Using GIS and LiDAR DTMs to characterize terrain features associated with gopher tortoise (*Gopherus polyphemus*) burrows

By

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Limited knowledge exists of the terrain variables that have an influence on gopher tortoise (*Gopherus polyphemus*) burrow locations. Previous studies suggest that terrain features may play a role in preference of burrow location. LiDAR- (Light Detection and Ranging) derived terrain features can be evaluated through GIS (Geographic Information System) analysis at a fine spatial scale. LiDAR data acquired at 0.5 meter post spacing over three locations on Camp Shelby Joint Forces Training Center, MS were used to develop DTMs (Digital Terrain Models) for use in burrow site characterization. Terrain variables (e.g. elevation, slope, aspect) were developed from the LiDAR DTM in ArcGIS. Burrows and randomly allocated non-burrow points were used in logistic regression analysis to model the relationship between burrow occurrence and terrain features. Four models correctly classified more than 83% of the burrow locations. The R^2 were 34.83%, 49.31%, 28.09%, and 31.51%.

DEDICATION

To my boys, Colton and Corbin, and to my wife, Shennia: thank you for your love. I thank God everyday for blessing me with the three of you.

Colton and Corbin, thank you for keeping me focused on the goal of providing the best I possibly can for you.

Shennia, thank you for being my best friend and for helping me build the family we have.

I want to thank God for allowing me the opportunities that I have had in life and for making it possible for me to finish this. I would also like to thank my parents, Mary Ann Elmore and Rob Mosley, and my step-mother, Gail Mosley. Without your support and guidance, I would not have the ability to finish something of this magnitude. I also want to thank my wife’s parents, Steve and Jeanene Heatherly, for the support. It is greatly appreciated. To all of my friends and family who I have not named specifically that has helped us, thank you.

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It is impossible to name everyone that has helped me throughout this process. To everyone that I could not name specifically, I sincerely appreciate your help.

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CHAPTER I

INTRODUCTION

The range of the gopher tortoise (*Gopherus polyphemus* Daudin) is throughout the Southern Coastal Plain from southeastern Louisiana to the southern portion of South Carolina and south to Florida (Alexy et al. 2003; Jones and Dorr 2004). This species was listed as threatened under the Endangered Species Act of 1987. This listing protects gopher tortoises located west of the Tombigbee and Alabama River systems throughout southeastern Louisiana, southern Mississippi, and southwestern Alabama. It is estimated that the gopher tortoise population has decreased 80% over the past 100 years. This decline is thought to be due to habitat loss, degradation, and conversion of native pine forests for urban development, agriculture, or commercial pine forest (Jones and Dorr 2004). Historically, the longleaf pine (*Pinus palustris* Mill.) ecosystem has been preferred by the gopher tortoise, but only 2% of this native ecosystem remains in its original range. Presently, most viable populations of the tortoise exist on private land or military installations (Tuberville et al. 2007).

In the southeastern United States, gopher tortoises have been documented on seven military installations. Camp Shelby Joint Forces Training Center (JFTC), MS is a military installation located in southern Mississippi in Perry and Forrest counties. Due to the threatened status of the gopher tortoise, this area is currently under training restrictions. In order to conduct proper military training without negative consequence on the gopher tortoise population, the specific habitat characteristics which are necessary to support a healthy population of the tortoise need to be evaluated across the landscape.

A recent study conducted for the Construction Engineering Research Laboratory (ERDC/CERL) used field and remote sensing data to assess differences in habitat conditions for the gopher tortoise on three study sites located on Camp Shelby JFTC, MS. The study was conducted by a team of researchers from the Forest and Wildlife Research Center located at Mississippi State University with assistance from the University of Texas Applied Research Laboratories and Center for Space Research, U.S. Army Engineer Research and Development Center (ERDC), Camp Shelby JFTC, and the MS Army National Guard. The objective of the study was to assess differences in understory, midstory, and overstory conditions between gopher tortoise burrows and randomly allocated non-burrow plots using a combination of field, GIS (Geographical Information System), and LiDAR (Light Detection and Ranging) derived variables. The study also looked at differences in terrain features for the burrow and non-burrow plots. It concluded that tree height, basal area, and legume abundance were the most important factors in determining presence or absence of gopher tortoise burrows. During the study, it was observed that burrows tended to be located along ridge tops with well drained sandy soils. The higher topographic areas on the study sites primarily consist of longleaf pine and have a high frequency of fire. Due to frequent burning, there is a lower stem density which seems to provide habitat suitable for gopher tortoise.[1]

The study mentioned above acted as the parent study for the research discussed here. This research took a more in depth look into the terrain features at and surrounding the gopher tortoise burrows by use of GIS and LiDAR derived variables. The theory behind this work was that burrows could be located along ridge tops due more to underlying terrain features as opposed to forest conditions. The primary focus was placed on analyzing the relationships between the area surrounding gopher tortoise burrows and site conditions potentially influencing the burrow locations.

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[1] Evans, D.L., Roberts, S.D., Jones, J.C., Edwards, K.E., Londo, H.A., Fan, Z., 2010. Field and remote sensing assessment of gopher tortoise habitat in forested conditions on Camp Shelby, MS. ERDC/CERL Final Technical Report. (Unpublished). 99 p.

CHAPTER II

LITERATURE REVIEW

Gopher Tortoise Habitat

Areas usually inhabited by the gopher tortoise are characterized by pine (*Pinus* spp.) forests with sandy soils and abundant herbaceous understory (Jones and Dorr 2004). Since longleaf pine forests are maintained by fire and typically consist of upland vegetation, they provide excellent habitat for the tortoise (Hermann et al. 2002). Burrows are excavated and maintained by the species in order to provide refuge during winter dormancy periods (Jones and Dorr 2004). Alexy et al. (2003) found that approximately 95% of the foraging activities of the tortoise are within 30 meters of the burrow. This foraging activity is related to temperature as most foraging activity occurs during the warmest part of the day (Alexy et al. 2003). Jones and Dorr (2004) showed that burrow occurrence is most frequent in deep, sandy soils, and an open overstory canopy is also preferred. Over the entire study area, Jones and Dorr (2004) found the greatest number of active burrows on sites which consist of sandy soils greater than one meter in depth, total canopy coverage < 65%, midstory coverage < 35%, and herbaceous ground coverage > 35%. These findings support the parent study of this research that as total overstory height and basal area decrease, the occurrence of burrows increases.[1] Jones and Dorr (2004) also found that sites which exhibited little or no evidence of recent tortoise activity were characterized by dense loblolly (*Pinus taeda* L.) or slash (*Pinus elliotti*

Eng.) pine plantations which were 6 – 20 years old and located on loamy soils. These sites were lacking deep sandy texture in the upper soil horizons and had > 80% canopy coverage, > 40% mid-story coverage, and < 10% herbaceous coverage (Jones and Dorr 2004).

BenDor et al. (2009) states that three conditions must exist in order for the tortoise to survive: 1) well-drained sandy soils for burrowing, 2) intermittent sunny areas for basking and nesting, and 3) abundant low growing forage. This may be explained by the observations of Baskaran et al. (2006), who found that the probability of burrow occurrence increased as the distance to a road decreased. Road edges often offer herbaceous cover and low foraging conditions as well as sunny areas. Furthermore, roads and trails are often located along ridge tops and are typically positioned to avoid wet conditions (Baskaran et al. 2006).

Site Conditions/Terrain Features

Previous studies have indicated that site conditions may play a significant role in the activities of the gopher tortoise, since the location of burrows tended to be more on ridge tops. In the previously mentioned parent study, non-burrow plots, which were allocated at specific distances from the burrows, were found to be more on side slopes and drainages where the soils were much wetter.[1] The location of non-burrow plots may be of some importance due to the specific distances from the burrows (i.e. burrow occurrence may be more probable at certain distances from streams or drainages). This observation is also supported by Baskaran et al. (2006) who stated "gopher tortoise burrows were more common along ridges than flat terrain." Baskaran et al. (2006) initially entered slope into the habitat model but it was not retained as a significant variable. Landsat TM imagery was used to derive land cover variables for their study, and therefore slope had to be resampled to 30 meter resolution. Slope may have not been useful at this resolution. It was also observed that as distance from streams increases, the probability of burrow occurrence also increases (Baskaran et al. 2006).

Remote Sensing and GIS for Habitat Assessment

Statistical modeling is a method for investigators to analyze habitat variables. The method uses the relationships between species location and the surrounding habitat to identify other suitable locations for species (Sellars and Jolls 2007). Although statistical habitat modeling can be very useful, field measurements needed to develop models may be extremely time consuming and costly to collect (Tweddale et al. 2008). Remote sensing coupled with GIS (Geographic Information System) provides an efficient way to obtain and analyze such data. Environmental factors (soil type, vegetation type and cover, topography, species occurrence) as well as human activities (roads, political boundaries, and public-use patterns) may be integrated into conservation plans with the use of remote sensing and GIS (Sellars and Jolls 2007).

Remote sensing along with GIS has been used extensively in habitat modeling, particularly for threatened or endangered species (Alexy et al. 2003; Baskaran et al. 2006; Graf et al. 2009; Muller and Brandi 2009; Osborne et al. 2001; Sellars and Jolls 2007; Thompson et al. 2006; Tweddale et al. 2008; [1]). Thompson et al. (2006) used a spatial modeling approach and remote sensing techniques to determine potential sites for the restoration of butternut (*Juglans cinerea* L.), which is a hardwood species that has been declining in population numbers due to an exotic fungus. By use of these techniques, Thompson et al. (2006) was able to correctly classify 85.2% of the butternut locations used to create the model. From the study area, it was determined that 11.6% was suitable habitat for butternut restoration. Osborne et al. (2001) used GIS and AVHRR (Advanced Very High Resolution Radiometer) data to successfully model the habitat of the Great Bustard (*Otis tarda* L.) which is a globally threatened bird species. This study found that terrain variables were significant but would be more useful at a finer scale than provided by the AVHRR data (1 km; Osborne et al. 2001).

LiDAR is an active sensor which transmits pulses of infrared light toward the ground and measures the amount of time it takes for the pulse to return. The time of pulse return is used to calculate the distance between the sensor and objects on the ground (Lillesand et al. 2008). By laser ranging, these systems generate X, Y, Z coordinate data from aerial platforms (Tweddale et al. 2008). LiDAR systems make use of airborne GPS in order to accurately determine the X, Y, Z sensor location. These systems also utilize an IMU (Inertial Measurement Unit) which measures the angular orientation of the sensor to the ground (Lillesand et al. 2008 p. 715). The typical accuracy of LiDAR data is in the range of 0.15 – 0.20 m vertically.

In the past, DTMs (Digital Terrain Models) have been a limiting factor to habitat modeling due to the lower resolution of prior remote sensing technologies used to generate DTMs. With its high resolution, LiDAR has provided a more accurate source of creating DTMs (Sellars and Jolls 2007). When compared to other means of DTM development (IFSAR, USGS Level 1 and Level 2 DTMs), LiDAR proved to be the most accurate with a RMSE (Root Mean Square Error) of only 93 cm in leaf-on conditions. DTMs created from LiDAR data obtained in ideal (leaf-off) conditions can result in a RMSE of only 15 cm (Hodgson et al. 2002). Muller and Brandi (2009) state that the main advantage of LiDAR is that it “allows sampling of habitat characteristics with a high resolution at large spatial scales providing statistically well-behaved data.”

