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# EFFECTS OF OFF-ROAD VEHICLES ON THE BIOTA OF THE ALGODONES DUNES, IMPERIAL COUNTY, CALIFORNIA

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## SUMMARY

(1) The Algodones Dunes, the largest dune complex in California, contains many unique species. This dune system also receives the greatest use by off-road vehicles (ORVs).

(2) Studies of paired plots (unused *v.* ORV-used) and animal tracks along sand sweeps clearly demonstrate that ORV activities in the Algodones Dunes significantly reduced the biota.

(3) There were marked declines in herbaceous and perennial plants, arthropods, lizards and mammals in ORV-used areas compared with nearby controls. All sand-adapted species, including several plants considered rare or threatened species, were greatly reduced in habitats where ORVs operate.

(4) The biota was negatively affected even by relatively low levels of ORV activities. Areas heavily used by ORVs had virtually no native plants nor wildlife.

## INTRODUCTION

Sand dune areas constitute only 7% of the California Desert. They are disjunct in distribution and function as habitat islands for a variety of arenicolous plant and animal species. Although California sand dunes are generally geologically young (post-pluvial in age), some species are restricted to them and many species in the resident biota show distinctive adaptations. Study of these organisms provides an understanding of the nature of adaptations to extremes of temperature, drought, intense sunlight, and locomotion on a soft substrate. The Algodones Dunes (also known as the Imperial Sand Hills) in Imperial County in south-eastern California are one of the driest and hottest regions in the United States and represent one of the most severe environments inhabited by plants and animals.

Sand dunes are also centres for intense recreational use by dune buggy and other off-road vehicle (ORV) enthusiasts. Of the five major dune systems in the California Desert, four are open to vehicular recreation; the Algodones Dunes receive the greatest use. In 1969 the Bureau of Land Management estimated that on an average weekend there were 5000 dune buggies and 34 000 visitor-use-days (defined as one person spending 12 h). According to Roy Schneider, Recreation Specialist from the Bureau of Land Management's El Centro office, the total use figures for the entire dune complex in 1977 amounted to 484 147 visitor-use-days, and by 1978, had increased to 527 276 visitor-use-days. About 82% of the Algodones Dunes is currently open to unrestricted ORV-use.

The biological impact of ORV-use on creosote scrub habitat and associated animals in the Mojave Desert is significant (Bury, Luckenbach & Busack 1977). In the spring of 1977

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and 1979, studies were undertaken to determine the ecological impacts of ORV-use on the biota of the Algodones Dunes. The objective was to assess the impact on perennial and annual vegetation, on populations of invertebrates, and on the reptiles and mammals that inhabit the dunes.

## STUDY AREA

The Algodones Dunes are an accumulation of wind-blown sand derived from beach deposits of Pleistocene Lake Cahuilla (Norris & Norris 1961). The dunes are linear and oriented in a northwesterly direction (Fig. 1). They are 64 km long, between 6 and 10 km wide, and up to 100 m high. They are bounded by the Coachella Canal on the west and the Southern Pacific railroad on the east. State Highway 78 transects them in the north and Interstate 8 in the south. Low rainfall and humidity, and high summer temperatures characterize the area. The town of Niland at the north end has an average annual rainfall of 53·6 mm. Air temperatures of 40–45 °C are common in the summer months.

Four basic vegetative communities occur on the dunes: Creosote Bush Scrub, Desert Psammophytic Scrub, Desert Microphyll Woodland, and occasional open areas with scant vegetation (Thorne 1976). Creosote Bush Scrub occurs on both flanks of the dunes.

On the western edge of the dunes, dense stands of creosote bush (*Larrea divaricata*) predominate on East Mesa (Fig. 1) and these plants assume large size (up to 2 m tall). The Creosote Bush Scrub makes a transition to Desert Psammophytic Scrub on deep sands, where burro weed (*Ambrosia dumosa*) and coldenia (*Coldenia palmeri*) occur as associates of the creosote bush.

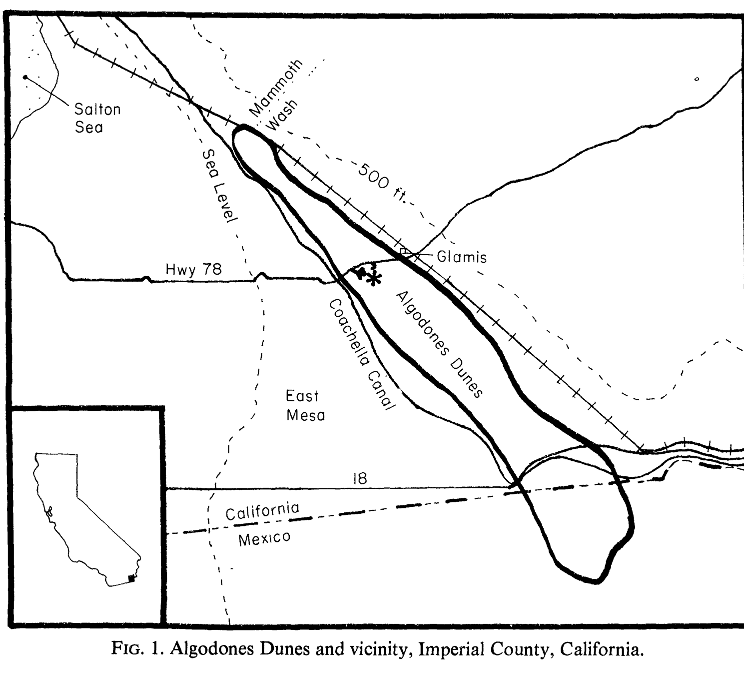


FIG. 1. Algodones Dunes and vicinity, Imperial County, California.

Creosote Bush Scrub also occurs on the alluvial aprons of the Cargo Muchacho and Chocolate Mountains, penetrating the eastern flanks of the dunes along washes. The eastern flanks have a community more typical of the Colorado Desert. Associated plants include white ratany (*Krameria grayi*), Indigo bush (*Dalea emoryi*), and cheese-bush (*Hymenoclea salsola*). Arborescent species also occur along these runoff channels and they form a Desert Microphyll Woodland. The drainage of the nearby mountains terminates in the eastern flanks of the dunes. Thus, the water table is high and water may stand on the surface for extended periods after precipitation. The Desert Microphyll Woodland interdigitates on the eastern flank of the dunes in its runoff channels, and in some areas is widespread on the dunes proper. The composition of this woodland includes phreatophytic species: desert willow (*Chilopsis linearis*), palo verde (*Cercidium floridum*), screw-bean (*Prosopis glandulosa*), and desert ironwood (*Olneya tesota*).

Although the aspect of the dunes proper is one of bleakness, nearly all of the area supports some vegetation. Most of the deep sand is covered by a low-growing Desert Psammophytic Scrub that is adapted to deep water percolation and to relatively high sand fluidity and mobility. Many of the perennial shurbs of the deep sand are endemic to the Algodones Dunes. Five of the perennials are considered either rare or endangered (California Native Plant Society 1980) and are being reviewed for possible federal protection as threatened or endangered plants: desert buckwheat (*Eriogonum deserticola*), giant Spanish needle (*Palafoxia arida* var. *gigantea*), desert sunflower (*Helianthus niveus* spp. *tephrodes*), croton (*Croton wigginsii*), and sandfood (*Ammobroma sonorae*). Other common species of Desert Psammophytic Scrub include: sandpaper plant (*Petalonyx thurberi*), panic grass (*Panicum urvilleanum*), milkvetch (*Astragalus magdalenae* var. *peirsonii*), Mormon tea (*Ephedra trifurca*), desert dicoria (*Dicoria canescens*), and coldenia (*Coldenia plicata*). In blowout depressions and more stable sand areas, evening primrose (*Oenothera deltoides*) and, occasionally, desert-lily (*Hesperocallis undulata*) occur as winter annuals, often persisting throughout the year as dried plants. Only a small fraction of the dunes normally is devoid of vegetation.

