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Developing a survey protocol for landscapes with a low-density of gopher tortoises

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Executive Summary

The gopher tortoise (*Gopherus polyphemus*) has been declining throughout most of its geographic range. It was listed as federally threatened under the Endangered Species Act (ESA) in the western portion of its range in 1987 and is a candidate for listing under the ESA in the eastern portion of its range (USFWS 2011). We developed an occupancy modeling approach to evaluate the distribution of gopher tortoises on Eglin Air Force Base (Eglin), a large military installation with the highest potential gopher tortoise habitat (155,600 ha) of all Department of Defense lands (USFWS 2011). Despite large expanses of suitable habitat and intensive habitat management on Eglin, tortoises appear to occur at low densities. Our results suggest that tortoises are occupying only a small proportion of suitable habitat on Eglin and that occupied areas are patchily distributed across the installation. Management should prioritize habitats near existing gopher tortoise populations and also focus on increasing connectivity among existing population centers.

Introduction

The gopher tortoise (*Gopherus polyphemus*) occurs within the coastal plain of the southeastern United States and primarily inhabits the longleaf pine-dominated sandhill community (Auffenberg and Franz 1982). It also occurs in other habitats, including frequently disturbed habitats (Auffenberg and Franz 1982, Diemer 1986). The gopher tortoise is a keystone species because it excavates burrows that are important in the life histories of many other species (Jackson and Milstrey 1989, Alexy et al. 1997). Gopher tortoise burrows provide shelter, habitat, and other benefits for up to 60 vertebrate and 302 invertebrate commensal species (Jackson and Milstrey 1989), including several imperiled species that are dependent on tortoise burrows for population stability. As frequent fire is restored to the landscape, gopher tortoise burrows may be critical to the survival of many terrestrial organisms. The burrowing activities of gopher tortoises have also been purported to increase plant diversity and environmental heterogeneity (Kaczor and Hartnett 1990). The species has been declining throughout most of its geographic range. It was listed as federally threatened under the Endangered Species Act (ESA) in the western portion of its range in 1987 and is a candidate for listing under the ESA in the eastern portion of its range (USFWS 2011). In Florida, it is currently listed as state threatened (Florida Fish and Wildlife Conservation Commission 2007), and in Georgia is listed as state endangered.

Line transect distance sampling (LTDS) has rapidly become one of the most accepted methods for monitoring gopher tortoise populations (e.g., Smith et al. 2009a, 2009b, Stober and Smith 2010). While the evidence does indicate this is a reliable approach for estimating population size at sites with moderate to high population densities, this approach is unfeasible when tortoise densities are low (Smith et al. 2009a). The success of LTDS has been reported to be contingent upon 60-80 observations of gopher tortoises (Smith et al. 2009b). Smith et al. (2009a) were not able to estimate population size at 7 of the twenty sites surveyed due to low tortoise densities, and they found the LTDS method "prohibitively time consuming" at these low-density sites. Therefore, we investigated the use of occupancy modeling to monitor the tortoise population on Eglin Air Force Base (Eglin), because this population is within this low-density category.

Occupancy modeling does not offer a means to estimate population size, but it does offer a platform to track population trends through changes in occupancy. It can also be used to compare relative occurrence across different habitat types. Furthermore, LTDS requires the number of gopher tortoises to be calculated along the transect (i.e., through use of burrow cameras), whereas occupancy modeling estimates the proportion of an area occupied, so it only requires signs of presence (i.e., tortoise burrows), allowing for more efficient use of resources and greater area coverage. Zylstra et al. (2010) compared the use of LTDS with occupancy estimation and found that occupancy estimation was a more efficient and robust approach, capable of detecting 5% annual population changes, and recommended the approach for desert tortoise (*Gopherus agassizii*) population monitoring.

Despite large expanses of suitable habitat and intensive habitat management on Eglin, gopher tortoises occur at low densities. This is primarily attributed to past human collection and consumption (Taylor 1982; Jackson Guard, pers. comm.) and past fire suppression along with other factors affecting tortoise populations throughout Florida (Florida FWC 2012). Over the last two decades Jackson Guard, Eglin's Natural Resource Division, has conducted or funded (Printiss and Hipes 1999) area-constrained and clearance surveys across portions of the installation. Analyses of this data reveals densities ranging from zero to 3.4 burrows per hectare and an overall burrow density of 0.13 burrows per hectare. The higher density sites tended to be smaller confined sites (less than 15 ha) surrounded by urbanization or otherwise unsuitable habitat. More recently, surveys (2010-2014) conducted by Virginia Tech personnel at five sites previously known to be occupied (Goodman, Gorman, and Haas unpublished data) have shown densities ranging from 0.8 to 3.2 burrows/ha and an overall burrow density of 0.6 burrows/ha. We also surveyed paired sites (n=5) in areas adjacent (similar habitat and size) to the above known sites. These paired sites collectively had a density of only 0.2 burrows/ha.

Burrow densities on Eglin are mostly lower than those reported from other survey efforts in Florida and beyond (Auffenberg and Franz 1982; McCoy and Mushinsky 1995). For purposes of comparison, tortoise burrows can be converted to estimates of actual tortoises by applying a correction factor based on burrow occupancy rates of local populations. These rates can vary based on population, season, or location. Auffenberg and Franz (1982) reported a rate of 0.61, and Mushinsky and McCoy (1994) reported a mean rate of 0.33 (range 0.22 to 0.47 across sites) tortoises per burrow. Using correction factors, Mushinksy and McCoy (1994) reported mean estimated tortoise densities on their large (> 5000 ha) study sites of 1.3 to 4.4 tortoises per ha. In the case of Eglin, regardless of the correction factor applied, estimated tortoise density was low overall.