Due to the high spatial resolution and ability to include vertical forest structure (Zimble et al. 2003) as a habitat variable, LiDAR has improved the ability to quantify habitat suitability. Many studies have used this technology to determine specific habitat variables which are associated with threatened or endangered species (Graf et al. 2009; Muller and Brandi 2009; Sellars and Jolls 2007; Tweddale et al. 2008, [1]). Using first and last return LiDAR data, Graf et al. (2009) developed a habitat suitability model for the Capercaillie (*Tetrao urogallus* L.), an endangered grouse in Central Europe. Observed presence-absence was explained moderately well by the final habitat suitability models with an AUC (Area Under the Receiver Operating Characteristic Curve) of 0.71 and 0.77 (Graf et al. 2009). By extracting topographic variables from LiDAR datasets, Sellars and Jolls (2007) predicted 46% - 100% of the observed occurrences of *Amaranthus pumilus* R., a federally threatened flowering annual which occurs in the Atlantic Barrier Islands. Tweddale et al. (2008) used LiDAR and multispectral imagery to assess forest conditions associated with Red-cockaded Woodpecker (*Picoides borealis* V.; RCW) habitat. The RCW is an endangered woodpecker of the Southern United States. It was found that detailed habitat information could be provided by combined use of LiDAR and multispectral imagery. In conclusion, Tweddale et al. (2008) states that these techniques “provide the capability to assess and monitor RCW habitat suitability in areas that are inaccessible to field surveys, including impact area safety zones on military installations and adjoining private land.”

Summary

Limited knowledge is available on the specific habitat variables that have an influence on preference of habitat for the gopher tortoise. Previous studies have hypothesized that terrain features may play a major role on the preference of burrow location for the species (Baskaran et al. 2006, [1]). Remote sensing technologies, specifically LiDAR, provide a method of broad-scale terrain assessment which is accurate and efficient. LiDAR-derived measures have been used extensively in habitat modeling (Graf et al. 2009, Muller and Brandi 2009, Sellars and Jolls 2007, Tweddale et al. 2008, [1]). Since, LiDAR provides very high resolution DTMs, the significance of specific terrain features which are hypothesized to influence the gopher tortoise can be examined.

Objectives

The objective was this study was to identify the specific terrain variables which might have a major influence on the activities of the gopher tortoise using GIS and LiDAR derived variables. This knowledge would contribute to management decisions that would aid in the conservation efforts of the species. The primary objectives of this study were to: 1) identify clusters of burrows which were in close proximity possibly due to underlying terrain features, 2) describe the local terrain features at the burrow sites, and 3) evaluate differences in terrain features between burrows and non-burrow points that were randomly dispersed in the area surrounding the burrow clusters.

CHAPTER III

METHODS

Study Area

The study area (Figure 1) consists of three sites located on Camp Shelby JFTC, MS. The three sites, 1) T44, 2) East Area, and 3) Mars Hill, are all located in Perry County, MS and consist of approximately 713, 383, and 1414 acres, respectively. These sites exhibit various gradients of gopher tortoise habitat. In the parent study previously mentioned, surveys were conducted to assess the understory, midstory, and overstory conditions. To estimate the understory and midstory conditions, data was collected on one 100 ft line transect at each burrow and non-burrow plot throughout the study sites. To estimate the overstory conditions, 10 meter radius field plots were sampled at each burrow and non-burrow plot throughout the study sites. To estimate canopy closure, densitometer readings were collected at each burrow and non-burrow plot and at the eight cardinal directions leading away from the plot. The readings at the eight cardinal directions were collected 10 meters from plot center. The study found that all three sites were primarily upland sites with the majority of tree species being longleaf pine and the majority of soils being of sandy texture. Hardwoods such as oak (*Quercus* spp.), red maple (*Acer rubrum* L.), flowering dogwood (*Cornus florida* L.), sweetgum (*Liquidambar styraciflua* L.), yellow poplar (*Liriodendron tulipifera* L.), sweet bay magnolia (*Magnolia virginiana* L.), and black tupelo (*Nyssa sylvatica* M.) occur in the wetter areas such as drainages.[1]

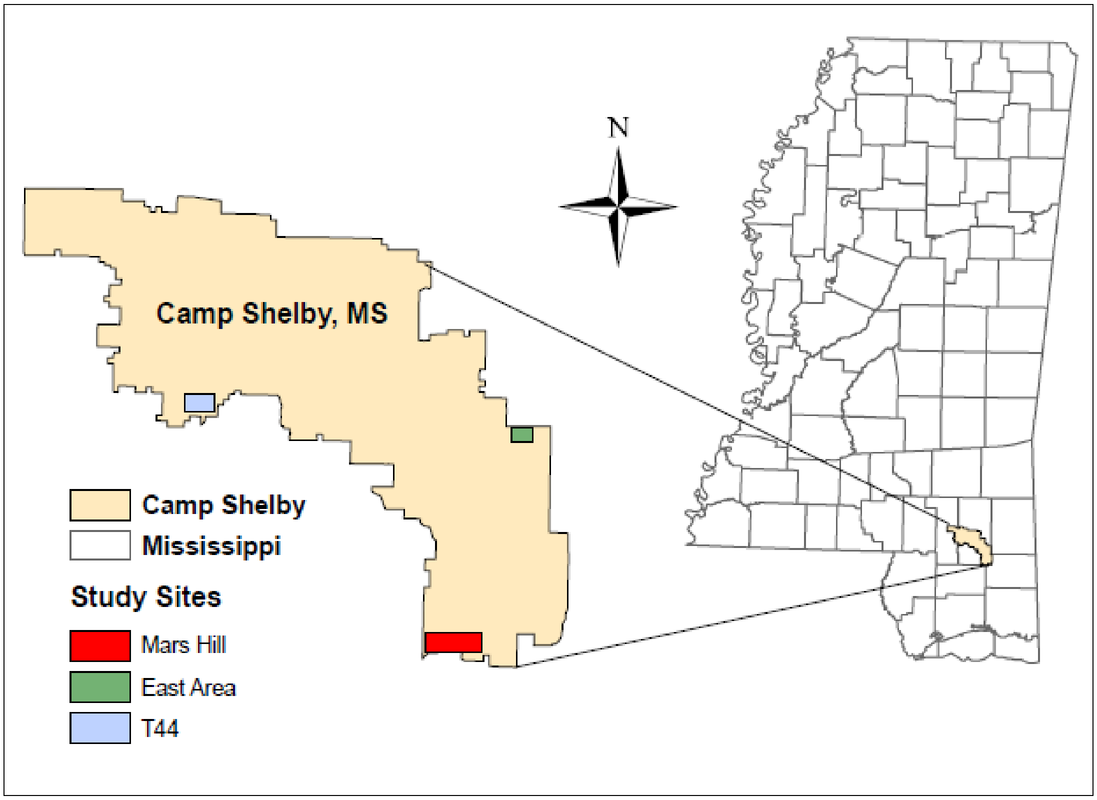

Figure 1 General boundary of Camp Shelby Joint Forces Training Center, MS with three study sites.

The T44 site had the greatest amount of bare ground coverage (burrow = 7.7%, non-burrow = 8%) and understory herbaceous coverage (burrow = 65%, non-burrow = 73.9%). It also had the lowest amount of debris coverage (burrow = 19.5%, non-burrow = 18.6%), understory woody coverage (burrow = 25.6%, non-burrow = 19.1%), and midstory stem count (burrow = 20.6 stems/plot, non-burrow = 7.6 stems/plot). This is likely due to the frequent prescribed burning that takes place on T44. The mean basal area per acre for pine was 46.5 ft^2 and 4.3 ft^2 for hardwood. The mean TPA (trees per acre) for pine was 52.7 and 13.5 for hardwood. The mean DBH (diameter at breast height) for pine was 12.9 inches and 7.2 inches for hardwood. The mean tree height for pine was 66.3 feet and 42.4 feet for hardwood. The mean percent open sky was 60.3%.[1]

The Mars Hill site had the greatest amount of debris coverage (burrow = 42.1%, non-burrow = 34.4%) and midstory stem count (burrow = 52.7 stems/plot, non-burrow = 22.2 stems/plot). The percent bare ground coverage for burrows was 3.4% and 3.5% for non-burrow plots. The understory herbaceous coverage was 29.9% for burrows and 42.7% for non-burrow plots. The understory woody coverage was 40.3% for burrows and 38.3% for non-burrow plots. The basal area per acres for pines was 40.0 ft^2 and 11.6 ft^2 for hardwoods. The mean TPA for pines was 95.2 and 35.8 for hardwoods. The mean DBH for pines was 9.7 inches and 6.7 inches for hardwoods. The mean tree height for pines was 57.4 feet and 34.7 for hardwoods. The mean percent open sky was 40.6%.[1]

The East Area site had the greatest amount of understory woody coverage (burrow = 50.7%, non-burrow = 53.7%) of the three sites. The percent bare ground coverage for burrows was 0.5% and 0.4% for non-burrow plots. The percent debris coverage for burrows was 35.3% and 23.1% for non-burrows plots. The understory herbaceous coverage for burrows was 25.7% and 38.2% for non-burrow plots. The midstory stem count for burrows was 35.7 stems per plot and 31.94 stems per plot for non-burrow plots. The basal area per acres for pines was 51.2 ft^2 and 23.7 ft^2 for hardwoods. The mean TPA for pines was 73.8 and 58.8 for hardwoods. The mean DBH for pines was 12.4 inches and 7.2 inches for hardwoods. The mean tree height for pines was 67.6 feet and 39.5 feet for hardwoods. The percent open sky was 33.0%.[1]

Geospatial Data (GIS/LiDAR)

On October 26 – 27, 2007, the Center for Space Research, University of Texas acquired discrete-return LiDAR data over the three study sites at Camp Shelby. The LiDAR data were collected with a nominal post spacing of 0.5 m. A dual-return Airborne Laser Terrain Mapping (ALTM) system with a laser pulse repetition rate of 25 kHz was used to collect the data.

Geospatial data for Camp Shelby JFTC, MS were acquired through the Mississippi Army National Guard GIS Coordinator, Lindsey Murphy. The data layers included were past surveyed gopher tortoise burrow locations, soils, roads, streams, and installation boundaries.

Preliminary Assessment

As part of the parent study, a preliminary assessment on the three study sites was conducted to determine activity status of the gopher tortoise burrows. The burrows surveyed during this assessment were categorized as active, inactive, or abandoned. Burrows with an opening similar in shape to a tortoise carapace, a soil apron that was mostly free of vegetation, and had tracks or plastron scrapings leading into the burrow were classified as active (Auffenberg and Franz 1982, Guyer and Hermann 1997). If the burrow opening was intact but partially covered with vegetation, the burrow was categorized as inactive. If there was no evidence of gopher tortoise activity, soil or vegetation obstructed the opening, and the opening was eroded, the burrow was classified as abandoned.[1]

For this study, two datasets were developed. Group 1 consisted of active and inactive burrows for each of the three study sites. Group 2 consisted of active, inactive, and abandoned burrows for each of the study sites. The distribution of these burrows over the three study sites is given in Table 1. For all Group 2 burrows, there were a higher percentage of abandoned burrows than active or inactive. This should not be regarded as evidence of population decline on Camp Shelby, because there was no measure of time in which the burrows were abandoned.

Table 1 Distribution of Group 1 and Group 2 burrows over the three gopher tortoise habitat study sites located on Camp Shelby Joint Forces Training Center, MS.

Study Site	**# Burrows**	**% Active**	**% Inactive**	**% Abandoned**
Mars Hill				
Group 1	152	59%	41%	N/A
Group 2	264	34%	24%	42%
East Area				
Group 1	85	48%	52%	N/A
Group 2	166	25%	27%	48%
T44				
Group 1	149	54%	46%	N/A
Group 2	253	32%	27%	41%

Terrain Variables

In the parent study, it was observed that burrows were located more on ridge tops with well drained sandy soils and that non-burrow plots were located more on side slopes and drainages.[1] Baskaran et al. (2006) also stated that there were more burrows found on ridge tops than on flat terrain. Because of these observations, elevation at the burrow sites was examined in this study. This study also investigated terrain variables such as slope, slope curvature, and flow accumulation which affect soil moisture levels. Since various landforms (ridges, slopes, valleys, etc.) exhibit various gradients of local elevation and soil moisture/drainage, a categorical variable named Slope Position was tested. The variability of the terrain (Terrain Roughness) surrounding the burrow was tested. Innes (2009) stated that physical features such as rivers, lakes, ponds, cliffs, sinkholes, and other features create barriers to movement for the gopher tortoise. It is possible that high variability in the terrain surrounding the burrow may not be preferred, since the species is relatively immobile. Since gopher tortoises need sunlight (BenDor et al. 2009) and many of their daily activities depend on the warmest part of the day (Alexy et al. 2003), aspect was also tested.

