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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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INTRODUCTION

The desert tortoise (*Gopherus agassizii*) is currently listed as federally threatened in the northern one-third of its geographic range (Figure 1; USFWS 1990). Declines in the Mojave and Colorado desert populations (located in southern California, southern Nevada, the southwestern tip of Utah, and Arizona north of the Colorado River) have been attributed to direct and indirect human-caused mortality and inadequate regulatory mechanisms to protect desert tortoises and their habitat. Specific stressors identified in the listing included destruction, degradation, and fragmentation of habitat from urbanization, agricultural development, livestock grazing, mining, and roads. This situation is exasperated by continuing drought conditions, disease transmission, accidental or intentional removal, and/or mortality relative to human activities (USFWS 1990).

The Mojave, Colorado, and Sonoran desert tortoise populations likely experience similar threats despite differences in habitat (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). In August 2009, the U.S. Fish and Wildlife Service (USFWS) issued a 90-day finding on a petition to list desert tortoises in the Sonoran Desert as a distinct population segment under The Endangered Species Act (ESA) of 1973 (http://edocket.access.gpo.gov/2009/pdf/E9-20835.pdf). The USFWS has not been issued a final decision as of the writing of this technical report.

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. As a result, impacts are generally limited to specific locations rather than diffused across the landscape as is the case with areas open to unrestricted public access. Tortoise activity within these intensively used areas tends to be less than in adjacent habitat that remains relatively intact (Grandmaison et al., *In Press*). Despite access restrictions for the general public, conflicts between desert tortoise conservation and military readiness may exist. Given the possibility for 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.

The range management responsibilities of the three participating military installations are assigned to the Secretaries of the Army, Air Force, and Marines 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.

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.

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 (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 Mojave 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 (Grandmaison et al., *In Press*, Andersen et al. 2000). 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 primary objective of this study is to develop a landscape-level pattern recognition model based on existing knowledge of desert tortoise habitat requirements (i.e., importance of shelter sites) 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, specifically Aridisol soil sub-groups (AGFD, unpublished data). 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 1 m of the surface (USDA 1975). Entisol soils have a more recent origin without diagnostic horizons and do not provide the structural integrity for permanent burrows (USDA 1975, Hendricks 1985). Thus, we hypothesize that desert tortoise occupancy varies among soil designations at the landscape-scale. Specifically, we predict that tortoise occupancy will be higher in Aridisol soil sub-groups than Entisol sub-groups and that the presence of washes will influence occupancy.

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 appraising the potential impacts of military activities on desert tortoise populations. Project completion will entail two full field seasons for data collection and model development. This technical report details our progress during the first field season.

Our second objective is to collect genetic samples from all 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 Mojave assemblage (USFWS 1990). More recently, desert tortoises in the Black Mountains of Mohave County (approximately 40 km east of the Colorado River) were identified as possessing genetic and morphometric traits similar to the federally threatened Mojave 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 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 Yuma Proving Ground (YPG), Barry M. Goldwater Range (BMGR) - East, and BMGR-West with the responsibility assigned to the Secretaries of the Army, Air Force, and Marines, respectively. The land base encompasses approximately 12,000 km^2 (Figure 2). The YPG lies within La Paz and Yuma counties northeast of Yuma, Arizona and encompasses approximately 3,450 km^2. 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 (*Psorothamnus spinosa*), acacia (*Acacia* sp.), mesquite (*Prosopis* sp.), mixed cacti (including various *Opuntia* species), and various herbaceous and shrub species. The mountainous areas on these military ranges support vegetation more characteristic of the Arizona Upland subdivision of the Sonoran Desert, including a variety of shrubs and cacti although at lower density than in the southeastern part of the state.

Study 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 Sauceda 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 Sauceda 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).

The stratification for our probabilistic sampling design reflected our hypothesis that desert tortoise occupancy varies 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 (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 sub-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 1).

Once we obtained soil data for the entire study area, we randomly located 52 3-ha tortoise survey plots within each of 14 soil sub-groups found on the military ranges. During the 2009 field season, we surveyed a total of 26 plots within each soil sub-group (total # of plots surveyed in 2009 = 364). During the 2010 field season, we intend to survey a minimum of 26 additional plots within each sub-group (total # of plots surveyed after two field seasons will = 728).

Desert Tortoise Surveys

We conducted standardized surveys for tortoises and their sign (i.e., carcasses, scat, tracks, etc.) within each 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 (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 sub-groups to avoid observer bias and that the order in which sub-groups are surveyed were 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 sub-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. All equipment coming into contact with the tortoise was sterilized with a veterinary disinfectant (Chlorhexidine diacetate; AIDTT 1996) after processing was completed. 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. 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 will be sent to the University of Arizona genetics laboratory for DNA analysis at the conclusion of this study. Results will be compiled and modeled similar to Edwards et al. (2004) to assess phylogenetic grouping within the three SW military ranges.

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 could 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), an index of the extent of washes or drainages within the plot, and linear distance and type of roads within the plot. We will also incorporate site-specific characteristics such as vegetation community type and elevation in our final model evaluation.

