Species Status Assessment for the Sonoran Desert Tortoise

Version 1.0

September 2015

U.S. Fish and Wildlife Service
Southwest Region
Albuquerque, NM

Arizona Ecological Services Field Office
Tucson, AZ

Suggested citation:

U.S. Fish and Wildlife Service. 2015. Species status assessment for the Sonoran desert tortoise. Version 1.0, September 2015. U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, NM.

Executive Summary

Background

This Sonoran Desert Tortoise Species Status Assessment Report documents our use of the best available scientific information to characterize the biological status of the Sonoran desert tortoise. The purpose of the assessment was to inform the listing decision for the species under the Endangered Species Act and also to serve as an information source to inform future conservation efforts.

Species Biology and Needs

The Sonoran desert tortoise (*Gopherus morafkai*) (tortoise) occurs in various habitat types, mainly rocky outcrops along the base of mountain ranges and, to a limited degree, in intervening lands, in parts of Arizona in the United States and Sonora in Mexico. In general and compared to many other animals, tortoises have relatively low fecundity (females lay about 5 eggs on average every other year) and are slow-growing (they may take 15 years to reach sexual maturity), but are long-lived (they may live more than 50 years in the wild). Individual tortoises grow to sizes of about 15 inches in shell length. They feed on a variety of vegetation and spend the majority of their time in underground shelters coming out mainly to drink, forage, and breed.

For the Sonoran desert tortoise to maintain viability over the long term, it needs populations of adequate size and distribution to support resiliency, redundancy, and representation. Sonoran desert tortoise populations need large number of individuals in order to improve the changes of withstanding stochastic events (a measure of resiliency). The tortoise also needs to have resilient populations spread across its range in both the U.S. and Mexico, supported by suitable habitat quantity and quality, to provide for rangewide redundancy (species ability to withstand catastrophic events such as potential large-scale drought) and representation (species genetic and ecological diversity to maintain adaptive capacity).

Predicted Potential Habitat

We constructed a coarse potential habitat map based on elevation, slope, and vegetation type across the species' range. We categorized the potential habitat as high, medium, or low based on our judgment for the parameters measured to support tortoises. This rangewide geospatial analysis resulted in a prediction of approximately 38,000 sq mi (24 million ac, 9.8 million ha) of potential tortoise habitat (Figure ES-1). Of this total, 64% occurs in the U.S. and 36% occurs in Mexico.

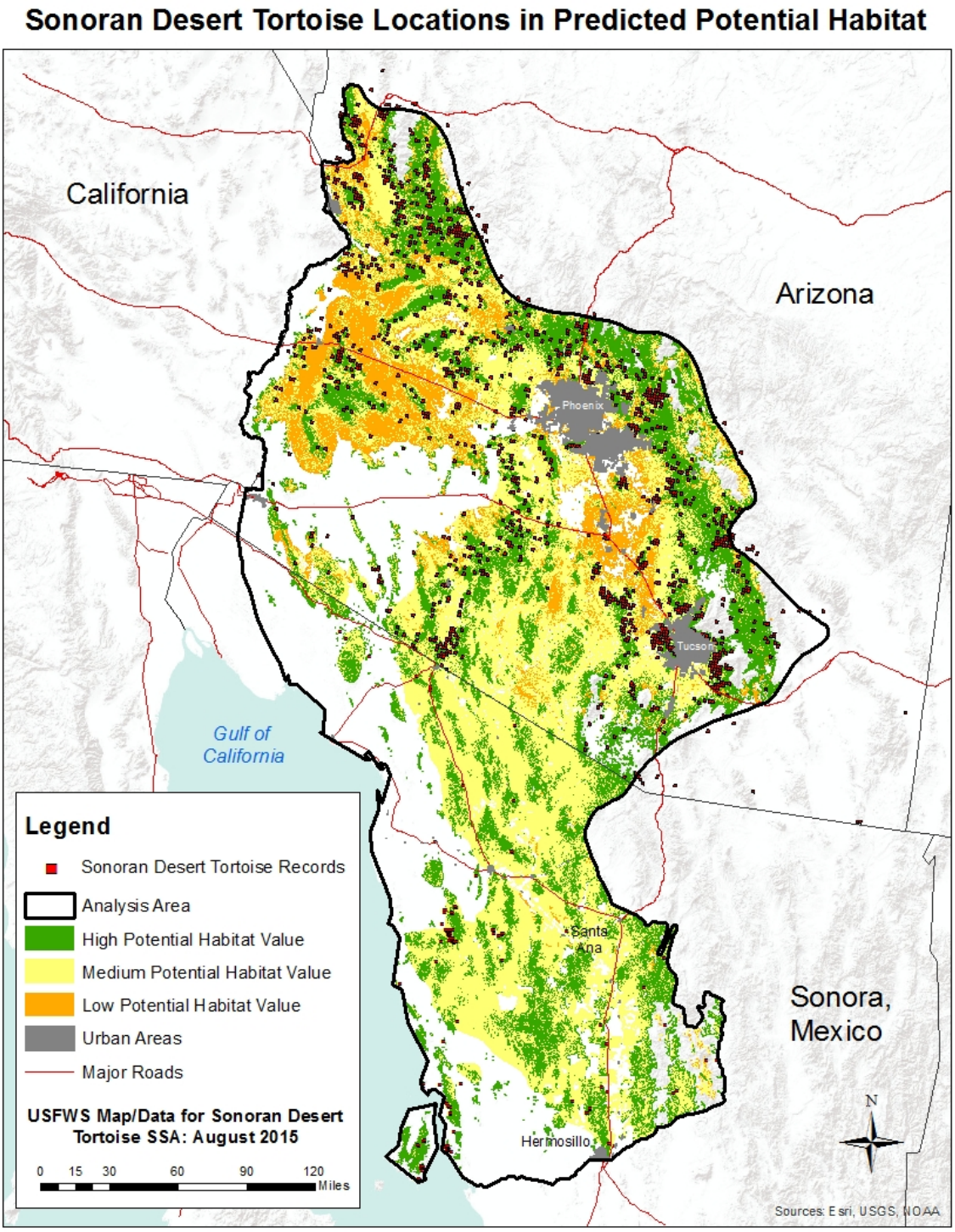

Figure ES-1. Predicted potential habitat for the Sonoran desert tortoise based on elevation, slope, and vegetation type with tortoise occurrence records identified.

Risk Factors

We reviewed the potential risk factors that could be affecting the tortoise. Concerns about the tortoise's status revolve around six primary risk factors: 1) altered plant communities, primarily due to the invasion of nonnative grasses; 2) altered fire regimes, also related to the changes in plant communities; 3) habitat conversion of native vegetation to developed landscapes; 4) habitat fragmentation by the construction of permanent linear structures like highways and canals; 5) human-tortoise interactions such as handling, collecting, and killing individual tortoises intentionally or unintentionally (especially by vehicle strikes); and 6) climate change as it relates to increases in the frequency, scope, and duration of drought conditions in the Sonoran Desert.

We evaluated each of these factors in detail for their potential to have population and species-level effects to the Sonoran desert tortoise. While many of them could be having effects on individual tortoises, most have not been shown to have population-level effects on the species. Some factors may have population-level effects, but, because of the long-life span, relatively high abundance, and wide range of the Sonoran desert tortoise, these effects would likely take many decades or longer to have measurable impacts on the species. In addition, many of these factors are ameliorated to some degree by ongoing and future conservation efforts through land management; an estimated 73% of potential habitat in the U.S. has some conservation management, and 55% of potential habitat in the U.S. was included in a recent interagency conservation agreement committing Federal land managers to continuing conservation efforts for the tortoise. However, because of the uncertainty about the actual effects of many of these factors, and to evaluate the potential for cumulative effects, we analyzed current and future conditions of the tortoise under varying scenarios to assess a range of possible conditions ranging from high management and low threats to low management and high threats.

Current Conditions

To our knowledge, the tortoise has not experienced any measurable reduction in its overall range and past population loses are presumed to be limited to areas that have been converted to urbanization that may have historically served as habitat for the species.

We evaluated the current condition of the tortoise by developing habitat quality categories (primary, secondary, and tertiary) that are based on the suitability of potential habitat (high, medium, and low) and the possible presence of risk factors that could have population-level effects. We used four geospatial layers to measure those risk factors: land management, presence of nonnative vegetation, high fire risk potential, and proximity to urban areas. We used the spatial information from these four geographic layers to categorize all of the potential habitat within the species' range as either primary, secondary, or tertiary habitat quality. We did this analysis under two alternative assumptions related to the effects of the risk factors (high or low threats) and the effects of conservation measures (high or low management). For the U.S. analysis area, this resulted in a range of 8% to 25% of all potential tortoise habitat being in the primary quality category; 62% to 75% being in secondary quality; and 13% to 17% being in tertiary quality. In Mexico, this resulted in a range of 0% to 2% of potential habitat being in the primary quality category; 79% to 98% being in secondary quality; and 0.2% to 21% being in tertiary quality.

