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Comparison of Desert Tortoise (*Gopherus agassizii*) Populations in an Unused and Off-Road Vehicle Area in the Mojave Desert

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Abstract. – We examined habitat, abundance, and life history features of desert tortoises (*Gopherus agassizii*) on two nearby 25-ha plots in the western Mojave Desert. An unused, natural plot had 1.7 times the number of live plants, 3.9 times the plant cover, 3.9 times the number of desert tortoises, and 4 times the active tortoise burrows than a nearby area used heavily by off-road vehicles (ORVs); these differences between the plots were all statistically significant. Further, the few large-sized tortoises in the ORV plot had less mass than those in the unused area. Although the scope of this study was limited to one paired-plot comparison, current data suggest that the operation of ORVs in the western Mojave Desert results in major reductions in habitat and tortoise numbers, and possibly the body mass of surviving tortoises. Recent ORV activities in the unused area negated our original design for a long-term comparison of tortoises in two relatively large, nearby control vs. treatment plots. Operation of ORVs is now a major recreation in the southwestern USA and its effect on wildlife merits increased research studies and management attention to better protect remaining natural resources.

Key Words. – Reptilia; Testudines; Testudinidae; *Gopherus agassizii*; tortoise; population sizes; burrows; off-road vehicles; conservation; Mojave Desert; California; USA

The desert tortoise (*Gopherus agassizii*) is a large herbivorous reptile occurring in southwestern deserts of North America. Many populations of the species have experienced declines in the Mojave Desert (Berry, 1986a; Bury and Corn, 1995; Lovich and Bainbridge, 1999; Freilich et al., 2000). The tortoise is of high interest to the public, fully protected by California law, and is listed as a Federal threatened species in the Mojave portion of its range (U.S. Dept. of Interior, 1989). In the southwestern United States, operation of off-road vehicles (ORVs) is a major regional activity that degrades the landscape (Kockelman, 1983a, 1983b). For example, dust plumes covering 1700 km^2 have been detected by satellite imagery, and the cause of several of these was related to ORV activities that destabilized the surface (Bowden et al., 1974; Nakata et al., 1976). Desert soils and vegetation are highly vulnerable to disturbance by ORV use and may require decades for recovery from damage (Webb and Wilshire, 1983). In particular, herbaceous plants are greatly reduced in areas with heavy use by recreational vehicles (Davidson and Fox, 1974; Adams et al., 1982a, 1982b; Luckenbach and Bury, 1982). The Mojave Desert in California is one of the most accessible aridlands in the world because about 50% of the land is within 1.6 km of a road or trail (95% is within 4.8 km) and there are 15 million visitor-use-days or more per year (Bureau of Land Management, 1980). In California deserts, Berry (1986a, 1989) indicated that ORV-use areas occurred on 67% of the habitats where tortoise densities are high (> 97 tortoises/km^2). Recently, Lovich and Bainbridge (1999) stated that a major restoration program to improve recovery for just ORV-damaged areas in the California desert region could exceed one billion dollars.

Although the use of ORVs is one factor suspected to be a threat to survival of tortoises and their habitats (Bury and Marlow, 1973; Vollmer et al., 1976; Berry, 1978, 1989; Luckenbach, 1982; Bury et al., 1994; Lovich and Bainbridge, 1999; Easthouse, 2000), there is little empirical evidence to support these contentions beyond obvious loss of desert ecosystems by human activities. To our knowledge, there is only one published study comparing the effects of ORVs on desert tortoises. Earlier, we studied small mammal and reptile populations in unused and ORV-impacted areas in the western Mojave Desert (Bury et al., 1977). Included in reptile surveys of 2-ha plots, we found 21 tortoises in 8 pristine areas (mean = 2.6 tortoises/ha) but only 5 in 8 ORV plots (mean = 0.6 tortoises/ha). Results suggested that ORVs detrimentally affect wildlife populations in shrub communities of the Mojave Desert, and that the decrease in the fauna (including desert tortoises) was correlated with the level of ORV activities.

The objective of the present study was to examine and compare vegetation and population features of tortoises in an unused and ORV-disturbed site on large-sized plots of 25 ha each.

METHODS

Study Area. — We established two 25-ha plots off Sidewinder Road, 11 km southwest of Barstow, San Bernardino Co., California (Figs. 1–2). The ORV-used plot (T.8N, R.2W, Sec. 3, NW1/4) was east of Interstate 15, and the unused area (T.9N, R.2W, Sec.32, NE1/4) was west of I-15. The centers of the two plots were 2.5 km apart, and we considered them similar (pretreatment state) because they are in close proximity to each other, occur at about the same elevations (unused, 747–757 m; ORV-area, 774–786 m), both slope gently to the N or NW, and likely had comparable vegetation prior to the advent of ORV use.

