Mojave Desert vegetation have been found to increase along roadsides. This enhancement was, of course, accompanied by a strip devoid of vegetation.

Sprouting by damaged shrubs was observed in the test area but did not occur in control areas. This sprouting may have had some bearing on numbers of young rodents trapped in the test area during April and June 1974. For example, both Beatley (1969) and Van de Graaff and Balda (1973) reported an association between herb production and reproduction by rodents, and Chew (1975) further evaluated this work in connection with his research in Rock Valley. These analyses emphasized the role of winter annuals (or succulent green vegetation) and pertained almost entirely to heteromyid rodents. In our experiment we dealt with sprouting by perennials, and most of the juvenile rodents trapped during the spring of 1974 were antelope ground squirrels. It is important to bear in mind that sprouting by damaged shrubs was supported by energy reserves that are not inexhaustible. A short-term compensatory response of this nature cannot be sustained indefinitely. Destruction of above-ground portions of shrubs (both live and dead) will probably increase litter production and may affect rates of decomposition and mineral cycling. The short- and long-term consequences of such changes on other components of the ecosystem are not predictable at present.

In our study, which involved limited use of vehicles, we observed definite effects on vegetation. If no other deferred damage to our area occurs, we believe the vegetation will recover--although this process may require some years. Mispagel and Zembal (1976) studied areas exposed to one-time use by military vehicles and concluded that after 11 years only slight effects (on creosotebush) were still detectable. But when areas are subjected to heavy and continued use, damage to soils, plants, and animals can be enormous (Wilshire and Nakata 1976, Duck 1976, Berry 1973, Busack and Bury 1974). There is little hope of saving areas subjected to heavy chronic usage. The major questions are: how much land can be sacrificed to this purpose, and where should it be located? Once these decisions are made, we believe it important that users of recreational vehicles recognize that setting aside additional lands in the future will be stringently limited. If an area is reduced to rubble and dust it cannot be abandoned in the search for new and intact environments. We make this recommendation because we suspect that some satisfactions derived from use of ORVs are related to environmental quality, and that severely damaged areas lose their appeal. For example, Davidson (1973) observed ORV users enlarging pit areas by camping around the fringes and making new trails even though an adequate number of old trails existed. It is important to resist from the outset policies that permit the destruction and abandonment of driven areas and the continued acquisition of new ones.

ACKNOWLEDGMENTS

We thank T. Ackerman, R. Arndt, L. Byers, H. Hill, J. Parker, L. Parker, M. Skivington, and K. Sullivan, who participated in the field work. We are grateful to R.C. Stebbins, H.G. Wilshire, and K. Berry for valuable criticisms. R.I. Jennrich gave advice concerning statistical tests. We thank Y. North and M. Melchizedek for keypunching and secretarial assistance. Cooperation and support of A. Morrow of the Civil Effects Test Operations office at the Nevada Test Site is gratefully acknowledged. This study was supported under contract E (04-1) GEN-12 between the U.S. Energy Research and Development Administration and the University of California, and by the US/IBP Desert Biome Program.

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