We used the amount of habitat in each quality category combined with reported density estimates for tortoises to produce rangewide abundance estimates under varying assumptions of habitat conditions and density estimates. The current rangewide abundance estimates ranged from 470,000 to 970,000 total adult tortoises. The current estimate in the U.S. was from 310,000 to 640,000 adult tortoises, and in Mexico the estimate was 160,000 to 330,000 adult tortoises.

Future Conditions and Viability

We used our habitat-based geospatial system to project future habitat conditions, and a population simulation model to project the species response to those habitat conditions. . The simulation model projected the future abundance, population growth rates, and risks of quasi extinction of the tortoise in the U.S. and Mexico areas of analysis.

We ran the model under a range of different scenarios representing key areas of uncertainty in the analysis including the amount and quality of habitat (as a function of risk factors and management efforts), the starting and maximum abundance, the extent of future droughts, and the quasi-extinction threshold. As we projected habitat conditions into the future, we included scenarios that accounted for the conversion of habitat to urbanization and future degradation of habitat quality due to the potential effects of nonnative grasses and fire risk. The simulation model included a component to account for the future effects of climate change by simulating an increasing extent of drought and variation in the magnitude of the effects of drought on tortoise reproduction and survival. We conducted the analysis using nine different scenarios for the U.S. analysis area and nine different scenarios for the Mexico analysis area. Although the simulation model is not spatially explicit at a smaller scale than the U.S. and Mexico areas of analysis, it provides a robust, objective method to measure the potential effects of changing habitat conditions and the potential effects of climate change.

The results of our analysis characterized resiliency by projecting the future abundance and risk of quasi extinction annually over a 200-year time frame. These projections of risk were largely influenced by the starting population size estimates and the quasi-extinction thresholds. However, the future scenarios were also influenced by the potential for climate change to result in an increase in the magnitude of droughts.

The resulting population growth rates for all scenarios ranged from 0.9915 to 0.9969 indicating very slightly decreasing numbers of tortoises in the areas of analysis. As a result all of the scenarios showed declining overall abundances into the future in each of the areas of analysis. However, because of the relatively large current estimated population sizes and the long life span of these tortoises, our simulation model suggests no measurable risks of quasi extinction in the next 50 years in either the U.S. or Mexico areas of analysis under any scenarios even though slow population declines are projected. At 75 years, the risks increased, ranging from 0 in some scenarios to as high as 0.033 probability of quasi extinction (in other words, a 3.3% risk of quasi extinction in 75 years) in the worst case future scenario for the Mexico analysis area. All but 3 (of 18) scenarios resulted in less than 0.01 probability of quasi extinction in 75 years. When we look farther into the future at 100 years, our simulation model suggests the risks of quasi extinction for some scenarios increased to near 0.05 probability of quasi extinction (ranging from 0 to 0.089, with 8 of 18 scenarios exceeding 0.03 probability of quasi extinction). At 200 years,

several scenarios exceeded 0.2 probability of quasi extinction (ranging from 0.07 to 0.323, with 14 of 18 scenarios exceeding 0.1 probability of quasi extinction).

We characterized the redundancy (number and distribution of tortoise populations) and representation (diversity) indirectly through projecting the likely quality and quantity of tortoise habitat distributed across the species ranger under different scenarios. Under worst case future scenarios that include low management, high threats, habitat loss and degradation, the distribution of habitats in the U.S. (considering a 60-year future condition) is projected to include about 11,800 sq mi (7.5 million ac, 3 million ha) of habitat categorized as primary or secondary quality. In Mexico, under the worst case scenario about 10,550 sq mi (6.8 million ac, 2.7 million ha) of secondary quality habitat is projected to be maintained. Other scenarios project more favorable conditions in both the U.S. and Mexico. The habitat quality under the worst case condition is projected to be distributed across the species range, although in Arizona the habitat for this scenario is quite reduced compared to more favorable scenarios or current conditions.

By its very nature, any status assessment is forward-looking in its evaluation of the risks faced by a species, and future projections will always be dominated by uncertainties which increase as we project farther and farther into the future. This analysis of the tortoise is no exception. In spite of these uncertainties, we are required to make decisions about the species with the best information currently available. We have attempted to explain and highlight many of the key assumptions as part of the analytical process documented in this SSA report. We recognize the limitations in available information and we handled them through the application of scenario planning, geospatial modeling, and population simulation modeling.

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List of Acronyms

ac- acre (1 ac = 0.0016 sq mi; = 0.04 ha)

Act- Endangered Species Act

AGFD- Arizona Game and Fish Department

AIDTT- Arizona Interagency Desert Tortoise Team

BLM- Bureau of Land Management

CCA- Candidate Conservation Agreement

cm- centimeter

ft- feet

GIS- Geographic Information Systems

ha- hectare (1 ha = 0.0039 sq mi; = 2.47 ac)

km- kilometer

m- meter

mi- mile

mm- millimeter

PEP- Potassium Excretion Potential

REA SOD- Rapid Ecological Assessment for the Sonoran Desert

Service- U.S. Fish and Wildlife Service

SSA- Species Status Assessment

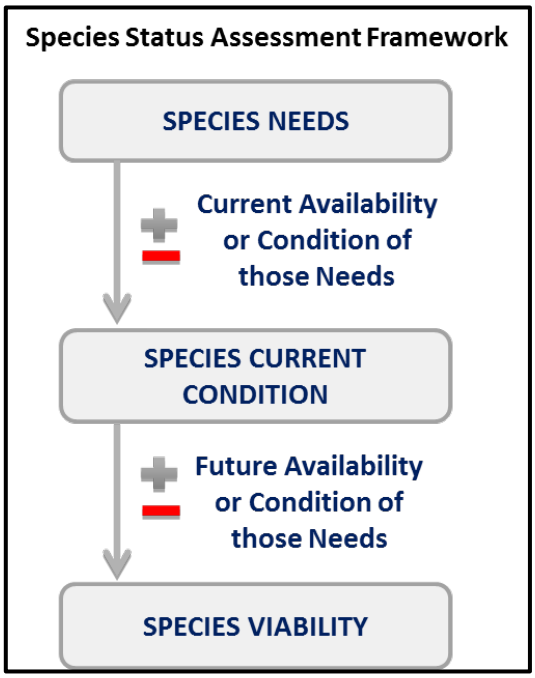
sq mi- square mile (1 sq mi = 640 ac; = 259 ha)

USFWS- U.S. Fish and Wildlife Service

Chapter 1: Introduction

The Sonoran desert tortoise (*Gopherus morafkai*) occurs in various habitat types in Arizona and northern Mexico. It was made a candidate for listing in 2010 by the U.S. Fish and Wildlife Service (Service) under the Endangered Species Act of 1973, as amended (Act) (75 FR 78094, December 14, 2010). The species is now being reviewed for listing as a threatened or endangered species under the Act. This Sonoran Desert Tortoise Species Status Assessment Report (SSA Report, SSA) is a summary of the information assembled and reviewed by the Service and incorporates the best scientific and commercial data available. This SSA Report documents the results of the comprehensive status review for the Sonoran desert tortoise to inform the listing decision under the Act and to inform future conservation efforts.

The Service is engaged in a number of efforts to improve the implementation of the Act (see www.fws.gov/endangered/improving_ESA). As part of this effort, our Endangered Species Program is developing a new framework to guide how we assess the biological status of species. Because biological status assessments are frequently used in all of our Endangered Species Program areas, developing a single, scientifically sound document is more efficient than compiling separate documents for use in our listing, recovery, consultation, and other conservation programs. Therefore, we have developed this SSA Report to summarize the most relevant information regarding life history, biology, and considerations of current and future risk factors facing the Sonoran desert tortoise. In addition, we forecast the possible response of the species to various future risk factors and environmental conditions to provide a complete risk analysis for the Sonoran desert tortoise.



The objective of the SSA is to thoroughly describe the viability of the Sonoran desert tortoise based on the best scientific and commercial information available. Through this description, we will determine what the species needs to remain viable, its current condition in terms of those needs, and its forecasted future condition. In conducting this analysis, we take into consideration the likely changes that are happening in the environment – past, current, and future – to help us understand what factors drive the viability of the species.

For the purpose of this assessment, we define **viability**[1] as a description of the ability of a species to sustain populations in the wild beyond a biologically meaningful time frame. Using the SSA framework, we consider what the species needs to maintain viability by characterizing the status of the

[1] Viability is not a specific state, but rather a continuous measure of the likelihood that the species will sustain populations over time. From, USFWS. 2015. Draft Species Status Assessment Framework. Version 3.1 for FWS ES HQ and Science Applications Review. January 2015.

species in terms of its **resiliency**, **redundancy**, and **representation**.

- **Resiliency** is having sufficiently large populations for the species to withstand stochastic events. Stochastic events are those arising from random factors such as weather, flooding, or fire. We can measure resiliency based on metrics of population condition; in the case of the Sonoran desert tortoise, the primary indicators of resiliency are population abundance, population growth rates, and quasi-extinction risk.

- **Redundancy** is having a sufficient number of populations for the species to withstand catastrophic events. A catastrophic event is defined here as a rare destructive event or episode involving many populations and occurring suddenly. Redundancy is about spreading the risk and can be measured through the duplication and broad distribution of resilient populations across the range of the species. The more resilient populations the species has, distributed over a larger area, the better chances that the species can withstand catastrophic events. For the Sonoran desert tortoise, we are using the geographic distribution of predicted potential habitat, as described by geospatial analyses and quasi-extinction risk, to measure redundancy.

