Evaluation and Review of Field Techniques Used to Study and Manage Gopher Tortoises

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Abstract.—This paper reviews methods used to census gopher tortoises as well as techniques for demographic, reproduction, and movement studies. We also evaluate a refinement for line transect estimates of gopher tortoise abundance. In situations where dense vegetation structure may hinder abilities to locate burrows along transects, Fourier series estimators of abundance can be used to overcome the problem. However, our results indicate that many transects may be needed to provide precise estimates of gopher tortoise abundance over large areas. The collection of vegetation data along transects may also be helpful in evaluating habitat preference in this species.

Introduction

Of the approximately 107 genera and 267 species of North American reptiles, two species of tortoises have received a relatively large amount of scientific attention. Organizations dedicated to the conservation and protection of the gopher tortoise (*Gopherus polyphemus*) (The Gopher Tortoise Council) and the desert tortoise (*G. agassizii*) (The Desert Tortoise Council) attest to heightened levels of amateur and scientific interest in these species. Past bibliographies (Diemer 1981, Douglass 1975, Douglass 1977, Hohman et al. 1980) together record over 775 different publications concerning the genus, and more have been published since then. Compared to most other reptile species, an exceptional diversity of techniques has been employed, and many field methods have been developed and used to study their status and biology.

The gopher tortoise is a large terrestrial turtle (15-37 cm carapace length, 3.6-5.0 kg) that exhibits low rates of juvenile recruitment, extreme adult longevity, and persistent use of a small number of burrows, often in a loose aggregation of 10 to 15 individuals. As a result, tortoises display a social system that involves individuals who may have interacted regularly for decades (Douglass 1976, Landers et al. 1980, McRae et al. 1980). Tortoises were once a common feature of the upland habitats of the southeastern coastal plain (Auffenberg and Franz 1982), but the species is now less common and appears on several state and federal lists of rare or endangered species (Lohofener and Lohmeier 1984, Wood 1987). The principal forces driving these population declines are rapid urbanization, certain forest management practices, and human predation (Diemer 1986).

Gopher tortoise burrows are important to a large wildlife community, and 332 other species have been documented to use tortoise burrows at least occasionally (Jackson and Milstrey in press). Included among the several rare species that rely heavily on tortoise burrows are the Florida mouse (*Podomys floridanus*), Florida and dusky crawfish frogs (*Rana areolata asopus* and *R. areolata sevosa*), sand skink (*Neosoma reynoldsi*), Florida pine snake (*Pituophis melanoleucus mugiitus*), and eastern indigo snake (*Drymarchon corais couperi*).

In this paper we review techniques used in field research on the gopher tortoise community. We also discuss future areas of research and analyze the use of Fourier series estimators (Burnham et al. 1980) in line transect censusing techniques. In doing so, we suggest appropriate methods for future work, standardize some techniques, bring some lesser known techniques to the fore, and suggest refinements to commonly used methods.

Estimating Population Size

Burrow Count Transects

Burrow-count transects are currently the most widely used method for estimating the size of local gopher tortoise populations, though some tortoise populations do not dig burrows (Auffenberg 1969), while others may use seven or more burrows per individual (McRae et al. 1980). Burrows are particularly amenable to transect analysis since they are stationary and generally visible in many of the open areas occupied by gopher tortoises. Transects also require little equipment, can be used to cover relatively large areas in a short time, and can be used to estimate abundance over a large area using random or stratified-random sampling procedures. A conversion factor (Auffenberg and Franz 1982) is used to relate the number of different tortoise burrows to the number of gopher tortoises in an area.

The dimensions of reported transects ranges from 100 to 250 m in
traverse an area and search intensively for burrows. Later searches by a more experienced researcher did not reveal any previously undiscovered burrows, except for a few cryptic hatching burrows.

Trained dogs and aerial searches by helicopter (Humphrey et al. 1986) have also been used to locate gopher tortoise burrows. Gopher tortoises often defecate in or near their burrows, and a motivated dog can detect and locate the resulting olfactory source. Scats and carcasses are also important field sign used as indices of desert tortoise populations (Berry and Nicholson 1984, Woodman and Berry 1984).