## MATERIALS AND METHODS

### *Study plots*

The study area (a transect) was located across the northern part of the dunes and adjacent to Highway 78 (Fig. 2). Six sets of paired plots were established. Five of them (A–B, C–D, G–H, I–J and K–L) were in Desert Psammophytic Scrub; C–D and K–L were in the central part of the dune system where there is deep sand (Fig. 3). Plots E–F were in Desert Microphyll Woodland (Fig. 4). Each pair consisted of an ORV-use area and a control area in undisturbed habitat (Figs 2, 3 and 4), following the techniques used by Bury *et al.* (1977). The paired plots were of equal size (see below) in comparable habitat and dune microtopography. Distances from paved roads were similar (Table 1). Within each plot separate but adjacent areas were surveyed for mammals (1 ha area) and lizards (2 ha area).

In 1977 the procedure each time was to check the control plot for 2 days, then immediately thereafter sample the comparable ORV plot for 2 days. Although weather conditions were uniform over the entire check period on each visit to the study area, we decided to do some surveys (paired plots) at the same time. Thus, in 1979 control and ORV areas were sampled simultaneously on paired plots I–J and K–L.

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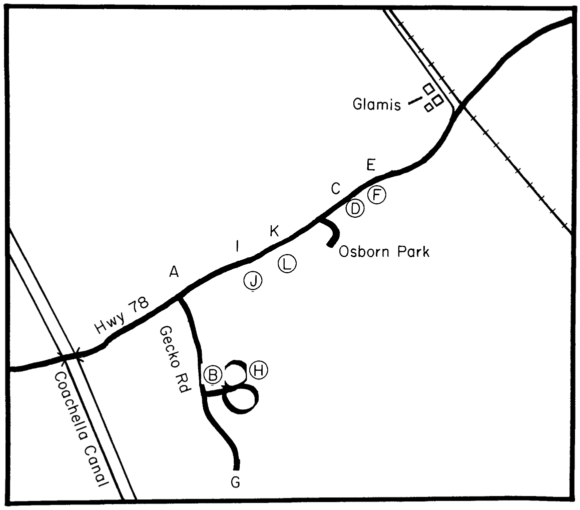


FIG. 2. Location of paired study plots. Circled letters indicate plots in ORV-use areas.

### *Vegetation*

An estimate of plant density was made on all plots by counting all perennial plants in a 10 × 100 m swath through the centre of each mammal plot. Height and canopy width of each plant was measured and volume calculated, by the formula given by Pianka (1967). Coverage was also computed. Annual vegetation was counted in a 10 × 10 m square randomly located in each plot.

### *Lizards*

Plots were 2 ha in size. On each visit, 8 man-hours were spent in search for lizards over a 2-day period. Two persons systematically walked each plot. Because temperature affects lizard activity, searches were conducted at the same time(s) each day (Table 1). In 1979, the searches were done simultaneously on the same days. Only animals collected were used in data analysis.

### *Tail loss*

To examine the relation of tail-loss frequency to ORV activity, we made a search of museum specimens to determine 'natural' tail-loss frequencies before widespread ORV usage on the Algodones Dunes. Any animals with recently lost tails, presumably lost in the act of collecting or during preservation, were not tabulated. Only those with regeneration in process were counted. These data were then compared with frequencies derived from recent specimens in museums, or animals examined in the field from the Algodones area.

### *Mammals*

Plots were 1 ha containing fifty stations (two traps per station). Museum specials (seventy-five) and rat traps (twenty-five) were set in seven lines having seven stations/line, and one extra station in the centre of the plot. Traps were baited with rolled oats and set on two consecutive nights. They were reset and baited each morning to sample diurnal species.

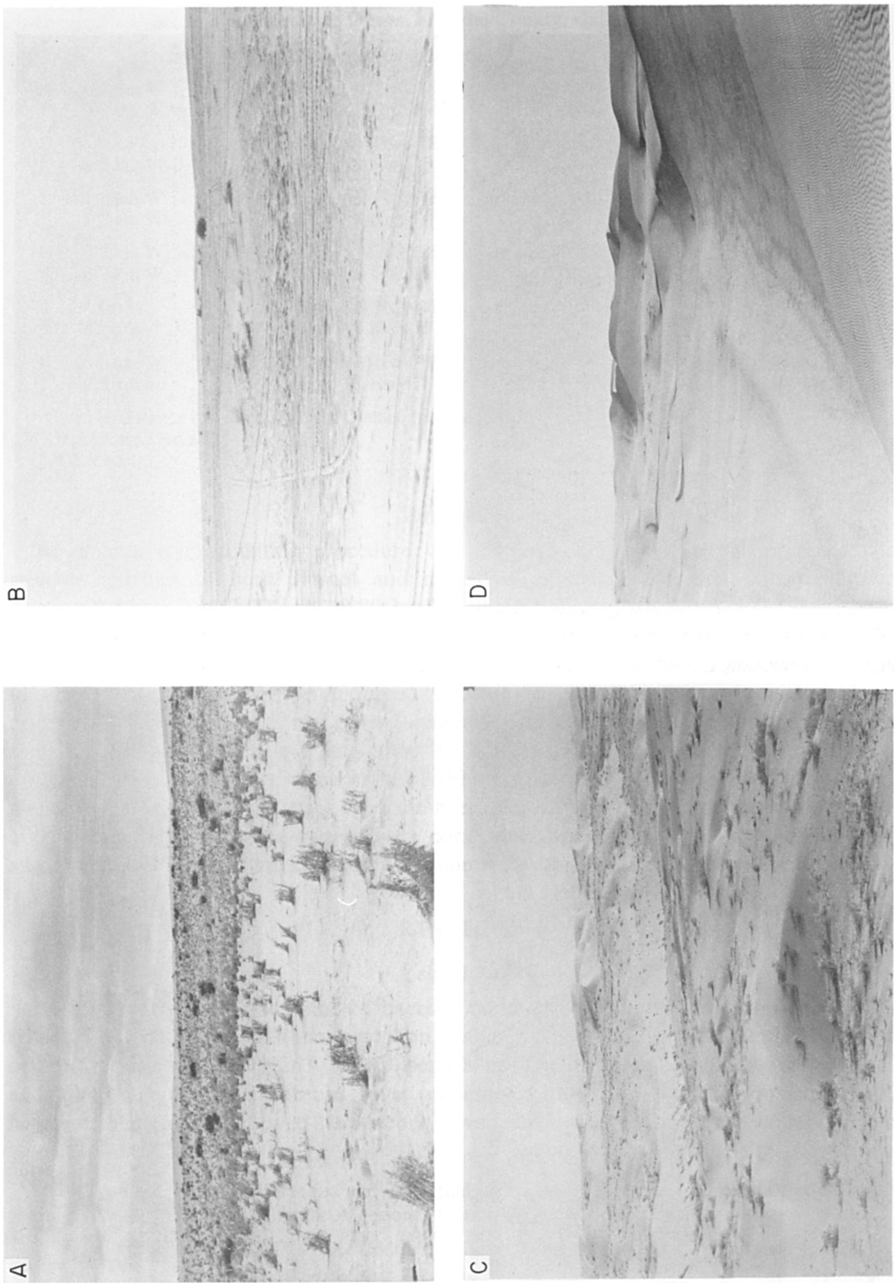


FIG. 3. Photographs of paired plots (Control: ORV). Upper: A–B; Lower: C–D.