- **Representation** is having the breadth of genetic makeup of the species to allow for potential future adaptation to changing environmental conditions. Representation can be measured through the genetic diversity within and among populations and the ecological diversity (also called environmental variation or diversity) of populations across the species' range. Theoretically, the more representation, or diversity, the species has, the higher its potential of adapting to changes (natural or human caused) in its environment. Quasi-extinction risk and geographic distribution of predicted potential habitat (via geospatial analyses) are also being used to describe representation for the Sonoran desert tortoise.

To evaluate the viability of the Sonoran desert tortoise both currently and into the future, we assessed a range of conditions to allow us to consider the species' resiliency, redundancy, and representation.

The format for this SSA Report includes the following chapters:

1. Introduction.
2. Species Biology and Needs. The resource needs of individuals and a framework for what the species needs across its range for species viability;
3. Predicted Potential Habitat. The predicted rangewide potential habitat analysis;
4. Risk Factors. The likely causes of the current and future status of the species, and determining which of these risk factors affect the species' viability and to what degree;
5. Current Conditions. The species' current range, habitat conditions, and population estimates; and
6. Future Conditions and Viability. A quantitative description of the viability in terms of resiliency, redundancy, and representation using geospatial analysis and a population simulation model.

Additional supplemental information and analysis was used to complete this SSA Report. For a glossary of some of the terms used in this SSA Report, please refer to Appendix A. We prepared a geospatial analysis using Geographic Information Systems (GIS), and the corresponding GIS Analysis Report is presented in Appendix B. The detailed analysis of risk factors summarized in Chapter 4 is found in Appendix C. We conducted an analysis to quantitatively characterize the possible future risks to the Sonoran desert tortoise using a simulation model as described in Appendix D. Finally, the literature cited in this SSA Report is in Appendix E.

Importantly, this SSA Report does not result in, nor predetermine, any decisions by the Service under the Act. In the case of the Sonoran desert tortoise, the SSA Report does not determine whether the Sonoran desert tortoise warrants protections of the Act, or whether it should be proposed for listing as a threatened or endangered species under the Act. That decision will be made by the Service after reviewing this document, along with the supporting analysis, any other relevant scientific information, and all applicable laws, regulations, and policies. The results of the decision will be announced in the *Federal Register*. Instead, this SSA Report provides a strictly scientific review of the available information related to the biological status of the Sonoran desert tortoise.

Chapter 2: Species Biology and Needs

In this chapter, we provide basic biological information about the Sonoran desert tortoise, including its taxonomic history, range, morphological description, and known life history traits. We then outline the resource needs of individuals. Lastly, we provide our rationale for defining populations and outline the species' rangewide needs.

2.1 Taxonomy

The Sonoran desert tortoise was first described by Cooper in 1863 (pp. 118–123). Since that time, the Sonoran desert tortoise was recognized as a population of the desert tortoise (*Gopherus agassizii*) until advanced genetic analysis supported elevating the Sonoran population of the desert tortoise as a unique species, Morafka's desert tortoise (*Gopherus morafkai*) (Murphy *et al.* 2011, p. 53). This genetic analysis confirmed the taxonomic distinction previously hypothesized by Lamb *et al.* (1989, p. 83), Lamb and McLuckie (2002, p. 74), and Van Devender (2002a, p. 24). As a result, the Sonoran desert tortoise is recognized as a distinct species (*G. morafkai*), but retains its common name[2], Sonoran desert tortoise, as recommended in Crother *et al.* (2012, pp. 76–77), to avoid potential confusion of the abbreviation for Morafka's desert tortoise with that of the Mojave desert tortoise (*G. agassizii*). The Sonoran desert tortoise is known in Mexico with the common names of "tortuga del monte," "Galápago de desierto," or the "xtamóosni" (Rorabaugh 2008, p. 35).

The currently accepted species classification is:

Class: Reptilia
Order: Testudines
Family: Testudinidae
Species: *Gopherus morafkai*

2.2 Species Description

In Arizona, adult Sonoran desert tortoises (Figure 1) range in total carapace (straight-line top shell) length from 8 to 15 inches (in) (20 to 38 centimeters [cm]), with a relatively high domed shell (Arizona Game and Fish Department (AGFD) 2001, p. 1; Brennan and Holycross 2006, p. 54). The maximum recorded length for a Sonoran desert tortoise in Arizona is 19.4 in (49 cm) total carapace length (Jackson and Wilkinson-Trotter 1980, p. 430). The carapace is usually brownish or dark in color with a definite pattern and prominent growth lines (AGFD 2001, p. 1; Murphy *et al.* 2011, p. 56). The plastron (bottom shell) is yellowish and is not hinged (AGFD 2001, p. 1; Brennan and Holycross 2006, p. 54). The hind limbs are very stocky and elephantine; forelimbs are flattened for digging and covered with large conical scales (AGFD 2001, p. 1; Brennan and Holycross 2006, p. 54). Male Sonoran desert tortoises are differentiated from females by having elongated gular (throat) shields, chin glands visible on each side of the lower jaw (most evident during the breeding season), and a concave plastron (AGFD 2001, p. 1). Murphy *et al.* (2011, pp. 55–56) offers a detailed description of the species' holotype.

[2] Taxonomic nomenclature for this report: *Gopherus morafkai* = Morafka's desert tortoise, referred to as Sonoran desert tortoise in this SSA report; *Gopherus agassizii* = Agassiz's desert tortoise, referred to as Mojave desert tortoise in this SSA report. Unless otherwise noted, "tortoise" in this report refers to the Sonoran desert tortoise.

Figure 1. Image of a Sonoran desert tortoise in Arizona. (Jeff Servoss, USFWS)

2.3 Range

The Sonoran desert tortoise occupies portions of western, northwestern, and southern Arizona in the United States, and the northern two-thirds of the Mexican State of Sonora. According to our analysis (Appendix B), roughly 40% of the geographic range of the Sonoran desert tortoise genotype occurs in Mexico. The total area within the estimated range of Sonoran desert tortoise in Arizona and Mexico is about 66,000 square miles[3] (sq mi) (about 42 million acres (ac), about 17 million hectares (ha)). This range includes about 40,000 sq mi (about 26 million ac, 11 million ha) in the United States and about 26,000 sq mi (about 16 million ac, 11 million ha) in Mexico.

Previous Sonoran desert tortoise range maps identified two areas that we chose to exclude from our analysis as part of the species' range, based upon genetic information as described below. These two areas are in the Black Mountains region of Arizona in the northwestern portion of species' previously identified range and the area south of Rio Sonora in Mexico (Figure 2).

2.3.1 Black Mountains

Recent genetic analysis supports that desert tortoises in the southern portion of the Black Mountains in Arizona have been determined to be Mojave desert tortoises (*Gopherus agassizii*); this determination was also supported by habitat and topographical variables and modeling (Edwards *et al.* 2015, entire). Genetic admixture (hybridization) has been demonstrated between the Sonoran and Mojave genotypes in many areas surrounding the Black Mountains, including in the Hualapai Mountains and the White Hills area (Figure 2; Edwards *et al.* 2015, p. 2105).

[3] For the purpose of simplified communication, some of the area metrics in this SSA Report are provided in square miles without conversion to metric units. One square mile is equivalent to about 640 acres and 259 hectares.

Genetic data presented in Edwards *et al.* (2015, p. 2107) suggest that hybridization of Sonoran and Mojave desert tortoises is minimized farther away from the Colorado River. Genetic data also indicate a disproportionate distribution of hybrid classes, with Mojave desert tortoise backcrosses dominant in the Black Mountains and Sonoran desert tortoise backcrosses primarily distributed in the Hualapai Mountains (Edwards *et al.* 2015, p. 2107, Table 4). Existing data also suggest the Mojave desert tortoise genotype extends further north into the White Hills although a lack of samples from this area precludes confirmation (Edwards *et al.* 2015, p. 2105). Although hybridization between the two species has been documented south and east of Interstate-40, including the Hualapai Mountains, we used this highway as our boundary for Sonoran desert tortoise range due to the lower apparent frequency of hybridization east of the Interstate-40. The geographic distribution of hybrid individuals, and thus the hybrid zone, is likely a result of proximity to phylogenetic recontact zones (Edwards *et al.* 2015, p. 2107). This predominance of Sonoran desert tortoises over Sonoran-Mojave hybrids east of Interstate-40, including in the Hualapai Mountains, is why we used Interstate-40 as our boundary for separating the two tortoise species (Figure 2). Therefore, we removed the areas in the Black Mountains north and west of Interstate-40 from our Sonoran desert tortoise analysis.

