



Modeling Habitat of the Desert Tortoise (*Gopherus agassizii*) in the Mojave and Parts of the Sonoran Deserts of California, Nevada, Utah, and Arizona



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U.S. Department of the Interior
U.S. Geological Survey

COVER PHOTOGRAPH

(2005) Mojave Desert Tortoise found in Piute Valley in Clark County, Nevada (Kenneth E. Nussear)

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By Kenneth E. Nussear, Todd C. Esque, Richard D. Inman, Leila Gass, Kathryn A. Thomas, Cynthia S. A. Wallace, Joan B. Blainey, David M. Miller, and Robert H. Webb

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Conversion Factors, Datums, and Abbreviations and Acronyms

Conversion Factors

Multiply	By	To obtain
Length		
kilometer (km)	0.6214	mile (mi)
millimeter (mm)	0.03935	inch (in.)
Area		
square kilometer (km ²)	0.3861	square mile (mi ²)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
 $^{\circ}\text{F} + (1.8 \times ^{\circ}\text{C}) + 32.$

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations and Acronyms

AGP – Annual Growth Potential
AUC – Area Under the ROC Curve
CV – Coefficients of Variation
DEM – Digital Elevation Map
EVI - Enhanced Vegetation Index
MODIS – Moderate Resolution Imaging Spectroradiometer
NAD – North American Datum
NED – National Elevation Database
RBG – Random Background
ROC – Receiver Operating Characteristic
STATSGO - State Soil Geographic (STATSGO) Database
USGS – U.S. Geological Survey

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Abstract

Habitat modeling is an important tool used to simulate the potential distribution of a species for a variety of basic and applied questions. The desert tortoise (*Gopherus agassizii*) is a federally listed threatened species in the Mojave Desert and parts of the Sonoran Desert of California, Nevada, Utah, and Arizona. Land managers in this region require reliable information about the potential distribution of desert tortoise habitat to plan conservation efforts, guide monitoring activities, monitor changes in the amount and quality of habitat available, minimize and mitigate disturbances, and ultimately to assess the status of the tortoise and its habitat toward recovery of the species. By applying information from the literature and our knowledge or assumptions of environmental variables that could potentially explain variability in the quality of desert tortoise habitat, we developed a quantitative habitat model for the desert tortoise using an extensive set of field-collected presence data. Sixteen environmental data layers were converted into a grid covering the study area and merged with the desert tortoise presence data that we gathered for input into the Maxent habitat-modeling algorithm. This model provides output of the statistical probability of habitat potential that can be used to map potential areas of desert tortoise habitat. This type of analysis, while robust in its predictions of habitat, does not account for anthropogenic changes that may have altered habitat with relatively high potential into areas with lower potential.

Introduction

Spatial models that predict areas of potential habitat for plants and animals are extremely useful for evaluating management actions, particularly recovery plans for threatened or endangered species (Graham and others, 2004). Using spatially defined environmental variables, which may be either continuous numbers, integers, or categorical data, these habitat models can be very robust at detailed scales and are useful when designing of conservation programs and evaluating changes in species distributions owing to anthropogenic effects or global change. Data on species occurrence, combined with spatially explicit environmental data, can be used with recently developed statistical techniques and analytical tools without specific absence data (Elith and others, 2006; Phillips and others, 2006; Phillips and Dudik, 2008).

The desert tortoise (*Gopherus agassizii*, cover photograph) occupies a variety of habitat types in the Mojave Desert including creosotebush – white-bursage (*Larrea tridentata* – *Ambrosia dumosa*) communities (Fig. 1). The species is widely distributed in southwestern North America, ranging from the Sierra Nevada in California to southwestern Utah and southwards into Sonora and Sinaloa, Mexico (Fig. 2). North and west of the Colorado River, the desert tortoise is a federally listed threatened species owing to reductions in habitat quality and extent caused by human activities, land-use practices, increasing populations of subsidized predators, disease, and other factors (Luckenbach, 1982; Department of the Interior, 1990; Berry and others, 2002). Urbanized areas within Clark County, Nevada, typify several fast-growing urban areas within former tortoise habitat ([http://www.censuscope.org/us/m4120/chart_popl.html](http://www.censusscope.org/us/m4120/chart_popl.html)) that have caused significant displacements of these animals. Land-use practices leading to habitat degradation or destruction include development (urban and rural), military training activities, habitat fragmentation from roads and utility corridors, recreational activities, livestock grazing, and previously uncommon fires fueled mostly by non-native species (Tracy and others, 2004). Extensive habitat changes and reduction in populations prompted wildlife managers to create a recovery plan (U.S. Fish and Wildlife Service, 1994) and a subsequent revision of the recovery plan (Tracy and others, 2004; U.S. Fish and Wildlife Service, 2008). The results of this modeling project will be a useful element of the Revised Recovery Plan.



Figure 1. Creosote scrub habitat (one type of preferred desert tortoise habitat) in the Mojave Desert.