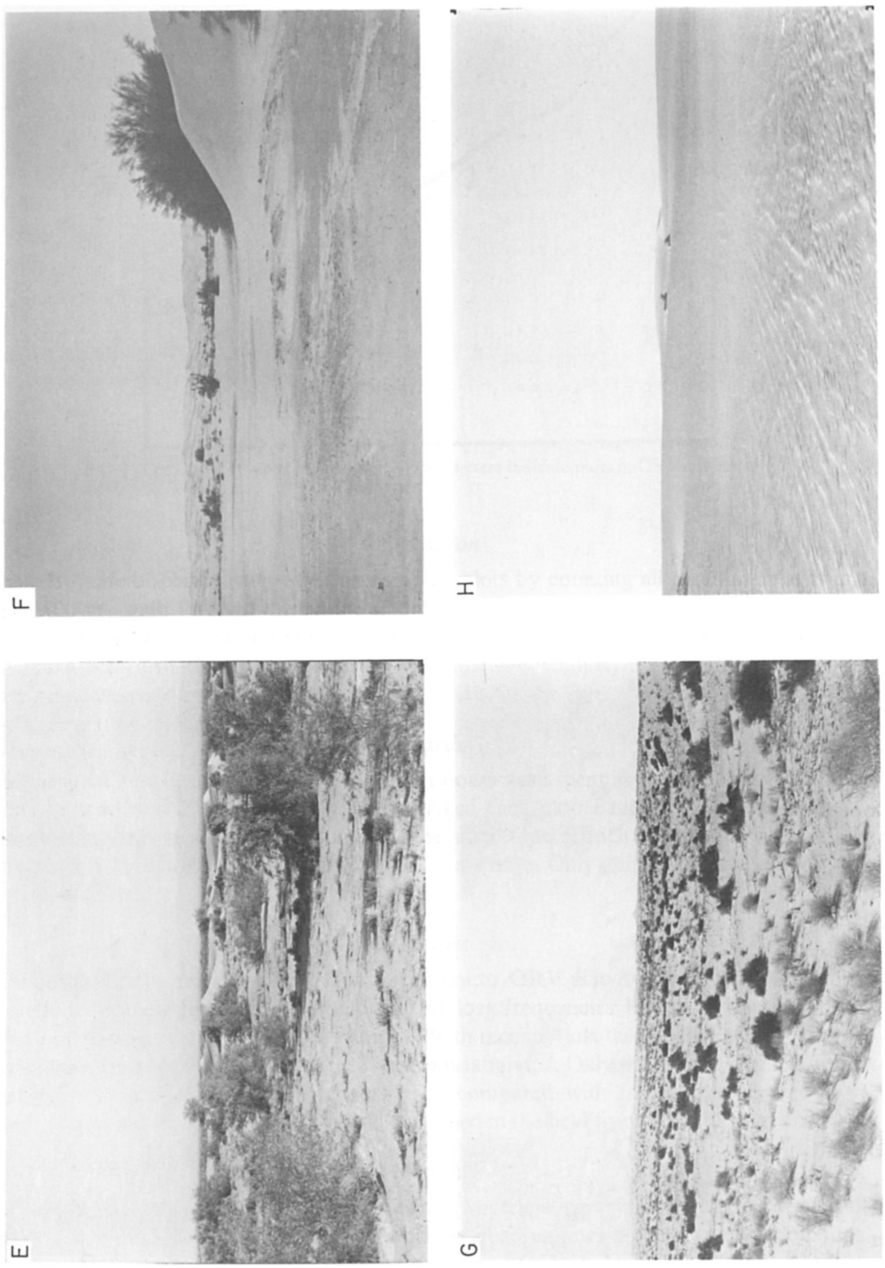


FIG. 4. Photographs of paired plots (Control:ORV). Upper: E–F; Lower: G–H.

TABLE 1. Location of study plots and times and dates of animal surveys made at the Algodones Dunes, Imperial County, California

| Plot | Location* | Distance from nearest road | | Times of surveys | Dates |
|---|---|---|---|---|---|
| A | 9·7 km W | 150 m | N Hwy 78 | 08.30–10.30 | 26–27/4/77 |
| Ⓑ | 9·7 km W, 5 km S | 100 m | E G.C. Rd.† | 08.30–10.30 | 28–29/4/77 |
| C | 6 km W | 100 m | N Hwy 78 | 08.30–10.30 | 30/4–1/5/77 |
| Ⓓ | 5·8 km W | 100 m | S Hwy 78 | 08.30–10.30; 11.00–13.00 | 3–4/5/77 |
| E | 1·6 km W | 100 m | N Hwy 78 | 08.30–10.30; 11.00–13.00 | 2–3/5/77 |
| Ⓕ | 1·8 km W | 100 m | S Hwy 78 | 08.30–10.30;11.00–13.00 | 4–5/5/77 |
| G | 9·7 km W, 9·5 km S | 100 m | S G.C. Rd.† | 10.00–12.00 | 6–7/5/77 |
| Ⓗ | 9·7 km W, 5·5 km S | 100 m | E G.C. Rd.† | 10.00–12.00 | 9–10/5/77 |
| I | 8 km W | 100 m | N Hwy 78 | 10.00–12.00 | 8–9/5/79 |
| Ⓙ | 8 km W | 100 m | S Hwy 78 | 10.00–12.00 | 8–9/5/79 |
| K | 6·6 km W | 100 m | N Hwy 78 | 10.00–12.00 | 10–11/5/79 |
| Ⓛ | 6·6 km W | 100 m | S Hwy 78 | 10.00–12.00 | 10–11/5/79 |

* Given as distance and direction from Glamis, Imperial County, California.
† Gecko Camp Road.
○, ORV plots.

### *Sand sweep*

An animal track-counting procedure was employed to determine the presence and relative activities of both diurnal and nocturnal animals. To obtain information on nocturnal forms, at 19.00 and 20.00 h (PST) each evening, we swept a 0·5 by 100 m transect clean of tracks with a broom. Tracks were then counted in the morning (07.00–08.00 h) and classified into several categories: kangaroo rat (*Dipodomys*), kit fox (*Vulpes*), cottontail rabbit (*Sylvilagus*), and reptiles (including lizards and snakes), arthropods (mostly beetles), and other (unidentified). To assess daytime activity, transects were swept again in the morning after the enumeration of the nocturnal tracks. On occasion, the large number of nocturnal arthropod tracks precluded total counts so they alone were estimated by counting tracks in five 0·3-m lengths and then extrapolating to the 100 m long transects. Sand sweeps were conducted on the same days that lizards were sampled (Table 1). Only tracks that made a complete crossing of the sweep were counted.

## RESULTS

### *Vegetation*

All six control plots had some herbaceous cover although much variation was found, reflecting the patchiness of dune vegetation (Table 2, Appendix 1). Mean number of plants on control plots was 254 $\pm$ 263 (3–693) per 100 $m^2$. On ORV-impacted areas, only plots F and J had identifiable herbaceous cover on sampled quadrats. All ORV-impacted plots, however, had some destroyed herbaceous cover which was present only as debris. The

TABLE 2. Number of species and individuals of herbaceous plants recorded in study plots (10 $m^2$) in the Algodones Dunes, Imperial County, California

| | Control | | | | | | Impacted | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | C | E | G | I | K | B | D | F | H | J | L |
| No. of individuals | 365 | 128 | 11 | 3 | 693 | 323 | 0 | 0 | 16 | 0 | 72 | 0 |
| No. of species | 6 | 3 | 3 | 2 | 2 | 3 | 0 | 0 | 2 | 0 | 1 | 0 |

TABLE 3. Comparison of shrubby vegetation recorded on 10 × 100 m quadrats on the Algodones Dunes, Imperial County, California

| Control plots ($N = 6$) | | | | Impacted plots ($N = 6$) | | | |
|---|---|---|---|---|---|---|---|
| No. of individuals | No. of species | Cover | Volume | No. of individuals | No. of species | Cover | Volume |
| 139 ± 134 (9–339) | 5·3 ± 1·5 (4–7) | 94 ± 67 (3–191) | 553 ± 688 (12–1921) | 14 ± 29 (0–66) | 2·2 ± 1·8 (0–5) | 10 ± 21 (0–53) | 14 ± 345 (0–851) |

Cover is given as $m^2$; volume as $m^3$.
Numbers are given as $\bar{x}$ ± S.D. (Range).

mean number of species on control plots was 3·2 ± 1·5 (2–6); the impacted plots F and J had only two and one species, respectively.

