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Keywords: Collecting methods; Lizards; Habitat destruction; Rock outcrops; Commercially valuable reptiles

Abstract

Declines in biodiversity caused by habitat loss have been well documented on large spatial scales, however, effects of habitat loss on small scales have received little attention. Some common methods of reptile collection, primarily for commercial harvest, result in destruction of cracks, crevices, and other cool, moist microhabitats in desert rock outcrops. We developed a method for identifying habitat destruction associated with reptile collecting. We surveyed lightly and heavily disturbed areas near Phoenix, Arizona to determine if microhabitat loss caused by collectors was associated with decreased relative abundance of reptiles. Of four diurnal lizard species studied, relative abundance of two rock-dwelling species was negatively correlated with level of microhabitat destruction, whereas relative abundance of one ground-dwelling species and one habitat generalist species was not. Habitat destruction caused by collectors may have negative effects, not only at the individual level, but at the population and community levels as well. We recommend regulation of commercial trade in reptiles; disallowing collecting activities that cause habitat damage; increased law enforcement; and educational programs directed primarily at novice collectors.

1. Introduction

Many forms of anthropogenic habitat disturbance affect herpetofauna (e.g., Dodd, 1993; Van Rooy and Stumpel, 1995). For example, timber management (e.g., Welsh, 1990; Petranka et al., 1993), off-highway vehicle activity (Luckenbach and Bury, 1983; Webb and Wilshire, 1983), and livestock grazing (e.g., Bock et al., 1990; Jones, 1981) can have a negative impact on reptile and amphibian abundance. With growing human populations, pressure on reptile populations for collection as pets and as raw materials for clothing and curios has increased (Dodd, 1986). Effects of increased exploitation of reptile and amphibian populations are largely unknown. Several studies have called attention to the effects of rattlesnake roundups on rattlesnake populations and habitats and on non-target species (reviewed in Arena et al., 1995). Harvest of gopher tortoises has negative impacts not only on tortoises, but also on other species (e.g., *Crotalus adamanteus*) inhabiting gopher tortoise burrows (e.g., Diemer, 1986). Collection of animals or eggs has been implicated as a source of population declines and endangerment for some species, such as red-legged frogs (*Rana aurora*, Jennings and Hayes, 1985), loggerhead sea turtles (*Caretta caretta*, Crowder et al., 1995), timber rattlesnakes (*Crotalus horridus*, Brown, 1993), and New Mexico ridgenose rattlesnakes (*Crotalus willardi obscurus*, Baltosser and Hubbard, 1985).

Depending on collection methods, loss or degradation of habitat may accompany removal of reptiles and amphibians from wild populations. Destruction of microhabitats that provide refuge from harsh environmental conditions may be especially detrimental. In arid regions, rock outcrops support diverse assemblages of species, many of which do not occur in surrounding habitats (Maser et al., 1986; Rumble, 1989). Cracks, crevices, and spaces below rocks that are sealed from the external environment by soil or detritus provide protection from heat and desiccation in the summer and from cold in the winter. When collectors destroy rock outcrops, loss of these microhabitats has the potential to affect all species that use them, not just the individuals collected.

Collecting methods that destroy microhabitats have been employed for decades, even by professional herpetologists (Klauber, 1935), but reptile collection for the burgeoning pet trade has led to accelerated microhabitat loss and degradation in recent years (Grismer and Edwards, 1988; Mellink, 1995). Some collectors use their hands, crowbars, and even hydraulic jacks to displace or break rocks in an attempt to collect reptiles. Similar damage is caused by collection of rocks for use in construction and landscaping (Schlesinger and Shine, 1994), leading to the endangerment of an Australian snake species (*Hoplocephalus bungaroides*, Shine and Fitzgerald, 1989; Goldingay and Newell, 2000).

Although microhabitat loss associated with collecting has been documented previously (e.g., Fritts et al., 1982; McGurty, 1988; Mellink, 1995), to our knowledge its effects on herpetofauna have not been closely examined. To test the hypothesis that high levels of microhabitat disturbance result in decreased abundance of reptiles, we conducted a comparative field study to determine the relationship between microhabitat destruction and reptile abundance. We compared relative abundance of lizards on heavily and lightly disturbed plots for which we also characterized habitat damage. Because habitat damage is focused on rocky habitats, we also tested the hypothesis that habitat destruction has a greater effect on lizards closely associated with these habitats.

2. Materials and methods

The South Mountains lay immediately south of Phoenix in Maricopa County, Arizona, USA, and are almost entirely encompassed by Phoenix South Mountain Park, the largest municipal park in the United States (Weir, 1986). We chose this park as our study site because it is a well-known reptile-collecting locality that has experienced extensive habitat destruction due to reptile collecting activities (Montanucci, 1997). The park also supports several commercially valuable species, including a population of chuckwallas highly prized by collectors due to their striking color pattern (*Sauromalus ater*). The park is characterized by rocky slopes with numerous outcrops, providing extensive habitat for a variety of rock-dwelling species, including lizards, snakes, and other animals that use deep crevices and exfoliating granite as refugia (e.g., bats and a variety of invertebrate species).

