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Construction Engineering
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Field Assessment of Gopher Tortoise Habitat at Camp Shelby, MS

Phase II: Overstory and Combined Assessments

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Katherine E. Edwards, H. Alexis Londo, Daniel Nicholson,
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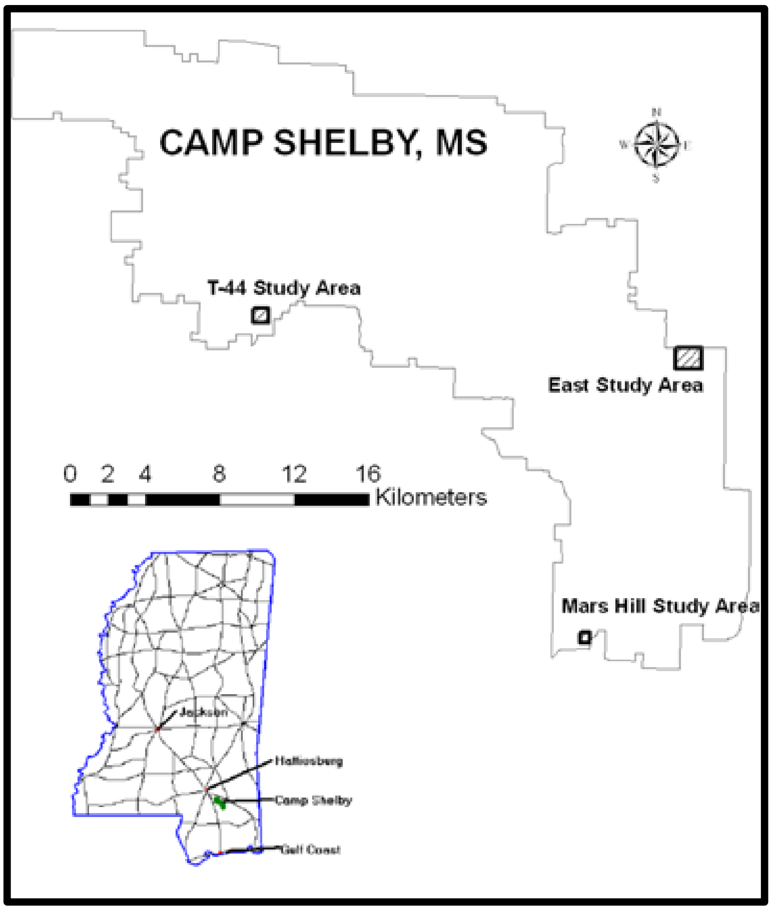
October 2010



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Under Work Unit 5FJ37G, "Gopher Tortoise Habitat Analysis and Remote Characterization."

Abstract: The western population of the gopher tortoise (*Gopherus polyphemus*) is listed as Federally threatened; its presence on the Camp Shelby, MS has resulted in training restrictions. To determine the specific habitat variables that influence gopher tortoise habitat selection, this research assessed overstory habitat conditions between active, recently active and randomly selected non-burrow locations at this site. Field surveys were completed in three study areas at the installation. On average, burrow sites had a much higher overall occurrence of longleaf pine and significantly lower total basal area as compared to non-burrow sites. Overstory mean height was significantly lower on burrow than non-burrow sites. When considering all variables (understory, midstory, overstory), stepwise logistic regression identified seven significant explanatory variables. Burrow presence was positively correlated with understory legume cover, midstory woody cover, percentage of overstory pine, bare ground coverage, and debris coverage. Burrow presence was negatively correlated with overstory species richness and overstory percent open canopy. The strongest explanatory variable for predicting the occurrence of burrows was understory legume coverage. Within-model cross-validation correctly predicted the presence or absence of active burrows for 83.9 percent of the observed outcomes.

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Preface

This study was conducted for the Construction Engineering Research Laboratory (ERDC-CERL) under "Training Lands Management – Characterization, Analysis, and Mitigation," under program element A896, "Army Environmental Quality Technology"; Work Unit 5FJ37G, "Gopher Tortoise Habitat Analysis and Remote Characterization." The CERL technical monitor is Dr. Timothy J. Hayden, Technical Director, Sustainable Ranges and Lands.

The work was performed under the Gulf Coast Cooperative Ecosystem Studies Unit, Agreement No. W9132T-07-2-0004, "Field and Remote Sensing Assessment of Gopher Tortoise Habitat" by the Mississippi State University, Forest and Wildlife Research Center. Mississippi State University Principal Investigators are Dr. David L. Evans, Department of Forestry, Dr. Jeanne Jones, Department of Wildlife Fisheries, and Dr. Scott D. Roberts, Department of Forestry. Scott A. Tweddale is the ERDC-CERL Principal Investigator. Dr. Timothy Hayden is Program Manager of the Habitat-centric Species At Risk (SAR) Research To Avoid Future Training Restrictions Program. Alan Anderson is Chief, Ecological Processes Branch (CN-N) of the Installations Division (CN), and Dr. John Bandy is Chief, CN. The Director of ERDC-CERL is Dr. Ilker R. Adiguzel.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL Gary E. Johnston, and the Director of ERDC is Dr. James R. Houston.

1 Introduction

Background

Gopher tortoises have been documented on seven Army installations in the southeastern United States (Wilson et al. 1997), on which there are more than 16,000 acres* of land with training restrictions, and an additional 883 acres that are off limits to military training (Schreiber et al. 1997a,b). The Camp Shelby Joint Forces Training Center is the only Army installation currently under training restrictions due to the threatened status of the western population of gopher tortoises (USFWS 1987), though a committee is being established to investigate the possible Federal listing of the Florida population of gopher tortoises. Population numbers of gopher tortoises are estimated to have declined by 80 percent over the past 100 years (Auffenberg and Franz 1982). Habitat loss and degradation are thought to be primary reasons for the decline (McCoy and Mushinsky 1992), though disease and invasive species may be accelerating the decline in some populations (Epperson and Heise 2003).

