Detection of Gopher Tortoise Burrows Before and After a Prescribed Fire: Implications for Surveys

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Abstract

Gopher tortoise *Gopherus polyphemus* populations have declined by as much as 80% over the past century, primarily as a result of habitat loss. In 2006, the eastern population of the gopher tortoise was petitioned for federal listing as threatened. In response, a Candidate Conservation Agreement was developed for the gopher tortoise. A Candidate Conservation Agreement is a voluntary agreement between the U.S. Fish and Wildlife Service and other interested parties to address the conservation needs of a species before it becomes federally listed and to enact measures to preclude the need to list the species. The gopher tortoise Candidate Conservation Agreement identified an assessment of the status of populations on protected lands as a priority and line transect distance sampling (LTDS) was adopted as the standardized survey methodology. Surveys with LTDS rely on detection of gopher tortoise burrows because tortoises are fossorial. However, gopher tortoise burrows vary greatly in size and small burrows of juveniles are rarely detected. Although LTDS is statistically robust and allows for imperfect detection, few studies have examined how detection varies with tortoise burrow size and whether habitat structure may influence detection of gopher tortoise burrows. Both factors could affect the accuracy of population estimates using LTDS and interpretation of demographic parameters needed for the Candidate Conservation Agreement. Therefore, we conducted surveys for burrows using LTDS before (28 March–13 April 2016) and after (9–18 May 2016) a prescribed burn, which reduced vegetation cover. We detected significantly more burrows (*P* < 0.001, *n* = 651) of all sizes after the burn, and the burrow abundance estimate was 64% higher postburn. Our study showed that conducting gopher tortoise surveys after a prescribed burn increased detections and provided a more accurate population estimate. We therefore recommend conducting surveys immediately after a burn. However, varying burn cycles on large sites may make it difficult to survey following a prescribed burn and because the effects of a burn on habitat structure may vary within a site, methods to account for variation in detection due to habitat structure are needed. Population estimates for gopher tortoises using LTDS that do not account for variation in detection due to habitat structure likely underestimate population size.

Keywords: burrow; detection; gopher tortoise; *Gopherus polyphemus*; line transect distance sampling; prescribed fire

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Introduction

The gopher tortoise *Gopherus polyphemus* is endemic to upland habitats in the U.S. southeastern coastal plain and is of conservation concern across its range. West of the Mobile-Tombigbee River, the species has been listed as threatened under the U.S. Endangered Species Act (ESA 1973, as amended) since 1987 (USFWS 1987). The eastern population was petitioned for listing as threatened in the Endangered Species Act in 2006 (Save Our Big Scrub, Inc. and Wild South 2006), and in 2011 the USFWS released its finding that listing was warranted but precluded due to other listing priorities (USFWS 2011); thus, the eastern population is currently a candidate for...
A Candidate Conservation Agreement (CCA) for the gopher tortoise was drafted in 2008 (USFWS 2012). A CCA is a voluntary, nonbinding agreement between the USFWS and other interested parties to enact proactive conservation measures to alleviate threats and potentially preclude the need to list a species. The gopher tortoise CCA identified a need for baseline data on tortoise abundance to assess population status and trends in response to conservation actions. Line transect distance sampling (LTDS; Buckland et al. 2001) was adopted as the standard method for estimating gopher tortoise population size because the method is efficient for gopher tortoise surveys and provides estimates of error and precision to assess population trends through time (Nomani et al. 2008; Stober and Smith 2010; Stober et al. 2017).