Due to these low tortoise densities, we tested an occupancy modelling approach, which represents a new approach to monitoring gopher tortoises. We had two main objectives: (1) determine if occupancy modeling is an effective technique for assessing gopher tortoise presence and distribution and (2) to describe the current distribution of gopher tortoises on Eglin in relation to available habitat. Additionally, through our surveys we planned to document potential habitat for, and possibly confirm locations of, the federally threatened Eastern Indigo Snake (*Drymarchon couperi*), the federally petitioned Eastern Diamondback Rattlesnake (*Crotalus adamanteus*), and the State of Florida species of special concern Florida Pine Snake (*Pituophis melanoleucus mugitus*).

Methods

Study site

Eglin Air Force Base (Figure 1) is an active military installation covering 188,459 ha. It contains the highest potential gopher tortoise habitat (155,600 ha) of all Department of Defense lands (USFWS 2011) and represents one of the largest intact and contiguous upland landscapes left in Florida. It is primarily comprised of longleaf-dominated sandhills community interspersed with significant acreages of treeless open test ranges and pine production. In addition, moderate amounts of upland pine and mesic flatwoods habitats are present. Over the last two decades, Eglin has maintained an active habitat management program through prescribed burning, sand pine and oak removal, and longleaf replanting. Eglin currently burns approximately 40,000 ha annually through a combination of winter and growing season burns.

Site selection and sampling design

We used the Florida Cooperative Land Cover Map (FWC and FNAI 2014) and the Ecological Condition Model (ECM) developed by the Air Force Wildland Fire Center at Eglin (Wiens et al. 2009, Hiers et al. 2012) to develop a GIS layer of potential gopher tortoise habitat using ArcGIS 10.2. We divided Eglin into five habitat categories: 1) high-quality sandhills; 2) low-quality sandhills; 3) cleared vegetation including test ranges and powerline right of ways; 4) pine production consisting of row plantations and post-logging natural regeneration; and 5) other uplands including upland pine and xeric hammock. Originally we planned to treat sandhills as a single category, however we were able to use the ECM to develop two separate categories of sandhills. Sandhills habitat is the primary habitat type used by tortoises, and this model allowed us to investigate this habitat type at a finer resolution. The ECM is structured from high quality (Tier 1) to poor quality (Tier 4) (Wiens et al. 2009, Hiers et al. 2012). For our purposes we combined Tiers 1 and 2 and designated them as high-quality and combined Tiers 3 and 4 with a designation of low-quality. Tiers 1 and 2 represents habitats with low to medium canopy cover and herbaceous cover ranging from 25-75% (Williams 2008). Tiers 3 and 4 represent habitats with canopy covers ranging from high to completely closed and herbaceous cover ranging from nonexistent to less than 25% (Williams 2008). In ArcGIS, we intersected our 1 ha sandhills survey plots with the 1 ha habitat pixels of the ECM and used a 50% rule to denote the two categories (i.e., high or low-quality). Cleared vegetation primarily consists of test ranges that vary in management histories and habitat conditions. Habitats can vary from minimal shrub cover and planted non-native grasses to high native shrub and herbaceous cover and diversity. The latter condition may approach a sandhills community without pine trees. Pine production consists of row and naturally-regenerating plantations of longleaf (primarily) and slash pine of various ages and management histories. Upland pine habitat is similar to sandhills, but generally contain more clay in the soil, and in the case of Eglin, are generally underlain by soils with a lesser depth to the water table. We excluded scrubby pine flatwoods, because, although suitable for tortoises, this habitat type was not well mapped and is a very small feature on the landscape (<200 ha). We also excluded mesic and wet pine flatwoods (<6,200 ha), because, although either may provide seasonal foraging and burrow opportunities, neither is considered suitable for year-round tortoise occupancy due to high water tables. Additionally, we excluded other unsuitable areas such as wetlands, urban development and recently cleared areas (e.g., construction sites). The five categories above represented the potential tortoise habitat (155,600 ha) and our first stratification, which we partitioned into one-ha survey blocks ($100m^2$).

The second stratification represents prior tortoise status for each 1 ha habitat block based on past occurrence records and data from previous limited area-constrained surveys. Each potential survey block was assigned to one of 3 categories: 1) within 60 m of an occupied (two or more burrows present) area within past 20 years; 2) not documented, but >60 m and ≤ 1500 m of an area that has been occupied in that past 20 years; and 3) not documented and >1500 m from an area that has been occupied in that past 20 years. The 60 m criterion represents average male home ranges based on Eubanks et al. (2003). The straight-line distance of 1500 m is an estimate of tortoise dispersal/immigration (Eubanks et al. 2003). We randomly selected 1 ha survey blocks in proportion to availability of habitat type (Strata 1) and in proportion to each distance category (Strata 2).