2.3.2 Sinaloa

In the region of Sonora, Mexico, bisected by the Rio Sonora and characterized as largely Sinaloan thornscrub, Edwards (2015, p. 68) found that desert tortoises are comprised of genetically and geographically distinct “Sonoran” and “Sinaloan” lineages. Sinaloan thornscrub habitat in this region of Mexico is thought to represent a shifting, ephemeral boundary over geologic time that drove adaptations unique to both the core Sinaloan lineage found in tropical deciduous forest and the core Sonoran lineage, found in Sonoran desertscrub (Edwards 2015, p. 77). Despite the presence of a narrow contact zone of limited introgression between tortoise lineages and incomplete reproductive isolation, the Sonoran and Sinaloan lineages of the desert tortoise are on separate evolutionary trajectories exhibited by deep divergence in their respective genotypes which is consistent with species-level divergence in other turtle and tortoise genera (Edwards 2015, p. 78).

Although desert tortoises south of the Rio Sonora are taxonomically considered part of the *G. morafkai* species published range, the best available information makes a compelling case (Edwards 2015, p. 78) that the tortoises in the tropical deciduous forest should be identified as a separate species from the Sonoran desert tortoise. Therefore, we have excluded them the taxonomic entity that we are reviewing in this SSA. While we recognize the difficulty in identifying a specific range boundary line on a map given the incomplete reproductive isolation resulting in the admixture of genetic lineages present on either side of an artificial boundary, we removed the area of the range south of Rio Sonora from our Sonoran desert tortoise analysis based subjectively on results from recent genetic research (Edwards 2015, pp. 67–101, Figure 3). The map on the following page (Figure 2) illustrates our adjusted distribution boundary for the Sonoran desert tortoise.

Throughout the remainder of this SSA report, references to the range of the Sonoran desert tortoises refers to the analysis area as indicated in Figure 2.

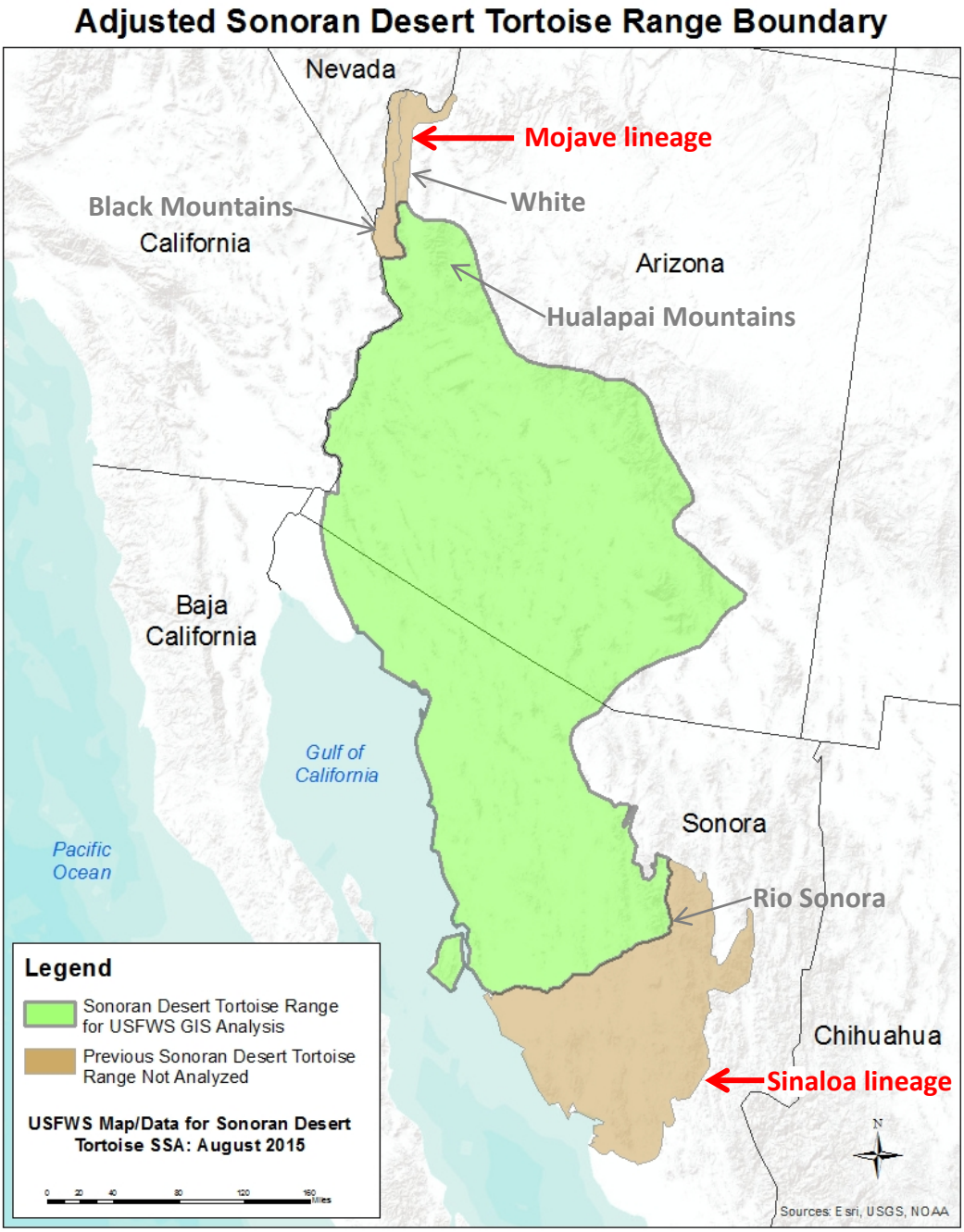


Figure 2. Our adjusted Sonoran desert tortoise range boundary highlighting areas that were previously included as portions of the Sonoran desert tortoise species range. Recent genetic analyses support that tortoises in the brown areas do not wholly represent the pure Sonoran desert tortoise genetic lineage and, therefore, are not considered in the Sonoran desert tortoise SSA Report. Note that tortoises in the Sinaloa lineage occur further south than the southern brown area identified on this map.

2.4 Life History

Sonoran desert tortoises are long-lived and grow slowly. In this analysis, we consider the Sonoran desert tortoise to have three life stages: young juveniles, older juveniles (or subadults), and adults. Time spent in each of these life stages is size-dependent. In the following paragraphs, we discuss each of these life stages. This information is summarized in Figure 3, which shows the basic life history profile of the Sonoran desert tortoise.

The young juvenile size class includes hatchlings and very small juveniles. Tortoises generally remain in this size class for approximately 5 years until their shells ossify (harden). Eggs hatch in September and October (Van Devender 2002, pp. 10–11; Averill-Murray 2002b, p. 295), following the end of the monsoon season. The behavior and ecology of young juveniles is poorly understood because their small size makes them difficult to detect in the wild. Desert tortoises are most vulnerable to predation while in this age class, predominantly because of their small size and their softened shells, which provide little protection and are easily compromised until they ossify at approximately 4.3 in (110 millimeters (mm)) maximum carapace length (Nagy *et al*. 2011, p. 194). Gila monsters (*Heloderma suspectum*) may be a primary predator on tortoise eggs (Barrett and Humphrey 1986, p. 262); coachwhips (*Coluber* (=Masticophis) *flagellum*) and gophersnakes (*Pituophis catenifer*) have been reported to consume young juvenile tortoises (Amarello *et al.* 2004, p. 178; Ernst and Lovich 2009, p. 563), as have a variety of predatory mammal species (Boarman 2002, p. 17; Ernst and Lovich 2009, p. 563). Higher mortality rates in the young juvenile stage may also be partially due to their higher metabolic rates, which may necessitate longer periods of surface activity to obtain potential amounts of forage. Thus, the annual survival rates during the young juvenile stage are relatively low.

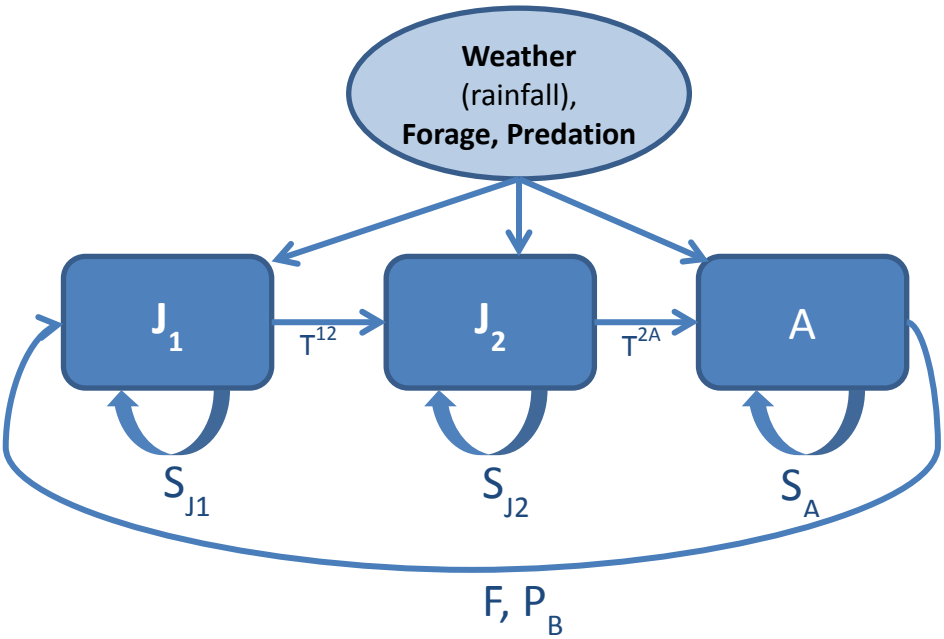
Once their shells are completely ossified (usually by the time they are 4.3 in (110 mm) MCL), we consider Sonoran desert tortoises to be large juveniles and they remain in this size class from approximately age 6 to 15, depending on environmental conditions that affect individual growth rates and transition time to the adult stage. In one study examining tortoise at 15 sites monitored multiple times between 1987 and 2008, survival rates during the older juvenile stage were estimated at 77% in one study (Zylstra *et al*. 2013, pp. 113–115). Older juvenile survivorship is presumably higher than that of the young juvenile age class given their slightly larger size and completely hardened shells. Time spent in this size class ends when tortoises reach sexual maturity, which typically occurs when their shells reach approximately 8.7 in (221 mm) maximum carapace length and is strongly influenced by precipitation trends (Averill-Murray and Klug 2000, p. 69; Averill-Murray *et al.* 2002b, p. 119; Bury *et al.* 2002, p. 100; Germano *et al.* 2002, p. 265).