Vegetation is classified as Sonoran desertscrub, Arizona upland subdivision (Turner and Brown, 1982), with triangle-leaf bursage (*Ambrosia deltoidea*) and brittlebush (*Encelia farinosa*) being the dominant perennial shrubs. Common cacti include saguaro (*Carnegia gigantea*), several prickly pears and cholla species (*Opuntia spp*.), and barrel cactus (*Ferocactus wislizenii*). Trees, often abundant along washes, include foothill paloverde (*Cercidium microphyllum*), ironwood (*Olneya tesota*), and mesquite (*Prosopis glandulosa*). Elevation in the park ranges from 430 to 897 m.

To gain insight into the severity of anthropogenic disturbance on lizard abundance, we chose six study plots reflecting extreme differences in collector disturbance level, locating plots in both lightly and heavily disturbed areas, based on visual inspection of the study area. Plots were similar in elevation, slope, vegetation, and amount of exposed rock based on visual inspection. Plots were several hundred to several thousand meters apart, greatly reducing the chance that reptiles could move between plots. Heavily disturbed plots exhibited obvious and pervasive evidence of destructive collecting activities. Evidence included freshly exposed surfaces that appear light in color because they lack desert varnish, which consists of a dark layer of dust that accumulates on rocks over thousands of years (Dorn, 1983). Other evidence of collecting activities included large numbers of unnaturally displaced and overturned rocks, and enlarged and damaged crevices. On one occasion, we even found part of a hydraulic jack. These characteristics were far less common on lightly disturbed plots. Heavily disturbed areas were also more accessible (by road or trail) than lightly disturbed areas.

Next we developed a collector disturbance index (CDI). We first identified twenty three collector disturbance attributes which are listed in no particular order in Table 1. We then established ten randomly selected transects (25 m long and 10 m wide) on each of the six 1-ha plots. In February and March of 1994, we walked the ten random transects on each plot a single time, searching for unique collector disturbances. A unique collector disturbance is an area on a transect exhibiting one or more of our 23 attributes. Each unique collector disturbance was counted and its attributes recorded; the CDI is the total count of unique collector disturbances for the 10 random transects of each plot. Although some disturbance events consisted of multiple attributes, we

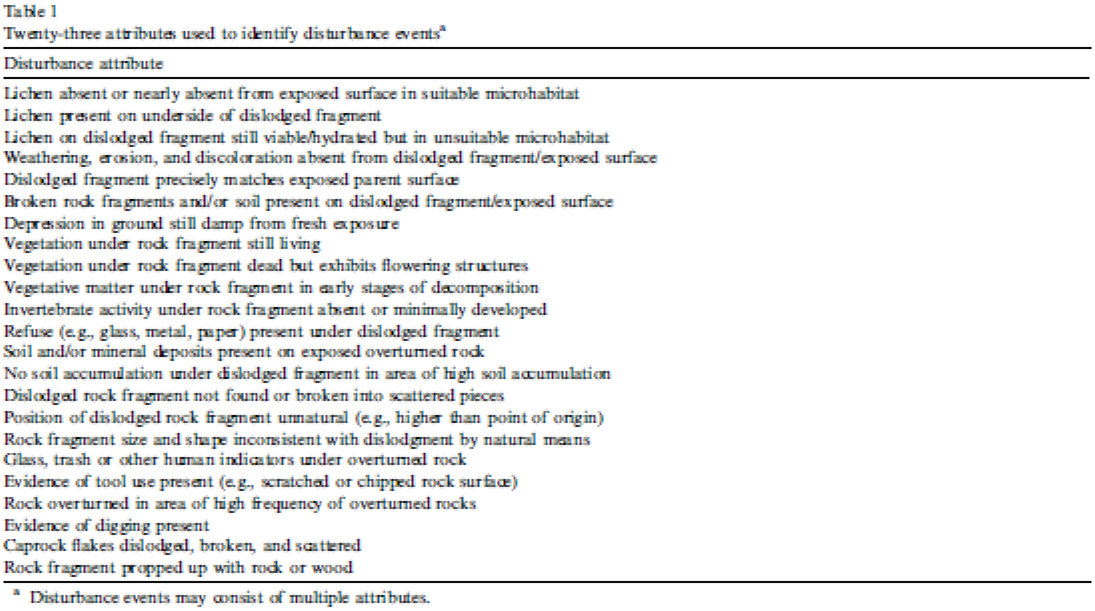

Table 1
Twenty-three attributes used to identify disturbance events[a]

Disturbance attribute
Lichen absent or nearly absent from exposed surface in suitable microhabitat
Lichen present on underside of dislodged fragment
Lichen on dislodged fragment still viable/hydrated but in unsuitable microhabitat
Weathering, erosion, and discoloration absent from dislodged fragment/exposed surface
Dislodged fragment precisely matches exposed parent surface
Broken rock fragments and/or soil present on dislodged fragment/exposed surface
Depression in ground still damp from fresh exposure
Vegetation under rock fragment still living
Vegetation under rock fragment dead but exhibits flowering structures
Vegetative matter under rock fragment in early stages of decomposition
Invertebrate activity under rock fragment absent or minimally developed
Refuse (e.g., glass, metal, paper) present under dislodged fragment
Soil and/or mineral deposits present on exposed overturned rock
No soil accumulation under dislodged fragment in area of high soil accumulation
Dislodged rock fragment not found or broken into scattered pieces
Position of dislodged rock fragment unnatural (e.g., higher than point of origin)
Rock fragment size and shape inconsistent with dislodgment by natural means
Glass, trash or other human indicators under overturned rock
Evidence of tool use present (e.g., scratched or chipped rock surface)
Rock overturned in area of high frequency of overturned rocks
Evidence of digging present
Caprock flakes dislodged, broken, and scattered
Rock fragment propped up with rock or wood

[a] Disturbance events may consist of multiple attributes.

counted these events only once. Some disturbance events exhibited more severe attributes than others, however, we counted these events only once (i.e., we did not try to weight these events more than others).

