IMPACTS OF URBANIZATION ON DESERT TORTOISES AT SAGUARO NATIONAL PARK: TORTOISE DENSITY ALONG THE SOUTHERN PARK BOUNDARY

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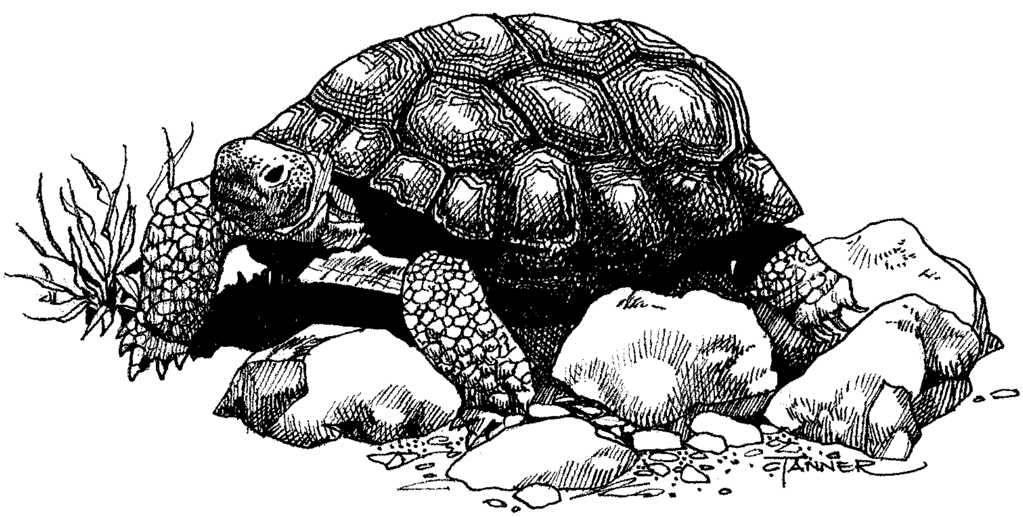

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Roy C. Averill-Murray
and
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INTRODUCTION

Urban development increasingly encroaches on wild lands that were once distant from human population centers. Parks and reserves are no longer immune from the effects of urbanization as they become "islands" in an urban landscape. We are working with numerous collaborators to study the effect of urban development on wildlife, particularly the desert tortoise *Gopherus agassizii* at Saguaro National Park, Pima County, Arizona.

Saguaro National Park is facing increasing threats to its natural resources due to rapid development of private lands along its boundary. Impacts to wildlife include harassment and predation by cats and dogs, releases of exotic species that may transmit diseases to native populations, mortality on roads, and illegal collections of animals as pets. In the Rincon Mountain (East) District of the park, urban development is currently most intense in the Rincon Valley along the southern edge of the district. One development, the Rocking K Ranch, is a former cattle ranch located in this area. Part of this ranch was incorporated into Saguaro National Park during the mid-1990s, but the remaining portion is slated to become a residential community and resort during the next several years.

Research on both the Rocking K Ranch and the formerly private lands now in the park (the expansion area) was initiated in 1993 by a partnership between Saguaro National Park, the Rincon Institute, the University of Arizona, the Arizona Game and Fish Department, and other organizations. In addition to desert tortoises, scientists are monitoring changes in populations of tiger rattlesnakes and elf owls as well as changes in overall biological diversity (Harris and Schwalbe 1995; Harris 1996).

Although research indicates that habitat loss negatively impacts wildlife, many people believe that individual animals simply move out of harm's way during development activities, especially when parks and protected areas exist nearby. Few studies have examined wildlife population-level changes as a result of urban development in desert areas, especially for long-lived species such as the desert tortoise. Documentation of the specific effects of development can be important in providing examples for public discussion about land use planning.