The recovery plan for the Federally threatened western population of gopher tortoise offers only limited recommendations on how to manage habitat. While a variety of habitat-based recommendations have been made since the recovery plan was completed (Wilson et al. 1997, Aresco and Guyer 1999, Tuberville et al. 2007), there is no consensus on what constitutes high, medium, and low quality habitat for gopher tortoises, nor on how habitat-based management recommendations might vary depending on region or habitat type. To what degree specific habitat variables influence gopher tortoise life history characteristics under varying habitat quality conditions is unknown. Some of the habitat variables that have been studied to assess gopher tortoise habitat are:

- basal area (total, hardwood and pine; Aresco and Guyer 1999)
- canopy cover (Wilson et al. 1997)
- herbaceous cover (Auffenberg and Iverson 1979, Diemer 1986, Cox et al. 1987)
- prescribed burning (Cox et al. 1987, Wilson et al. 1997, Aresco and Guyer 1999, Berish 2001)
- scrub cover (Cox et al. 1987)

* 1 acre = 0.405 hectare.

- soil compaction (Boglioli et al. 2000)
- soil drainage (Auffenberg and Franz 1982)
- tree density (Aresco and Guyer 1999).

Detailed knowledge of gopher tortoise ecology, including habitat requirements and the processes that govern habitat use and occupancy, are essential to balance successful conservation and restoration of gopher tortoise populations on military installations while sustaining the training mission. Landscape wide assessment of gopher tortoise habitat potential can provide information to assess the effects of encroachment on both the recovery of the species and the sustained capability to execute the DOD training mission. This work was undertaken to determine specific habitat variables that influence gopher tortoise habitat selection under varying habitat quality conditions.

Objective

The primary objective of this work was to determine overstory habitat conditions at active and recently active gopher tortoise burrow locations versus randomly-selected non-burrow locations at Camp Shelby, MS. A related, secondary objective was to summarize additional progress to date on understory and LiDAR data analysis.

Approach

Field surveys were completed in three study areas at Camp Shelby, MS (Figure 1) that represent a gradient of both habitat quality and military training intensity. Field sampling for overstory woody vegetation (>7.6 cm [3 in] DBH; diameter at breast height [1.37m above ground]) variables was conducted at active and inactive burrows and randomly selected non-burrow locations at varying distances from known burrow locations. Species frequency of occurrence was summarized between each of the three study areas and for burrow and non-burrow locations.

Field surveys for understory (herbaceous and woody vegetation ≤1m in height) and midstory (woody vegetation >1–3m in height) were conducted and completed between 4 – 21 June 2007 on Mars Hill, at T-44, and in the East Area locations. The specific variables and measurement techniques for understory and midstory analysis are detailed in the Phase I report from this study (Evans et al. 2008).

All data were analyzed for development of predictive relationships between field variables and burrow presence/absence through logistic regression and discriminant analysis.

Mode of technology transfer

Results summarized in this report will be combined with a Phase I assessment of differences in understory and midstory habitat conditions between presence and absence sites to identify specific biophysical variables that significantly influence gopher tortoise habitat selection. A third research phase will evaluate LiDAR (light detection and ranging) remote sensing as a means to spatially characterize and quantify important habitat characteristics at landscape scales. The primary modes of technology transfer will be through publication in scientific literature the contents of this and other reports. These findings will also be presented/discussed at scientific meetings (i.e., symposia, conferences, technical meetings) as opportunities arise.

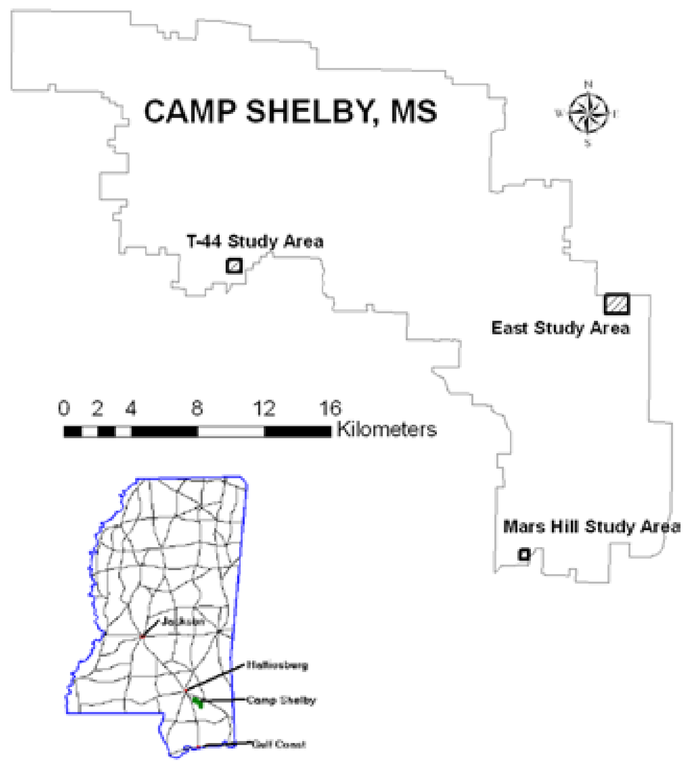

Figure 1. Location of three study sites at Camp Shelby, MS.

2 Methods

Plot allocation according to burrow activity status

Assessments of gopher tortoise burrows were conducted 14–17 May 2007 on Mars Hill, at T-44, and in the East Area sites of Camp Shelby (see Figure 1, p 3) to determine burrow activity status categorized as active, inactive, or abandoned. A total of 150 burrows were examined for activity. Burrows were classified as active if they had an opening with an outline similar to that of a tortoise carapace, a soil apron at the burrow entrance relatively free of vegetation, and the presence of tracks or plastron scrapings leading into the burrow (Auffenberg and Franz 1982, Guyer and Hermann 1997). Burrows were classified as inactive if the opening was intact, but was occluded by some vegetation. Burrows were considered abandoned if there was no evidence of tortoise activity, the burrow entrance was eroded, and the burrow opening was obstructed with undisturbed vegetation or soil.

