Recent Trends of Desert Tortoise Populations in the Mojave Desert

by

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Abstract. The desert tortoise, *Gopherus agassizii* (Cooper), was listed as threatened in the Mojave Desert in 1990. Important factors for the listing were severe recent mortality in tortoise populations and a general decline throughout this century. Recent trends in tortoise populations were examined by plotting total captures of adult and juvenile tortoises from 2.6-km^2 study plots, rather than by mark-and-recapture population estimates. Changes in relative abundance of tortoises were greatest among large tortoises in the western Mojave Desert, which may reflect high levels of human disturbance, and among small tortoises, which may reflect either lower ability of searchers to detect small tortoises or greater mortality of tortoises during drought conditions in 1986–90, or both factors. Further collection of data on population trends is needed, particularly in years with higher-than-average precipitation. Retention of the threatened status of the tortoise is a conservative strategy for the conservation of natural resources but should be reassessed when additional data are available.

Key words: Drought, *Gopherus agassizii*, human disturbance, population analysis, size.

The status of the desert tortoise, *Gopherus agassizii*, has been followed for several years. Woodbury and Hardy (1948) and Carr (1952) expressed concern about overcollection of tortoises for the pet trade. Jaeger (1955) observed that human encroachment was causing the gradual disappearance of *G. agassizii*, and Bury and Marlow (1973) predicted that urbanization would eliminate the tortoise from the northwestern Mojave Desert in California. Luckenbach (1982:1) stated that "a pronounced and steady decline" had been noted in some populations for several years. Besides these long-term trends related mostly to habitat destruction, significant decreases of numbers of tortoises were reported in several populations in the western Mojave Desert during the 1980's, related perhaps to the outbreak of an upper respiratory disease in some locations (Berry 1990). These reported declines in part prompted the U.S. Fish and Wildlife Service to declare Mojave Desert populations of *Gopherus agassizii* as threatened (U.S. Fish and Wildlife Service 1990). This paper evaluates the evidence for short-term declines of populations of *G. agassizii* in the Mojave Desert in Arizona, California, Nevada, and

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Utah since 1977 with data from the Bureau of Land Management.

The Bureau of Land Management Data Set and Critique of Existing Analyses

Bureau of Land Management personnel collected trend data on populations of *G. agassizii* from 2.6-km^2 study plots (Berry and Nicholson 1984). Standardized surveys usually involved 60 days (fewer calendar days if more than one person was employed). Data from study plots were used to calculate densities of tortoises with the Lincoln–Peterson mark-and-recapture model by dividing the 60-day survey into two approximately equal sampling efforts (Turner and Berry 1984).

There are four assumptions for estimating population size with mark-and-recapture techniques (Otis et al. 1978; White et al. 1982): (1) the population is demographically and geographically closed; (2) marks are persistent; (3) all marks are recorded correctly; and (4) the probability of capture for each animal at each trapping occasion is equal and constant. Data on *G. agassizii* from 2.6-km^2 study plots, however, violate assumptions 1 and 4. Assumption 1 is violated because study plots are not geographically closed but part of larger expanses of suitable tortoise habitat. Tortoises may move freely between the study area and adjacent habitat. Assumption 4 is violated often in two ways: different-sized tortoises have different probabilities of capture (Turner and Berry 1984), and capture probabilities may vary over time. Because tortoises are usually more active during or immediately after rain (Turner and Berry 1984; Nagy and Medica 1986), rainfall during a 60-day survey probably creates unequal capture probabilities. If there is heterogeneity of capture probabilities among animals and across time, a statistically valid population estimate cannot be calculated (Otis et al. 1978; White et al. 1982).