A LiDAR-derived DTM with 0.5 meter resolution was used to derive all variables for this study which included elevation, relative elevation, slope, terrain roughness, slope curvature, flow accumulation, aspect, and slope position. Elevation above mean sea level was used as a variable. Also, in an effort to gain more useful information from elevation as a variable, relative elevation for each of the sites was calculated from the DTMs by subtracting the minimum elevation value on each of the sites from every cell value. By doing this, the elevation values within each site are scaled within the same range of numbers therefore acting more as an elevation index. Having the elevation values within the same range on each study site allows comparisons to be made about the position of burrows across the three study sites. By use of Spatial Analyst in ArcGIS, grids were calculated for slope, aspect, surface curvature, and flow accumulation. The aspect grid was reclassified into 8 groups (North, Northeast, East, Southeast, South, Southwest, West, and Northwest). The slope curvature calculation created a continuous grid which determined if each cell within the DTM is upwardly convex or upwardly concave. On the study sites, the slope curvature values ranged from - 8.0 to 12. A positive value is upwardly convex, and a negative value is upwardly concave. A zero value is a flat surface. To calculate slope curvature, ArcGIS calculates three different surface curvature grids: curvature, profile curvature, and plan curvature. Profile curvature is calculated parallel to the direction of maximum slope. Plan curvature is calculated perpendicular to the direction of maximum slope. Curvature is the difference in values when plan curvature is subtracted from profile curvature (Chang 2010). Terrain roughness was also calculated and used as a variable in this study. This was done by calculating the second derivative of the slope (slope of the slope) which is the rate of change in slope (Chang 2010). On the study sites, the terrain roughness values ranged from 0 – 80.0. The values are index values in which a zero value means flat. A higher terrain roughness index should be interpreted as higher variation in the surrounding terrain.

In order to combine elevation and slope into a single categorical variable, slope position of burrows was assessed in this study. This was accomplished by use of the ArcGIS 9.3 extension “Topography Tools” developed by Dilts (2010). This tool was modeled after an ArcView extension developed by Jenness (2006). Slope position is classified by the calculation of a Topographic Position Index (TPI) which is the difference in elevation of a point and its specified neighborhood. Slope position is classified based on different ranges within the TPI grid as well as a slope grid. It is classified into 6 groups (Valley, Toe Slope, Flat, Midslope, Upper Slopes, and Ridge).

Jenness (2006) states that the TPI produces classifications which are "entirely dependent on the scale you use to analyze the landscape." For example, a mountain top may be considered a ridge top to a human but a flat area to a mouse (Jenness 2006). For this study, slope position was calculated with a 55 meter circular neighborhood to reduce statistical noise. This was the smallest neighborhood that developed a slope position grid that resembled the landscape at the study sites.

Spatial Analyst calculates flow accumulation using what is referred to as the D8 algorithm. The flow direction is determined by the steepest slope over the shortest distance. The flow direction can only contribute to one of the eight neighboring cells. After flow direction throughout the grid is determined, the flow accumulation is developed. The value of each cell in a flow accumulation grid is the count of how many cells contributed flow into that cell (Chang 2010). Table 2 lists all of the variables used in this study.

Table 2 List of all terrain variables used to study gopher tortoise habitat on Camp Shelby Joint Forces Training Center, MS.

Variable (Abbreviation)	Type
Elevation (Elev)	Continuous
Relative Elevation (RelElev)	Continuous
Slope (Slope)	Continuous
Aspect (Aspect)	Nominal
Surface Curvature (SlCurv)	Continuous
Terrain Roughness (TerrRough)	Continuous
Slope Position (SlPos)	Nominal
Flow Accumulation (FlowAcc)	Continuous

Burrow Cluster Identification (Excluding Outliers)

Average Nearest Neighbor was used to assess the pattern distribution of burrows across the landscape. The pattern distribution was calculated for both Group 1 and Group 2 burrows to determine if they were significantly clustered, random, or dispersed based on spatial location. This technique also calculates the average distance between burrows (Observed Mean Distance) which was of use in the cluster identification.

Clusters of burrows were developed in order to analyze burrows that were in close proximity to each other and to exclude any burrows that were standing alone. The burrows standing alone were thought of as statistical outliers. The following technique was patterned after the disease cluster identification methods discussed in Gatrell et al.

(1996). By use of a kernel density function, burrow clusters were identified based on their spatial proximity. A kernel function is expressed as a bivariate probability density function which is centered at a known point and tapers from one to zero at a specified distance also referred to as the bandwidth (Chang 2010). A kernel function was placed on all Group 1 and Group 2 burrows within each study site. The bandwidth was set to the Observed Mean Distance between burrows which was obtained during the Average Nearest Neighbor analysis. By use of the Kernel Density Estimator in Hawth's Tools, percent volume contours can be observed. Since the kernel density function is expressed as a probability density function, a 95% volume contour would contain points which occur within 95% of the probability distribution function of another point. Separate clusters were identified by breaks in this volume contour. Burrows that were standing alone were treated as outliers and were excluded from analysis. This technique enabled the identification of burrow clusters in which the burrows may be in close proximity due to underlying terrain variables. These burrow clusters were used as a method of excluding burrows which were not located within similar areas as the majority of the burrows. Also, since the burrows seemed to be clustered around some feature, non-burrow points were excluded from landing within the cluster polygons. The burrows within the cluster polygons were used as samples to determine the terrain characteristics preferred by the gopher tortoise for burrowing.

Drainage Basin Stratification (Non-Burrow Point Allocation)

In order to correctly assess the correlation of terrain features to burrow locations, the data were stratified by drainage basin. This was done so that random non-burrow points could be dispersed throughout each basin associated with burrow clusters instead of being dispersed throughout the entire raster grid. Other areas within the LiDAR DTM may have not been surveyed extensively for gopher tortoise burrows. Therefore, there were areas in other drainage basins that were similar in terrain features, but did not contain documented burrow sites.

The Basin tool in ArcGIS Spatial Analyst was used to delineate the drainage basins throughout the three study sites. When creating the flow accumulation grid, a flow direction grid was developed. This grid determines the flow direction for each cell within the DTM. By using the flow direction grid, the Basin tool determines the pour points at the edge of the grid. A pour point is a cell at the edge of the raster grid in which the flow would theoretically run off. It then identifies the contributing area above each pour point. Each contributing area is a drainage basin. For both Group 1 and Group 2 burrow datasets, the number of burrows within each basin was counted. In order to maintain a large sample size for statistical purposes, burrow samples were not included in the analysis unless there were at least 30 burrows within the drainage basin.

Non-burrow points were dispersed throughout the drainage basin which contained the burrows selected for analysis. For the Group 1 dataset, 100 non-burrow points per study site were randomly distributed. For the Group 2 dataset, 150 non-burrow points per study site were randomly distributed. The sample size of non-burrow points was selected based on the total number of burrows used in analysis over the three study sites. The non-burrow samples were allocated to be approximately the same as the overall number of burrows. Non-burrow points were excluded from landing within the burrow cluster polygons previously described.

To help better illustrate this process, Figure 2 has been provided below. The light grey boundary lines show the delineation of drainage basins on East Area. Also shown are the locations of gopher tortoise burrows and burrow cluster polygons. There was only one drainage basin on this site that contained at least 30 burrows. The burrows shown in red were used in further analysis, because they are located within the drainage basin of interest (> 30 burrows). The burrows shown in black were excluded from analysis, because they are located outside of the drainage basin of interest. Also shown are the non-burrow points (yellow) that were randomly allocated throughout the drainage basin of interest.

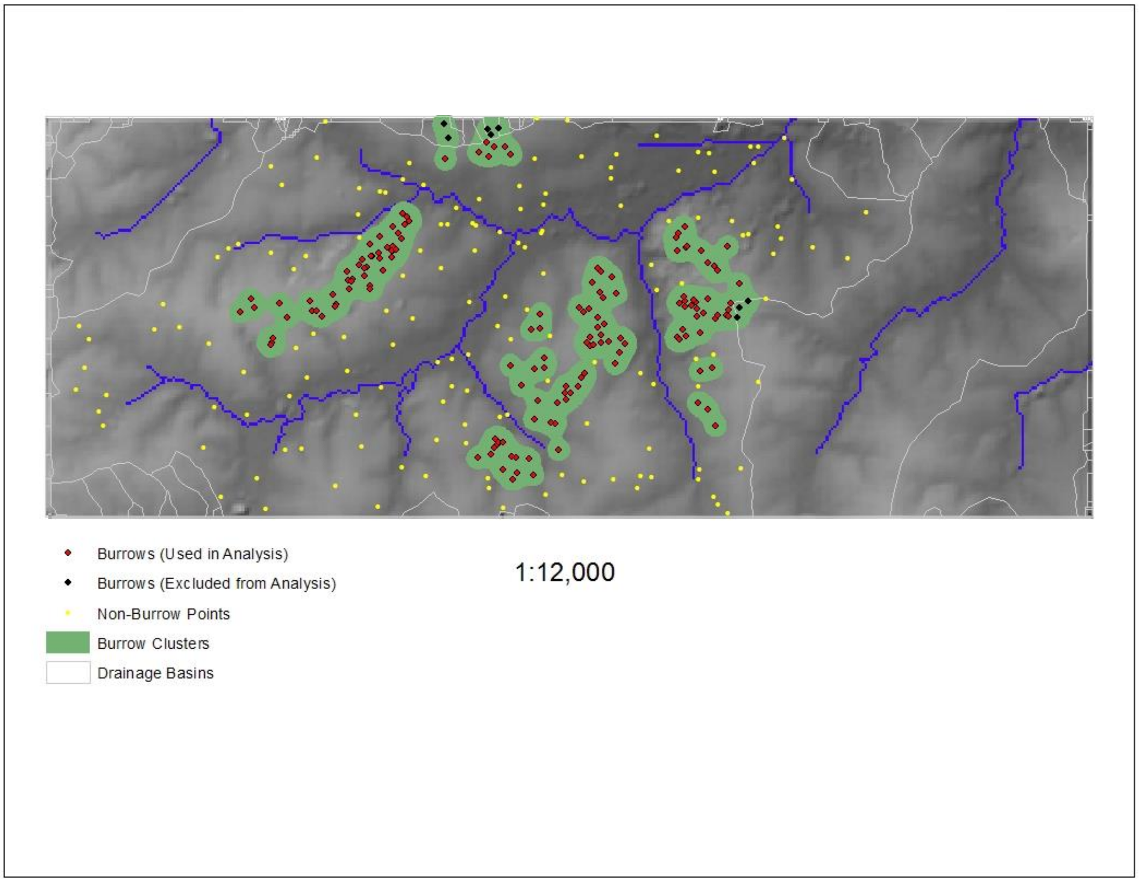

Figure 2 Map showing delineation of drainage basins (light grey boundary lines), Group 2 Burrows, Group 2 burrow clusters, Group 2 random non-burrow points, and streams for the extent of the LiDAR DTM on the East Area study site on Camp Shelby JFTC, MS.

Summary Statistics and Two-Way ANOVA

Descriptive statistics for all terrain variables were calculated separately for both the Group 1 and Group 2 burrows and non-burrow points on each of the three sites. The Group 1 burrows included burrows that were classified as active and inactive during the preliminary assessment. The Group 2 burrows included burrows that were classified as active, inactive, and abandoned during the preliminary assessment. For each subset of data, the mean, standard deviation, and 95% CI (confidence interval) of the mean were calculated for the continuous terrain variables. These included Elevation, Relative Elevation, Slope, Slope Curvature, Terrain Roughness, and Flow Accumulation. For Aspect and Slope Position, the frequency of occurrence within each category was observed for both burrows and non-burrow points. Summary statistics were observed for the following six subsets of data: 1) Group 1 T44, 2) Group 1 Mars Hill, 3) Group 1 East Area, 4) Group 2 T44, 5) Group 2 Mars Hill, and 6) Group 2 East Area.