Regularly used burrows often have several well-defined trails leading to foraging areas and other burrows (Ernst and Barbour 1972). We have used these trails to find burrows hidden in extremely dense vegetation.

**Activity Patterns and Correction Factors for Burrow Counts**

Although estimates of gopher tortoise burrow abundance are relatively easy to collect, calculating the number of tortoises associated with those burrows can be difficult. It seems logical that the number of tortoise burrows would be positively correlated with the number of gopher tortoises in an area, but the precise nature of this relationship is poorly understood. Complicating factors include the level of human disturbance, soil type, and factors that influence gopher tortoise activity patterns (e.g., time of day, season, and weather conditions).

Most researchers have used a correction factor of 0.614 times the number of "active" and "inactive" burrows to estimate tortoises abundance from burrow counts. This conversion factor is based on information presented in Auffenberg and Franz (1982) that was derived from long-term data on the occupation rates of 122 burrows. Burrow activity was defined by Auffenberg and Franz (1982) in the following manner:

- **Active (burrow)** if the soil of the burrow had been recently disturbed by the tortoise, **inactive** if the soil were undisturbed but the burrow appeared to be maintained, and **old** if the mouth had been washed in or covered with debris (1982:96) (italics ours).

Little experience is needed to learn to make these distinctions, but different investigators' classifications may vary, increasing the imprecision of tortoise abundance estimates. The precision is also affected by the activity level of tortoises. During warm periods tortoises may move among several burrows during a day; during cooler periods a tortoise may stay in a burrow for several weeks.

R. Stratton (Pers. comm.) suggests that it is possible to determine whether a burrow is occupied (i.e., active) by the direction of foot tracks on the burrow apron. Stratton was able to identify correctly 14 of 15 occupied burrows using this technique, but he incorrectly identified 19 unoccupied burrows as being occupied.

J. Stout (Pers. comm., University of Central Florida, Orlando Florida) has successfully used a "sewer snake" to determine if a burrow is occupied. When extended to the end of the burrow, the sound of the end of the wire tapping a tortoise shell is distinctive. Other methods include "feeling" for tortoises using long PVC pipes (Pers. comm., J. Diemer, Florida Game and Fresh Water Fish Commission Wildlife Research Laboratory, Gainesville, Florida) and listening for tortoises using either a flexible garden hose (Pers. comm., D.B. Means, Coastal Plains Institute, Tallahassee, Florida) or an electronic "ear" to amplify breathing sounds (Pers. comm., D. W. Speake, Alabama Cooperative Research Unit, Auburn, Alabama).

Several small twigs stuck vertically into the soil at the burrow mouth can also be used to determine if a burrow is occupied (Hallinan 1923, Beininger et al. in press). If properly spaced, one or more twigs will be knocked over the next time a tortoise passes. Direction of travel can be determined by uniquely marking the top of each twig (or using a "Y" shaped stick) and noting which di-

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**Table 2 — Examples of reported correction factors.**

<table>
<thead>
<tr>
<th>Tortoises/active Burrow</th>
<th>Tortoises/inactive Burrow</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>49/103 (48%)**</td>
<td>8/30 (7%)</td>
<td>Burke (pers.obs.)</td>
</tr>
<tr>
<td>43/64 (66%)</td>
<td>3/16 (19%)</td>
<td>Doornan (1986)</td>
</tr>
<tr>
<td>4/19 (21%)</td>
<td>0/25 (0%)</td>
<td>Fucigna and Nickerson (in press)</td>
</tr>
<tr>
<td>35/174 (20%)</td>
<td>0/44 (0%)</td>
<td>Unley (1986)</td>
</tr>
<tr>
<td>1/6 (16%)</td>
<td>12/41 (31%)</td>
<td>Lohofenlau (1982)</td>
</tr>
<tr>
<td>7/9 (79%)</td>
<td>0/47 (0%)</td>
<td>Speake (1985)</td>
</tr>
<tr>
<td>7/10 (70%)</td>
<td>0/47 (0%)</td>
<td>Stollers and Speake (1986)</td>
</tr>
<tr>
<td>66.0%</td>
<td>10/89 (11%)***</td>
<td>Stout et al. (in press)</td>
</tr>
</tbody>
</table>