Violation of the assumptions of mark-and-recapture models may lead to density estimates that are biased and that may be too large. One of the strengths of the 60-day survey, however, is that sampling effort is generally equivalent among years. Thus, ignoring recaptures, the total number of tortoises captured (registered) during a 60-day survey may be a more useful index of population trends because the probability of observing adult tortoises is high (Berry and Turner 1986). Lower capture probabilities of smaller tortoises and variation in activity because of weather, however, create greater uncertainty about the total numbers of captured juvenile tortoises. Still, I prefer this technique to estimating numbers based on few recaptures. Here, I analyze recent trends in tortoise populations based on total numbers captured during 60-day surveys.

Methods

I analyzed captures of desert tortoises from 1977 to 1989 at 16 sites in the Mojave Desert (for which multiple years of observations were available) with published data or data in the public domain (Table 1): 2 study plots in Arizona (Duck and Snider 1988; Duck and Schipper 1989), 13 study plots in California (Berry and Nicholson 1984; Turner et al. 1987a; Berry 1990; Berry et al. 1990), and 1 study plot in Nevada (Bureau of Land Management, unpublished data). I did not use data from plots in which sampling was conducted in only one year or in which sampling efforts differed across years. For example, the Fremont Peak plot in California with 15-, 30-, and 60-day sampling efforts and the Sheep Mountain plot in Nevada with 30- and 60-day sampling efforts (Esque and Duncan 1989) were excluded from the analysis. I excluded data from a 30-day sampling effort in the Piute plot in Nevada in 1979 but used data from 60-day efforts in 1983 and 1989 at this site.

To account for size-related differences in capture probabilities, I partitioned my analysis between small (<180-mm maximum carapace length [MCL]) tortoises—immature and juvenile size classes of Turner and Berry (1984), and large (≥180-mm MCL) tortoises—subadult and adult size classes of Turner and Berry (1984). I used the total number of tortoises captured during 60-day surveys; recapture data were not used. I transformed the data to

Table 1. Number of small (<180-mm maximum carapace length) and large (≥180-mm maximum carapace length) desert tortoises (*Gopherus agassizii*) observed at 16 study plots in the Mojave Desert. Data are from Berry (1990, 1994), Berry and Nicholson (1984), Duck and Snider (1988), Duck and Schipper (1989), and Turner et al. (1987a).

Study site	Year	Number observed	
		Large	Small
Eastern Mojave–Colorado Deserts			
Chemehuevi, California	1979	81	70
Chemehuevi, California	1982	99	108
Chemehuevi, California	1988	112	145
Chuckwalla Bench, California	1979	153	112
Chuckwalla Bench, California	1982	178	84
Chuckwalla Bench, California	1988	86	34
Chuckwalla Valley, California	1980	48	37
Chuckwalla Valley, California	1987	47	31
Goffs, California	1980	188	111
Goffs, California	1983	219	230
Goffs, California	1984	179	100
Goffs, California	1985	175	103
Goffs, California	1986	173	78
Ivanpah Valley, California	1979	94	67
Ivanpah Valley, California	1986	104	64
Littlefield Control, Arizona	1977	24	16
Littlefield Control, Arizona	1981	28	18
Littlefield Control, Arizona	1988	30	19
Littlefield Exclosure, Arizona	1977	13	7
Littlefield Exclosure, Arizona	1981	23	13
Littlefield Exclosure, Arizona	1989	17	3
Piute, Nevada	1983	29	52
Piute, Nevada	1989	30	16
Upper Ward Valley, California	1980	83	57
Upper Ward Valley, California	1987	78	38
Western Mojave Desert (California)			
DTNA[a] Interpretive Center	1979	402	191
DTNA Interpretive Center	1985	388	93
DTNA Interpretive Center	1989	175	42
DTNA Interior	1979	138	51
DTNA Interior	1982	184	50
DTNA Interior	1988	142	20
Fremont Valley	1979	116	87
Fremont Valley	1981	108	99
Fremont Valley	1987	49	27
Johnson Valley	1980	50	29
Johnson Valley	1986	19	7
Kramer Hills	1980	84	62
Kramer Hills	1982	95	90
Kramer Hills	1987	56	30
Lucerne Valley	1980	80	35
Lucerne Valley	1986	69	27
Stoddard Valley	1981	71	26
Stoddard Valley	1987	99	19