Each plot was divided into 1-ha sections using an engineering transet/compass to determine bearings. We measured off distances with a 25 m piece of rope. Then, we temporarily placed 2-3 m tall poles with flagging at 50 and 100 m marks along outside lines and one in the center of each section to enable plotting locations of burrows and tortoises on a grid (see Bury and Luckenbach, 1977).

Burrows. — We counted tortoise burrows on both plots, and we defined these as dug shelters at least as deep or deeper into the soil as the width of the hole. We used a meter stick and tree calipers to measure the burrow height (distance between floor and roof at the entrance), width (maximum distance across mouth), and depth (edge of mouth to farthest depth). We identified two types of burrows: an active burrow had recent tortoise sign (tracks, fresh scats, open entrance) and were domes (semi-circles) in cross-section with sides scraped clean, whereas inactive burrows lacked these signs of use and often were obstructed with debris or overgrown with spider webs. Burrow width is correlated to the carapace width of the individual tortoise (Luckenbach, 1982; Morafka, 1982), but the burrow width may increase somewhat due to wear along the sides (Burge, 1978). Pallets are defined as roofless depressions or shallow burrows (depth less than width) that appeared to be dug by tortoises; only pallets > 5 cm deep were recorded.

Vegetation. — We recorded the number of perennial shrubs within one belt transect (10 m x 500 m) which ran across the middle of each plot along the east-to-west axis. We also estimated plant cover using the equation Area = πr^2 by measuring the average diameter (then dividing by 2 for the radius) of shrubs and perennials in the first and last 100 m of each transect (0–100 m and 400–500 m).

Tortoise Surveys. — We systematically searched plots by walking with 1 or 2 observers on routes parallel to and about 4–5 m from the last search route (or other person). The bases of creosote shrubs (*Larrea divaricata*) were observed at close range (1–2 m) because tortoises and their sign often are present under plant cover. A small hand mirror illuminated burrows to differentiate between rodent holes (round shape) and small tortoise burrows (crescent-shaped roofs, flat floors).

We found tortoises in the open or extracted them from burrows by hand, but some burrows were > 1 m deep and could not be searched. Captured animals were measured, weighed, marked with notches in the marginal scutes, painted with a number on the posterior of the shell, and immediately released where found. We measured straight-line carapace length (CL) and mid-body carapace width (CW) in mm, and mass (g) with field Pesola scales. We excluded measurement time from the search time.

We searched the ORV-used area from 13–17 May 1976, and the unused area on 18–24 May 1976 (eastern 12.5 ha) and 22–25 May 1977 (western 12.5 ha). Amount of time in each area varied somewhat as it took more time to search the more complex plant community in the unused plot. We revisited each plot on two later trips. The ORV area was revisted and searched 26 May 1977 (12.5 person-h) about one year after the initial study, but the unused site was checked 27–28 May 1977 (15 person-h) soon after the completion of the first complete search. These revisits were fast walks through the plots with spacing of observers 10–15 m apart. In 1985, we revisited both plots and new ORV trails were found across the previously unused plot, which may compromise its value as a long-term study site of undisturbed tortoise habitat.

Statistical Analyses. — We used the Chi-square test (χ^2) to test for differences between the number of perennial plants, tortoises, and burrows between the ORV-used (= treatment) and unused plot (= control). Differences were considered significant at $p < 0.05$. We used analysis of variances (ANOVA, ANCOVA) to test for differences in body mass of tortoises calculated from slopes of mass to plastron length. No tests are provided for obvious differences. In southern Nevada, Medica et al. (1975) found that tortoise mass is related to plastron length (r = 0.96) and described this in the equation: mass (g) = $0.000258X^{2.98}$ where X is the plastron length in mm. We used the same formula to determine the relationship of body mass to shell length.