Two-way ANOVA (Analysis of Variance) was used to determine differences among the datasets, study sites, and burrows/non-burrow points. It was also used to determine which variables should be used in further analysis. An ANOVA test was performed for each of the continuous variables (Elevation, Relative Elevation, Slope, Slope Curvature, Terrain Roughness, and Flow Accumulation). A Pearson test statistic was used to make inference about the two categorical variables (Aspect and Slope Position). All tests were performed at $\alpha = 0.05$ levels, which include:

1. Group 1 Burrows vs. Group 2 Burrows: (Study site was used as a block to account for any variation between sites.) This test was used to determine the validity of including both Group 1 and Group 2 burrows in further analysis.
2. Study Site Comparisons: Fisher's LSD (least square difference) was used to assess differences between the three study sites (T44, Mars Hill, and East Area). Only burrows were used in this test. This test was used to determine if further analysis is useful on the study sites separately.
3. Burrows vs. Non-burrow points: (Study site was used as a block to account for any variation between sites). This test was used to determine variables for further analysis.

Logistic Regression

Logistic Regression was used to evaluate the significance of each variable and interaction terms on preference of burrow location for the gopher tortoise. A logistic regression model was developed for the burrows across all three study sites. There was also separate logistic regression models developed for each of the three sites. Elevation was not entered into the site specific models. Due to the calculation methods of Relative Elevation, a perfect correlation exists between Elevation and Relative Elevation. This caused errors in the final output. Relative Elevation was chosen instead of Elevation, because it is more useful as a terrain position index since it's scaled to the minimum. For all analyses, the response variable was a binary response labeled BURROW. This variable defined whether the location had a burrow (Burrow = 1) or not (Non-burrow point = 0). Categorical variables were entered into the model as a set of dummy variables.

The four following logistic regression models were developed:

1. General Model – includes data from all three study sites.
2. T44 Site Specific Model – only includes data from the T44 study site.
3. Mars Hill Site Specific Model – only includes data from the Mars Hill study site.
4. East Area Site Specific Model – only includes data from the East Area study site.

In order to ensure that all influential polynomial and interaction terms were found, a stepwise approach was used. The first iteration of the model was calculated with only the first order terms entered into the model. For the continuous variables that were significant at $\alpha = 0.05$ levels, the squared term for that variable would enter the model on the second iteration. Also, the interaction between any significant variables was tested on the second iteration. Variables that were non-significant were removed from the model. If any squared terms were found to be significant, the third order term for that variable would then enter the model. This process was repeated until there were no new significant polynomial terms selected in the model. To ensure model improvement, the R^2 and Lack of Fit test statistic were observed following each iteration.

CHAPTER IV

RESULTS AND DISCUSSION

Burrow Cluster Identification (Excluding Outliers)

The burrow cluster identification performed well with at least 95% of the burrows within each study site and group falling within a cluster. With Average Nearest Neighbor, it was determined that both Group 1 and Group 2 burrows on all three sites were significantly clustered (<0.0001). The observed mean distance (O.M.D.), nearest neighbor ratio, and p-value for each group throughout the study sites are given in Table 3. The O.M.D. is the average distance between the burrows. The nearest neighbor ratio is the ratio of the O.M.D. between the set of burrows and the expected O.M.D. of a set of hypothetical random points. The nearest neighbor ratio of the hypothetical random points is 1. A value less than 1 means the points have a clustered distribution whereas a value greater than 1 means the points have a uniform distribution (Chang 2010). East Area Group 1 had an O.M.D. of 43.75 meters, and East Area Group 2 had an O.M.D. of 26.18 meters. On Mars Hill, Group 1 had an O.M.D. of 28.19 meters, and the O.M.D. for Group 2 was 22.43 meters. On T44, the O.M.D. for Group 1 was 33.41 meters, and the O.M.D. for Group 2 was 26.05 meters.

Table 3 Results of Average Nearest Neighbor gopher tortoise burrow cluster analysis for the Group 1 and Group 2 datasets for each study site located at Camp Shelby JFTC, MS.

Site	Group	Observed Mean Distance (m)	Nearest Neighbor Ratio	p-value
East Area	1	43.75	0.7350	<0.0001
East Area	2	26.18	0.6087	<0.0001
Mars Hill	1	28.19	0.3327	<0.0001
Mars Hill	2	22.43	0.3435	<0.0001
T44	1	33.41	0.5466	<0.0001
T44	2	26.05	0.5427	<0.0001

In Table 4, the distribution of clustered gopher tortoise burrows across the three study sites are given. This table also includes the number and percentage of burrows which were not clustered within the 95% volume contour. These burrows were treated as outliers and excluded from further analysis. In Group 1, there were 17 burrows excluded from further analysis. In Group 2, there were 16 burrows excluded from further analysis. The 95% volume contour is made up of the area within 95% of the probability density function placed on each burrow. The probability density function extends from zero at the burrow to the O.M.D. for that set of burrows. Therefore, points that fall within the 95% volume contour can be interpreted as falling within 95% of the average distance between burrows.

Table 4 Distribution of gopher tortoise burrow clusters within the Group 1 and Group 2 datasets for the three study sites located on Camp Shelby JFTC, MS.

Site	**Group**	**95% Volume Contour**			**Not Clustered**	
		# Clusters	**# Burrows**	**%**	**# Burrows**	**%**
East Area	1	4	82	96.47%	3	3.53%
East Area	2	9	160	96.39%	6	3.61%
Mars Hill	1	10	145	95.39%	7	4.61%
Mars Hill	2	14	260	98.48%	4	1.52%
T44	1	7	142	95.30%	7	4.70%
T44	2	12	247	97.63%	6	2.37%

Drainage Basin Stratification

After observing the number of burrows within each drainage basin, only one basin per study site was selected for analysis. The majority of the burrows were positioned within these basins. Therefore, they were the only three basins which contained greater than 30 burrows. In Table 5, the distribution of burrows and non-burrow points across the three study sites is given.

Table 5 Number of gopher tortoise burrows and non-burrow points for both Group 1 and Group 2 datasets for the three study sites located on Camp Shelby JFTC, MS following drainage basis stratification.

Site	Group 1		Group 2	
	Burrows	Non-Burrows	Burrows	Non-Burrows
East Area	77	100	152	150
Mars Hill	132	100	223	150
T44	66	100	118	150
Total	**275**	**300**	**493**	**450**

Summary Statistics and Two-Way ANOVA

Summary statistics are listed in Tables 7 – 18 (Appendix A). The mean, standard deviation, and 95% CI of the mean are listed for the burrows and non-burrow points within the following subsets of data: 1) Group 1 T44, 2) Group 1 Mars Hill, 3) Group 1 East Area, 4) Group 2 T44, 5) Group 2 Mars Hill, and 6) Group 2 East Area. Frequency tables are shown for the categorical variables (Aspect and Slope Position).

Group 1 vs. Group 2 Burrows (ANOVA)

There were no significant differences among any of the variables between the Group 1 and Group 2 burrows. The chi-square test p-value and Pearson test p-value for each variable can be observed in Table 19 (Appendix B). The Group 1 burrows and non-burrow points were not used for any further analysis. The Group 2 dataset was selected for further analysis because it provides that largest sample size.

Study Site Comparisons (Fisher's LSD)

Fisher's LSD was to determine that significant differences ($\alpha = 0.05$) among the burrows between study sites did exist. Table 6 shows the study site comparisons for each continuous terrain variable. The Pearson test determined that there were significant differences among both categorical variables (Aspect and Slope Position) between study sites (p-value = < .0001). Since significant differences exist between the study sites, a specific logistic regression model was developed for each site.

Table 6 Results of Fisher's LSD comparisons between T44, Mars Hill, and East Area located on Camp Shelby JFTC, MS.

	Site Comparisons		
Terrain Variable	**T44 vs. Mars Hill**	**T44 vs. East Area**	**Mars Hill vs. East Area**
Elevation	SIG	SIG	SIG
Relative Elevation	SIG	SIG	SIG
Slope	SIG	SIG	SIG
Slope Curvature	NS	NS	NS
Terrain Roughness	NS	SIG	SIG
Flow Accumulation	SIG	NS	SIG

Burrows vs. Non-Burrows (ANOVA)

Elevation, Relative Elevation, Slope, Terrain Roughness, Flow Accumulation and Slope Position had significant differences between the burrows and non-burrow points. Slope Curvature and Aspect had no significant difference between burrows and non-burrow points and were not used for further analysis. The chi-square test p-value and Pearson test p-value for each variable can be observed in Table 20 (Appendix B).

Logistic Regression Models

General Model

Five iterations of the General Model were calculated. The fifth model did not select any new polynomial terms as significant. The model was significant at $\alpha = 0.05$ level ($\chi^2 = 454.61$, p-value = <.0001) with an R-square value of 34.83%. The following variables were selected as significant at $\alpha = 0.05$ levels: Elevation (Elev), Relative

Elevation (RelElev), and Terrain Roughness (TerrRough). These variables form the following equation:

$$\begin{aligned}\text{Logit(Burrow)} = {} & 22.2088 - 0.5734(\text{Elev}) + 0.5505(\text{RelElev}) - \\ & 0.1220(\text{TerrRough}) + 0.3384(\text{Elev*RelElev}) - \\ & 0.0228(\text{Elev*TerrRough}) + 0.0304(\text{RelElev*TerrRough}) - \\ & 0.1282(\text{Elev}^2) + 0.0019(\text{Elev}^3) - 0.0001(\text{Elev}^4) - 0.1986(\text{RelElev}^2)\end{aligned}$$

$$\text{RMSE} = 0.3865 \qquad \text{(Eq. 1)}$$

The lack of fit test showed that the model fit the data well (p-value = 0.9544). The model correctly classified 90.0% of the burrows. It misclassified 34.7% of the non-burrow points as burrows. The Area Under Curve (AUC) for the General Model was 0.8542 meaning that the model has a good chance of discriminating between burrows and non-burrow points. The results for each model step are shown in Tables 21 and 22 (Appendix C). Graphs showing the significant relationships (Elevation, Relative Elevation, and Terrain Roughness) can be observed in Figures 3 – 5 (Appendix D).

T44 Site Specific Model

Three iterations of the T44 Site Specific Model were calculated. The third model did not select any new polynomial terms as significant. The model was significant at $\alpha = 0.05$ levels ($\chi^2 = 181.30$, p-value = <.0001) with an R-square value of 49.31%.The following variables was selected as significant at $\alpha = 0.05$ levels: Relative Elevation

(RelElev) and Terrain Roughness (TerrRough). These variables form the following equation:

$$\text{Logit(Burrow)} = -17.7263 + 0.5962(\text{RelElev}) - 0.1480(\text{TerrRough}) - 0.0294(\text{RelElev}*\text{TerrRough}) - 0.0398(\text{RelElev}^2)$$

$$\text{RMSE} = 0.3369 \qquad \text{(Eq. 2)}$$

The lack of fit test showed that the model fit the data well (p-value = 0.9998). The model correctly classified 83.1% of the burrows. It misclassified 16.9% of the non-burrow points as burrows. The AUC this model was 0.9224 meaning that it has an excellent chance of discriminating between burrows and non-burrow points. The results for each model step are shown in Table 23 (Appendix C). Graphs of the significant relationships (Relative Elevation and Terrain Roughness) can be observed in Figures 6 and 7 (Appendix D).

Mars Hill Site Specific Model

Three iterations of the Mars Hill Site Specific Model were calculated. The third model did not select any new polynomial terms as significant. The model was significant at $\alpha = 0.05$ levels ($\chi^2 = 141.19$, p-value = <.0001) with an R-square value of 28.09%.The following variables was selected as significant at $\alpha = 0.05$ levels: Relative Elevation (RelElev) and Terrain Roughness (TerrRough). These variables form the following equation:

$$\text{Logit(Burrow)} = -2.3944 + 0.1468(\text{RelElev}) - 0.0865(\text{TerrRough}) + 0.0174(\text{RelElev*TerrRough}) - 0.0059(\text{RelElev}^2)$$

$$\text{RMSE} = 0.3980$$

(Eq. 3)

The lack of fit test showed that the model fit the data well (p-value = 0.5121). The model correctly classified 91.9% of the burrows. It misclassified 45.3% of the non-burrow points as burrows. The AUC this model was 0.8262 meaning that it has a good chance of discriminating between burrows and non-burrow points. The results for each model step are shown in Tables 24 (Appendix C). Graphs showing the significant relationships (Relative Elevation and Terrain Roughness) can be observed in Figures 8 and 9 (Appendix D).