All active burrows that were found within the three study sites were included as burrow sample points; however, due to variable usage of these sites by gopher tortoises, an unequal number of active burrows were found within the Mars Hill, T-44, and East Area study sites. Of the 150 burrows initially inspected for activity (50 from each study area), 30% (n = 45) were active. Of the active burrows, 53% (n = 24) were found on Mars Hill, 40% (n = 18) at T-44, and 7% (n = 3) in the East Area. A random selection of 45 total inactive burrows was included as sample sites for habitat data collection. Fifteen burrows were selected from each site. This provided 90 sample points associated with burrows that are currently or were recently used by tortoises.

Additionally, 168 random points (56 per site [seven in each of eight distance zones]) were included for evaluation of habitat not associated with burrow sites. These non-burrow sample points were equally distributed in concentric zones radiating out at 30m intervals starting at 60m from known burrow locations provided by Camp Shelby.

Overstory field surveys

Overstory measurements were completed in the summer and fall of 2007 on 258 10m radius field plots (90 burrows and 168 non-burrows) distributed across the three study sites. On each plot, all trees over 7.62 cm (3 in) in DBH were tallied and identified by species. Information collected on each tree included DBH (nearest 0.25 cm; 0.1-in.), total height (nearest 0.30m; 1.0 ft), height to base of the live crown (BLC: nearest 0.30m; 1.0 ft), and azimuth and distance to tree (nearest 0.30m; 1.0 ft) from plot center. Trees less than 7.62cm DBH were tallied and separated into three size classes: 2.54 cm (1-in.), 5.08 cm (2-in.), and 7.62 cm (3-in.).

Nine densitometer readings for estimating crown closure were taken on each plot at plot center and in the eight cardinal directions. Readings to the north, south, east, and west were taken 20m from plot center while the other readings were taken from 10m from plot center.

Hemispherical photographs were taken on a random subsample of 36 plots on T44 and 13 plots on Mars Hill allocated between both burrow and non-burrow locations. At each plot, one photo was acquired at plot center and eight additional photos were taken at alternating 10m and 20m distances in the eight cardinal directions around plot center, giving nine photos per plot. Photos were retaken on the first six plots to test for changes that may have occurred in canopy characteristics from the beginning to the end of the period over which the photos were taken. The data for the hemispherical photographs are still being analyzed at the time of this writing.

Overstory data analysis

Means for basal area (BA), trees per acre (TPA), DBH, height, BLC, and crown closure were calculated. All means were separated by burrow and non-burrow for each of the three sites. A Two-Way Analysis of Variance (PROC GLM, SAS 9.1) was used to determine whether means differed significantly between sites and between burrow and non-burrow plots. A critical value of alpha = 0.05 was used to determine statistical significance. Pearson Correlation coefficients were used to measure co-linearity relationships among explanatory variables.

Stepwise logistic regression was used to predict burrow absence/presence. Independent variables included: open sky (OS; derived from densitometer data), TPA, BA, DBH, and mean total height of trees (MHT).

Stem maps are being constructed from the field data. The center point for each plot has been attributed with all overstory observations. Azimuth and distance measurements taken from plot center will be used to create a stem map for all burrow and non-burrow plots. These stem maps will be matched with results from the LiDAR tree finding algorithm to assess the accuracy of LiDAR procedures. The stem maps will be used to correlate LiDAR-derived information with field observations for habitat model development.

Combined data analysis

Twenty-two variables were initially selected for analyses. Explanatory variables related to understory habitat conditions (<1m in height) were: herbaceous ground coverage, species richness of understory (<1m height) herbaceous plants, understory woody coverage, species richness of understory woody plants, mean litter depth, bare ground coverage, debris coverage, understory coverage separated by growth form including grasses, forbs (excluding leguminous plants), legumes, shrubs/tree seedlings, vines, and ferns. Midstory (1–6m in height) variables included: stem count, species richness, and woody coverage. Overstory (>6m in height) variables were: total number of trees, tree species richness, percentage of overstory pine trees, mean DBH, mean overstory height, and percent open sky in overstory canopy.

Discriminant function analysis

A discriminant function analysis (DA) was used to develop a model that differentiated sample units into three categories: active burrow, inactive burrow, and non-burrow (Johnson 1998; PROC DISCRIM, SAS Institute 1999). In addition, separate logistic regressions (PROC LOGISTIC, SAS Institute 1999) were performed to test: (1) the binary response variable of burrow presence or absence, and (2) the binary response variable of active or inactive burrow status relative to continuous explanatory variables of vegetation composition and structure (Myers 1990). For each binary response, a general model was developed identifying habitat conditions (understory, midstory, and overstory components) that influenced occurrence of burrows and use of selected burrows.

Pearson's correlation coefficients were used to assess co-linearity among explanatory variables (Myers 1990). Variables with a coefficient >0.70 were evaluated as candidates for exclusion from the data set. The variable with the greatest biological significance for gopher tortoises was retained in the data set and the other was excluded. Decisions concerning exclusion of collinear variables were based on scientific information on gopher tortoise habitat assessment. Square root transformations on stem count data and arc-sine square root transformations on data recorded as percentages were used prior to regression analysis and discriminant function analysis (Johnson 1998).

Logistic regression analysis

Regression analysis for burrow occurrence vs. non-burrow plots

Ninety plots with gopher tortoise burrows were measured for understory, midstory, and overstory habitat conditions. Variation in the number of non-burrow plots sampled was due to differences in protocol for understory (n=123 plots) and overstory (n=168 plots) components. Plots characterized as moist-soil areas, wetlands, or drainages were excluded from understory data collection, but were included in overstory measurements for comparison with LiDAR. Only plots measured for both understory and overstory variables were included in logistic regression analyses (n=123).

A stepwise logistic regression was used to identify variables related ($P<0.05$) to the presence of gopher tortoise burrows. Independent variables included in regression analysis included understory grass coverage (Grass), understory legume coverage (Legume), understory vine coverage (Vine), understory fern coverage (Fern), midstory woody coverage (Midstory), total overstory count (Ovrcnt), overstory species richness (Ovrich), percentage of overstory pine (Ovpine), percentage of opening in overstory canopy (OS), mean litter depth (cm) (Litdpth), bare ground coverage (Bg), and debris coverage (Debris). The Hosmer-Lemeshow test of goodness-of-fit was performed to test for lack of fit of the model (Cody and Smith 2006).