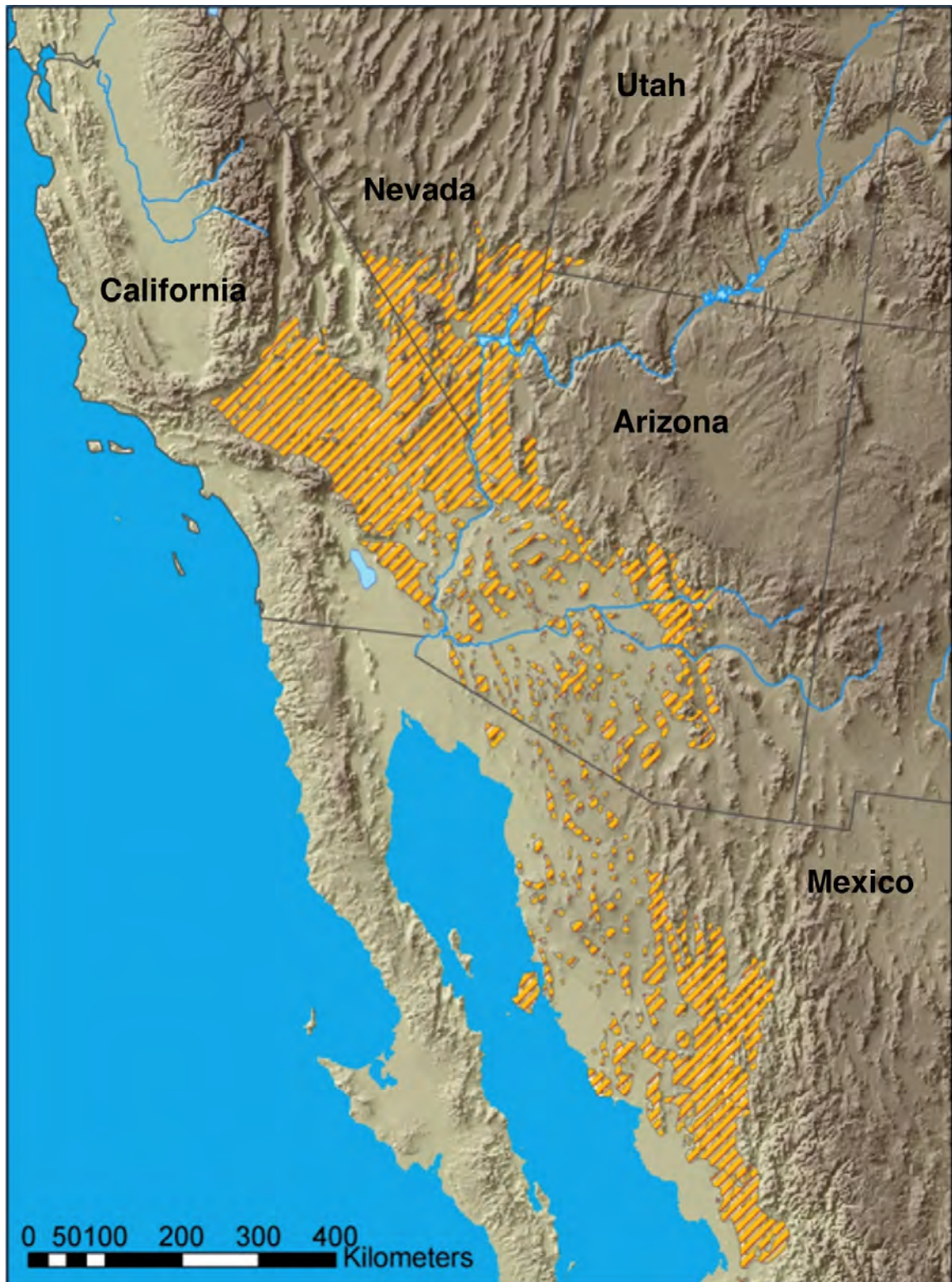


Figure 2. Map showing distribution of desert tortoise (*Gopherus agassizii*) in western North America (adapted from Germano and others, 1994).

We assembled an interdisciplinary team to create a model of potential habitat for the listed Mojave Desert populations of the desert tortoise. After assembling a unique set of presence data (Fig. 3) gleaned from the scientific literature, state and federal land-management agencies, scientists, and biologists, we used a series of innovative techniques (for example; remote sensing and spatial interpolation; Blainey and others, 2007; Wallace and Gass, 2008; Wallace and Thomas, 2008; Wallace and others, 2008) to develop environmental data layers at a common spatial scale of 1 km² to help define potential habitat. We used the Maxent algorithm (Phillips and others, 2006) to predict potential desert tortoise habitat in the Mojave Desert and parts of the Sonoran Desert.