Desert Tortoise Telemetry

Standard VHF radio-telemetry and GPS tracking units were used to track adult desert tortoise movements within the study area. We deployed VHF and GPS units on a subset of tortoises detected during formal surveys and opportunistically when hiking to survey plots. We glued VHF radio-transmitters to the first left costal scute with epoxy and positioned the device below the highest point on the carapace. The transmitter antenna was inserted into short (1/4”) segments of shrink tubing which are glued to the marginal scutes. Care was taken to ensure that epoxy is not applied to the seams between scutes. Similarly, GPS units were glued to the top of the carapace to ensure adequate communication with satellites and care was taken to avoid applying epoxy to scute seems by placing a short piece of electrical tape over the seams. GPS units were deployed for two-week intervals after which the units were removed, the data was downloaded, and the unit batteries recharged before being re-deployed.

Tortoises were located every two weeks after being instrumented with tracking units. GPS tracking units were programmed to collect location data every 30 minutes during specified periods during the day: 5am to 10am and 4pm to 9pm. Locations were mapped using ArcGIS 9.3 for graphical examination. All tracking units and epoxy will be removed from the animals at the end of the study. At the completion of this study, we will examine desert tortoise movements relative to soil sub-groups as a means to validate the habitat models developed for use in predicting areas with a high probability of tortoise occupancy.

Data Analysis

A complete analysis of the survey data, including the development of the soil model will be conducted at the completion of the second field season. This technical report summarizes the progress made during the first field season and includes descriptive statistics documenting emerging relationships between desert tortoises and soil sub-groups on the three military ranges.

At the completion of this two-year study, we will use Program PRESENCE to estimate probabilities of use and detection under the maximum likelihood framework developed by

MacKenzie et al. (2002) where survey plots are stratified by soil sub-group. The data will be analyzed for each stratum separately and then combined using standard stratified random sampling methods (Cochran 1977). This procedure will yield an occupancy estimate and detection probability for each soil sub-group. We will incorporate additional survey-specific (e.g., temperature, humidity, and time) and site-specific covariates (e.g. shelter sites, washes, roads, elevation and vegetation type) to examine their influence on model performance. We will evaluate models under a model selection framework (Burnham and Anderson 2002) to determine the final specification of the occupancy model.

RESULTS

Desert Tortoise Surveys

During the 2009 field season, a total of 364 desert tortoise surveys were completed across 14 soil sub-groups found on the three military ranges (Table 1; Figures 4 - 6). A total of 11 desert tortoises were detected during our surveys efforts. Tortoise sign was detected on 32 survey plots in 3 soil sub-groups (Table 1). Calcic petrocalids had the highest proportion of occupied plots, followed by lithic torriorthents, and typic haplocalcids (Figure 7). There were a total of 66 locations with evidence of tortoise occupancy when including tortoises and tortoise sign detected opportunistically while hiking to survey plots or when conducting tortoise telemetry. Tortoises (n = 2) and tortoise sign (n = 2) were detected in the southern extent of the Dome Rock Mountains on the YPG (Figure 4). We found tortoise sign (n = 1) in the Tinajas Altas Mountains on the BMGR-West (Figure 5). Tortoises (n = 7) and tortoise sign (n = 54) were detected in the Aguila, Sauceda and Sand Tank mountains on the BMGR-East (Figure 6). The overall frequency of tortoise and tortoise sign followed the same pattern as that for on-plot detections alone.

We deployed a total of 7 VHF and 4 GPS tracking units (Figure 8) during the first field season on a total of 7 individual tortoises. The mean number of GPS locations acquired per individual during the first tracking season was 526 (Range: 21-931). As the tracking continues, we will deploy additional VHF and GPS tracking units to obtain detailed movement maps (Figure 9). We also collected 8 blood samples for later genetic analysis.

DISCUSSION

While our results are tentative pending the completion of the second year of surveys, there appears to be a pattern emerging in which tortoise locations appear to be concentrated in three specific soil sub-groups. Two of these sub-groups are Aridisols which we predicted would be the soil group with the highest desert tortoise occupancy rates due to their characteristic soil horizon, often cemented by calcium carbonate, which supports the creation of stable burrows for tortoise shelter sites.

Calcic petrocalids exhibited the highest proportion of survey plots that contained signs of desert tortoise occupancy (Figure 7). These soils are 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. The petrocalcic horizon is characterized by a high concentration of calcium carbonate. This accumulation of calcium carbonate cements the parent soil material and creates what is more commonly referred to as the caliche layer (Figure 3) with acts as a stable ceiling for desert tortoise burrows.

Typic haplocalcids, also Aridisols, are considered typical haplocalcids that do not fit any of the other haplocalcid soil categories. Likewise, haplocalcids are an inclusive category of calcids that do not fit the petrocalcid category described above. However, as typical of other calcids, these soils are characterized by the accumulation of calcium carbonate (USDA 1975, Hendricks 1985). Like other Aridisols, both calcic petrocalcids and typic haplocalcids are considered very old soils in that it takes a long time for the leaching and deposition required for the development of the distinct horizons that characterize this soil type.