For each plot, we then repeatedly walked a permanent (non-random) 300-m transect, counting reptiles on either side within 5 m of the centerline. Reptile counts were recorded for each ‘‘walk of the transect’’ (or simply for each ‘‘walk’’). We conducted morning surveys that coincided with high lizard activity. We identified each individual by species and recorded whether the lizard was observed on rocks or on the ground (among other things). Because encounter frequencies were low for most species, we confined our analyses to four common diurnal lizard species: tree lizard (*Urosaurus ornatus*), side-blotched lizard (*Uta stansburiana*), western whiptail (*Cnemidophorus tigris*), and chuckwalla (*Sauromalus ater*).

Weather conditions were similar during all sampling periods. We did not conduct surveys if there was excessive cloud cover, high wind or abnormal temperature and humidity. We surveyed one plot per morning, starting 2 h after sunrise and continuing until three walks were completed, by which time lizards likely began to retreat to avoid midday heat. We allowed transects to ‘‘rest’’ for 30 min between each of the three walks to minimize potential effects of the previous walk on lizard observations, and to allow for some degree of independence across replications. (Simple regressions revealed no causal relationship between the number of lizard observed on the first walk and the number observed on the second walk. Similarly for the second and third walks.) We used the total number of lizards observed per walk and the number of lizards observed per minute per walk as our measures of relative abundance. We surveyed each plot twice during the spring, a period of high lizard activity (between 6 April and 27 May 1994), so our data consisted of two surveys of three walks per survey for each of six plots, or 36 total walks. Of these 36 walks, 18 were on the three lightly disturbed plots and 18 were on the three heavily disturbed plots.

We used chi-square tests to categorize lizard species by ecotype (rock-dwelling, ground-dwelling or habitat generalist). We used multiple regression to explore the relationship among lizard relative abundance, measured as the number of lizards observed per walk, degree of collector disturbance or CDI (fixed per walk for a particular plot), and other environmental factors that we felt may have an effect on the number of lizards observed. These factors included time of sunrise, ambient air temperature when sampling began, and whether or not we began sampling before or after 0900 h, the average time at which sampling began. Specifically,

$$\mathrm{abundance}_{it} = \alpha + \beta_1 \mathrm{CDI}_i + \beta_2 \mathrm{sunrise}_{it} + \beta_3 \mathrm{temp}_{it} + \beta_4 before9_{it} + \varepsilon_{it},$$

where $i = 1, \ldots, 6$ represents plot, $t = 1, \ldots, 6$ represents walks on each plot, α and β_j are parameters for estimation, and ε_{it} is the usual zero-mean, homoskedastic error independent across both i and t. We chose time of sunrise ($\mathrm{sunrise}_{it}$) as a proxy variable for seasonal effects on lizard activity. That is, the sun comes up increasingly earlier as spring progresses, and more lizards may be active later in the season. We recorded ambient air temperature (temp_{it}) at the start of sampling to account for effects of temperature on reptile activity. We recorded whether or not we started the survey before or after the average start time of 0900 ($before9_{it}$) because we felt it may have an effect on the number of reptiles observed as they become active at varying times throughout the morning.

We also estimated a regression of lizard encounter rates (lizards observed per minute) on CDI and the other environmental factors above. We were interested in encounter rates because the more lizards we observed along transects, the longer it took to walk transects. In turn, the longer it took to walk transects, the more lizards we tended to observe. (A single lizard observation involved stopping to record species, habitat, time, behavior, etc., so a single observation could take between 30 and 60 s to record.)

We used SPSS for Windows version 11.0 (SPSS, 2001) for all statistical analyses.

3. Results

For CDI, we observed 10, 20 and 22 unique disturbance events on the three lightly disturbed plots, and 60, 235 and 288 unique disturbance events on the three heavily disturbed plots. Lizard counts varied by species and level of disturbance (Table 2).

Frequency plots of ‘‘lizards on rocks’’ and ‘‘lizards on the ground’’ for each species are depicted in Fig. 1. We observed *U. ornatus* (χ^2 = 186.8, *d*f = 1, *p* < 0.0001) and *S. ater* (χ^2 = 84.6, *d*f = 1, *p* < 0.0001) more frequently on rocks than on the ground. We observed *C. tigris* on the ground more frequently than on rocks (χ^2 = 51.8, *d*f = 1, *p* < 0.0001). We detected no difference in the number of times we observed *U. stansburiana* on rocks compared with on the ground (χ^2 = 3.7, *d*f = 1, *p* = 0.056), although our observations were in the direction of greater ground use. We subsequently categorized *U. ornatus* and *S. ater* as ‘‘rock-dwellers’’ in the analyses that follow. Our results generally confirm what is already known about the habitat preferences of each of these species (see Tinkle, 1967; Dunham, 1981; Abts, 1987; and Anderson, 1993).