Many potential methods exist for evaluating environmental impacts on animals. At the population level, the most common approach is to monitor changes in population size (abundance) or the number of animals per unit area (density). Methods used to estimate the size of desert tortoise populations include indices of abundance, mark-recapture techniques on 1-mi^2 plots (Averill-Murray and Klug 2000), and line transect distance sampling (Anderson and others 2001; Buckland and others 2001). Distance sampling, which involves searching along a randomly-located transect and measuring the distance to each tortoise encountered, is currently the favored method for estimating desert tortoise density in the Mojave Desert (Anderson and others 2001). This method has not been widely used in the Sonoran Desert in part because of the greater vegetative cover and topographic relief found in this area, but it appears to be a valid method for sampling (Swann and others 2002).

The purpose of the current study was to provide baseline data for studying the effects of urbanization on desert tortoises at Saguaro National Park. Specifically, the objectives of this phase of the project were to use distance sampling to estimate the number and density of tortoises in the expansion area of the park where we expect desert tortoises may be impacted either directly or indirectly by future development.

STUDY AREA

The expansion area of Saguaro National Park is located in the Rincon Valley on the eastern edge of Tucson, Arizona. Elevation in the study area ranges from approximately 945 m to 1040 m. Our study area included the 450.8-ha portion of the park on southern boundary east of the Rocking K and north of other developing private lands (Fig. 1). The area is within the palo verde-mixed cacti series of the Arizona Upland subdivision of the Sonoran Desert (Turner and Brown 1982). Vegetation is characterized by a diversity of cacti, shrubs, and leguminous trees. Topography typically consists of steep, rocky slopes with many large boulders and rock outcrops, but also includes deeply incised dry washes with riparian trees and shrubs. Annual rainfall ranges from 30-35 mm and usually falls in 2 distinct periods: a winter wet season from November to April and a summer monsoon season from July to September (Adams and Comrie 1997).

METHODS

DISTANCE SAMPLING

Assumptions

We used distance sampling to survey for desert tortoises. This method uses measured distances between sampled objects and a central point or line (that is, transect) and a set of assumptions regarding detectability to estimate population density (Burnham and others 1980; Buckland and others 2001). Measured distances allow for the creation of a detection function, a curve with object detectability decreasing with increasing distance from the centerline. The major assumptions of distance sampling include: 1) objects on the centerline are always detected; 2) objects are detected at their initial location, prior to movement in response to the observer; and 3) perpendicular distances are measured accurately (Buckland and others 2001).