Lithic torriorthents, on the other hand, belong to the Entisol soil group. Entisols are soils that do not display any significant profile development and lack diagnostic horizons (USDA 1975, Hendricks 1985). Lithic torriorthents, like all orthents, lack horizon development are often characterized by a shallow soil covering that is unaltered from their parent material (generally unconsolidated sediment or rock). 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), lithic torrirothents exhibited a high level of tortoise occupancy. In fact, many of these hillslopes contain boulder piles that provide a plethora of excellent shelter sites for desert tortoises. In general, most of the desert tortoise detections that occurred during the first year of survey were located in the foothills and in, or adjacent to, mountainous portions of the three ranges.

CONTINUING RESEARCH

We obtained funding through the Department of Defense Legacy Program for the second year of study. Surveys and telemetry are currently underway for the 2010 field season. The final report that will be submitted in 2011 will include a complete data set for the entire two-year study period.

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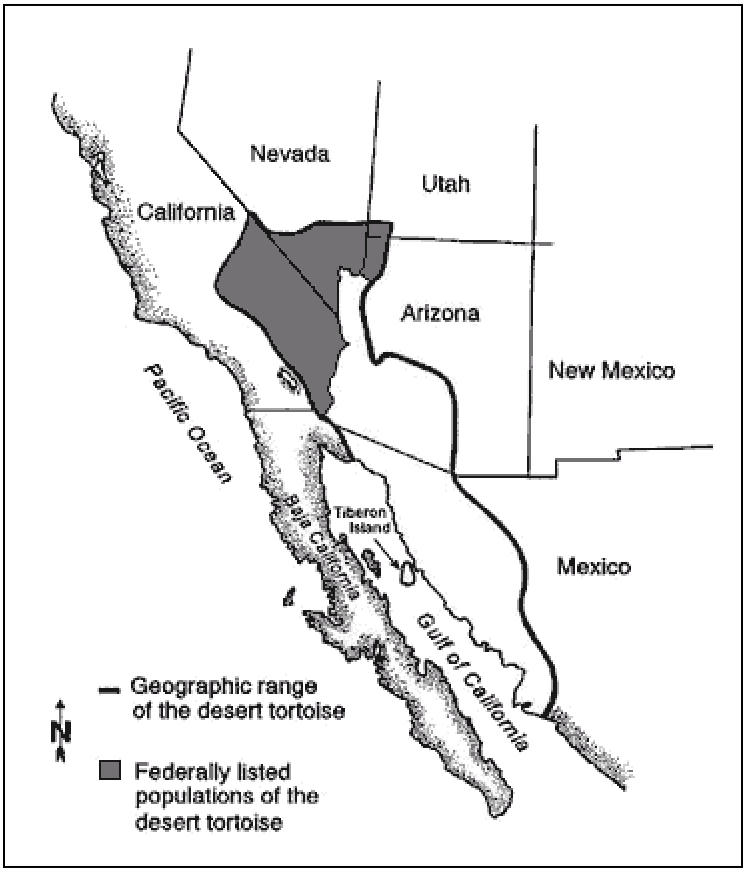

Figure 1. Geographic distribution of the desert tortoise (from Stebbins 1985 and Berry 1997).