Surveys for gopher tortoises using LTDS rely on detection of their burrows because tortoises are fossorial (Smith et al. 2009; Stober and Smith 2010). However, several factors may influence detection of burrows. First, the opening of a gopher tortoise burrow varies with the size of the resident tortoise (e.g., from 5 cm for hatchlings to >30 cm for adult tortoises; Martin and Layne 1987; Wilson et al. 1991). Data indicate that detection of burrows varies with size (Ballou 2013), as is the case with other tortoise surveys (Allison and McCoy 2014). Incorporating burrow width as a covariate in LTDS models can account for some of this variation (Marques et al. 2007; Thomas et al. 2010); however, detections of small burrows (<12 cm) during surveys are rare (Smith et al. 2009), suggesting they are either absent or undetected. This problem may be compounded by the fact that hatchling tortoises sometimes shelter in shallow depressions under vegetation, or construct burrows under woody debris (Pike 2006). Second, the height and density of herbaceous groundcover and midstory vegetation surrounding burrows can also influence detection of burrows during surveys (J.M. Howze and L.L. Smith, personal observation). Tortoises inhabit longleaf pine *Pinus palustris* savanna, sandhills, scrub, pine flatwoods, and ruderal land including pastures (Auffenberg and Franz 1982; Diemer 1986), all of which vary in vegetation structure. Therefore, burrow detection likely also varies among habitat types. Lastly, vegetation structure is often heterogeneous within a site, suggesting that detection of burrows may vary at small scales (i.e., along individual transects).

Line transect distance sampling methodology accounts for imperfect detection, provided that all objects on the line are detected and that observations decrease predictably with distance from the line (Buckland et al. 2001). These assumptions have not been explicitly tested with gopher tortoise surveys. However, the scarcity of detections of juvenile tortoises indicates that individuals in this life stage may be rare in some populations or that juveniles are present, but not detected, during surveys (Smith et al. 2009; Ballou 2013) and that small burrows can be missed on or near the line, which violates the assumptions mentioned above (Smith et al. 2009). Stober et al. (2017) addressed this concern by constraining their LTDS analyses to burrows >12 cm. However, this approach underestimates the total population size and provides no information on presence of juveniles within a population.

Accurate population estimates are needed to assess the status and trends of gopher tortoise populations in response to actions implemented under the CCA. Specifically, an evaluation of detection of juvenile burrows (<12 cm) and improved methods for detection of this age class are needed because low survival of juveniles has been identified as a threat to the species (USFWS 2011, 2012). As an initial step in addressing these needs, we conducted an LTDS survey for tortoise burrows before and immediately after a prescribed burn. Prescribed burns, which are often used to manage upland habitats, temporarily remove leaf and pine litter, herbaceous groundcover, and midstory vegetation, potentially increasing detection of small gopher tortoise burrows.

**Methods**

The study was conducted within a 139.2-ha tract of upland habitat on Ichauway, the 12,000-ha research site of the Joseph Jones Ecological Research Center in Newton, Georgia. The tract consisted of longleaf pine forest with dense herbaceous cover dominated by wiregrass *Aristida stricta* (78%); mixed longleaf pine/hardwood *Quercus* spp. (18%), agricultural plots (2%), and hardwood forest (2%) comprised the remaining habitat. The site was burned on a 2-y rotation.

We used program Distance 6.2 (http://distancesampling.org/Distance/index.html) and ArcGIS 10.3 (Environmental Systems Research Institute, Redlands, CA) to create transects in a systematic random sampling design (Thomas et al. 2010). Transects were spaced 50 m apart to maximize survey coverage of the site but also limit the number of burrows that might be

![Figure 1](http://example.com/fimage.png)
observed from multiple transects (Smith and Howze 2016). Preburn surveys were conducted from 28 March to 13 April 2016 using three observers (Stober and Smith 2010). One observer navigated the transect by using a Nomad hand-held computer/global positioning system (GPS; Trimble Navigation, Ltd., Sunnyvale, CA) with a Crescent A100 smart antenna (CSI Wireless, Calgary, Alberta, Canada) that operated at submeter accuracy. This observer also searched for burrows on the transect, and the two additional observers searched for burrows 5–10 m on either side of the transect (center line). We collected a GPS point at the beginning and end of each transect or where unsuitable tortoise habitat was encountered (i.e., agricultural fields) to allow for an accurate measure of total transect length surveyed in ArcGIS software. In addition, we collected a GPS point at each detected burrow and recorded the width of each burrow at 50 cm inside the opening (Martin and Layne 1987). We also used ArcGIS to calculate the perpendicular distance from the transect to the detected burrow. We did not attempt to determine occupancy of burrows by tortoises due to the time constraints of completing the preburn survey before the prescribed fire was applied. Therefore, our results apply to burrow detection only. The site was burned on 4 May 2016. From 9 to 18 May 2016 before groundcover vegetation had regen-
erated, we resampled transects using identical methodology from the previous survey with two exceptions. To reduce observer bias, we 1) switched observer positions and 2) started sampling on the opposite ends of the transects. All observers had the same training and previous experience conducting tortoise surveys before the study began.