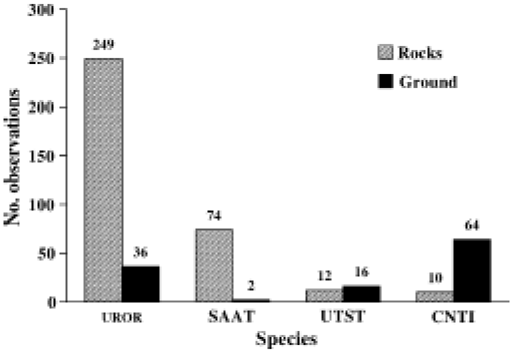

Fig. 1. Frequency at which lizards were observed on rocks compared with on the ground. UROR = *Urosaurus ornatus*, SAAT = *Sauromalus ater*, UTST = *Uta stansburiana*, CNTI = *Cnemidophorus tigris*.

We estimated 6 multiple regressions of various lizard-type counts (in units of ‘‘number of lizards per walk’’), which are designated by the dependent variable and numbers 1–6 (Table 3). We natural log transformed the continuous variables (CDI, sunrise and temp) to account for non-linearity in the relationship between explanatory and dependent variable, keeping the dependent variable in units of ‘‘lizards observed per walk’’. A maximal variance inflation factor (VIF) of 1.922 on the temp variable indicated that collinearity was not a problem in the data (Belsley et al., 1908). Regression 1 is a jointly significant regression ($F_{4,31}$ = 6.29, R^2 = 0.38) of the number of tree lizards per walk on the natural log transformed variables. Slope coefficients are standardized. Results indicate that a one standard deviation increase in CDI log-points causes a statistically significant decrease in average tree lizards per walk of

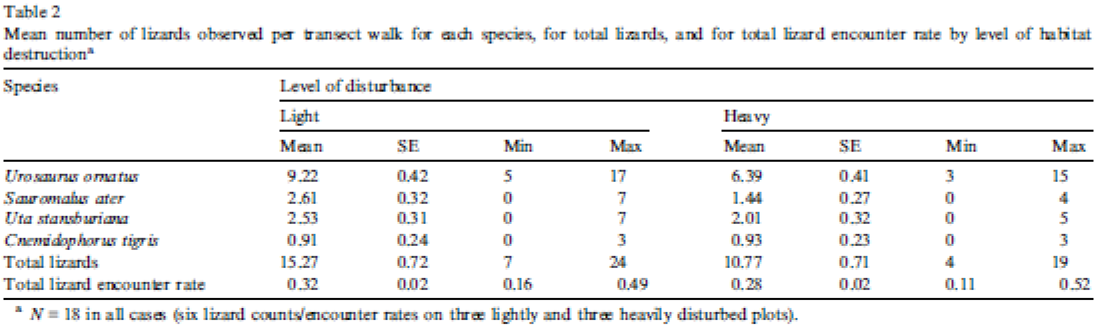

Table 2

Mean number of lizards observed per transect walk for each species, for total lizards, and for total lizard encounter rate by level of habitat destruction[a]

Species	Level of disturbance							
	Light				Heavy			
	Mean	SE	Min	Max	Mean	SE	Min	Max
Urosaurus ornatus	9.22	0.42	5	17	6.39	0.41	3	15
Sauromalus ater	2.61	0.32	0	7	1.44	0.27	0	4
Uta stansburiana	2.53	0.31	0	7	2.01	0.32	0	5
Cnemidophorus tigris	0.91	0.24	0	3	0.93	0.23	0	3
Total lizards	15.27	0.72	7	24	10.77	0.71	4	19
Total lizard encounter rate	0.32	0.02	0.16	0.49	0.28	0.02	0.11	0.52

[a] $N = 18$ in all cases (six lizard counts/encounter rates on three lightly and three heavily disturbed plots).

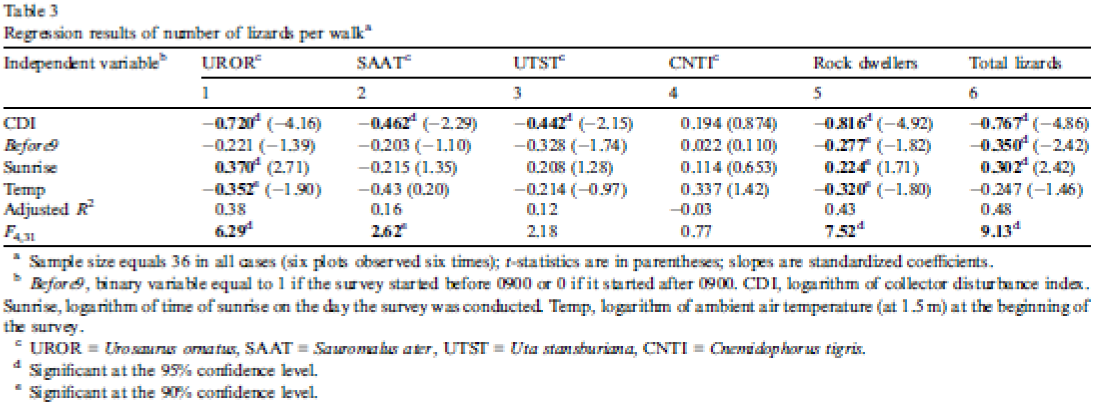

Table 3

Regression results of number of lizards per walk[a]