RESULTS

Vegetation. — There were significantly more (1.7x) live perennials on the 10 x 500 m transects in the unused plot ($n = 439$) as on the ORV-used area ($n = 252$). The number of dead perennials was 2.4x greater on the ORV-plot ($n = 244$) than the unused area ($n = 102$). Most (75%) of the dead material was burroweed, *Ambrosia dumosa*, with most in the ORV-used plot ($n = 183$) compared to the unused area ($n = 102$). The dominant perennial was creosote bush (*Larrea divaricata*). Although the number of live shrubs ($n = 192$) on the unused plot was about 15% greater than on the used area ($n = 162$), the difference was not significant. However, all creosote on the unused area were alive and intact, but 61 bushes (37.7% of total *Larrea*) on the ORV-used plot were dead (mounds of rubble, stems, and broken branches). Still, the number of live plus dead creosote were not statistically different on the unused ($n = 192$) and ORV plot ($n = 223$). Other shrubs and perennials included turpentine-brush (*Acamptopappus* spp), box-thorn (*Lycium* spp.), Mormon tea (*Ephedra* spp.), and ratany (*Krameria* spp.), and their total numbers were significantly different between the unused ($n = 95$) and ORV-used plot ($n = 12$). Plant cover was much greater in the unused area (146.3 m^2) than in the ORV plot (37.4 m^2). The amounts of perennial cover other than creosote were 24.7 m^2 for the unused area, and 1.8 m^2 for the ORV plot.

Tortoise Abundance. — We spent more time in the unused area (58:35 person-h) than in the ORV-used plot (16:00 person-h) on the first surveys. Time differences were due to the more complex plant community in the unused plot requiring extra search effort. There were significantly more tortoises (mean = 1.25 tortoises/ha; $n = 31$) on the unused plot than in the

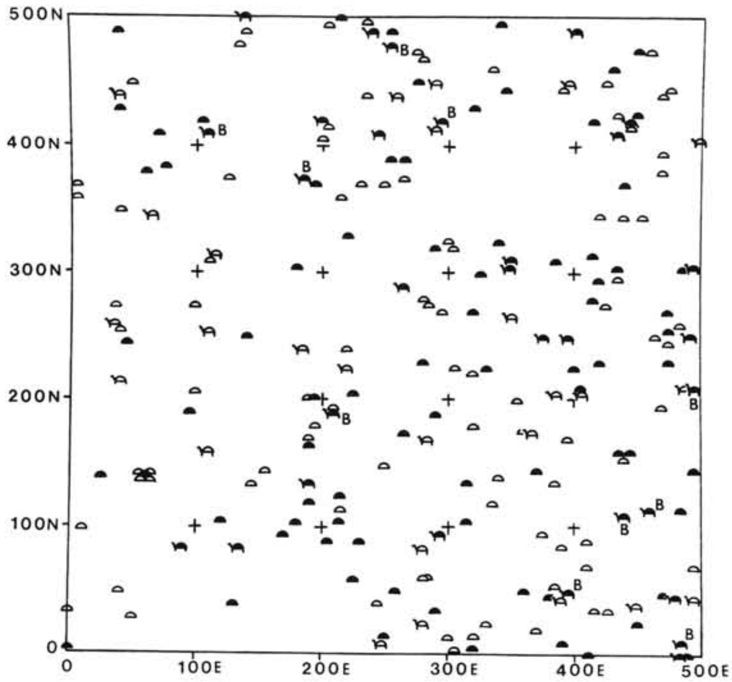

Figure 1. Spatial distribution of tortoises and their sign on a pristine unused 25-ha plot near Sidewinder Road, Barstow, San Bernardino Co., California. Tortoise symbols: solid = live tortoise; open = shell or fragments; B = tortoise in burrow; half-done symbols: solid = active burrow; open = inactive burrow.

ORV-used area (mean = 0.32 tortoises/ha; $n = 8$). Six of the tortoises (75%) in the ORV area were juveniles or immatures; we found 6 (19%) immatures on the unused site.

Burrow Number and Distribution. — There were significantly more burrows ($n = 171$) in the unused area than in the ORV-used plot ($n = 62$). We found a greater proportion of actively used burrows in the unused area (50.9%) than in the ORV plot (35.5%). We counted 206 pallets on the unused area but only 92 on the ORV plot. The spatial distribution of burrows differed markedly between the two areas. In the unused plot, only one section (southwest corner) lacked an active burrow and only three sections (each 1-ha) had one active burrow. The other 21 sections all had ≥ 2 active burrows (Fig. 1). In contrast, only 9 of the 25 sections in the ORV plot had 1 or more active burrows present (Fig. 2); of these, 5 sections with burrows were in the easternmost tier.

