Department of Defense

Legacy Resource Management Program

PROJECT 16-818

Gopher Tortoises and Test Ranges: Developing an Understanding for the Wildlife-Habitat Relationships of this Novel Habitat

Steven J. Goodman, William M. Moore, Nicholas M. Caruso, Jennifer A. Smith, Thomas A. Gorman, and Carola A. Haas,
Virginia Tech

Final Report:
Gopher Tortoises and test ranges: Developing an understanding for the wildlife-habitat relationships of this novel habitat

Legacy Project # 16-818
Cooperative agreement #HC0034-16-2-0010

Principal Investigators:
Thomas A. Gorman and Carola A. Haas
Department of Fish & Wildlife Conservation
College of Natural Resources and Environment
Virginia Tech
Blacksburg, VA 24061
540-250-8594 gormant@vt.edu or 540-231-9269 cahaas@vt.edu

Fiscal Officer:
David Price, Post-Award Administrator
E-mail: dprice30@vt.edu
Phone: 540-231-7988
Office of Sponsored Programs (MC 0170)
Virginia Tech
North End Center, Suite 4200
300 Turner Street NW
Blacksburg, VA 24061

9 July 2018

Table of Contents

Gopher Tortoises and test ranges: developing an understanding of the wildlife-habitat relationships for this novel habitat

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). It is vital that assessments of Gopher Tortoise populations are made in order to increase understanding of its ecology so that sound management plans can be developed to avoid future listings. These efforts are also important for the conservation of a wide range of species that rely on tortoise burrows for food, shelter, and habitat (hereafter burrow associates), some of which are known predators of Gopher Tortoise eggs and juveniles. With the most potential Gopher Tortoise habitat (155,600 ha) of all Department of Defense lands, Eglin Air Force Base (Eglin) is a regionally significant landscape for current and future tortoise conservation (USFWS 2011). Yet, the ecology of tortoises and their burrow associates across dominant habitats in this landscape is poorly understood. Here, we report results from Year 1 of a 2-year study conducted on Eglin in which we compared habitat characteristics, tortoise burrow densities, tortoise activity, and the prevalence of their burrow associates between 8 treeless military test ranges and 4 forested sites.

Preliminary results indicated that ecological conditions on some test range sites may have been more favorable to tortoises than those on forested sites because ranges had higher percent cover of grasses and lower cover of shrubs and litter. Tortoises spent most time out of their burrows during spring on range sites and forested sites. They had longer bouts of activity (activity time was measured as the duration of time out of the burrow) during the winter compared to other seasons, and on forested sites than on range sites. The frequency of tortoise activity was also higher on forested sites but was highest during the spring compared to other seasons. Burrow density was higher on test range as compared to forested sites, and test ranges had a considerably higher range of densities, including for smaller burrows. One test range site had the highest burrow density and the highest ratio of young (juvenile and subadult) to adult burrows of any of the 12 sites, with more than double the burrow density and the age ratio of the next closest site, suggesting that test ranges can be highly productive habitat for Gopher Tortoises. Burrow density did not differ significantly with plant species richness or with management activity. On average, tortoise burrows on test ranges supported a lower diversity of burrow associates than those on forested sites. However, the federally-petitioned Gopher Frog (*Lithobates capito*) was significantly more abundant on test ranges, but we cannot rule out that this may be an artifact of pond location. The occurrences and richness of burrow associates that are potential predators of Gopher Tortoise eggs and juveniles were lower on test ranges, suggesting a potential advantage to nesting tortoises at those sites. Finally, we use our preliminary results to suggest potential management actions that may increase recruitment.

For Year 2 of this project, we have expanded the number and distribution of sites to represent better the tortoise population on Eglin. With these additional data, we anticipate increasing our knowledge of tortoise populations on test ranges. Additionally, this effort will provide more comprehensive guidance for future habitat management programs that may increase population growth, while also minimizing impacts to the military mission.

INTRODUCTION

The Gopher Tortoise (*Gopherus polyphemus*) is declining throughout its historic range. It was listed as federally threatened under the Endangered Species Act (ESA) in the western portion of its range in 1987 and as a candidate for listing in the eastern portion of its range in 2011 (USFWS 2011). Gopher Tortoises have experienced declines primarily due to habitat loss and fragmentation, and are increasingly confined to small islands of suitable habitat (Auffenberg and Franz 1982). Therefore, increasing growth of extant populations, particularly those that occur in large landscapes, is key to conservation of this species. For the eastern population, an opportunity exists to ameliorate the need for future ESA listing by implementing management measures per the Candidate Conservation Agreement for the Gopher Tortoise Eastern Population (USFWS 2012). For such management strategies to be effective, they need to be informed by data collected through empirical studies.

Gopher Tortoises primarily inhabit the Longleaf Pine (*Pinus palustris*) sandhill community (Auffenberg and Franz 1982) of the southeastern coastal plain, but also occur in other habitats, including those disturbed by human activity (Auffenberg and Franz 1982, Diemer 1986). Some of the largest remaining tracts of available habitat occur on military installations (USFWS 2011). Many of these installations include large treeless areas (formerly forested sandhills) used for ground training exercises and munitions testing. The largest of these installations is Eglin Air Force Base (Eglin). Eglin is an active military installation covering 188,459 ha in the panhandle of Florida (Figure 1) and contains approximately 155,600 ha of potential Gopher Tortoise habitat, making it a regionally critical landscape for tortoise conservation (USFWS 2011). The habitat primarily consists of Longleaf Pine sandhills, but is interspersed with approximately 15,000 ha of non-forested test ranges, ranging in size from <1 ha to 4000 ha. Most test ranges were deforested decades ago and are used primarily for munitions testing, and to a lesser extent drop zones, artillery ranges, and ground troop maneuvers. The munition-testing ranges include the impact zones as well as safety buffer areas (also non-forested).

Based on prior survey work (Printiss and Hipes 1999, Gorman et al. 2015, FNAI 2016, Haas et al. 2017) and a general consensus of Eglin land managers and researchers, the Gopher Tortoise population on Eglin is considered low density, fragmented, and well below carrying capacity. Tortoises became established on many of these ranges decades ago, most likely as they emigrated from surrounding forests that were fire-suppressed. Prior to full legal protection in Florida in 1988 (FWC 2012), the persistence of tortoises on test ranges may have been greater than on surrounding forested sites because the threat from human collection was minimized due to limited public access to these active military sites, whereas a large portion of the forested habitat is open to the public. Once established, tortoises have remained on test ranges, even after adjacent forested areas have been restored through mechanical and fire management. During a base-wide occupancy survey, Gorman et al. (2015; Legacy Project 14-762) found test ranges more likely to be occupied by tortoises compared to other habitat types within Eglin, including mature sandhills. It is possible this is due to at least some test ranges providing higher quality habitat for tortoises than forested sites, including low canopy cover (which may increase basking sites and nesting success) and high herbaceous cover (which may increase foraging opportunities). Tortoise densities are sometimes higher in disturbed or ruderal areas, even when adjacent forested habitat appears to be high quality (Auffenberg and Franz 1982, L. Smith, Jones Center, pers. comm.). Among test ranges, plant abundance, species diversity, and level of disturbance-prone species appear highly variable, likely due to differences in past and current habitat management practices and intensities. One goal of this study was to better understand the association between habitat and tortoise occupancy on Eglin.

Habitat management on test ranges includes, or has included as recently as the mid to late 1990s, bush hogging (hereafter mowing), prescribed fire, herbicide treatments (i.e., Velpar), and roller drum chopping. The purpose of habitat management depends on the individual range and specific missions and includes maintaining and creating conditions suitable for munitions scoring, line-of-sight, drop zone safety, and fire control. Intensity of management can vary from annual routine maintenance (primarily once-a-year mowing) to 2-3 mowing events per year along with fire or herbicide management to meet mission-specific needs (pers. comm., Don McRaney and USAF Wildland Fire Center). Mechanical treatments and other mission activities can result in tortoise burrow collapse or nest destruction and could result in mortality of eggs, hatchlings, or even adults. Past research by Mendonca et al. (2007) indicated that most adult tortoises are able to dig themselves out after burrow collapse. However, little is known about the effects of machinery and ground disturbance on nests (usually at shallow depths in burrow aprons) or hatchlings and small juveniles (which often occupy very shallow burrows) though Landers et al. (1980) reported three nests crushed by heavy machinery. If management activities occur during the nesting season, especially if disturbance is repeated, these activities might cause complete reproductive failure by destroying nests. One goal of this study was to examine Gopher Tortoise population age structure by assessing the distribution of burrow sizes, to determine whether successful reproduction appears to occur on all sites or whether there are differences according to habitat type or management practices.

The Gopher Tortoise is a keystone species because it excavates burrows that provide shelter, habitat, food, and other benefits for many associated species, including up to 60 vertebrate and 302 invertebrate species (Jackson and Milstrey 1989). Several imperiled species are especially dependent on tortoise burrows for population stability, including the Eastern Diamondback Rattlesnake (*Crotalus adamanteus*), Gopher Frog (*Lithobates capito*), and Indigo Snake (*Drymarchon couperi*). Despite the importance of burrows for a wide range of species, the relationship between habitat and land management on Eglin and the diversity of burrow associates is poorly understood.

For this project, we addressed the following objectives:

(1) Use Gopher Tortoise surveys to determine age-size distributions and activity between and among test range and forested sites.
(2) Use vegetation surveys to compare habitat characteristics between test range and forested sites and within test ranges to determine if vegetation communities, habitat, or management techniques can explain the variation in burrow densities among our sites.
(3) Use wildlife camera deployment at tortoise burrow entrances to compare commensal community composition between test ranges and forested sites and within test ranges among different management techniques.

To begin to address these objectives, in Year 1 of this project, we conducted tortoise burrow surveys at 8 sites on test ranges and 4 sites on forested sandhills on Eglin. We also conducted camera trapping to assess tortoise activity patterns and burrow associate use of burrows at each of the 12 sites across 4 seasons in 2016–2017. Finally, between June and August 2017, we completed vegetation surveys (1-m^2 plots, Daubenmire cover classes, all plants identified to genus or species) at (1) the site-wide scale and (2) the burrow-scale (10 burrows/site). Because of time-constraints and limited access due to mission schedules, we were unable to complete vegetation surveys at all 12 sites. We conducted site-wide vegetation surveys at 3 of 4 forested sites and 6 of the 8 test range sites. We conducted burrow-scale vegetation surveys at 3 of 4 forested sites and all 8 of the test range sites.

In Year 2, we have added an additional 4 test ranges and 2-4 forested sites (some shown in Figure 2). The burrow surveys were completed at these sites in Fall 2017. Camera trapping will begin in Winter 2017 and vegetation survey work and radiotelemetry will begin in late Spring 2018.

METHODS

Study Site Selection. — Using Jackson Guard's (Eglin Natural Resources Branch) Gopher Tortoise burrow observation database, we selected study sites (8 test range and 4 forested; Figure 2) where we expected to observe at least 10 burrows within a 10-ha survey plot. We used current and historical management information obtained from Eglin's long-time Test Range Habitat Manager and fire management and herbicide application records from the United States Air Force Wildland Fire Center and Jackson Guard Forestry Division on Eglin to develop a qualitative habitat management profile for each site. For Year 2, we have selected 4 additional test ranges and 2 forested sites that improved site distribution across the base (Figure 2). Though not randomly selected or assigned to a particular habitat management profile in advance, the 8-12 total test range sites selected over the course of the study are approaching the spectrum of management practices used on test ranges known to be occupied by Gopher Tortoises on Eglin.