The complete linear logistic model had the following form:

$$\text{Logit}(p) = a + B1\,(\text{Grass}) + B2\,(\text{Legume}) + B3\,(\text{Vine}) + B4\,(\text{Fern}) + B5\,(\text{Midstory}) + B6\,(\text{Ovrcnt}) + B7\,(\text{Ovrich}) + B8\,(\text{Ovpine}) + B9\,(\text{OS}) + B10\,(\text{Litdph}) + B11\,(\text{Bg}) + B12\,(\text{Debris}).$$

where:

Logit (*p*)	=	logistic probability of presence of tortoise burrows
A	=	intercept
Bi	=	parameter estimates

The resulting model was tested by cross-validation methods to estimate accuracy (SAS Institute 1999).

Regression analysis for active vs. inactive gopher tortoise burrows

Ninety plots with gopher tortoise burrows were selected for analysis; 45 active or recently active burrows and 45 inactive burrows. Stepwise logistic regression was used to identify variables related ($P<0.05$) to active or recently active gopher tortoise burrows. Independent variables included in the analysis included: understory grass coverage (Grass) , understory legume coverage (Legume), understory vine coverage (Vine), understory fern coverage (Fern), midstory woody coverage (Midstory), total overstory count (Ovrcnt), overstory species richness (Ovrrich), percentage of overstory pine (Ovpine), percentage of opening in overstory canopy (OS), mean litter depth (cm) (Litdph), bare ground coverage (Bg), and debris coverage (Debris). The Hosmer-Lemeshow test of goodness-of-fit was performed to test for lack of fit of the model (Cody and Smith 2006).

The complete linear logistic model had the following form:

Logit (p) = a + $B$1 (Grass) + $B$2 (Legume) + $B$3 (Vine) +$B$4 (Fern) +$B$5 (Midstory) +$B$6 (Ovrcnt) +$B$7 (Ovrich) +$B$8 (Ovpine) +$B$9 (OS) +$B$10 (Litdph) +$B$11 (Bg) +$B$12 (Debris). Where: Logit (p)=logistic probability of presence of active burrows, a = intercept, and Bi = parameter estimates. The resulting model was tested by cross-validation methods to estimate accuracy (SAS Institute 1999).

LiDAR analyses

Discrete LiDAR returns were delivered in columnar format as: time stamp, x1, y1, z1, x2, y2, z2, i1, and i2; with x and y as the UTM easting and northing, “z” as the elevation and “i” as the intensity of return for 1st and 2nd returns. The data were delivered in three files consisting of 36 individual flight lines. Initial investigation of these data raised concerns over “shadowing” (false low readings in the derived canopy height surface model) in the crowns of trees located at the edge of the flight lines. Further investigation compared the first returns with the second returns and revealed that virtually all points that fell within the suspect areas were probable ground points. These ground returns that were compromising the integrity of the canopy height models were removed from consideration as canopy model points. The removed points had first and last returns for a given timestamp that were essentially identical ($<|0.2|$ m in the difference between z1 and z2 and no difference between i1 and i2). Work is now proceeding on development of ground and canopy height models for tree identification and height determination. All data points are also being considered for midstory/understory analysis.

The data points removed from consideration in the canopy models are being used in the ground determination procedures using MARS software by Merrick. A series of filters obtained from Merrick are initially being used to determine the ground points. The layers are being individually investigated to determine if additional ground points are needed or if some ground points should be excluded as non-ground points. Non-ground points will be combined with the remaining first and second returns from the raw data files (i.e., data points not previously meeting the criteria for removal) and used to create the canopy models. Use of all data as either ground points or in the canopy models will be important in the midstory/understory analyses.

The majority of the waveform LiDAR data files have been received from the data provider (The University of Texas). Each file includes the following data records for each waveform:

1. Easting
2. Northing
3. Elevation
4. Range Difference (Range Diff between peak and last detected range)
5. Gauss. Amplitude
6. Gauss. Mode
7. Gauss. Sigma
8. Shot Number
9. Peak Number
10. Correlation (Corr between raw waveform and Gaussian fit)
11. Ratio (CanEnergy:GroundEnergy)
12. Canopy Width (ns)
13. Total Energy
14. Ground Energy
15. Canopy Energy
16. Risetime (on first peak)
17. Rise Slope
18. Fall Slope (on last peak)
19. Skewness
20. Scan Angle (in degrees)
21. Home (Height of median Energy)
22. RH25 (Relative Height of 25% energy above Last Peak)
23. RH50 (Relative Height of 50% energy above Last Peak)
24. RH75 (Relative Height of 75% energy above Last Peak)
25. Last Peak Flag.

3 Results

Overstory analysis results

Frequency of occurrence

Table 1 lists overstory vegetation species occurrence by site and plot type.

For burrow versus non-burrow analysis at each site, overstory species have been grouped into two categories—pine and hardwood. For each site, summary statistics are provided for pine, hardwood, and the total overstory. On average, burrow sites have much higher overall occurrence of longleaf pine (*Pinus palustris*) as compared to non-burrow sites (Table 1).

Table 1. Percentage of species frequency occurrence of overstory trees on T-44, Mars Hill, and East Area burrow and non-burrow locations, Camp Shelby, MS 2007.