[a] Desert Tortoise Natural Area.

relative abundance (RA) of the two age classes with the formula

$$RA = (N_i + N_0) \times 100,$$

where N_i = number captured in year i and N_0 = number captured in the first survey at each plot. Transforming captures to RA allowed easier comparisons among plots and comparisons among sites where sampling intensities differed. For example, sampling effort in the Interpretive Center plot at the Desert Tortoise Natural Area, California (DTNA) was more intensive (180 days) and over a larger area than in other 60-day plots (Berry 1990). However, the sampling intensity at this site was the same across years, so that transforming to RA allowed a direct comparison of these data with data from plots with standard 60-day surveys.

I analyzed trends in tortoise numbers by plotting relative abundance versus year and used locally weighted regression scatterplot smoothing (LOWESS regression; Cleveland 1979) to produce trend lines. LOWESS regression derives predicted values of Y (RA) for a given X (year) with weighted Y-values associated with neighboring X-values (Trexler and Travis 1993). A tension parameter (f) determines the proportion of data points to predict each Y (f = 1 is equivalent to a standard linear regression). I used LOWESS regression because the RA of tortoises in a given year is probably influenced to a greater degree by recent conditions rather than by conditions throughout the time covered by the data set (Trexler and Travis 1993). I plotted LOWESS regressions with SYSTAT (Wilkinson et al. 1992).

The analysis was split between the western Mojave Desert, including the study plots at the DTNA Interpretive Center, DTNA interior, Fremont Valley, Kramer Hills, Stoddard Valley, Lucerne Valley and Johnson Valley in California, and the eastern Mojave Desert (and the Colorado Desert), including study plots at Ivanpah, Goffs, Upper Ward Valley, Chemehuevi, Chuckwalla Valley, and Chuckwalla Bench in California, and Piute Valley in Nevada and control and exclosure plots at Littlefield, Arizona.

I compiled data on precipitation from seven stations in the eastern Mojave Desert: Beaver Dam and Willow Beach in Arizona; Searchlight and the Desert National Wildlife Range in Nevada; and Blythe, Needles, and Baker in California. I also used data from five stations in the western Mojave Desert in California: Barstow, China Lake, Mojave, Twentynine Palms, and Victorville (Earthinfo, Inc. 1989; National Oceanic and Atmospheric Administration 1989). Precipitation amounts of two 6-month periods each year were summed: winter (October–March) and summer (April–September) because tortoise behavior may be related to seasonal variation in precipitation. The summer period corresponds to the primary activity period of tortoises. Rain during the winter period is necessary for successful germination of annual plants (Beatley 1974), and variation in forage may also affect tortoise behavior (U.S. Fish and Wildlife Service, Portland, Oregon, unpublished data). I did not include precipitation totals from any year at any station with missing data. I used Pearson product–moment correlation to compare the relative abundances of small and large tortoises with winter and summer precipitation and used the data from all surveys (first and revisits) at the 16 sites.

Results

LOWESS trend lines revealed differences between the numbers of large and small tortoises and between study plots in the eastern Mojave Desert and the western Mojave Desert. The f for the LOWESS regression was 0.4. This was the smallest value of f that did not show any relation between the residual of RA minus the LOWESS predicted value and year (Trexler and Travis 1993) and which produced trend lines that could be interpreted. Smaller values of f produced trend lines that responded too strongly to individual data points.

Relative abundance of large tortoises apparently declined in the western Mojave Desert during the latter 1980's, but, during the same time, RA of large tortoises was stable or increased in the eastern Mojave Desert (Fig. 1). The downturn in the trend in the western Mojave Desert was largely influenced by low numbers of large tortoises recorded at the DTNA Interpretive Center plot in 1989 (175 or 44% of the 402 tortoises captured in 1979).

from two plots, the Piute Valley and the Littlefield exclosure.