Burrow surveys. — Our survey goal for each study site was to observe at least 10 active and/or inactive tortoise burrows. If we did not observe this number in the original 10 ha surveyed, we expanded the survey boundary until we did. We conducted all surveys during Spring-Summer 2016 (Year 1) using a two-observer 10 m transect method with repeat surveys conducted by different observers (Gorman et al. 2015). Upon detection of each burrow, we recorded the location (UTM) using a Garmin GPSMap78 (Garmin International, Inc., Olathe, KS), measured burrow tunnel width at 50 cm depth (McCoy et al. 2006), measured burrow aspect, and assigned burrow status as active, inactive, or abandoned (Gorman et al. 2015).

Tortoise shells are particularly soft at the juvenile stage, which, coupled with small body size, results in high levels of predation (Landers et al. 1982, Wilson 1991). Beginning at the early subadult stage, the shell begins to harden, resulting in higher survival. The adult stage is typically reached at carapace measurements between 220-230 mm (Wilson 1991, Landers et al. 1982, Diemer 1992a, Berish and Leone 2014, Rostal et al. 2014, Tuberville et al. 2014). Adults have few natural predators and experience high survival (Ernst and Lovich 2009). Given the above, we used three size classes, juvenile (<130 mm), subadult (≥ 130 mm < 230 mm), and adult (≥ 230 mm) to characterize burrow densities (i.e., burrow density was calculated for each site, broken down by burrow size class). Widths of Gopher Tortoise burrows are correlated with individual carapace lengths (Alford 1980) and size and age class (Landers et al. 1982). Thus, small burrows are likely indicative of production of younger age classes, while the ratio of juvenile to adult, and sub-adult to adult burrows (i.e., small to large burrows) provides insight into the age structure of the population. To assess age-structure we calculated the density of juvenile, subadult, and adult burrows, and the ratio of juvenile plus subadult to adult burrows.

CAMERA TRAPPING. — We conducted camera trapping at all sites across all seasons and defined seasons as calendar dates of astronomical seasons. Actual trapping dates within each season were as follows: Summer, 1 July to 05 September 2016; Fall, 14 October to 15 December 2016; Winter, 23 December 2016 to 24 February 2017; and Spring, 20 March to 18 June 2017. Cameras were placed 1.5 m from burrow entrances atop 0.6 m stakes and angled to include within the viewing frame, the burrow entrance, most of the apron, and approximately 6–12 cm behind the burrow entrance. To maximize the capabilities of the camera model chosen (Moultrie M-990i Gen 2), and to maximize tortoise and burrow associate detections based on estimated seasonal activity periods, we programmed the cameras to record activity via time lapse during specified time periods (Table 1). When time lapse was inactive, the cameras were programmed so that the motion detection function was active. Once deployed, cameras were checked after approximately 4 trap days (i.e., one trapping period) at which time the cameras were retrieved. Test range (n=8) and forested sites (n=4) were paired for each camera trapping period to minimize intra-seasonal differences. Because we only had 4 forested sites, they were each sampled twice per season so we could pair them with one of the eight test range sites for each trapping period (n=8 trapping periods per season, all forested sites sampled twice, each range site sampled once; Appendix One). During each trapping period, camera traps were set at 10 burrows at each site, except for the winter, when only 5 adult burrows were camera trapped per site. The breakdown of camera deployment (other than winter) by burrow size category (when possible) was the following: ≥230 mm (n=6), 180–210 mm (1), 130–180 mm (1), 100–130 mm (1), 60–90 mm (1) for a total of 10 burrow setups per site. For sites with few small burrows (<230 mm), the breakdown was skewed toward larger size classes (i.e., adult).

We reviewed all photos from the cameras and recorded the times at which tortoises exited from, and returned to, burrows. A unique observation record (or bout) consisted of, at minimum, a burrow exit time and burrow entrance time. We calculated the per bout activity time across all seasons for all tortoises. For fall, winter, and spring we were able to break above-ground activity time into two components: the total time spent basking (hereafter basking time) and the total time spent foraging (hereafter foraging time). For the summer trapping period, only combined above-ground activity time was recorded. We defined basking time as the time spent by the tortoise at least half way out of its burrow, but within the camera viewing frame. Basking time included tortoise emergence during rain events and burrow maintenance. However, the majority of time represented a stationary posture by the tortoise just outside the burrow entrance, presumably for basking purposes. Foraging time was defined as the time spent by the tortoise out of the camera view (i.e., approx. 1 m or more away from the burrow). Basking time and foraging time were used to calculate combined activity time (i.e., time spent at least half way out of the burrow). We also calculated the mean frequency of tortoise activity periods (i.e., number of observed activity periods per burrow per camera deployment) across sites and seasons.

While reviewing photos, we also recorded incidences of burrow associates (i.e., other species that use tortoise burrows). All vertebrate species observed entering the burrow, using any part of the apron, or observed within 6–12 cm behind the burrow were recorded as burrow associates. Of the vertebrate burrow associates observed, several have been reported as natural predators of Gopher Tortoises (Roosevelt 1917, Douglas and Winegarner 1977, Causey and Crude 1978, Landers et al. 1980, Maehr and Brady 1984, Butler and Sowell 1996, Mushinsky et al. 2006, Ernst and Lovich 2009, Aresco et al. 2010, Perez-Heydrich et al. 2012, and Smith et al. 2013), or as potential predators based on reports of predation on other turtle species, including those in the genus *Gopherus* (Nelson 1933, Hamilton 1951, Fordham et al. 2006, Fordham et al. 2008, Mayer and Brisbin 2009, Jolley et al. 2010, Holcomb and Carr 2013, Whytlaw et al. 2013, and Lovich et al. 2014). Gopher Tortoise predators primarily prey on eggs and/or juveniles as adults have few natural predators (Ernst and Lovich 2009). For quality control and future reference, at least one representative photo was typically archived for each species encountered for each burrow during each trapping round.

When we tallied occurrences of each species of burrow associate, we made a conservative estimate within each trapping period. We considered an occurrence to be a unique individual determined either because we could see multiple individuals in a single camera frame (for example, 3 Gopher Frogs in a single camera frame would be counted as three occurrences) or observation of individuals of the same species that were clearly distinct (for example, a juvenile Eastern Coachwhip (*Masticophis flagellum*) and a large adult Eastern Coachwhip exiting and entering the burrow multiple times during a trapping period would count as two occurrences). Across burrows and across trapping periods, we summed occurrences, so it is possible that the same individuals were counted multiple times if they were using multiple burrows and/or were present in multiple seasons. We compared mean number of occurrences and richness of all burrow associates combined, herpetofauna, and potential Gopher Tortoise predators for test ranges and forested sites across seasons. Our measures of occurrence and richness consider all burrow associates detected. Because we were unable to identify individual burrow associates, we acknowledge that our approach is not an accurate estimate of abundance.

VEGETATION SURVEYS. — To assess site-wide (within study site boundaries) vegetation characteristics (Figure 3), surveys were conducted at 3 of our forested sites and 6 range sites (n=9 sites total) by establishing 3 evenly spaced north-south running transects within each site which divided the survey area into equal-width quarters. Along each transect, ten 1-m^2 plots (n=30 per site) were placed randomly within a range of distances from one another that averaged out to roughly the transect length (i.e. for a 600 m transect, plots were placed randomly between 50-70 m from one another). Within each 1-m^2 plot, all plants were identified to the lowest taxonomic level possible (usually to species, though sometimes genus) and standard Daubenmire (1959) classes (1–6) were used to estimate percent cover for each taxon as well as for bare ground, litter, lichen, and moss. Stem counts were taken for all shrubs within a plot. At the sites mentioned above and 2 additional range sites (n = 11 sites total), we assessed vegetation characteristics at the burrow-scale (Figures 4 and 5) for 10 burrows per-site (n=110 burrows total). Using the aforementioned cover-class method, 5 x 1 m^2 plots were randomly placed within a buffer (30 m for adults, 8 m for juveniles) around each burrow based on typical maximum-foraging distances for adult (McRae et al. 1981) and juvenile Gopher Tortoises (McRae et al. 1981, Diemer 1992b, Wilson et al. 1994). To determine if burrow site-selection was influenced by vegetation availability, we established 5 additional random plots within a larger buffer around each burrow that was beyond the typical foraging area, but still accessible to the tortoise inhabiting the burrow. The buffer sizes were as follows: 60–85 m for adults and 16–30 m for juveniles. These buffer sizes were equivalent in size to at least double the foraging radius but within reported daily maximum distances traveled by adult Gopher Tortoises (Eubanks et al. 2003) and juveniles (Pike 2006), respectively.

HABITAT MANAGEMENT PRACTICES. — We compiled information on habitat management, timing and intensity (past and present), on test ranges through conversations with the Eglin Range Maintenance Supervisor (Don McCraney, pers. comm.). He stated that there were no written records of mechanical management history. Fire and chemical management data (2006 to present) were provided by the Air Force Wildland Fire Center and Jackson Guard Forestry Division. We combined this information with mechanical management (i.e., mowing) observed during our field visits during Year 1 of this study (we were on each site multiple dates every quarter, and mowing evidence was apparent for several months). To make the one year of data on mechanical management comparable to ten years of data on fire and chemical management data, we multiplied the number of mechanical management activities by ten. Assuming consistent management practices over the past decade may not be correct, but based on our conversations with range managers it appears to be the best approximation we can obtain.

STATISTICAL ANALYSIS. — Because we only had all four seasons represented for adult tortoises, we limited our activity analyses to adults only. To determine the influence of season and habitat type on adult tortoise activity, we used a generalized linear mixed effect model with a Poisson error distribution to model both length of each activity bout and activity frequency. To account for repeated measurement for a given tortoise and site, we included site identification and burrow identification nested within site as random intercepts in our models. For activity frequency, we added the total number of trap days across all burrows sampled during each survey event as a fixed effect to control for the disproportionate sampling (both number of burrows samples and amount of time per burrow) among sites and seasons. We determined significance using likelihood ratio tests and when final models yielded significant interactions, we made post hoc comparisons using a Tukey's test.

To determine vegetation community composition, we calculated alpha, gamma, and beta (i.e., gamma divided by alpha minus one; Whittaker, 1972) diversity indices using the site-specific mean cover for each species. Additionally, we determined if forested and range communities were significantly different in community composition by first computing a distance matrix using the Jaccard method (Minchin, 1987), and performing an analysis of variance using these distance matrices. For all sites, we determined the relationship between habitat type or species richness and tortoise burrow density, and we determined the relationship between management practices (using an estimate of frequency of management), habitat type, (see table 2) and burrow densities. We modeled both response variables using a generalized linear model with a quasi-Poisson error distribution and determined significance using likelihood ratio tests.

To determine burrows commensal associate community composition, we used the site-specific number of observations for each species to estimate alpha (i.e., average species richness), gamma, and beta diversity indices. Lastly, we determined if forested and range communities were significantly different in community composition by first computing a distance matrix using the Jaccard method (Minchin, 1987), and performing an analysis of variance using these distance matrices. We subsequently visualized these data by using nonmetric multidimensional scaling (NMDS), and represented these data along two axes along with each habitat type.

We used Program R for all statistical analyses (R Core Team, 2017). We used the *lme4* package (Bates et al., 2015) for mixed effects models, *lmtest* package (Zeileis and Hothorn,

2002) for likelihood ratio tests, *multcomp* package (Hothorn et al., 2008) to perform posthoc comparisons, and the *vegan* package (Oksanen et al., 2017) for all community analyses. When we report results, we use the following abbreviations: χ^2 is the chi-square test statistic, P represents p-value or probability value, df represents degrees of freedom, F is F-statistic, SE is standard error. For the F-statistic (the ratio of two sums of squares), degrees of freedom are shown as subscripts after the F, first numerator, which corresponds to the treatment effect and then denominator, which refers to the error.