Independent variable[b]	UROR[c]	SAAT[c]	UTST[c]	CNTI[c]	Rock dwellers	Total lizards
	1	2	3	4	5	6
CDI	**−0.720**^{d} (−4.16)	**−0.462**^{d} (−2.29)	**−0.442**^{d} (−2.15)	0.194 (0.874)	**−0.816**^{d} (−4.92)	**−0.767**^{d} (−4.86)
Before9	−0.221 (−1.39)	−0.203 (−1.10)	−0.328 (−1.74)	0.022 (0.110)	**−0.277**^{e} (−1.82)	**−0.350**^{d} (−2.42)
Sunrise	**0.370**^{d} (2.71)	−0.215 (1.35)	0.208 (1.28)	0.114 (0.653)	**0.224**^{e} (1.71)	**0.302**^{d} (2.42)
Temp	**−0.352**^{e} (−1.90)	−0.43 (0.20)	−0.214 (−0.97)	0.337 (1.42)	**−0.320**^{e} (−1.80)	−0.247 (−1.46)
Adjusted R^2	0.38	0.16	0.12	−0.03	0.43	0.48
$F_{4,31}$	**6.29**^{d}	**2.62**^{e}	2.18	0.77	**7.52**^{d}	**9.13**^{d}

[a] Sample size equals 36 in all cases (six plots observed six times); t-statistics are in parentheses; slopes are standardized coefficients.

[b] *Before9*, binary variable equal to 1 if the survey started before 0900 or 0 if it started after 0900. CDI, logarithm of collector disturbance index. Sunrise, logarithm of time of sunrise on the day the survey was conducted. Temp, logarithm of ambient air temperature (at 1.5 m) at the beginning of the survey.

[c] UROR = *Urosaurus ornatus*, SAAT = *Sauromalus ater*, UTST = *Uta stansburiana*, CNTI = *Cnemidophorus tigris*.

[d] Significant at the 95% confidence level.

[e] Significant at the 90% confidence level.

0.720 standard deviations. Turning to the environmental variables, we determined that time of sunrise was a significant determinant of the number of tree lizards observed (and to a lesser extent temperature). In relative terms, CDI was the most important determinant of lizard abundance, since it possessed the largest standardized coefficient. Likewise, regression 2 revealed that CDI had a significant effect on chuckwallas. Regressions 3 and 4 revealed that jointly none of the variables considered significantly affected the number of sideblotched lizards or western whiptail lizards observed ($F_{4,31}$ = 2.18 and 0.77, respectively). When we combined rock-dwelling lizards (tree lizards and chuckwallas), regression 5 revealed that CDI, time of sunrise, temperature, and whether or not we started the survey before or after 0900 significantly affected the number of lizards observed. This regression also had the best overall fit (R^2 = 0.43 and $F_{4,31}$ = 7.52). Again, CDI possessed the largest coefficient. Regression 6 revealed a significant effect of CDI, time of sunrise and whether or not we started the survey before or after 0900 on total number of lizards observed, but did not fit the data as well as the rock-dwelling regression (regression 5).

For comparative purposes we ran the same 6 multiple regressions, but with the dependent variables measured as encounter rates (lizards encountered per minute per walk) in Table 4. Focusing on rock-dwellers (regression 5, R^2 = 0.48, $F_{4,31}$ = 8.90, best overall fit), CDI was a significant determinant of lizard abundance whether measured as a lizard count (-0.816 in Table 3) or as a lizard encounter rate (-0.384 in Table 4). Effectively, increased collector disturbance had a negative effect on either measure of rock-dweller abundance. Since the coefficients are standardized and effectively unit-less, the difference (-0.816 vs. -0.384) is attributable to differences in the time to complete each walk, which is only accounted for in the encounter rate regression of Table 4. A formal test of the hypothesis that the CDI coefficients were the same yields t = 1.91, implying that the difference is statistically *insignificant* at the 5% level (although significant at the 10% level). Regardless of which measure we examine, one can conclude that collector disturbance adversely affects rock-dwelling lizard abundance in this sample by as little as 0.384 standard deviations and by as much as 0.816 standard deviations (ignoring sampling variability).