On control plots there was 2·4 times the number of species, ten times the density, 9·4 times the cover, and forty times the volume of shrubby perennials as compared with ORV-impacted plots (Table 3, Appendix 2 and 3).

Areas with heavy ORV damage had little or no vegetation. Impacted sites, B, D, H, and L had virtually no herbaceous cover remaining; sites D and H were also devoid of any identifiable shrubby vegetation. Because of the presence of palo verde trees and other woody vegetation which restricted ORV use, site F was the only ORV-impacted area with any appreciable intact vegetation.

### *Lizards*

Nine species were found on control plots; the fringe-toed lizard (*Uma notata*) was the most numerous. Only five species were obtained from the ORV-impacted plots; again, the fringe-toed lizard was the most abundant reptile (Appendix 4). Three control plots had more species of lizards than ORV-impacted plots; two had the same species present; and only one (C *v.* D) had fewer species (Appendix 4). A total of 234 individuals with a biomass of 2925 g were removed from control plots, but only sixty-four individuals with a biomass of 497 g were removed from the ORV-impacted plots. *Uma notata* showed the greatest differences in number of individuals: 149 were taken on control plots, whereas only thirty-one were taken on impacted plots.

TABLE 4. Comparison of lizards and rodents removed from control and ORV-impacted sites.

| Sites | Mean number of lizard species (and range) | Mean number of lizards collected (and range) | Mean wet wt (g) of lizards (and range) |
|---|---|---|---|
| Controls ($N = 6$) | 3·5 (1–7) | 39 (9–76) | 488 (15–928) |
| Impacted ($N = 6$) | 2 (1–3) | 11 (1–30) | 83 (26–197) |
| | Mean number of rodent species (and range) | Mean number of rodents collected (and range) | Mean wet wt (g) of rodents (and range) |
| Controls ($N = 6$) | 2 (1–3) | 39 (6–28) | 1483 (577–2304) |
| Impacted ($N = 6$) | 1·3 (1–3) | 7·6 (1–24) | 685 (110–2136) |

For lizards, sites were 2 ha; for small mammals, 1 ha.

For all lizards there were 1·8 times the number of species, 3·5 times the number of individuals, and 5·9 times the biomass on control plots as were taken in ORV-impacted areas (Table 4).

### *Tail loss in lizards*

Tail loss by the lizard *Uma notata* was appreciably greater on ORV-impacted areas than in undisturbed areas (Table 5). A test of percentages (Sokol & Rohlf 1969) indicated that the cumulative percentages of tail loss after 1970 in the Algodones Dunes were significantly different ($P = 0{\cdot}001$) from percentages based on lizards taken before 1970. The mean percentage of tail loss in *U. notata* collected from ORV areas (60%) is three times greater than for lizards from pre-1970 samples (20·5%) and post-1970 non-ORV areas (20%). Sample sizes are sufficient to be significantly different at the 1% level of significance (Sokol & Rohlf 1969).

TABLE 5. Tail loss in *Uma notata* from the Algodones Dunes

| Natural conditions | | | | Off-road vehicle areas | | | |
|---|---|---|---|---|---|---|---|
| Source | $N$ | With tail regeneration | % | Source | $N$ | With tail regeneration | % |
| Pre-1960 (LACM) | 114 | 21 (9♂:12♀) | 18% | Post-1970 (MVZ) | 6 | 4 (2♂:2♀) | 66% |
| Pre-1970 (MVZ) | 31 | 7 (1♂:6♀) | 23% | 1975 (RAL & MVZ) | 16 | 11 (7♂:4♀) | 69% |
| 1977-DWRC | 94 | 23 (10♂:13♀) | 24% | 1978-DWRC | 43 | 24 (12♂:12♀) | 56% |
| | 239 | 51 (20♂:31♀) | $\bar{x} = 21\%$ | | 65 | 39 (21♂:18♀) | $\bar{x} = 60\%$ |

LACM, Los Angeles County Museum of Natural History; RAL, Roger A. Luckenbach (personal collection); MVZ, Museum of Vertebrate Zoology; DWRC, Denver Wildlife Research Center (Fort Collins, Co).

### *Mammals*

There were 1·5 times the number of species, 5·1 times the number of individuals, and 2·2 times the biomass on control plots than were on ORV areas (Table 4, Appendix 5). The desert kangaroo rat (*Dipodomys deserti*) was the most common small mammal sampled and was usually the only species present on deep sand areas. The numbers of *D. deserti* sampled on ORV-impacted plots was 53% lower than those taken on the matched control plots; biomass was lower by 51%. Mean number of *D. deserti* occurring on control plots was $13{\cdot}2 \pm 8$ ($N = 79$) compared with $7 \pm 7{\cdot}5$ ($N = 42$) from ORV-impacted plots. Mean weight of individuals between control and impacted plots was not significantly different ($t$ test, $P < 0{\cdot}05$).

In two comparisons (G *v.* H and K *v.* L), there were fewer species present on the impacted plots. Three comparisons (A–B, C–D, and I–J) yielded only *D. deserti.* A pallid bat (*Antrozous pallidus*) taken on control plot E is not a resident species and thus the pair E–F also had the same number of resident species present. However, the species composition was different: *Dipodomys merrami* was only taken on the control plot (E) along with *D. deserti*; whereas *Perognathus penicillatus* were recorded from the impacted plot (F). Plot F was the only ORV-impacted plot that had more *D. deserti* present than did its control counterpart. However, when both species of *Dipodomys* occurring on plot E are pooled, then similar numbers occurred on both plots (E–F). Since *D deserti* is the larger heteromyid, the biomass on the impacted plot was greater than for the control. The number of individuals and diversity were less on the impacted plot.

*Comparison of numbers, diversity and biomass of lizards and rodents*

Pooled capture data for all parameters and paired plots are given in Table 6 and Fig. 5. There was an average of 1·9 more species of lizards and rodents, thirty-eight more individuals, and 1200 more grams of biomass on the control plots than on the impacted plots. Undisturbed plots had an average of 3·1 times the number of individuals and 2·6 times the biomass of ORV-impacted sites. The number of individuals, number of species, and biomass of these small vertebrates on control plots are significantly greater than on impacted plots (Wilcoxon's signed rank test, $\alpha = 0{\cdot}05$; Sokol & Rohlf 1969).