From 1977 to 1989, when data from trend plots were collected, rainfall varied considerably (Table 2). Whereas 1983 was the wettest year since 1950, 1989 was one of the driest. The relative abundance of neither large nor small tortoises correlated with winter precipitation (in both cases $P > 0.5$). The relative abundance of large tortoises also did not increase with increasing summer precipitation (Fig. 3; $r = 0.353$; $P = 0.07$), but RA of small tortoises increased with summer precipitation (Fig. 3; $r = 0.677$; $P < 0.001$).

Table 2. Mean precipitation (cm) in winter (October–March) and summer (April–September) from 1977 to 1989 at seven reporting stations in the eastern Mojave Desert and at five stations in the western Mojave Desert.

	Eastern Mojave		Western Mojave	
Year	Winter	Summer	Winter	Summer
1977	4.5	7.1	6.5	7.7
1978	13.3	7.1	19.6	2.8
1979	19.1	5.8	14.0	4.7
1980	14.2	4.6	15.3	3.4
1981	5.3	5.3	5.7	1.8
1982	7.3	9.8	10.1	4.4
1983	12.9	10.1	24.9	8.2
1984	4.6	10.2	5.7	9.2
1985	12.1	3.8	9.5	2.8
1986	7.6	5.0	10.7	1.8
1987	8.7	4.6	8.8	3.5
1988	10.6	8.5	11.1	4.1
1989	4.8	1.7	3.2	1.6

Discussion

The decline of large tortoises in the western Mojave Desert may in part be due to increased human disturbance. A slightly different trend analysis in the Draft Desert Tortoise Recovery Plan (U.S. Fish and Wildlife Service, Portland, Oregon, unpublished data) showed a large decline

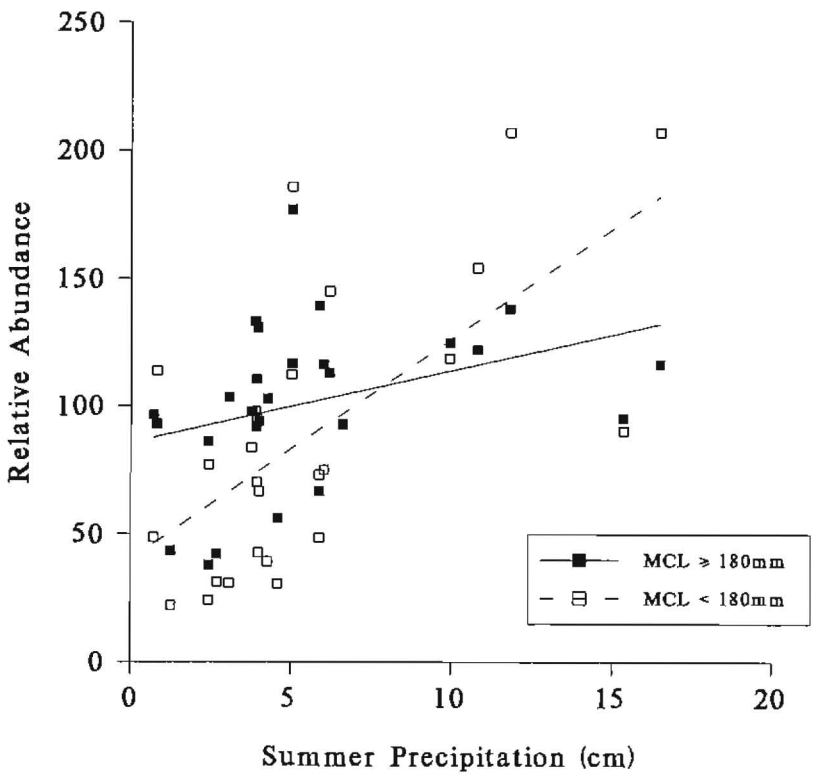

Fig. 3. Relation between relative abundances of large and small desert tortoises (*G. agassizii*; percent of first survey) and summer precipitation (April through September).