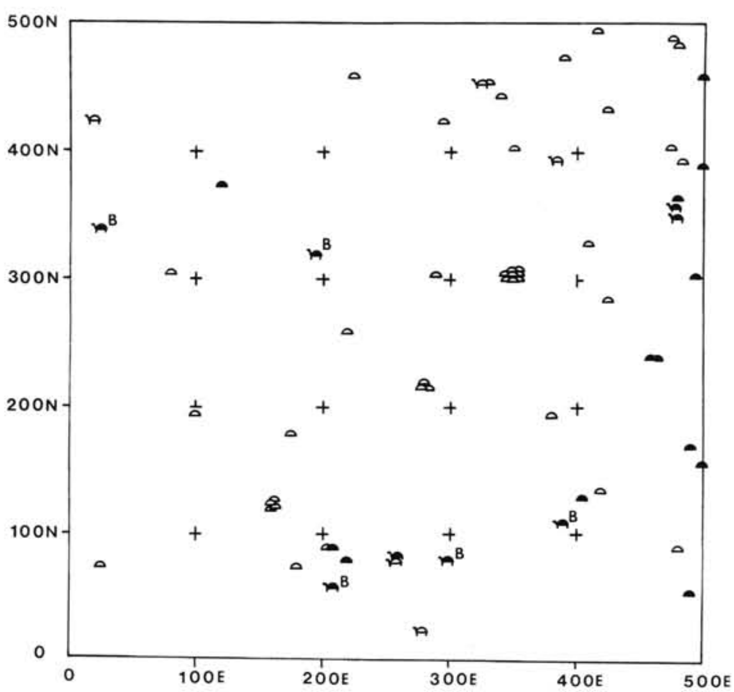

Figure 2. Spatial distribution of tortoises and their sign on a 25-ha plot used for off-road vehicle (ORV) activities near Sidewinder Road, Barstow, San Bernardino Co., California. Symbols same as in Fig. 1.

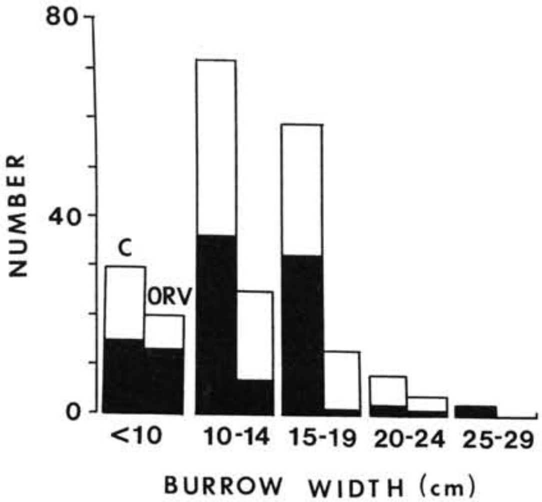

Figure 3. Histograms showing numbers of tortoise burrows in an unused plot (C) and off-road vehicle area (ORV). Solid portion is number of active burrows; open represents number of inactive burrows.

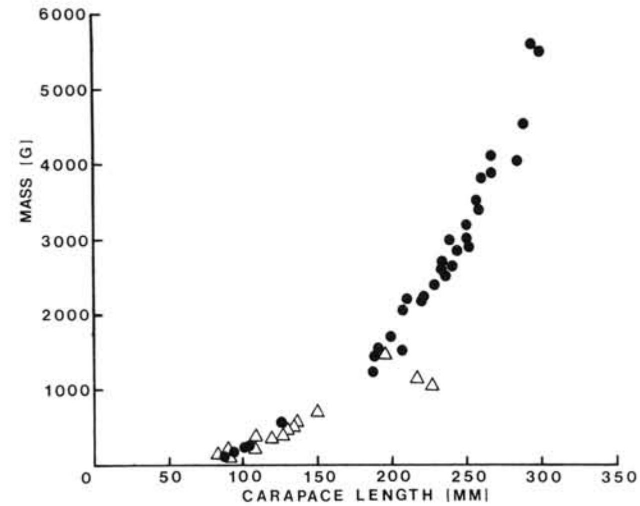

Figure 4. Comparison of mass (g) to carapace length (in mm) for desert tortoises found in a 25-ha unused area (solid circles) and a 25-ha ORV-used plot (open triangles) near Sidewinder Road, Barstow, San Bernardino Co., California.

The unused area had one cluster of burrows (1 active and 4 inactive). There were 3 burrow clusters (n = 3, 4, and 8) located in the ORV plot running across the diagonal from southwest to northeast (Fig. 2). All were inactive burrows. One large cluster (300 N x 350 E) in the ORV plot was noted in 1976 and 1977. In a quick revisit in 1985, we found that these burrows were all collapsed or filled with soil.