TABLE 6. Comparison of pooled data on density, diversity, and biomass of small terrestrial vertebrates on paired plots in the Algodones Dunes, Imperial County, California, 1977 and 1979

| Control | | | | Impacted | | | |
|---|---|---|---|---|---|---|---|
| Site | Species | Number | Total biomass (g) | Site | Species | Number | Total biomass (g) |
| A | 2 | 27 | 2151 | B | 2 | 13 | 1124 |
| C | 2 | 39 | 1062 | D | 3 | 5 | 206 |
| E | 11 | 76 | 3025 | F | 5 | 30 | 2186 |
| G | 8 | 65 | 3043 | H | 3 | 8 | 413 |
| I | 4 | 48 | 1408 | J | 4 | 22 | 239 |
| K | 4 | 82 | 1133 | L | 3 | 32 | 437 |
| $\bar{x} =$ | 5·2 | 56 | 1970 | $\bar{x} =$ | 3·3 | 18 | 768 |

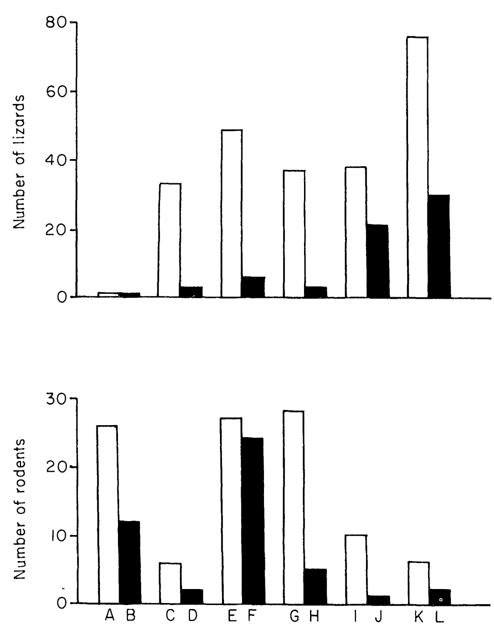


FIG. 5. Comparison of the numbers of rodents and lizards taken on control plots (□) and ORV-impacted plots (■).

### *Animal tracks*

Results of three sets of sand sweep surveys of nocturnal surface movements of animals are shown in Fig. 6. No comparisons were made for G–H because all tracks were obliterated by high winds on the nights of 7–9 May 1977. Evening winds also precluded accurate track counts during the 1979 field surveys.

Arthropod (mostly beetle) tracks were twenty-four times more abundant in control plots than in ORV-impacted plots. There was an average of five times more kangaroo rat (*Dipodomys*) tracks on undisturbed plots than on ORV-plots. Further, control areas had twice the number of kit fox (*Vulpes*) tracks and ten times the cottontail rabbit (*Sylvilagus*) tracks as ORV areas.

There were insufficient data for analysis of tracks made between morning and evening, principally because winds obscured the sweep areas but also because of vehicles running across sweeps in the ORV areas.

## DISCUSSION

### *Vegetation*

The high levels of vegetative destruction in the Algodones Dunes (Tables 2 & 3) are attributable to ORV usage. Most commonly, plants were destroyed by direct destruction or damage to the root systems of psammophytic shrubs. Vehicular traffic similarly destroys vegetation of coastal dune ecosystems (e.g. Godfrey, Leatherman & Buckley 1978; Liddle & Greig-Smith 1975a; Hosier & Eaton 1980).

Edaphic changes could also harm plants but these factors were not tested. Changes due to ORV impact may include increased bulk density (compaction), reduced porosity, altered thermal structure and reduced moisture content.

Studies of compaction on sand dunes in Wales and England, by vehicles and human trampling (Liddle & Moore 1974; Liddle & Greig-Smith 1975b) revealed that increases in soil bulk density, penetration resistance and thermal capacity were correlated with the number of vehicle passes and human treads. They also noted that passages by a vehicle increased the soil bulk density by 30% and the penetration resistance by 100% more than did the same number of passages by walkers. Vegetation removal increased diurnal soil temperature fluctuations, but compaction reduced thermal fluctuations. The combination of compaction and vegetation removal increased diurnal soil and air temperature fluctuations in trampled and vehicle-use areas.

Comparable soil effects are expected in ORV-used areas on the Algodones Dunes. The level of alteration at which these soil characteristics begin to be detrimental to the dune biota is unknown. It is likely that a change in sand moisture content would have pronounced effects on vegetation and, in turn, on the immature stages of arthropods, and egg sites and food for reptiles. Reduction of vegetation and primary production is a severe loss to the primary consumers, which inevitably leads to a disruption of the energy transfer system of the dunes. Also, destruction of root systems results in a loss of shelter and burial avenues of many invertebrate and vertebrate species.

### *Arthropods*

Judging from the numbers of tracks, a drastic reduction in beetles has apparently occurred in areas used by ORVs (Fig. 6). Such declines may be due primarily to removal of available plant food and shelter. Hardy & Andrews (1976) reported that in areas where there are pockets of accumulated vegetative material or crusted deposits, ORVs could

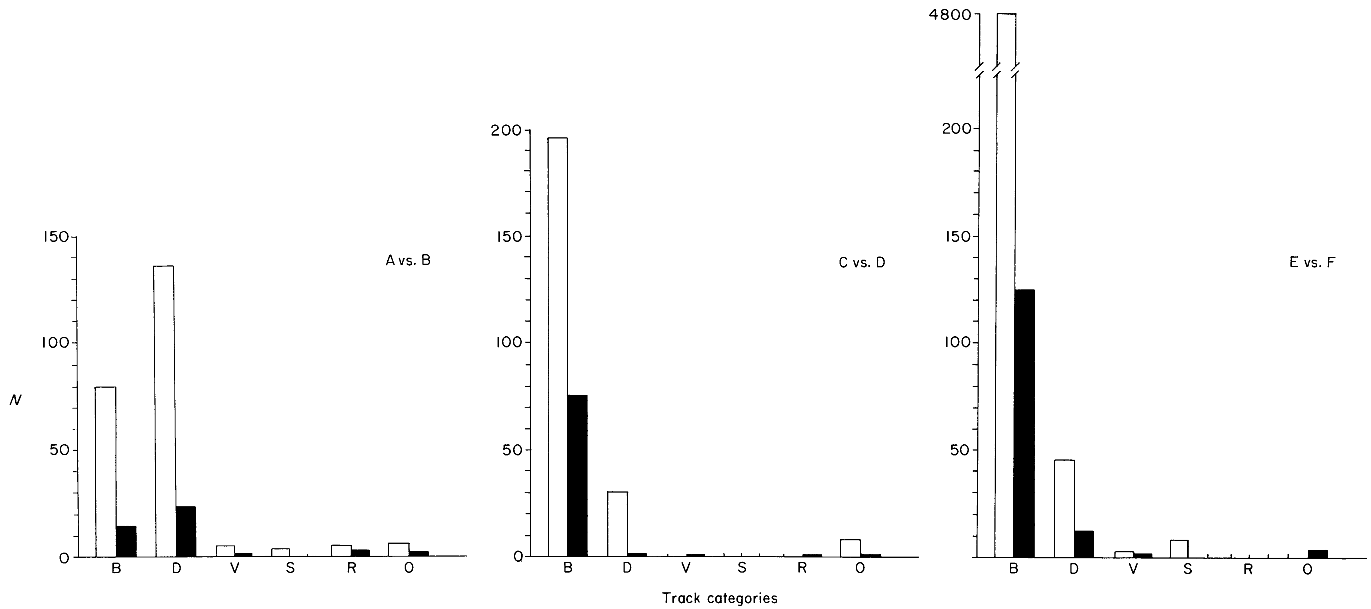


FIG. 6. Comparison of tracks recorded on 0·5 × 100 m sand sweeps: Control (□) and ORV-impacted areas (■). B = Beetles, D = *Dipodomys*, V = *Vulpes*, S = *Sylvilagus*, R = Reptiles, and O = Others.

break up the surface to such an extent that these niches for desert beetles would be destroyed. Further, they indicated that the use of ORVs on sand dunes may adversely affect the life histories of dune restricted or adapted insects in several ways. Many species only come to the surface for brief intervals during the year to breed. During this time the entire population may concentrate in an area of only a few square metres. For example, the large sand dwelling scarab, *Pseudocotalpa andrewsi*, is active on the dune surface for only 5–15 min each evening for a few weeks a year, in breeding clusters which may be only 2–3 m wide. For the rest of the year it lives buried in the sand (Stebbins 1974). ORVs probably crush many arthropods because there is considerable ORV traffic during evening and night-time hours (sunset to about 2400 h), a period of major surface activity for desert arthropods.