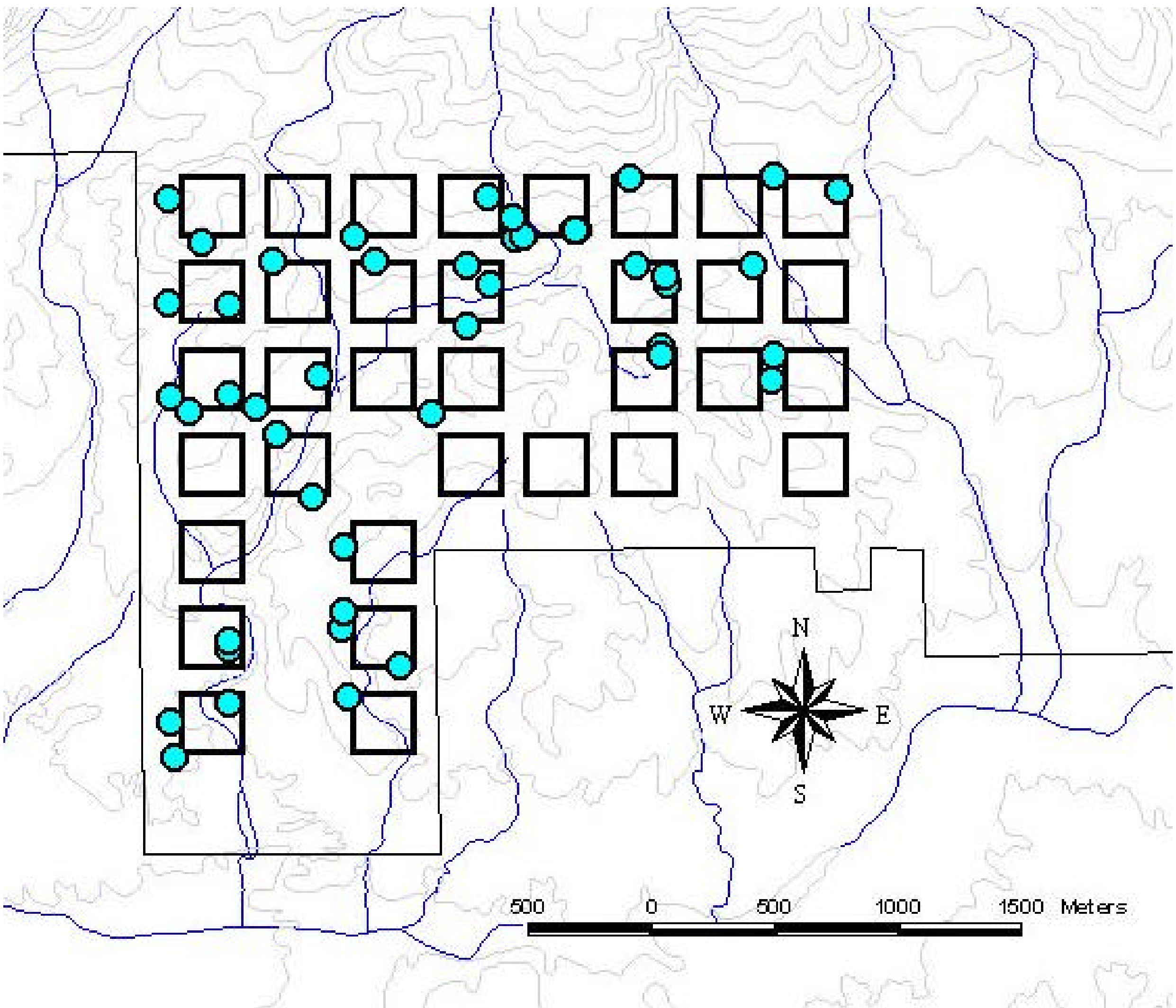

Figure 1. Map of study area within Saguaro National Park, East Unit, Pima County, Arizona. Squares are 1-km transects (250 m on each side). Circles are observations of desert tortoises during this study.

Survey Protocol

We systematically placed 34 transects (Fig. 1) based on a starting point located a random distance and direction from the northeast corner of the study area; any point in the study area had an equal chance of being sampled. Each 1-km transect was a square measuring 250 m (map distance) on each side and separated from adjacent squares by 100 m. We used Global Positioning System (GPS) receivers (Garmin emap) to locate corner coordinates in the field. We surveyed transects on 35 days between 10 July and 16 September 2001. All surveys took place between approximately 0545 hr and 1130 hr. We surveyed pairs of transects in a randomly selected order without replacement. Each transect was surveyed twice, once each during 2 rounds of sampling.

Field technicians worked in pairs. The starting corner of the square to be surveyed was randomly selected. One technician (FT 1) dragged a 50-m fiberglass tape along one edge of the square, following a straight north-south or east-west line using a GPS receiver. After stretching the tape out 50 m, FT 1 walked back toward the beginning of the tape in a sinusoidal pattern on his or her right side of the tape while searching for tortoises. At the same time a second field technician (FT 2) walked in a similar sinusoidal pattern on the opposite side of the tape, heading toward the end of the tape. Anderson and others (2001) recommended that in habitat similar to that at our site more effort should be expended searching near the centerline, so technicians were instructed to concentrate their searches within 5 m of the centerline. When FT 1 returned to the beginning of the tape, he or she turned around and walked directly along the tape, ensuring that no animals along the line were missed. Then FT 2 began pulling the tape forward another 50 m, and the process repeated itself, with the 2 technicians' roles reversing. Technicians attempted to maintain as straight a line as possible with the tape, but drift in the GPS coordinates and obstacles such as rock outcrops sometimes resulted in crooked transects. Technicians recorded the actual measured distance between each flagged transect corner.