East Area Site Specific Model

Four iterations of the T44 Site Specific Model were calculated. The fourth model did not select any new polynomial terms as significant. The model was significant at $\alpha = 0.05$ level ($\chi^2 = 131.93$, p-value = <.0001) with an R-square value of 31.51%. The following variables were selected as significant at $\alpha = 0.05$ level: Relative Elevation (RelElev) and Slope. These variables form the following equation:

$$\text{Logit(Burrow)} = -0.2564(\text{Slope}) - 0.1172(\text{RelElev}^2)$$

$$\text{RMSE} = 0.4035$$

(Eq. 4)

The lack of fit test showed that the model fit the data well (p-value = 0.5925). The model correctly classified 86.8% of the burrow points. It misclassified 39.9% of the non-burrow points as burrows. The AUC this model was 0.8430 meaning that it has a good chance of discriminating between burrows and non-burrow points. The results for each model step are shown in Tables 25 and 26 (Appendix C). Graphs showing the significant relationships (Relative Elevation and Slope) can be observed in Figures 10 and 11 (Appendix D).

Discussion

The burrow cluster identification method used in this study performed very well by grouping at least 95% of the burrows on each study site and within each group into clusters. It provided an excellent method to exclude burrows that were spatial outliers. Less than 5% of the burrows on each study site and within each group had to be excluded from analysis. It also provided polygons from which randomly allocated non-burrow points could be excluded. The burrows seemed to be clustered around some feature. Allowing non-burrow points to fall within the cluster boundaries would confuse the analysis, since they would have fallen within the areas that the species seems to prefer. The O.M.D. of the Group 2 burrows was higher than the Group 1 burrows on all three sites. The abandoned burrows were located within the same areas as the active and inactive burrows. This further supports the theory that the burrows are clustered on or around some feature(s). Although the Group 2 clusters were made up of more burrows, the area within the Group 2 clusters did not differ greatly from the Group 1 clusters.

Elevation or Relative Elevation was selected as significant for all four models developed in this study. Terrain roughness was also selected as significant in the General

Model and two out of the three site specific models. Two primary conclusions were made from these data:

1. As elevation increases, the probability of burrow occurrence increases.
2. As the variability of the surrounding terrain (Terrain Roughness) increases, the probability of burrow occurrence decreases.

This phenomenon is supported by observations made in the parent study where it was stated that burrows were located more on ridge tops. Ridge tops are typically well drained and, on the study sites, have abundant low growing forage. The higher topographic areas, on the three sites, primarily consist of longleaf pine and have a high frequency of fire. Due to burning, there is a lower stem density which promotes an abundant herbaceous understory.[1] Jones and Dorr (2004) support this with the finding that the greatest number of burrows were found in areas with a total canopy coverage < 65%, midstory coverage < 35%, and herbaceous ground coverage > 35%. BenDor et al. (2009) also supports these findings by stating that a gopher tortoise needs: 1) well drained sandy soils for burrowing, 2) intermittent sunny areas for basking, and 3) abundant low growing forage. The lower midstory stem density caused by high fire frequency would also allow more sunlight to penetrate the canopy and hit the ground allowing the gopher tortoise an area for basking and nesting. Gopher tortoise nests are typically located in open, sunny areas in close proximity to the burrow (Innes 2009).

The amount of canopy coverage may also affect the tortoise's daily activities. Excessive shade may not allow the tortoise to reach its minimum thermal requirements for daily activities such as basking and foraging. If the temperature inside the burrow is less than 55ºF, the tortoise will remain inactive inside the burrow. Once this temperature rises above 55ºF, it becomes active and usually exits the burrow to bask. Basking is very important for the tortoise as it helps to maintain efficiency of physiological processes (Innes 2009).

Another reason for preference of relatively high terrain for burrowing may be explained by the process of soil erosion. Since sandy soils are typically well drained and consist of larger, heavier particles, they are not carried as far by water. The smaller, lighter soil particles, such as silt and clay, are carried farther by water runoff leaving the sandier-textured soil at higher elevations across the landscape. Previous research has concluded that sandy soil is needed for burrowing. Jones and Dorr (2004) found the greatest number of active burrows in sandy soils. BenDor et al. (2009) stated that well drained sandy soil is needed for burrowing.

Innes (2009) states that dense vegetation, abundant woody debris, ponds, lakes, rivers, marshes, cliffs, and sinkholes as well as other physical features are barriers to movement for the species. This supports three out of the four models (General, T44, and Mars Hill) which selected Terrain Roughness as a significant variable. It is likely that as the variability in the surrounding terrain (Terrain Roughness) increases, it creates a barrier to movement for the gopher tortoise. Alexy et al. (2003) states that the species usually stays within 30 meters of the burrow while foraging. High variability in the terrain surrounding the burrow location may limit the species in mobility.

It is likely that the forest conditions on the three sites affected the accuracy of the LiDAR DTMs used in this study. A pattern exists between model fit and forest conditions. The model fit is higher on sites with a more open overstory and midstory. The amount of debris on the ground seems to have an effect on model fit, since DTMs were the starting point for every variable used in this study. Sites with higher amounts of debris have lower model fit. Of the site specific models, the T44 model performed better than the East Area and Mars Hill models. It had the highest R^2 (49.31%) and correctly predicted 83.1% of burrows and 83.3% of non-burrow points. The AUC value for this model was .9224 meaning that it has a very high probability of discriminating between burrows and non-burrow points. From the findings of the parent study, T44 had significantly more bare ground coverage and significantly less debris and woody understory. T44 also had the highest percent open sky and a significantly lower TPA than Mars Hill and East Area.[1] These forest conditions allow good penetration of LiDAR pulses to the ground. The Mars Hill Site Specific Model performed the worst of the three site models. It had the lowest R-square (28.09%) and lowest AUC value (.8262) of the three models. It correctly predicted 91.9% of burrows, but only 54.7% of non-burrow points. The Mars Hill study site had a significantly higher midstory stem count and a significantly higher amount of debris on the ground as compared to T-44.[1] With a high amount of midstory coverage and debris, the laser pulses may have not been able to penetrate all the way through to the ground, therefore making somewhat inaccurate DTMs. The East Area Site Specific Model was intermediate to T44 and Mars Hill in all regression model diagnostics except RMSE. The RMSE for the East Area model was slightly higher than the Mars Hill RMSE (0.4035 versus 0.3980). East Area had a similar percent woody understory and TPA as Mars Hill, but both were significantly higher than T44. The average midstory stem count and percent debris on the ground for East Area fell in between the averages of Mars Hill and T44. The performance of these models seems to be highly related to the ability to make accurate DTMs from LiDAR data. It is likely that errors in the DTM on Mars Hill and, to a lesser extent, East Area diminished the ability of those models to discern burrows from non-burrows points. The General Model was able to correctly predict 90.0% of burrows, but only predicted 65.3% of non-burrow correctly. This is likely due to the variability in forest conditions between study sites and the ability of the LiDAR system to develop accurate DTMs.

Slope was only selected as significant in the East Area Site Specific Model. The data show that as slope increases, the probability of burrow occurrence decreases. This model was also the only model that did not select Terrain Roughness as significant. Terrain Roughness was significantly higher on East Area than on Mars Hill and T44. The slope values were significantly different between the three sites with Mars Hill being the highest and T44 being the lowest. The East Area model had the largest RMSE (0.4035). Again, errors in LiDAR accuracy due to forest conditions may have masked some significant relationships.

The categorical variable, Slope Position, did not perform as well as expected. The "Topography Tools" extension for ArcView (Dilts 2010) is highly dependent on the scale used in the topographic position index grid. Due to high statistical noise in the final outputs, a 55 meter circular neighborhood had to be used to define the Slope Position categories. This extension could possibly work better for areas that have greater local variability (e.g. mountainous) than the study sites used in this research.

CHAPTER V

CONCLUSIONS

Overall, Elevation was the most important variable throughout the study. It was selected as significant in all three site specific models as well as the general model. Gopher tortoises seem to favor areas of higher local topography. This is consistent with research previously discussed which observed that burrows were found more on ridge tops. On the study sites, the high topographic areas are frequented by fire which promotes excellent habitat for the gopher tortoise such as abundant herbaceous forage and low densities of woody understory/midstory. The location of burrows also seems to depend on the variability of the local terrain. Terrain Roughness was selected as significant in two of the site specific models and the general model. Gopher tortoises seem to favor relatively smooth terrain. It could be that terrain with high variability creates a barrier to movement for the species. On each of the three study sites, the burrows were grouped together in clusters. The burrow cluster identification method determined that at least 95% of the burrows belonged to a cluster. The burrow clusters were found along ridge tops with relatively smooth terrain.

The variation in management regimes between the three study sites seems to have influenced the robustness of the final models. Sites with a less open overstory and midstory as well as more debris on the ground had lower RMSE, R^2, and AUC values. T44, which is specially managed for gopher tortoise, was the best model overall. T44 has a high frequency of fire creating an open overstory and midstory. T44 also had the lowest amount of debris and woody understory as well as the most amount of bare ground. This probably resulted in more accurate DTMs as opposed to Mars Hill and East Area.

It is recommended for future research that soil types on the three study sites be analyzed. Previous research has concluded that gopher tortoises favor sandy soils for burrowing. The majority of the soils on the three sites are of sandy texture, but specific soil characteristics could affect the specific locations of burrows. It is also recommended that more importance be placed on categorizing different terrain positions for terrain with low variability. The categorical variable, Slope Position, was not useful at the low resolution needed to reduce statistical noise in the data (55 meters). The Topogrphay Tools extension (Dilts 2010) seems to have been developed for highly variable terrain.

The gopher tortoise is a long-lived and relatively immobile species. Since they do not travel far from their already established burrow locations, they may not find conditions that are more ideal than their current location. Obviously, the gopher tortoise must also key on other factors not explored in this study for its survival such as foraging conditions, sunlight, and soil type. Hopefully, the information presented here can be used in conjunction with previous studies that have explored these other factors to have a positive impact on the species population.

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APPENDIX A

SUMMARY STATISTICS: BURROW AND NON-BURROWS POINTS

Table 7 Mean, standard deviation, and 95% CI of mean values for burrows and non-burrow points in the T44 Group 1 subset of data located on Camp Shelby JFTC, MS for variables as listed.

	Variable	n	Mean	Standard Deviation	Mean	
					Lower 95% CI	Upper 95% CI
Burrows	Elevation (m)	66	75.0	2.7	74.3	75.6
	Relative Elevation (m)	66	36.5	2.7	35.8	37.1
	Slope (deg)	66	2.6	1.2	2.3	2.9
	Slope Curvature (index)*	66	0.0	0.8	-0.2	0.2
	Terrain Roughness (index)**	66	3.8	2.4	3.2	4.4
	Flow Accumulation (index)***	66	5.7	15.1	2.0	9.4
Non-Burrows	Elevation (m)	100	48.9	5.5	47.8	50.0
	Relative Elevation (m)	100	18.7	5.5	17.6	19.8
	Slope (deg)	100	4.4	2.9	3.8	4.9
	Slope Curvature (index)*	100	-0.1	1.2	-0.3	0.2
	Terrain Roughness (index)**	100	8.4	6.2	7.2	9.7
	Flow Accumulation (index)***	100	263.2	2545.8	0.0	768.3

* Slope Curvature values on the three study sites ranged from -8 to 12.

** Terrain Roughness values on the three study sites ranged from 0 to 80.0.

*** Flow Accumulation values on the three study sites ranged from 0 to 9339.

Table 8 Frequency of occurrence within each category of Aspect and Slope Position (Dilts 2010) for burrows and non-burrow points within the T44 Group 1 subset of data located on Camp Shelby JFTC, MS.