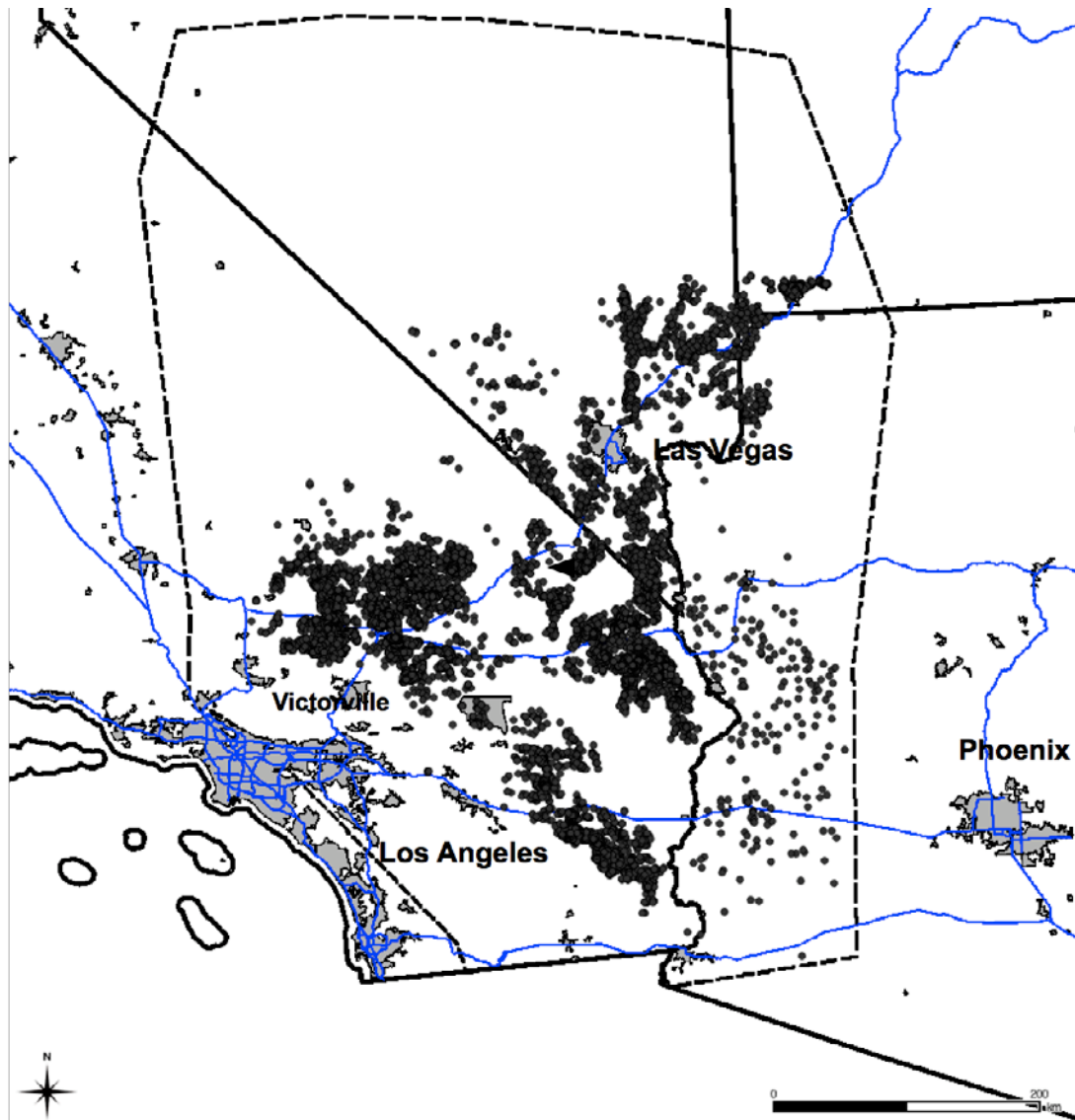


Figure 3. Distribution of desert tortoise (*Gopherus agassizii*) presence observations at sites in the Mojave Desert and parts of the Sonoran Desert of California, Nevada, Utah, and Arizona. *Solid circles* indicate records of one or more observations of live or dead tortoises. The dashed line indicates the study area boundary for the habitat model. Major highways are indicated by blue lines, and urban areas are indicated by gray shaded areas.

Purpose and Scope

The purpose of this report is to document the methods and data sources used to model the potential habitat of the desert tortoise in the Mojave and parts of the Sonoran Desert and to present a map showing this potential habitat. We discuss some of the limitations of our data and caution that our results do not account for other factors that affect habitat quality, notably significant changes brought about by land-use practices.

Background

Geography and Topography

Our study encompasses the range for the Mojave population of desert tortoises north and west of the Colorado River, as well as a small portion of the northwest Sonoran Desert, and comprises 336,594 km² of basin-and-range topography (Fig. 3). The study area was used to create spatially coincident environmental-data layers for environmental variables known from the literature and our experience for defining potential habitat. Within this area, we created a spatial grid of 1-km² cells for which we assessed habitat potential. Although the habitat for the desert tortoise is thought to occur primarily at elevations between 600 and 1,200 m above sea level (Germano and others, 1994, Fig. 2), we used the entire elevation range within the distributional limits of this species, which ranges from the rugged mountain ranges to the flat-lying playa systems that characterize the study area.

Climate

Owing to relatively sparse climatological data for the study area, the range in temperatures and precipitation within the current desert-tortoise habitat is only generally known. In the Mojave Desert, annual precipitation within known habitat ranges from 100 to 210 mm (Germano and others, 1994), mostly occurring during the winter months (> 50-75%) and infrequently as snow below 1,200 m. The temperature range of known habitat is extreme, with average daily low temperatures in January typically at or slightly below 0 °C and average daily high temperatures in July ranging from 37 to 43 °C (Germano and others, 1994). Both precipitation and temperature are strongly and complexly related to elevation, aspect, and position within this desert; the closed-basin playa systems that characterize the Mojave Desert tend to control air movement, leading to low-level temperature inversions in winter and thermal trapping of heat in some valleys during summer. Winter precipitation is usually dependent on frontal storms or the residual effects of gulf storms penetrating northward with increasing amounts of rain or snow at higher elevations. Summer precipitation is associated with the North American monsoon, which is more reliable in the easterly parts of the desert tortoise range. Precipitation events, especially the monsoon, may be highly local depending strongly on orographic effects.

The complex interactions between topography and climate are perhaps best illustrated by the differing results of studies of preferred aspect by the desert tortoise. Weinstein (1989) found a significantly greater abundance of desert tortoises on northwest to north-northwest facing slopes, a result that he attributed to ground heating and possibly illumination. However, Andersen and others (2000), working in a different part of the Mojave Desert, found a preference for southwestern facing slopes, again for possible effects of soil heating during winter. This apparent shift in habitat preference on the basis of aspect underscores the complexity of topography and climate interactions as they affect habitat preference for this species and illustrates the need for robust environmental data over the entire range of this species.

