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Landscape-Level Habitat Associations and Phylogenetics of Desert Tortoises on Southwestern Arizona Military Ranges Managed by the Army, Air Force, and Marines

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**Landscape-Level Habitat Associations and Phylogenetics of Desert Tortoises on
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2012 Technical Report

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INTRODUCTION

A recent taxonomic investigation has identified two species of desert tortoise that occur in the desert southwest (Murphy et al. 2011). The Mohave desert tortoise (*Gopherus agassizii*), which occurs north and west of the Colorado River, is currently listed as federally threatened in the northern one-third of its geographic range (Figure 1; USFWS 1990). The Sonoran desert tortoise (*Gopherus morafkai*) occurs in Arizona and was recently identified as warranted for listing as threatened under the Endangered Species Act (ESA) of 1973 but precluded by higher priority species (USFWS 2010). Observed tortoise declines in the Mohave Desert have been attributed to direct and indirect human-caused mortality and inadequate regulatory mechanisms to protect desert tortoises and their habitat. In both tortoise species, specific threats to long-term population persistence include destruction, degradation, and fragmentation of habitat from urbanization, agricultural development, livestock grazing, mining, and roads. The Mohave and Sonoran desert tortoises likely experience similar threats despite differences in habitat use (Germano et al. 1994), albeit at different intensity and scope across their range. Evolutionary traits (i.e., longevity, delayed sexual maturity, low fecundity, and low survivorship of juveniles) that the desert tortoise shares with other chelonian species make it vulnerable to environmental and anthropogenic impacts (Wilbur and Morin 1988, Congdon and Gibbons 1990, Germano et al. 1994). This situation is exasperated by continuing drought conditions, disease transmission, accidental or intentional removal, and/or mortality relative to human activities (USFWS 1990, USFWS 2010).

Anthropogenic disturbances within the range of the desert tortoise (e.g., military training, recreational activity, grazing, etc.) have the potential to reduce habitat quality (Krzysik 1997, Berry et al. 2006) through impacts to vegetation structure and soil characteristics. While impacts

to desert tortoise habitat on active military training areas can be substantial, these ranges often provide important refuges where public access is limited and military activities are restricted to specific training areas. As a result, impacts are generally limited to specific locations rather than being diffused across the landscape, as is the case with areas open to unrestricted public access or urban/suburban expansion. However, tortoise activity within intensively used training areas tends to be less than in adjacent habitat that remains relatively intact (Grandmaison et al. 2010) and conflicts between desert tortoise conservation and military readiness may exist. Given the possibility of future ESA listing and the challenges that such a decision would impose upon the Department of Defense (DoD), it is prudent to understand the distribution of desert tortoises on military ranges within the Sonoran Desert so that appropriate management decisions can be made to reduce conflicts while maintaining the military readiness mission.

At the scale of an individual's home range, shelter availability is a crucial component of suitable habitat given that tortoises spend approximately 98% of their life inactive in these shelter sites (e.g., soil burrows, caliche burrows, boulder piles, woodrat nests, etc.; Woodbury and Hardy 1948, Nagy and Medica 1986, Bailey et al. 1995). Shelter sites are important for tortoises because they provide nest sites, protection from predators, and refuge from extreme temperatures (Bailey et al. 1995). In fact, tortoise density is positively correlated with shelter site density in the Mohave Desert (Bury et al. 1994, Duda et al. 2002, Krzysik 2002) and the Sonoran Desert (Fritts and Jennings 1994, Averill-Murray et al. 2002, Riedle et al. 2008). Individual tortoises will use multiple shelter sites during a given season but have preferred shelters that are frequently reused (Woodbury and Hardy 1948). In addition, desert tortoises select habitat characterized by a high percentage of canopy cover and in close proximity to desert washes within their home ranges (Andersen et al. 2001, Grandmaison et al. 2010). Areas with sufficient

canopy cover are likely to provide adequate shade for escaping the desert heat (Burge 1978). Anthropogenic disturbances that degrade or destroy shelter sites and vegetation (e.g., military training, recreational activity, grazing, etc.) will reduce habitat suitability for desert tortoises (Krzysik 1997, Berry et al. 2006) and may impact survival rates and population persistence if alternative shelter sites are not available.

The range management responsibilities of the three participating military installations are assigned to the Secretaries of the Army, Air Force, and Navy for the Yuma Proving Ground (YPG), Barry M. Goldwater Range (BMGR) - East, and BMGR-West, respectively. This area represents the largest tracts of relatively undisturbed Sonoran Desert in the southwestern United States (Figure 2) outside of active training and testing areas. Historical desert tortoise accounts exist for these military ranges but a systematic regional survey has not been conducted. This creates a situation which limits informed management decisions and collaborative efforts across range boundaries to ensure the coexistence of robust desert tortoise populations and the military mission.

The first step in developing management recommendations that allow for the coexistence of desert tortoises and military training is the development of a landscape-level habitat model that identifies locations with the highest likelihood of tortoise occupancy. Coupled with training area maps, these data will allow range management to identify specific locations where there is overlap and take appropriate measures to reduce potential conflicts. Once the location and nature of potential conflicts are identified, responsible management decisions can be made.

The primary objective of this study is to develop a landscape-level pattern recognition model based on existing knowledge of desert tortoise habitat requirements that predicts the locations on the three military ranges where desert tortoise occupancy is most likely. Studies

within the Black Mountains of northwestern Arizona have shown a possible link between tortoise occurrence and soil type, particularly Aridisol soils (Grandmaison et al. 2011). Aridisol soils are characterized by a well developed subsurface horizon containing clays, calcium carbonate, silica, salts and/or gypsum that when exposed by incised washes, allow for the creation of deep, permanent desert tortoise shelters (USDA 1975, Hendricks 1985, Figure 3). Aridisols can be distinguished from Entisols by the presence of a distinct calcic or petrocalcic horizon within 1m of the surface (USDA 1975). Entisol soils have a more recent origin without diagnostic horizons and do not provide the structural integrity generally required for permanent burrows (USDA 1975, Hendricks 1985).

Given the perceived variability of soil suitability for tortoise shelter sites in the Sonoran Desert, we hypothesized that desert tortoise occupancy would vary among soil designations at the landscape-scale. Specifically, we predict that tortoise occupancy will be higher in Aridisol soils than Entisol soils. The usefulness of this predictive model, if validated with empirical data, could be extremely valuable given the importance of region-wide planning for desert tortoise conservation and the projections for increased military activities associated with the three targeted southwestern military ranges. This information will aid natural resource managers when evaluating the potential impacts of military activities on desert tortoise populations.

Our second objective was to collect genetic samples from tortoises detected during our surveys in an effort to accurately characterize their phylogenetic grouping. Under current regulatory designation, desert tortoises east and south of the Colorado River are considered members of the Sonoran assemblage while those north and west of the river belong to the federally protected Mohave assemblage (USFWS 1990). More recently, desert tortoises in the Black Mountains of Mohave County (approximately 40 km north of the study area) were

identified as possessing genetic and morphometric traits similar to the federally threatened Mohave assemblage (McLuckie et al. 1999. Berry et al. 2002). Uncertainty as to the phylogenetic designation for desert tortoises near what were once thought to be virtually impenetrable geographic barriers (e.g., The Colorado River) have been identified as being in need of further clarification (Berry et al. 2002). Given the proximity of the three military ranges on which this project is being conducted, the collection of genetic samples will help resolve this uncertainty.

METHODOLOGY

Study Area and Previous Efforts

The geographic scope of this project included the YPG, BMGR - East, and BMGR-West. This land base encompassed approximately 12,000 km² (Figure 2). The YPG lies within La Paz and Yuma counties northeast of Yuma, Arizona and encompasses approximately 3,450 km². The BMGR-East is located in portions of Yuma, Maricopa, and Pima counties from the Sand Tank Mountains west to the Mohawk Mountains. The BMGR-West is located just east of Yuma, Arizona and west of the Mohawk Mountains. In total, the BMGR covers approximately 8,000 km². The dominant vegetation community on the three ranges is classified as the Lower Colorado River subdivision of the Sonoran Desert (Brown 1994), the most arid subdivision within the Sonoran Desert, with summer temperatures often exceeding 110 °F and annual rainfall averaging less than 70 mm. Dominant landforms include broad, flat valleys with scattered small mountain ranges. In the valleys, vegetation is generally characterized by drought-tolerant species such as creosote (*Larrea tridentata*) and bursage (*Ambrosia dumosa*) (Brown 1994). Broad desert plains are dissected by numerous incised washes that support paloverde (*Cercidium* sp.),

ironwood (*Olneya tesota*), smoketree (*Psoralea spinosa*), acacia (*Acacia* sp.), mesquite (*Prosopis* sp.), mixed cacti (including various *Opuntia* species), and various drought tolerant herbaceous and shrub species. The mountainous areas on these military ranges support vegetation more characteristic of the Arizona Upland subdivision of the Sonoran Desert.

Sampling Design

A 1994 report filed with Luke Air Force Base, the primary management custodian for the BMGR-East, indicated that extensive desert tortoise inventory surveys had been conducted on areas within and adjacent to East TAC Range, the Sand Tank Mountains and the Saucedo Mountains, although no citations were provided for evaluating the results of the surveys (Geo-Marine Inc. 1994). The report documented the results of surveys conducted in the Granite, Growler, Crater, Aguila, Sand Tank, and Saucedo mountain ranges. Similar location-specific surveys have been conducted on portions of the YPG in the Dome Rock, Tank, Trigo, and Chocolate Mountain ranges (Palmer 1986, LaDuc 1992, Blackman et al. 2008). While these efforts contributed a substantial amount of information regarding tortoise occurrence within the areas surveyed, inference regarding regional distribution and habitat associations are limited because sampling units were selected non-randomly (i.e., sampling was biased to areas where desert tortoises were thought to be most likely to occur).

The intended purpose of these previous survey efforts was not to provide inference regarding the regional desert tortoise population. However, landscape-level inference regarding desert tortoise distribution and habitat use is a key component in developing management strategies that can be implemented at large spatial scales. Given the need for occurrence and habitat association data to reflect a spatial scale that matches the spatial extent of the potential

impacts, a probabilistic sampling approach is required. In the case of military training, landscape-level information is required for responsible management. As such, we implemented a stratified random sampling design (Cochran 1977) in which random samples were taken from soil strata defined by the National Cooperative Soil Survey (NCSS) division of the Natural Resources Conservation Service (NRCS), a branch of the United States Department of Agriculture (USDA). The main benefit of stratified random sampling is that stratification may improve the precision of the parameter of interest (in this case occupancy) when sampling units are heterogeneous across strata, but homogenous within strata (Cochran 1977).

Given the geographic scope of the study area and the study objectives regarding the spatial distribution, we chose tortoise occupancy (detection/non-detection) as the population parameter of interest. However, unlike traditional occupancy estimation studies in which defined sampling units are visited on multiple occasions and the species of interest is either detected or not detected, the study substituted spatial replicates for temporal replicates (Kendall and White 2009). Under this sampling methodology, “sites” were defined as distinct soil patches with survey locations representing spatial sub-units within sites.

The stratification for our probabilistic sampling design reflected our hypothesis that desert tortoise occupancy varied among soil designations at the landscape-scale. Specifically, we predicted that tortoise occupancy would be higher in Aridisol soils (i.e., soils with subsurface horizon development containing clays, calcium carbonate, silica, salts and/or gypsum) than in Entisol soils (i.e., soils of recent origin with no diagnostic horizons) given the ability of Aridisol soils to support deeper, more long-lasting burrows for desert tortoises (AGFD, unpublished data). To test this hypothesis, we designed our study to compare desert tortoise occupancy among soil groups. First, we obtained existing NCSS soil data for the YPG and the eastern

portion of the BMGR. Soil characterization mapping for the BMGR-West was completed by a private remote sensing firm (Nauman Geospatial, LLC). Briefly, their approach used existing data from mapped portions of the study area to build a predictive model for the unmapped portions (the full report and details regarding this soil mapping methodology are included in Appendix I). Once we obtained soil data for the entire study area, we randomly located 711 3-ha tortoise survey plots within 219 soil patches across the 11 soil groups found on the military ranges.

Desert Tortoise Surveys

We conducted standardized surveys for tortoises and their sign (i.e., carcasses, scat, tracks, etc.) within each 3-ha plot using an area search methodology for complete coverage within the plot boundaries. All shelter sites detected during these surveys were examined for tortoises and their sign. In addition, we collected survey-specific data regarding the temperature, humidity, and timing (i.e., time of year and time of day) of each survey. Surveys were conducted such that the potential effects of heterogeneity in detection were minimized (MacKenzie and Royal 2005). Specifically, field protocols ensured that observers were rotated among soil groups to avoid observer bias and that the order in which soil patches were surveyed was changed each day to avoid biases related to survey timing. Surveys were conducted such that an approximately equal number of survey plots were visited within each of the soil groups each week during the survey season.