Variable	Category	Burrow Count	Non-Burrow Count
Aspect	East	3	21
	North	5	11
	Northeast	4	19
	Northwest	11	16
	South	3	6
	Southeast	2	10
	Southwest	22	7
	West	16	10
Slope Position	Flat	42	23
	Midslope	2	12
	Ridges	3	13
	Toeslope	1	18
	Upper Slopes	18	16
	Valley	0	18

Table 9 Mean, standard deviation, and 95% CI of mean values for burrows and non-burrow points in the T44 Group 2 subset of data located on Camp Shelby JFTC, MS for variables as listed.

	Variable	n	Mean	Standard Deviation	Mean Lower 95% CI	Mean Upper 95% CI
Burrows	Elevation (m)	118	74.0	3.2	73.4	74.5
	Relative Elevation (m)	118	35.4	3.2	34.8	36.0
	Slope (deg)	118	2.8	1.6	2.5	3.1
	Slope Curvature (index)*	118	0.0	0.7	-0.1	0.1
	Terrain Roughness (index)**	118	4.3	3.0	3.8	4.9
	Flow Accumulation (index)***	118	6.4	12.9	8.8	4.1
Non-Burrows	Elevation (m)	150	66.3	5.7	65.3	67.2
	Relative Elevation (m)	150	27.7	5.7	26.8	28.6
	Slope (deg)	150	4.5	2.6	4.1	4.9
	Slope Curvature (index)*	150	0.1	0.8	0.0	0.2
	Terrain Roughness (index)**	150	8.9	7.9	7.6	10.1
	Flow Accumulation (index)***	150	97.3	772.9	0.0	222.0

* Slope Curvature values on the three study sites ranged from -8 to 12.

** Terrain Roughness values on the three study sites ranged from 0 to 80.0.

*** Flow Accumulation values on the three study sites ranged from 0 to 9339.

Table 10 Frequency of occurrence within each category of Aspect and Slope Position for burrows and non-burrow points within the T44 Group 2 subset of data located on Camp Shelby JFTC, MS.

Variable	Category	Burrow Count	Non-Burrow Count
Aspect	East	4	22
	North	7	7
	Northeast	8	16
	Northwest	21	18
	South	10	20
	Southeast	2	27
	Southwest	32	16
	West	34	24
Slope Position	Flat	68	24
	Midslope	6	27
	Ridges	6	14
	Toeslope	3	14
	Upper Slopes	35	41
	Valley	0	30

Table 11 Mean, standard deviation, and 95% CI of mean values for burrows and non-burrow points in the Mars Hill Group 1 subset of data located on Camp Shelby JFTC, MS for variables as listed.

	Variable	n	Mean	Standard Deviation	Mean	
					Lower 95% CI	Upper 95% CI
Burrows	Elevation (m)	132	66.0	6.6	64.8	67.1
	Relative Elevation (m)	132	30.3	6.6	29.2	31.5
	Slope (deg)	132	3.9	2.2	3.5	4.3
	Slope Curvature (index)*	132	0.0	0.9	-0.1	0.2
	Terrain Roughness (index)**	132	4.6	3.3	4.0	5.2
	Flow Accumulation (index)***	132	20.6	57.5	10.7	30.5
Non-Burrows	Elevation (m)	100	65.5	5.3	64.4	66.5
	Relative Elevation (m)	100	26.9	5.3	25.9	28.0
	Slope (deg)	100	4.4	2.3	4.8	3.9
	Slope Curvature (index)*	100	0.0	1.2	-0.3	0.2
	Terrain Roughness (index)**	100	8.7	6.0	7.5	9.9
	Flow Accumulation (index)***	100	387.3	1980.7	0.0	780.4

* Slope Curvature values on the three study sites ranged from -8 to 12.

** Terrain Roughness values on the three study sites ranged from 0 to 80.0.

*** Flow Accumulation values on the three study sites ranged from 0 to 9339.

Table 12 Frequency of occurrence within each category of Aspect and Slope Position for burrows and non-burrow points within the Mars Hill Group 1 subset of data located on Camp Shelby JFTC, MS.

Variable	**Category**	**Burrow Count**	**Non-Burrow Count**
Aspect	East	10	12
	North	6	9
	Northeast	16	14
	Northwest	21	8
	South	10	14
	Southeast	30	15
	Southwest	14	11
	West	25	17
Slope Position	Flat	68	19
	Midslope	21	14
	Ridges	3	13
	Toeslope	18	12
	Upper Slopes	18	18
	Valley	4	24

Table 13 Mean, standard deviation, and 95% CI of mean values for burrows and non-burrow points in the Mars Hill Group 2 subset of data located on Camp Shelby JFTC, MS for variables as listed.

	Variable	n	Mean	Standard Deviation	Mean	
					Lower 95% CI	Upper 95% CI
Burrows	Elevation (m)	223	64.8	7.1	63.9	65.7
	Relative Elevation (m)	223	29.2	7.1	28.2	30.1
	Slope (deg)	223	3.8	2.1	3.6	4.1
	Slope Curvature (index)*	223	0.0	1.0	-0.1	0.2
	Terrain Roughness (index)**	223	5.1	4.0	4.6	5.7
	Flow Accumulation (index)***	223	21.0	82.4	10.2	31.9
Non-Burrows	Elevation (m)	150	56.1	9.2	54.6	57.6
	Relative Elevation (m)	150	20.4	9.2	18.9	21.9
	Slope (deg)	150	4.5	2.9	4.0	5.0
	Slope Curvature (index)*	150	0.3	1.4	0.0	0.5
	Terrain Roughness (index)**	150	8.3	7.0	7.2	9.4
	Flow Accumulation (index)***	150	133.9	794.0	5.8	64.8

* Slope Curvature values on the three study sites ranged from -8 to 12.

** Terrain Roughness values on the three study sites ranged from 0 to 80.0.

*** Flow Accumulation values on the three study sites ranged from 0 to 9339.

Table 14 Frequency of occurrence within each category of Aspect and Slope Position for burrows and non-burrow points within the Mars Hill Group 2 subset of data located on Camp Shelby JFTC, MS.

Variable	Category	Burrow Count	Non-Burrow Count
Aspect	East	26	16
	North	14	11
	Northeast	24	14
	Northwest	28	17
	South	26	21
	Southeast	50	17
	Southwest	21	29
	West	34	25
Slope Position	Flat	117	52
	Midslope	33	24
	Ridges	9	18
	Toeslope	26	14
	Upper Slopes	31	25
	Valley	7	17

Table 15 Mean, standard deviation, and 95% CI of mean values for burrows and non-burrow points in the East Area Group 1 subset of data located on Camp Shelby JFTC, MS for variables as listed.

	Variable	**n**	**Mean**	**Standard Deviation**	**Mean**	
					Lower 95% CI	**Upper 95% CI**
Burrows	Elevation (m)	77	52.1	2.9	51.4	52.7
	Relative Elevation (m)	77	21.9	2.9	21.3	22.6
	Slope (deg)	77	3.4	2.2	2.9	3.9
	Slope Curvature (index)*	77	0.0	1.2	-0.3	0.3
	Terrain Roughness (index)**	77	6.1	5.4	4.9	7.4
	Flow Accumulation (index)***	77	6.4	12.3	3.6	9.2
Non-Burrows	Elevation (m)	100	57.6	11.1	55.4	59.8
	Relative Elevation (m)	100	22.0	11.1	19.7	24.2
	Slope (deg)	100	4.8	4.3	3.9	5.6
	Slope Curvature (index)*	100	0.4	2.1	0.0	0.8
	Terrain Roughness (index)**	100	8.3	8.0	6.7	9.9
	Flow Accumulation (index)***	100	407.9	3922.2	0.0	1186.1

* Slope Curvature values on the three study sites ranged from -8 to 12.

** Terrain Roughness values on the three study sites ranged from 0 to 80.0.

*** Flow Accumulation values on the three study sites ranged from 0 to 9339.

Table 16 Frequency of occurrence within each category of Aspect and Slope Position for burrows and non-burrow points within the East Area Group 1 subset of data located on Camp Shelby JFTC, MS.

Variable	**Category**	**Burrow Count**	**Non-Burrow Count**
Aspect	East	7	15
	North	13	8
	Northeast	5	9
	Northwest	12	15
	South	9	16
	Southeast	8	11
	Southwest	12	11
	West	11	15
Slope Position	Flat	31	39
	Midslope	10	16
	Ridges	8	9
	Toeslope	8	10
	Upper Slopes	13	17
	Valley	7	9

Table 17 Mean, standard deviation, and 95% CI of mean values for burrows and non-burrow points in the East Area Group 2 subset of data located on Camp Shelby JFTC, MS for variables as listed.

	Variable	n	Mean	Standard Deviation	Mean Lower 95% CI	Mean Upper 95% CI
Burrows	Elevation (m)	152	52.3	2.6	51.9	52.8
	Relative Elevation (m)	152	22.2	2.6	21.8	22.6
	Slope (deg)	152	3.3	2.3	2.9	3.7
	Slope Curvature (index)*	152	0.1	1.3	-0.1	0.3
	Terrain Roughness (index)**	152	6.3	5.9	5.3	7.2
	Flow Accumulation (index)***	152	9.1	23.3	5.3	12.8
Non-Burrows	Elevation (m)	150	47.7	5.6	46.8	48.6
	Relative Elevation (m)	150	17.5	5.6	16.6	18.4
	Slope (deg)	150	4.6	3.0	4.2	5.1
	Slope Curvature (index)*	150	0.1	1.8	-0.2	0.4
	Terrain Roughness (index)**	150	9.0	7.4	7.8	10.2
	Flow Accumulation (index)***	150	36.8	157.5	11.4	62.2

* Slope Curvature values on the three study sites ranged from -8 to 12.

** Terrain Roughness values on the three study sites ranged from 0 to 80.0.

*** Flow Accumulation values on the three study sites ranged from 0 to 9339.

Table 18 Frequency of occurrence within each category of Aspect and Slope Position for burrows and non-burrow points within the East Area Group 2 subset of data located on Camp Shelby JFTC, MS.

Variable	Category	Burrow Count	Non-Burrow Count
Aspect	East	14	23
	North	19	18
	Northeast	19	24
	Northwest	25	15
	South	17	6
	Southeast	14	30
	Southwest	21	16
	West	23	18
Slope Position	Flat	61	38
	Midslope	12	17
	Ridges	22	23
	Toeslope	20	24
	Upper Slopes	27	26
	Valley	10	22

APPENDIX A

TWO-WAY ANOVA TEST RESULTS

Table 19 Two-way ANOVA results Group 1 vs. Group 2 burrows blocked by study site located on Camp Shelby JFTC, MS.

Variable	**p-value**	
Elevation	0.1311	
Relative Elevation	0.0826	
Slope	0.8446	
Slope Curvature	0.8246	
Terrain Roughness	0.1841	
Flow Accumulation	0.8426	
Aspect	0.8539	Likelihood Ratio
	0.8586	Pearson
Slope Position	0.7959	Likelihood Ratio
	0.8045	Pearson

Table 20 Two-way ANOVA results of Group 2 burrows vs. non-burrow points blocked by study site located on Camp Shelby JFTC, MS.

Variable	**p-value**	
Elevation	<.0001	
Relative Elevation	<.0001	
Slope	<.0001	
Slope Curvature	0.1667	
Terrain Roughness	<.0001	
Flow Accumulation	0.0002	
Aspect	0.1181	Likelihood Ratio
	0.1193	Pearson
Slope Position	<.0001	Likelihood Ratio
	<.0001	Pearson

APPENDIX B

LOGISTIC REGRESSION RESULTS

Table 21 Logistic regression output for Iterations 1 – 3 of the General Model which includes data from all three study sites (T44, Mars Hill, East Area) located on Camp Shelby JFTC, MS.