We used program Distance 6.2 to estimate burrow density, burrow abundance, and effective strip width (http://distancesampling.org/; Thomas et al. 2010; Smith and Howze 2016) for both the pre- and postburn surveys. In Distance, we created models using the multiple covariate distance sampling analysis engine with half-normal and hazard rate key functions and cosine and simple polynomial series expansion terms. We included burrow width as a covariate to account for differences in detection due to burrow size. Both data sets were truncated to remove the most distant 5% of observations before analyses. We used Akaike’s Information Criterion to select the model that best fit our data. We compared the size class (width) distribution of detected burrows pre- and postburn using a Fisher’s exact test.

Results

We surveyed 26,540 m of transect for both the pre- and postburn survey. In preburn surveys, we detected 251 burrows compared to 400 burrows in the postburn survey (Data S1, Supplemental Material). In both surveys, the majority of burrows detected were between 26 and 50 cm in width. The size of burrows detected in preburn surveys was significantly smaller than those detected in postburn surveys (Fisher’s exact test: p < 0.05).

Table 1. Model selected, number of observations included in the model, effective strip width (ESW), density \((D)\), abundance \((N)\), and coefficient of variation \((CV)\) for preburn (28 March–13 April 2016) and postburn (9–18 May 2016) gopher tortoise \(Gopherus polyphemus\) burrow surveys using line transect distance sampling at a 139.2-ha upland site at the Joseph Jones Ecological Research Center, Baker County, Georgia. Confidence limits (95% CI) are included.

<table>
<thead>
<tr>
<th>Survey</th>
<th>Model</th>
<th>No. of observations</th>
<th>ESW</th>
<th>(D) (95% CI)</th>
<th>(N) (95% CI)</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preburn</td>
<td>Half-normal</td>
<td>238</td>
<td>12.98</td>
<td>3.45 (2.80–4.27)</td>
<td>481 (389–594)</td>
<td>0.11</td>
</tr>
<tr>
<td>Postburn</td>
<td>Hazard rate</td>
<td>381</td>
<td>12.69</td>
<td>5.66 (4.58–6.99)</td>
<td>788 (637–973)</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Figure 2. Relationship between perpendicular distance (m) from a transect and width (cm) of gopher tortoise \(Gopherus polyphemus\) burrows missed during the preburn line transect distance survey but detected during the postburn line transect distance survey. Data were collected preburn (28 March–13 April 2016) and postburn (9–18 May 2016) at a 139.2-ha upland site at the Joseph Jones Ecological Research Center, Baker County, Georgia.
Figure 3. Gopher tortoise Gopherus polyphemus survey site before (March 28–April 13, 2016) (a) and after (May 9–18, 2016) (b) a prescribed burn at the Joseph Jones Ecological Research Center, Baker County, Georgia. The burrow of an adult gopher tortoise is indicated by an arrow.
46 cm in width (Figure 1); however, one burrow in the smallest size class (<12 cm) was detected in the preburn survey compared to 24 burrows in this size class detected in the postburn survey. Significantly more burrows were detected after the burn for every size class (Fisher’s exact test: \( P < 0.001, n = 651 \); Figure 1).

Burrow density \( (D) \) and abundance \( (N) \) estimates were 64% higher in the postburn survey than in the preburn survey: \( D = 3.45 \) burrows per hectare (95% confidence interval [CI], 2.80–4.27) and \( N = 481 \) (95% CI, 389–594) preburn and \( D = 5.66 \) (95% CI, 4.58–6.99) and \( N = 788 \) (95% CI, 637–973) postburn (Table 1). Burrows missed on the preburn survey but detected on the postburn survey had a mean size of 31.0 cm (95% CI, 26.3–35.7 cm; range, 5–50 cm), and we missed burrows of all sizes on or near the transect (Figure 2; see also Figure 3a and 3b). The coefficient of variation (CV) was similar for the pre- and postburn surveys, 0.106 and 0.107, respectively, as was the effective strip width, 12.98 and 12.69, respectively (Table 1).