RESULTS AND DISCUSSION

BURROW SURVEYS. — Plot size ranged from 10.0 to 16.5 ha for test range sites (n = 8) and 9.9 to 13.0 ha for forested sites (n = 4). Total burrow density was generally higher (but more variable) on test range sites compared to forested sites and ranged from 0.84/ha to 1.72 on forested sites and from 0.30 to 4.33 on test range sites (Table 3). The ratio of subadult and juvenile burrows to adult burrows was similar on test range sites (mean = 2.14; SE = 0.88) compared to forested sites (mean = 1.99; SE = 0.55; table 3). The test range site with the highest total burrow density (C61A) also had a ratio of subadult and juvenile burrows to adult burrows of 8.0, more than three times higher the average for either forested or range sites. This high ratio of burrows of tortoises in smaller size classes suggests that either or both survival of smaller tortoises and reproduction may be higher at this site than at other sites. If this site might be serving as a source for tortoise production on Eglin, it is worth examining how management practices on that site might differ from those on sites that appear to be aging, remnant populations with a greater number of older than younger tortoises (e.g., B70).

TORTOISE ACTIVITY. — We found that above-ground activity time was significantly affected by season (χ^2 = 651.520; df = 3; P < 0.001; χ^2 is chi squared test statistic, df is degrees of freedom, and P is the associated probability value for that test statisitic and degrees of freedom) and habitat type (χ^2 = 4.274; df = 1; P = 0.039; Tables 4 and 5). Gopher Tortoises had longer bouts of activity on forested sites compared to test range sites and had the longest bouts of activity during the winter, followed by the fall, spring, and then summer (Table 5; Figure 6). Activity frequency was affected by season (χ^2 = 163.830; df = 3; P < 0.001); activity frequency was highest in the spring, followed by summer, and then fall and winter (Table 5; Figure 7). Activity frequency, however, was not affected by habitat type (χ^2 = 0.144; df = 1; P = 0.705) or total trap days (χ^2 = 2.027; df = 1; P = 0.155). When looking at the total amount of activity time (corrected for the total number of trap days and burrows surveyed at each site and during each season) across seasons, adults in forested habitats had higher activity in the spring (mean = 59.0; SE = 20.4) and summer (mean = 58.0; SE = 9.1), followed by the fall (mean = 26.2; SE = 15.8) and winter (16.7; SE = 1.0). However at range sites, adults were most active during the spring (mean = 79.6; SE = 8.4), followed by summer (mean = 44.7; SE = 8.9), winter (mean = 40.6; SE = 8.2), and then fall (mean = 31.6; SE = 10.5). Therefore, tortoises generally had lower total activity times in forested habitats compared to test range habitats except during the summer.

VEGETATION SURVEYS (DIFFERENCES BETWEEN TEST RANGES AND FORESTED SITES). — We completed vegetation surveys at the site-wide scale (i.e., within boundaries of each roughly study site) for nine (six test range, three forested) of 12 sites, and at the burrow scale (burrow-level and random) for 11 of 12 sites (eight test range, three forested). We found that forested sites had a higher alpha diversity compared to test range sites but lower beta and gamma diversity indices (Table 6). Therefore, forested sites, compared to test range sites typically had a greater plant diversity at an individual site (i.e., alpha diversity), but a lower total (gamma) diversity and diversity was more similar among forested sites compared to among test range sites (i.e., lower beta diversity; Table 6). Moreover, we found that the vegetation communities were significantly different between our two habitat types ($F_{1, 19} = 3.250$; $P = 0.001$; $F_{1, 19}$ refers to the F statistic with a numerator degrees of freedom, or treatment effect, of 1 and a dominator degrees of freedom, or error, of 19) but did not different between burrows and random locations in the burrow-scale surveys ($F_{1, 19} = 0.555$; $P = 0.975$). Generally, forested sites had a greater percent cover of leaf litter and shrubs but a lower percent cover of forbs and grasses compared to test range sites (Figure 8A). However, we did not find a significant relationship between total burrow density with habitat type ($\chi^2 = 0.002$; df = 1; $P = 0.907$) or vegetation richness ($\chi^2 < 0.001$; df = 1; $P = 0.992$; Figure 9). While our initial analyses of vegetation communities did not explain the variation in tortoise burrow densities, we plan to explore these differences in more detail. We will add additional data during 2018, as well as further explore the habitat characteristics (e.g., different species or vegetation groups) between forested and test range sites and if these community characteristics explain the variation in tortoise burrows.

We identified a suite of plant species hypothesized to be indicators of past soil disturbance based on the literature, experience of Eglin land managers, and their abundances in ruderal sites relative to undisturbed forested areas. This list included non-native grasses planted for erosion control, Carpet Grass (*Axonopus fissifolius*) and Bahiagrass (*Paspalum notatum*), as well as common native ruderal species, Poor Joe (*Diodia teres*), Rustweed (*Polypremum procumbens*), and Woody Goldenrod (*Chrysoma pauciflosculosa*) (Hunter 1972, Provencher et al. 2000, Kirkman et al. 2013). We also included Slender Bluestem (*Schizachyrium tenerum*), which is not typically reported as a ruderal grass. However, this species was rare or absent in our forested sites, was a dominant grass on some test ranges, and became dominant after treatment in Sand Pine (*Pinus clausa*) removal sites on Eglin (Provencher et al. 2000). Heavy past mechanical disturbance may have promoted the exposed, nutrient-poor soils on these ranges to which slender bluestem is well-adapted (Leithead et al. 1976, Walsh 1994). We identified disturbance-associated species at both forested and test range sites; however, these species were typically found at a higher percent cover on test range sites compared to forested sites (Figure 8B).

Forage value for disturbance-associated species is unknown (though see exception below) and their presence may be beneficial to tortoises in some cases, but negative in others. For example, at least one ruderal species common in disturbed sites on Eglin, *Diodia teres*, was reported as a high-quality forb that is readily eaten by Gopher Tortoises (Macdonald and Mushinsky 1988). Alternatively, *Chrysoma pauciflosculosa* produces compounds that inhibit germination of nearby plants, including common sandhill grasses (Menelaou et al. 1992), and may limit herbaceous forage availability where it is a dominant shrub. Its abundance on B70E in particular may contribute to the relatively low species diversity and patchy vegetation observed at that site. While adult tortoises are fairly indiscriminant foragers, hatchlings and juveniles may be more selective (Garner and Landers 1981, MacDonald and Mushinsky 1988, Mushinsky et al. 2003). In two diet studies (MacDonald and Mushinsky 1988, Mushinsky et al. 2003) younger tortoises appeared to include a higher proportion of protein-rich forbs and legumes in their diets while avoiding wiregrass (*Aristida* sp.), which was abundant and readily consumed by adults.

Test range management strategies that limit forb and legume availability may therefore be particularly detrimental to smaller size classes. Even if mechanical disturbance does not considerably alter forage quality or availability, heavy machinery can collapse burrows and destroy nests (Landers et al. 1980).

HABITAT MANAGEMENT. — We combined information on management activities gathered from Air Force databases and personnel with mechanical management (i.e., mowing) observed during our field visits during Year 1 of this study (we were on each site multiple dates every quarter, and mowing evidence was apparent for several months), to describe management type and intensity across sites (Table 2). For our available data, we found that the habitat type (forested vs. test range) was a significant predictor of burrow density ($\chi^2 = 0.499$; df = 1; P = 0.005) but neither the estimate of management practices ($\chi^2 = 0.215$; df = 1; P = 0.064) nor the interaction between habitat type and management predicted burrow density ($\chi^2 = 0.100$; df = 1; P = 0.206); test range sites had a greater density of Gopher Tortoise burrows (Figure 10). While not significant, our preliminary data show that managament practices may have opposing effects in forest and test range habitats. At test range habitats, sites with higher intensity management tended to have lower density of burrows whereas the opposite was true of forested sites (Figure 10). Additional forest and test range sites will likely elucidate these relationships. In year 2, we will explore whether mission records can be used to determine how often ranges might have been closed for management activities.

Mowing is conducted on a given test range for two primary reasons: annual maintenance and/or for more time-sensitive, mission-specific needs. Annual mowing typically covers an entire test range, whereas mission-driven mowing is limited to smaller impact or study areas and may lead to a particular area being mowed 2-3 times in a given year. Though levels of mission activity are variable from year to year, it is likely, because of their proximity to actual impact areas, study sites B70C1, B70C2, and C64 are more heavily managed on an annual basis than all other sites studied in Year 1 of our study. This may explain the lower densities of juvenile and subadult burrows recorded for those test ranges. Interestingly site C64, despite apparently high management intensity and no juvenile or subadults, had high plant species richness, graminoid/forb cover, and relatively low cover of disturbance-associated plant species.

Landers et al. (1980) reported that Gopher Tortoises in southwestern Georgia began depositing eggs in May, primarily in burrow aprons at depths from 15–25 cm. Pike and Seigel (2006) reported depths between 3–14 cm in central Florida and Epperson and Heise (2003) reported mean nest depth of 16 cm in southern Mississippi. Landers et al. (1980) reported hatching dates from August-October with 88% of hatchings occurring in September. Data collected from Year 1 of our camera trapping and from data collected from previous survey work, indicates that at least some hatchlings on Eglin begin emerging from their nests during the first few weeks of September. Considering the shallow depth of Gopher Tortoise nests, it is possible mowing during May-September increases the likelihood of nest disturbance and associated mortality of eggs and hatchlings.

Site B70E, while not at present one of the more heavily managed test range areas, has a plant composition that appears to be heavily influenced from past soil disturbance (e.g., from roller drum chopping) as disturbance-related plant coverage was 26% (the highest of all sites by 1.5–2X). *Schizachyrium tenerum* and *Chrysoma pauciflosculosa* were two of the most dominant species at this site. This may at least partially explain the very low density of juvenile and subadult burrows, despite the highest density of adult burrows of all 12 sites (test range and forest) surveyed in Year 1. This habitat condition may be persisting because of minimal fire return over the last decade that would otherwise promote greater diversity in plant composition.

The two other test range sites with the lowest density of juvenile and subadult burrows, B70C1 and B70C2 (Table 3) had below average plant species diversity and above average total disturbance species coverage. These two sites were some of the most heavily managed sites (Table 2), likely due to their close proximity to mission-related impact areas. These sites received frequent fire and mowing and were the only sites treated with herbicide.

Roller drum chopping, heavily used in the past, appears to have been mostly discontinued as routine maintenance on test ranges starting in the 1990s due to environmental and erosion concerns (USAF 2008, USAF 2015, Don McCraney, pers. comm.), but is being reconsidered (Don McCraney, pers. comm.), particularly for areas with higher shrub cover. If roller drum chopping negatively affects Gopher Tortoise populations, then we expect burrow densities to decrease in areas where this management practice is used.

Burrow Associates. — For all seasons combined, we had 1,197 camera trap days for test ranges and 1,054 trap days for forested sites. The number of photos taken and analyzed for test ranges were 4,824,735 and for forested sites, 4,282,892. We observed 451 occurrences of 31 species of burrow associates on test ranges (n = 8 sites) and 475 occurrences of 48 species on forested sites (n = 4 sites) (Tables 7 and 8). We also observed 66 individuals of 7 species of known or likely Gopher Tortoise predators on test ranges (n = 8) and 111 individuals of 12 species on forested sites (n = 4; Table 7). Forested sites had higher values for all three diversity indices (except predator beta diversity) compared to test range sites, which indicates that forest sites had a greater total diversity, site-level diversity, and a greater variation in diversity among sites compared to test range sites (Table 8). Furthermore, commensal communities were significantly different between forested and test range sites ($F_{1, 64} = 3.371$; $P = 0.001$). Species found on test range sites were typically also found in forested sites whereas forested sites contained many unique species that were not found to be associated with burrows on test ranges (Figure 11). While occurrences and richness were, on average, generally lower on test ranges, the federally-petitioned Gopher Frog was more abundant on test ranges (Table 9). We expect this is because test range sites were closer to known Gopher Frog breeding ponds than the forested sites were.