Generally, tortoises transition to the adult size class around the age of 16. Recent estimates of longevity in wild tortoises range from 42 to 54 years (Curtin *et al*. 2009, p. 4), and many tortoises are presumed to live longer. Annual survivorship for adult Sonoran desert tortoises in Arizona (according to monitoring plot data from 1987-2008) has been estimated to average 92% (Zylstra *et al.* 2013, p. 112) which is well within values of survivorship that would be expected for long-lived species in general, and tortoises in particular (Heppell 1998, p. 370). As adults, tortoises are relatively protected from natural predation because of their size and hard shells. Sustaining the adult, reproductive age class within Sonoran desert tortoise populations is

important because mortality rates of juveniles are high, and it takes a long time for a Sonoran desert tortoise to reach sexual maturity (Howland and Rorabaugh 2002, p. 339). Rates at which juveniles transition into adulthood are estimated to range from 7–13% (Campbell *et al.* 2014, pp. 2, 14).

The Sonoran desert tortoise's breeding season generally occurs from July through October. Approximately half of the adult females in a population reproduce in any given year (Campbell *et al.* 2014, p. 2). Females may store sperm for up to two years, meaning that one season's mating could produce the following season's clutch of eggs (Palmer et al. 1998, pp. 704–705; Averill-Murray *et al*. 2002a, p. 141). Female Sonoran desert tortoises may lay one clutch of 1–12 eggs per year, usually around the onset of the summer rainy season (monsoon), although they may not produce a clutch every year (Averill-Murray 2002b, p. 295). The average egg clutch size is 5.15 with a 61% hatch rate (Campbell *et al*. 2014, p. 2). Female Sonoran desert tortoises that survive to reproductive age can produce as many as 85 eggs over the course of their lives. However, given the survival rates for Sonoran desert tortoises, only two or three of those hatchlings may survive to reproductive age (Van Devender 2002a, p. 11). Hatching success may be improved by nest defense behavior that has been observed in female Sonoran desert tortoises (Barrett and Humphrey 1986, pp. 261–262).

Tortoise behavior varies greatly among the seasons; tortoises exhibit the most notable surface activity during the early–mid spring, and again during the summer monsoon, spending the rest of the year in their burrows unless surfacing in response to precipitation (Sullivan *et al.* 2014, pp. 116–118) or other physiological needs. Sonoran desert tortoise surface activity largely mimics the warm-season precipitation pattern (Averill-Murray *et al.* 2002a, p. 139; Van Devender 2002, p. 7). During the winter months from mid-November through mid-February, tortoises are largely dormant within their burrows, although they may exhibit some level of surface activity in response to thermoregulatory needs, to move between shelter sites, or to rehydrate during or after rainfall (Averill-Murray and Klug 2000, p. 66; Sullivan *et al.* 2014, pp. 116–118). Periods of dormancy in Sonoran desert tortoises appear to vary greatly among populations and among years but appear to correlate with seasonal temperatures (Bailey *et al.* 1995, p. 367; Averill-Murray and Klug 2000, p. 66). During the spring, gravid (egg-bearing) females are typically the first tortoises to emerge and become surface active every year (Averill-Murray *et al.* 2002a, p. 138), seeking to forage on spring annual plants generated by winter rains to acquire energy for egg development. While a small percentage of adult males may emerge during the spring, their primary surface-active season coincides with the summer monsoon (July through September), as it does for both sexes and all age classes of Sonoran desert tortoises (Averill Murray *et al.* 2002a, pp. 139–140). The Sonoran desert tortoise is diurnal (active during daylight hours) but may emerge at night to drink in response to rainfall (Ernst and Lovich 2009, p. 544). Availability of free-standing water, both spatially and temporally (for drinking) (Sullivan *et al*. 2014, entire) is thought to be critical to the survival of Sonoran desert tortoises.



Where:

J_1 = Young Juveniles, from age 0 to approximately 5 years; the time in this stage is size-dependent and ends with firm calcification of the shell; stage includes hatchlings

J_2 = Older Juveniles from approximately age 6 to approximately 15 years; the time in this stage is size-dependent and ends with sexual maturity

A= Adults, from approximately age 16 years to death; life span is something beyond 50 years, as long as 100 years

S_{J1} = Survival rates during the Young Juvenile stage (Relatively Low)

S_{J2} = Survival rates during the Older Juvenile stage (Uncertain)

S_A = Survival rates during the Adult stage (Really High)

F = Fecundity, approximately 4 to 6 eggs per female, per breeding year; can vary; includes egg survival; only about 60% of females breed year

P_B = Probability of breeding

T^{12} = Transition rate from Young to Older Juvenile

T^{2A} = Transition rate from Older Juvenile to Adult

Weather (timing and amount of rainfall), **Forage Availability**, and **Predation** are the primary natural influences affecting all survival rates and fecundity.

Figure 3. The basic life history profile for the Sonoran desert tortoise.

2.5 Resource Needs (Habitat) of Individuals

Sonoran desert tortoises primarily inhabit rocky, steep slopes and bajadas of Mojave Desertscrub and the Arizona Upland and Lower Colorado River subdivisions of Sonoran desertscrub. Ninety-five percent of all Sonoran desert tortoise records in Arizona are located between elevations ranging from approximately 900 to 4,200 feet (ft) (275 to 1,279 meters (m)). They most often occur in the paloverde-mixed cacti associations (Ortenburger and Ortenburger 1927, p. 120; Barret 1990, entire; deVos *et al.* 1983, p. 144; Vaughan 1984); however, records have also been documented in Madrean Evergreen Woodland, Semidesert Grassland, Interior Chaparral, Plains of Sonora, and Sinaloan Thornscrub habitats [as defined in Brown (1994, entire]; see Figure 4). Their habitat extends throughout the Sonoran Desert Ecoregion, from central-western Arizona south to the Rio Sonora in Mexico.

The Sonoran desert tortoise is an herbivore, and has been documented to eat 199 different species of plants, including herbs (55.3%), woody plants (22.1%), grasses (17.6%), and succulents (5%) (Ogden 1993, pp. 1–8; Van Devender *et al.* 2002, pp. 175–176; Brennan and Holycross 2006, p. 54; Oftedal 2007, p. 21; Ernst and Lovich 2009, p. 562; Meyer *et al.* 2010, pp. 28–29, 44–48). Sonoran desert tortoises may also consume some species of nonnative plants which provide various degrees of nutritional benefit (Nagy *et al*. 1998, entire) and avoid consuming others (Gray and Steidl 2015, entire). Sonoran desert tortoises may obtain less of their metabolic water from their diet than previously thought, as Sullivan *et al*. (2014, entire) found a high proportion of telemetered Sonoran desert tortoises became surface-active to drink free-standing water in response to precipitation regardless of time of year. However, plant species eaten by Sonoran desert tortoises can directly affect their hydration-state. Many plant species contain potassium and tortoises lose water in the process of metabolizing potassium (Oftedal 2002, p. 214). The potassium excretion potential (PEP) is an index of water, nitrogen, and potassium levels in a plant that affects a tortoise's ability to efficiently excrete potassium. A positive PEP value for a plant species (preferred by tortoises) means there is more water and nitrogen in the food than is needed to excrete potassium (water gained), and the opposite being true for a negative PEP value (water lost) (Oftedal 2002, p. 215). Tortoises have been documented selectively foraging on high-PEP plant species (Oftedal 2002, p. 223; 2007, pp. 3, 22). High PEP values can be found in certain species of primroses, filaree, legumes, mustards, and spurges (Ernst and Lovich 2009, p. 545) and access to high PEP plant species may be especially important for tortoises to overcome the effects of drought (Averill-Murray *et al.* 2002a, p. 146; Ernst and Lovich 2009, p. 545). A tortoises' large, bi-lobed bladder is also critical for withstanding the effects of drought because it stores a high volume of water, dilutes excess dietary salts and metabolic wastes, and reabsorbs water into the bloodstream, allowing tortoises to forage on dried vegetation while reducing the effect of dehydration (Averill-Murray *et al.* 2002a, p. 146; Ernst and Lovich 2009, p. 545). When free-standing water for drinking becomes available, tortoises drink to flush salts and reset the electrolytic balance in preparation for the next dry period (Averill-Murray *et al.* 2002a, pp. 140, 146).