Species	East Area		Mars Hill		T44	
	Burrow	Non-burrow	Burrow	Non-burrow	Burrow	Non-burrow
Acer rubrum	0	2.1	0	3.7	0	2.8
Carpinus caroliniana	0	0.7	0	0	0	0
Carya spp.	0	0	0	0.9	0.7	0
Cornus florida	1.0	3.3	1.4	8.8	5.2	1.2
Cyrilla racemiflora	0	0.5	0	0	0	0.3
Ilex opaca	0	0	0	0.2	0	0
Liquidambar styraciflua	0.3	2.2	0	4.4	0	1.6
Liriodendron tulipifera	0	0.2	2.8	2.8	0	5.9
Magnolia virginiana	0	4.5	0	3.3	0	8.4
Nyssa sylvatica	0	6.7	0	8.8	0	2.5
Pinus echinata	0	0.2	1.8	0.7	0	0
Pinus elliotii	0	0	0.9	0	0.7	0
Pinus palustris	93.0	53.4	71.9	38.2	88.1	73.6
Pinus taeda	0.5	5.3	0.9	8.8	0.7	1.9
Prunus serotina	0	6.7	1.4	1.1	0	0
Quercus spp. (red)	4.9	16.7	16.1	10.6	3.0	1.6
Quercus spp. (white)	0.3	0.5	2.8	7.5	1.5	0.3
Ulmus spp.	0	0	0	0.2	0	0

Summary of site differences

Basal Area (BA) (Table 2)

Total overstory BA in the East Area is significantly higher than on Mars Hill and T44 (P=0.0001). Pine BA in the East Area is significantly higher than on Mars Hill (P=0.0185). East Area hardwood BA is significantly higher than on Mars Hill and on Mars Hill is significantly higher than T44 (P < 0.0001–0.0439).

Table 2. Mean basal area per acre for pine and hardwood on T-44, Mars Hill, and East Area locations, Camp Shelby, MS 2007.

Site	# Plots	Mean BA[1] Pine	Mean BA[1] Hardwood	Mean BA[1] Total
T44				
Burrow	33	39.822	1.546	41.368
Non-Burrow	56	50.505	5.932	56.437
Total	89	46.544	4.306	50.850
Mars Hill				
Burrow	39	30.265	1.268	31.533
Non-Burrow	56	43.355	18.836	62.192
Total	95	37.982	11.624	49.605
East Area				
Burrow	18	42.758	10.353	53.110
Non-Burrow	56	53.935	28.036	81.971
Total	74	51.216	23.735	74.951

[1]BA – Basal area per acre (sq ft/acre).

Trees Per Acre (TPA) (Table 3)

Total overstory TPA on T44 is significantly lower than on Mars Hill and in the East Area (P<0.0001). Pine TPA on T44 is significantly lower than on Mars Hill and in the East Area (P=0.0002–0.0395). East Area hardwood TPA is significantly higher than on Mars Hill and Mars Hill is significantly higher than T44. (P<0.0001–0.487).

Diameter Breast Height (DBH) (Table 4)

Mean overstory DBH on T44 is significantly higher than in the East Area and the East Area is significantly higher than on Mars Hill (P<0.0001–0.0212). Mars Hill is significantly lower than T44 and in the East Area in mean pine DBH (P<0.0001–0.0013). Hardwood DBH does not significantly differ on any of the sites.

Table 3. Mean trees per acre for pine and hardwood on T-44, Mars Hill, and East Area locations, Camp Shelby, MS 2007.

Site	# Plots	Mean TPA[1] Pine	Mean TPA[1] Hardwood	Mean TPA[1] Total
T44				
Burrow	33	47.232	5.465	52.697
Non-Burrow	56	55.897	18.172	74.069
Total	89	52.684	13.461	66.145
Mars Hill				
Burrow	39	118.576	8.257	126.834
Non-Burrow	56	78.899	54.977	133.3876
Total	95	95.188	35.797	130.985
East Area				
Burrow	18	117.365	37.929	155.294
Non-Burrow	56	59.807	65.558	125.365
Total	74	73.808	58.837	132.645
1TPA – Trees per acre.				

Table 4. Mean diameter at breast height for pine and hardwood on T-44, Mars Hill, and East Area locations, Camp Shelby, MS 2007.

Site	# Plots	Mean DBH[1] Pine	Mean DBH[1] Hardwood	Mean DBH[1]
T44				
Burrow	33	11.918	6.611	11.577
Non-Burrow	56	13.556	7.552	12.577
Total	89	12.932	7.176	12.205
Mars Hill				
Burrow	39	7.210	5.299	6.913
Non-Burrow	56	11.835	7.272	9.828
Total	95	9.733	6.658	8.613
East Area				
Burrow	18	9.039	5.675	8.273
Non-Burrow	56	13.645	7.806	10.851
Total	74	12.426	7.174	10.215
1DBH – Diameter at breast height (inches), (4.5 feet from base of tree).				

Height (Table 5)

Mean overstory height for T44 is significantly higher than in the East Area and the East Area is significantly higher than on Mars Hill ($P<0.0001$–0.0127). Mean pine and hardwood height is significantly different for Mars Hill to East Area and T44 ($P=0.0003$–0.0289).

Table 5. Mean height for pine and hardwood on T-44, Mars Hill, and East Area locations, Camp Shelby, MS 2007.

Site	# Plots	Mean Height[1] Pine	Mean Height[1] Hardwood	Mean Height[1]
T44				
Burrow	33	61.233	31.728	59.621
Non-Burrow	56	69.457	49.528	66.604
Total	89	66.324	42.408	64.006
Mars Hill				
Burrow	39	45.084	28.171	42.918
Non-Burrow	56	67.681	37.699	55.155
Total	95	57.410	34.735	50.056
East Area				
Burrow	18	53.335	30.581	47.832
Non-Burrow	56	72.728	43.267	59.887
Total	74	67.595	39.508	56.914
1Height – Total tree height (ft).				

Height to Crown Base (BLC) (Table 6)

Mean overstory BLC for all sites and pine BLC did not significantly differ. Mars Hill hardwood BLC is significantly lower than in the East Area and T44 ($P<0.0001–0.0009$).

Table 6. Mean height to the base of the live crown for pine and hardwood on T-44, Mars Hill, and East Area locations, Camp Shelby, MS 2007.

Site	# Plots	Mean BLC[1] Pine	Mean BLC[1] Hardwood	Mean BLC[1]
T44				
Burrow	33	37.287	10.953	29.441
Non-Burrow	56	30.475	24.915	35.159
Total	89	34.692	19.330	33.031
Mars Hill				
Burrow	39	25.855	9.368	23.920
Non-Burrow	56	40.282	14.136	30.094
Total	95	33.724	12.653	27.523
East Area				
Burrow	18	28.503	11.525	24.725
Non-Burrow	56	43.670	19.101	32.013
Total	74	39.655	16.856	30.216
1BLC – Height to the base of the live crown (ft).				