Burrowing Owl (*Athene cunicularia)* are not native to Eglin AFB and were only established on one test range (B70) studied in Year 1, so they were not included in any of the analyses.

MANAGEMENT IMPLICATIONS

Our first year results indicate variation in burrow density and in the ratio of juvenile and subadult burrows to adult burrows among test ranges and forested sites and between individual test ranges especially with management practices. Upon completion of Year 2 of this project, if better information on range management practices can be obtained, we intend to provide habitat management recommendations that will improve habitat conditions and survival of tortoises, while also minimizing impacts to the military mission. In the interim, a few measures could be enacted that likely would benefit tortoise populations:

1) When feasible, avoid mowing over burrow aprons, and schedule test range mowing events outside of the Gopher Tortoise nesting season between May–September.
2) Consider increasing fire frequency to promote plant diversity and desired species composition on test ranges that have high coverage of disturbance-related species (e.g., B70E).
3) Consider forest management, such as hardwood thinning or increasing fire frequency and intensity, on forested sites to promote more open canopies and more dense and diverse herbaceous vegetation.

ACKNOWLEDGEMENTS

We thank the Department of Defense, Legacy Resource Management Program, Natural Resources Branch of Eglin Air Force Base (Jackson Guard), and the Department of Fish and Wildlife Conservation at Virginia Tech for financial and logistical support. We thank Jeremy Preston, Justin Johnson, Kathy Gault, and Bruce Hagedorn of Jackson Guard and Kelly Jones, Vivian Porter, and Brandon Rincon of Virginia Tech for their support, input, and encouragement on this project. We thank Brett Williams, Nathan Price, and Thomas Harrison of the USAF Wildland Fire Center for planning and logistical support. We especially thank Don McCraney, Eglin Test Range Manager, for planning and logistical support, and also for sharing his time educating us on the goals, logistics, constraints, and challenges of test range maintenance. We are indebted to Robert Bilbow, Kerndja Bien-Aime, Amanda Briant, Emma Browning, Cody Ewers, Jenna Nierman, Sara Piccolomini, and Dylan Smith for their outstanding fieldwork and enthusiasm.

LITERATURE CITED

Alford, R. A. 1980. Population structure of *Gopherus polyphemus* in northern Florida. Journal of Herpetology, 14:177–182.

Aresco, M. J., R. N. Walker, and M. Greene. 2010. Site fidelity, movements, survival, and minimum area required of gopher tortoises (*Gopherus polyphemus*) translocated from development sites to managed conservation lands. Status Report of the Florida Fish and Wildlife Conservation Commission, Permit WX06116b, Tallahassee, FL. 68pp.

Auffenberg, W., and R. Franz. 1982. The status and distribution of the Gopher Tortoise (*Gopherus polyphemus*). Pages 95–126. In: North American Tortoises: Conservation and Ecology, R.B.Bury, editor. U.S. Fish and Wildlife Service, Wildlife Research Report 12. Washington, D.C., 204pp.

Bates, D., M. Maechler, B. Bolker, and S. Walker. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67:1–48.

Berish (Diemer), J. E., and E. H. Leone. 2014. Follow-up demographic survey of a Florida Gopher Tortoise population. Southeastern Naturalist, 13(4): 639–648.

Butler, J. A., and S. Sowell. 1996. Survivorship and predation of hatchling and yearling gopher Tortoises, *Gopherus polyphemus*. Journal of Herpetology 30:455–458.

Causey, M. K., and C. A. Cude. 1978. Feral dog predation of the gopher tortoise, *Gopherus polyphemus* (Reptilia, Testudines, Testudinidae) in southeast Alabama. Herpetological Review 9:94-95.

Daubenmire, R.F. 1959. Canopy-coverage method of vegetation analysis. Northwest Science 33:43–64.

Diemer, J. E. 1986. The ecology and management of the Gopher Tortoise in the southeastern United States. Herpetologica 42:125–133.

Diemer, J. E. 1992a. Demography of the tortoise *Gopherus polyphemus* in northern Florida. Journal of Herpetology: 281–289.

Diemer, J. E. 1992b. Home range and movements of the tortoise *Gopherus polyphemus* in Northern Florida. Journal of Herpetology 26:158–165.

Douglas, J. F., and C. E. Winegarner. 1977. Predators of eggs and young of the gopher tortoise, *Gopherus polyphemus* (Reptilia, Testudines, Testudinidae), in southern Florida. Journal of Herpetology 11:236–238.

Epperson, D. M., and C. D. Heise. 2003. Nesting and hatchling ecology of gopher tortoises (*Gopherus polyphemus*) in southern Mississippi. Herpetologica 37:315–324.

Ernst, C. H., and J. E. Lovich. 2009. Turtles of the United States and Canada, second edition. Johns Hopkins University Press, Baltimore, Maryland, USA. 827 pp.

Eubanks, J. O., W. K. Michener, and C. Guyer. 2003. Patterns of movement and burrow use in a population of Gopher Tortoises (*Gopherus polyphemus*). Herpetologica 59:311–321.

Florida Fish and Wildlife Conservation Commission (FWC). 2012. Gopher Tortoise management plan (*Gopherus polyphemus*), 243 pp.

Florida Natural Areas Inventory (FNAI). Contributors: Dan Hipes and Amy Jenkins. 2016. Gopher Tortoise survey within selected sites at Eglin Air Force Base, FL. Florida Natural Areas Inventory, Tallahassee FL, 23 pp.

Fordham, D., A. Georges, B. Corey, and B. W. Brook. 2006. Feral pig predation threatens the indigenous harvest and local persistence of snake-necked turtles in northern Australia. Biological Conservation 133:379–388.

Fordham, D. A., A. Georges, and B. W. Brook. 2008. Indigenous harvest, exotic pig predation and local persistence of a long-lived vertebrate: Managing a tropical freshwater turtle for sustainability and conservation. Journal of Applied Ecology 45:52–62.

Garner, J., and J. Landers. 1981. Foods and habitat of the gopher tortoise in southwestern Georgia. Proceedings in the annual conference of southeastern association of fish and wildlife agencies. 35:120-134.

Gorman, T. A., S. J. Goodman, and C. A. Haas. 2015. Developing a survey protocol for landscapes with a low-density of Gopher Tortoises. Legacy Resource Management Program, Department of Defense. Project 14–762.

Haas, C. A., S. J. Goodman, K. C. Jones, G. C. Brooks, J. A. Smith, V. H. Porter, and B. K. Rincon. 2017. Endangered species management on Eglin Air Force Base and Hulbert Field, Florida: 2016 annual report on amphibian and reptile objectives. Department of Fish and Wildlife Conservation, Virginia Tech, Blacksburg, VA. 22 pp.

Hamilton, W. J. 1951. The food of the Opossum in New York State. Journal of Wildlife Management 15: 258-264.

Holcomb, S. R., and J. L. Carr. 2013. Mammalian depredation of artificial Alligator Snapping Turtle (*Macrochelys temminckii*) nests in north Louisiana. Southeastern Naturalist 12:478–491.

Hothorn, T., F. Bretz, and P. Westfall. 2008. Simultaneous inference in general parametric models. Biometric Journal 50:346–363.

Hunter, J. H. 1972. Vegetative succession studies on a defoliant equipment test area, Eglin AFB Reservation, Florida. Air Force Armament Laboratory. Technical Report AFATL-TR-72-31. Eglin Air Force Base, Florida.

Jackson, D. R. and E. G. Milstrey. 1989. The fauna of Gopher Tortoise burrows. Pages 86–98 in Gopher Tortoise relocation symposium proceedings (Diemer, J.E., D.R. Jackson, J.L. Landers, J.N. Layne and D.A. Wood, eds.). Florida Game and Fresh Water Fish Commission Nongame Wildlife Program Technical Report No. 5, Tallahassee, FL.

Jolley, D. B., S. S. Ditchkoff, B. D. Sparklin, L. B. Hanson, M. S. Mitchell, and J. B. Grand. 2010. Estimate of herpetofauna depredation by a population of wild pigs. Journal of Mammalogy 91:519–524.

Kirkman, L. K., A. Barnett, B. W. Williams, J. K. Hiers, M. Pokswinski, and R. J. Mitchell. 2013. A dynamic reference model: a framework for assessing biodiversity restoration goals in a fire-dependent ecosystem. Ecological Applications 23: 1574-1587.

Landers, J. L., J. A. Garner, and W. A. McRae. 1980. Reproduction of Gopher Tortoises (*Gopherus polyphemus*) in southwestern Georgia. Herpetologica 36:353–361.

Landers, J. L., W. A. McRae, and J. A. Garner. 1982. Growth and maturity of the Gopher Tortoise in southwestern Georgia. Bulletin of the Florida State Museum, Biological Sciences 27 (2): 81-110.

Leithead, H. L., L. L. Yarlett, and T. N. Shiflett. 1976. 100 native forage grasses in 11 southern states. USDA SCS Agriculture Handbook No. 389. Washington, DC.

Lovich, J., D. Delaney, and J. Briggs. 2014. Black Bears (*Ursus americanus*) as a novel potential predator of Agassiz's Desert Tortoises (*Gopherus agassizii*) at a California wind energy facility. Bulletin of the Southern California Academy of Sciences 113:34–41.

MacDonald, L. A., and H. R. Mushinsky. 1988. Foraging ecology of the gopher tortoise, *Gopherus polyphemus*, in a sandhill habitat. Herpetologica 44:345–353.

Maehr, D. S., and J. R. Brady. 1984. Food habits of Florida Black Bears. Journal of Wildlife Management 48:230-235

Mayer, J. J., and I. L. Brisbin. 2009. Wild pigs: Biology, damage, control techniques and management.

McCoy, E. D., H. R. Mushinsky, and J. Lindzey. 2006. Declines of the Gopher Tortoise on protected lands. Biological Conservation 128:120–127.

McRae, W. A., J. L. Landers, and J. A. Garner. 1981. Movement patterns and home range of the Gopher Tortoise. The American Midland Naturalist 106:165–179.

Mendonca, M., R. Beauman, and H. Balbach. 2007. Burrow collapse as a potential stressor on the Gopher Tortoise (*Gopherus polyphemus*). No. ERDC/CERL-TR-07-33. Construction Engineering Research Laboratory, Engineer Research and Development Center, Champaign, IL.

Menelaou, M. A., M. Foroozesh, G. B. Williamson, F. R. Fronczek, H. D. Fischer, and N. H. Fischert. 1992. Polyacetylenes from *Chrysoma pauciflosculosa*: effects on Florida sandhill species. 31:3769–3771.

Minchin, P.R. 1987. An evaluation of relative robustness of techniques for ecological ordination. *Vegetatio* 69:89–107.

Mushinsky, H. R., T. A. Stilson, and E. D. McCoy. 2003. Diet and dietary preferences of the juvenile gopher tortoise (Gopherus polyphemus). Herpetologica 59:475–483.

Mushinsky, H. R., E. D. McCoy, J. S. Berish, R. E. Ashton and D. S. Wilson. 2006. *Gopherus polyphemus*– gopher tortoise. In: Biology and Conservation of Florida Turtles, pp. 350-375 (Chelonian Research Monographs 3, Meylan, Ed.).

Nelson, A. L. 1933. A preliminary report on the winter food of Virginia foxes. Journal of Mammalogy 14:40-43.