**Discussion**

As outlined in the gopher tortoise CCA, the need for baseline information on the status of tortoise populations led to the adoption of LTDS as a standardized method for gopher tortoise surveys. The method has been used to derive estimates of population size and to identify probable viable populations across a range of habitat types and conditions (USFWS 2012; Gopher Tortoise Council 2013), but the effects of vegetation on detection and on population estimates have not been considered. Surveys have revealed low detections of juvenile tortoises (Smith et al. 2009), indicating that juveniles are rare in most populations and/or that detection of juveniles is low, making it difficult to evaluate recruitment into a population. Our study indicates that vegetation structure significantly affects detection of both juvenile and adult burrows and that surveys in unburned habitat may underestimate population size. We also demonstrated that the assumption of 100% detection on the line was not met (Buckland et al. 2001). Moreover, we missed at least 96% of juvenile burrows (<12 cm in width) in the preburn survey, suggesting that demographic data derived from LTDS is biased toward adults. In our study, the model output in program Distance for the preburn survey suggested the population estimate was reasonably precise (CV < 0.11), but it was clearly not accurate.

Our results suggest that surveying for gopher tortoises after a prescribed burn increases detections and provides a more accurate population estimate,
including more accurate information on the presence of juvenile tortoises. However, it may not always be logistically feasible to complete a survey immediately after a prescribed burn. On large sites, burns are often applied to discrete areas (i.e., burn units) with burn cycles that vary spatially and temporally; thus, an entire survey area would not be burned at any given time. Moreover, groundcover vegetation regenerates quickly after a fire (e.g., within weeks), and surveys often could not be completed before this occurs. Also, prescribed burns can be patchy, leaving intact vegetation within a plot such that detection probability may vary at small scales (i.e., along a transect).

Our study site within a mesic longleaf pine woodland had dense groundcover vegetation, dominated by wiregrass, rendering detection of even large burrows difficult in the preburn survey. Hence, detection after the prescribed burn increased significantly (Figures 3a and 3b). However, burrow detection pre- and postburn may vary by site because vegetation structure is influenced by soil type and soil moisture, fire history, topography, and disturbance level (Mitchell et al. 1999; Kirkman et al. 2001, 2016; Florida Natural Areas Inventory 2010). For example, detection of burrows in xeric sandhill habitat, which is characterized by sparse groundcover, may be more comparable in unburned and burned sites than we observed in this study. Therefore, improvement of current LTDS methodology for gopher tortoises needs to include a means of accounting for changes in vegetation structure (i.e., vertical and horizontal cover) to address issues of detection on both burned and unburned sites.

Management Implications

For sites with similar habitat conditions as Ichauway, we recommend surveys <3 mo after a prescribed burn to detect juvenile gopher tortoise burrows (Figure 4) and to improve population estimates. Development of targeted methods (e.g., plot-based searches) focused on detecting juveniles that have smaller-sized burrows may be beneficial to document juvenile recruitment at unburned sites. Lastly, results of LTDS surveys on unburned sites should be considered conservative, as they most likely yield underestimates of true population size. In the context of CCA goals, these baseline estimates provide useful information on population status of the species; however, our ability to detect population trends and recruitment is limited.

Supplemental Material

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Data S1. Gopher tortoise Gopherus polyphemus burrows detected during preburn (28 March–13 April 2016) and postburn surveys (9–18 May 2016) by using line transect distance sampling at a 139.2-ha upland site at the Joseph Jones Ecological Research Center, Baker County, Georgia. The data file (xls) included 1) descriptions of data collected, 2) data used to estimate burrow density and abundance estimates during preburn surveys, and 3) data used to estimate burrow density and abundance estimates during postburn surveys.

Found at DOI: https://doi.org/10.3996/052018-JFWM-045.S1 (36 KB XLSX).


Found at DOI: https://doi.org/10.3996/052018-JFWM-045.S3 (2.34 MB PDF); also available at http://www.fws.gov/90-day-finding/candidate-conservation-agreement-for-the-gopher-tortoise-gopherus-polyphemus-eastern-population-

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