Other Environmental Constraints on Habitat

The characteristics of high-quality habitat for the desert tortoise have been proposed by numerous researchers, possibly beginning with Woodbury and Hardy (1948) and Miller (1932, 1955) and more recently including Luckenbach (1982), Weinstein (1989), Germano and others (1994), U.S. Fish and Wildlife Service (1994), and Andersen and others (2000). A conceptualized array of these environmental characteristics are related to the core variables of soils, landscape, climate, and biological characteristics (Fig. 4). As summarized most recently in U.S. Fish and Wildlife Service (2008), desert tortoise habitat typically consists of alluvial fans and plains and colluvial/bedrock slopes with vegetation alliances of creosote bush (*Larrea tridentata*) or, less commonly, blackbrush (*Coleogyne ramosissima*), Joshua tree (*Yucca brevifolia*), and even juniper (*Juniperus* sp.) at higher elevations and saltbush (*Atriplex* sp.) at lower elevations. In general, tortoises prefer *Larrea* habitat with high diversity and cover of perennial species and high production of ephemeral plants, which comprise their primary diet (Esque, 1994; Jennings, 1997; Avery, 1998).

Soils tend to be of sufficient strength to accommodate burrows without collapse but allow excavation by the animals (Andersen and others, 2000); in some cases, tortoises take advantage of natural shelters in rock formations or exposed calcic soil horizons. Both from constraints on mobility and their inability to easily construct shelters, tortoises tend not to use rocky or shallow bedrock habitat, particularly on very steep slopes, in the Mojave Desert. Home ranges of desert tortoises can cover 3.9 km² (Berry, 1986) or more over their long lifespans, suggesting that a spatial modeling unit of 1 km² is appropriate.

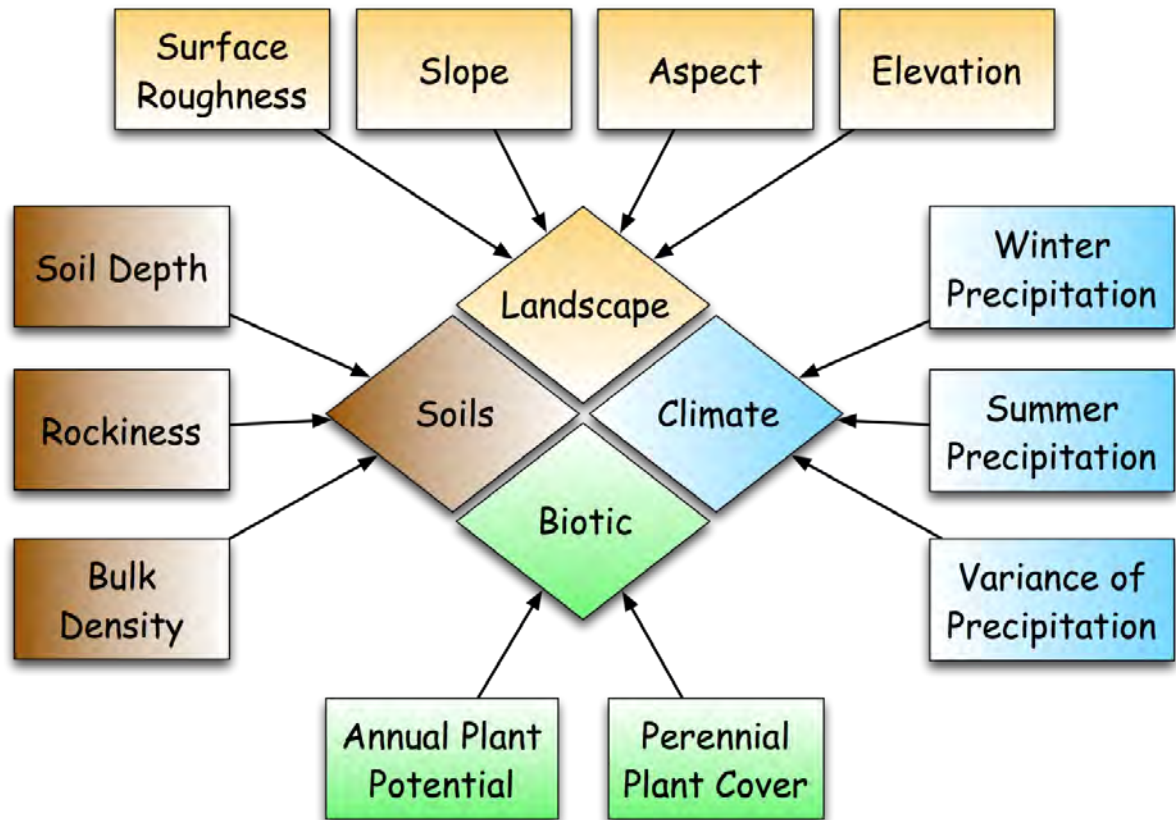


Figure 4. Array of variables used to predict desert tortoise habitat. Environmental variables were generally related to four categories of influence on the landscape and were hypothesized to influence tortoise ecology/habitat potential through a variety of mechanisms.

Methods

Tortoise Presence Data

We combined several datasets of desert tortoise occurrence collated from a variety of sources to assemble presence points in the Mojave and parts of the Sonoran Deserts (see Acknowledgments). Presence records included data from 1970 through 2008, although most of the data were collected after 1990. These data resulted from at least 23 different data-collection initiatives. Although methods of data collection varied among the primary sources, we were able to use the observations of tortoises (live or dead) as point sources of presence. We used only data involving evidence of live tortoises or carcasses, discarding locations reported on the basis of burrows, scat, or other sign, as these can be easily misidentified. The locations represent “potential” presence because carcasses may have been moved into unsuitable habitat by predators or humans. Our geospatial database includes 15,311 points representing presence (Fig. 3).