	Iteration 1		Iteration 2		Iteration 3	
Model χ^2	309.15		371.97		410.30	
p-value	<.0001		<.0001		<.0001	
R2	0.2368		0.2850		0.3143	
RMSE	0.4166		0.4025		0.3952	
Lack of Fit p-value	0.0469		0.3638		0.7004	
Variables (p-value)	Elev	<.0001	Elev	<.0001	Elev	<.0001
	RelElev	<.0001	RelElev	<.0001	RelElev	<.0001
	Slope	0.0745	TerrRough	<.0001	TerrRough	<.0001
	TerrRough	0.0002	SlPos - Flat	0.0482	SlPos - Flat	0.1421
	FlowAcc	0.2306	SlPos - Midslope	0.4584	SlPos - Midslope	0.5607
	SlPos - Flat	0.0298	SlPos - Ridges	0.3384	SlPos - Ridges	0.1871
	SlPos - Midslope	0.6639	SlPos - Toeslope	0.3679	SlPos - Toeslope	0.3323
	SlPos - Ridges	0.2902	SlPos - Upper Slopes	0.9929	SlPos - Upper Slopes	0.7274
	SlPos - Toeslope	0.1581	Elev * RelElev	<.0001	Elev * RelElev	<.0001
	SlPos - Upper Slopes	0.1901	Elev * TerrRough	0.0004	Elev * TerrRough	0.0005
			RelElev * TerrRough	0.0005	RelElev * TerrRough	0.0004
			$Elev^2$	<.0001	$Elev^2$	<.0001
			$RelElev^2$	<.0001	$RelElev^2$	<.0001
			$TerrRough^2$	0.4482	$Elev^3$	<.0001
					$RelElev^3$	<.0001

Table 22 Logistic regression output for Iterations 4 - 5 of the General Model which includes data from all three study sites (T44, Mars Hill, East Area) located on Camp Shelby JFTC, MS.

	Iteration 4		**Iteration 5**	
Model χ^2	455.76		454.61	
p-value	<.0001		<.0001	
R2	0.3492		0.3483	
RMSE	0.3864		0.3865	
Lack of Fit p-value	0.9549		0.9544	
Variables (p-value)	Elev	<.0001	Elev	<.0001
	RelElev	<.0001	RelElev	<.0001
	TerrRough	<.0001	TerrRough	<.0001
	Elev * RelElev	<.0001	Elev * RelElev	<.0001
	Elev * TerrRough	0.0012	Elev * TerrRough	0.0012
	RelElev * TerrRough	0.0014	RelElev * TerrRough	0.0018
	$Elev^2$	<.0001	$Elev^2$	<.0001
	$RelElev^2$	<.0001	$RelElev^2$	<.0001
	$Elev^3$	<.0001	$Elev^3$	<.0001
	$RelElev^3$	0.5841	$Elev^4$	0.0004
	$Elev^4$	<.0001	$Elev^5$	0.2328
	$RelElev^4$	0.6308		

Table 23 Logistic regression output for the T44 Site Specific which includes data from the T44 study site located on Camp Shelby JFTC, MS.

	Iteration 1		**Iteration 2**		**Iteration 3**	
Model χ2	164.55		179.66		181.30	
p-value	<.0001		<.0001		<.0001	
R2	0.4475		0.4886		0.4931	
RMSE	0.3482		0.3390		0.3369	
Lack of Fit p-value	0.9936		0.9997		0.9998	
Variables (p-value)	RelElev	<.0001	RelElev	<.0001	RelElev	<.0001
	Slope	0.6365	TerrRough	0.0623	TerrRough	0.0036
	TerrRough	0.0132	RelElev * TerrRough	0.0466	RelElev * TerrRough	0.0401
	FlowAcc	0.3541	RelElev^2	<.0001	RelElev^2	0.0052
	SlPos - Flat	0.3804	TerrRough^2	0.6040	RelElev^3	0.0503
	SlPos - Midslope	0.4308				
	SlPos - Ridges	0.4167				
	SlPos - Toeslope	0.4229				
	SlPos - Upper Slopes	0.3975				

Table 24 Logistic regression output for the Mars Hill Site Specific which includes data from the Mars Hill study site located on Camp Shelby JFTC, MS.

	Iteration 1		**Iteration 2**		**Iteration 3**	
Model χ2	115.46		141.20		141.19	
p-value	<.0001		<.0001		<.0001	
R2	0.2297		0.2809		0.2809	
RMSE	0.4071		0.3982		0.3980	
Lack of Fit p-value	0.1463		0.5122		0.5121	
Variables (p-value)	RelElev	<.0001	RelElev	<.0001	RelElev	<.0001
	Slope	0.5432	TerrRough	0.0468	TerrRough	0.0112
	TerrRough	0.0082	RelElev * TerrRough	0.0005	RelElev * TerrRough	0.0006
	FlowAcc	0.3723	RelElev^2	0.0002	RelElev^2	0.0008
	SlPos - Flat	0.9590	TerrRough^2	0.8155	RelElev^3	0.8129
	SlPos - Midslope	0.4577				
	SlPos - Ridges	0.2996				
	SlPos - Toeslope	0.1640				
	SlPos - Upper Slopes	0.6103				

Table 25 Logistic regression output for Iterations 1 – 2 of the East Area Site Specific which includes data from the East Area study site located on Camp Shelby JFTC, MS.

	Iteration 1		**Iteration 2**	
Model χ2	95.11		129.44	
p-value	<.0001		<.0001	
R2	0.2272		0.3092	
RMSE	0.4265		0.4065	
Lack of Fit p-value	0.0792		0.4689	
Variables (p-value)	RelElev	<.0001	RelElev	<.0001
	Slope	0.0175	Slope	0.0101
	TerrRough	0.4682	SlPos - Flat	0.7968
	FlowAcc	0.2365	SlPos - Midslope	0.5704
	SlPos - Flat	0.9705	SlPos - Ridges	0.1966
	SlPos - Midslope	0.5838	SlPos - Toeslope	0.4985
	SlPos - Ridges	0.4671	SlPos - Upper Ridges	0.0580
	SlPos - Toeslope	0.5407	RelElev * Slope	0.6136
	SlPos - Upper Slopes	0.0357	RelElev^2	<.0001
			Slope^2	0.3253

Table 26 Logistic regression output for Iterations 3 - 4 of the East Area Site Specific which includes data from the East Area study site located on Camp Shelby JFTC, MS.

	Iteration 3		Iteration 4	
Model χ2	130.89		131.93	
p-value	<.0001		<.0001	
R2	0.3127		0.3151	
RMSE	0.4046		0.4035	
Lack of Fit p-value	0.5917		0.5925	
Variables (p-value)	RelElev	0.0238	RelElev	0.5593
	Slope	0.0002	Slope	0.0001
	$RelElev^2$	0.0002	$RelElev^2$	0.0011
	$RelElev^3$	0.0074	$RelElev^3$	0.0957
			$RelElev^4$	0.3277

APPENDIX C

GRAPHS

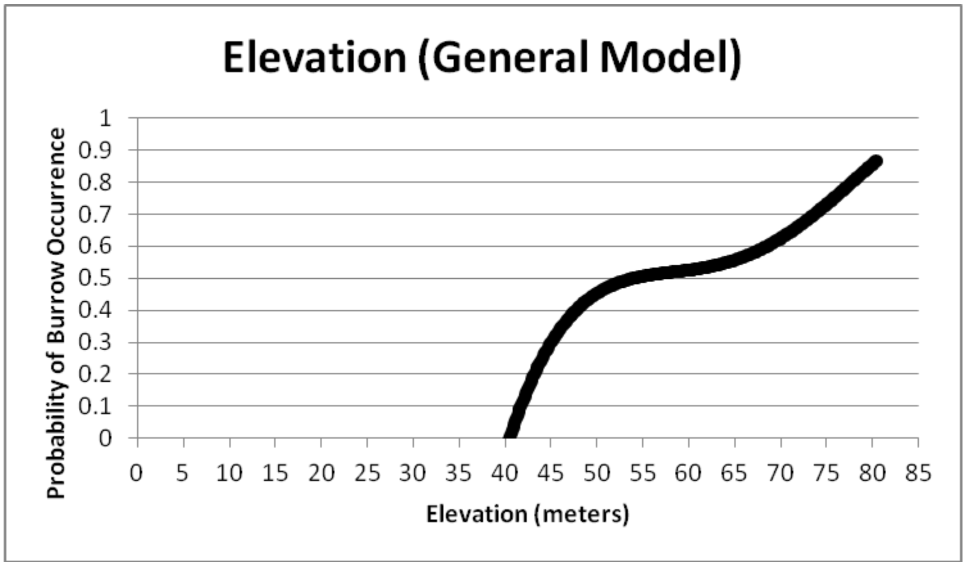

Figure 3 Relationship between elevation and probability of gopher tortoise burrow occurrence as derived in the General Model developed from data collected at Camp Shelby JFTC, MS.

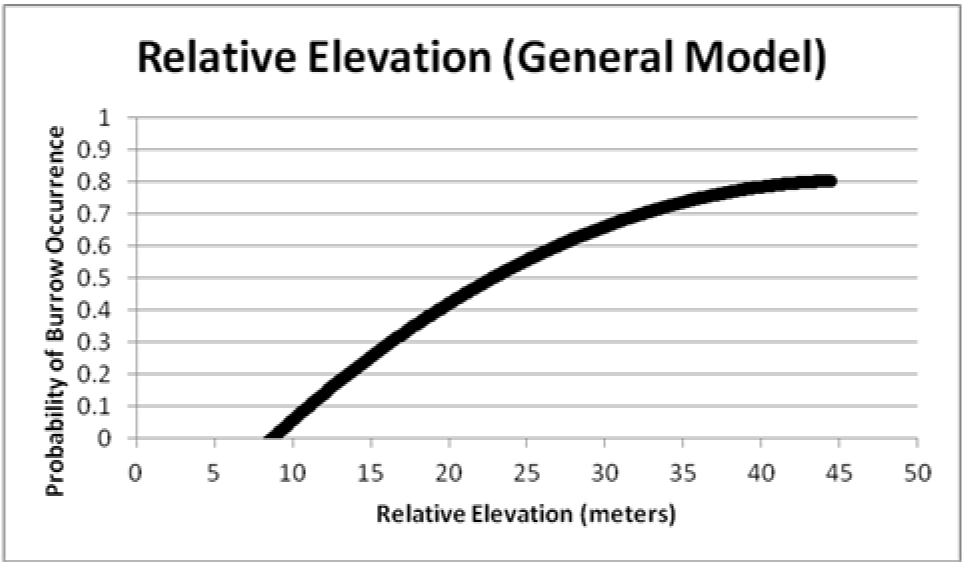

Figure 4 Relationship between relative elevation and probability of gopher tortoise burrow occurrence as derived in the General Model developed from data collected at Camp Shelby JFTC, MS.

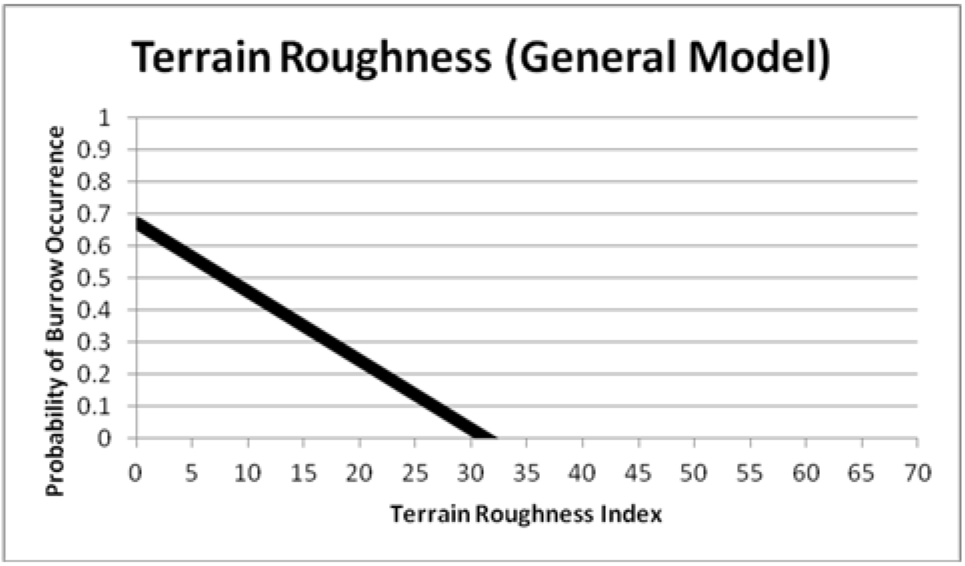

Figure 5 Relationship between terrain roughness and probability of gopher tortoise burrow occurrence as derived in the General Model developed from data collected at Camp Shelby JFTC, MS.