*Not reported or additional details not reported.
**Includes "maybe active" activity classification.
***Unknown number of tortoises had been harvested prior to survey.
Burrow Excavation and Pulling

Digging up the entire burrow with a backhoe or hand shovel is both time consuming and destructive. At one South Florida site, it took an experienced backhoe operator 2.5 hours to excavate one burrow that was over 11 m long and 6 m deep. Most burrows are excavated in less than 45 minutes using a backhoe, which compares favorably to the approximately 30 days of bucket trapping required to remove all tortoises from an area (Diemer et al. in press).

When excavating a burrow, a sewer snake or garden hose should be extended to the end of the burrow to keep track of the tunnel path. The entire process is complicated by loose, sandy soils at some sites, and it is difficult to retain burrow structure and avoid potentially dangerous cave-ins. The difficulty of the process may be reduced by using an electronic device to locate the burrow end before digging (see Wolcott 1981). Small commensal species are likely to be buried when a burrow is excavated mechanically, but excavation by hand is extremely labor-intensive (Ernst and Barbour 1972).

Taylor (1982) describes the history of a pulling "hook" first reported by Fisher (1917). It is the only simple, quick, and moderately reliable method for capturing tortoises, used principally by tortoise hunters. Pulling requires the use of a long flexible rod attached to a short stout piece of bent wire. The apparatus is fed into the burrow, maneuvered behind the tortoise, and wedged between the rear of the plastron and the flared carapace. Success rate is influenced by a puller's skill and by the length and curvature of the burrow. In regions that have been heavily "pulled" in the past, remaining tortoises are most often found in winding burrows that are particularly difficult to pull (R. Stratton, Pers. comm.). Taylor (1982) gives details on the procedure, as well as statistics on the damage to captured tortoises.

Techniques for Studying Tortoise Demography and Reproduction

Estimates of Population Structure Using Burrow Width

Alford (1980) and Martin and Layne (1987) have demonstrated that a simple mathematical relationship exists between the width of a burrow and the size of the resident tortoise. Thus, on the basis of a burrow census, burrow widths, and a reliable correction factor, it is possible to estimate population size and evaluate demographic structure (Alford 1980, Sauer and Slade 1987). The relationship between burrow width and size of occupant may be slightly biased, however, since small tortoises can occupy large burrows but the reverse is impossible.

Marking Techniques and Determining Sex and Age

Marking tortoise shells is an easy way to follow the fate of individuals over long periods of time. Techniques for marking marginal scutes of turtles have been reviewed by Fernald (1979) and Plummer (1979).

Based on variation in the shell dimensions of 183 adult tortoises of known sex, McCrae et al. (1981) developed a discriminate equation that can be used to determine accurately the sex of adult tortoises from north Florida and south Georgia. The applicability of the technique to tortoises from other areas, and to smaller size classes, is untested (Wester 1986).

Graham (1979) reviews four age-determination techniques: mark/recapture, records of captive specimens, examination of long bone sections, and scute ring counts. Of these, only scute ring counts have been reported for gopher tortoises. W. Auffenberg (Pers. comm., Florida State Museum, Gainesville, Florida) suggested that a pencil rubbing of the plastron was an accurate way both to record true scute rings and to avoid counting false rings. This has been confirmed by L. Landers (unpub. data, Tall Timbers Research Station, Tallahassee, Florida). Additional methods of counting and recording scute rings are given by Galbraith and Brooks (1987).

Landers et al. (1982) demonstrated that, in southern Georgia, age can be accurately estimated by carefully counting plastron scute rings. Germano and Fritts (in press) used mark/recapture data to show a high correlation between age and scute ring counts of 17 known-age desert tortoises (less than 25 years old) from Nevada. They propose microscopic examination of thin scute sections can help determine age of older tortoises. However, Berry (in press) presents data from 190 desert tortoises from 11 study sites in which scute rings were not annual. Ring deposition varied from 0 to 3 rings per year. Berry and Woodman (1984) discuss the use of shell wear classes for age determination of adult desert tortoises.