All detected tortoises were handled under guidelines established in Berry and Christopher (2001) to prevent unnecessary stress and potential disease transmission. Specifically, personnel handling tortoises wore a fresh pair of disposable gloves for each tortoise. If a tortoise voided the

contents of its bladder during handling, or showed signs of extreme dehydration (e.g., sunken eyes, boney head, sunken forelimb muscles), the tortoise was rehydrated with a saline solution injection or by soaking the tortoise in a water bath. Tortoises were examined for clinical signs of upper respiratory tract disease (URTD; nasal discharge, ocular discharge, palpebral edema, and conjunctivitis), shell anomalies, and parasites according to established guidelines (Jones 2008). When feasible, we examined oral cavities for clinical signs of herpesvirus (presence of plaque or open sores in the mouth). Tortoises were weighed and midline carapace length (MCL) was measured with pottery calipers to provide an estimate of each tortoise's age based on size-class. Tortoises over 180 mm MCL with concave plastrons, long gular horns, long tails, and well-developed chin glands were classified as males. All tortoises were marked with a unique identification number following the guidelines in Berry and Christopher (2001). We used a triangular file to notch marginal scutes according to a predefined marking scheme used in previous tortoise studies in Arizona (Cagle 1939). We avoided notching the bridge scutes since the notches in this area have the potential to weaken the carapace. In addition to the notches, we also assigned each tortoise an identification number which was applied to the areola of the fourth right coastal scute with correction fluid and black permanent marker and covered with epoxy (Murray and Schwalbe 1997) to facilitate easy identification if recaptured. All equipment coming into contact with the tortoise was sterilized with a veterinary disinfectant (Chlorhexidine diacetate; AIDTT 1996) after processing was completed. The geographic coordinates of all tortoise sign (e.g., scat, tracks, shells, etc.) and live individual tortoises encountered were recorded with a GPS unit. Blood was collected from each tortoise by brachial or jugular venipuncture and sent to the University of Arizona genetics laboratory for DNA.

In addition to recording the presence of tortoises and/or tortoise sign and survey-specific data for each survey, we collected additional information related to the survey plot that may influence occupancy (i.e., site-specific). These data included the number and location of potential shelter sites (i.e., burrows, caliche caves, and woodrat nests), linear distance to desert washes or drainages, and linear distance and type of roads within the plot. We also incorporated site-specific characteristics such as slope, aspect, and elevation in our final model evaluation.

Analysis of Survey Data

We calculated occupancy estimates using the likelihood-based approach described by MacKenzie et al. (2002). This method allowed us to estimate the proportion of area occupied (PAO), accounting for the fact that desert tortoises may go undetected during a survey, even when present. For desert tortoises, which spend a considerable amount of time below ground, this technique reduced the inherent negative bias of naïve occupancy estimators that assume a detection probability equal to one. Estimable parameters included: the probability that a species is present at site i (Ψ_i) and the probability that a species is detected at site i during visit t (p_{it}). In addition, both parameters were expressed as a function of site- and survey-specific covariates (e.g., slope, elevation, survey period, temperature, etc.).

Desert tortoise detection/non-detection data from all 219 survey sites (i.e., soil patches) were used to estimate Ψ and p using Program PRESENCE, which provides a single-season approach to estimating PAO when species detection is less than one (MacKenzie et al. 2002). We considered the influence of variables thought to influence detection and occupancy (Table 1). Correlated variables (i.e., correlation coefficients $[r] \geq 0.50$, $P < 0.05$) were not included in the same model in order to avoid multicollinearity (Glanz and Slinker 1990, Graham 2003).

We used a 3-step approach to this model-based analysis following Zylstra and Steidl (2009). First, we determined which factors best explained variation in Ψ while maintaining a general model for p . The general model for p included all the variables thought to influence tortoise detection: year, Julian day, relative humidity, temperature, and the presence or absence of an incised wash (Grandmaison 2009, Grandmaison et al. 2010). We evaluated two categories of variables with the potential to influence Ψ : topography (i.e., aspect, elevation, and slope) and variables identified by Riedle et al. (2008) and Grandmaison et al. (2010) as influencing habitat selection (i.e., presence of incised wash, distance to nearest wash, distance to nearest road, and soil subgroup classification). We ranked models using the small sample correction for Akaike's Information Criterion (AIC_c ; Hurvich and Tsai 1989, Burnham and Anderson 2001, Vaida and Blanchard 2005) and identified the most well-supported models (i.e., $\Delta AIC_c \leq 2.0$) for inclusion in the final set of candidate models (Burnham and Anderson 2002). In the second step of our analysis, we determined which factors explained variation in p while maintaining a general model for Ψ that included all the potential variables from the first step. Finally, we combined the results of these initial analyses to identify variables for inclusion in the final set of candidate models and used a parametric bootstrap procedure to assess the goodness-of-fit of the global detection model (Burnham and Anderson 2002, MacKenzie and Bailey 2004). We retained candidate models where $\Delta AIC_c \leq 2.0$ and adjusted AIC model weights (w ; Buckland et al. 1997) so that the combined weight of the retained models = 1.0 (MacKenzie and Bailey 2004, Zylstra and Steidl 2009b).

We utilized the most well supported occupancy models to develop a graphical representation of the occupancy probability across all three military installations. We first created a raster data layer representing the soil groups clipped to the installation boundaries. We

then created a series of raster layers representing each soil group by reclassifying the original soil raster using a binary indicator variable where a “1” represented the soil group of interest and a “0” represented all other soil groups. Similarly, we clipped a 30m digital elevation model (DEM) to the installation boundaries and created a new raster data layer representing aspect using the Spatial Analyst extension for ArcGIS 9.3 (ESRI, Inc.). Aspect values (i.e., values between 0 and 360°) were reclassified to north (0-45° and 315-360°), east (45-135°), and south (135-225°). As with the soil data, we created a single raster layer for each aspect category. We then calculated a new raster using the mean occupancy probability for each soil group and the natural log(e) of the elevation and aspect parameters which represents the odds ratio or probability that the event (i.e., tortoise occupancy) would occur divided by the probability that it failed to occur (Ayalew and Yamagishi 2005, Arekhi 2011). The resulting raster therefore represented the relative likelihood of desert tortoise occupancy across the three military installations.

Desert Tortoise Telemetry

Radio transmitters (Telonics, Inc., Mesa, Arizona) were glued to the first left costal scute of 14 desert tortoises with epoxy and positioned below the highest point on the carapace (Boarman et al. 1998; Figure 4). The transmitter antenna was inserted into 0.25-inch (6.3-mm) segments of shrink tubing that were glued to the marginal scutes. Epoxy was not applied to the seams between scutes to avoid damage to scute seams. In addition, all 14 desert tortoises were instrumented with Sirtrack MicroGPS (mean weight = 1.89 ounces [53.5 g]) tracking units (Sirtrack, New Zealand). The GPS tracking units were glued to the top of the carapace to ensure adequate communication with satellites (Figure 4). Short pieces of electrical tape were placed over the scute margins to ensure that epoxy was not applied to the seams between scutes.

GPS tracking units were programmed to collect detailed location data (≤ 50 -foot [15-m] resolution) once every 30 minutes from 5 am to 10 am and 5 pm to 9 pm, coinciding with peaks in daily activity (AGFD, unpublished data). GPS tracking units were deployed for a minimum of two weeks and then retrieved for data download and battery charging before being redeployed. The use of GPS tracking units allowed the research team to collect fine-scale movement pattern information that allowed them to identify tortoise activity areas, evaluate tortoise space use, and identify habitat characteristics within tortoise home ranges. Radio-tagged tortoises were monitored until they entered hibernacula in mid-November. During hibernation, the researchers located tortoises monthly until they resumed activity in the spring.

Home Range Estimation

We used the Brownian Bridge Movement Model (BBMM; Horne et al. 2007) to assess desert tortoise space use within the project area. Tortoise home ranges were estimated based on location data collected using geographic positioning system (GPS) tracking units programmed to record tortoise locations every 30 minutes and analyzed the data using the BBMM approach (Horne et al. 2007). GPS tracking units obtained location estimates with an estimated location error of ± 50 feet (± 15 m). We used the program Animal Space Use (Horne and Garton 2009) to estimate the Brownian movement variance parameter using maximum likelihood estimation techniques and output the resulting probability distribution of desert tortoise space use within the study area. Core areas (i.e., areas of concentrated use within an individual home range; Samuel et al. 1985) were defined as the 50% contour estimated from the BBMM (Harless et al. 2009). We then calculated the mean \pm SE home range size and core area for both males and females. We

compared home range size and core area size between males and females using ANOVA (Zar 1999).

Characteristics of Tortoise Home Ranges

We examined habitat characteristics associated with desert tortoise home ranges at two spatial scales. We began by comparing soil categories within desert tortoise home ranges to the proportion of soil categories within the study area. Tortoise home ranges were defined by the BBMM home range estimator (Horne et al. 2007). The mean proportion of each soil category within tortoise home ranges was compared with the proportion found within a 1 km buffer surrounding the home range using the Z-test (Zar 1999). We then examined soil characteristics within tortoise home ranges using compositional analysis to identify whether soil categories were used in proportion to their availability (Aebischer et al. 1993). For this analysis, used resources for each individual tortoise were defined by the percentage of locations within each soil category. Available resources were defined by the percentage of soil categories within each individual's home range. Percentages equal to zero (i.e., corresponding to an unutilized but available soil category) were replaced with 0.001%, an order of magnitude less than the smallest recorded nonzero percentage (Aebischer et al. 1993, Leban 1999). Used and available soil compositions were then transformed to log-ratios using haplodurid soils as the denominator and the difference in log-ratios between used and available percentages were calculated for each tortoise (Leban 1999). Finally, we calculated the mean and standard error for each of the elements in the resulting matrix for all of the tortoises and created ranking matrices to assess relative preferences for soil groups (Aebischer et al. 1993).

Desert Tortoise Genetic Analysis

We collected blood samples from 13 desert tortoises during the 2009 and 2010 field season using standardized techniques for sample collection using sub-carapacial blood draws. Samples were submitted to the University of Arizona Genetics Core (UAGC) for analysis. A full description of the extraction, amplification, and sequencing processes provided by the lead desert tortoise genetics analyst at UAGC, Taylor Edwards, is included in Appendix II.

RESULTS

Desert Tortoise Surveys

During the 2009 and 2010 field seasons, we conducted 711 tortoise surveys within 219 soil patches located on YPG and BMGR. We detected seven live desert tortoises on six survey plots and documented tortoise sign (i.e., scat, tracks, or carcasses) on 31 plots (Figures 5-7). An additional 18 desert tortoises were detected while traveling to and from survey plots or while conducting radio-telemetry (Table 2). Overall, 31 survey plots (4%) and 22 soil patches (10%) were identified as occupied given the presence of tortoises and/or tortoise sign.

Desert Tortoise Occupancy

In the first step of our occupancy analysis, we identified a single model that accounted for >99% of the model weight (Table 3). No additional models were supported by the data based on a comparison of ΔAIC_c values. This top-ranked occupancy model included aspect, elevation, and soil group as additive covariates for explaining variation in desert tortoise occupancy.

In the second step of our analysis, we identified Julian day and relative humidity as important covariates for explaining variation in desert tortoise detection probability (Table 4).

Only two models were supported based on comparison of ΔAIC_c values and accounted for >66% of the model weight. More complex models for desert tortoise detection failed to converge on meaningful parameter estimates and were therefore excluded from the final model specification. There was little evidence that detection probability varied among years (2009 and 2010) or depending on the presence or absence of an incised wash on the survey plot.

After combining desert tortoise occupancy and detection models from steps one and two of our analysis, we identified two models that explained desert tortoise occupancy across YPG, BMGR – East and West (Table 5). Goodness-of-fit for the most general model in the candidate set indicated a suitable fit to the data ($\chi^2 = 170.52$, $P = 0.19$). Occupancy estimates based on the top-ranked models ranged from 0.29 – 0.31 (Table 5).

Based on the two top-ranked models, desert tortoise occupancy increased with elevation (Figure 8). Aspect was positively associated with desert tortoise occupancy although the magnitude of this relationship was highest for north-facing slopes (Table 6). Finally, desert tortoise occupancy was related to soil categories (Figure 9). Occupancy was highest for petrocalcic soils with the probability of occupancy being ≤ 0.40 for the remaining five soil categories.

Our geospatial analysis derived a raster layer representing the probability of desert tortoise presence across the three military installations (Figures 10-12). On the YPG, this model indicated that the probability of desert tortoise occupancy was low overall. However, there was some elevated probability of desert tortoise occupancy at the southern end of the Dome Mountains, the northern extent of the Trigo Mountains, and around the vicinity of Mohave Peak (Figure 10). Similarly, the western expanse of BMGR exhibited a generally low probability of desert tortoise occupancy (Figure 11). According to our model, the eastern portion of BMGR

(i.e., east of San Cristobal Wash) contained areas with the highest probability of tortoise occupancy relative to the entire study area (Figure 12). Specifically, the northern extent of the Growler Mountains, the Crater Mountains, some patches of the Saucedo Mountains, and portions of the Sand Tank Mountains exhibited a relatively high probability of desert tortoise occupancy.

Home Range Characteristics

The mean BBMM home range estimate for females and males (Table 7) were 38.27 ha (\pm 5.62 SE) and 38.90 ha (\pm 7.26 SE), respectively (females: 94.57 acres \pm 13.89 SE; males: 96.12 acres \pm 17.94 SE). Home range size did not differ between sexes ($F_{1,14} = 0.212$, $P = 0.652$). Mean core area estimates for females and males were 1.02 ha (\pm 0.19 SE) and 1.52 ha (\pm 0.33 SE), respectively. Core area size did not differ between sexes ($F_{1,14} = 1.043$, $P = 0.325$).