### *Lizards*

Few undamaged shrubs occurred on the impacted plots (Table 3). Thus a greater search effort was made at the few existing shrubs on the impacted plots than was given to individual shrubs on control plots. Further, on control plots more time was needed to cover the entire plot because the greater numbers of undamaged shrubs forced a decreased amount of time spent at each individual shrub. It is also likely that the few shrubs on impacted plots serve as refuges and thus act to concentrate lizards. In 1977, on Plot D, the only lizards encountered (two *Uma* and one *Urosaurus*) were found in the destroyed stump of an *Ephedra trifurca*. On plot J, on 8 May 1979, two-thirds of the lizards (two *Uma* and four *Urosaurus*) were removed from one undamaged *Ephedra* and its associated sand hummock.

Further, because individual shrubs occurring on ORV-impacted plots received a greater search effort than did individual shrubs occurring on control plots, the numbers of *Urosaurus* sampled on paired plots in 1979 probably do not reflect true densities. Control plots undoubtedly had many more *Urosaurus* that eluded detection because of the lesser search effort per shrub. The large amount of vegetative cover on control plots also meant that many *Uma* encountered in the census could not be taken because of the availability of retreats such as rodent burrows or heavily vegetated sand hummocks where they could bury. At the end of the 2-day census periods, the control plots still had many *Uma* escaping from collectors, whereas few *Uma* remained on the impacted plots. The low number of lizards sampled on Plot A is probably due to cooler than normal air temperatures which prevailed during the 2-day sampling period (26–27 April 1977) which restricted surface activity by lizards (Fig. 5).

### *Death and injury to lizards*

Direct evidence of death of dune reptiles due to ORV activities is frequently encountered. A total of eleven dead *Uma* were located in the course of this study (or 0·12 per man-h searching)—an unusually high rate in view of the presence of scavengers that often quickly remove them. One of the two *Uma* on ORV Plot D was found dead. Most were partly buried in the sand indicating that they had been killed in that position.

We commented elsewhere (Luckenbach & Bury in press) on the high frequency of tail autotomy of *U. notata* in areas of ORV usage. Of the four *Uma* obtained during 1977 on impacted plots (including one found partially buried in sand, dead and desiccated), three had lost their tails. Since *Uma* buries in the sand at shallow 1–6-cm depths (Stebbins 1944; Norris 1958) for cover and as an escape mechanism, they are vulnerable to crushing by passing ORVs. *Uma* often retire on east-facing slip faces at night where they are in a position to receive direct insolation from the early morning sun; these lizards are particularly vulnerable because of the popularity of these slip faces for use by dune buggies. Dune buggies thus no doubt contribute to crushing and maiming lizards buried under the sand. They may die hidden from view.

Tail loss can be expected with moderate pressures. Even light contact can cause *Uma* to cast its tail when it is excited and warm. Frequency of tail loss in lizards has been studied by several workers (Pianka 1967, 1970; Pianka & Pianka 1976; Werner 1968; Vitt *et al.* 1974; Vitt 1974; Huey & Pianka 1977). Their work demonstrated that tail loss is correlated with predator density. However, this is not the only factor that can influence it.

In addition to predation, tail loss may result from fighting between males or in courtship when a male may seize a female's tail (Carpenter 1963). Probably as a result of fighting, males usually exhibit higher frequencies of tail loss than females (Pianka 1967; Vitt *et al.* 1974; Vitt 1974). In *U. notata*, however, we found no sex differences in the frequency of tail loss. The observed major increase in frequency of tail loss in *Uma* in the Algodones Dunes seems clearly related to the increase of ORV activities in recent years.

The tail of many lizards serves in part as a food storage depot (Bellairs 1957). In two species of Australian desert skinks, Smyth (1974) found that tail-stored fat was used by females for producing eggs and by males for activities associated with reproduction. Females that had their tails removed produced fewer eggs than controls with intact tails. When fasting, both species of skinks used more fat from their tails than from any other source. Thus, it is likely that tail loss could lead to reduced survivorship and lowered fecundity in *Uma*, particularly when food is scarce or during prolonged aestivation.

Brattstrom & Bondello (1980) experimentally tested auditory evoked responses of a related lizard, *U. scoparia*, to stimuli of known intensities before and after exposure to dune buggy sounds (95 dBA) for a cumulative exposure time of 500 s. These sounds were equivalent to those actually monitored in the desert at distances of 50 m and they were sufficient to cause severe hearing loss in test animals for several days.

Pronounced reduction in numbers of the flat-tailed horned lizard (*Phrynosoma m'calli*) have been noted by scientists who have been familiar with the Algodones Dunes for many years (R. C. Stebbins and K. S. Norris, personal communications). Since these animals are slow moving and escape by shallow burial in the sand (Norris 1958), they would be expected to suffer injury and death from ORV traffic. Only three individuals were located in the course of our study (two on control plots), whereas they had been previously reported to be common within the Coachella–Imperial Valley in areas of wind-blown sand (Stebbins 1944; Norris 1949, 1958).

### *Rodents*

All rodents trapped in the present study are fossorial in their nesting and shelter requirements. Off-road vehicle usage causes destruction of rodent burrow systems. Direct mortality due to sub-surface destruction (entrapment in burrows) or crushing is difficult to evaluate but probably occurs. On ORV Plot D, a male *D. deserti* was found crushed on the surface next to a partially destroyed *Ephedra* shrub. In the Algodones Dunes, kangaroo rats tend to locate burrow complexes in areas of blowouts on lee sides of ridges or on incipient barchans. Sand grains are sorted in blowout depressions and afford the best burrowing locations. Blowout depressions also receive a high concentration of dune buggy use because the slopes are 'challenges' to vehicle use. As a result, many large colonies of *D. deserti* have been driven over.

Alteration of bulk density and destruction of the surface crust of the sand in areas of heavy ORV usage may prevent rodents from successfully constructing burrows and negate recolonization from less disturbed populations in adjacent areas.

The lower number of kangaroo rats sampled in 1979 than in 1977 is probably a result of decreased surface activity during and near the time of the full moon (11 April) in 1979. Strong night-time winds also occurred on all evenings when rodents were sampled in 1979. These winds may have caused a reduction in above-ground activity by kangaroo rats.

The highest levels of mammal diversity were at sites E–F and are associated with the greater habitat heterogeneity of the Microphyll Woodland habitat of these sites.

### *Relation between perennial vegetation and animal numbers and diversity*

We found several correlations between the number of individuals and the number of species, and three measurements of perennial vegetation (Table 7). The total number of individuals of lizards and rodents combined were positively correlated ($P < 0{\cdot}05$) with all measurements of perennial vegetation. The total number of lizards was positively correlated with the density and coverage of perennial vegetation ($P < 0{\cdot}05$) and the total number of species sampled was correlated only with the total volume of perennial vegetation ($P < 0{\cdot}05$). The appropriate linear regressions for the terrestrial fauna are

TABLE 7. Comparison of vertebrate fauna sampled on the Algodones Dunes, Imperial County, California, and measures of perennial vegetation

| | Perennial vegetation | | |
|---|---|---|---|
| | Density | Coverage | Volume |
| Total no. of lizards | 0·78* | 0·88* | 0·41 |
| Total no. of rodents | 0·12 | 0·02 | 0·76* |
| Total no. of individuals | 0·73* | 0·94* | 0·63* |
| Total no. of species | 0·26 | 0·19 | 0·86* |

* Correlation coefficient ($r$: $P < 0{\cdot}05$).

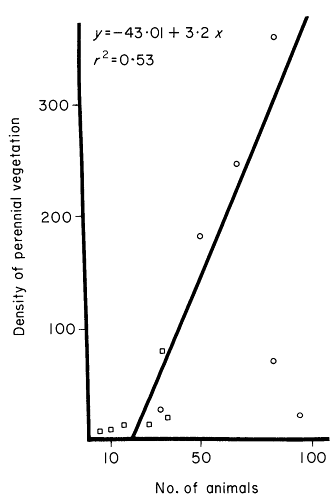


FIG. 7. Relation of the number of animals (reptiles and mammals) and the density of perennial vegetation on paired study plots. ○, control plots; □, ORV-impacted plots.