Eglin is a large active base, and thus access can be complicated due to many missions conducted daily. To increase survey efficiency (e.g., survey multiple blocks in the same general area) while still maintaining a randomness to our approach, we used Eglin's Tactical Training Area (TTA) grid (Figure 2) and daily mission updates to guide our survey schedule. Every few days we randomly selected sites from the list of TTAs that contained sample points and typically surveyed 10-20 survey blocks. To ensure equal coverage across all TTAs (all of Eglin) and proportional coverage across habitat types, we randomly worked through the entire list before returning to a particular TTA for additional surveys. For some areas, where access is permanently restricted due to security or safety concerns, we did not survey, but these areas generally were small compared to our overall survey area.

We conducted surveys from late July through early December 2014. For each site, the presence or absence of gopher tortoise burrows was determined. We used a team of two observers and repeat surveys to estimate occupancy and detection probability (MacKenzie et al. 2006). For each 1 ha survey plot, we employed a survey method (Haas et al. 2014) consisting of two observers walking 10 meter wide transects (Figure 3) across the survey block (11 transects/ha), starting in the northwest corner and moving east along north-south lines. A navigator, using a compass and Garmin GPSMap78 (Garmin International, Inc., Olathe, KS) navigated the team, recorded data, and surveyed 1 meter on either side of the navigation line (Figure 3). The primary observer, positioned 5 meters from the center line, was responsible for surveying 4m on either side of his/her position. A separate team of observers then returned to >50% of the survey plots to do repeat surveys to assess detectability of gopher tortoise burrows.

Upon detection of a gopher tortoise burrow, we determined its status using the following criteria:

> *<u>Active</u> - Shows evidence of recent tortoise activity, such as footprints around the entrance or scrape-marks within the burrow caused by the plastron abrading the sand (McCoy and Mushinsky 1995). Soil at the mouth has recently been disturbed by a tortoise (Auffenberg and Franz 1982). Obvious tracks or shell scraping signs at burrow mouth (Smith et al. 2005).*
> *<u>Inactive</u> – Potentially could be used by a tortoise but lacked evidence of recent tortoise activity (McCoy and Mushinsky 1995). Soil is undisturbed but the burrow appears to be maintained (Auffenberg and Franz 1982). No tracks or shell scrapings; burrow occluded by debris, but recent use apparent (Smith et al. 2005).*
> *<u>Abandoned</u> – Could not be used by a tortoise without modification, because they were overgrown or damaged (McCoy and Mushinsky 1995). The mouth has been washed in or*

covered with debris (Auffenberg and Franz 1982). Burrow covered with sticks, weeds, grass; burrow collapsed, dilapidated (Smith et al. 2005).

If the burrow was active or inactive, we ended the survey, and the block was determined to be occupied. We also recorded abandoned burrows, but these were not used as indicators of occupancy. For all active and inactive burrows encountered (inside and outside survey blocks), we measured burrow widths at 50 cm inside the burrow with a caliper (McCoy et al. 2006). Finally, we recorded all snake observations inside each survey block and also documented any sensitive status snake species outside of the survey boundary while walking or driving between sites.

Habitat types were determined on site for each 1 ha block surveyed. This served to ground-truth our original habitat designations generated from ArcGIS. Sometimes blocks were comprised of multiple habitat types, including, on occasion, areas of unsuitable habitat. In those circumstances, the dominant type (i.e., > 50%) became the habitat type used for analyses, and if blocks contained >50% unsuitable habitat type (wetlands, highways, etc.) they were not surveyed or used for analysis.

As a small pilot study to gather information on burrow occupancy rates, we successfully deployed wildlife trail cameras at 9 and 8 burrows during the first and second weeks of October (13 total different burrows) within the boundaries of one of our long-term monitoring plots. Cameras, each deployed for one week, were staked at the edge of the burrow apron and set to take two pictures per motion trigger with a 1 minute delay. After additional camera work is completed, occupancy rates (or correction factors) can be used for tortoise density estimates in future long-term monitoring efforts on Eglin.

Statistical Analyses

We used a single-season occupancy model (MacKenzie et al. 2002) to estimate the occupancy of gopher tortoises (via burrows) across Eglin. We developed a suite of *a priori* models that incorporated habitat type and distance class to better describe occupancy and detection. We hypothesized that distance from previously known sites and habitat type would have an impact on probability of occupancy (psi) and that detection would be influenced by time or habitat type or would be constant between sampling occasions. We used Program Presence 8.3 (Hines 2006) and an information theoretic approach using Akaike's Information Criteria (AIC) to examine the relative strength of each model (Burnham and Anderson 2002). The resulting "best" model was then integrated with GIS. This resulted in a distribution map that highlights areas of the base that have the highest likelihood of being occupied.

Results

We conducted a total of 795 surveys of 507 sites (507 initial surveys and 288 repeat surveys) of which 82 were cleared vegetation, 179 were high-quality sandhill, 106 were low-quality sandhills, and 102 pine production sites (Table 1). A total of 93 were located in the 60 m distance class, 180 were between 60 - 1500 m, and 234 were >1500 m. Overall, we detected gopher tortoise burrows during 91 surveys at 53 sites (25 at cleared vegetation sites, 22 at high-quality sandhills sites, 2 at low-quality sandhills sites, and 4 at pine production sites). We excluded 52 surveys of 38 upland pine sites (19 each in 60 - 1500 m and >1500 m distance categories), because this habitat feature occurred on the landscape infrequently and was not

represented in all three distance classes. Also, no detections were made within this habitat type. Our occupancy modeling was therefore based on 743 surveys of 469 sites.