In addition to using vegetation within these biotic communities to meet energy and nutritional needs, the Sonoran desert tortoise uses vegetation (cover plants) for predator avoidance, thermal protection, and in social behaviors (Avery and Neibergs 1997, p. 13; Grandmaison *et al.* 2010, p. 585).

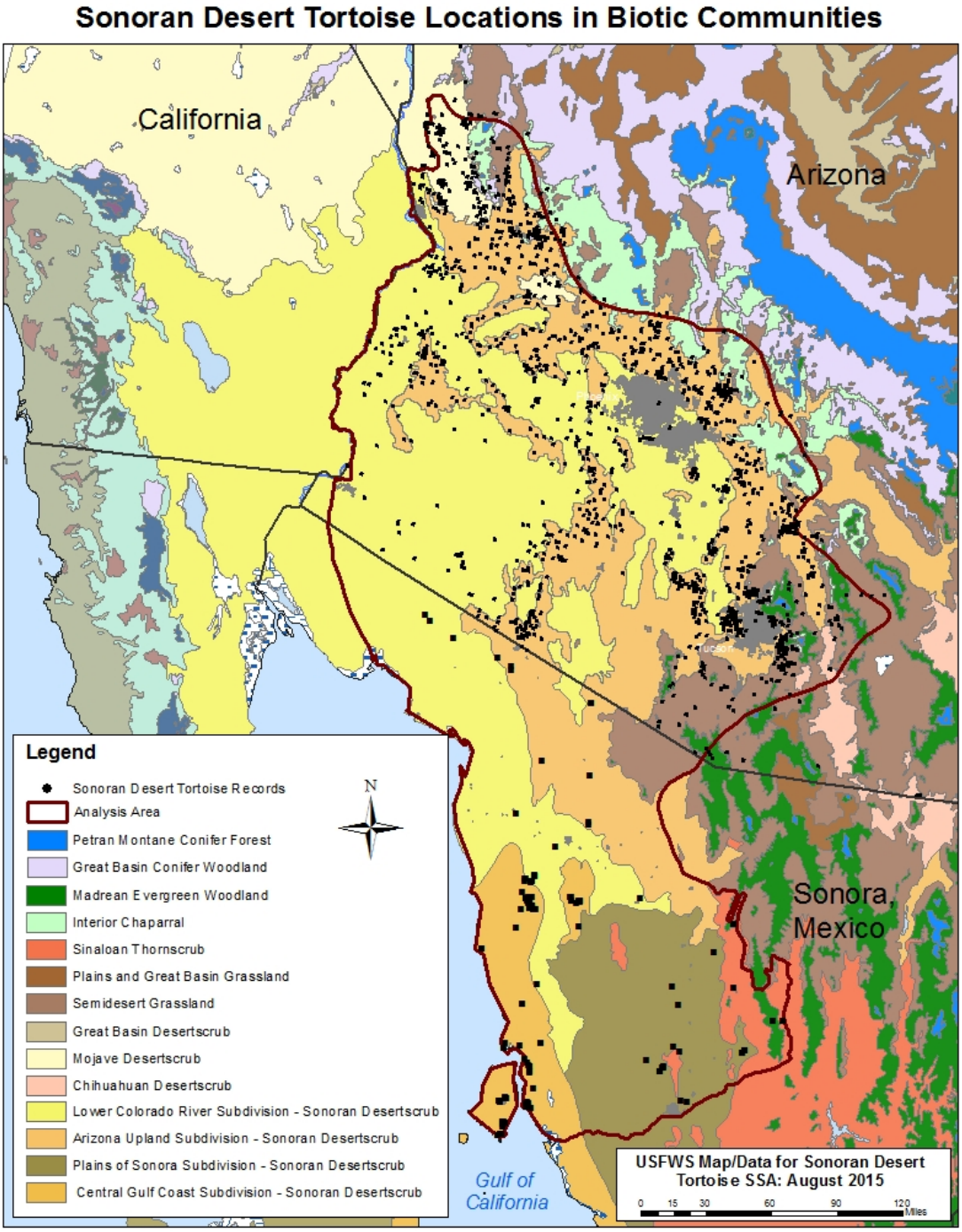


Figure 4. Biotic communities (from Brown 1994) within the Sonoran desert tortoise's range encompassing portions of Arizona and the Mexican State of Sonora with tortoise records identified. Species records for Mexico were obtained from field investigations, museums, literature, and photo-vouchers as provided by Rosen *et al*. (2014a, Figure 1.2). Records for Arizona are from the Heritage Database Management System, provided as a courtesy of the Arizona Game and Fish Department.

In addition to herbivory, Sonoran desert tortoises are also geophagous (e.g., consume bones, stones, and soil for additional nutrient and mineral supplements, for mechanical assistance in grinding plant matter in the stomach, or to expel parasites in the intestinal tract) (Sokol 1971, p. 70; Marlow and Tollestrup 1982, p. 475; Esque and Peters 1994, pp. 108–109; Stitt and Davis 2003, p. 57; Walde *et al.* 2007b, p. 148). Sonoran desert tortoises are highly attracted to sites with exposed calcium carbonate and have been observed congregating at these sites year after year eating these soils (Meyer *et al.* 2010, p. 11). Soil condition and quality are important to the Sonoran desert tortoise, not only for nutrients derived from eating soil, but also production and maintenance of vegetation that is consumed by tortoises (Avery and Neibergs 1997, p. 13).

Sonoran desert tortoises may spend up to 98% of their lives within burrows (Nagy and Medica 1986, p. 79). As such, adequate shelter is one of the most important habitat features for Sonoran desert tortoises (Averill-Murray *et al.* 2002a) and is correlated with population densities (Averill-Murray and Klug 2000, p. 69; Averill-Murray *et al.* 2002b, p. 126; Riedle 2015a). Burrows stay cooler in the summer and warmer in the winter than outside temperatures, providing opportunity for tortoises to escape temperature extremes. Shelters are also used for nesting and protection from predators (Barrett and Humphrey 1986, p. 262; Bailey *et al.* 1995, p. 366; Zylstra and Steidl 2008, p. 752). Tortoises require loose soil in which to excavate shelters below rocks and boulders, beneath vegetation, on semi-open slopes, and within caliche caves of washes, or they may find refuge in rocky crevices (Burge 1979, p. 44; 1980, pp. 44–45; Barrett 1990, p. 205; Averill-Murray *et al.* 2002a, pp. 136–137; Grandmaison *et al.* 2010, p. 582).

In addition to steep, rocky slopes and bajadas, Sonoran desert tortoises also use inter-mountain valleys as part of their home ranges and for dispersal at all age classes (Averill-Murray and Averill-Murray 2002, pp. 16, 22). In the Ironwood Forest National Monument, Averill-Murray and Averill-Murray (2005, p. 65) found tortoises or their sign (such as scat (droppings) and shelters) up to 1 mile (mi) (1.6 kilometers [km]) away from the nearest slope, indicating that they occur in low densities in inter-mountain valleys (Averill-Murray and Averill-Murray 2005, p. 65). Sonoran desert tortoises have not been documented in flatter areas between mountain ranges in Sonora, Mexico (Bury *et al.* 2002, p. 89), although they likely use these areas for dispersal much as they do in similar inter-mountain basins of Arizona.

Averill-Murray and Klug (2000, p. 67) found home range size varied with precipitation levels, contracting during wet years and expanding during dry years in response to the availability of forage plants; the opposite was found in Mojave desert tortoises (Harless *et al*. 2010, p. 383). The difference between the species may be attributed to differing ecology and precipitation levels and patterns between the Mojave and Sonoran desert ecoregions although more study is needed. Sonoran desert tortoises often use a group of relatively closely located shelters as focal areas of activity in their home range. Sonoran desert tortoises may develop movement patterns in their use of home ranges, exploiting resources (for example, location of mates, water catchments, mineral licks, and shelter sites) (Berry 1986a, p. 113) where they are the most plentiful (Sullivan *et al.* 2014, pp. 116–118). Estimates for annual average home range sizes for males have varied from 0.04 to 0.10 sq mi (23 to 64 ac, 10 to 25 ha); females generally have smaller home ranges, with averages ranging from 0.01 to 0.09 sq mi (6 to 58 ac, 2 to 23 ha) (Barrett 1990, p. 203; Averill-Murray and Klug 2000, pp. 55–61; Averill-Murray *et al.* 2002a, pp. 150–151). In the lower San Pedro River Valley, Meyer (1993, p. 99) reported that Sonoran

desert tortoise home ranges varied between 0.07 to 1 sq mi (45 and 640 ac, 1 to 259 ha) in size. Sonoran desert tortoises are known to exhibit high fidelity to their home ranges, with the exception of dispersal movements when they expand to new areas (Zylstra and Swann 2009, p. vi).