Desert tortoise home ranges encompassed five soil categories (Table 8). Torriorthents comprised most and, in some cases, all of the soil within desert tortoise home ranges. However there was no statistically significant difference between the proportion of soil categories within tortoise home ranges and the proportion of soil categories within the 1 km buffer (Table 9; Figure 13). Compositional analysis results examining resource use within desert tortoise home ranges indicated that soil groups were used in proportion to their availability ($\chi^2 = 4.31$, $P = 0.37$).

Desert Tortoise Genetics

The UAGC successfully produced STR genotypes and mtDNA sequences for each of the 13 individuals sampled on YPG and BMGR (Appendix II). Their analysis indicated that all of the desert tortoises sampled on the YPG and BMGR were classified as Sonoran desert tortoises (*G.*

morafkai) based on mtDNA and short tandem repeat (STR) assignments. In contrast, genetic analyses for tortoises in the Black Mountains (approximately 40 km north of the study area) indicated that a proportion of the local population were classified as Mohave desert tortoises (*G. agassizii*) or hybrids of the two (Appendix II).

DISCUSSION

Desert Tortoise Occupancy

The primary objective of this study was to develop a landscape-level pattern recognition model to predict areas that exhibited a high probability of desert tortoise occupancy across a broad geographic region. After a considerable survey effort spanning two years, and despite few desert tortoises being detected on the YPG and BMGR, we demonstrated that spatially replicated occupancy models (Tyre et al. 2003, Kendall and White 2009) based on detection/non-detection desert tortoise surveys can be used to identify patterns in tortoise occupancy over broad geographic scales.

The modeled PAO for YPG and BMGR ranged between 0.29 – 0.31 and was much higher than the naïve estimate (0.13) which assumed detection rates equal to 1. While the modeled PAO estimates for YPG and BMGR were comparable to estimates obtained in other parts of Arizona (0.48-0.61; Grandmaison 2011), they were substantially lower than estimates from Saguaro National Park (0.68-0.74; Zylstra and Steidl 2009). We believe variation in occupancy rates across the range of the desert tortoise in Arizona are driven by variation in tortoise abundance, especially given the link between these two state variables (Royle and Nichols 2003, MacKenzie et al. 2006).

Our hypothesis that desert tortoise occupancy would be influenced by soil composition was supported by our analysis. Desert tortoise occupancy was higher in soils with well-defined horizons (i.e., Aridisols) when compared to soils lacking horizons (i.e., Entisols). Desert tortoises were detected in four Aridisol soil groups compared to two Entisol soil groups. The well-defined calcic and hardened petrocalcic or duripan horizons in Aridisol soil groups maintain shelter structure and support deeper, more permanent shelter sites and are therefore more suitable for desert tortoise occupancy.

The probability of desert tortoise occupancy was highest for petrocalcic soils. While two subgroups of petrocalcic soils existed within the study area, more desert tortoises were detected in calcic petrocalcic soils compared to argic petrocalcic soils. Calcic petrocalcids were characterized by a calcic horizon overlying a petrocalcic horizon (USDA 1975). The calcic horizon is essentially a mineral soil horizon with a secondary calcium carbonate deposition, the petrocalcic horizon characterized by a high concentration of calcium carbonate. In advanced stages of soil development, calcic horizons are cemented into hardened petrocalcic horizons (Hendricks 1985). This accumulation of calcium carbonate cements the parent soil material and creates what is more commonly referred to as the caliche layer (Figure 3) provides as a stable ceiling for desert tortoise burrows. When caliche is exposed by erosional processes such as wind or the flow of water, desert tortoises are able to take advantage of the stability of the caliche layer and create deep, permanent shelters beneath it (Germano et al. 1994, Riedle et al. 2008). Argic petrocalcids contain an argillic horizon which contains hardened clay (Hendricks 1985) that may also be exposed by erosional processes and provide stable shelter sites for desert tortoises.

Desert tortoises were detected in three additional Aridisol soil groups. Haplocalcid and haplodurid soils contain well defined horizons, the former comprised of calcic or petrocalcic horizons with a high concentration of carbonates and the latter with a hard duripan layer (USDA 1975). These characteristics provide conditions suitable for the creation of stable shelter sites similar to petrocalcids. Haplocambid soils, on the other hand, are characterized by a low degree of soil development and may lack a significant accumulation of carbonates (USDA 1975).

Although Entisol soils lack diagnostic horizons, we did detect tortoises on two Entisol soil groups. We identified a low probability of desert tortoise occupancy in torrifluent soils. Given that torrifluents were typically located on alluvial fans (Hendricks 1985) which have been shown to support low tortoise densities in Arizona (Averill-Murray and Averill-Murray 2005), this is not an unexpected result. These soils reflected the sandy substrate found within large desert washes within, and adjacent to, tortoise home ranges. Washes are an important component of desert tortoise habitat because they provide access to forage, shelter sites and are used as travel routes (Barrett 1990, Jennings 1997, Riedle et al. 2008, Grandmaison et al. 2010). Washes provide access to friable caliche soils as the erosional processes of flowing water cut through adjacent Aridisol soils. Subsequently, the exposed horizons in Aridisol soils then allow for the construction of permanent shelter sites.

Torriorthents, another Entisol soil group, had a surprisingly high probability of occupancy. Like all orthents, torriorthents lacked horizon development and were characterized by a shallow soil covering that is unaltered from their parent material (generally unconsolidated sediment or rock; Hendricks 1985). These soils are often found in steep mountainous terrain where erosional forces prevent permanent deposition and, as a result, the formation of deeper soils (Hendricks 1985). Given their location on the landscape and their association with

hillslopes and mountain slopes (Hendricks 1985), it is not surprising that given desert tortoise habitat associations with rocky outcrops in the Sonoran Desert (Barrett 1990, Germano et al. 1994), tortirothents exhibited a relatively high level of tortoise occupancy. In fact, hillslopes within the study area often contained boulder piles that provided potential shelter sites for desert tortoises. In general, most of the desert tortoise detections during this study were located in the foothills and in, or adjacent to, mountainous portions of the three ranges.

Desert tortoise occupancy was also influenced by elevation and aspect, two variables that have been identified as important predictors of desert tortoise habitat in the Mohave Desert (Andersen et al. 2000). Interestingly, we did not identify slope as a key predictor of desert tortoise occupancy as did Zylstra and Steidl (2009) in Saguaro National Park. Similarly, Grandmaison (2011) identified the presence of an incised wash and vegetation community structure to best predict tortoise occupancy.

The importance of aspect was common between Zylstra and Steidl (2009) and this study. However, whereas the former found higher occupancy probabilities for east-facing slopes, we found higher probabilities for north-facing slopes. Although substantial differences in spatial scale exist between Zylstra and Steidle (2009), Grandmaison (2011) and this study, differences seem to suggest that considerable regional variation is likely to exist in the factors influencing tortoise occupancy. Tortoises on the YPG and BMGR may utilize northern and eastern slopes as thermoregulatory response to the high temperatures and dry conditions in southwestern Arizona. As observed in the Mohave Desert, nuances in microhabitat selection may reflect adaptations for minimizing energy expenditures and reducing water loss (Zimmerman et al. 1994, Bailey et al. 1995). These slopes would be shielded from direct sunlight during parts of the day and may support different vegetation composition and microhabitats than southern and western slopes.

Home Range Characteristics

Analysis of desert tortoise home ranges corroborates the results of occupancy analyses relative to the composition of soil types within those home ranges. With the exception of torrifluent soils, desert tortoise home ranges contained each of the soil types identified as having a >0 probability of tortoise occupancy. Interestingly, torriorthents comprised the largest soil type represented within tortoise home ranges. Given the association of torriorthents with hillslopes and mountain slopes (Hendricks 1985), this result is not surprising given desert tortoise habitat associations with rocky outcrops in the Sonoran Desert (Barrett 1990, Germano et al. 1994).

Desert Tortoise Genetics

Our second objective was to characterize the phylogenetic grouping of desert tortoises on the YPG and BMGR. As expected, all of the tortoises included in the analysis were identified as Sonoran desert tortoises. The hybridization observed in the Black Mountains (McLuckie et al. 1999) does not appear to have been extended south to YPG and BMGR. The origin of the Black Mountain hybrid population is unclear. McLuckie et al. (1999) propose several hypotheses that include dispersal, river meander, and human transport. Regardless, the mechanism behind the establishment of Mojavean traits east of the Colorado River does not appear to have been replicated on the YPG and BMGR.

Future Directions

What remains to be considered with using spatial rather than temporal replication when conducting desert tortoise occupancy surveys is the presence and degree of spatial dependence among surveys within spatial subunits (i.e., soil patches). Hines et al. (2010) demonstrated that in

the absence of spatial dependence, standard occupancy models perform well whereas the existence of spatial dependence yields biased occupancy estimates. Recent developments in the design of occupancy studies (e.g., Guillera-Arroita 2011) provide additional tools for evaluating the bias of alternative methodologies related to the selection of spatial subunits and will inform the design of future occupancy studies for desert tortoises where spatial sub-units are preferred over repeat visits to discrete sites. Future evaluations of spatial dependence among spatial subunits should be used to evaluate this potential bias for modeling desert tortoise occupancy. Other methodologies for evaluating single-survey occupancy data, for example the penalized maximum-likelihood method (Lele et al. 2012) should also be explored.

Another possible source of bias in estimating occupancy for desert tortoises is the potential for false-negative errors due to sign decay (Rhodes et al. 2011) when tortoise presence and the presence of tortoise sign are used to determine occupancy. The use of indirect observations of site occupancy, in our case desert tortoise tracks and scat, are especially useful for cryptic and rare species (Jachmann 1991). This is certainly the case for desert tortoises which are notoriously difficult to detect given their cryptic nature and biology (Nagy and Medica 1986, Freilich and LaRue 1998, Andersen et al. 2000, Zylstra et al. 2010). We therefore recommend that a controlled study be conducted to quantify the decay rates of desert tortoise scat and the influence of microclimatic and/or habitat factors on those rates.

Finally, we recommend that the results of this study be tested on other military installations where desert tortoises are of conservation priority to validate the applicability of the resulting habitat model to additional planning areas. This type of model validation would evaluate the model's utility across a larger region with potential benefits for military lands in southern California, southern Nevada, and southern Utah. Combined with new sampling

methodologies currently being evaluated in the context of occupancy modeling (i.e., adaptive cluster sampling; Thompson 1990, Hines et al. 2010), these tools could be used to streamline decisions regarding desert tortoise management on military installations in the southwestern United States.

Similarly, we recommend that additional surveys be conducted in areas identified as having a relatively high probability of desert tortoise occupancy on the YPG and BMGR. Specifically, we suggest focused surveys in the Dome and Trigo mountains on YPG and the Growler and Crater mountains on BMGR. These surveys would serve to test and refine the predictive model and elucidate patterns in tortoise habitat use in this challenging environment. Annual occupancy surveys could be used to track desert tortoise populations and are likely to be more efficient than survey methodologies designed to estimate abundance and/or density (Tyre et al. 2001, MacKenzie et al. 2002, Manley et al. 2002, Zylstra et al. 2010).

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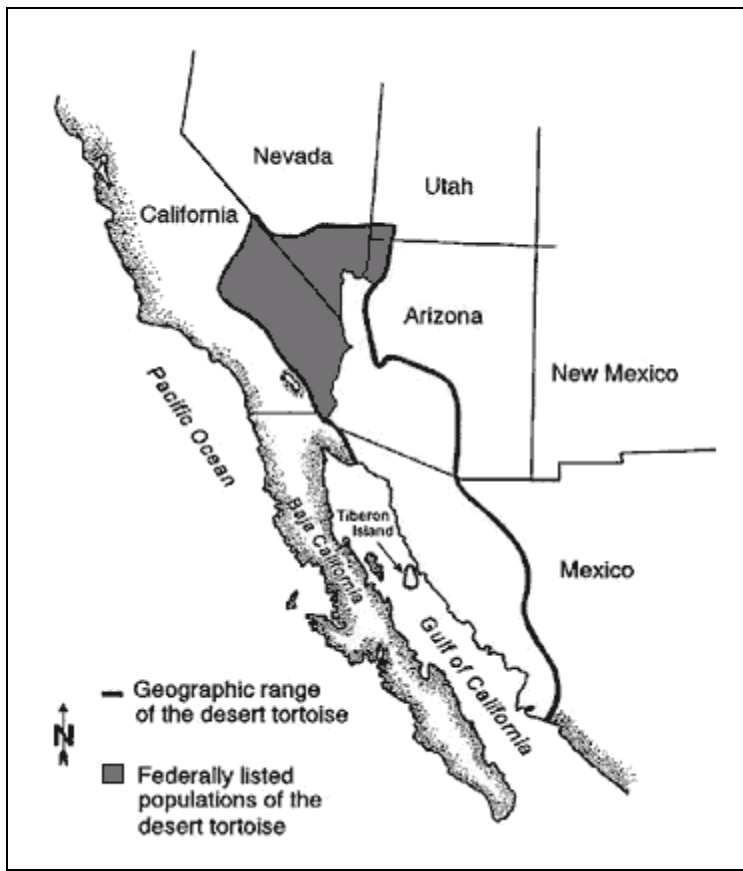


Figure 1. Geographic distribution of the desert tortoise (from Stebbins 1985 and Berry 1997).