Oksanen, J., F.G. Blanchet, M. Friendly, R. Kindt, P. Legendre, D. McGlinn, P.R. Minchin, R.B. O'Hara, G.L. Simpson, P. Solymos, M. Henry, H. Stevens, E. Szoecs, and H. Wagner. 2017. vegan: community ecology package. R package version 2.4-5.

Perez-Heydrich, A. C., K. Jackson, L. D. Wendland, B. B. Mary. 2012 Gopher tortoise hatchling survival: field study and meta-analysis. Herpetologica 68:334–344.

Provencher, L., B. J. Herring, D. R. Gordon, H. L. Rodgers, G. W. Tanner, L. A. Brennan, J. L. Hardesty, E. Air, and F. Base. 2000. Restoration of Northwest Florida Sandhills through harvest of invasive *Pinus clausa*. 8:175–185.

Pike, D.A. 2006. Movement patterns, habitat use, and growth of hatchling tortoises, *Gopherus polyphemus*. Copeia 2006:68–76.

Pike, D.A. and R.A. Seigel. 2006. Variation in hatchling tortoise survivorship at the three geographic localities. Herpetologica 62:125–131.

Printiss, D., and D. Hipes. 1999. Rare amphibian and reptile survey of Eglin Air Force Base, Florida. Final Report, Florida Natural Areas Inventory, Tallahassee, Florida, USA. 57 pp.

R Core Team. 2017. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Roosevelt, T. 1917. Notes on Florida turtles. American Museum Journal. 17:288-291.

Rostal, D.C., E.D. McCoy, and H.R. Mushinsky, eds. 2014. Biology and Conservation of North American Tortoises. Johns Hopkins University Press, Baltimore, Maryland, USA. 208 pp.

Smith, L. L., D. A. Steen, L. M. Conner, and J. C. Rutledge. 2013. Effects of predator exclusion on nest and hatchling survival in the gopher tortoise. Journal of Wildlife Management 77:352–358.

Tuberville, T.D., B.D. Todd, S.M. Hermann, W.K. Michener, and C. Guyer. 2014. Survival, demography, and growth of Gopher Tortoises (*Gopherus polyphemus*) from three study sites with different management histories. The Journal of Wildlife Management, 78(7):1151–1160.

U.S. Air Force (USAF). 2008. Final Environmental Assessment for Long-term Vegetation Control for Eglin Air Force Base, Florida. RCS 06–475.

U.S. Air Force (USAF). 2015. Final Range Environmental Assessment for Test Area C-74 Complex at Eglin Air Force Base, Florida. RCS 14–390.

U.S. Fish and Wildlife Service (USFWS). 2011. Endangered and threatened wildlife and plants; 12-month finding on a petition to list the Gopher Tortoise as threatened in the eastern portion of its range. Federal Register 76:45130–45162.

U.S. Fish and Wildlife Service (USFWS). 2012. Candidate Conservation Agreement for the Gopher Tortoise (*Gopherus polyphemus*), Eastern Population.

Walsh, R. A. 1994. *Schizachyrium tenerum*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer).

Whittaker, R. 1972. Evolution and measurement of species diversity. Taxon 21:213–251.

Whytlaw, P. A., W. Edwards, and B. C. Congdon. 2013. Marine turtle nest depredation by feral pigs (*Sus scrofa*) on the Western Cape York Peninsula, Australia: implications for management. Wildlife research 40:377–384.

Wilson, D.S. 1991. Estimates of survival for juvenile Gopher Tortoises, *Gopherus polyphemus*. Journal of Herpetology, 25:376–379.

Wilson, D.S, H.R. Mushinsky, and E.D. McCoy. 1994. Home range, activity and use of burrows of juvenile Gopher Tortoises in central Florida. Pages 147–160, in R.B. Bury and D.J. Germano, editors. Biology of North American tortoises. U.S. Department of the Interior, National Biological Survey, Fish and Wildlife Research 13.

Zeileis, A. and T. Hothorn. 2002. Diagnostic checking in regression relationships. R News 2:7–10.

TABLES

Table 1. Time periods during which the trail cameras were programmed to record the activity of Gopher Tortoises and their burrow associates at burrows on Eglin Air Force Base, FL between 2016 and 2017. Times are based on the 24-hour clock (EST).

Camera Settings	Summer 2016	Fall 2016	Winter 2016	Spring 2017
Time lapse 1	0600-1300	0600-0900	0600-1600	1000-2100
Time lapse 2	1800-2200	1200-2000	–	–

Table 2. Management actions on study sites on Eglin Air Force Base were reported or estimated as described in the methods (some from a 10-year period and others from a 1-year period). Number of fire and chemical management actions since 2006 were obtained from Jackson Guard database. The frequency of mechanical management (i.e., mowing) on test range sites were observed during the study period (Summer 2016–Spring 2017). We assumed the frequency of mechanical management observed during our study period was representative of actions taken since 2006, so we multiplied these values by 10 to keep all management practices on the same time scale (i.e., Mowing*10). We used the total for subsequent analyses.

Habitat Type	Site ID	Chemical	Fire	Mowing	Mowing*10	Total
Test Range	C64	0	5	2	20	25
	B70C1	1	8	1	10	19
	B70C2	1	8	1	10	19
	C62S	0	6	1	10	16
	C62N	0	2	1	10	12
	B70E	0	2	1	10	12
	C72	0	1	1	10	11
	C61A	0	0	1	10	10
Forested	201E	1	4	0	0	5
	McQuage Branch	0	4	0	0	4
	Pine Log	0	4	0	0	4
	Rogue Creek	0	3	0	0	3

Table 3. Burrow density for different Gopher Tortoise size classes by site with mean and SE (parentheses) for each habitat (bolded). The final column shows the ratio of the number of burrows of smaller (subadult and juvenile) tortoises to those of larger (adult) tortoises, which is indicative of age structure.

Habitat	Site ID	Density				Number of Burrows
		Adult	Subadult	Juvenile	Total	(SA+J)/A
Range	C61A	0.48	1.73	2.12	4.33	8.00
	C62S	0.58	0.10	0.96	1.63	1.83
	C72	0.38	0.66	0.38	1.42	2.75
	B70E	0.94	0.00	0.14	1.08	0.15
	C62N	0.40	0.00	0.60	1.00	1.50
	B70C2	0.50	0.33	0.00	0.83	0.67
	B70C1	0.34	0.25	0.00	0.59	0.75
	C64	0.12	0.18	0.00	0.30	1.50
	TOTAL	**0.47 (0.08)**	**0.41 (0.20)**	**0.53 (0.26)**	**1.40 (0.45)**	**2.14 (0.88)**
Forested	201E	0.51	0.71	0.51	1.72	2.40
	Pine Log	0.29	0.10	0.86	1.24	3.33
	Rogue Creek	0.40	0.32	0.24	0.97	1.40
	McQuage Branch	0.46	0.15	0.23	0.85	0.83
	TOTAL	**0.41 (0.05)**	**0.32 (0.14)**	**0.46 (0.15)**	**1.19 (0.19)**	**1.99 (0.55)**

Table 4. Mean and SE (parentheses) of basking, foraging and combined (basking and foraging) activity times for different size classes of Gopher Tortoise by habitat and season. Values represent the average duration (in minutes) of each bout of above-ground activity. ("Combined activity time [basking and foraging]" is abbreviated as "Com." in column labels.)

Habitat	Season	Test range			Forest		
		Basking	Foraging	Com.	Basking	Foraging	Com.
Adult	Fall	22.02 (2.25)	16.66 (1.84)	30.93 (2.53)	27.65 (3.25)	17.09 (2.09)	38.39 (3.76)
	Spring	20.37 (1.11)	9.11 (0.37)	23.85 (1.15)	27.04 (1.60)	15.88 (0.94)	31.33 (1.65)
	Summer	–	–	24.62 (1.78)	–	–	28.60 (1.58)
	Winter	56.77 (8.22)	19.67 (4.08)	61.31 (8.18)	48.82 (9.22)	22.38 (4.60)	59.35 (12.29)
Subadult	Fall	8.29 (1.59)	8.28 (1.58)	11.67 (1.59_	7.60 (2.13)	6.00 (1.26)	10.00 (2.61)
	Spring	13.38 (0.97)	7.44 (0.37)	16.14 (0.95)	16.25 (1.16)	8.24 (0.45)	18.55 (1.15)
	Summer	–	–	16.37 (1.42)	–	–	16.67 (1.42)
	Winter	–	–		–	–	–
Juvenile	Fall	–	–	–	19.73 (4.49)	37.57 (3.05)	31.68 (5.13)
	Spring	7.61 (0.64)	13.77 (0.52)	10.08 (0.70)	8.82 (0.77)	9.72 (0.62)	11.09 (0.86)
	Summer	–	–	29.25	–	–	27.16 (5.00)
	Winter	–	–	–	–	–	–

Table 5. Model estimates and statistics for the relationship between above ground activity time and frequency with season, habitat, and trap days. Estimates with standard errors (SE) are presented. Tukey's method for multiple comparisons was used for post-hoc comparisons. χ^2 is chi squared test statistic, df is degrees of freedom, and P is the associated probability value (indicating statistical significance) for that test statistic and degrees of freedom.

Response	Predictor Variable	Estimate (SE)	χ^2 (df); P value	Post-hoc comparisons	Estimate (SE)	P value
Activity Time	Season (Spring)	-0.187 (0.017)	651.520 (3); < 0.001	Spring-Fall	-0.187 (0.017)	< 0.001
				Summer-Fall	-0.340 (0.020)	< 0.001
	Season (Summer)	-0.340 (0.020)		Winter-Fall	0.352 (0.031)	< 0.001
				Summer-Spring	-0.153 (0.016)	< 0.001
	Season (Winter)	0.352 (0.031)		Winter-Spring	0.539 (0.028)	< 0.001
				Winter-Summer	0.692 (0.030)	< 0.001
	Habitat (Forest-Range)	-0.213 (0.101)	4.274 (1); 0.039	–	–	–
Activity Frequency	Season (Spring)	1.014 (0.092)	163.830 (3); < 0.001	Spring-Fall	1.014 (0.092)	< 0.001
				Summer-Fall	0.895 (0.110)	< 0.001
	Season (Summer)	0.895 (0.110)		Winter-Fall	0.023 (0.190)	0.999
				Summer-Spring	-0118 (0.081)	0.437
	Season (Winter)	0.023 (0.190)		Winter-Spring	-0.990 (0.175)	< 0.001
				Winter-Summer	-0.872 (0.178)	< 0.001
	Trap days	0.010 (0.007)	2.027 (1); 0.155	–	–	–
	Habitat (Forest-Range)	-0.070 (0.200)	0.144 (1); 0.705	–	–	–

Table 6. Diversity indices for vegetation species measured at Gopher Tortoise burrows and those measured at random locations within 85 m of a burrow, on both forested and test range sites on Eglin Air Force Base.

		Burrow-centered		Random point-centered	
	Index	Range	Forest	Range	Forest
All Species	Alpha	59.13	62.33	62.75	63.67
	Beta	0.76	0.36	0.61	0.40
	Gamma	104	85	101	89
Non-Disturbance Species	Alpha	54.88	59.67	58.38	60.33
	Beta	0.80	0.36	0.64	0.41
	Gamma	99	81	96	85

Table 7. Observations of Gopher Tortoise burrow associates during camera trapping on test ranges (n=8) and forested (n=4) sites for all seasons from 2016-2017. The number of sites within each habitat that each species was found is shown in parentheses. Known or likely Gopher Tortoise predators are highlighted in gray.