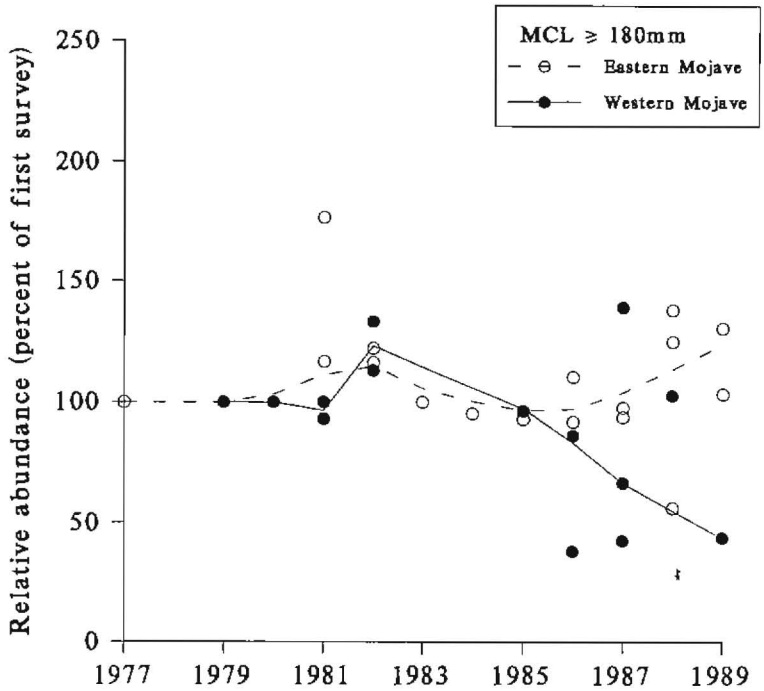

Fig. 1. Relative abundance of large desert tortoises (*G. agassizii*) at seven permanent study plots in the western Mojave Desert (*filled circles*) and nine permanent study plots in the eastern Mojave Desert (*empty circles*), 1977–89. Data were derived from Table 1.

The relative abundances of small tortoises on study plots decreased markedly from the mid-1980's in the western Mojave Desert (Fig. 2). There was also a downturn in RA of small tortoises in the eastern Mojave Desert in 1989. This decrease in RA of small tortoises resulted from data

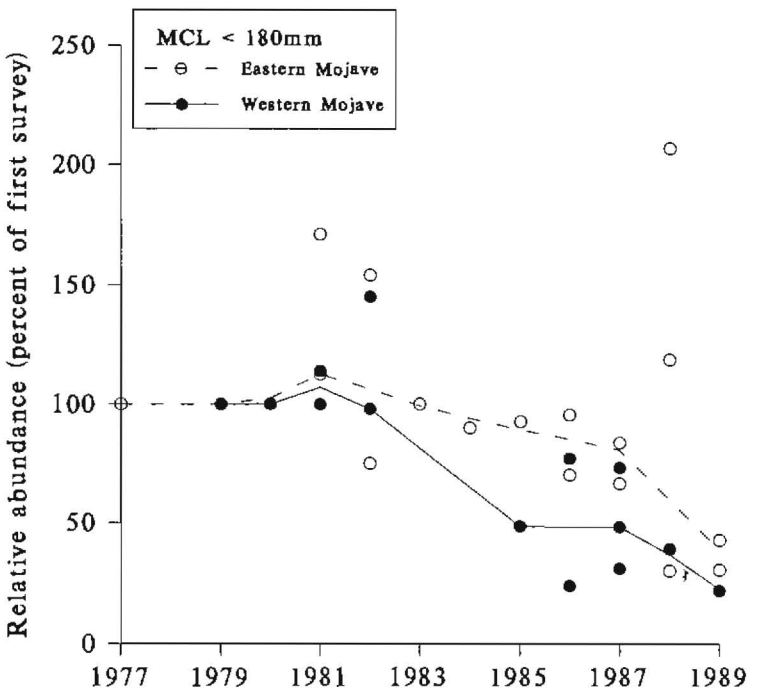

Fig. 2. Relative abundance of small desert tortoises (*G. agassizii*) at seven permanent study plots in the western Mojave Desert (*filled circles*) and nine permanent study plots in the eastern Mojave Desert (*empty circles*), 1977–89. Data were derived from Table 1.