2.6 Defining Populations

An important step for understanding a species status is identifying populations within the species' range. We generally refer to clustered, localized areas with inter-breeding individuals of Sonoran desert tortoises as populations, with these areas roughly defined by mountain ranges or other geographical features. This is the scale of "populations" referred to in the analysis of risk factors potentially affecting the species (Chapter 4 and Appendix C). However, genetic analysis from across the species' range identified little if any genetic structuring between these populations (Edwards *et al*. 2004, entire), presumably indicating that historically there has been gene flow between smaller populations. Given the long generation time for tortoises, and in the absence of gene flow, it likely takes centuries for genetic differentiation to occur. Absent existing genetic support for dividing the rangewide population into numerous, smaller populations, we considered using linear developments (such as major interstates, etc.) which may act as barriers to movement, as population boundaries. However, while certain types of linear developments likely prevent some tortoise movements on the landscape, many are not absolute barriers and may allow population connectivity to some unknown degree. Thus, there are no boundaries which clearly support the identification of smaller populations within the range-wide distribution of the Sonoran desert tortoise.

Due to the lack of evidence supporting a smaller population structure within the Sonoran desert tortoises' rangewide distribution, we used the U.S.-Mexico border as a division between the U.S. area of analysis and the Mexico area of analysis for the tortoise in our population viability modeling. The U.S.-Mexico border is an appropriate place to divide the range because there are meaningful differences in the quality and level of information available about status and risk factors between the two areas, and because there are actual differences in habitat quality due to differences in land management between the two countries. Figure 5 illustrates these two areas. However, our qualitative analysis of risk factors (Chapter 4: Risk Factors and Appendix C: Cause & Effects Tables) considers the potential for population-level effects of stressors on a smaller scale consistent with the traditional reference to small Sonoran desert tortoise populations.

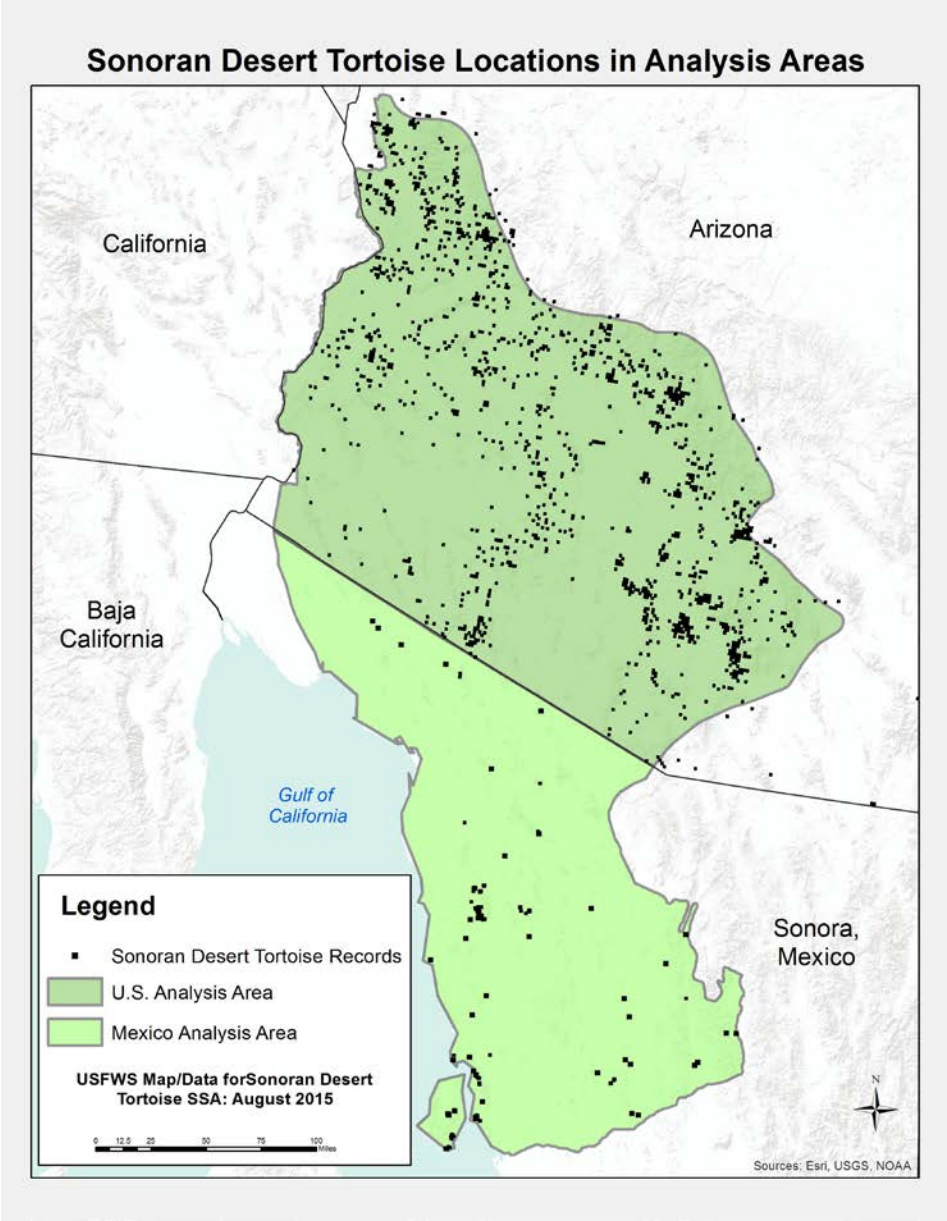


Figure 5. The extent of the U.S. and Mexico areas of analysis for the Sonoran desert tortoise with tortoise records identified. Species records for Mexico were obtained from field investigations, museums, literature, and photo-vouchers as provided by Rosen *et al*. (2014a, Figure 1.2). Records[4] for Arizona are from the Heritage Database Management System, provided as a courtesy of the Arizona Game and Fish Department.

[4] We note that a number of tortoise observations are outside of the eastern boundary of our study area that we are using as the range of the Sonoran desert tortoise for this analysis. For the eastern and western boundaries of the range, we used our range map previously developed as part of past assessments. We received the tortoise occurrences after much of our work had been completed for this assessment. Some of the locations further from our study area may be escaped pets, others likely represent small expansion of the range. We chose not to revise the eastern border of the analysis area because it was expected to result in a minor change in the overall analysis.

2.7 Species' Rangewide Needs

As described in Chapter 1, for the purpose of this assessment, we define **viability** as the ability of a species to sustain populations in the wild beyond a biologically meaningful time frame. Using the SSA framework, we describe the species' viability by characterizing the status of the species in terms of its **resiliency, redundancy, and representation** (the 3Rs). Using various time frames and the current and projected levels of the 3Rs, we describe the species' level of viability over time. To measure these factors, we have created a geospatial database that describes the quantity and quality of potential habitat (see Appendix B) and a stochastic simulation model that forecasts abundance, population growth rates, and quasi-extinction risk for the areas of analysis (see Appendix D). This information is used to describe the current condition of the species and to forecast the species' condition into the future in Chapters 3 and 5 of this report, respectively.

2.7.1 Population Resiliency

For the Sonoran desert tortoise to maintain its viability, its populations must be resilient and able to withstand stochastic events. For the quantitative analysis of population resiliency, we consider the full extent of the species' range in Arizona as the U.S. area of analysis and the full extent of the species' range in Sonora as the Mexico area of analysis to be separate "populations," as described above. To measure resiliency, we estimated the population abundance, population growth rates, and probability of quasi-extinction of both areas of analysis over 25, 50, 100, and 200 years (See Appendix D, Stochastic Simulation Model). In general, the higher the projected abundance and population growth rates and the lower the risk of quasi-extinction, the higher will be the resiliency of Sonoran desert tortoises.

2.7.2 Species Redundancy and Representation

The Sonoran desert tortoise needs to have resilient populations (low quasi-extinction risk and high abundances) in the U.S. and Mexican areas of analysis and sufficient habitat quantity and quality throughout the species' range to provide for rangewide redundancy and representation. Because the information we had did not support measuring populations on a smaller scale for the species and our simulation model was not spatially explicit beyond the large analysis areas, we are using the geographic distribution of predicted potential habitat quantity and quality, as described below in Chapters 3 and 5, as measures of redundancy and representation.

For the Sonoran desert tortoise to have sufficient redundancy to withstand catastrophic events such as potential large-scale drought, it needs to have populations distributed across its range. While we did not define these populations, we were able to estimate current and future distributional patterns indirectly through the projection of the quantity, quality, and spatial location of habitats. A wider distribution of primary and secondary habitats[5] throughout the

[5] The habitat quality metrics that we analyzed are discussed in more detail in section 5.2, below, and considers land management, presence of invasive vegetation, high fire risk potential, and the proximity to urban areas; using this information, we ranked areas within the species' potential habitat as primary, secondary, or tertiary habitat as measures of overall habitat quality.

species' range reduces the risk that any large portion of the species' range will be negatively affected by any catastrophic natural or anthropogenic event at any one time.