Our modeling suggested that distance from a previously documented gopher tortoise location and habitat type were both relevant predictors of occupancy (Table 2). Distance was the primary factor that drove this relationship and this covariate was included in the top 5 models. However, the inclusion of habitat did provide additional support for the top two models (Table 2). Cleared vegetation had the highest probability of being occupied at all distance classes (Figure 4). Within the 60 m distance class, cleared vegetation was similar to high-quality sandhills, but probability of occupancy was nearly 2 times > pine production and 3.3 times > low-quality sandhills. Similarly, high-quality sandhills at the 60 m distance class was 2.7 times > than low-quality sandhills, but was more similar to both cleared vegetation and pine production (Figure 4). Lastly, this same trend in habitat type was similar at the other 2 distance classes, however at the greater distance classes probability of a site being occupied declined precipitously across all habitat types. Probability of detection was high (0.95, SE = 0.0235, 95% confidence interval = 0.88-0.98) and was constant between surveys.

Within the survey plots, we observed 25 snakes: 13 black racer, 3 eastern coachwhip, 2 eastern diamondback rattlesnakes, 2 pygmy rattlesnakes, 2 rough green snakes, 2 eastern cottonmouths, and 1 Florida pine snakes. Outside of our survey boundaries, we documented 3 additional eastern diamondback rattlesnakes and 1 additional Florida pine snakes.

Within the 53 sites with detections, we observed 65 active and inactive burrows. Sizes ranged from 65 to 380 mm with mean of 237 mm (SE = 11.2 mm). Burrow occupancy rates determined by preliminary camera work conducted during this study indicate a mean correction factor of 0.65 tortoises per burrow (5/9 for week 1 and 6/8 for week 2).

Discussion

Our approach provides a rigorous assessment of the current distribution of gopher tortoises on Eglin Air Force Base. While relatively few sites were occupied (Table 1), our detection probability was high and did not vary among habitat types. Additionally, it allowed for a relatively efficient way to sample a large landscape. Based on our results the tortoise population on Eglin is best characterized as patchily distributed and low-density with intervening areas having a low-probability of occupancy by tortoises. Overall, cleared vegetation (primarily test ranges) had the highest probability of occupancy. This is not surprising since many of the ranges have been maintained, more or less, in their current condition for decades, resulting, generally, in high herbaceous cover that is associated with tortoise habitat. In the past, tortoises may have been isolated to these areas due to fire suppression of the surrounding sandhills. At present, tortoises appear reluctant (or slow) to leave test ranges, even though habitat quality has improved over the last several decades in the surrounding sandhills.

Few additional unknown tortoise populations of considerable size are likely to exist on Eglin. Therefore, existing known populations distributed widely across Eglin are vital to eventual recovery of tortoises. Encouragingly, many of the known populations that were first documented in the late 1990s are still active and exhibiting at least some signs of recruitment, though evidence is lacking that this indicates a growing and expanding population (Goodman, Gorman, and Haas, unpublished data). Future management of this species should entail increased attention to known population centers and the corridors that connect them.

We found that only 11.3% (naïve estimate) of surveyed sites were occupied by gopher tortoises, with the result (corrected for detection) that some habitat types contribute to greater

levels of occupancy than others. Our results strongly indicate that not all suitable habitat on Eglin is currently being occupied. Additionally, the decrease in the probability of occupancy as distance from existing populations increases suggests that the patchy nature of populations and the distances between patches may be a limiting factor for tortoises to exploit much of the suitable habitat available (Figure 5). As with other wildlife populations, habitat fragmentation has been reported to be a significant limitation on gopher tortoise dispersal (BenDor et al. 2009).

From a regional conservation context, Eglin is part of the eastern population of gopher tortoises that is currently a candidate for listing. However, evidence suggests it occurs within the same Evolutionary Significant Unit (ESU) as the federally listed population west of the Mobile River (Clostio et al. 2012). Three phylogeographic studies have been conducted across the gopher tortoise range, and all three indicate a major phylogenetic break along the Apalachicola River basin, with either side representing distinct genetic lineages (Osentoski and Lamb 1995; Clostio et al. 2012; Ennen et al. 2012), though a few non-concordant haplotypes were present. The estimated time of divergence is over one million year ago (Osentoski and Lamb; Clostio et al. 2012). Therefore, the expansive habitat on Eglin may be critical to the future conservation of this already threatened population. Furthermore, the vast majority of potential tortoise habitat on Air Force lands is on Eglin (USFWS 2011) making this installation central to future recovery efforts and overall mission flexibility. By understanding the relationship of potential habitat and gopher tortoise occupancy we can develop an understanding of the factors that need to be addressed to further conserve this species on complex landscapes such as Eglin and beyond.

Management Implications

Our distribution model allows managers to focus on locations for future population monitoring and to focus on areas that need increased management to facilitate connectivity of existing populations (Figure 5). Further, it provides site-specific information that managers can use to assess impacts of future projects relating to the military mission, possibly minimizing fragmentation that is currently occurring across the Eglin landscape. Because the detection probability was high, and uniform across habitat types, using the two-observer survey method would be suitable to confirm presence/absence for a particular area before road-building or other major disturbances. Additionally, these results provide a baseline from which population trends can be detected in the future. For example, Zylstra et al. (2010) used an occupancy approach to detect changes in population trends through time. If additional surveys are conducted in the future using this occupancy approach, results will be directly comparable to our current results to determine if population changes have occurred.