We searched visually for tortoises, scanning open ground and looking under vegetation and in rocky crevices and underground holes. We used supplemental light (flashlight, reflected sunlight) as needed, but did not probe burrows for tortoises that were out of sight due to variability in tortoise response to "tapping" (Medica and others 1986). We measured the perpendicular distance to the nearest centimeter between the tortoise and the survey tape and recorded location (UTM coordinates) using a GPS receiver. We gently removed tortoises found inside shelter sites by hand or by using a snake hook. We identified the sex of each tortoise, measured midline carapace length (MCL), and noted health characteristics. If we were unable to extract a tortoise from a burrow, we estimated whether its MCL was greater or less than 150 mm. Tortoises with a MCL <150 mm are more easily overlooked, so they were not included in data analysis. We marked individuals with numbered tags epoxied to the shell and also by notching the marginal scutes (Ernst and others 1974). During handling, technicians wore latex gloves as a precaution against potential disease transfer among individuals. After handling, we rinsed equipment with the veterinary disinfectant chlorhexidine diacetate (Nolvasan, American Home Products

Corporation, Madison, NJ). Tortoise handling protocols were approved by the University of Arizona (IACUC 00-084).

RADIO TELEMETRY

One of the principal assumptions of distance sampling is that all individuals on the centerline are detected (Buckland and others 2001). Because desert tortoises spend a significant amount of time underground, the proportion of the population visible must be independently estimated in order to meet the above assumption. To determine tortoise detectability (g_0) on our study site - that is, the proportion of time that a tortoise would be visible to an observer during distance sampling, with or without supplemental light - we tracked 23 individuals ($\geq$150 mm MCL) with radio telemetry concurrently with transect surveys.

We tracked tortoises using a directional antenna and receiver (Telonics Model TR4, Phoenix, AZ) on 29 occasions during the study period. We did not track all tortoises during each occasion (mean = 8.6, SE = 0.84). In addition to data on habitat, behavior, health, and other parameters, technicians recorded whether the tortoise would have been visible by an observer during distance sampling (g_0) with or without the use of supplemental light (flashlight or reflected sunlight). We calculated g_0 as the mean daily proportion of tortoises visible; we included only days on which $\geq$4 tortoises were monitored (n = 18 days). We estimated the standard error of g_0 as the mean of the daily binomial standard errors of the proportion visible (Zar 1984).

DENSITY AND ABUNDANCE ESTIMATION

We used Program DISTANCE 3.5 (Thomas and others 1998) to estimate density of tortoises $\geq$150 mm MCL. We used the models (key function/series expansion) recommended by Buckland and others (2001): uniform/cosine, uniform/simple polynomial, half-normal/cosine, half-normal/hermite polynomial, hazard-rate/cosine, and hazard-rate/simple polynomial. We first applied the uniform/cosine model to the complete data set. Examination of the detection probability histogram indicated that while the model did fit the raw data ($P > 0.09$; Fig. 2a), a better fit was possible. Truncating the largest observation and grouping the data (Buckland and others 2001) into 5-m intervals eliminated spikes in the middle and on the tail of the curve and provided a better fit ($P = 0.914$; Fig. 2b). We chose the best-fitting model as that with the lowest Akaike Information Criterion (AIC) (Buckland and others 2001). We report percent coefficient of variation (CV) output by Program DISTANCE for all estimates. Upper and lower confidence intervals (CIs) were taken as the 2.5% and 97.5% quantiles of 999 bootstrap estimates computed by the program. Program DISTANCE converted density estimates to estimates of absolute abundance based on the study area of 450.8 ha.