Burrow Widths. — In the unused area, we found 9 smaller-sized tortoises (< 190 mm CL) and 102 burrows ≤ 14 cm (11.3 burrows/tortoise) compared to 25 large tortoises (> 200 mm CL) using 68 burrows > 15 cm (2.7 burrows/tortoise). Most burrows were 10 to 19 cm wide (Fig. 3), but most tortoises (70.5%) were adults over 160 mm CW (> 207 mm CL). We found two large active burrows in the unused plot that were both 25 cm wide and they likely were dug by one large tortoise 230 mm CW that we found nearby. There were also 5 tortoises on the unused plot measuring 200–220 mm CW. In the unused area, 8 tortoises were within 25 m of the edge of the plot. Further, 34 captured tortoises had mean CW 78% (range, 75–85%) of the CL, and this was highly correlated (r = 0.995).

The width of 87 active burrows in the unused area (Fig. 3) was: < 10 cm, 17.2%; 10–14 cm, 41.4%; 15–19 cm, 36.8%; 20–24 cm, 2.3%; and 25–29 cm, 2.3%. There were only 22 active burrows in the ORV-used plot with most being relatively narrow: < 10 cm, 59.1%; 10–14 cm, 31.8%; 15–19 cm, 4.5%; and 20–24 cm, 4.5%. No large active burrows occurred in the ORV plot, and the largest adult tortoise found was 170 mm CW.

Tortoise Remains. — Few tortoise shells (n = 3) were found on the ORV plot but 26 remains (shells, bones) were found over 17 of 25 1-ha sections in the unused area (Figs. 1 and 2). We found one young dead tortoise (110 mm CL) smashed on a motorcycle trail in the ORV plot; it was included with other tortoise remains.

Body Mass. — At our unused Barstow site, mass was highly correlated with carapace length (r = 0.93) and with plastron length (r = 0.95). The formulae for Barstow tortoises (Fig. 4) were:

ORV Plot	Mass (g) = $0.000324X^{2.45}$
Unused Plot	Mass (g) = $0.000332X^{2.96}$

where X is the plastron length in mm. We also found that carapace length was positively correlated with plastron length (r = 0.99).

The unused plot had 28 individuals of known sex and there was no significant difference between the slopes of mass to plastron length between the sexes (ANCOVA, F = 0.081, p = 0.78), and the slopes of juveniles (88–138 mm CL) and subadults–adults (188–301 mm CL) (F = 1.454, p = 0.24). Similarly, there were no differences in the slopes of 6 juveniles from the unused area and 10 juveniles in the ORV plot (ANOVA, F = 0.105, p = 0.75).

When all size classes were compared between the two plots (totals for initial and revisit surveys), there was a significant difference between masses of tortoises (F = 9.998, $p < 0.01$) with those in unused plots heavier than those from the ORV area. Two adult tortoises in the ORV plot (Fig. 4) had appreciably less mass than similar-sized tortoises in the unused area. One female (227 mm CL) weighed only 1050 g, which is 1100 g less than similar-sized individuals in the unused plot. Also, one male (217 mm CL) in the ORV plot weighed 600–1000 g less than similar-sized tortoises in the unused plot. These adults were found on the revisit to the ORV-plot, and both occurred near the easternmost border (less impacted by ORVs) of the plot.

DISCUSSION

We visited sites during peak tortoise activity season and during the temperature range for surface activity (Luckenbach, 1982). Although we thoroughly searched each plot, counts represent minimum estimates of live tortoises found as some may have been underground in deep burrows or otherwise missed during our surveys (see Duda et al., 1999; Freilich et al., 2000). Our minimum population estimate in the unused site was 124 tortoises/km^2, which is comparable to nearby areas where populations reach over 200 tortoises/km^2 (Luckenbach, 1982; Berry, 1986b). The same estimate for the ORV-used area was 32 tortoises/km^2, which is low.

Greater search time (3.7x) was required in the unused area than the ORV-used plot because more plant cover occurred in the unused site, which required increased effort to search. Further, the unused plot had many more burrows and pallets to check than the ORV plot. Searches were fairly rapid in the western half of the ORV plot because most vegetation was obliterated, which occurs in areas with heavy ORV use (see Bury et al., 1977; Webb and Wilshire, 1983).