Additionally, by identifying key areas that are not occupied, but could form a connection between occupied sites, managers could effectively target releases of displaced animals from military project areas or from areas in which tortoises are existing in small islands of habitat surrounded by development or completely fire-suppressed habitat.

Future Needs

Our data highlights the importance of conserving or restoring connectivity among occupied habitat patches. For example, while cleared vegetation (i.e., test ranges) and high-quality sandhills had the highest occupancy rates in areas near known populations, the greater the distance from these core areas, the less likely a site was to be occupied. Developing a strategy to increase occupancy for these suitable habitats is a critical next step. Some combination of

habitat improvements and translocations may be necessary, but more information will be needed to learn how to effectively target resources.

A first priority should be documenting density and recruitment rates of gopher tortoises on test ranges compared to high-quality sandhills to determine whether both can function as source habitats. Ranges are managed and maintained using different methods (mowing, herbicide, or roller-chopping), so it will also be important to determine the effects of different management practices on tortoise density and recruitment. Additional work could include a radio-telemetry study of gopher tortoises at the interface of test ranges and sandhills to document movement within and between these habitat types, and perhaps begin to address emigration/immigration trends.

Tortoises are not only themselves a species of conservation concern, but serve as ecosystem engineers, constructing burrows that are used by a large number of other species, including many sensitive species such as the federally threatened indigo snake (*Drymarchon couperi*), the federally petitioned eastern diamondback rattlesnake (*Crotalus adamanteus*), and Florida species of special concern gopher frog (*Lithobates capito*) and Florida pine snake (*Pituophis melanoleucus mugitus*. Comparing the presence and abundance of these burrow commensals between test ranges and sandhills should be another priority for future research, which could be accomplished by the deployment of wildlife trail cameras.

Gaining a better understanding of the higher use of test ranges and whether tortoises are selecting for these areas is important to moving forward with effective tortoise management on military lands. To avoid conflicts between training and gopher tortoises, managers may need to translocate tortoises off ranges and into other habitats. If tortoises continue to recolonize ranges, however, this could be an ongoing and expensive process. Our results can assist managers in selecting key areas that are not occupied, but may otherwise connect low-density populations that are in areas of suitable habitat (Figures 4 and 5).

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Table 1. Original (n=507) and repeat (n=288) 1-ha survey plots stratified by habitat type and distance to historic tortoise areas. Number of occupied plots during each survey period is presented in parentheses.

	Distance category					
Habitat category	60m		>60m<1500m		>1500m	
	original	repeat	original	repeat	original	repeat
High-quality sandhills	39 (16)	36 (13)	55 (5)	19 (0)	85 (0)	35 (0)
Low-quality sandhills	6 (2)	6 (2)	34 (0)	15 (0)	66 (0)	31 (0)
Cleared vegetation	41 (19)	41 (20)	36 (3)	36 (4)	5 (1)	2 (0)
Pine production	7 (0)	6 (0)	36 (2)	21 (0)	59 (2)	26 (2)
Upland pine*	0 (0)	0 (0)	19 (0)	6 (0)	19 (0)	8 (0)

*not used in occupancy analysis

Table 2. Modeling results including AIC, change in AIC (ΔAIC), model weight (W_i), and the number of parameters (K) for occupancy (psi) and detection (p) of gopher tortoise burrows on Eglin Air Force Base, Florida.

Model	AIC	ΔAIC	W_i	k
psi (habitat + distance), p (.)	276.65	0.00	0.47	7
psi (habitat + distance), p (time)	277.84	1.19	0.26	8
psi (distance), p (.)	278.70	2.05	0.17	4
psi (distance), p (time)	279.85	3.20	0.09	5
psi (distance), p (habitat)	283.97	7.32	0.01	7
psi (habitat), p (.)	329.43	52.78	0.00	5
psi (habitat), p (time)	330.18	53.53	0.00	6
psi (.), p (habitat)	358.31	81.66	0.00	5
psi (.), p (.)	365.58	88.93	0.00	2
psi (.), p (time)	365.76	89.11	0.00	3