Open Sky (Table 7)

Total overstory open sky in T44 is significantly higher than in the East Area and on Mars Hill (P=0.0001).

Table 7. Mean percent open sky on T-44, Mars Hill, and East Area locations, Camp Shelby, MS 2007.

Site	# Plots	Mean OS[1] Total
T44		
Burrow	33	56.193
Non-Burrow	56	62.580
Total	89	60.257
Mars Hill		
Burrow	39	43.674
Non-Burrow	56	38.482
Total	95	40.614
East Area		
Burrow	18	42.9545
Non-Burrow	56	29.865
Total	74	33.049
1OS– % Open sky.		

Summary of burrow status differences

Total Overstory

Basal area on burrow plots is significantly lower at all three sites than on non-burrow plots (P<0.0001–0.0354). Overstory TPA did not differ significantly at any of the sites between burrow and non-burrow plots. Mars Hill and the East Area overstory DBH is significantly lower on burrow than on non-burrow plots (P<0.0001-.0041). Overstory height is significantly lower on burrow than on non-burrow plots for all sites (P<0.0001–0.0183). Overstory BLC in the East Area and T44 is significantly lower on burrow than on non-burrow (P = 0.0026–0.0045). The mean open sky is 45.16% open canopy. The open sky between burrow presence/absence is not significant.

Pine

Pine BA is significantly lower on burrow plots on Mars Hill than on non-burrow plots (P=0.0284). In the East Area, pine TPA is significantly higher on burrow than on non-burrow plots (P=0.0010). Pine DBH is significantly lower on burrow plots in the East Area and on Mars Hill than on non-burrow plots (P<0.0001). Pine heights are significantly lower on burrow plots than on non-burrow plots at all sites (P<0.0001–0.0030). Pine BLC is significantly lower on burrow than on non-burrow plots on the Mars Hill and in the East Area sites (P<0.0001–0.0012).

Hardwood

At the Mars Hill site, hardwood BA is significantly lower on burrow plots than on non-burrow plots (P=0.0018). Hardwood TPA is significantly lower on burrow than on non-burrow plots on Mars Hill (P=0.0009). Hardwood DBH is significantly lower on Mars Hill and in the East Area burrow than on non-burrow plots (P=0.0045–0.0048). Hardwood height is significantly lower on burrow than on non-burrow plots all sites (P=0.0005–0.0106). For all sites hardwood BLC is significantly lower on burrow than on non-burrow plots (P=0.0003–0.0029).

Overstory Logistic Regression Analysis

The final form of the logistic function was:

$$\text{Logit (p)} = a + B1\ (\text{BA}) + B2\ (\text{MHT})$$

where:

A	= intercept
*B*i	= parameter estimates
Logit (p)	= logistic probability of presence of burrows.

The final significant model for stepwise logistic regression was:

$$\text{Logit (burrow presence)} = 3.5298 + -0.0295\ (\text{BA}) + -0.0457\ (\text{MHT})$$

Two explanatory variables contributed to the model:

BA (x=35.4394, df=1, and p<0.0001)

MHT (x=18.2951, df=1, and p<0.0001)

This equation has a 79.2% probability of predicting the presence of burrows. Parameter estimates indicate that as BA and MHT decrease, the probability of presence increases.

Combined analysis results

Burrow vs. non-burrow plots

The logistic regression model was significant at the $P < 0.001$ ($\chi 2$ = 65.5529, df =7) level in determining the occurrence of tortoise burrows. Logistic regression and stepwise procedures revealed seven explanatory variables from all variables (Table 8) that significantly influenced the occurrence of gopher tortoise burrows:

1. Understory legume coverage ($\chi 2 = 17.5914$, df = 1, $P < 0.0001$)
2. Midstory woody coverage ($\chi 2 = 25.9377$, df = 1, $P < 0.0001$)
3. Overstory species richness ($\chi 2 = 6.4921$, df = 1, $P = 0.0108$)
4. Percentage of overstory pine ($\chi 2 = 5.1301$, df = 1, $P = 0.0235$)
5. Percentage of open sky in overstory canopy ($\chi 2 = 4.6714$, df = 1, $P = 0.0307$)
6. Bare ground coverage ($\chi 2 = 5.5876$, df = 1, $P = 0.0181$)
7. Debris coverage ($\chi 2 = 4.4912$, df = 1, $P = 0.0341$).

Table 8. Habitat variables initially included in discriminant function and logistic regression analyses.

Variable	Measurement
HERB	Total understory herbaceous coverage (grasses, forbs, and legumes <1m height)/plot measured using line-intercept method
HERBRICH	Total # of understory herbaceous species (<1m height)/plot
WOODY	Total understory woody coverage (trees, shrubs, and vines <1m height)/plot measured using line-intercept method
WOODRICH	Total # of woody species (<1m height)/plot
LITDPTH	Mean litter depth (cm)/plot measured from the midpoint and endpoint of each line-intercept
BG	Total bare ground coverage/plot measured using line-intercept method
DEBRIS	Total debris coverage/plot measured using line-intercept method
GRASS	Total understory grass coverage (<1m height)/plot measured using line-intercept method
FORB	Total understory forb coverage (<1m height)/plot measured using line-intercept method
LEGUME	Total understory legume coverage (<1m height)/plot measured using line-intercept method
SHRUB	Total understory coverage of shrubs and tree seedlings (<1m height)/plot measured using line-intercept method
VINE	Total bare ground coverage/plot measured using line-intercept method
FERN	Total fern coverage/plot measured using line-intercept method
MIDSTEM	Total # of stems/plot for shrubs and trees (1m-6m in height) measured using elevated line-intercept method
MIDRICH	Total # of woody species/plot (1m-6m in height)
MIDSTORY	Total midstory woody coverage (trees, shrubs, and vines 1m-6m in height)/plot measured using elevated line-intercept method
OVRCNT	Total # of overstory trees/plot (>6m in height)
OVRICH	Total # of overstory tree species/plot (>6m in height)
OVPINE	Percentage of overstory trees that were loblolly or longleaf pine/plot (>6m in height)
DBH	Mean diameter-at-breast-height averaged across all overstory trees (>6m in height)/plot
OVRHT	Mean height of overstory trees (>6m in height)/plot
OS	Percentage of open overstory canopy coverage/plot

The reduced logistic model for burrow occurrence was:

Logit (burrow presence) = 0.0362 + 8.7852 (Legume) + 5.4742 (Midstory) -1.2759 (Ovrich) + 0.4873 (Ovpine) -2.2304 (OS) + 4.7268 (Bg) +4.1474 (Debris).