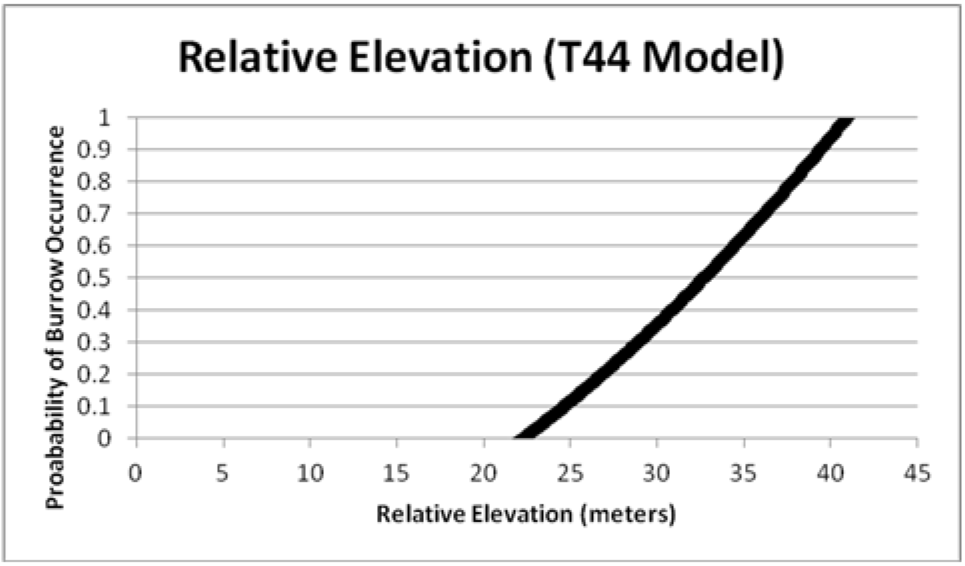

Figure 6 Relationship between relative elevation and probability of gopher tortoise burrow occurrence as derived in the T44 Site Specific Model developed from data collected at Camp Shelby JFTC, MS.

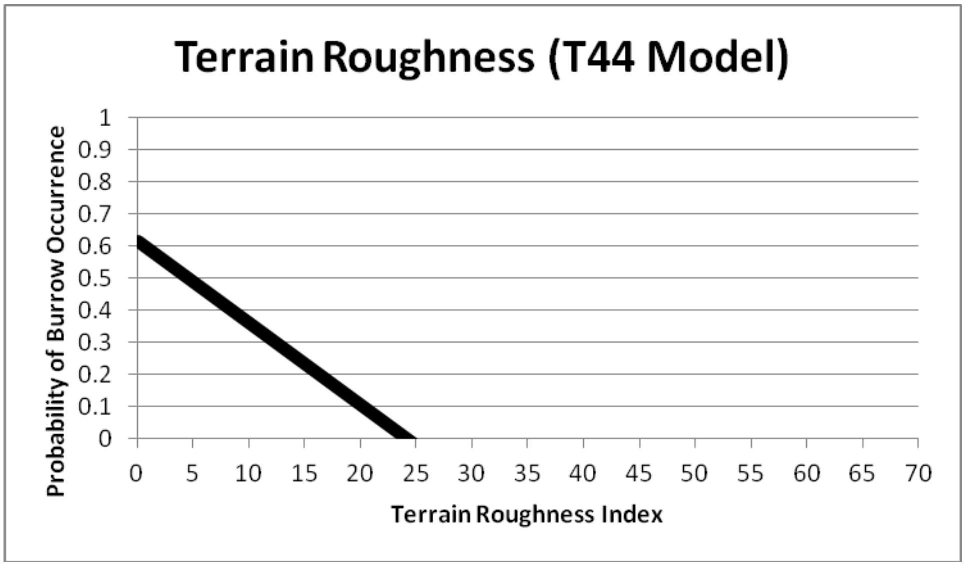

Figure 7 Relationship between terrain roughness and probability of gopher tortoise burrow occurrence as derived in the T44 Site Specific Model developed from data collected at Camp Shelby JFTC, MS.

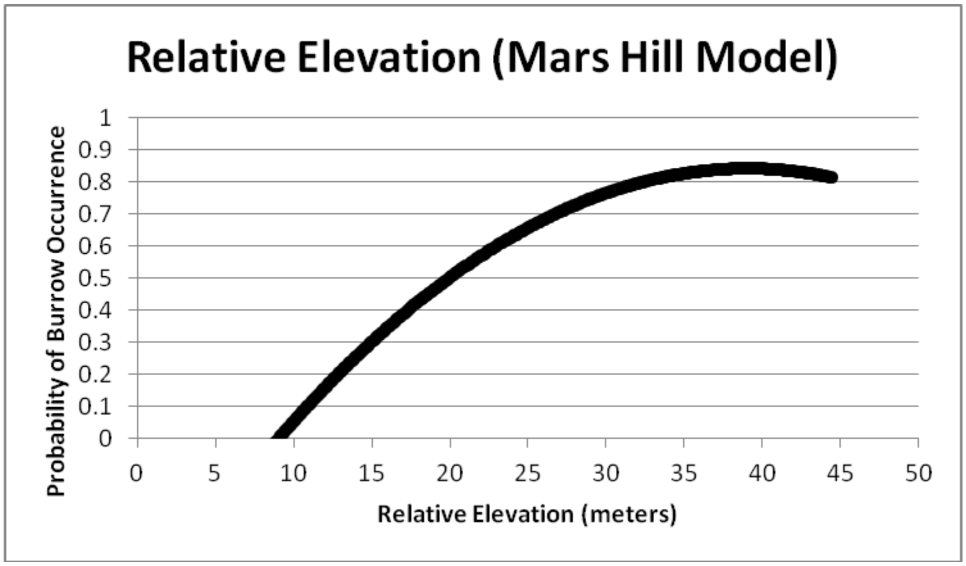

Figure 8 Relationship between relative elevation and probability of gopher tortoise burrow occurrence as derived in the Mars Hill Site Specific Model developed from data collected at Camp Shelby JFTC, MS.

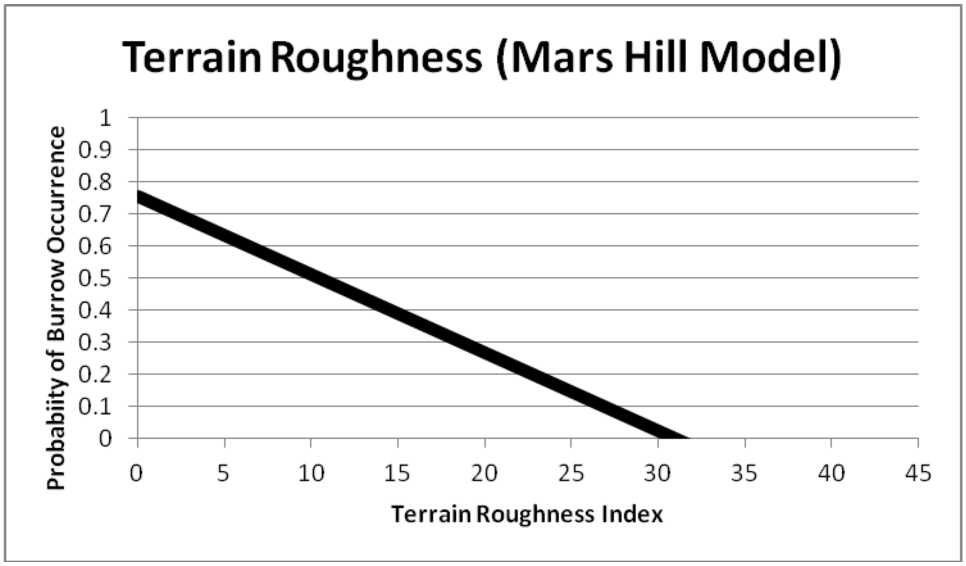

Figure 9 Relationship between terrain roughness and probability of gopher tortoise burrow occurrence as derived in the Mars Hill Site Specific Model developed from data collected at Camp Shelby JFTC, MS.

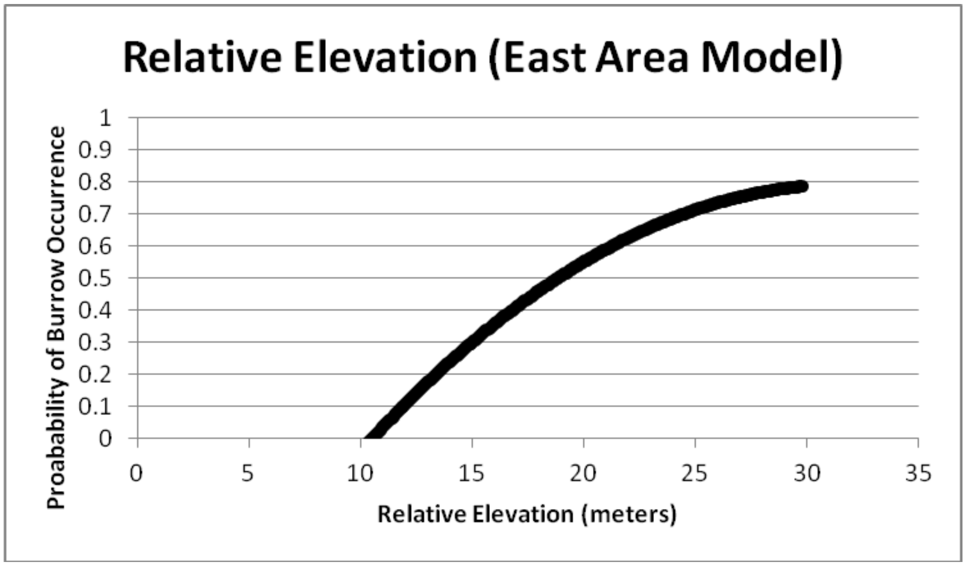

Figure 10 Relationship between relative elevation and probability of gopher tortoise burrow occurrence as derived in the East Area Site Specific Model developed from data collected at Camp Shelby JFTC, MS.

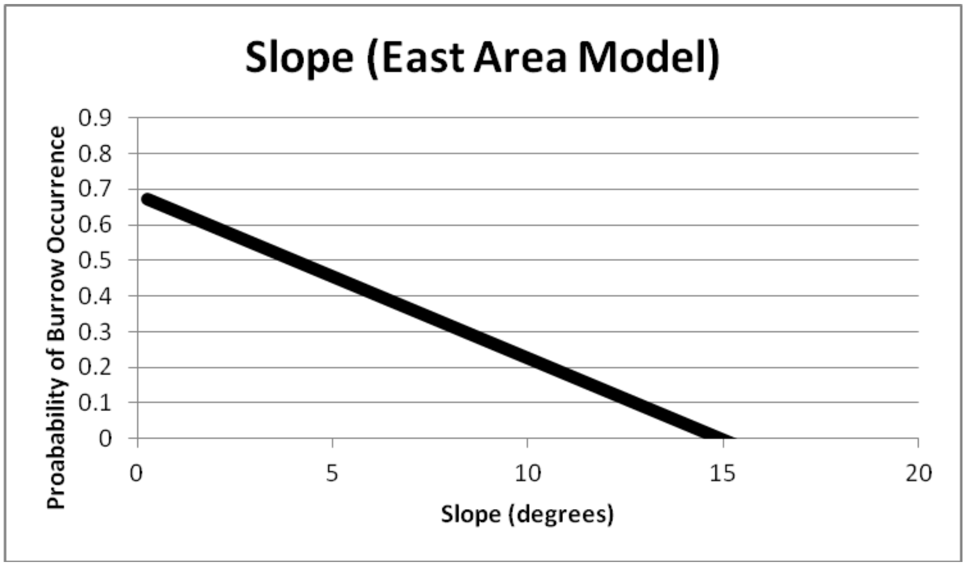

Figure 11 Relationship between slope and probability of gopher tortoise burrow occurrence as derived in the East Area Site Specific Model developed from data collected at Camp Shelby JFTC, MS.