Group	Species	Common Name	Range	Forested
Herpetofauna	*Anaxyrus terrestris*	Southern Toad	18 (7)	38 (4)
	Anolis carolinensis	Green Anole	2 (1)	22 (4)
	Aspidoscelis sexlineata	Eastern Six-lined Racerunner	97 (8)	95 (4)
	Cemophora coccinea	Scarlet Snake	1 (1)	1 (1)
	Coluber constrictor priapus	Southern Black Racer	11 (6)	6 (3)
	Crotalus adamanteus	Eastern Diamondback Rattlesnake	0	1 (1)*
	Eurycea cirrigera	Southern Two-lined Salamander	0	1 (1)
	Heterodon platirhinos	Eastern Hognose Snake	1 (1)	1 (1)
	Hyla sp.		0	1 (1)
	Lithobates capito	Gopher Frog	58 (6)	16 (2)
	Masticophis flagellum flagellum	Eastern Coachwhip	33 (8)	68 (4)
	Micrurus fulvius	Eastern Coral Snake	0	1 (1)
	Pantherophis guttatus	Eastern Corn Snake	2 (2)	0
	Pituophis melanoleucus mugitus	Florida Pine Snake	2 (2)	1 (1)
	Plestiodon egregius	Northern Mole Skink	0	1 (1)
	Plestiodon laticeps	Broad-headed Skink	0	3 (3)
	Sceloporus undulatus	Eastern Fence Lizard	0	8 (2)
	Scincella lateralis	Ground Skink	1 (1)	5 (2)
	Sistrurus miliarius barbouri	Dusky Pygmy Rattlesnake	5 (4)	1 (1)
	Tantilla coronata	Southeastern Crowned Snake	0	5 (3)
	Terrapene carolina carolina	Eastern Box Turtle	0	1 (1)
Mammals	*Canis latrans*	Coyote	12 (5)	5 (1)
	Dasypus novemcinctus	Nine-banded Armadillo	1 (1)	7 (1)

	Didelphis virginiana	Virginia Opossum	1 (1)	5 (3)
	Geomys pinetis	Southeastern Pocket Gopher	0	1 (1)
	Glaucomys volans	Southern Flying Squirrel	0	1 (1)
	Lynx rufus	Bobcat	0	2 (2)
	Mephitis mephitis	Striped Skunk	3 (1)	12 (2)
	Neotoma floridana	Florida Woodrat	1 (1)	0
	Odocoileus virginianus	White-tailed Deer	4 (4)	12 (4)
	Peromyscus polionotus	Oldfield Mouse	125 (8)	47 (4)
	Procyon lotor	Common Raccoon	0	5 (3)
	Sciurus carolinensis	Eastern Grey Squirrel	0	3 (1)
	Sciurus niger	Fox Squirrel	0	3 (2)
	Sigmodon hispidus	Hispid Cotton Rat	0	1 (1)
	Sus scrofa	Feral Pig	1 (1)	3 (2)
	Sylvilagus floridanus	Eastern Cottontail	32 (4)	40 (4)
	Urocyon cinereoargenteus	Grey Fox	0	3 (2)
	Ursus americanus	Florida Black Bear	0	1 (1)**
Birds	*Ammodramus savannarum*	Grasshopper Sparrow	1 (1)	0
	Antrostomus carolinensis	Chuck-will's-widow	0	1 (1)
	Athene cunicularia	Burrowing Owl	78 (5)	0
	Catharus guttatus	Hermit Thrush	0	3 (1)
	Colinus virginianus	Northern Bobwhite	0	5 (2)
	Corvus brachyrhynchos	American Crow	15 (7)	1 (1)
	Falco sparverius	American Kestrel	0	1 (1)
	Megascops asio	Eastern Screech Owl	2 (1)	7 (4)
	Mimus polyglottos	Northern Mockingbird	1 (1)	0
	Myiarchus crinitus	Great Crested Flycatcher	0	1 (1)
	Passerculus sandwichensis	Savanah Sparrow	14 (7)	0
	Peucaea aestivalis	Bachman's Sparrow	0	2 (1)
	Polioptila caerulea	Blue-gray Gnatcatcher	0	1 (1)
	Sayornis phoebe	Eastern Phoebe	3 (1)	19 (4)
	Setophaga palmarum	Palm Warbler	1 (1)	5 (3)

Spizella passerina	Chipping Sparrow	0	1 (1)
Troglodytes aedon	House Wren	1 (1)	0
Turdus migratorius	American Robin	0	3 (2)
Tyrannus tyrannus	Eastern Kingbird	1 (1)	0
Zonotrichia albicollis	White-throated Sparrow	1 (1)	0

*A single individual was observed entering a study burrow during camera setup.
**Bear knocked down camera on first day

Table 8. Diversity indices for vertebrate species associated with Gopher Tortoise burrows on Eglin Air Force Base. We separated indices for herpetofauna and potential Gopher Tortoise predators (see species list in Table 7).

	Total		Herpetofauna		Predators	
Index	Range	Forest	Range	Forest	Range	Forest
Alpha	1.34	1.65	0.68	0.91	0.21	0.35
Beta	22.10	28.18	16.55	19.92	32.91	27.48
Gamma	31	48	12	19	7	10

Table 9. Number of Gopher Frog observations across seasons from camera trapping on test ranges and forested sites on Eglin Air Force Base.

Season	Test Range	Forest
Summer	24	11
Fall	14	4
Winter	9	0
Spring	11	1
Total	58	16

FIGURES

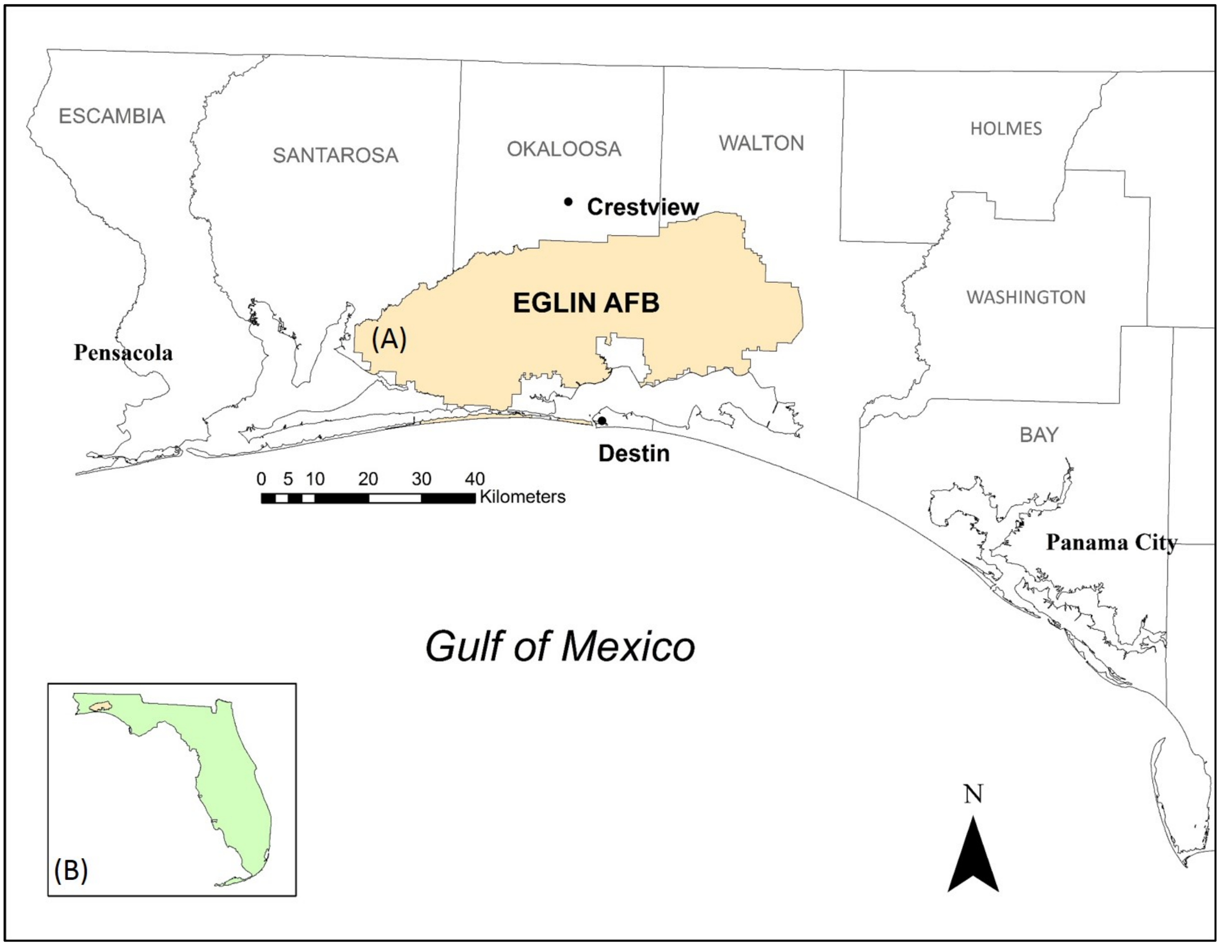

Figure 1. Eglin Air Force Base (Eglin) (A) is approximately 184,000 ha and spans Santa Rosa, Okaloosa, and Walton counties in the Florida panhandle (B).

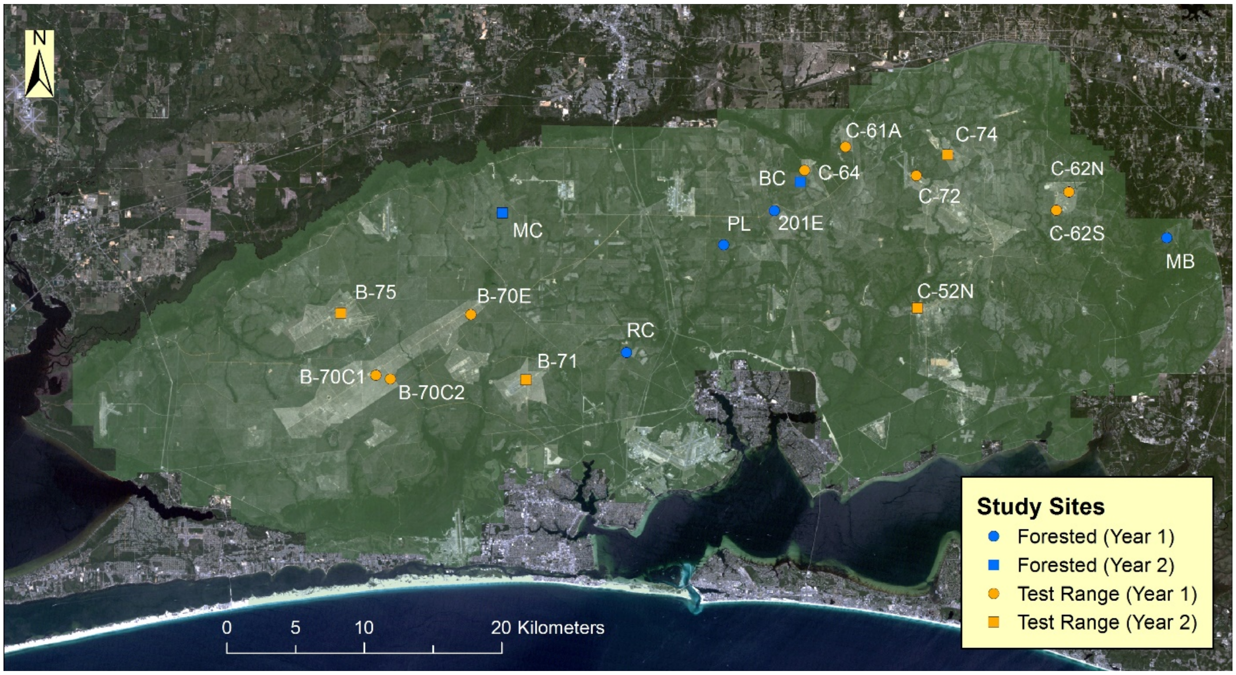

Figure 2. Gopher Tortoise study sites 2016-2017 (Year 1) and 2017-2018 (Year 2) on Eglin Air Force Base (Legacy Project 16-818).