Within-model cross-validation correctly predicted the presence or absence of active burrows for 83.9% of the observed outcomes. The Hosmer and Lemeshow Goodness-of-Fit Test showed that the specified model fit the data ($\chi 2$ = 6.1804, df = 8, P = 0.6270). Burrow presence was positively correlated with understory legume cover, midstory woody cover, percentage of overstory pine, bare ground coverage, and debris coverage. Burrow presence was negatively correlated with overstory species richness and overstory percent open canopy.

Active vs. inactive gopher tortoise burrows

The logistic regression model was significant at the P = 0.0079 ($\chi 2$ = 7.0620, df =1) level in determining the occurrence of active burrows. Logistic regression and stepwise procedures revealed that only one explanatory variable was significantly related to the activity status of gopher tortoise burrows:

Overstory species richness ($\chi 2$ = 7.0620, df = 1, P = 0.0079).

The reduced logistic model for active burrow occurrence was:

Logit (active burrow presence) = 1.8867 -1.6068 (Ovrich).

Within-model cross-validation correctly predicted the presence or absence of active burrows for 46.1% of the observed outcomes. The Hosmer and Lemeshow Goodness-of-Fit Test showed that the specified model fit the data ($\chi 2$ = 2.1088, df = 2, P = 0.3484). Presence of active burrows was negatively associated with overstory species richness.

Discriminant function analysis

The discriminant function analysis was moderately successful in grouping sample units. The cross-validation procedure correctly classified 53.3% for active burrows, 40.0% for inactive burrows, and 58.5% for non-burrow points (compared to 33.3% for a random allotment of sample units by treatment).

4 Discussion

Overstory findings

The overstory burrow vs. non-burrow predictive model can be expressed as:

Logit (burrow presence) = 3.5298 + -0.0295 (BA) + -0.0457 (MHT).

The model can be interpreted as predicting that the probability of burrows being present or absent increases as BA and MHT decreases. The probability of correctly predicting burrow presence from BA and MHT is approximately 79%. The relationship indicates that BA and MHT are higher on non-burrow sites verses burrow sites (Tables 2 and 5).

Site conditions could be one factor explaining the relationship between BA, MHT, and probability of burrow presence. More burrow sites were observed on ridge tops with well-drained sandy soils. Non-burrow sites included side slopes and drainages where the soils were more moist. This landscape is dominated by longleaf pine stands on the higher topographic positions. These higher areas have a history of more frequent fires, which, combined with lower stem density and overall height than found on non-burrow sites, seems to promote conditions suitable for the gopher tortoise. The highest overall basal area (Table 2) was noted in the East Area site, which also was the area with the fewest active burrows of all burrows surveyed by area. It is also likely that this area has seen relatively little burning activity in recent years

Tables 2 and 3 point to some other interesting observations. The East Area contained the fewest active burrows and yet had the highest overall BA and TPA. These observations support the finding of a negative relationship between BA and burrow presence in the model.

Table 5 also illustrates the direct finding in the model that mean canopy height is inversely related to burrow presence. This is reinforced by the data in Table 6, which indicates that the BLC is also lower on burrow plots. This stands to reason from a perspective of tree development since one would expect shorter, more open grown trees to have lower overall BLC positions.

The tendency to have larger trees on non-burrow plots in not entirely counterintuitive to what was observed. At the same stem densities, smaller, more open grown pine stands would seem to have more opportunity for herbaceous cover development provided burning or other activities held midstory development in check. This observation might be confirmed by closer examination of the site history over extended periods of time as compared to tortoise activity. These findings support this general observation as hardwood BA, TPA, DBH, height, and BLC (Tables 2–6) are all lower (less hardwood presence on site) for burrow than non-burrow sites.

The fact that open sky (crown closure) was not singularly useful in predicting burrow presence was somewhat counterintuitive, but probably indicates that other factors are more important in overall habitat quality (see combined findings discussion below).

These overstory findings further support the notion that some aspects of tortoise habitat (in this case site preference for burrows) might be predicted through remote sensing. In past studies of red-cockaded woodpecker (*Picoides borealis*) habitat, it has been demonstrated that tree heights and relative stem size may be derived from LiDAR data (Tweddale et al. 2008). These variables, coupled with analysis of multispectral data for detection of pine versus hardwood areas (see "Combined Findings" below), will be examined to develop a remote sensing predictive protocol for tortoise habitat evaluation.

Combined findings

The burrow vs. non-burrow predictive model can be expressed as:

$$\text{Logit (burrow presence)} = 0.0362 + 8.7852\,(\text{Legume}) + 5.4742\,(\text{Midstory}) - 1.2759\,(\text{Ovrich}) + 0.4873\,(\text{Ovpine}) - 2.2304\,(\text{Os}) + 4.7268\,(\text{Bg}) + 4.1474\,(\text{Debris}).$$

The combined predictive model developed for determination of influential habitat conditions in burrow and non-burrow areas correctly predicted approximately 84% of the burrow and non-burrow locations in the model cross-validation procedure. Therefore, this analysis produced a strong predictive model for the presence and absence of tortoise burrows.

Presence of burrows (both inactive and active) exhibited a positive relationship with understory legume cover, midstory woody cover, percentage of overstory pine, bare ground coverage, and debris coverage. The strongest explanatory variable for predicting occurrence of burrows was understory legume coverage. This finding supports and contributes to earlier studies that reported herbaceous cover including legumes to be an important component of good tortoise habitat. Because legumes are important food plants of gopher tortoises, abundance of these plants would be expected to influence tortoise occurrence and occupancy (Jones and Dorr 2004). Positive relationships with bare soil may be related to carrying capacity of sandy soils that generally support burrow construction by tortoises. Positive relationships to coverage of pine overstory indicated that tortoises in this study were most often found in pine forests with deep sands of >1m in depth (Jones and Dorr 2004). The negative relationships found with overstory species richness further supported tortoise occupancy of pine forest within the study area.