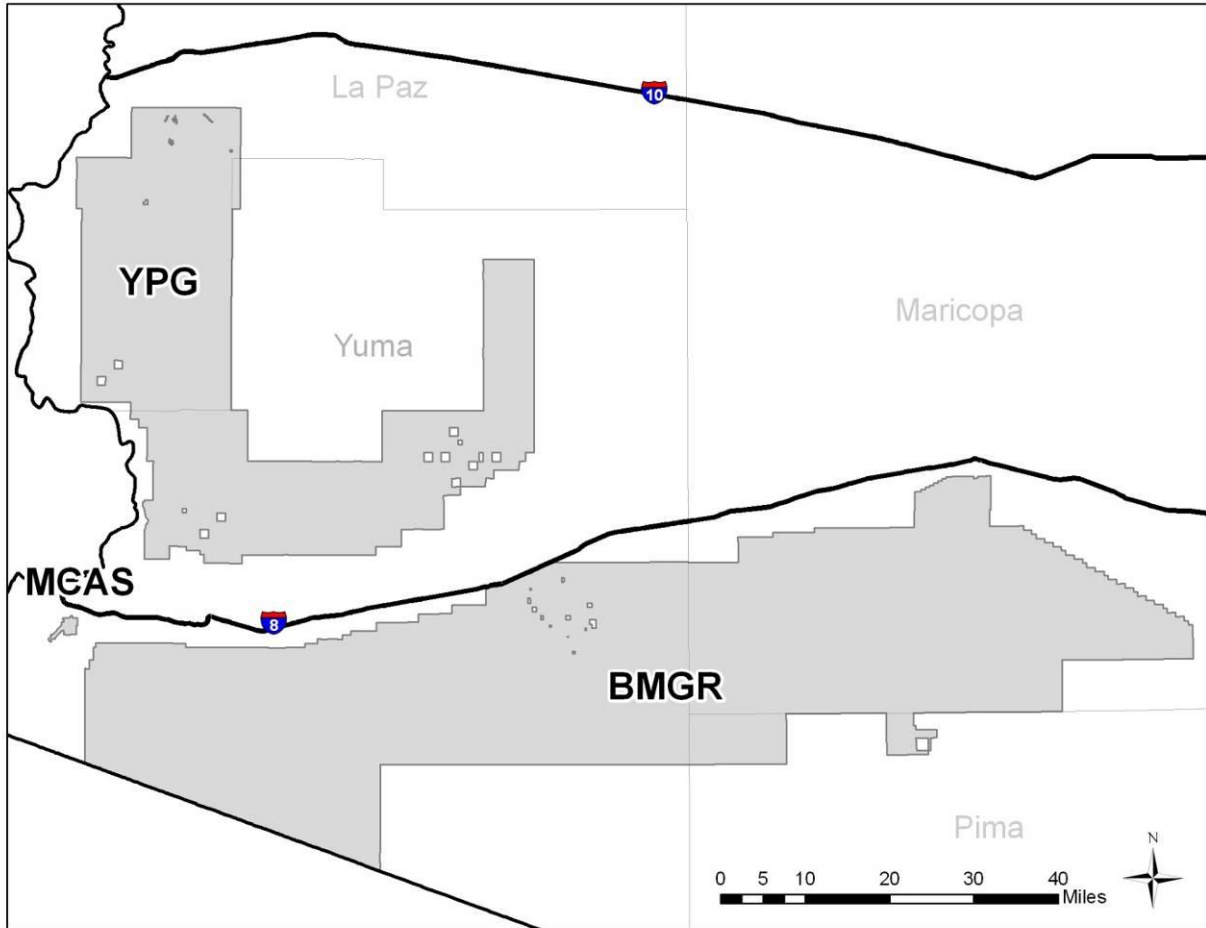


Figure 2. The three military ranges in Yuma, Maricopa and Pima counties in southwestern Arizona included in the desert tortoise landscape-level habitat modeling study. YPG (Army), BMGR-East (Air Force), and BMGR-West (Marines).



Figure 3. Biologists examining a tortoise burrow located under an exposed caliche (calcic) Aridisol soil layer in a desert wash.



Figure 4. VHF transmitter and GPS tracking unit placement on a desert tortoise.

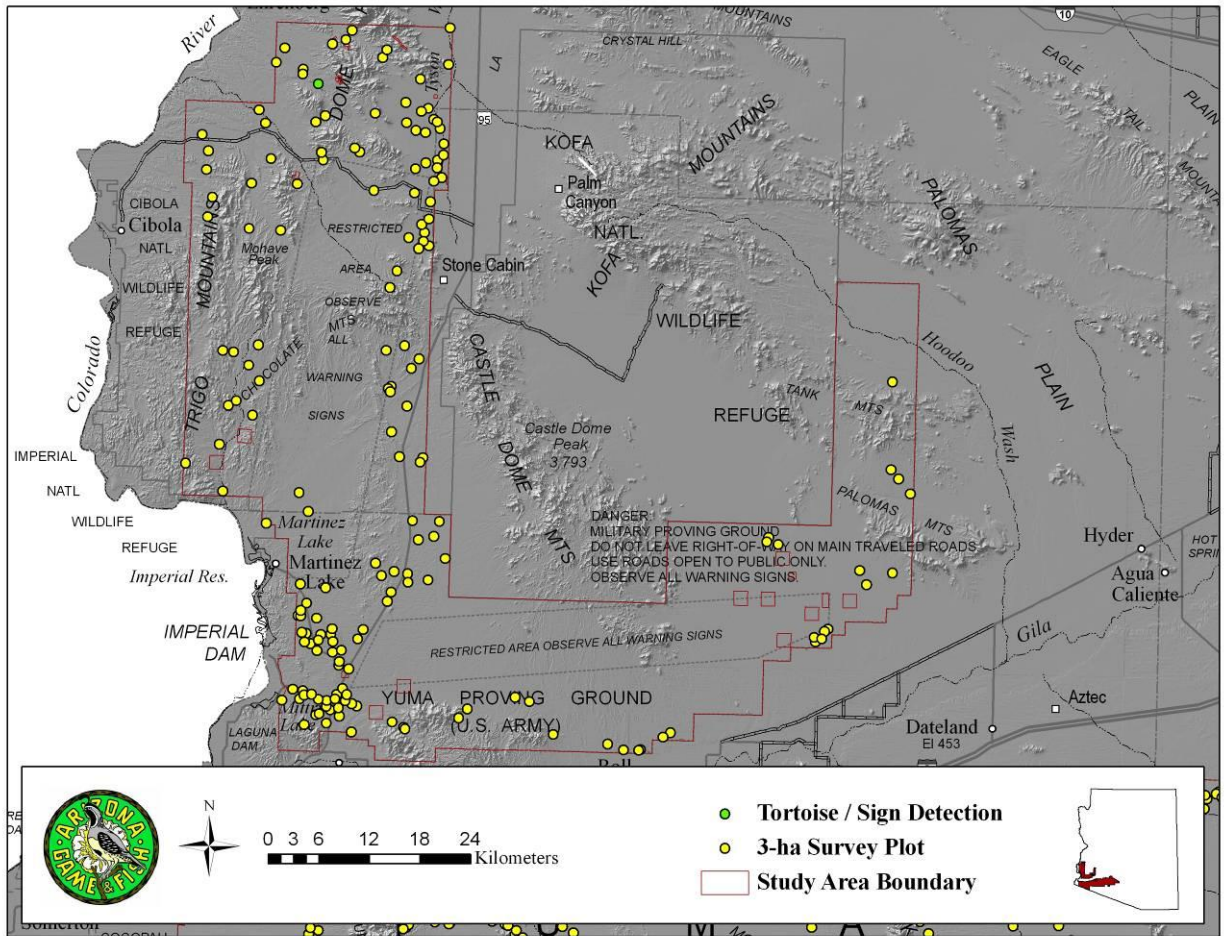


Figure 5. Distribution of 3-ha desert tortoise survey plots and detections of tortoises and/or tortoise sign on the Yuma Proving Ground in 2009 and 2010.

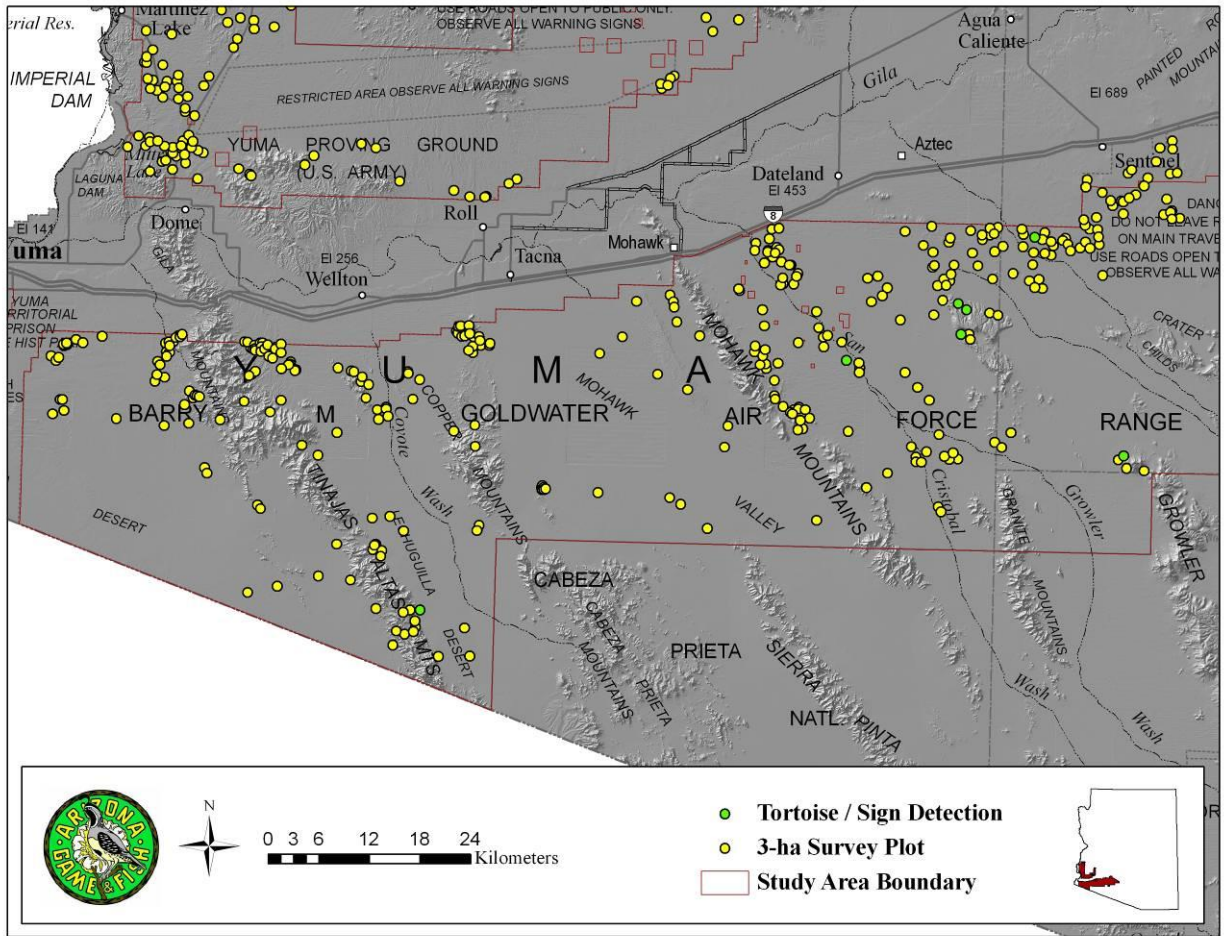


Figure 6. Distribution of 3-ha desert tortoise survey plots and detections of tortoises and/or tortoise sign on the western extent of the Barry M. Goldwater Range in 2009 and 2010.