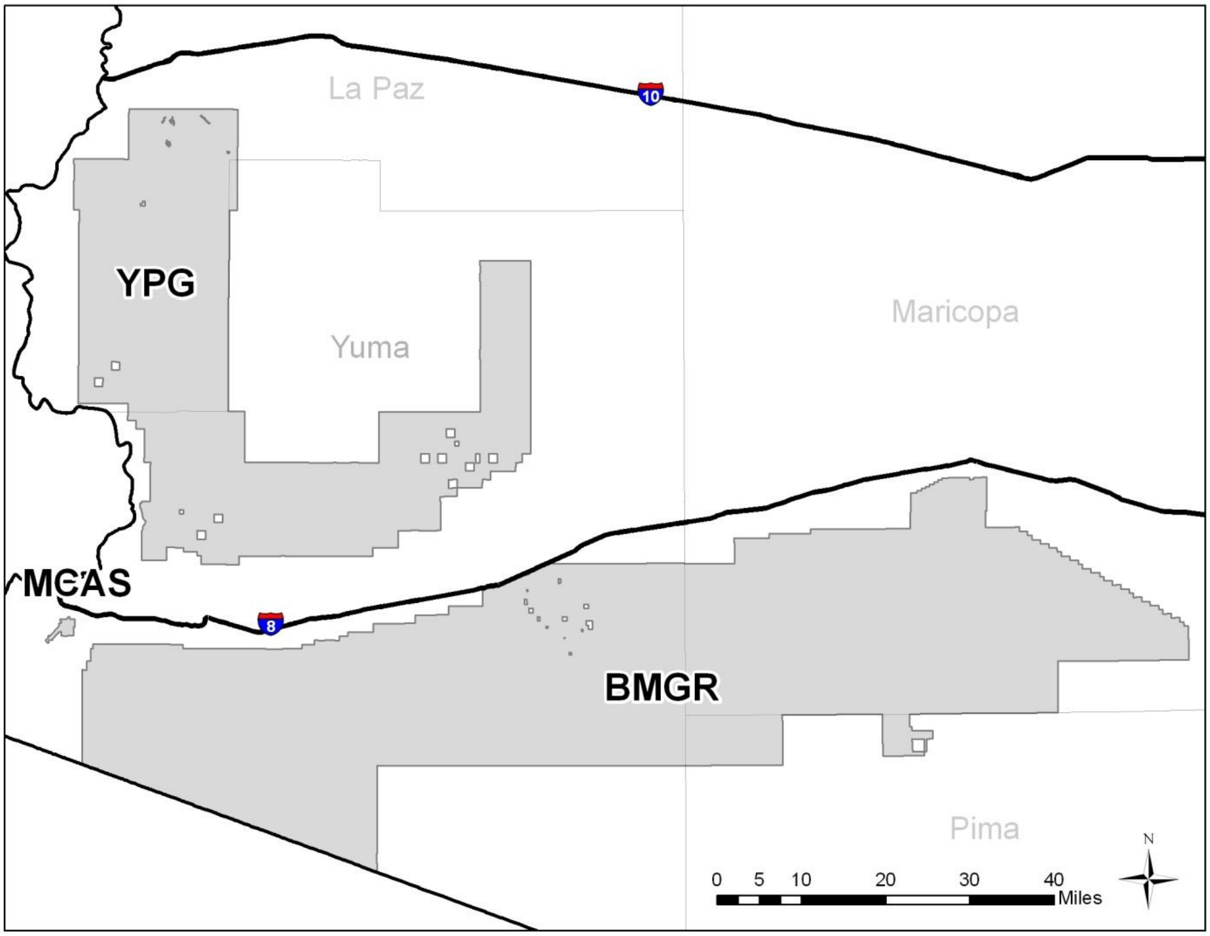

Figure 2. The three military ranges in Yuma, Maricopa and Pima counties in southwestern Arizona included in the desert tortoise landscape-level habitat modeling study. YPG (Army), BMGR-East (Air Force), and BMGR-West (Marines).

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

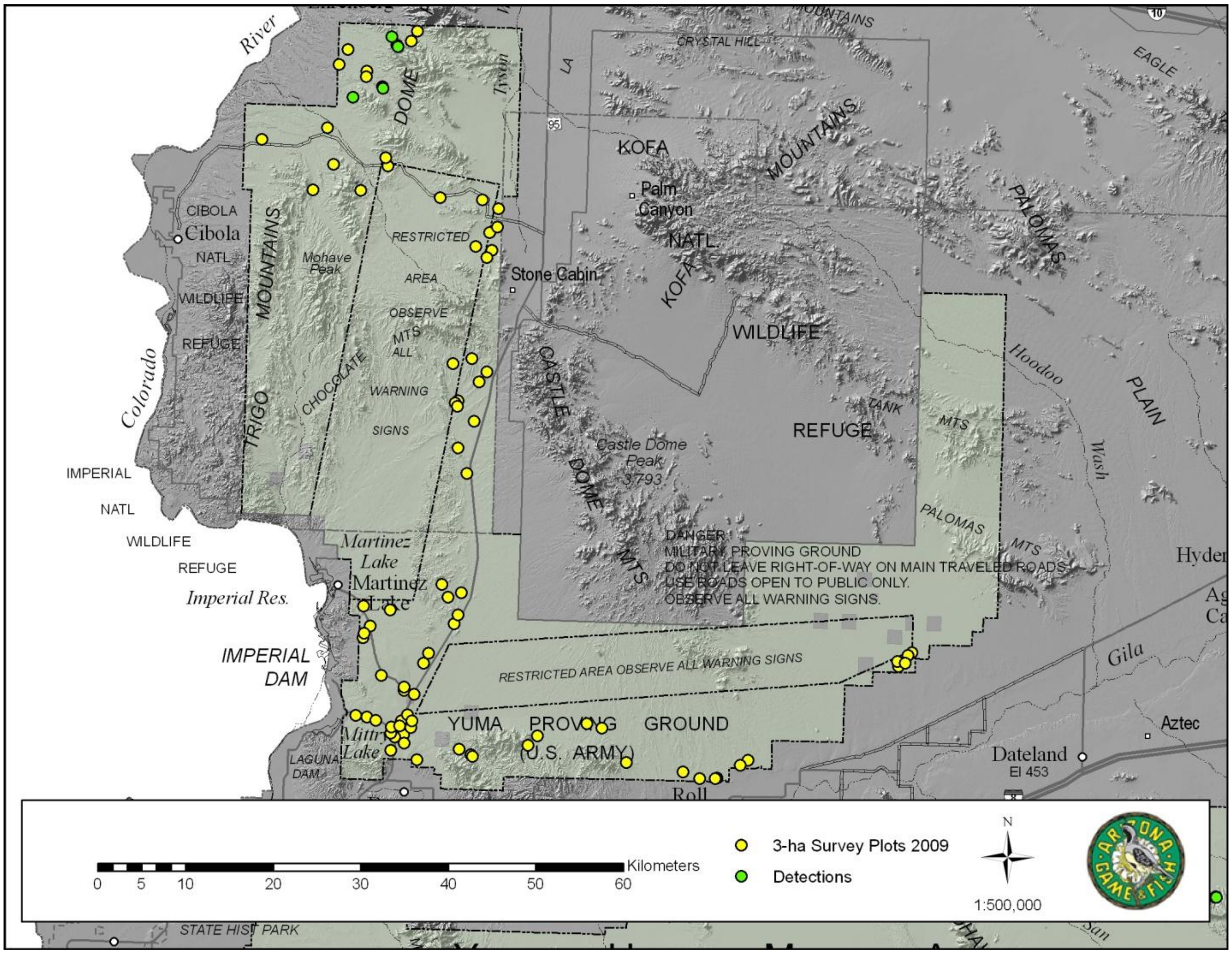

Figure 4. Distribution of 3-ha desert tortoise survey plots and detections of tortoises and/or tortoise sign during the 2009 field season on the YPG.