Studies of Tortoise Reproduction

Indirect indications of reproductive activity include swelling of the sub-dentary glands and recent evidence of gravidity. Auffenberg (1966) and Rose (1970) suggested that the sub-dentary glands produce pheromones important to courtship and mating behavior, and Landers et al. (1980) used the swollen condition of these glands in some captured tortoises as an index to sexual activity.

Although the clutch size of gravid tortoises can be determined by radiography (Turner et al. 1986), field methods are limited to palpation and weight loss. T. Linley (Pers. comm.) uses palpation to estimate clutch sizes for gravid females with well calcified eggs. Turner et al. (1986) also regularly weighed transmitted desert tortoises and used sudden weight loss to indicate oviposition.
tortoise burrows along each of the 32 transect segments was then plotted against the transect's vegetation score on the first principal component axis. This procedure helps gauge the degree to which variation in tortoise density along transects relates to variation in vegetation structure. The average values for vegetative samples recorded along transects was used to compute principal component scores. Too few samples were collected to produce a very precise evaluation between burrow density and vegetation structure, so the effort should be considered only as an example of the application of vegetation data collected along transects.

Principal component analysis of vegetation data accurately projected the differences we casually observed among sites. The first principal component axis explained 50.5% of the variation among samples and largely contrasted decreasing canopy cover and wiregrass percentages with increasing shrub and ground cover (table 3). High positive scores along this axis indicate decreasing percent-ages of canopy cover and wiregrass, increasing amounts of shrub cover and ground cover, and increasing ratios of deciduous to coniferous trees. The second principal component axis explained an additional 24.4% of the sample variance and is weighted by decreasing amounts of wiregrass cover and the ratio of deciduous to coniferous trees (table 3).

A plot of burrow densities against the first principal component shows a general trend of increasing burrow density with decreasing principal component value (fig. 1). Areas with greater burrow densities generally had a lower percentage of canopy cover, but higher percentages of shrub and ground cover, than areas with lower densities. The regression line drawn through the points has an adjusted $r^2$ of 0.37 ($p<0.05$).

### Table 3: Factor loadings for 6 habitat variables measured along transects. Weightings and contrasts were derived from a “varimax” principal component (PC) analysis (Wilkinson 1983).

<table>
<thead>
<tr>
<th>Variable</th>
<th>PC 1</th>
<th>PC 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canopy cover</td>
<td>0.807</td>
<td>-0.278</td>
</tr>
<tr>
<td>Shrub cover</td>
<td>-0.865</td>
<td>0.171</td>
</tr>
<tr>
<td>Ground cover</td>
<td>-0.832</td>
<td>0.044</td>
</tr>
<tr>
<td>Deciduous/coniferous</td>
<td>0.900</td>
<td>0.000</td>
</tr>
<tr>
<td>Percent wiregrass</td>
<td>0.607</td>
<td>0.550</td>
</tr>
<tr>
<td>Percent variance</td>
<td>-0.995</td>
<td>0.000</td>
</tr>
<tr>
<td>explained by axis</td>
<td>50.5%</td>
<td>24.4%</td>
</tr>
</tbody>
</table>

**Future Directions**

Burrow-count transects are efficient for estimating burrow density, but they may not produce sufficiently accurate estimates of gopher tortoise densities. The relationship between burrow density and tortoise density is poorly understood, and studies analyzing the relationship between burrow occupancy and burrow activity class are needed to strengthen abundance estimates. Whether transects are appropriate will depend on the questions being addressed.

The combined effects of variation in occupancy rates and variation in burrow counts among transects may easily produce estimates of tortoise abundance that span an order of magnitude. For example, a 95-confidence interval for the density of active and inactive burrows on our second study area (using the Fourier series estimate from table 1) is $3.326-12.55$ burrows per ha. If the occupancy rate of 20 active and inactive burrows was followed for a week on this site and determined to be 0.60 $\pm 0.20$ for any one day, then a 95-confidence interval for the estimated density of tortoises on the site could range from 0.69 to 12.4 tortoise per...