This finding supports earlier studies within the historical distribution range that assessed habitat conditions in historically occupied tortoise habitats. Within the historical distributional range, tortoises were most abundant in pine flatwoods and longleaf pine savannas of the Lower Gulf Coastal Plain. Under long-term fire regimes, these habitat types that occurred on sandy soils were dominated by longleaf pine with interspersed communities of scrub oaks. Although herbaceous and woody ground cover may often be diverse across these habitats, the overstory is typically dominated by pines (Ware et al. 1993). Increased species richness in the forest overstory could indicate more mesic soil conditions, which are marginal for tortoises, and a lower incidence of fire over time (Jones and Dorr 2004).

The debris measured in this study included woody debris resulting from Hurricane Katrina, which is still dominant on the landscape. Although no studies have been conducted to compare damage within various habitats of the study area, cursory observations indicated high levels of downed and damaged stems within sparse stands of trees, especially loblolly pine. Another important variable in this model was midstory coverage. Jones and Dorr (2004) found that abandoned burrow occurrence was positively related to increased coverage of midstory vegetation. The pooling of data to include all regimes of activity status, yielded a sample population of burrows in which 50% were abandoned or inactive burrows. Because midstory and overstory canopy closure can restrict sunlight at ground level, these habitat characteristics have been found to negatively influence nesting, basking, and foraging conditions for gopher tortoises. Therefore, grouping burrows into activity status is necessary to ascertain habitat quality assessment versus occurrence of burrows on a land base.

The occurrence of burrows of all activity status was negatively correlated with the percentage of open sky in overstory canopy. Open sky measurements were obtained in this study to assess the efficacy of LiDAR in determining major vegetation types and metrics. The inverse relationship between open sky and occurrence of burrows is not in agreement with many studies of tortoises. Most studies have reported that a greater openness of midstory and overstory canopy is most desirable; one would expect a greater incidence of burrows on more open sites. However, the openness of a site is not the only indicator of or influence on habitat suitability for tortoises. Also, similar considerations concerning the modeling effect of grouping all burrow types into a single use category are appropriate when considering the influence of open sky in the specific model.

Preliminary inferences may be drawn from the information on the condition of gopher tortoise habitat in many of the areas sampled for this study. Tortoises that were occupying habitats in which midstory canopy closure was well developed may be doing so because of the remaining herbaceous food within home ranges. However, as midstory continues to close, tortoise food plants, basking sites, and nesting sites will be degraded over time. Therefore, habitat management, such as prescribed burning, is needed to stimulate herbaceous plants and set back midstory coverage on many of the areas sampled in this study. Related to this condition was the landfall of Hurricane Katrina in August 2005. In the 3 years following Hurricane Katrina, prescribed burning has been viewed as dangerous because of immense fuel loads of coarse woody debris and downed trees. This hazardous situation was compounded by abnormally low rainfall levels during 2006–2007. Therefore, restrictions on burning impeded permitting and implementation of prescribed fires even on public lands until late of 2007 through 2008. However, with abundant rainfall and lower fuel loads in southern forests, aggressive approaches in implementation of prescribed burns within most of the forested areas included in this study are recommended.

Due to the dependence of tortoises on sandy soil types for burrow construction, inclusion of edaphic features must be included along with vegetation features in future modeling efforts. Soil suitability classes according to the Gopher Tortoise Recovery Plan (USFWS 1990) will be identified and used in future models as categorical variables. This effort may elucidate why selected explanatory variables influenced tortoise burrow occurrence.

Direct interpretation of this model that assumes the model delineates quality habitat conditions for tortoises would not be prudent. The following conditions should be met in future studies to develop habitat suitability indices for gopher tortoises due to the following conditions:

1. Delineation of current activity status of gopher tortoise burrows: abandoned, active, recently active
2. Selection of study sites based on historical management regimes, soil suitability criteria, and non-occupancy and occupancy status
3. Larger sample sizes within occupancy categories listed in #1 and edaphic and management regimes indicated in #2
4. Extended data collection periods
5. Scoping of burrows to determine exact status activity.

Predictive models should include soil types for determination of suitability for tortoises.

Information from LiDAR including slope, aspect, concavity or convexity, and other GIS variables such as soil type will be considered in the final combined model analysis.

5 Conclusions

This study determined overstory habitat conditions at active and recently active gopher tortoise burrow locations versus randomly-selected non-burrow locations at Camp Shelby, MS, and concludes that:

- The probability of burrows being present increases as basal are (BA) and mean total height of trees (MHT) decreases.
- The presence of burrows (both inactive and active) exhibited a positive relationship with understory legume cover, midstory woody cover, percentage of overstory pine, bare ground coverage, and debris coverage. The strongest explanatory variable for predicting occurrence of burrows was under-story legume coverage.

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14. ABSTRACT
The western population of the gopher tortoise (Gopherus polyphemus) is listed as Federally threatened; its presence on the Camp Shelby, MS has resulted in training restrictions. To determine the specific habitat variables that influence gopher tortoise habitat selection, this research assessed overstory habitat conditions between active, recently active and randomly selected non-burrow locations at this site. Field surveys were completed in three study areas at the installation. On average, burrow sites had a much higher overall occurrence of longleaf pine and significantly lower total basal area as compared to non-burrow sites. Overstory mean height was significantly lower on burrow than non-burrow sites. When considering all variables (understory, midstory, overstory), stepwise logistic regression identified seven significant explanatory variables. Burrow presence was positively correlated with understory legume cover, midstory woody cover, percentage of overstory pine, bare ground coverage, and debris coverage. Burrow presence was negatively correlated with overstory species richness and overstory percent open canopy. The strongest explanatory variable for predicting the occurrence of burrows was understory legume coverage. Within-model cross-validation correctly predicted the presence or absence of active burrows for 83.9 percent of the observed outcomes.

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