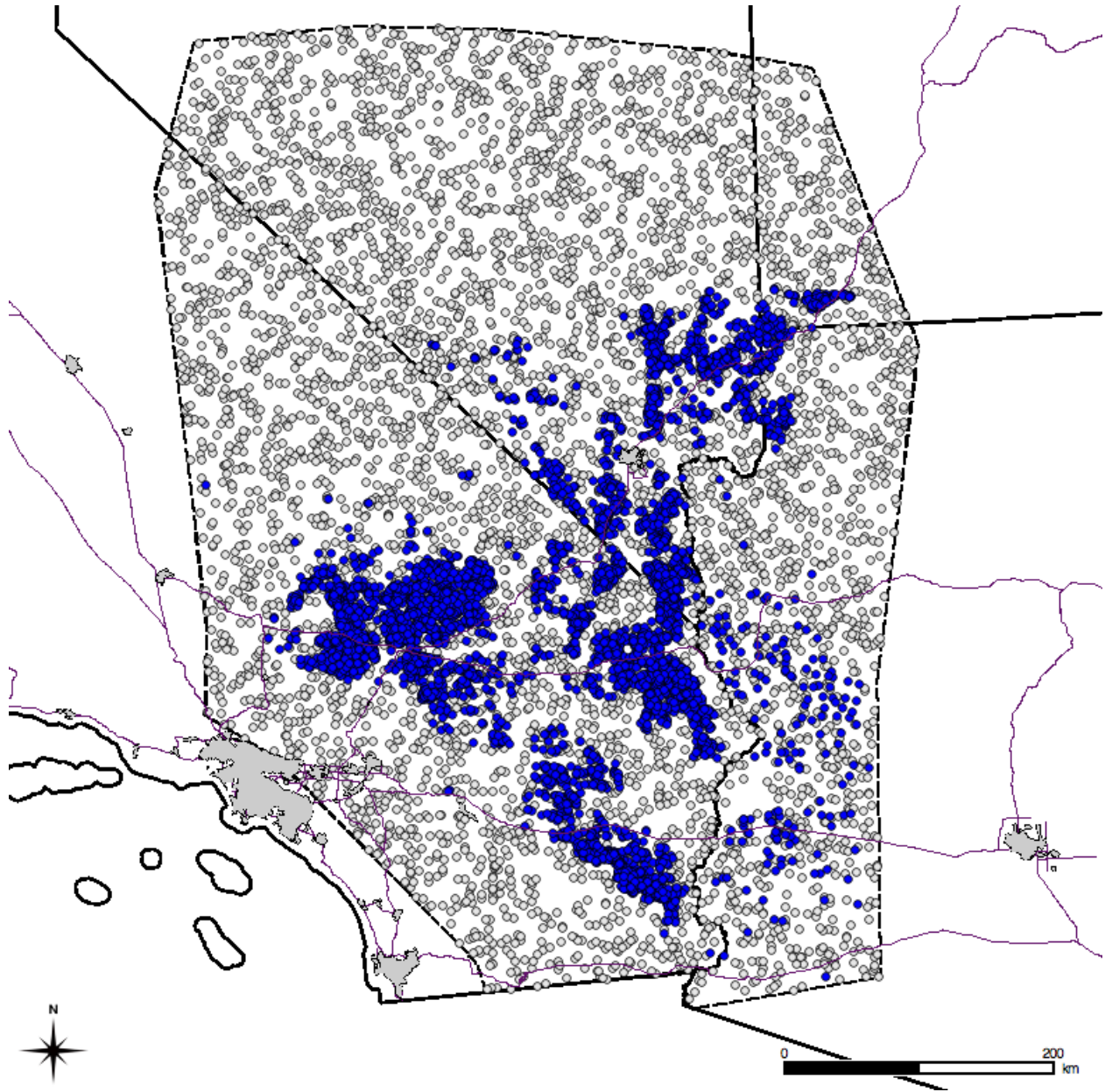


Figure 5. Distribution of presence data (blue circles) and random background data (gray circles) used in habitat modeling. Urban areas are defined by the gray shaded polygons.

We aggregated the presence observations to the 1-km² grid by merging all points within each grid cell to a single point at the grid-cell center. This reduced the 15,311 occurrences to 6,350 grid-cell points (Fig. 5). We randomly selected 20% of the presence points (1,270 points) for model testing; the remaining 80% (5,080 points) were used for model training.

Environmental Data Layers

Using the literature (e.g., Luckenbach 1982) and the experience of the authors of this report, we developed 16 environmental data layers that define or influence desert tortoise habitat. These data, assembled by an interdisciplinary team, include soil characteristics, perennial and annual vegetation, elevation and extracted topographic variables, and seasonality and variability of precipitation (Table 1). All environmental datasets were resampled to match our standard spatial grid using tools available in GRASS 6.4 (GRASS Development Team, 2008)

Table 1. Environmental data used in modeling potential habitat of the desert tortoise in the Mojave and parts of the Sonoran Deserts of California, Nevada, Utah, and Arizona.

[Dry season, May through October; wet season, November through April with statistics for 1961 to 1990 used as the climatic normal and coefficient of variation]

Description of Environmental Data Layer	Source of Environmental Data
CLIMATE	
Mean dry season precipitation for 30-year normal period	Blainey and others (2007)
Dry season precipitation, spatially distributed coefficient of variation *	Blainey and others (2007)
Mean wet season precipitation for 30-year normal period	Blainey and others (2007)
Wet season precipitation, spatially distributed coefficient of variation *	Blainey and others (2007)
TOPOGRAPHY	
Elevation	30 m NED DEM (USGS)
Slope *	derived from 30 m NED DEM (USGS)
Northness (aspect) *	derived from 30 m NED DEM (USGS)
Eastness (aspect) *	derived from 30 m NED DEM (USGS)
Average surface roughness	derived from 30 m NED DEM (USGS)
Percent smooth	derived from 30 m NED DEM (USGS)
Percent rough *	derived from 30 m NED DEM (USGS)
SOILS	
Average soil bulk density	STATSGO database
Depth to bedrock	STATSGO database
Average percentage of rocks > 254 mm B-axis diameter	STATSGO database
BIOLOGICAL CHARACTERISTICS	
Perennial plant cover	Wallace and others (2008)

* Environmental layers that were dropped from the final model after evaluation of the jackknife analyses.