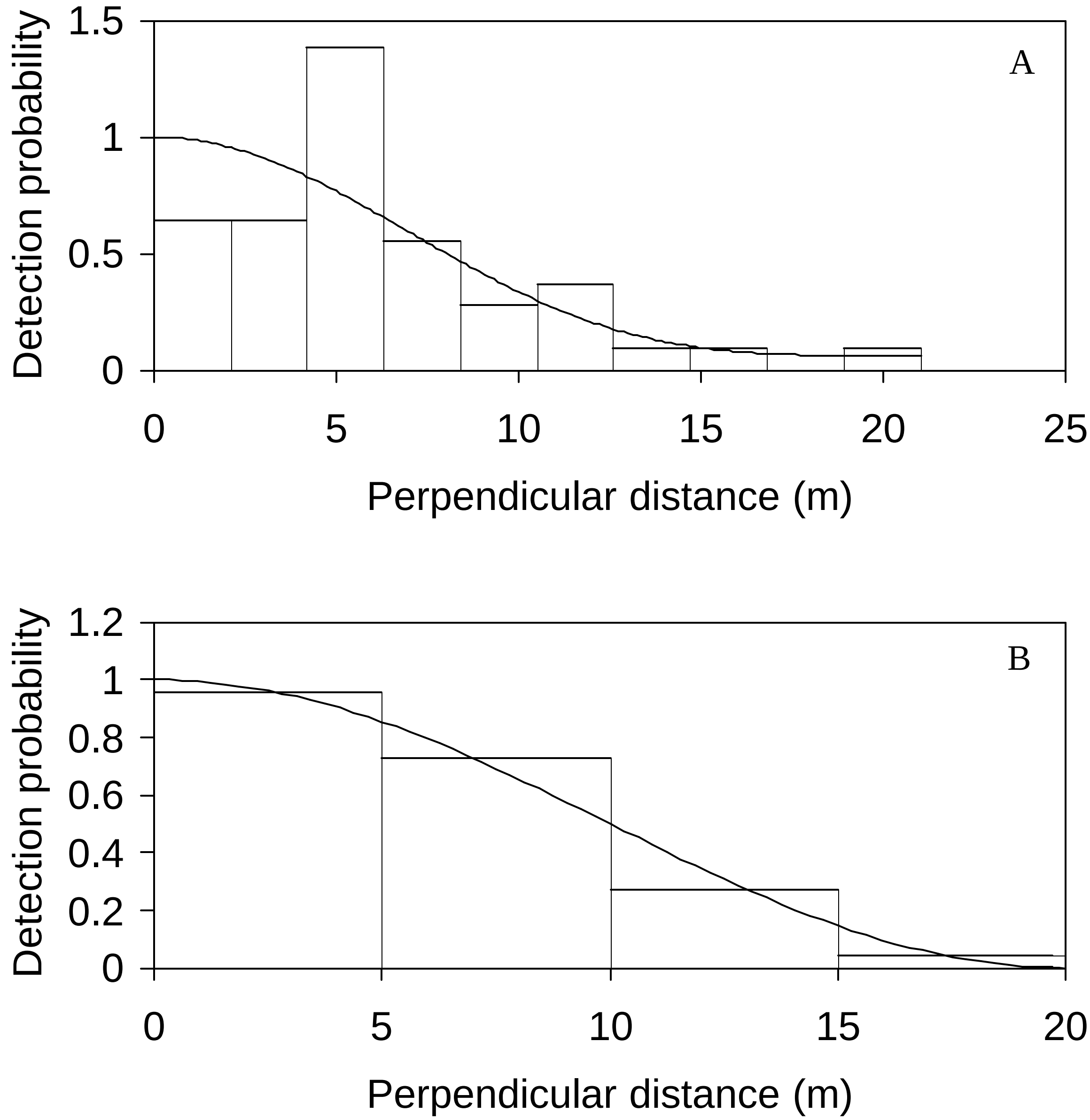

Figure 2. Detection probability histograms for desert tortoise distance sampling at Saguaro National Park, 2001. A) Raw data. B) Truncated data grouped into 5-m intervals.