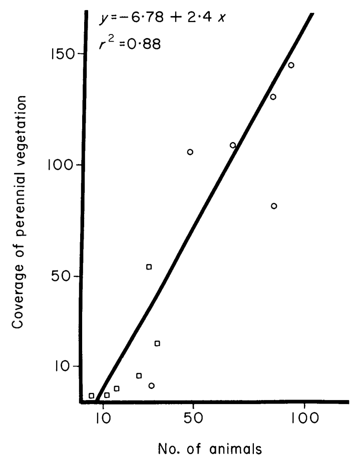


FIG. 8. Relation of the number of animals (reptiles and mammals) and the coverage of perennial vegetation on paired study plots. ○, control plots; □, ORV-impacted plots.

shown in Figs 7 and 8. There is a clear relation between the number of small vertebrates and the density and coverage of perennial vegetation.

These correlations indicate that the vertebrate fauna of the Algodones Dunes responds more to changes in volume of available perennial vegetation than to either changes in coverage or density. For small rodents, volume of vegetation is perhaps the best single measure of seed production and hence food availability. Likewise, volume of vegetation determines the primary production on which most dune arthropods depend. The arthropods in turn are fed upon by lizards. Initial direct damage to shrubs by vehicular use causes a reduction in volume rather than changes in coverage or density. Thus small vertebrates that live on the dunes are probably reduced by even minor levels of ORV use and initial vegetation volume alterations.

## CONCLUSIONS

The findings of this study clearly demonstrate that ORV activities in the Algodones Dunes are highly detrimental to dune biota. Both herbaceous and shrubby perennial vegetation are greatly reduced in habitats where ORVs operate. The sand-adapted desert kangaroo rat (*D. deserti*) and fringe-toed lizard (*U. notata*) are severely reduced in areas frequently used for ORV recreation. Judging from information obtained on tracks, there also is a marked decline in the number of arthropods in ORV-used areas.

The total number of vertebrate species sampled on paired plots was positively correlated with the total volume of perennial vegetation ($P < 0{\cdot}05$). Since volume of vegetation is altered by vehicular activity before either coverage or density, we conclude that even minor levels of ORV use can cause a reduction in the biota of dunes ecosystems.

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APPENDIX 1. Number of species and individuals of herbaceous plants recorded in study plots (10 m$^2$) in the Algodones Dunes, Imperial County, California

| | Control | | | | | | Impacted | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | A | C | E | G | I | K | B | D | F | H | J | L |
| *Oenothera deltoides* | 357 | 1 | 2 | 1 | | 25 | * | * | 15 | | | * |
| *Cryptantha angustifolia* | 1 | | | | | | | | | | | |
| *Langloisia matthewsii* | 3 | | | | | | | | | | | |
| *Ammobroma sonorae* | 1 | | | | 2 | 1 | | | | | | |
| *Orobanchie ludoviciana* | 2 | | | | | | | | | | | |
| *Abronia villosa* | 1 | | | | | | | | | | | |
| *Panicum urvillcanum* | | 123 | | | | | | * | | | | |
| *Mentzelia multiflora* | | | | | | | | | 1 | | | |
| *Dicoria canescens* | | | | | 691 | 297 | | | | | 72 | * |
| *Datura discolor* | | | 2 | | | | | | | | | |
| Unidentified | | 4 | 7 | 2 | | | * | * | * | * | * | * |
| No. of individuals | 365 | 128 | 11 | 3 | 693 | 323 | | | 16 | | 72 | |
| No. of species | 6 | 3 | 3 | 2 | 2 | 3 | | | 2 | | 1 | |

* Present as debris only.

APPENDIX 2. Shrubby vegetation on control sites in the Algodones Dunes, Imperial County, California, measured on a 10 × 100 m quadrat

| Sites: | A | | | C | | | E | | | G | | | I | | | K | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | D | C | V | D | C | V | D | C | V | D | C | V | D | C | V | D | C | V |
| *Ephedra trifurca* | 4 | 1·8 | 5·5 | | | | | | | 14 | 14·2 | 321·1 | | | | | | |
| *Helianthus niveus* spp. *tephrodes* | 2 | 0·1 | 0·1 | 10 | 7·5 | 7 | | | | 3 | 2·4 | 3·1 | (2*) 1 | 0·4 | 1·5 | 12 | 3·4 | 10·9 |
| *Palafoxia arida* var. *gigantea* | | | | 9 | 14·9 | 113·5 | | | | 3 | 2·4 | 28·3 | 30 | 20·3 | 3·6 | 130 | 130 | 95·9 |
| *Croton wiginsii* | 1 | 0·8 | 3·4 | | | | | | | 12 | 7·9 | 28·8 | 35 | 12·3 | 28·1 | 8 | 2·1 | 5·4 |
| *Eriogonum deserticola* | | | | 26 | 56·9 | 206·3 | 1 | 0·4 | 2·9 | 20 | 34·6 | 69·4 | 67 | 20·6 | 171·8 | 48 | 53·7 | 255·8 |
| *Larrea divaricata* | | | | | | | 2 | 10·2 | 146·6 | | | | | | | | | |
| *Petalonyx thurberi* | | | | | | | | | | | | | 10 | 3·5 | 23·7 | 1 | 0·3 | 1·2 |
| *Astragalus magdalenae* var. *peirsonii* | | | | | | | | | | | | | | | | 2 | 0·1 | 0·2 |
| *Cercidium floridum* | | | | | | | 2 | 91·9 | 829·4 | | | | | | | | | |
| *Chilopsis linearis* | | | | | | | 4 | 49·5 | 942·5 | | | | | | | | | |
| *Dalea emoryi* | 8 | 0·4 | 3 | | | | | | | 2 | 6·3 | 16·8 | | | | | | |
| *Coldenia plicata* | | | | 13 | 1·6 | 0·2 | | | | 191 | 13·5 | 2·4 | 26 | 0·4 | 0·1 | 138 | 1·1 | 10·9 |
| Totals | 15 | 3·1 | 12 | 58 | 80·9 | 327 | 9 | 152 | 1921·4 | 245 | 81·3 | 469·9 | 169 (2*) | 57·5 | 228·8 | 339 | 190·7 | 380·3 |

D, density (number per quadrat); C, coverage (m²); V, volume (m³). * Present as debris only.

APPENDIX 3. Shrubby vegetation on ORV-impacted sites in the Algodones Dunes, Imperial County, California, measured on a 10 × 100 quadrat

| Sites: | (B) | | | (D) | | | (F) | | | (H) | | | (J) | | | (L) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | D | C | V | D | C | V | D | C | V | D | C | V | D | C | V | D | C | V |
| *Ephedra trifurca* | | | | (1*) | | | | | | | | | (2*) | | | | | |
| *Helianthus niveus* spp. *tephrodes* | | | | | | | | | | | | | | | | | | |
| *Palafoxia arida* var. *gigantea* | | | | | | | 1 | 0·1 | 1·1 | | | | 2 | 0·2 | 0·2 | | | |
| *Croton wigginsii* | 2 | 0·4 | 1·1 | | | | | | | | | | | | | 3 | 0·5 | 1·5 |
| *Eriogonum deserticola* | | | | | | | 3 | 1·4 | 3·9 | | | | 3 | 1·8 | 9·8 | 1 | 1·1 | 20·1 |
| *Larrea divaricata* | | | | | | | 2 | 3·3 | 8·1 | | | | (5*) | | | | | |
| *Petalonyx thurberi* | | | | | | | | | | | | | | | | | | |
| *Astragalus magdalenae* var. *peirsonii* | | | | | | | | | | | | | | | | 62 | 4·4 | 7 |
| *Cercidium floridum* | | | | | | | 6 | 39·5 | 781·2 | | | | | | | | | |
| *Chilopsis linearis* | | | | | | | 1 | 9·1 | 57 | | | | | | | | | |
| *Dalea emoryi* | | | | | | | | | | | | | | | | | | |
| *Coldenia plicata* | | | | | | | | | | | | | | | | | | |
| Totals | 2 | 0·4 | 1·1 | 0 (1*) | 0 | 0 | 13 | 53·4 | 851·3 | 0 | 0 | 0 | 5 (7*) | 2·0 | 10 | 66 | 6·0 | 28·6 |

D, density (number per quadrat); C, coverage ($m^2$); V, volume ($m^3$). * Present as debris only.