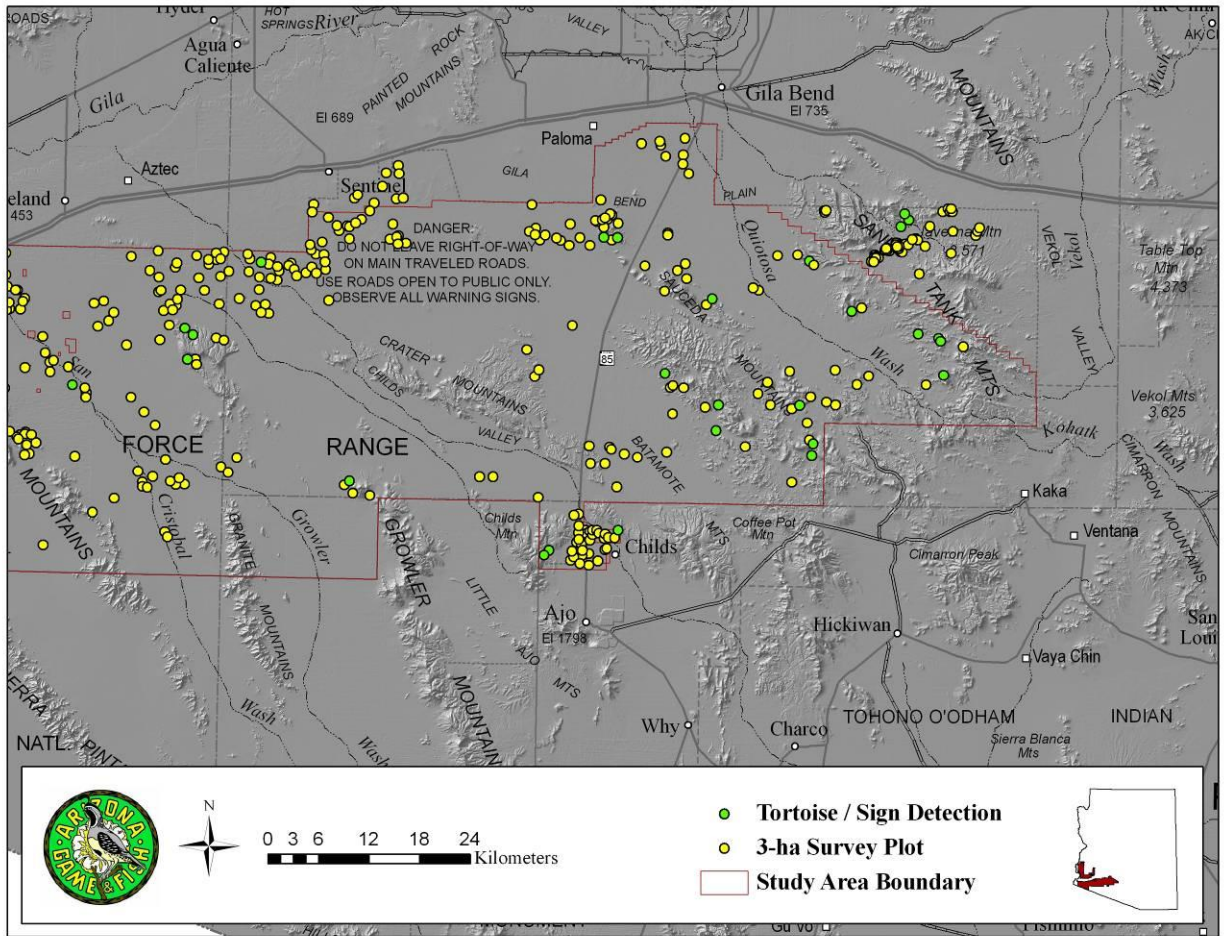


Figure 7. Distribution of 3-ha desert tortoise survey plots and detections of tortoises and/or tortoise sign on the eastern extent of the Barry M. Goldwater Range in 2009 and 2010.

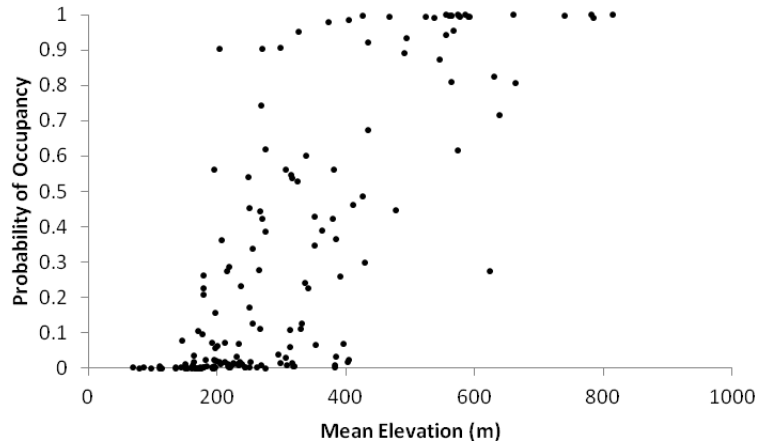


Figure 8. The relationship between elevation and the probability of desert tortoise occupancy on the Yuma Proving Ground (YPG), Barry M. Goldwater Range (BMGR) - East, and BMGR-West. Mean elevation was calculated for each soil patch and plotted against the patch-specific occupancy estimate.

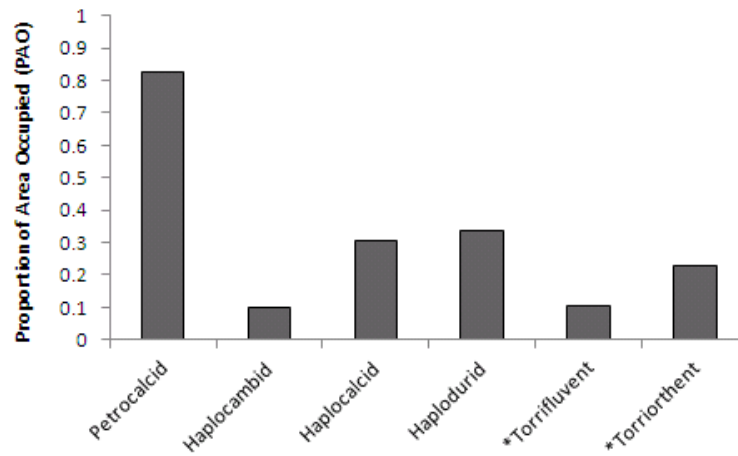


Figure 9. Proportion of area occupied by desert tortoises within each of the six soil subgroups on the Yuma Proving Ground (YPG), Barry M. Goldwater Range (BMGR) - East, and BMGR-West. Subgroups where no tortoises were detected were removed from analysis to improve model convergence. Asterisks indicate Entisol soil subgroups from Aridisol soil subgroups.

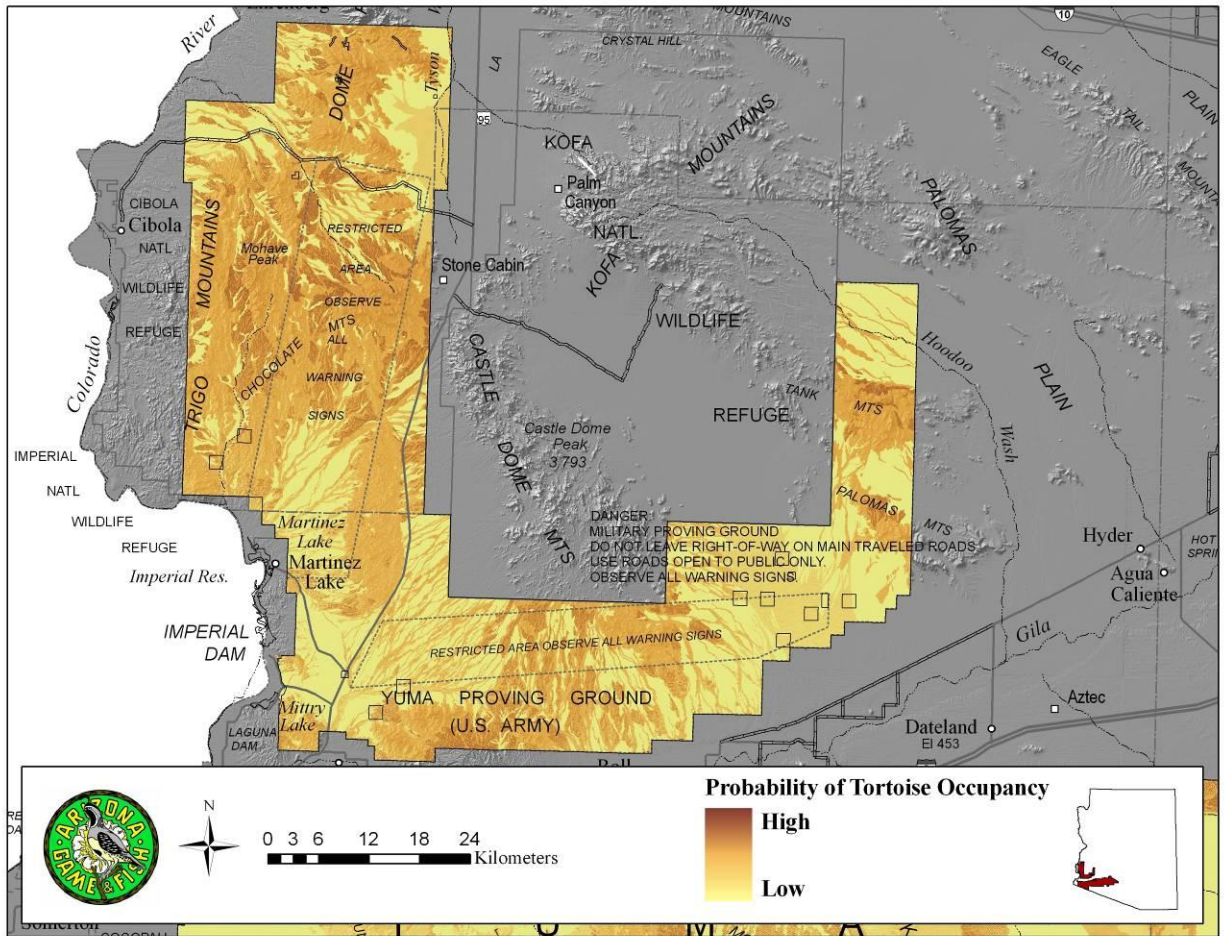


Figure 10. Modeled probability of desert tortoise occupancy on the Yuma Proving Ground.

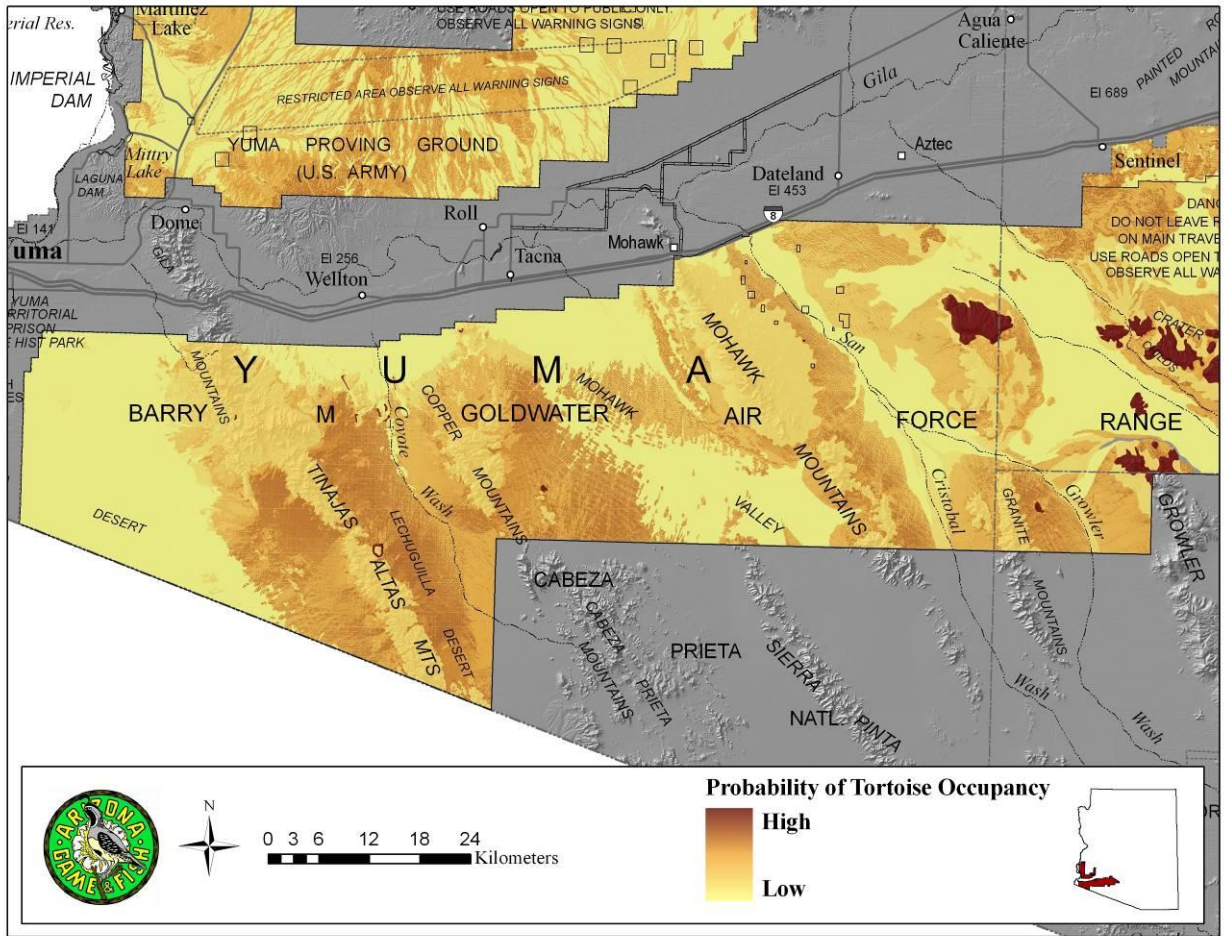


Figure 11. Modeled probability of desert tortoise occupancy on the western extent of the Barry M. Goldwater Range.