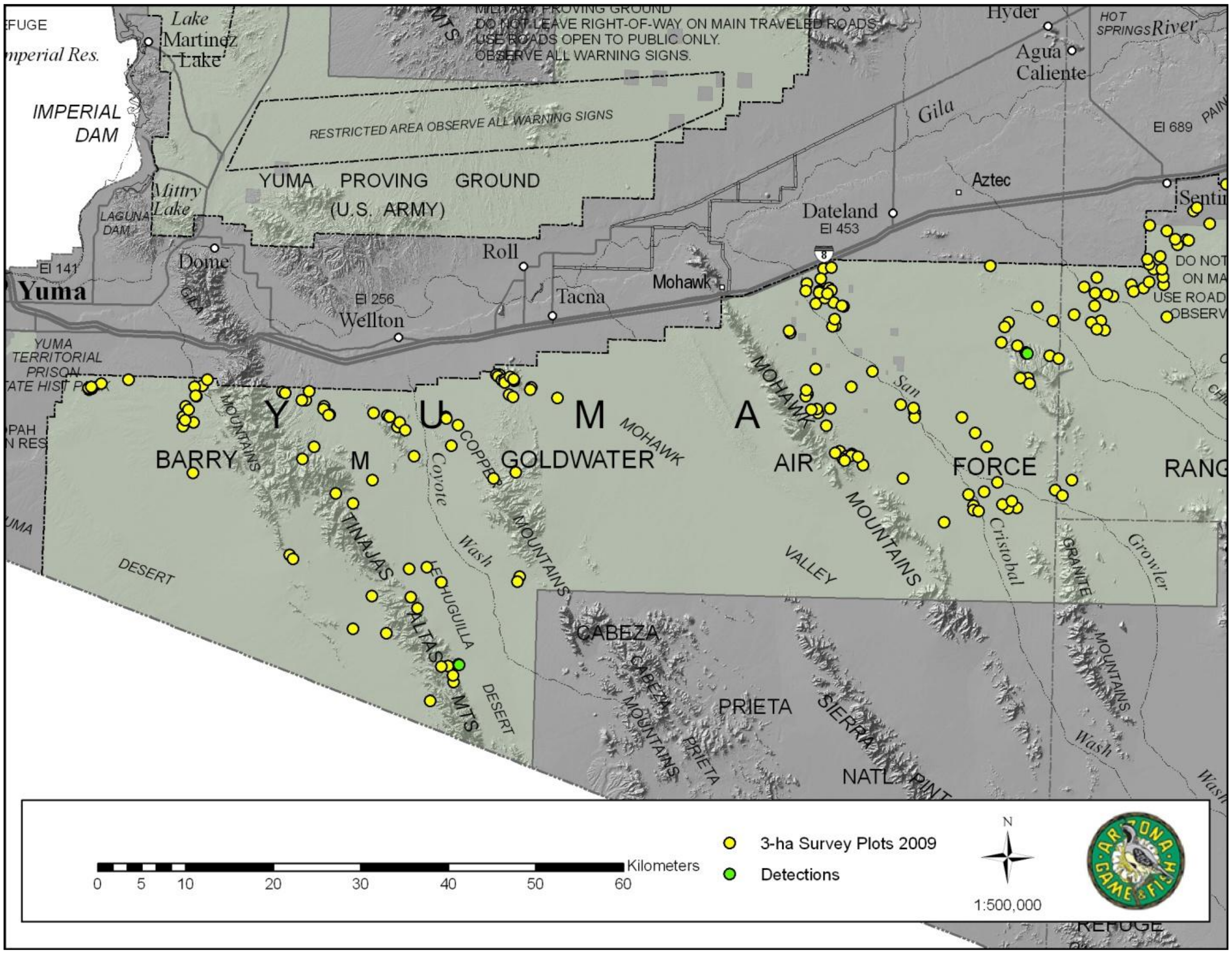

Figure 5. Distribution of 3-ha desert tortoise survey plots and detections of tortoises and/or tortoise sign during the 2009 field season on the BMGR-West.