Climate data consisted of two seasonal data layers representing average summer (May–October) and average winter (November–April) precipitation. Based on climatic normals calculated from conditions between 1961 and 1990, we used spatially distributed coefficients of variation (CV) for both seasons (Blainey and others, 2007). We did not use temperature as a variable, although some studies show a relation between temperature and tortoise physiological response (Naegle, 1976; Spotila and others, 1994; Rostal and others, 2002). In our experience, no data published to date definitively show direct temperature limitations on the extent of desert tortoise habitat. Temperature is likely to influence tortoises ecologically at several time periods and life history stages, which would require several complex hypothetical temperature interactions to be created as GIS layers of temperature, and was beyond the scope of this project. Despite this, temperatures indirectly were used in our model owing to their strong correlation with elevation and position, particularly in the northern parts of the study area.

We derived six topographic data layers from a 30-m DEM that, along with elevation, provided the suite of topographic variables that influence desert tortoise habitat at a 1-km² scale using methods similar to Wallace and Gass (2008). Surface roughness was calculated at a 30-m cell size using the method specified by Hobson (1972). Average surface roughness was calculated as the average value of surface roughness in each 1-km² grid cell. Separately, the percentage of each 1-km² cell that was “smooth” and “rough” was assessed by measuring the proportion of 30-m average roughness grid cells that were < 1.01 (threshold for smooth) or > 1.11 (threshold for rough), where the 25% and 75% quartiles of the 30-m surface roughness grid were used to define the thresholds, respectively.

The aspect of each 1-km² grid cell was represented by eastness and northness (Zar, 1999), which are variables that represent aspect by converting the 1 to 360° range of possible azimuths into a range of -1 to 1, where -1 = south or west and 1 = north or east for northness and eastness, respectively. This transformation avoids identical aspects (e.g., 0 and 360 degrees) and creates two data layers with unique numerical representation of aspect, and was calculated using

$$E = \sin\left(\frac{A \times \pi}{180}\right) \text{ and} \quad \text{eqn. (1)}$$

$$N = \cos\left(\frac{A \times \pi}{180}\right), \quad \text{eqn. (2)}$$

where E = eastness, N = northness, and A = aspect.

Spatial data for average soil bulk density, depth to bedrock, percent area with depth to bedrock greater than 1 m, and percent of soil mass with rocks greater than 254 mm B-axis (intermediate) diameter were previously created from the STATSGO database by the Natural Resource Conservation Service and modified by USGS (Bliss, 1998).

The total perennial plant cover data were modeled using Moderate Resolution Imaging Spectroradiometer (MODIS) Enhanced Vegetation Index (EVI) collected by the MODIS satellite and composited over 16-day intervals (Wallace and others, 2008), combined with field measurements of total perennial cover, estimated from line intercept transects at locations across the Mojave Desert (Webb and others, 2003, 2009; Thomas and others, *unpublished data*; Wallace and others, 2008). Total perennial cover was related to elevation and 2001 through 2004

MODIS-EVI data at the transect locations ($R^2 = 0.82$), and the resulting model was used to extrapolate cover estimates for the remaining study area. The resulting data used in our study represented the absolute cover of all perennials irrespective of species composition (Wallace and others, 2008).

Annual growth potential is an environmental data layer that is a proxy for annual plant biomass, which reflects potential forage for tortoises. This data layer was derived by calculating the difference in greenness (a measure of plant growth) between two highly contrasting years of annual plant production (Wallace and Thomas, 2008). The difference between MODIS-EVI images for 2002 (a very dry year) and 2005 (a very wet year) had high correlation with field measurements of annual plant cover collected on 36 plots in the Mojave National Preserve in 2005 ($R^2 = 0.63$, $p=0.01$). The proxy measure of annual growth potential, AGP, was calculated as

$$AGP = \left(\frac{EVI(2005) - EVI(2002)}{EVI(2005) + EVI(2002) + 1} \right) * 100, \quad \text{eqn. (3)}$$

where EVI (2005) and EVI (2002) are the average MODIS-EVI values for the years 2005 and 2002. This formula is analogous to the Normalized Difference Vegetation Index of Huete and others (2002). The resulting values represent the potential for site specific food availability for desert tortoise.

Background Data

If both presence and absence data are available, many statistical techniques exist to predict potential habitat (Guisan and Zimmermann, 2000). However, absence data are rarely available or reliable for animals that hibernate in shelters for part of the year, in part, because their absence from specific areas is difficult to confirm (Guisan and Thuiller, 2005; MacKenzie and others, 2005; Thompson, 2004). Moreover, current ranges for species that have been extirpated from a larger area are misleading when it comes to development of recovery plans. Models built with presence-only data do not incorporate information on the frequency of occurrence of a species in a region, and therefore, they cannot accurately predict probability of presence; these models only estimate a relative index of habitat potential (Elith and others, 2006). We used a random background set of data to serve as “absences.” Although these data do not reflect true absences, they do create comparable models for testing a variety of algorithms and models with different environmental data without embedding assumptions of pseudo-absence point generation models into the habitat model, and they perform similarly to models using pseudo-absence (Phillips and Dudik, 2008).