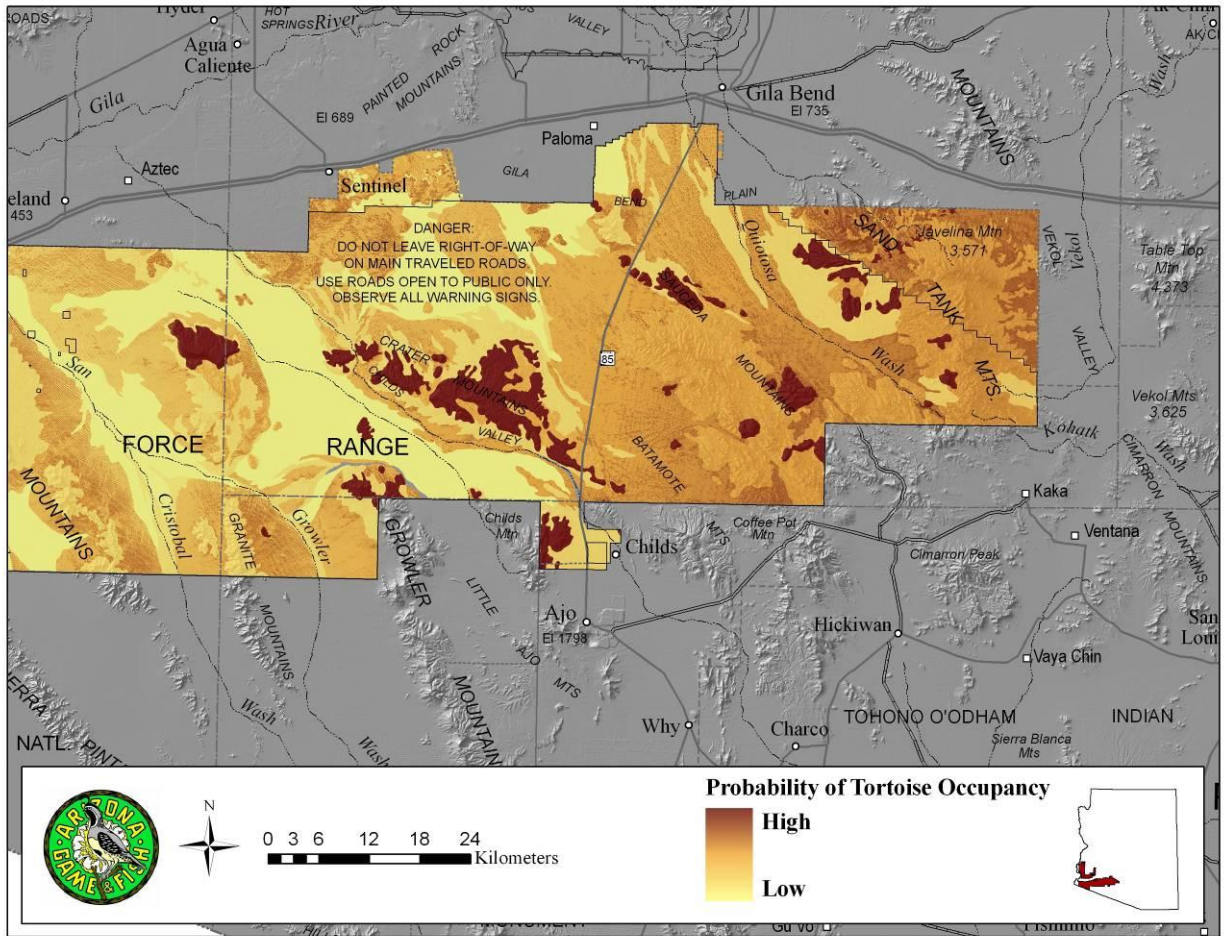


Figure 12. Modeled probability of desert tortoise occupancy on the eastern extent of the Barry M. Goldwater Range.

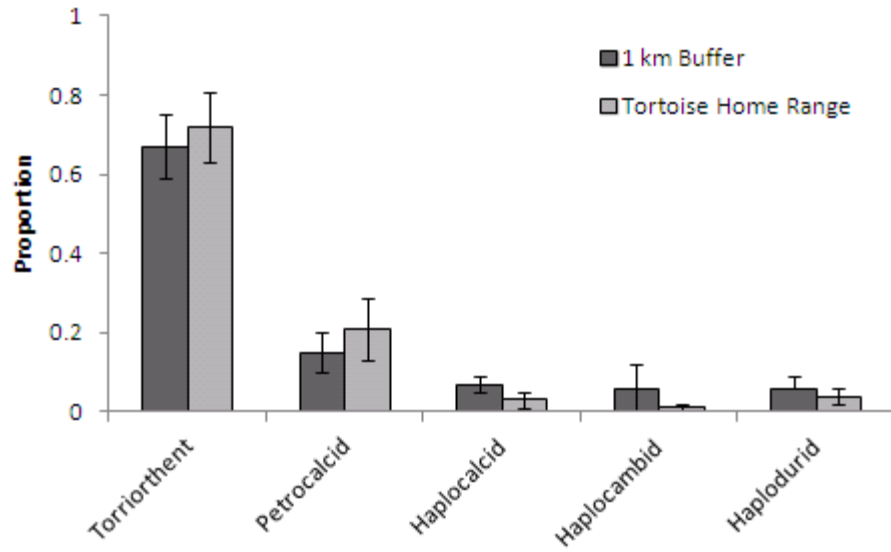


Figure 13. The mean proportion of soil categories (\pm SE) within tortoise home ranges and a 1 km buffer surrounding tortoise home ranges.

Table 1. Site- and survey-specific variables evaluated as covariates for desert tortoise occupancy and detection on military installations in southwestern Arizona.

Feature	Variable	Description
Year	YR	Indicator variable for 2009
Days Since 1 January	DAY	No. of days since 1 January of survey year
Soil	SOIL	NCSS ¹ soil subgroup designation
Relative Humidity	RH	Average relative humidity during survey (mmHg)
Temperature	TEMP	Average temperature during survey (°C)
Distance to Road	DROAD	Distance to nearest road (m)
Distance to Wash	DWASH	Distance to nearest wash (m)
Incised Wash	WASH	Indicator variable for ≥ 1 incised wash
Slope	SLOPE	Standardized mean slope of survey plot (°)
Elevation	ELEV	Standardized mean elevation of site (m)
Aspect	AspN	Proportion of site N-facing
	AspE	Proportion of site E-facing
	AspS	Proportion of site S-facing

¹National Cooperative Soil Survey

Table 2. Capture data for desert tortoises detected during survey and telemetry efforts in 2009 and 2010.

Capture Date	Tortoise ID	Survey Detection	Gender	MCL (mm)	Age Class	Mountain Range	Weight (g)
9/27/2009	500	X	Female	239	Adult	Sauceda	2,650
7/12/2010	502		Female	230	Adult	Sauceda	2,100
9/22/2010	503		Female	250	Adult	Sauceda	2,400
4/15/2010	505	X	Male	280	Adult	Sand Tank	3,300
9/7/2010	510	X	Unknown	163	Subadult	Batamote	1,150
9/22/2010	511		Female	243	Adult	Batamote	3,500
7/31/2010	520		Female	226	Adult	Sand Tank	2,600
7/31/2010	521		Unknown	145	Juvenile	Sauceda	600
7/24/2010	530	X	Female	222	Adult	Growler	1,600
6/8/2009	551		Female	168	Subadult	Sand Tank	820
6/9/2009	552		Female	240	Adult	Sauceda	2,900
6/9/2009	553		Female	250	Adult	Sauceda	2,300
6/9/2009	554		Male	252	Adult	Sauceda	2,900
6/9/2009	555		Male	253	Adult	Sauceda	1,900
10/9/2010	601		Male	205	Adult	Sauceda	2,100
7/18/2009	656		Female	224	Adult	Sand Tank	unk
9/27/2009	701		Male	221	Adult	Sauceda	1,900
8/14/2010	702		Female	250	Adult	Sauceda	1,540
10/6/2010	703	X	Female	204	Adult	Sand Tank	1,900
10/6/2010	704	X	Unknown	47	Hatchling	Sand Tank	30
10/9/2010	705	X	Male	222	Adult	Sand Tank	2,400
10/21/2010	721		Male	260	Adult	Sauceda	2,850
6/9/2009	.		Unknown	.	.	Sauceda	unk
9/7/2010	.		Unknown	.	Adult	White Hills	unk
9/7/2010	.		Unknown	.	Adult	White Hills	unk

Table 3. Comparison of models explaining the relationship between site-specific variables and desert tortoise occupancy (ψ) on the Yuma Proving Ground (YPG), Barry M. Goldwater Range (BMGR) - East, and BMGR-West. Results are based on a general model for tortoise detection: $p(\text{survey year} + \text{Julian day} + \text{relative humidity} + \text{temperature} + \text{presence of } \geq 1 \text{ incised wash})$.

Model	Log-Likelihood	No. Parameters	AIC	AIC _c	Δ AIC _c	w
$\psi(\text{Aspect} + \text{Elevation} + \text{Soil})$	147.06	15	177.06	180.30	0.00	0.9999
$\psi(\text{Elevation} + \text{Soil})$	172.23	12	196.23	198.30	17.99	0.0001
$\psi(\text{Soil})$	180.35	11	202.35	204.09	23.78	0.0000
$\psi(\text{Droad} + \text{Soil})$	178.21	12	202.21	204.28	23.97	0.0000
$\psi(\text{Slope} + \text{Soil})$	178.36	12	202.36	204.43	24.12	0.0000
$\psi(\text{Aspect} + \text{Soil})$	174.5	14	202.50	205.32	25.02	0.0000
$\psi(\text{DWash} + \text{Soil})$	180.23	12	204.23	206.30	25.99	0.0000
$\psi(\text{Wash} + \text{Soil})$	180.26	12	204.26	206.33	26.02	0.0000
$\psi(\text{Aspect} + \text{Slope} + \text{Soil})$	175.51	15	205.51	208.75	28.45	0.0000
$\psi(\cdot)$	196.39	6	208.39	208.93	28.62	0.0000
$\psi(\text{Wash})$	196.43	6	208.43	208.97	28.66	0.0000
$\psi(\text{DWash})$	197.02	6	209.02	209.56	29.25	0.0000
$\psi(\text{DWash} + \text{Slope})$	194.93	7	208.93	209.65	29.34	0.0000
$\psi(\text{Slope})$	197.31	6	209.31	209.85	29.54	0.0000
$\psi(\text{Elevation})$	197.7	6	209.70	210.24	29.93	0.0000
$\psi(\text{DRoad})$	198.05	6	210.05	210.59	30.28	0.0000
$\psi(\text{Elevation} + \text{Slope})$	197.31	7	211.31	212.03	31.72	0.0000
$\psi(\text{Aspect} + \text{Wash})$	193.91	9	211.91	213.08	32.78	0.0000
$\psi(\text{Aspect})$	197.16	8	213.16	214.09	33.79	0.0000
$\psi(\text{Aspect} + \text{Slope})$	195.02	9	213.02	214.19	33.89	0.0000
$\psi(\text{Aspect} + \text{Elevation})$	195.51	9	213.51	214.68	34.38	0.0000
$\psi(\text{Aspect} + \text{DWash})$	195.83	9	213.83	215.00	34.70	0.0000
$\psi(\text{Aspect} + \text{Elevation} + \text{Slope})$	194.56	10	214.56	216.00	35.69	0.0000

Table 4. Comparison of models explaining the relationship between survey-specific variables and desert tortoise detection probabilities (p) on the Yuma Proving Ground (YPG), Barry M. Goldwater Range (BMGR) - East, and BMGR-West. Results are based on the top model for tortoise occupancy identified in step 1 of the analysis: $\psi(\text{Aspect}+\text{Elevation}+\text{Soil})$.

Model	Log-Likelihood	No. Parameters	AIC	AIC _c	ΔAIC_c	w
$p(\text{Day}+\text{RH})$	176.99	12	200.99	203.06	0.00	0.4355
$p(\text{Day})$	180.62	11	202.62	204.36	1.30	0.2273
$p(\text{Day}+\text{TEMP})$	180.36	12	204.36	206.43	3.37	0.0808
$p(\text{Year}+\text{Day})$	180.43	12	204.43	206.50	3.44	0.0780
$p(\text{Year}+\text{Day}+\text{RH}+\text{TEMP})$	176.53	14	204.53	207.35	4.29	0.0509
$p(\text{TEMP})$	183.68	11	205.68	207.42	4.36	0.0492
$p(\text{Year}+\text{Day}+\text{TEMP})$	180.21	13	206.21	208.64	5.58	0.0267
$p(\text{RH})$	185.17	11	207.17	208.91	5.85	0.0234
$p(\text{Year}+\text{TEMP})$	183.28	12	207.28	209.35	6.29	0.0188
$p(\text{Year}+\text{RH})$	184.63	12	208.63	210.70	7.64	0.0095
$p(\text{Year})$	201.68	11	223.68	225.42	22.36	0.0000
$p(\text{Wash})$	206.67	11	228.67	230.41	27.35	0.0000

Table 5. Top-ranking models describing desert tortoise occupancy along with overall occupancy estimates and SE for the Yuma Proving Ground (YPG), Barry M. Goldwater Range (BMGR) - East, and BMGR-West.

Model	Log-Likelihood	No. Parameters	AIC	AIC _c	ΔAIC_c	w	Ψ	SE(ψ)
$\psi(\text{Aspect}+\text{Elevation}+\text{Soil}), p(\text{Day}+\text{RH})$	176.99	12	200.99	203.06	0.00	0.6571	0.31	0.07
$\psi(\text{Aspect}+\text{Elevation}+\text{Soil}), p(\text{Day})$	180.62	11	202.62	204.36	1.30	0.3429	0.29	0.58

Table 6. Parameter estimates and standard errors for aspect derived from the top ranked occupancy model for desert tortoises on the Yuma Proving Ground (YPG), Barry M. Goldwater Range (BMGR) - East, and BMGR-West.