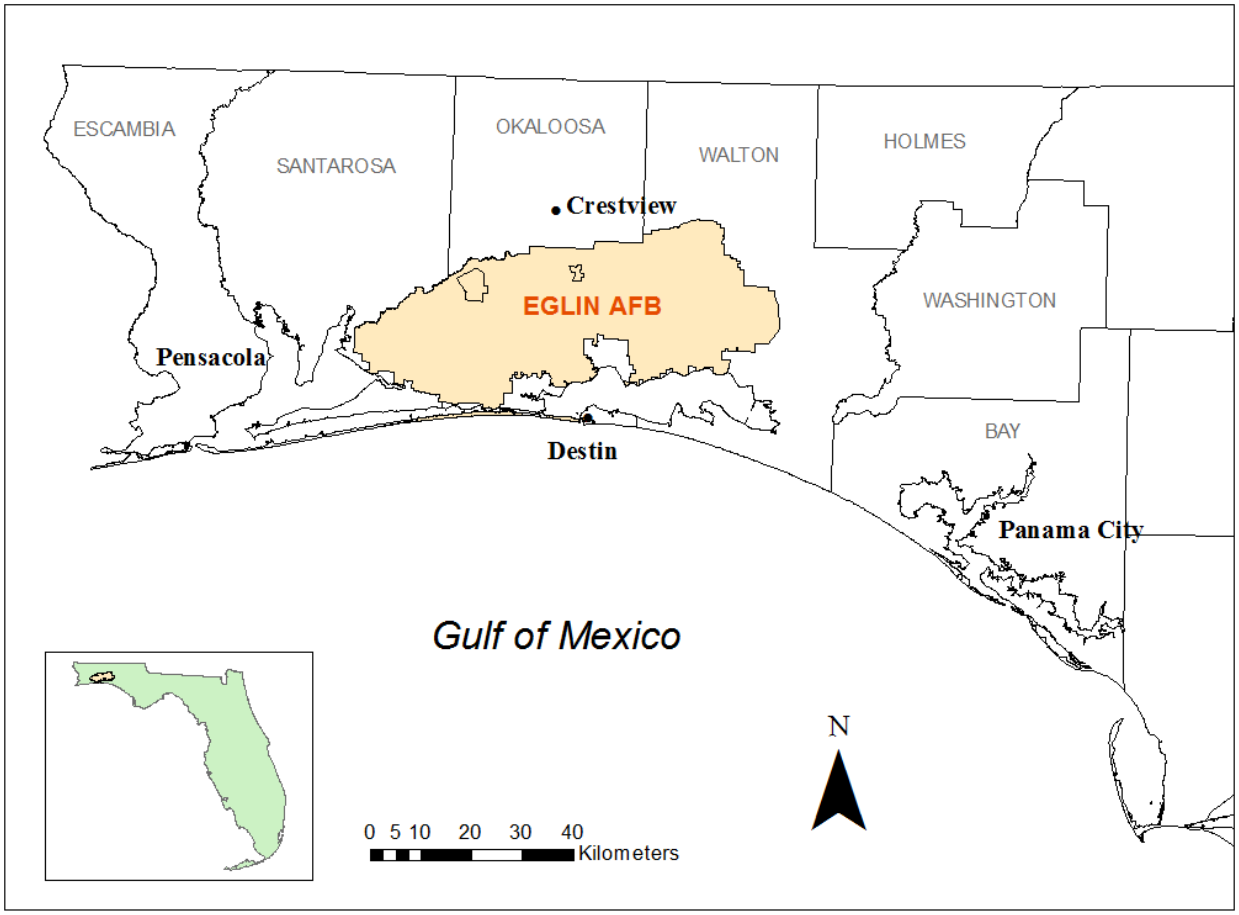

Figure 1. Eglin Air Force Base, Florida is >184,000 ha and spans the counties of Santa Rosa, Okaloosa, and Walton.

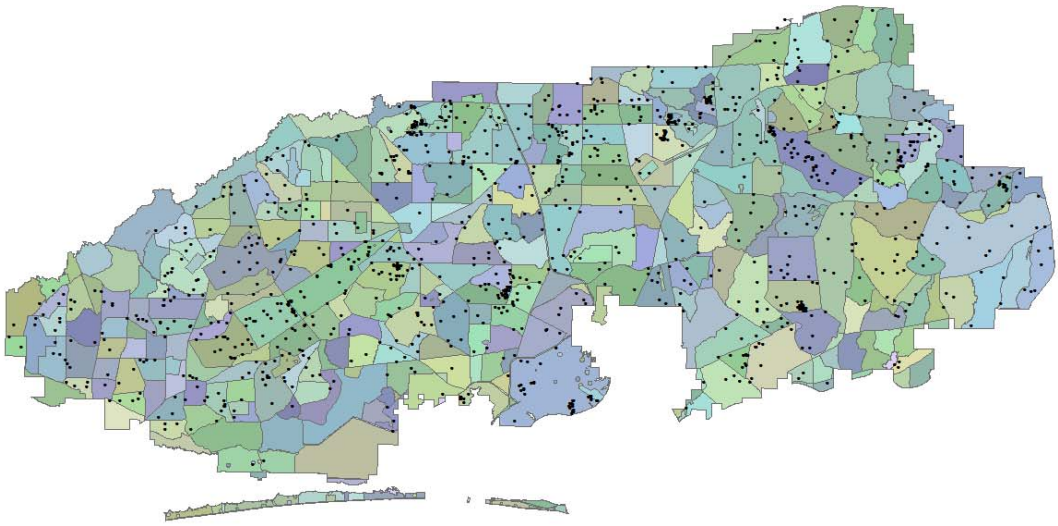

Figure 2. Randomly selected survey areas (black dots) and Tactical Training Areas (shape outlines) used for sampling gopher tortoise on Eglin Air Force Base. Shading of shapes does not convey any meaning but just clarifies boundaries.