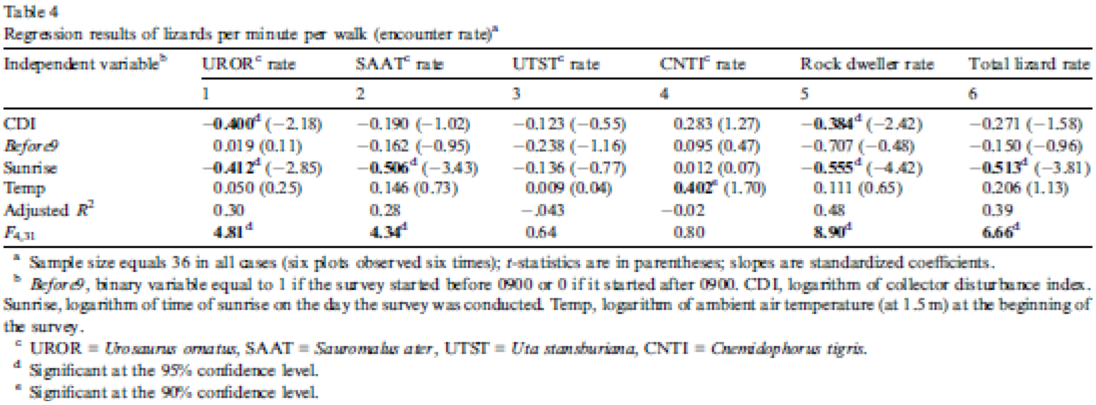

Table 4

Regression results of lizards per minute per walk (encounter rate)^{a}

Independent variable^{b}	UROR^{c} rate	SAAT^{c} rate	UTST^{c} rate	CNTI^{c} rate	Rock dweller rate	Total lizard rate
	1	2	3	4	5	6
CDI	**−0.400**^{d} (−2.18)	−0.190 (−1.02)	−0.123 (−0.55)	0.283 (1.27)	**−0.384**^{d} (−2.42)	−0.271 (−1.58)
Before9	0.019 (0.11)	−0.162 (−0.95)	−0.238 (−1.16)	0.095 (0.47)	−0.707 (−0.48)	−0.150 (−0.96)
Sunrise	**−0.412**^{d} (−2.85)	**−0.506**^{d} (−3.43)	−0.136 (−0.77)	0.012 (0.07)	**−0.555**^{d} (−4.42)	**−0.513**^{d} (−3.81)
Temp	0.050 (0.25)	0.146 (0.73)	0.009 (0.04)	**0.402**^{e} (1.70)	0.111 (0.65)	0.206 (1.13)
Adjusted R^2	0.30	0.28	−.043	−0.02	0.48	0.39
$F_{4,31}$	**4.81**^{d}	**4.34**^{d}	0.64	0.80	**8.90**^{d}	**6.66**^{d}

[a] Sample size equals 36 in all cases (six plots observed six times); *t*-statistics are in parentheses; slopes are standardized coefficients.

[b] *Before9*, binary variable equal to 1 if the survey started before 0900 or 0 if it started after 0900. CDI, logarithm of collector disturbance index. Sunrise, logarithm of time of sunrise on the day the survey was conducted. Temp, logarithm of ambient air temperature (at 1.5 m) at the beginning of the survey.

[c] UROR = *Urosaurus ornatus*, SAAT = *Sauromalus ater*, UTST = *Uta stansburiana*, CNTI = *Cnemidophorus tigris*.

[d] Significant at the 95% confidence level.

[e] Significant at the 90% confidence level.

4. Discussion

Our results suggest that relative abundance of rock-dwelling lizards decreases with increased habitat destruction caused by collectors. The effects of this destruction likely have important consequences that go beyond the loss of the individual being collected. Any collecting method that causes permanent damage to the habitat is likely to negatively affect the entire population of lizards. Destroying rocks to collect lizards may be analogous to cutting down a stand of trees to harvest a single deer or draining a lake to catch a single fish. In addition, habitat destruction caused by reptile collectors may have community-wide effects as well. Small mammals (mostly rodents and bats), a few amphibians, certain birds, innumerable invertebrates, and many plants use the microhabitats we studied (personal observations; Maser et al., 1986). The effect of habitat disturbance on these species is unknown, but in species for which lost microhabitats are essential or important, the effect is likely to be negative. This is especially true for species such as the rock-dwelling lizards in this study, which inhabit rocky habitats because they provide shelter from extreme temperatures and desiccation.

Among reptiles, the direct effects of collection and habitat damage probably affect target species (those sought for personal use or commercial purposes) to a greater degree than non-target or incidentally collected species. Of the two rock-dwelling species studied, chuckwallas are commercially valuable and may be under intense collection pressure (Montanucci, 1997), but tree lizards are not. We hypothesize that the influence of microhabitat destruction on target species would be generally stronger than on non-target species. Indeed, our data indicate that there was a 50% decrease in chuckwallas compared with a 33% decrease in tree lizards across lightly and heavily disturbed plots.

Decreased relative abundance of lizards on heavily disturbed plots could be due to a variety of reasons. Possibilities include: damage to habitat, including all of its direct and ancillary effects (e.g., actual habitat loss, decreased food availability, and increased competition for resources); actual collection of lizards; elevated mortality resulting from proximity of heavily disturbed plots to roads and trails; increased shyness of lizards on heavily disturbed plots; or emigration of lizards from heavily disturbed plots. It is possible that rather than causing a decrease in relative abundance of lizards on heavily disturbed plots, relative abundance of lizards may have been elevated on lightly disturbed plots. Because we did not gather data on lizard abundance prior to disturbance, we are unable to address this directly. However, if collectors begin to focus their efforts on the lightly disturbed plots where populations are potentially elevated, the subsequent declines in lizard abundance may be even more pronounced than those suggested in this study.

We suggest experimental testing of alternative hypotheses that may explain the observed negative relationship between disturbance and lizard relative abundance. If habitat damage is an important causative factor, the ultimate cause of decreased abundance remains unclear and may vary from one species to another. For some, the loss of shelter from predators may be important. For others, the relevant impact may be loss of food resources (e.g., many lizards feed on invertebrates that may be affected), loss of shelter from extreme temperatures or desiccation (potentially important for many animals and for plants whose root systems are exposed by disturbance), or loss of important microclimates for thermoregulation, hibernation, or oviposition.

Habitat destruction caused by reptile collectors is extensive and ongoing in deserts of the southwestern United States. During surveys of nine Arizona mountain ranges, we found damaged rock outcrops within short distances of roads in every range we visited. In California, destructive collecting practices have been prohibited for many years. One of us (JMH) observed damage in all 13 desert mountain ranges visited in southern California in the 1980s. This destruction has extended into Baja California in Mexico (Mellink, 1995). We expect microhabitat loss in deserts of the southwestern United States to accelerate as rapid growth of urban centers continues and reptile collectors from around the country and the world range farther afield.