in abundances of tortoises at six study plots that have had high levels of human disturbance. The six plots are in the western Mojave Desert. Many of the Bureau of Land Management study plots are near growing human populations, and one plot (Fremont Valley) had a large increase in off-road vehicle use during the 1980's (Berry 1990). Mortality, apparently from the upper respiratory disease, has been more severe at the DTNA than at most other plots (Berry 1990, 1994). The apparent differences in the trends in numbers of small and large tortoises may reflect biases inherent in tortoise surveys. Summer precipitation in the western Mojave Desert averaged 4.93 cm from 1979 to 1985 and 2.73 cm from 1986 to 1989. The decrease in the relative abundance of juvenile tortoises coincided with this reduction in precipitation. Adult *G. agassizii* construct water catchments and drink from these puddles during rainfall (Medica et al. 1980; Turner and Berry 1984), and surface activity of tortoises increases after rains (Camp 1916; Turner and Berry 1984; Nagy and Medica 1986). Differences in activity can be drastic. For example, one biologist observed 40 tortoises while driving along a 6.6-km stretch of dirt road in the Ivanpah Valley, California, during a rainstorm on 28 April 1980. Two days later the ground was still damp, but four people observed only two tortoises during several hours of laying out a study grid (P. A. Medica, REECO/BECAMP, Nevada test site, Mercury, Nevada, personal communication).

Small and large tortoises may have different activities, but, alternatively, small *G. agassizii* may suffer greater mortality in dry years. Decreases in numbers of juveniles captured in recent surveys, therefore, indicate significant decreases in numbers of animals. Juvenile herbivorous reptiles face greater constraints in the desert than adults in acquiring sufficient nutrients for growth and survival (Zimmerman and Tracy 1989). Less food may be available in dry years, and this combined with high temperatures reduces surface activity (Berry and Turner 1986). Data relating mortality of small tortoises to precipitation, however, are scant and contradictory (Turner et al. 1984, 1987b).

Data from 1977 to 1989 do not support a conclusion that *G. agassizii* is now declining throughout the entire Mojave Desert, but declines are apparent in the western Mojave Desert. However, continuing habitat destruction and the possibility of an uncontrolled epidemic (the upper respiratory disease) among tortoises justifies concern about the status of *G. agassizii*. Data presented at the annual meeting of the Desert Tortoise Council in Las Vegas in 1991 indicated continued high mortality of tortoises in the western Mojave Desert (Berry 1994).

Management and recovery of *G. agassizii* require accurate monitoring of population trends. The biases in capture probabilities render the standard 2.6-km^2 study plots unsuitable for this task. The draft Desert Tortoise Recovery Plan advocates short-term sampling in smaller (1-km^2) plots selected in a statistically valid sample from a larger area (U.S. Fish and Wildlife Service, Portland, Oregon, unpublished data). Population size would be estimated with removal techniques. However, this plan calls for sampling in plots during 7 days, and there is a high probability that tortoises will leave and enter the plot during this time. Thus, the bias of the study plot not being geographically closed still applies. Precipitation during the sampling period could also lead to biased capture probabilities. There is still a need to develop reliable techniques to estimate population size and trends of desert tortoises.