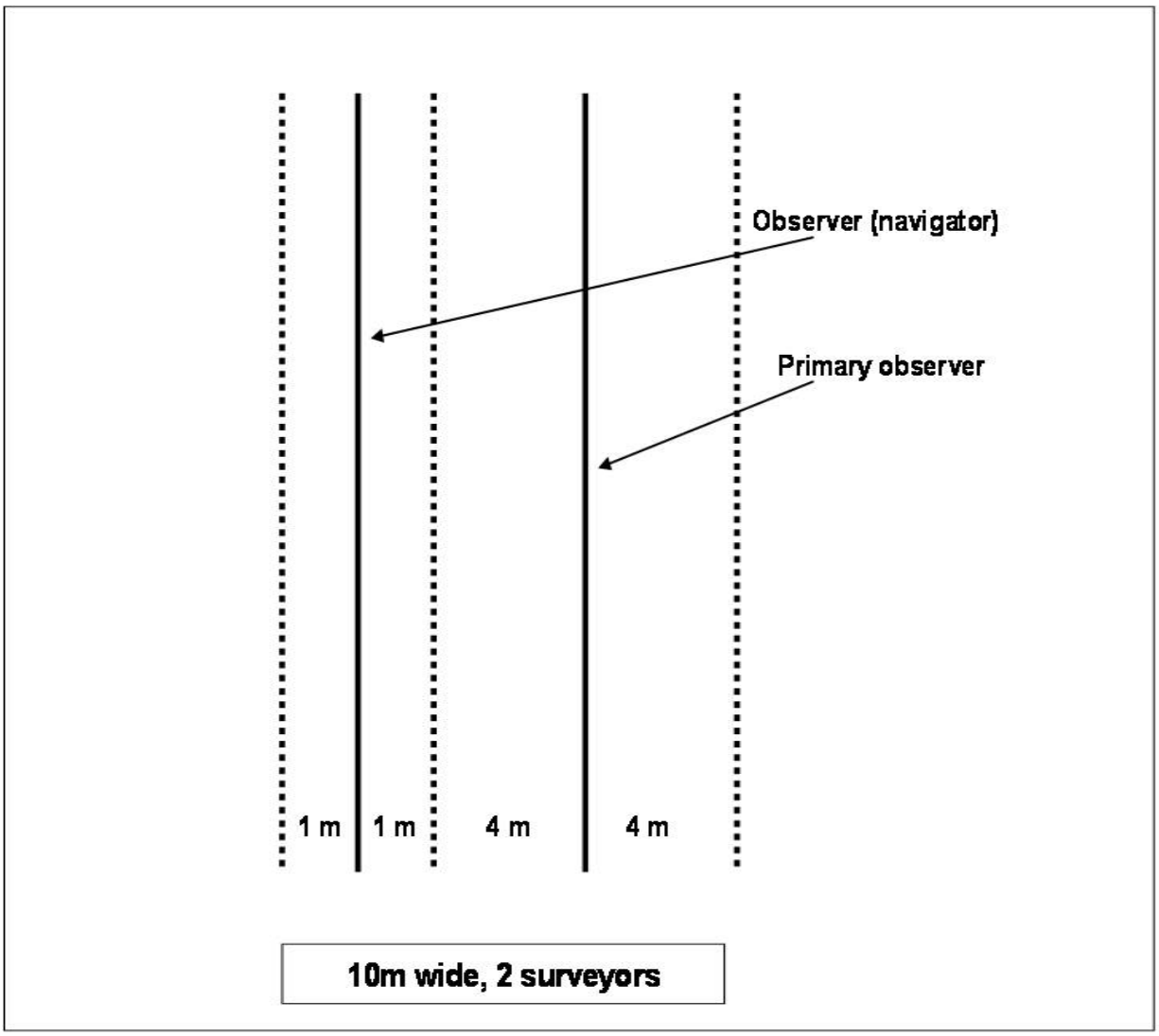

Figure 3. Survey method employed for initial and repeat surveys of gopher tortoise burrows on Eglin Air Force Base, Florida (Modified from FWC 2007).