Although we only investigated the effects of microhabitat loss on lizards, collection of arthropods, fossils, rocks and minerals, vandalism, rock climbing, off-highway vehicle activity, and mountain biking may cause similar damage. The combination of habitat loss or degradation and concomitant direct collection deserves greater attention from resource managers and conservation biologists.

We encourage resource management agencies to investigate regulatory options that limit surface-disturbing activities that damage rocky desert habitat and affect the organisms that use them. Our data suggest that habitat destruction of the sort we studied, which is often ignored because it is inconspicuous, can have a negative impact on lizard populations. These effects merit agency consideration, including the development of rules, regulations, management plans, and project review and mitigation protocols.

Specifically, we recommend regulation of collecting methods, including prohibition of those that are most damaging to wildlife habitat. At another level, disallowing commercial activity involving wildlife may help remove some of the incentive for collecting activities that damage habitats. Due to the remote locations involved, enforcement of regulations is difficult. We suggest increased management attention to rock outcrops as important wildlife habitats, including increased enforcement of existing regulations. Without immediate protection, rock outcrops may suffer the same fate as coral reefs (Richmond, 1993) and benthic habitats (Hall, 1999; Kaiser and de Groot, 2000), both of which have been affected by destructive fishing techniques. Destruction of these sensitive habitats has resulted in extensive legal protections. Damage to desert rock outcrops may warrant similar concern and action.

Although regulatory action is one option for controlling collection and habitat damage, regulations only address the symptoms of a broader problem. Education has the greatest potential for alleviating this problem. Young people, given the opportunity to develop a land and wildlife ethic, have more positive attitudes toward land and wildlife conservation (Kellert and Westervelt, 1983) and may be less likely to engage in practices that damage wildlife habitat. For example, education of reptile collectors, via local and regional herpetological and conservation societies, should emphasize the importance of leaving habitat in an unaltered state. If specimens must be obtained, effective and nondestructive collecting techniques exist (Stebbins, 1985; Gibbons and Semlitsch, 1991). For many species, habitat damage can be avoided by collecting specimens when they are away from critical microhabitats. Of course, this requires familiarity with the natural history of the animals being sought. At the level of resource management agencies, education of law enforcement officials on how to recognize the activities of collectors will result in more effective enforcement.

To preserve rock outcrops in the southwestern deserts of the United States, there is a need for prompt management action. We recommend: (1) regulation of commercial use of wildlife and of collecting and recreational activities that cause habitat damage; (2) increased law enforcement effort; and (3) expanded educational programs that target young, inexperienced collectors. The need is especially important for microhabitats that support diverse species assemblages and where damage is likely to be long term. The rocky habitats we studied are ancient and once lost may require geological time to re-form (McAuliffe, 1994).

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References

Abts, M.L., 1987. Environment and variation in life history traits of the chuckwalla, *Sauromalus obesus*. Ecological Monographs 57, 215–232.

Anderson, R.A., 1993. An analysis of foraging in the lizard, *Cnemidophorus tigris*. In: Wright, J.W., Vitt, L.J. (Eds.), Biology of Whiptail Lizards (genus *Cnemidophorus*). Oklahoma Museum of Natural History, Norman, Oklahoma, pp. 83–116.

Arena, P.C., Warwick, C., Duvall, D., 1995. Rattlesnake round-ups. In: Knight, R.L., Gutzwiller, K.J. (Eds.), Wildlife and Recreationists: Coexistence through Management and Research. Island Press, Washington, DC, pp. 313–324.

Belsley, D.E., Kuh, E., Welsh, R., 1908. Regression Diagnostics: Identifying Influential Data and Sources of Collinearity. Wiley, NY.

Baltosser, W., Hubbard, J., 1985. New Mexico Ridgenose Rattlesnake Recovery Plan. US Fish and Wildlife Service, Albuquerque, NM.

Bock, C.E., Smith, H.M., Bock, J.H., 1990. The effect of livestock grazing upon abundance of the lizard, *Sceloporus scalaris*, in southeastern Arizona. Journal of Herpetology 24, 445–446.

Brown, W.S., 1993. Biology, status and management of the timber rattlesnake (*Crotalus horridus*): a guide for conservation. Society for the Study of Amphibians and Reptiles, Herpetological Circular 22, 1–78.

Crowder, L.B., Hopkins-Murphy, S.R., Royle, J.A., 1995. Effects of turtle excluder devices (TEDs) on loggerhead sea turtle strandings with implications for conservation. Copeia 1995, 773–779.

Diemer, J.E., 1986. The ecology and management of the gopher tortoise in the southeastern United States. Herpetologica 42, 125–133.

Dodd Jr., C.K., 1986. Importation of live snakes and snake products into the United States, 1977–1983. Herpetological Review 17, 76–79.

Seigel, R.A., 1993. Strategies for snake conservation. In: Collins, J.T. (Ed.), Snakes: Ecology and Behavior. McGraw-Hill, New York, pp. 363–393.

Dorn, R.I., 1983. Cation-ratio dating: a new rock varnish agedetermination technique. Quaternary Research 20, 49–73.

Dunham, A.E., 1981. Demographic and life-history variation among populations of the iguanid lizard *Urosaurus ornatus*: implications for the study of life-history phenomena in lizards. Herpetologica 38, 208–221.

Fritts, T.H., Snell, H.L., Martin, R.L., 1982. *Anarbylus switaki* Murphy: an addition to the herpetofauna of the United States with comments on relationships with *Coleonyx*. Journal of Herpetology 16, 39–52.