The number and coverage of live perennial shrubs were greatly reduced in the ORV area we searched. Although tortoises do not forage on shrubs such as creosote bush, their loss is indicative of severe physical damage to the habitat by ORVs. Other studies also show a high impact to perennials and annual plants by ORV activities in the Mojave Desert (Wilshire et al., 1978; Lathrop, 1983) and military vehicles in semiarid areas (Milchunas et al., 2000). Annual plants bloomed prior to our surveys and, hence, could not be measured.

There were significantly more burrows (2.8x) in the unused area than in the ORV plot. In general, the widths of burrows > 10 cm appeared to reflect the population structure on both areas. The unused area had several large tortoises as well as large burrows (> 25 cm wide). There were few large individuals or burrows in the ORV area. One discrepancy was a relatively high count of moderate-sized burrows (10–14 cm wide) in the unused area because we found few small tortoises. We may have underestimated the number of smaller-sized individuals in the unused areas because they are difficult to locate due to their small size and cryptic habits.

We were conservative in counting small burrows as those of tortoises are near the same size as small mammals. In turn, we recorded relatively few tortoise burrows < 10 cm wide. These small burrows may not be as reliable as wider ones to indicate a general assessment of the number and size structure of tortoises in populations.

In the ORV plot, those areas furthest from concentrated activity (pit areas) had the least amount of ORV impact and more tortoises. The southwestern corner of the ORV plot is adjacent to a road and received the heaviest ORV activity; no tortoises or active burrows were in this sector. This suggests that tortoise occurrence is inversely related to the level of ORV activity, but this relationship needs further testing.

Auffenberg and Iverson (1979) pointed out that the home range size in the gopher tortoise, *Gopherus polyphemus*, is directly correlated with available food resources and tortoises exhibit greater movement distances in areas with low amounts of herbaceous ground cover. Similary, McRae et al. (1981) found that depletion of preferred foods can induce some adult *G. polyphemus* to leave colony areas. In *G. agassizii*, Burge (1978) suggested that tortoises have shorter trip distances to forage during wet years with abundant herbaceous production than in drier years when plants are few or more scattered. Thus, desert tortoises may need to forage over larger distances when plant abundance is reduced by ORVs. However, this relationship needs better documentation. Gibbons (1986) reported that there is no evidence that desert tortoises depart from unfavorable habitats. Tortoises have well-developed homing abilities (see Berry, 1986b) and may remain near home burrows to wait out perturbations rather than risk abandonment of known burrows. .

Tortoises were once frequently collected from desert areas (see Luckenbach, 1982; Berry, 1989), but public education has reduced such removal in recent years. Before or during our study, some of the larger adult tortoises (that are more visible) could have been taken from the ORV-plot, where people often visited. Alternatively, the low yield of immature tortoises in the unused area may reflect their ability to hide better in a complex environment as there was much more cover and burrows in the undisturbed habitat.

Although individual tortoises may increase body mass by about 400 g when drinking during periods of rainfall, few lost over 200 g in any short period of activity (Nagy and Medica, 1986). Mass may vary during egg laying, when females may lose 23–400 g during egg deposition (Turner et al., 1984). The two largest tortoises in the ORV area had mass less than would be expected from these seasonal fluctuations. Our sample size was small in the ORV plot because of low tortoise abundance, but the few adults we found appeared to have body masses appreciably less than individuals in natural habitat. Further study is needed on the body condition of tortoises in areas with perturbations.

Conservation Implications

Our prior study comparing 8 paired plots (2 ha each; Bury et al., 1977) and this study with one pair of larger plots (25 ha each) suggest both direct and sublethal effects on tortoises from operation of ORVs in their habitats. Such effects occur in areas with low to moderate ORV activities, which occupy large portions of the Mojave Desert. Although this recreational activity is clearly one of the foremost factors impacting tortoise abundance and well being, it remains among the least studied topics by desert ecologists. Thus, there is a dire need for further research and management attention on effects from operation of ORVs in desert environments.

Lovich and Daniels (2000) reported that most research on the desert tortoise has focused on areas removed from human population centers but much of the habitat occupied by desert tortoises has been affected by humans to some extent. We need more research in areas with land-use impacts, and not just attention to tortoises in nature reserves, to fully assess the status and trends of tortoise populations.

After nearly 3 decades of studies on desert tortoises (e.g., starting with Bury and Marlow, 1973), we call upon a new generation of scientists and land managers to address at least three remaining key environmental issues: how do different levels (e.g., low, medium, severe) of recreational activities by ORVs impact the desert tortoise, how can the impacts be minimized, and when will current trends be reversed?

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