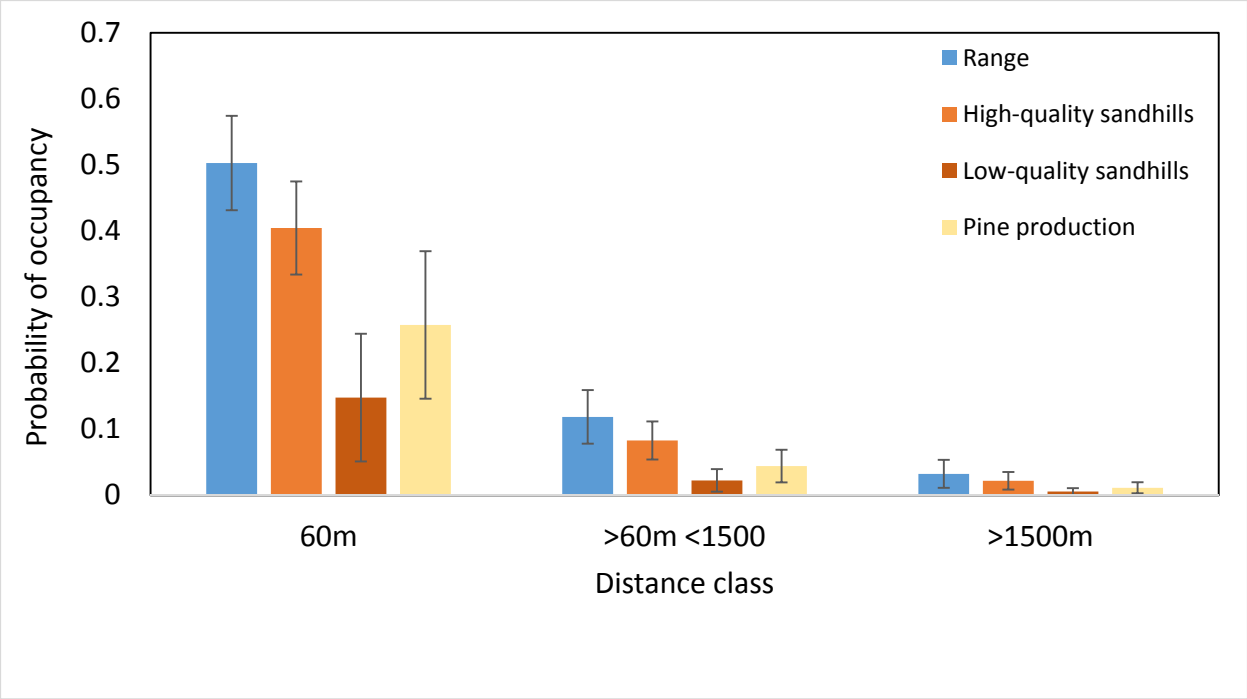

Figure 4. Comparison of gopher tortoise occupancy rates across four habitat types and three distance classes (based on historic gopher tortoise locations) on Eglin Air Force Base.

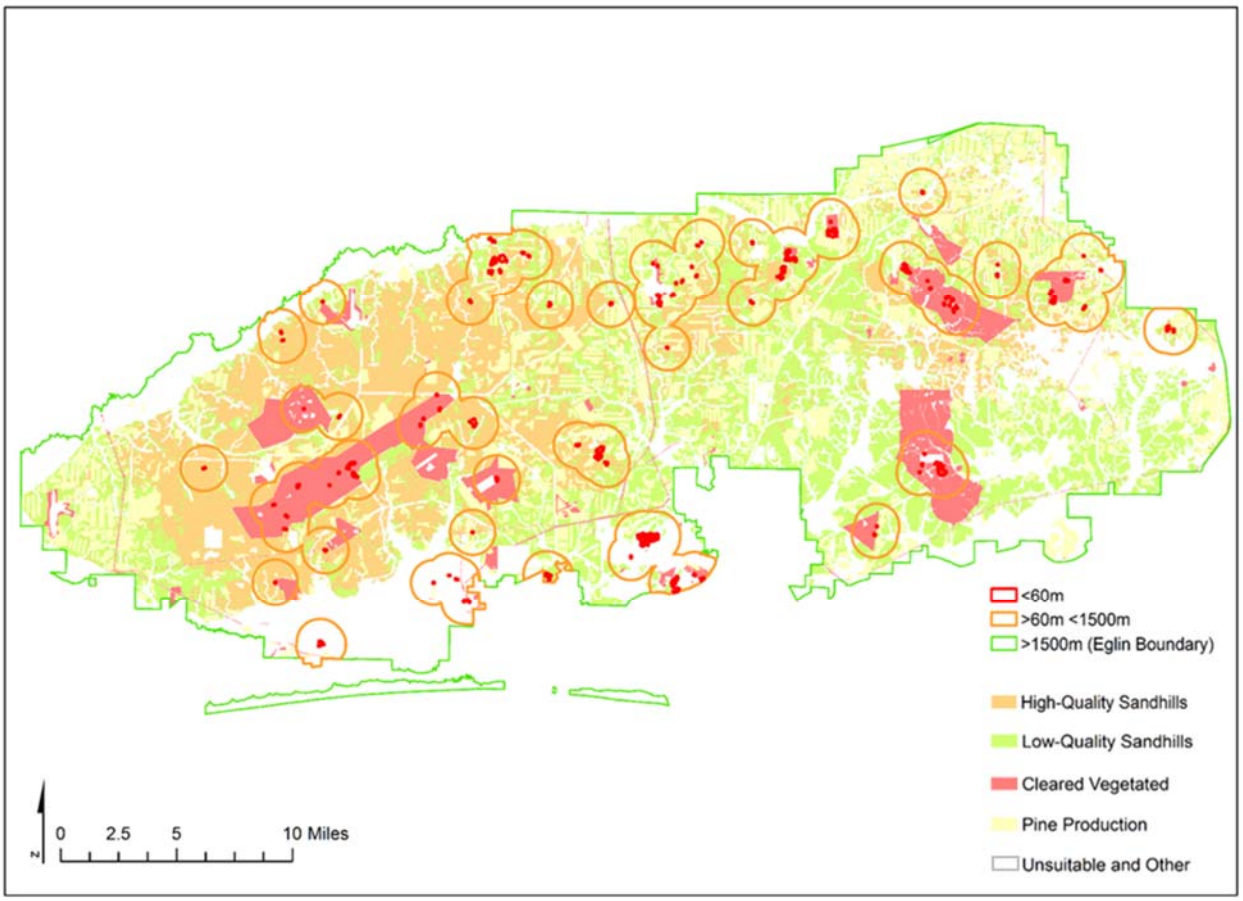

Figure 5. Probability of occupancy distributed across three distance classes (based on historic gopher tortoise locations) and four habitat types on Eglin Air Force Base. Based on the top model, occupancy of cleared vegetation (i.e., test ranges) ranged from 0.03 - 0.50, high-quality sandhills ranged from 0.02 - 0.40, low-quality sandhills ranged from <0.01 - 0.15, and pine production ranged from 0.01 - 0.26, depending on distance class.