Parameter	Estimate	SE
Aspect N	8.615	3.200
Aspect E	3.700	3.083
Aspect S	6.770	3.270

Table 7. Brownian Bridge Movement Model (BBMM) home range and core area estimates for 16 Sonoran desert tortoises (*Gopherus morafkai*) tracked with GPS tracking units in 2009 and 2010. Minimum convex polygon (MCP) home range estimates are also included for comparison with previous desert tortoise studies.

Tortoise ID	Sex	MCL ¹ (mm)	BBMM ² Home Range (ha)	BBMM Core Area (ha)	MCP ³ Home Range (ha)
500	Female	239	70.2181	1.5513	23.7570
502	Female	230	34.1703	0.8049	4.1031
505	Male	280	25.7968	2.2772	6.5238
510	Male	163	23.7621	0.4137	0.9219
520	Female	226	70.0473	0.9700	3.0405
551	Female	168	18.8387	0.1550	1.9516
552	Female	240	49.9057	1.2850	5.4038
553	Female	250	16.9440	1.3163	3.7618
554	Male	252	61.9845	1.7001	14.8815
656	Female	224	50.4561	0.6538	4.2108
701	Male	221	26.2842	0.8788	1.9855
702	Female	250	39.6982	0.3813	8.1241
703	Male	204	60.6523	2.9003	12.1856
720	Female	225	59.8661	0.8963	17.3710
721	Male	260	34.9182	2.0413	10.9731
723	Female	250	24.3681	2.0038	10.3018

¹MCL = Midline Carapace Length

²BBMM = Brownian Bridge Movement Model

³MCP = Minimum Convex Polygon

Table 8. Proportions of soil categories within desert tortoise home ranges estimated using Brownian Bridge Movement Models based on movement data collected in 2009 and 2010.

Tortoise ID	Torriorthent	Petrocalcid	Haplocalcid	Haplocambid	Haplodurid
500	0.22	0.78	0.00	0.00	0.00
502	0.39	0.61	0.00	0.00	0.00
505	0.62	0.00	0.00	0.00	0.38
510	0.00	0.77	0.00	0.23	0.00
520	1.00	0.00	0.00	0.00	0.00
551	1.00	0.00	0.00	0.00	0.00
552	0.67	0.00	0.33	0.00	0.00
553	0.56	0.44	0.00	0.00	0.00
554	0.88	0.12	0.00	0.00	0.00
656	1.00	0.00	0.00	0.00	0.00
701	1.00	0.00	0.00	0.00	0.00
702	1.00	0.00	0.00	0.00	0.00
703	0.19	0.63	0.09	0.00	0.09
720	1.00	0.00	0.00	0.00	0.00
721	1.00	0.00	0.00	0.00	0.00
723	0.91	0.00	0.00	0.00	0.09

Table 9. Comparison of the proportion of soil categories within tortoise home ranges and 1 km buffers surrounding tortoise home ranges.

Soil Category	1 km Buffer		Tortoise Home Range		Z	P
	Mean	SE	Mean	SE		
Torriorthent	0.67	0.08	0.72	0.09	0.39	0.69
Petrocalcid	0.15	0.05	0.21	0.08	0.61	0.54
Haplocalcid	0.07	0.02	0.03	0.02	-1.30	0.19
Haplocambid	0.06	0.06	0.01	0.01	-0.72	0.47
Haplodurid	0.06	0.03	0.04	0.02	-0.55	0.93

APPENDIX I



Digital Soil Subgroup Map of Selected Areas of the Barry M. Goldwater Range for Arizona Game and Fish

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Nauman Geospatial LLC

Deliverable for AZGF PO #E0075088

Overview

Soil resources in four areas of the Barry M. Goldwater Range (BMGR) of Arizona were never previously mapped leaving a gap in knowledge for this important resource. These unmapped areas are mostly located adjacent to areas that have been mapped in the past by the National Cooperative Soil Survey (NCSS) division of the Natural Resources Conservation Service (NRCS), a branch of the United States Department of Agriculture (USDA). Initial aerial survey of the area indicated that these adjacent surveys looked to cover areas with similar soils to those of the unmapped BMGR areas. So, this project aimed to use those adjacent soil surveys to create a predictive digital soil map of these unmapped areas of BMGR for use in analysis of Desert Tortoise monitoring done by Arizona Department of Game and Fish (AZGF). This report documents the methods and strength of the digital map created by Nauman Geospatial LLC in fulfillment of a purchase order from AZGF for a soil subgroup map of the unmapped BMGR lands.

Summary

The digital map for the deliverable was modeled with a maximum likelihood supervised classification technique linking NCSS map units with 8 environmental raster datasets derived from Landsat TM satellite imagery and the United States Geologic Survey National Elevation Dataset (NED). The four unmapped parts of BMGR were modeled separately so models could use only the nearby polygons that looked similar to each area to improve model detection power. Accuracy of map-unit classifications ranged from 53% to 78% with an overall accuracy of 63% in training areas. Since a field validation in the unmapped areas was beyond the resource scope of this project, no direct accuracy measures are available in those areas in this report. So although the goal of the project was to map these previously unmapped areas, the maps made were extrapolated from other surveys, and must be used with caution until field validations are implemented. However, the surrounding surveys did appear to have similar landscape to the unmapped areas and survey edges matched reasonably well. To the extent that the original NCSS surveys were done accurately it was observed that the models applied to the unmapped areas capture the same soil patterns.

Methods and Data

The overall theory for this mapping came from a body of work titled Digital Soil Mapping (DSM) or Predictive Soil Mapping (McBratney et al., 2003; Scull et al., 2003). This field has focused on using spatially intensive raster datasets to map soils and makes use of environmental data in these formats from Remote Sensing (RS) satellites and Digital Elevation Models (DEM) to help predict soils across areas too vast to fully field map.

Many different sampling techniques have been used in DSM studies, but of interest for this study was using an existing soil map to model an adjacent plot of land, in this case BMGR. Several studies have applied this with examples including mapping of relatively arid landscapes by Scull et. al. (2005) and Cole and Boettinger (2007). For this project, a maximum likelihood model was used to create the model in a similar fashion to Cole and Boettinger. Maximum likelihood models link independent continuous data variables (the spatially dense rasters) to a dependent nominal variable (NCSS soil classes in this case).

Data from three soil surveys was used to train the model to map the BMGR gaps. Polygons were selected from surveys az653 (U.S. Department of Agriculture, 2006), az649 (U.S. Department of Agriculture, 2008b), and az647 (U.S. Department of Agriculture, 2008a) for use in the model based on proximity to the gaps and visual similarity using a Landsat composite RGB (432) visualization. NCSS mapunits were used as the soil class category to be modeled.

B7B1	102.14	Band Ratio
B7B3	40.97	Band Ratio
CURVATURE	0.936	Elevation 2 nd derivative
NDVI_DRY*	204.97	June Landsat vegetation index (B4 - B3) / (B4 + B3)
NDVI_WET	103.06	MODIS based NDVI in August
NEDLP_DIFF25	10.68	Pixel elevation difference from the mean elevation in a 25 pixel radius: slope position proxy.
SCA_MERGE	1.475	D _{net} Upstream surface flow contribution (Tarboton, 1997)
SLOPE_NEDLP*	275.67	Slope calculated from NED elevation values
TWI_MERGED*	211.8	Topographic Wetness Index (Yang et al., 2007)

Final variable selection was based on a One Way ANOVAs done on each variable looking for variables that distinguished soil units in survey 647 as well as units of 653 and 649 adjacent to the unmapped BMGR areas. A 13,184 stratified random sample was created in Quantum GIS (<http://www.qgis.org/>), an open-source GIS, in these units to do the analysis. Actual One Way analysis was done in WinIDAMS, and open-source statistics software (http://portal.unesco.org/ci/en/ev.php-URL_ID=2070&URL_DO=DO_TOPIC&URL_SECTION=201.html).

Maximum likelihood modeling resulted in 30-meter pixel raster classifications which were ultimately transformed into polygons like those of NCSS soil maps. The process of transforming these included iteratively using a majority filter algorithm in ILWIS (<http://www.itc.nl/ilwis/>), another open source GIS software. This filter takes out noisy pixels and creates groupings of like pixels that form more polygonal shapes. Then, the raster is transformed to a vector representation in SAGA. Resulting polygons were then thinned of units smaller than the minimum unit size for the soil survey scale used in training. Units smaller than the minimum sized were merged with the adjacent polygon that occupies the greatest length border. In this case, the three surveys used were mapped at generally order 3 scale, and 10 hectares was used for a minimum mapping unit size because it was roughly the middle of the range specified in the NCSS soil survey manual (Staff, 1993). Quantum GIS was used to merge all polygons less than this size with the adjacent unit with the greatest boundary to get final map units.

Results

Overall classification accuracy was 63% with the classification parts varying from 53% to 78%. The smaller northern and southern unmapped areas showed the highest accuracy while the larger east and west gaps showed lower percentages (Table 2). Accuracies were measured before transforming raster classifications to polygons in order to directly reflect model performance. Table 2 summarizes correctly classified pixels in all the model areas for both the full model and the training/validation dataset. The similar accuracies seen in the full model and validation dataset indicate that the model was robust for prediction. This suggested that as long as the unmapped areas contained the same population of soils

as the training areas (as was assumed and expected for model design), accuracies should be similar in the unmapped areas. The larger Western and Eastern model areas showed lower accuracies probably due to their size and the large number of relatively similar soils in map units. Mapunits, especially in alluvial fans and basin floors, generally were composed of complexes that include multiple soil series which can dilute the purity of the mapunits for classification training, and probably lowered accuracies in the eastern and western models where there were larger areas of alluvial complexes.

Table 2 Classification accuracies are shown in % correct classified in training areas. The Full Classification columns show accuracies for the entire area used for model training. The other columns show accuracies of an independent validation sample taken from a model built from a separate training sample.

Piece	Full Classification			Randomly Sampled Training Area Validation			
	Correct	Total	% Correct	Correct	Total	% Correct	% Area Sampled for Validation Procedure
West	620478	1012163	61.3%	2031	3293	61.7%	1.0%
East	180714	340856	53.0%	1696	3269	51.9%	2.9%
South	96212	122627	78.5%	780	998	78.2%	2.4%
North	182712	239439	76.3%	2512	3273	76.7%	4.1%
OVERALL	1080116	1716085	63.0%	7018	10853	64.7%	1.9%

Discussion

Although accuracies seemed low at first glance, there are a number of factors considered that actually helped to support results as satisfactory. NCSS soil surveys are not done in a quantitative manner that documents true errors. As such, when using these soil surveys to model, the base data being used has an unknown error rate. To compound this, the NCSS mapunits in the surveys used were mainly multi-component complexes that include multiple distinct soils that might have quite different properties and also be present in other complexes making some complexes too generalized to predict well. This meant that the model was often generalizing multiple soil series into one map unit making discrimination between map units harder. Most map units in soil surveys also include 'inclusions' such as gullies and washes that were likely classified in error in many cases and would directly skew accuracy downwards at least 10 to 15 just because they were generalized in the soil survey as the same as the map unit. Indeed, other similar studies have shown accuracy rates in a similar range of 60% to 80% (McBratney et al., 2003; Scull et al., 2005; Scull et al., 2003). A model with a true statistical ground sample of actual soil properties would probably yield higher accuracies, but is more expensive. It is recommended that at least some kind of ground validation is done in unmapped areas in the future as accuracies now only apply to the training areas, and only by assumption can we infer that to the newly mapped areas.

Please direct any questions or comments to travis@naumangeospatial.com.

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APPENDIX II

Summary of Arizona Tortoise Data for Dave Grandmaison (AGFD)

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08 March 2012

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SUMMARY

We obtained a total of 156 wild tortoise blood samples collected in Arizona by David Grandmaison between 2006 and 2010. We genotyped each individual to determine its maternal lineage (mtDNA) and species assignment (25 STR loci). We observed that the majority of sampled individuals were consistent with other samples of *G. morafkai* in the Sonoran Desert of Arizona, but individuals at two sites (West Black Mountains and East Bajada) genotyped as *G. agassizii*. We observed two individuals at the East Bajada site that have conflicting STR and mtDNA assignments and are likely hybrids. This site occurs along an ecotone between Sonoran and Mojavian vegetative communities and these findings are consistent with previous studies.

METHODS

DNA isolation:

We isolated total DNA from red-blood cells by overnight lysis with proteinase K at 55°C, followed by robotic extraction using a QIAGEN BioSprint 96 robotic magnetic-particle purification system (Qiagen; Valencia, CA USA) and Invitrogen Dynal bead extraction chemistry (Life technologies, USA). We quantified recovered DNA using a BioTEK Synergy HT (BioTEK, Vermont, USA) and diluted working stocks to a 5ng/μl for polymerase chain reaction (PCR) amplifications.