APPENDIX 4. A comparison of lizards removed from control (undisturbed) and ORV impacted sites. Each site consists of 2 ha

| Site | Species | N (♂:♀:J) | Wt (g) | Sp. |
|---|---|---|---|---|
| A | *Uma notata** | 8* — | — | |
| | *Callisaurus draconoides** | 1* — | — | |
| | *Phrynosoma m'calli* | 1 ( 1: 0:0) | 15 | |
| | | 1 (9*) | 15 | 1 (3*) |
| C | *Uma notata* | 33 (15:15:3) | 485·5 | 1 |
| E | *Uma notata* | 5 ( 2: 2:1) | 92 | |
| | *Urosaurus graciosus* | 20 ( 9:11:0) | 72·4 | |
| | *Dipsosaurus dorsalis* | 14 ( 3: 7:4) | 638·5 | |
| | *Cnemidophorus tigris* | 7 ( 3: 4:0) | 106 | |
| | *Phrynosoma m'calli* | 1 ( 1: 0:0) | 12 | |
| | *Uta stansburiana* | 1 ( 0: 1:0) | 3·9 | |
| | *Coleonyx variegatus* | 1 ( 0: 1:0) | 4 | |
| | | 49 (18:26:5) | 928·8 | 7 |
| G | *Uma notata* | 23 (10:12:1) | 500·5 | |
| | *Urosaurus graciosus* | 2 ( 0: 2:0) | 4 | |
| | *Cnemidophorus tigris* | 3 ( 1: 2:0) | 51·5 | |
| | *Callisaurus draconoides* | 5 ( 1: 3:1) | 43·4 | |
| | *Gambelia wislizenii* | 4 ( 3: 1:0) | 140 | |
| | | 37 (15:20:2) | 739·4 | 5 |
| I | *Uma notata* | 27 (13:13:1) | 242·3 | |
| | *Urosaurus graciosus* | 9 ( 5: 4:0) | 29·1 | |
| | *Coleonyx variegatus* | 2 ( 2: 0:0) | 16·2 | |
| | | 38 (20:17:1) | 287·6 | 3 |
| K | *Uma notata* | 61 (25:36:0) | 425·2 | |
| | *Urosaurus graciosus* | 15 (10: 5:0) | 43·4 | |
| | | 76 (35:41:0) | 468·6 | 2 |

| Site | Species | N (♂:♀:J) | Wt (g) | Sp. |
|---|---|---|---|---|
| Ⓑ | *Uma notata* | 1 ( 1: 0:0) | 26 | 1 |
| Ⓓ | *Uma notata* | 2 ( 2: 0:0) | 70·5 | |
| | *Urosaurus graciosus* | 1 ( 0: 1:0) | 2·8 | |
| | | 3 ( 2: 1:0) | 73·3 | 2 |
| Ⓕ | *Urosaurus graciosus* | 3 ( 1: 1:1) | 38·3 | |
| | *Cnemidophorus tigris* | 3 ( 3: 0:0) | 11·7 | |
| | | 6 ( 4: 1:1) | 50·0 | 2 |
| Ⓗ | *Urosaurus graciosus* | 2 ( 1: 1:0) | 11·5 | |
| | *Phrynosoma m'calli* | 1 ( 1: 0:0) | 9·2 | |
| | | 3 ( 2: 1:0) | 20·7 | 2 |
| Ⓙ | *Uma notata* | 7 ( 3: 4:0) | 82·6 | |
| | *Urosaurus graciosus* | 13 ( 7: 6:0) | 40·3 | |
| | *Coleonyx variegatus* | 1 ( 1: 0:0) | 6 | |
| | | 21 (11:10:0) | 128·9 | 3 |
| Ⓛ | *Uma notata* | 21 (10:11:0) | 171 | |
| | *Urosaurus graciosus* | 9 ( 5: 4:0) | 26 | |
| | | 30 (15:15:0) | 197 | 2 |

* Observed, not removed.
Wt, weight in grams; Sp, number of species.

APPENDIX 5. A comparison of small mammals removed from control and ORV impacted sites. Each site is 1 ha

| Control | | | | | Impacted | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Site | Species | N (♂:♀:J) | Wt (g) | Sp. | Site | Species | N (♂:♀:J) | Wt (g) | Sp. |
| A. 25–26 April 1977 | | | | | (B.) 27–28 April 1977 | | | | |
| | *Dipodomys deserti* | 26 (12:14:0) | 2136 | 1 | | *Dipodomys deserti* | 12 ( 7: 5:0) | 1098 | 1 |
| C. 29–30 April 1977 | | | | | (D.) 3–4 May 1977 | | | | |
| | *Dipodomys deserti* | 6 ( 5: 1:0) | 577 | 1 | | *Dipodomys deserti* | 2 ( 1: 1:0) | 133 | 1 |
| E. 1–2 May 1977 | | | | | (F.) 3–4 May 1977 | | | | |
| | *Dipodomys deserti* | 13 (10: 3:0) | 1211 | | | *Dipodomys deserti* | 20 ( 8:12:0) | 1841 | |
| | *Dipodomys merriami* | 4 ( 2: 2:0) | 144 | | | *Perognathus penicillatus* | 2 ( 2: 0:0) | 34 | |
| | *Spermophilus tereticaudus* | 9 ( 5: 4:0) | 727 | | | *Spermophilus tereticaudus* | 2 ( 0: 2:0) | 258 | |
| | *Antrozous pallidus* | 1 ( 0: 1:0) | 14·5 | | | | 24 (10:14:0) | 2136 | 3 |
| | | 27 (17:10:0) | 2096·5 | 4 | | | | | |
| G. 6–7 May 1977 | | | | | (H.) 8–9 May 1977 | | | | |
| | *Dipodomys deserti* | 19 (11: 8:0) | 1899 | | | *Dipodomys deserti* | 5 ( 0: 5:0) | 393 | 1 |
| | *Dipodomys merriami* | 1 ( 0: 1:0) | 38·5 | | | | | | |
| | *Spermophilus tereticaudus* | 8 ( 6: 2:0) | 366·5 | | | | | | |
| | | 28 (17:11:0) | 2304 | 3 | | | | | |
| I. 7–8 May 1979 | | | | | (J.) 8–9 May 1979 | | | | |
| | *Dipodomys deserti* | 10 ( 5: 5:0) | 1120 | 1 | | *Dipodomys deserti* | 1 ( 1: 0:0) | 110 | 1 |
| K. 10–11 May 1979 | | | | | (L.) 10–11 May 1979 | | | | |
| | *Dipodomys deserti* | 5 ( 2: 3:0) | 494 | | | *Dipodomys deserti* | 2 ( 2: 0:0) | 240 | 1 |
| | *Spermophilus tereticaudus* | 1 ( 1: 0:0) | 170 | | | | | | |
| | | 6 ( 3: 3:0) | 664 | 2 | | | | | |

Wt, weight in grams; Sp., number of species.