Gibbons, J.W., Semlitsch, R.D., 1991. Guide to the Reptiles and Amphibians of the Savannah River Site. University of Georgia Press, Athens, GA.

Goldingay, R.L., Newell, D.A., 2000. Experimental rock outcrops reveal continuing habitat disturbance for an endangered Australian snake. Conservation Biology 14, 1908–1912.

Grismer, L.L., Edwards, D.D., 1988. Notes on the natural history of the barefoot banded gecko *Coleonyx switaki* (Squamata: Eublepharidae). In: De Lisle, H.P., Brown, P.R., Kaufman, B., McGurty, B.M. (Eds.), Proceedings of the Conference on California Herpetology. Southwestern Herpetologists Society, Special Publication 4. Sunlight Press, Lakeside, CA, pp. 13–24.

Hall, S.J., 1999. The Effects of Fishing on Marine Ecosystems and Communities. Blackwell Science, Oxford, United Kingdom.

Jennings, M.R., Hayes, M.R., 1985. Pre-1900 overharvest of California red-legged frogs (*Rana aurora draytonii*): the inducement for bullfrog (*Rana catesbeiana*) introduction. Herpetologica 41, 94–103.

Jones, K.B., 1981. Effects of grazing on lizard abundance and diversity in western Arizona. Southwestern Naturalist 26, 107–115.

Kaiser, M.J., de Groot, S.J., 2000. The Effects of Fishing on Nontarget Species and Habitats: Biological, Conservation, and Socioeconomic Issues. Blackwell Science, Oxford, United Kingdom.

Kellert, S.R., Westervelt,M.O., 1983. Childrens Attitudes, Knowledge and Behaviors toward Animals. US Fish and Wildlife Service. US Government Printing Office, Washington, DC.

Klauber, L.M., 1935. Notes on Herpetological Field Collecting. Collection Leaflet 1. San Diego Society of Natural History, San Diego, CA.

Luckenbach, R.A., Bury, R.B., 1983. Effects of off-road vehicles on the biota of the Algodones Dunes, Imperial County, California. Journal of Applied Ecology 20, 265–286.

Maser, C., Geist, J.M., Concannon, D.M., Anderson, R., Lovell, B., 1986. Geomorphic and edaphic habitats. Wildlife habitats in managed rangelands – the Great Basin of southeastern Oregon. General technical report PNW-99. US Forest Service, Corvalis, Oregon, pp. 1–84.

McAuliffe, J.R., 1994. Landscape evolution, soil formation, and ecological patterns and processes in Sonoran Desert bajadas. Ecological Monographs 64, 111–148.

McGurty, B.M., 1988. Natural history of the California mountain kingsnake *Lampropeltis zonata*. In: De Lisle, H.P., Brown, P.R., Kaufman, B., McGurty, B.M. (Eds.), Proceedings of the Conference on California Herpetology. Southwestern Herpetologists Society, Special Publication 4. Sunlight Press, Lakeside, CA, pp. 13–24.

Mellink, E., 1995. The potential effect of commercialization of reptiles from Mexicos Baja California peninsula and its associated islands. Herpetological Natural History 3, 95–99.

Montanucci, R.R., 1997. Captive management, behavior and conservation of chuckwallas, *Sauromalus obesus* (Lacertilia:Iguanidae). Bulletin of the Chicago Herpetological Society 32, 121–137.

Petranka, J.W., Eldridge, M.E., Haley, K.E., 1993. Effects of timber harvesting on southern Appalachian salamanders. Conservation Biology 7, 363–370.

Richmond, R.H., 1993. Coral reefs: present problems and future concerns resulting from anthropogenic disturbance. American Zoologist 33, 524–536.

Rumble, M.A., 1989. Wildlife associated with scoria outcrops: implications for reclamation of surface-mined lands. Research paper RM-285. US Forest Service, Rapid City, SD.

Schlesinger, C.A., Shine, R., 1994. Choosing a rock: perspectives of a bush-rock collector and a saxicolous lizard. Biological Conservation 67, 49–56.

Shine, R., Fitzgerald, M., 1989. Conservation and reproduction of an endangered species: the broad-headed snake, *Hoplocephalus bungaroides* (Elapidae). Australian Zoologist 25, 65–67.

SPSS, 2001. SPSS for Windows Version 11.0. SPSS, Chicago, Illinois.

Stebbins, R.C., 1985. A Field Guide to Western Reptiles and Amphibians, Second ed., revised. Houghton Mifflin, Boston, MA.

Tinkle, D.W., 1967. The life and demography of the side-blotched lizard, *Uta stansburiana*. Miscellaneous Publications of the Museum of Zoology, University of Michigan, No. 132.

Turner, R.M., Brown, D.E., 1982. Tropical-subtropical desertlands. Desert Plants 4, 180–221.

Van Rooy, P.T.J.C., Stumpel, A.H.P., 1995. Ecological impact of economic development on Sardinian herpetofauna. Conservation Biology 9, 263–269.

Webb, R.H., Wilshire, H.G., 1983. Environmental Effects of Off- Road Vehicles: Impacts and Management in Arid Regions. Springer-Verlag, New York.

Weir, B., 1986. Arizona Handbook. Moon Publications, Chico, CA.

Welsh Jr., H.H., 1990. Relictual amphibians and old-growth forests. Conservation Biology 4, 309–319.