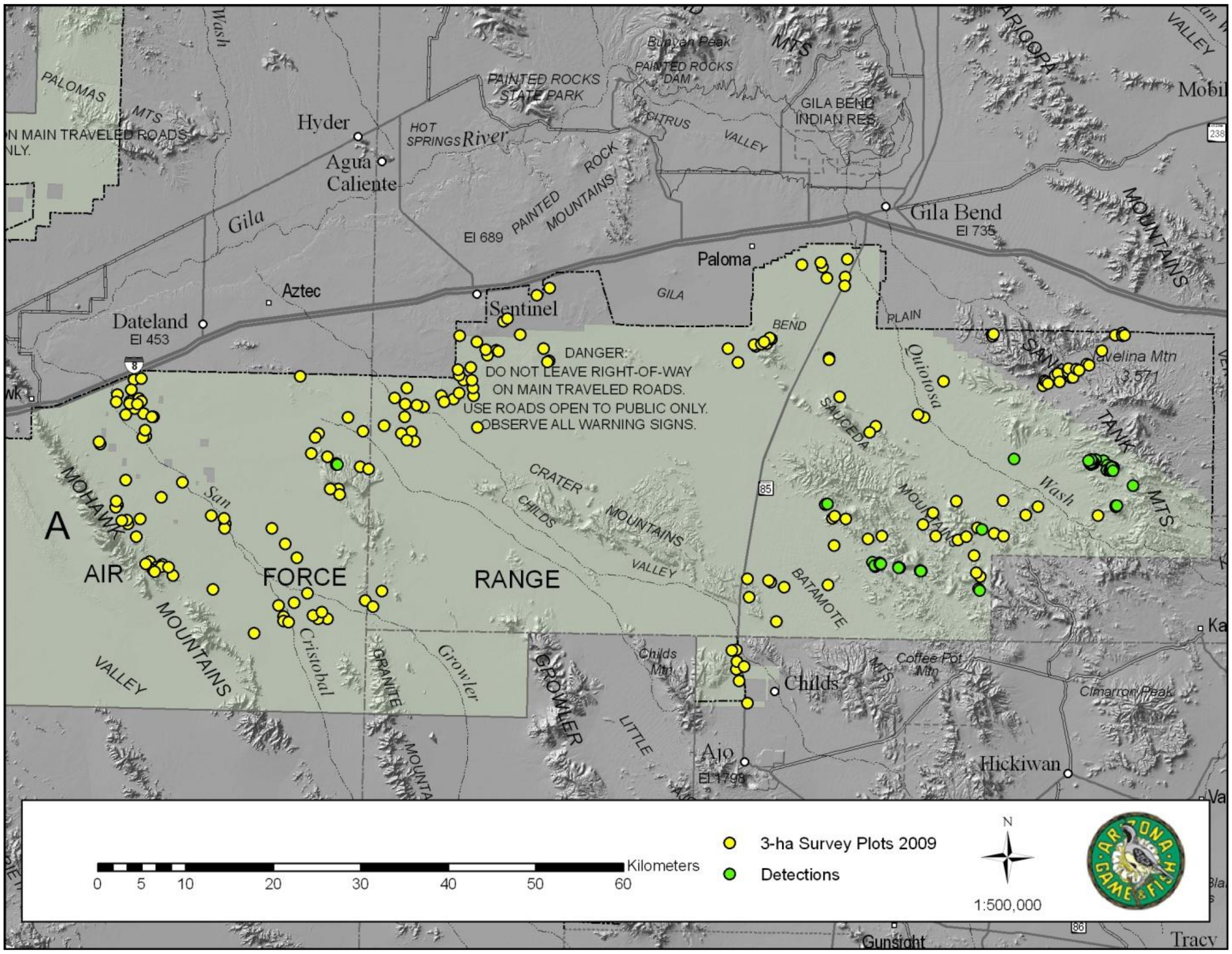

Figure 6. Distribution of 3-ha desert tortoise survey plots and detections of tortoises and/or tortoise sign during the 2009 field season on the BMGR-East.