We created random background points, which we refer to as RBG, by selecting random cells throughout our study area in locations constrained only to cells where desert tortoises were not observed. A total of 6,350 RBG points were selected; 20% of the RBG points (1,270) were used for model testing, and 80% (5,080) points were used for model training.

The Maxent Model

We modeled potential habitat using the Maxent algorithm (version 3.2.19, Phillips and others, 2006). Maxent uses a maximum entropy probability distribution to compare samples of occurrence data with background environmental data. Each of the included predictor variables were assessed using a jackknife test of variable importance and percent contribution (Phillips and others 2006). We used the logistic model output to represent an index of the potential of the habitat in a cell given the training data (Phillips and Dudik, 2008).

To assess the performance of this model, we used area under the curve (AUC) of the receiver operating characteristic (ROC) as a threshold-independent measure of model performance (Elith and others, 2006). ROC is plotted for all possible thresholds, with sensitivity (true positive rate) on the y-axis and 1-specificity (false positive rate) on the x-axis (Fawcett, 2003). The AUC characterizes the performance of the model at all possible thresholds and is summarized by a single number ranging from 0 to 1, where 1 indicates perfect model performance, 0.5 indicates the equivalent of a random guess, and less than 0.5 indicates performance worse than random. Here AUC tests the model discrimination between presence and the random background points rather than presence and true absence; therefore, the maximum possible AUC < 1 and random chance is AUC = 0.5 (Phillips and others, 2006). We also calculated the correlation between the test presence and RBG points (1 or 0) and the predicted values as Pearson's correlation coefficient (Zheng and Agresti, 2000; Elith and others, 2006). This performance metric is similar to AUC, but provides a more direct measure of how the model predictions vary from observations (Elith and others, 2006). The predicted habitat values from Maxent were continuous numbers between 0 (no habitat) to 1 (habitat), which we then binned into 12 intervals to represent various levels of potential habitat. These results were mapped to graphically represent potential habitat.

Results

The Maxent model produced a map of potential desert tortoise habitat for parts of the Mojave and Sonoran Deserts (Fig. 6). This model had a high AUC test score (0.93) and had a significant Pearson's correlation coefficient of 0.74 ($p < 0.01$), indicating a substantial agreement between the predicted habitat and the observed localities of desert tortoises. The final selected model excluded 6 of 16 habitat variables including eastness, northness, winter precipitation CV, summer precipitation CV, percent roughness, and slope (Table 1). These variables were dropped due to their low overall contributions to the model performance in jackknife tests. The model produced output with habitat-potential scores ranging from 0 to 1 (Fig. 7), plus an area that was not estimable because environmental data were not available for one or more layers (Fig. 6). These scores were placed in 12 different bins to provide an index of habitat potential (Table 2). Tortoises were present in 1-km² cells that spanned the entire range of model outputs. The mean model score for all tortoise presence cells was 0.84, and 95% of the cells with known presence had a model score greater than 0.7 (Fig. 7). The total area occupied by each of the 12 bins used as an index for habitat potential is presented in Table 2.