Figure 3. Site-wide vegetation sampling. Transect length, transect spacing, and distance between each 1x1 m vegetation plot was dependent on size and shape of the surveyed area. Ten

vegetation plots were placed along each of the three transects. In this example, transect length/spacing and plot spacing is shown for a hypothetical 1000 x 1000 m survey area.

Figure 4. Adult (left) and juvenile (right) foraging area buffers. Five 1x1 m vegetation plots were randomly placed within the immediate area around the burrow to estimate vegetation cover at the selected burrow site.

Figure 5. Adult (left) and juvenile (right) outside foraging area buffers. Five 1x1 m vegetation plots were randomly placed within a larger buffer around the burrow to estimate whether available vegetation cover differed from vegetation cover within the foraging buffer (i.e., use vs. availability).

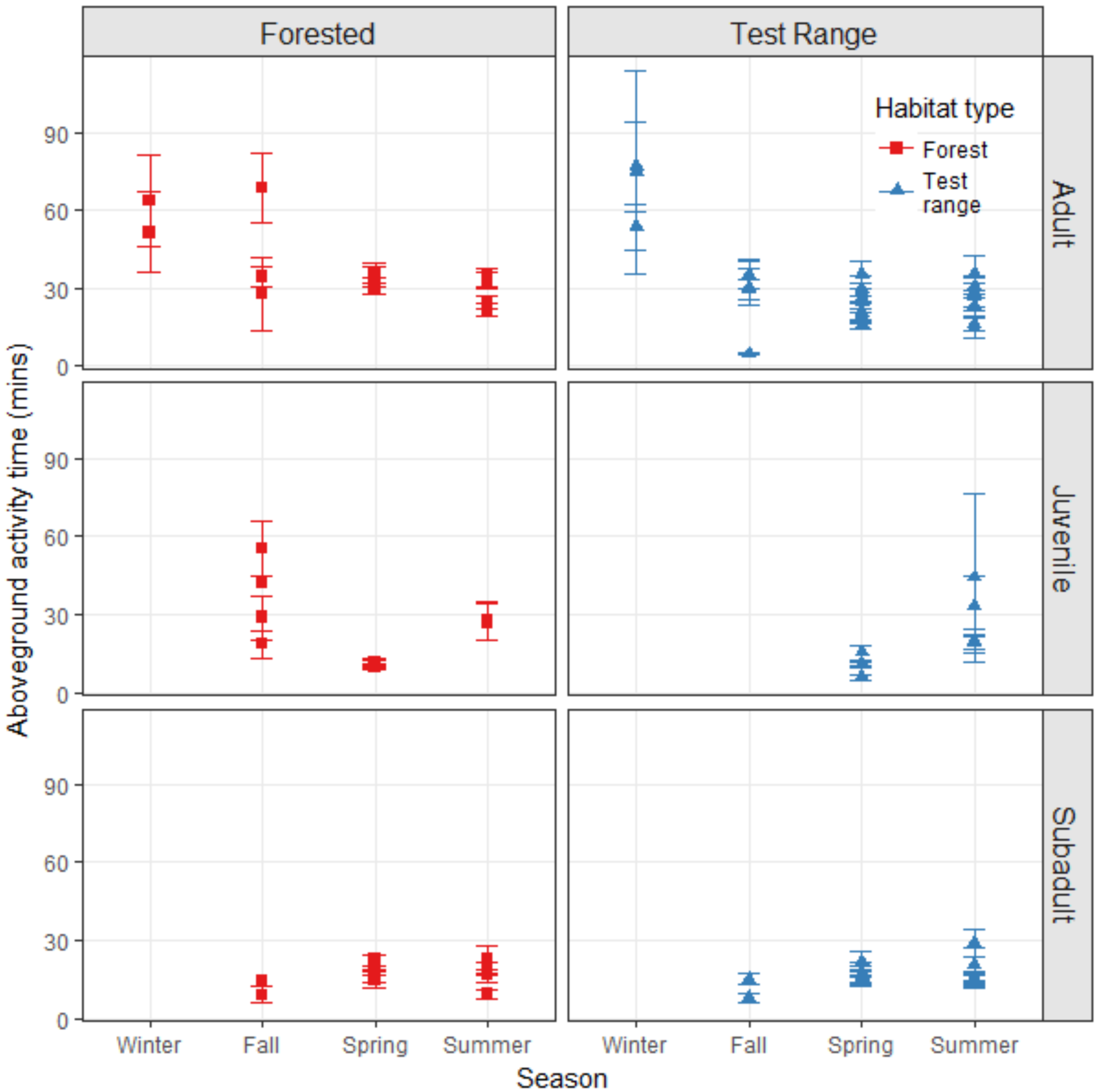

Figure 6. Site-specific mean (points) and standard errors (error bars) of combined above-ground activity time of Gopher Tortoises on Eglin Air Force Base with season (x axis), size class (facets) and habitat (color, shape, and facets). Only adults were analyzed with relevant statistics found in Table 5.

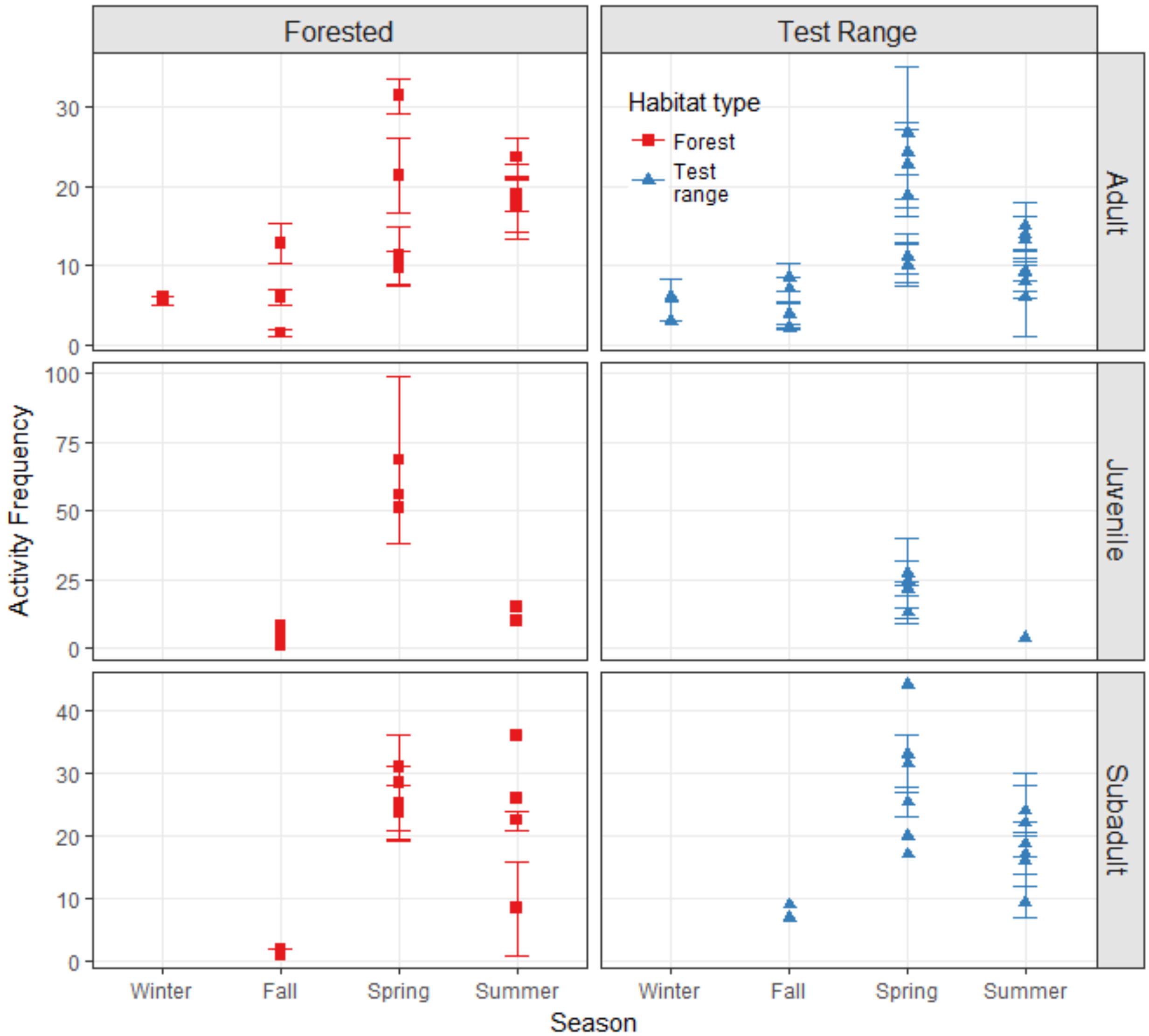

Figure 7. Site-specific mean (points) and standard errors (error bars) of activity frequency for Gopher Tortoises on Eglin Air Force Base with season (x axis), size class (facets) and habitat (color, shape, and facets). Only adults were analyzed with relevant statistics found in Table 5.

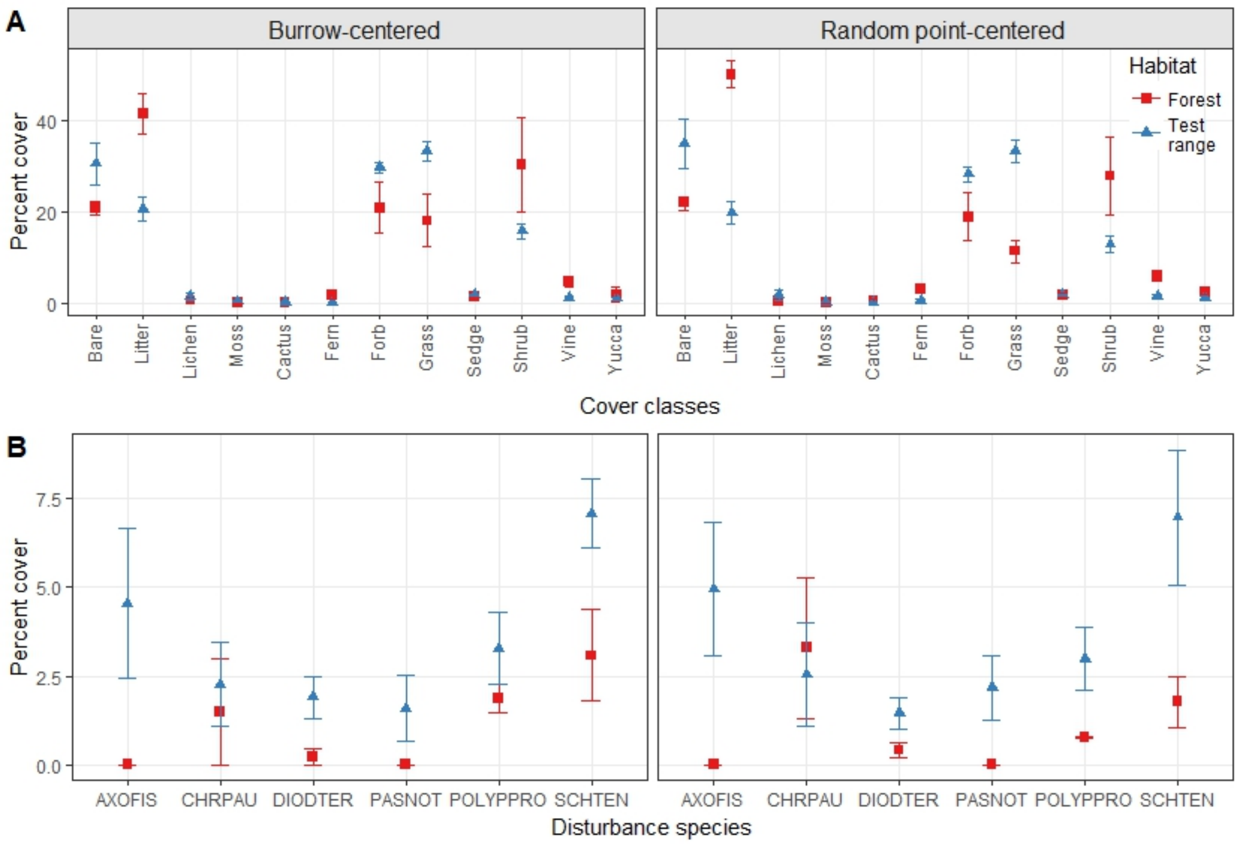

Figure 8. Mean (points) and standard error (error bars) for percent cover of (A) all vegetation groups and (B) disturbance species by habitat (color and shape) and location (facets) measured at Gopher Tortoise burrows and at random points within 85 m of burrows on Eglin Air Force Base.