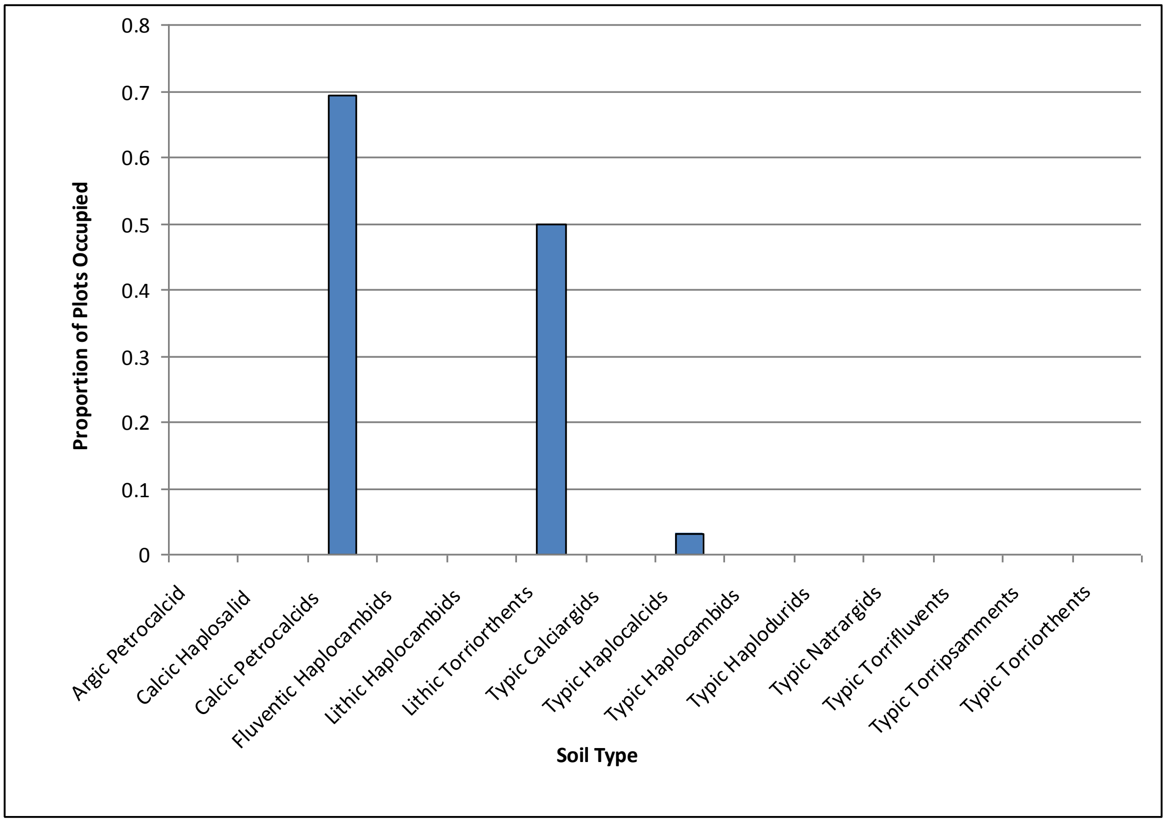
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion of Plots Occupied
Argic Petrocalcid
Calcic Haplosalid
Calcic Petrocalcids
Fluventic Haplocambids
Lithic Haplocambids
Lithic Torriorthents
Typic Calciargids
Typic Haplocalcids
Typic Haplocambids
Typic Haplodurids
Typic Natrargids
Typic Torrifluvents
Typic Torripsamments
Typic Torriorthents
Soil Type

Figure 7. The proportion of occupied survey plots within each of the 14 soil sub-groups found on the three military ranges surveyed as part of this study (YPG, BMGR-East, and BMGR-West).

Figure 8. GPS tracking unit deployed on a desert tortoise.