RESULTS

We observed 45 subadult-adult (≥150 mm MCL) and 3 juvenile tortoises on transects. Carapace lengths ranged from 54-275 mm. We observed 17 females and 22 males, excluding 4 individuals too young to sex and 5 individuals we could not retrieve from their burrows. The mean proportion of tortoises visible during radio telemetry throughout the study was 0.79 (SE = 0.122).

Program DISTANCE produced a density estimate of 0.41 tortoises/ha (CV = 25.8%, CI = 0.27-0.62), which resulted in an estimated abundance of 185 individuals ≥150 mm MCL in the study area (CV = 25.8%, CI = 123-279). The uniform/cosine model resulted in the best fit of the data (AIC = 97.098), 0.296 units better than the half-normal key with cosine series expansion (AIC = 97.394). The estimated encounter rate over 68 km of transects was 0.65/km (CV = 18.0%, CI = 0.45-0.93). Program DISTANCE also provided component percentages of the density variance due to the detection probability (4.3%), encounter rate (55.2%), and g_0 (40.5%).

DISCUSSION

Desert tortoises in the United States occur in two populations. The Mojave population is located north and west of the Colorado River, while the Sonoran population includes all tortoises south and east of the river in Arizona and Mexico (Arizona Interagency Desert Tortoise Team [AIDTT] 2000). The two populations differ in their legal status, with the Mojave population listed by the U.S. Fish and Wildlife Service as endangered and the Sonoran population having no federal status. Nevertheless, attention must also be directed toward the Sonoran population to ensure that the need to list that population under the Endangered Species Act may be precluded.

One threat facing tortoises in the Sonoran Desert is urban development (AIDTT 2000). Urbanization increases predation by pets and collection by people (Barrett and Johnson 1990; AIDTT 1996), roadkill (Nicholson 1978), and the introduction of diseases from non-native tortoises (Dickinson and others 1995). In addition, urban development causes fragmentation of habitat by disrupting or precluding movements of tortoises among populations. Long distance movements are periodically observed in desert tortoise studies (Averill-Murray and Klug 2000) and may be important for maintaining genetic diversity within the species.

In the Tucson area, development of excellent tortoise habitat in mountain foothills in the Rincon, Santa Rita, Santa Catalina, Tortolita, and Tucson mountains has probably led to large area-wide decreases in tortoise abundance. Anecdotal evidence from people living in foothills neighborhoods indicates that new neighborhoods with large numbers of tortoises lose them over a period of 5-10 years (D. Hardy, pers.

comm.). However, no scientific studies have estimated tortoise population size in areas prior to development or followed the fate of individual tortoises during and after development. As a result, no information is available on the overall effect of these land-use changes on tortoises. Our study provides an opportunity to learn about these changes on both the individual and population scale.

Our estimated tortoise density on this parcel of Saguaro National Park is similar to that on the Rocking K Ranch (0.52 tortoises/ha, CV = 23.0%, CI = 0.29-0.79), where 193 individual tortoises $\geq$150 mm MCL are at risk from the future development (CV = 23.0%, CI = 107-291) (Swann and others 2002). These estimated densities are among the highest recorded for this species in Arizona but are consistent with results found elsewhere in the Rincon Mountains. A 1996-1997 survey at the Javelina Picnic area site less than 8 km from our site estimated a density of 0.49 tortoises per ha (Wirt and Robichaux 2001).

These data will ultimately be used in combination with information on survival, home range, and habitat use (collected separately) to evaluate the effects of development on desert tortoises, including tortoises translocated into Saguaro National Park from adjacent private lands to avoid being directly killed by construction. Finally, the results of the study will be used to support management decisions relative to urban wildlife. Results will also be used in educational programs on the effects of urban development on wildlife and on living compatibly with wildlife on the urban edge.

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