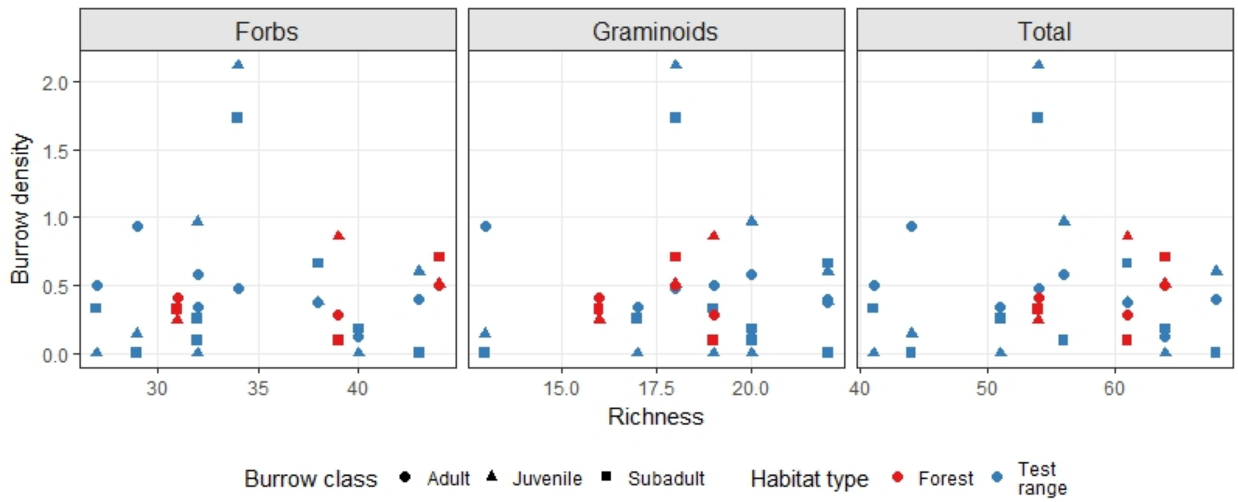

Figure 9. Mean density of Gopher Tortoise burrows on Eglin Air Force Base with vegetation richness for different burrow classes (shapes) and habitat type (color). Forbs, graminoids, and total vegetation richness are shown in facets.

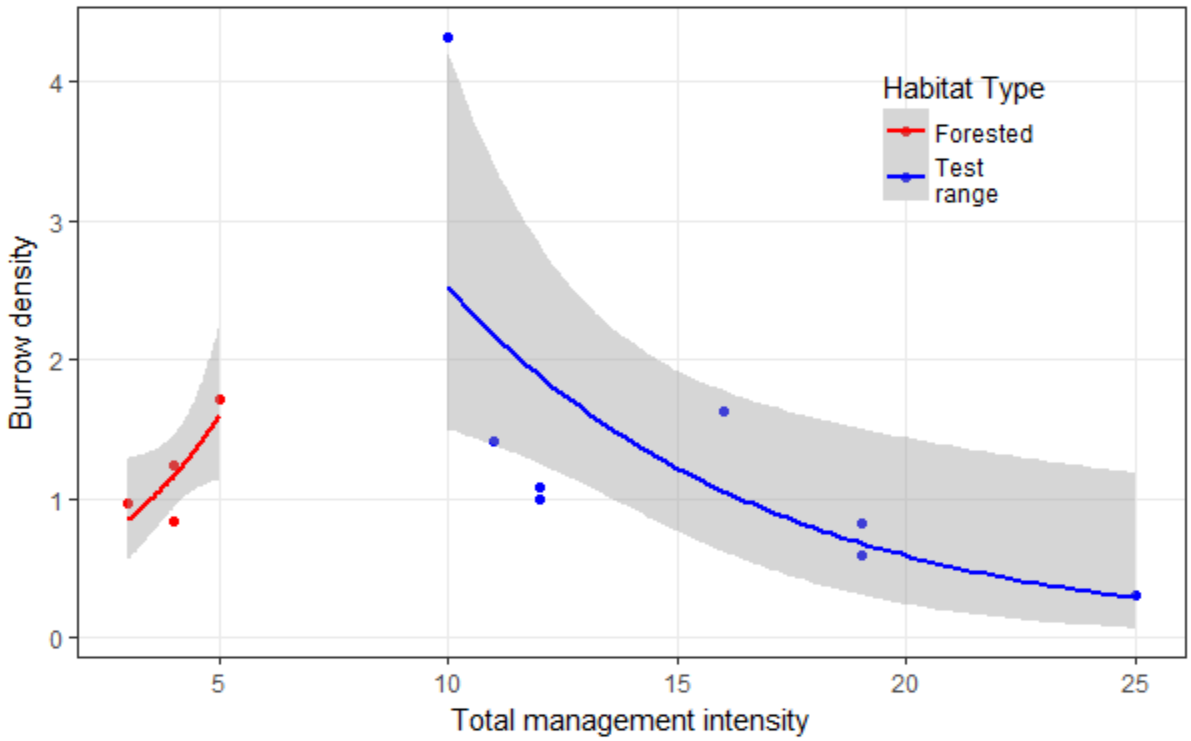

Figure 10. Relationships between burrow density, management, and habitat (color). The line shows the predicted relationship and the gray shaded ribbon shows standard error.

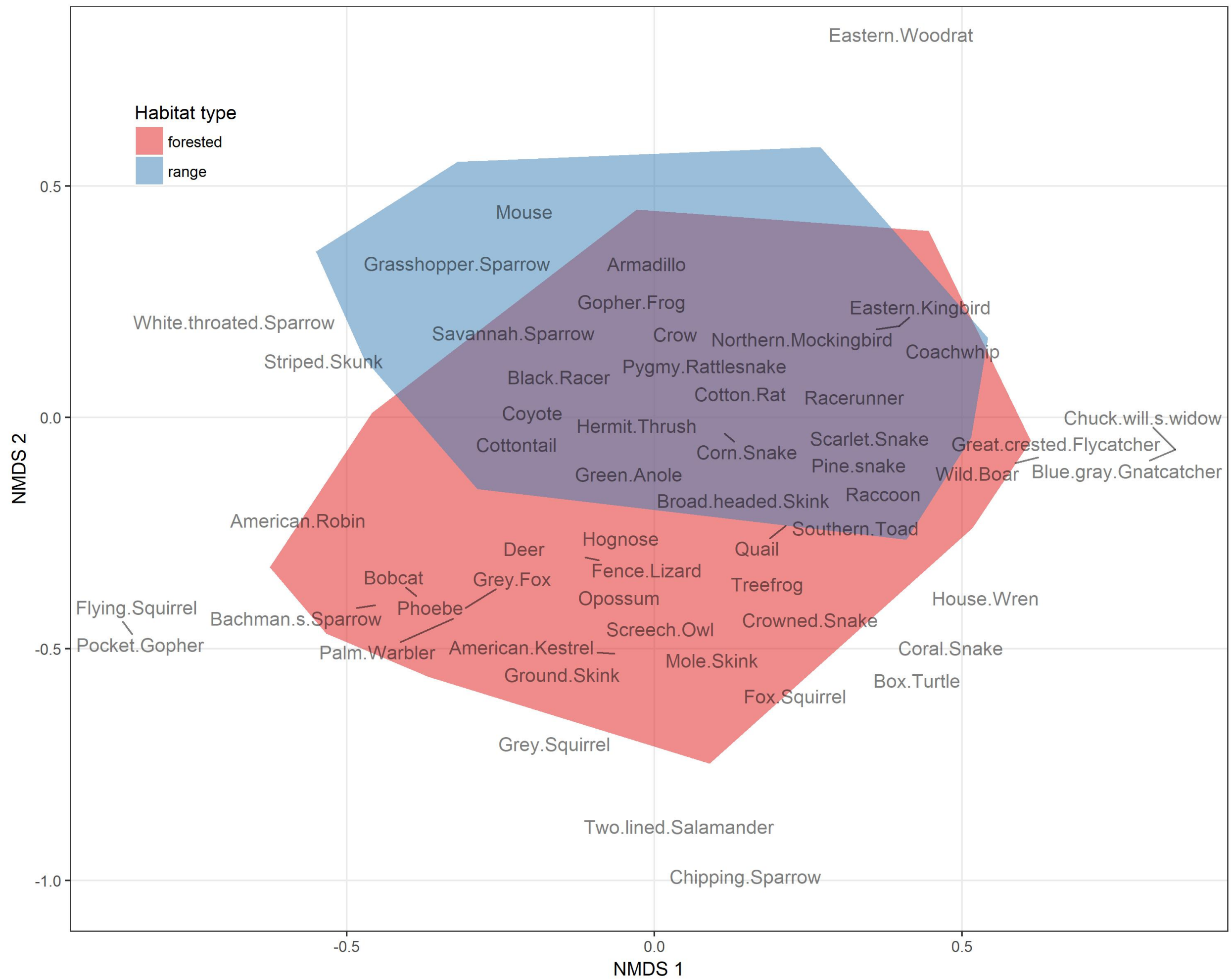

Figure 11. Forested and range habitats along the first two NMDS axes along with each species of Gopher Tortoise burrow associate on Eglin Air Force Base. See Table 7 for a complete list of species and numbers found in each habitat.

APPENDICES

Appendix One

Table A1. Sampling scheme used to evaluate tortoise activity and burrow associate communities at Gopher Tortoises burrows using camera trapping on test ranges (n=8) and forested sandhill (n=4) sites on Eglin Air Force Base, Florida in 2016–2017. A-Z are trapping periods; The numbers under each column indicates the number of cameras that were placed in that site during that trapping round.

Site	Habitat Type	# Trap Days	# Photos	SUMMER								FALL								WINTER					SPRING							
				A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C
B70C1	range	156	625,974							9	10							9					5		10							
B70C2	range	146	599,717			10								10										5								10
B70E	range	152	604,554	10								10								5	5					10						
C61A	range	160	660,945	10							10						13			5	5										10	
C62N	range	144	576,037						10						9									5				10				
C62S	range	151	607,134		10								10									5					10					
C64	range	135	540,733					9								10						5							10			
C72	range	154	609,641				10												10				5							10		
Totals		**1197**	**4,824,735**																													
201E	forested	240	994,782	10							10	10						10					5			10					10	
McQuage Branch	forested	290	1,192,207						10	10					10	10				5	5								10	10		
Pine Log	forested	266	1,051,118		10	9							10				10					5					9					10
Rogue Creek	forested	258	1,044,785				10	9						10					10					5	10			10				
Totals		**1054**	**4,282,892**																													