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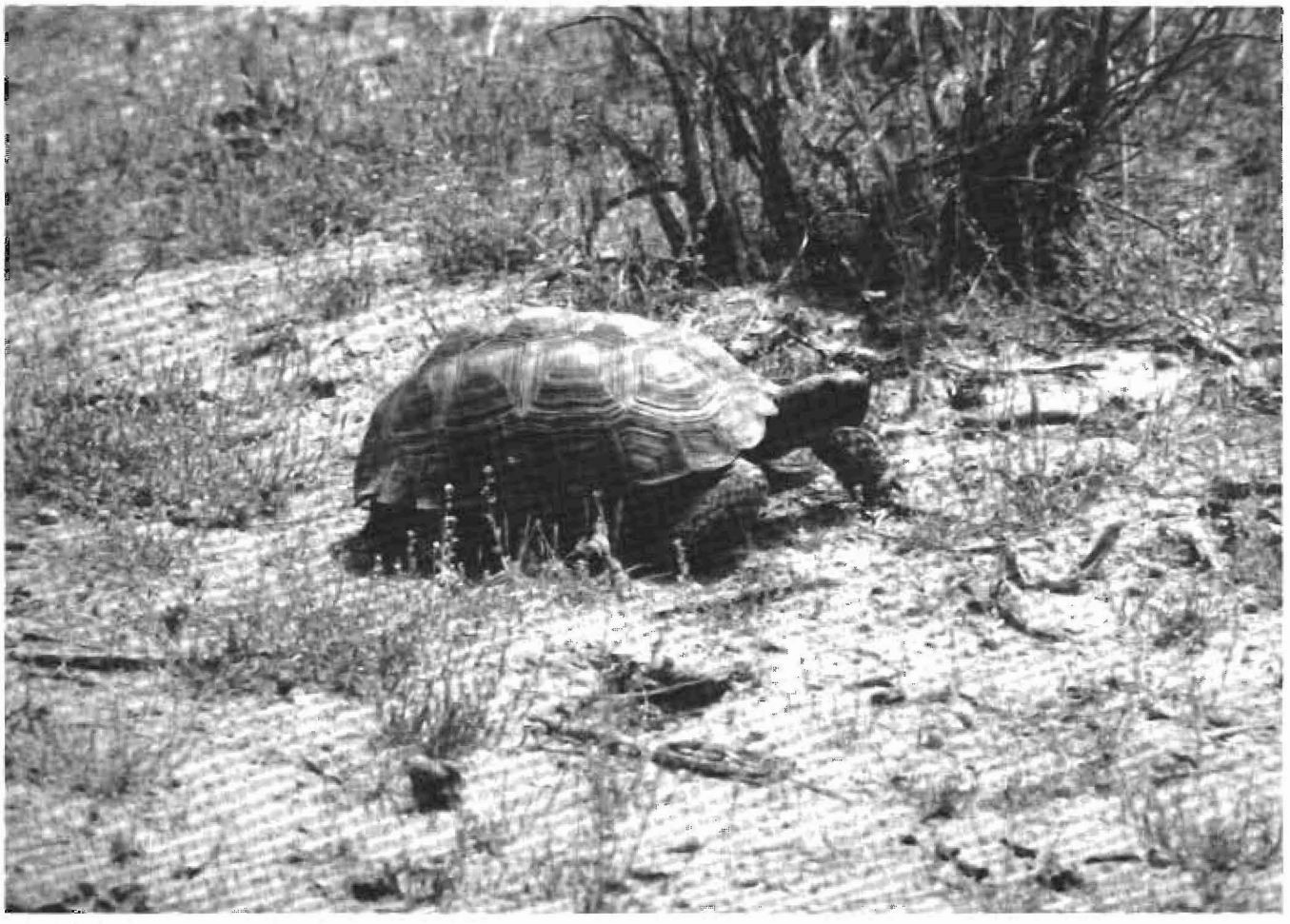

Female desert tortoise (*Gopherus agassizii*) in the Mojave Desert west of California City, Calif. *Photo by D. J. Germano.*