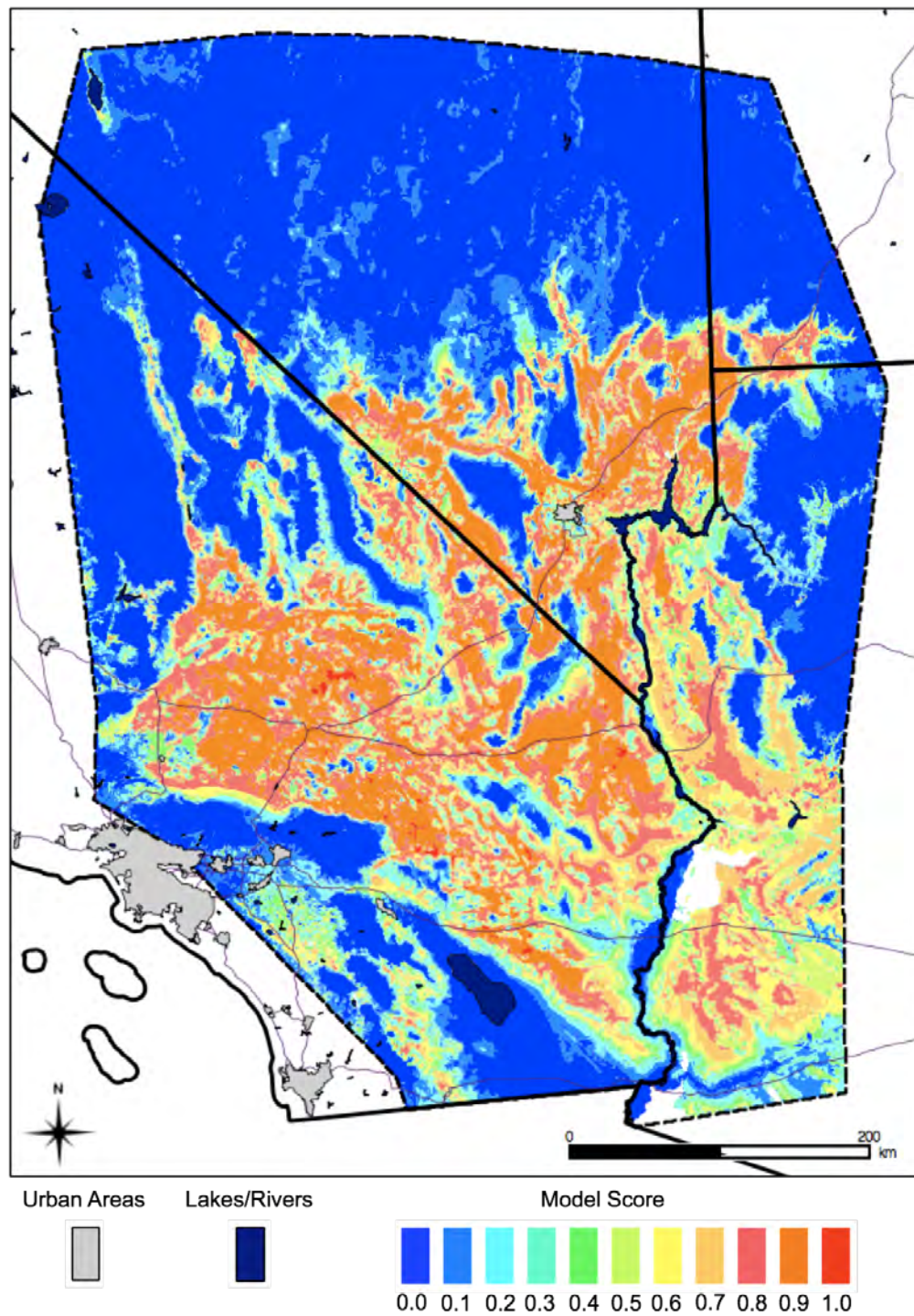


Figure 6. Spatial representation of the predicted habitat potential index values for desert tortoise (*Gopherus agassizii*) in the Mojave and parts of the Sonoran Deserts of Arizona, Nevada, Utah, and Arizona. White patches within the study area indicate areas where no environmental data were available for one or more layers. The Maxent model output used to develop this figure available as an ESRI ASCII GRID file at <http://pubs.usgs.gov/of/2009/1102/>.

Table 2. Total predicted area of desert tortoise habitat for each of 12 bins representing habitat potential values in the habitat potential model of the Mojave and parts of the Sonoran Deserts of California, Nevada, Utah, and Arizona.

[The item labeled as Not Estimable represents a relatively small area where supporting data layers were not available]

Habitat Potential Index Value	Area km ²
1	677
0.9	27,303
0.8	31,216
0.7	23,835
0.6	15,191
0.5	12,880
0.4	13,119
0.3	14,612
0.2	15,100
0.1	30,493
0	147,249
Not Estimable	4,919
Study Area Total	336,594

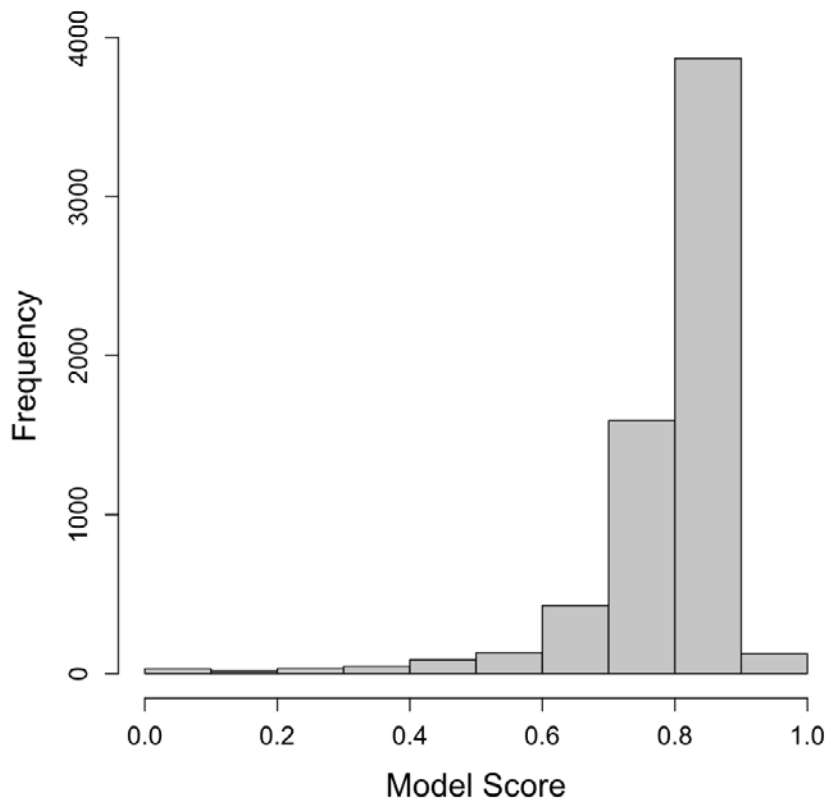


Figure 7. Frequency of the habitat potential index values for the 6,350 1-km² grid cells with known tortoise presence in the Mojave and parts of the Sonoran Deserts of California, Nevada, Utah, and Arizona.

Study Limitations

The quality of the spatial data used in this report is strongly dependent on the accuracy of previously reported presence points for desert tortoises and on the data used to calculate the environmental layers. Though all possible efforts were made to create a seamless and robust dataset, discrepancies are unavoidable since data were collected by different groups using different measurement techniques and sampling frequencies. Model scores reflect a hypothesized habitat potential given the range of environmental conditions where tortoise occurrence was documented. As such, there are likely areas of potential habitat for which habitat potential was not predicted to be high, and likewise, areas of low potential for which the model predicted higher potential. Finally, the map of desert tortoise potential habitat that we present does not account either for anthropogenic effects, such as urban development, habitat destruction, or fragmentation, or for natural disturbances, such as fire, which might have rendered potential habitat into habitat with much lower potential in recent years. Those topics are important foci for future analyses.

Acknowledgments

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