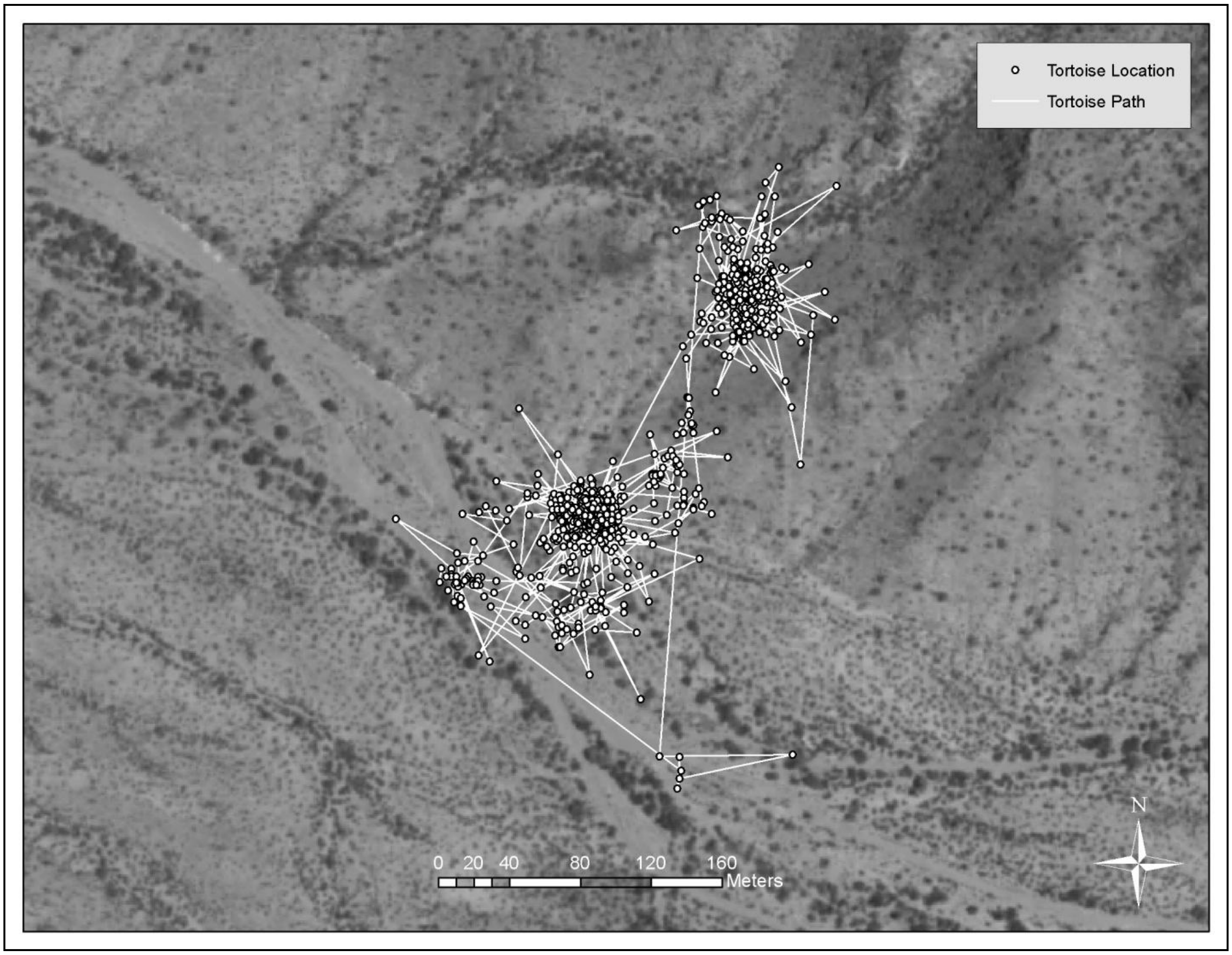

Figure 9. An example of the detailed movement data gathered using GPS tracking data from a single tortoise on BMGR.

Table 1. Desert tortoise survey plot totals for the 2009 field season along with the number of plots where tortoises or tortoise sign were detected and the total number of detections (tortoises or tortoise sign on plots or detected during transit or telemetry efforts).

Soil Type	YPG Plots	BMGRE Plots	BMGRW Plots	Total Plots	Number of Survey Plot Detections
argic petrocalcid	0	26	0	26	0
calcic haplosalid	0	0	26	26	0
calcic petrocalcids	0	22	4	26	18
fluventic haplocambids	0	26	0	26	0
lithic haplocambids	0	24	2	26	0
lithic torriorthents	10	16	0	26	13
typic calciargids	10	12	4	26	0
typic haplocalcids	9	11	12	26	1
typic haplocambids	0	11	15	26	0
typic haplodurids	0	26	0	26	0
typic natrargids	0	26	0	26	0
typic torrifluvents	10	7	9	26	0
typic torripsamments	20	0	6	26	0
typic torriorthents	24	0	2	26	0
Totals	83	207	80	364	32

APPENDIX 1

NAUMAN GEOSPATIAL LLC
www.naumangeospatial.com

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

Travis Nauman
Soils and GIS Specialist
Nauman Geospatial LLC

Deliverable for AZGF PO #E0075088

NAUMAN GEOSPATIAL LLC
www.naumangeospatial.com

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.

Final models were trained using the full areas of the polygons selected for training and are reported in the results section. In addition, a stratified random subsample of points in the training areas was taken and divided randomly into training points and independent validation points. A model was created with the training points and then validated with the independent validation points to assess robustness of the modeling strategy in the training areas. Lower accuracies in validation assessments than seen in the full model would indicate over-fitting and lower predictive potential.

The independent variables used in the model were derived from four June Landsat TM scenes downloaded from the USGS Earth Explorer website (http://edcsns17.cr.usgs.gov/EarthExplorer/) and NED elevation data downloaded from the National Map Seamless Server (http://seamless.usgs.gov/index.php). Landsat scenes used included locations p38r38, p38r37, p37r38 and p37r37 on dates 6/19/05, 6/22/06, 6/15/06, and 6/15/06 respectively. Table 1 shows the layers calculated from the Landsat and NED data using layers outlined in Scull et. al. (2005) and Cole and Boettinger (2007) with a couple small changes cited in the table. Satellite and DEM image correction and manipulation were done in **S**ystem for **A**utomated **G**eoscientific **A**nalyses (SAGA) (http://www.saga-gis.org/en/index.html), and open-source GIS software. Landsat images were corrected to reflectance using the COST method published by Chavez (1996). All data was sampled to 30-meter pixels in the NAD83 UTM 12N projection for analysis.

Table 1 Data Layers considered for use in maximum likelihood model with One Way Anova done for each variable among the soil mapping units in training areas. The "*" indicates variables chosen for the model due to high ANOVA scores and low correlation to other selected variables.

Variable	1Way ANOVA $F_{70,13,184}$	Description
B1	384.46	Landsat Reflectance
B2	357.38	Landsat Reflectance
B3*	387.38	Landsat Reflectance
B4	356.81	Landsat Reflectance
B5*	382.31	Landsat Reflectance
B7	374.76	Landsat Reflectance
DEM*	459.65	NED elevation
B3_SD_3PIX	10.28	Reflectance standard deviation in 3 pixel radius
B3_SD_7PIX	20.152	Reflectance standard deviation in 7 pixel radius
B5_SD_7PIX*	109.63	Reflectance standard deviation in 7 pixel radius
B5B1*	106.223	Band Ratio
B5B2	61.97	Band Ratio
B5B3	51.99	Band Ratio
B5B4	30.66	Band Ratio
B5B7	61.04	Band Ratio
B7B2	52.88	Band Ratio

B7B1	102.14	Band Ratio
B7B3	40.97	Band Ratio
CURVATURE	0.936	Elevation 2nd 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_{inf} 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 softaware (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 Classifiction			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%	1695	3289	51.5%	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	1715085	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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