Mitochondrial DNA

We amplified an approximately 1,500 base pair (bp) portion of the ND3, arginine tRNA, ND4L, and part of the ND4 genes using primers Nap2 and New Gly (Arévalo et al. 1994, Britten et al. 1997). We followed Edwards (2003) and Murphy et al. (2007) for polymerase chain reaction (PCR) conditions. We submitted PCR product to the University of Arizona Genetics Core for DNA sequencing on a 3730XL DNA Analyzer (Applied Biosystems). We aligned an 1109 bp sequence using CLC DNA Workbench ver. 5.7.1 (CLC bio, Denmark) and compared individuals to a reference database of mtDNA haplotypes representing all *Gopherus* species; *G. agassizii* (n = 125), *G. morafkai* (n = 192), *G. berlandieri* (n = 58), *G. flavomarginatus* (n = 78), and *G. polyphemus* (n = 1). A portion of these same reference individuals were used previously to describe desert tortoise genetic structure (Edwards 2003, Murphy et al. 2007, Edwards et al. 2010). The different species of *Gopherus* exhibit fixed differences in mtDNA (Lamb et al. 1989, McLuckie et al. 1999, Murphy et al. 2007, Edwards et al. 2010, Murphy et al. 2011).

STRs

We tested all samples for 25 previously described short tandem repeats (STRs): FitzSimmons et al. (1995), Cm58; Edwards et al. (2003), Goag03, Goag04, Goag05, Goag06, Goag07, Goag32; Hauswaldt and Glenn (2003), Test56; Schwartz et al. (2003), GP15, GP19, GP30, GP55, GP61, GP81, GP96 GP102; Edwards et al. (2011), ROM01, ROM02, ROM03, ROM04, ROM05, ROM07, ROM10; Davy et al. (2011), ROM08, ROM09. We combined loci into nine different multiplex PCRs following methods described in Edwards et al. (2003), Murphy et al. (2007), and Edwards et al. (2011). For loci that failed to amplify, we reran samples in uniplex reactions. We combined post-PCR products prior to fragment analysis and submitted them to the University of Arizona Genetics Core for fragment analysis on a 3730 DNA Analyzer (Applied Biosystems). We analyzed electropherograms using Genemarker 1.85 (SoftGenetics, State College, PA USA)

Analysis

For STR data, we assessed population association of the captive samples using the assignment test in program WHICHRUN (Ver. 4.1; Banks and Eichert 2000). The program calculates the likelihood of a given individual originating from ≥ 2 candidate populations, on the basis of its multilocus STR genotype. We made the assumption of Hardy-Weinberg and linkage equilibrium in reference populations. We assessed stringency for population allocation with the selection criterion of the log of the odds ratio (LOD) for the 2 most likely source populations. Assignments with a LOD ratio of ≥ 2 have a ≤ 0.01 chance of error. Our comparative reference database consisted of 656 *G. agassizii* samples (Murphy et al. 2007) and 226 *G. morafkai* samples collected in Arizona. A portion of these same reference individuals were used in previous studies (Edwards et al. 2004, Murphy et al. 2007, Edwards et al. 2010).

RESULTS

We successfully produced STR genotypes for 155 individuals and mtDNA sequences for 125 individuals (Table 1). The majority of samples collected in Arizona were consistent with being “native” *G. morafkai* both from STR assignment tests and mtDNA lineages. Two populations had individuals that were genotypically *G. agassizii* (West Black Mountains and East Bajada). Two individuals sampled from East Bajada (EB_35 and EB_36) had inconsistent assignments between mtDNA and STR assignments, suggestive that they are hybrids. These results are consistent with previous findings in this region (McLuckie et al. 1999, Edwards et al. 2010).

Table 1. MtDNA haplotype results and population assignment results for 156 desert tortoise samples collected in Arizona. Haplotypes were defined per Murphy et al. (2007): The “MOJ_A” haplogroup is ubiquitous in the Mojave Desert in California while SON_01 is the most abundant haplotype observed across the range of *G. morafkai*. For assignment testing, we compared a 25 locus genotype for captive individuals to a database of 656 *G. agassizii* and 226 *G. morafkai*. *P* indicates probability of assignment. LOD indicates the log of the odds ratio between the two source population assignment probabilities. Population assignments without an LOD score had <0.0001 probability of being assigned to the alternative population.

Sample	Most likely assignment	<i>P</i>	LOD	mtDNA haplogroup	Notes
WBM_500	Mojave	3.35E-23		MOJ_A01	
WBM_700	Mojave	2.21E-19		MOJ_A01	
WBM_702	Mojave	1.10E-22	7.83E+22		
WBM_708	Mojave	1.84E-28			
WBM_709	Mojave	1.87E-24		MOJ_A01	
WBM_710	Mojave	1.16E-16	8.25E+20	MOJ_B01	
WBM_801	Mojave	8.49E-17	5.31E+25		
WBM_802	Mojave	2.18E-27		MOJ_A01	
WBM_803	Mojave	2.29E-25		MOJ_A01	
WBM_810	Mojave	1.08E-27		MOJ_A01	
WBM_811	Mojave	1.24E-25		MOJ_A01	
WBM_902	Mojave	1.51E-26		MOJ_A01	
EB_041	Mojave	2.03E-16	1.31E+22		
EB_043	Mojave	1.90E-23	2.03E+19	MOJ_A1	
EB_048	Mojave	8.60E-23		MOJ_A01	
EB_049	Mojave	3.25E-25			
EB_046	Mojave	1.15E-32	1.70E+09	SON_01	Possible Hybrid
EB_035	Sonoran	1.80E-38		MOJ_A1	Possible Hybrid
AM_008	Sonoran	8.97E-22		SON_01	
AM_010	Sonoran	4.94E-28	1.39E+09	SON_01	
AM_021	Sonoran	2.34E-26		SON_01	
AM_024	Sonoran	5.37E-22	2.94E+15	SON_01	
BMGR_500	Sonoran	2.12E-25		SON_01	

BMGR_502	Sonoran	1.59E-22		SON_01
BMGR_510	Sonoran	4.78E-31		
BMGR_511	Sonoran	1.94E-30		
BMGR_551	Sonoran	4.42E-17		
BMGR_552	Sonoran	1.02E-28		SON_01
BMGR_554	Sonoran	1.23E-20	1.56E+23	SON_01
BMGR_656b	Sonoran	1.59E-28		SON_01
BMGR_701	Sonoran	7.86E-24		SON_01
BMGR_702	Sonoran	8.63E-28		SON_01
BMGR_721	Sonoran	8.61E-28		
BW_024	Sonoran	2.54E-19		SON_01
BW_031	Sonoran	1.09E-18	1.12E+16	SON_01
BW_034	Sonoran	8.46E-32		SON_05
BW_036	Sonoran	3.97E-30		SON_01
BW_039	Sonoran	4.54E-21		SON_01
ET_008	Sonoran	1.29E-22		SON_01
ET_009	Sonoran	2.43E-24		SON_01
ET_011	Sonoran	3.91E-20	1.50E+13	SON_01
ET_015	Sonoran	2.53E-27		SON_01
ET_018	Sonoran	4.57E-18		SON_01
ET_024	Sonoran	7.81E-26		SON_01
ET_027	Sonoran	2.15E-27		SON_01
ET_036	Sonoran	7.90E-24		SON_01
ET_037	Sonoran	1.24E-25	1.32E+16	SON_01
ET_043	Sonoran	7.43E-09	1.02E+11	SON_01
ET_052	Sonoran	3.37E-17	7.48E+25	SON_01
ET_081	Sonoran	2.97E-22		SON_01
ET_122	Sonoran	4.88E-20		SON_01
ET_124	Sonoran	2.01E-25		SON_01

GH_096	Sonoran	5.69E-21		SON_01
GH_112	Sonoran	3.78E-28		SON_01
GH_120	Sonoran	2.55E-30		SON_01
GH_126	Sonoran	2.82E-28		SON_01
GH_142	Sonoran	5.19E-29		SON_01
GH_148	Sonoran	1.25E-30		SON_01
GH_150	Sonoran	4.34E-24		SON_01
GH_168	Sonoran	4.07E-24		SON_01
GH_192	Sonoran	4.30E-28		SON_01
GH_198	Sonoran	1.96E-26		SON_01
GH_204	Sonoran	3.79E-28		SON_01
GH_210	Sonoran	3.81E-27		
GH_224	Sonoran	3.58E-26		
GH_225	Sonoran	7.35E-25		SON_01
GH_243	Sonoran	1.39E-19		
GH_251	Sonoran	4.67E-21		SON_01
GH_293	Sonoran	3.80E-25		
HARC_001	Sonoran	1.69E-25		SON_01
HARC_006	Sonoran	1.01E-29		SON_01
HARC_007	Sonoran	1.75E-30		SON_01
HARC_012	Sonoran	4.91E-29		SON_01
HARC_038	Sonoran	3.70E-28		SON_01
HARC_059	Sonoran	1.27E-23		
HARC_078	Sonoran	2.01E-25	7.18E+19	
HARC_086	Sonoran	3.26E-20	1.36E+22	
HARC_095	Sonoran	2.22E-18		
HARC_104	Sonoran	6.53E-27		
HARC_114	Sonoran	1.33E-22		SON_01
HARC_115	Sonoran	1.91E-24		SON_01

HARC_125	Sonoran	3.14E-26		SON_01	
HARC_143	Sonoran	5.46E-22		SON_01	
HARC_157	Sonoran	2.57E-22		SON_01	
HARC_159	Sonoran	3.56E-27		SON_01	
LS_011	Sonoran	2.18E-21		SON_01	
LS_014	Sonoran	6.67E-22			
LS_064	Sonoran	2.24E-23		SON_01	
LS_071	Sonoran	5.18E-29		SON_01	
LS_105	Sonoran	2.13E-20		SON_01	
LS_127	Sonoran	3.22E-19			
LS_146	Sonoran	1.94E-30		SON_01	
LS_224	Sonoran	1.20E-17	2.14E+26	SON_01	
LS_236	Sonoran	1.40E-20		SON_01	
LS_432	Sonoran	5.12E-25		SON_01	
NW_006	Sonoran	8.61E-16		SON_05	
NW_012	Sonoran	5.52E-24		SON_05	
NW_017	Sonoran	4.37E-24			
NW_037	Sonoran	5.70E-27		SON_01	
SDM_505	Sonoran	1.83E-25		SON_01	
SDM_703	Sonoran	7.02E-23		SON_01	
SP_194	Sonoran	1.56E-21	2.60E+21	SON_01	
SP_219	Sonoran	9.99E-20		SON_01	
SP_265	Sonoran	9.68E-11	3.93E+25	SON_01	1 step away from modal haplotype
SP_320	Sonoran	2.11E-17			
SP_324	Sonoran	6.51E-24		SON_01	
SP_326	Sonoran	2.06E-23		SON_01	
SP_406	Sonoran	1.11E-29		SON_01	1 step away from modal haplotype
TOR_002	Sonoran	1.22E-18		SON_01	

TOR_004	Sonoran	2.84E-21		SON_01	
TOR_026	Sonoran	8.01E-17		SON_01	
TOR_029	Sonoran	2.51E-15	3.24E+20	SON_01	
TOR_055	Sonoran	1.35E-19		SON_01	1 step away from modal haplotype
TOR_058	Sonoran	2.56E-20		SON_01	
TOR_059	Sonoran	4.75E-20		SON_01	
TOR_060	Sonoran	7.19E-27		SON_01	
TOR_061	Sonoran	6.25E-25		SON_01	
TOR_065	Sonoran	1.20E-18		SON_01	
TOR_154	Sonoran	3.20E-22		SON_01	
TOR_155	Sonoran	6.55E-18	7.68E+23	SON_01	
TOR_156	Sonoran	9.73E-24		SON_01	
US93_002	Sonoran	3.94E-15	6.81E+25	SON_01	
US93_003	Sonoran	4.41E-24		SON_01	
US93_007	Sonoran	4.41E-23			
US93_008	Sonoran	9.09E-30		SON_05	
US93_009	Sonoran	7.39E-12	5.05E+14		
US93_010	Sonoran	2.31E-25	8.23E+19	SON_01	
US93_011	Sonoran	3.73E-27		SON_01	
US93_012	Sonoran	1.58E-17	4.92E+09	SON_01	
US93_013	Sonoran	5.67E-21	1.16E+11	SON_01	
US93_018	Sonoran	5.40E-23	1.85E+17		
WM_006	Sonoran	1.12E-25			
WM_009	Sonoran	4.10E-19		SON_01	
WM_013	Sonoran	9.00E-21		SON_01	
WM_017	Sonoran	1.53E-21		SON_01	
WM_026	Sonoran	4.24E-25		SON_01	
WM_029	Sonoran	1.20E-29		SON_01	
WM_039	Sonoran	8.75E-23	5.97E+19	SON_01	

WM_042	Sonoran	1.03E-20	SON_01
WM_071	Sonoran	4.38E-25	SON_01
WSB_001	Sonoran	5.23E-25	SON_01
WSB_006	Sonoran	3.97E-26	SON_01
WSB_008	Sonoran	4.08E-18	
WSB_011	Sonoran	8.31E-31	SON_01
WSB_024	Sonoran	2.01E-19	
WSB_025	Sonoran	1.96E-21	SON_01
WSB_034	Sonoran	9.71E-25	SON_01
WSB_036	Sonoran	7.57E-27	SON_01
WSB_037	Sonoran	1.55E-28	SON_01
WSB_043	Sonoran	1.08E-28	
WSB_050	Sonoran	6.48E-30	SON_01
WSB_114	Sonoran	5.99E-28	
WSB_181	Sonoran	4.13E-20	SON_01
WSB_253	Sonoran	8.28E-22	
WSB_350	Sonoran	2.05E-23	SON_01
TOR_089	N/A		SON_01

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