The Sonoran desert tortoise also needs to have sufficient representation to maintain genetic and ecological diversity for future adaptive capabilities to respond to changing environmental conditions. Genetic studies of the Sonoran desert tortoise in both Arizona (Edwards *et al*. 2004, entire) and Sonora (Edwards 2015, entire) have not indicated that critical genetic differences currently exist across the range that would support identifying particular parts of the range that are more important than others for long-term maintenance. The species occurs in a wide range of ecological conditions and it is unknown if any particular setting is more important than another. Therefore, we assume that we can best reduce the risk of loss of any unidentified genetic or ecological diversity through maintaining a broad distribution of the species across its range. We are measuring this distribution indirectly through the spatial analysis of primary and secondary habitats. The broader the distribution of these habitats, the higher the overall representation of the species and the more the adaptive potential for the species can be maintained.

Key Assumption: We did not have sufficient information to conduct a spatially explicit demographic model of the Sonoran desert tortoise. Therefore, our measures of redundancy and representation are based on habitat. The assumption is that the abundancy and distribution of tortoises are directly related to the quality and distribution of its habitat. This is a reasonable assumption given our understanding of the ecology of this species, but it is an important limitation in our analysis.

Chapter 3: Predicted Potential Habitat

As a first step in our status assessment of the Sonoran desert tortoise, we conducted a rudimentary analysis to predict the occurrence of potential habitat throughout the analysis area. The results of this analysis served as our base habitat layer by which we built our analysis of the scope of individual stressors (Chapter 4), and the combined habitat quality and quantity assessments currently (Chapter 5) and in the future (Chapter 6).

3.1 Predicted Potential Habitat Analysis

We generated a potential habitat model using GIS to provide a geospatial representation of the location and extent of predicted potential habitat for the Sonoran desert tortoise. We used three primary criteria in the potential habitat model: elevation, vegetation type, and slope[6] (Figure 6). Here, we provide our rationale for the generation of this model. For more detail on the data sources and methodology of the analysis, please see Appendix B.

The first step in creating the potential habitat model was to identify areas with used by Sonoran desert tortoises. Approximately 95% of Sonoran desert tortoise records in Arizona occur at an elevation of about 904 to 4,198 ft (275 to 1,279 m) (Zylstra and Steidl 2009, p. 8). The few records in Arizona that occur outside of this range include one Sonoran desert tortoise population in Arizona occurring at approximately 5,000 ft (1,500 m) elevation (Van Devender 2002, p. 23), individuals known from similar elevations in the Atascosa and Pajarito Mountains in south-central Arizona (Babb *et al.* 2013, p. 623), and one individual observed at 7,808 ft (2,379 m) in Saguaro National Park (Aslan *et al.* 2003, p. 57). In Mexico, all Sonoran desert tortoise records range in elevation from 16 to 3,970 ft (5 to 1,210 m) (Rosen *et al*. 2014a, p. 16). We recognize that the elevation range we selected for the purpose of the potential habitat model does not encompass all areas where Sonoran desert tortoises may occur, but we elected to use the identified range as it likely captures the large majority of tortoise habitat. We did not include areas with elevations below or above the range in the potential habitat layer.

The second criterion we used to develop the potential habitat model is slope. Areas with slope angles of 5% or greater were considered most potential, whereas areas with slope angles below 5% were considered less potential. The available information supports that Sonoran desert tortoises often occur on rocky, steep slopes and bajadas. Furthermore, Zylstra and Steidl (2009, p. 752) found that, after accounting for the number of potential shelter sites, slope was the best predictor of tortoise occupancy in the Sonoran Desert.

Vegetation type was the third and final criterion we used in preparing the geospatial database representing potential habitat for the Sonoran desert tortoise. Using existing geospatial data sets, we classified cover type as high, medium, or low value to the tortoise. For example, in the Arizona analysis area, we ranked Sonoran granite outcrop desert scrub, mid-elevation desert scrub, and paloverde-mixed cacti desert scrub as the cover types with the highest value to the Sonoran desert tortoise. This is consistent with the habitat information provided in Chapter 2,

[6] We recognize that this is a very coarse habitat model for the Sonoran desert tortoise and many other physical factors would be included for a more robust intensive habitat model. However, for our purposes at the rangewide scale, this habitat analysis provides an adequate approximation of potential habitat on which to base our assessment.

Species Needs. The ranking system we used for vegetation types considered as potential habitat is described in Tables B-1 and B-2 of Appendix B.

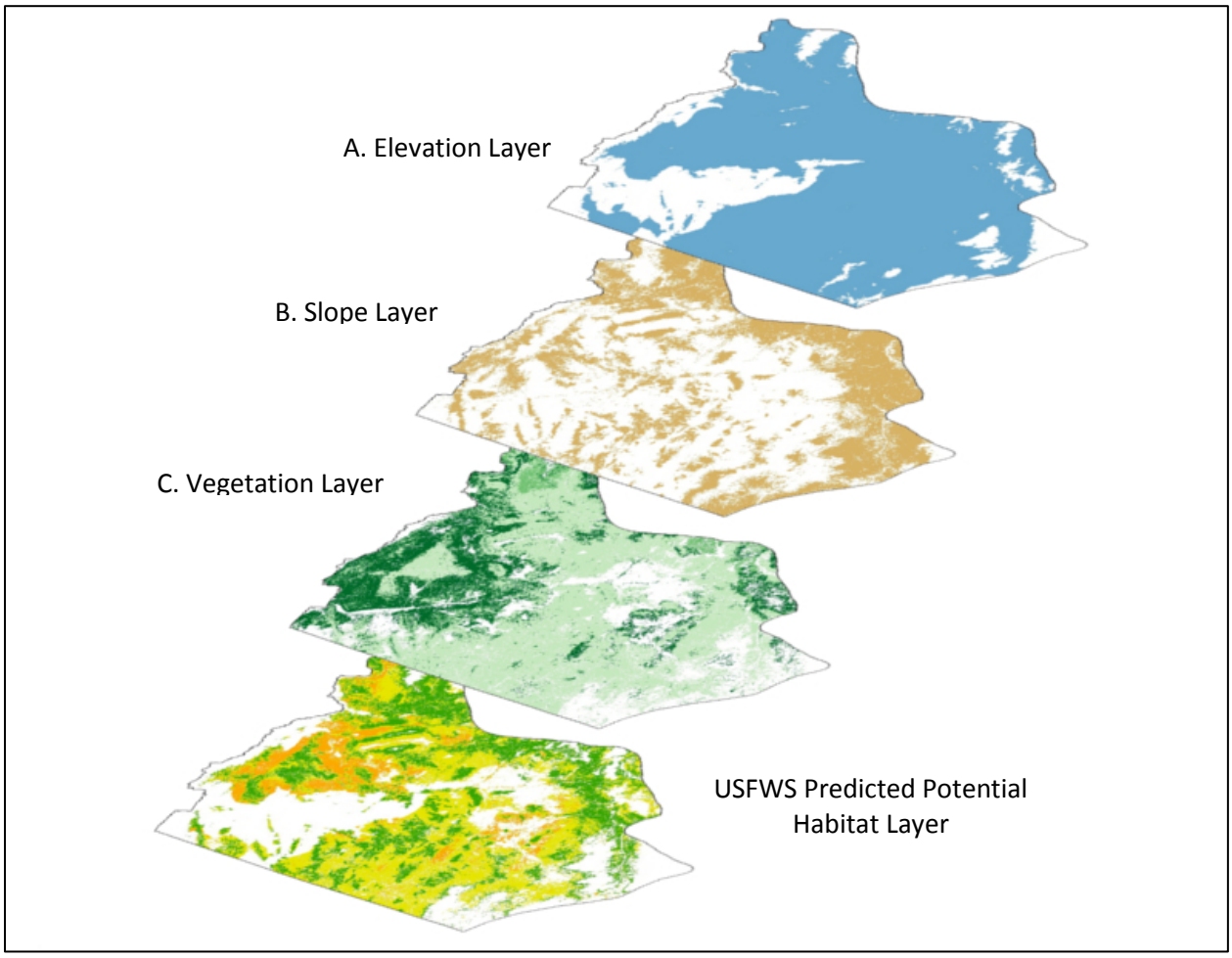


Figure 6. Visualization of the union of three data layers to produce predicted potential habitat map for the Sonoran desert tortoise.

Using these three parameters, we were able to identify the extent of potential habitat within Mexico and Arizona. This rangewide geospatial analysis resulted in an estimate of approximately 38,000 sq mi (24.3 million ac, 9.8 million ha) of potential habitat across the species' range (Table 1) based solely on those three parameters. Of this total, 64% occurs in Arizona and 36% occurs in Mexico. Depending on each cell combination of the three parameters explained above, we were able to classify the potential habitat as high, medium, or low across the species' range (Figure 7). In Arizona, 36, 51, and 13% of the area is categorized as high, medium, and low potential, respectively. In Sonora, 32, 68, and 0.2% is categorized as high, medium, and low potential, respectively (Figure 8).

Table 1. Total areas in square miles of predicted potential habitat of the Sonoran desert tortoise in Arizona, US, and Sonora, MX, as identified into three categories.

Potential Habitat Ranking	Arizona, US	Sonora, MX	Total Rangewide
High Rank	8,625	4,350	12,975
Medium Rank	12,474	9,377	21,851
Low Rank	3,097	34	3,131
Total Habitat	**24,196**	**13,762**	**37,957**
Total Not Potential Habitat	15,982	12,000	27,982
Total Project Area	**40,178**	**25,762**	**65,939**

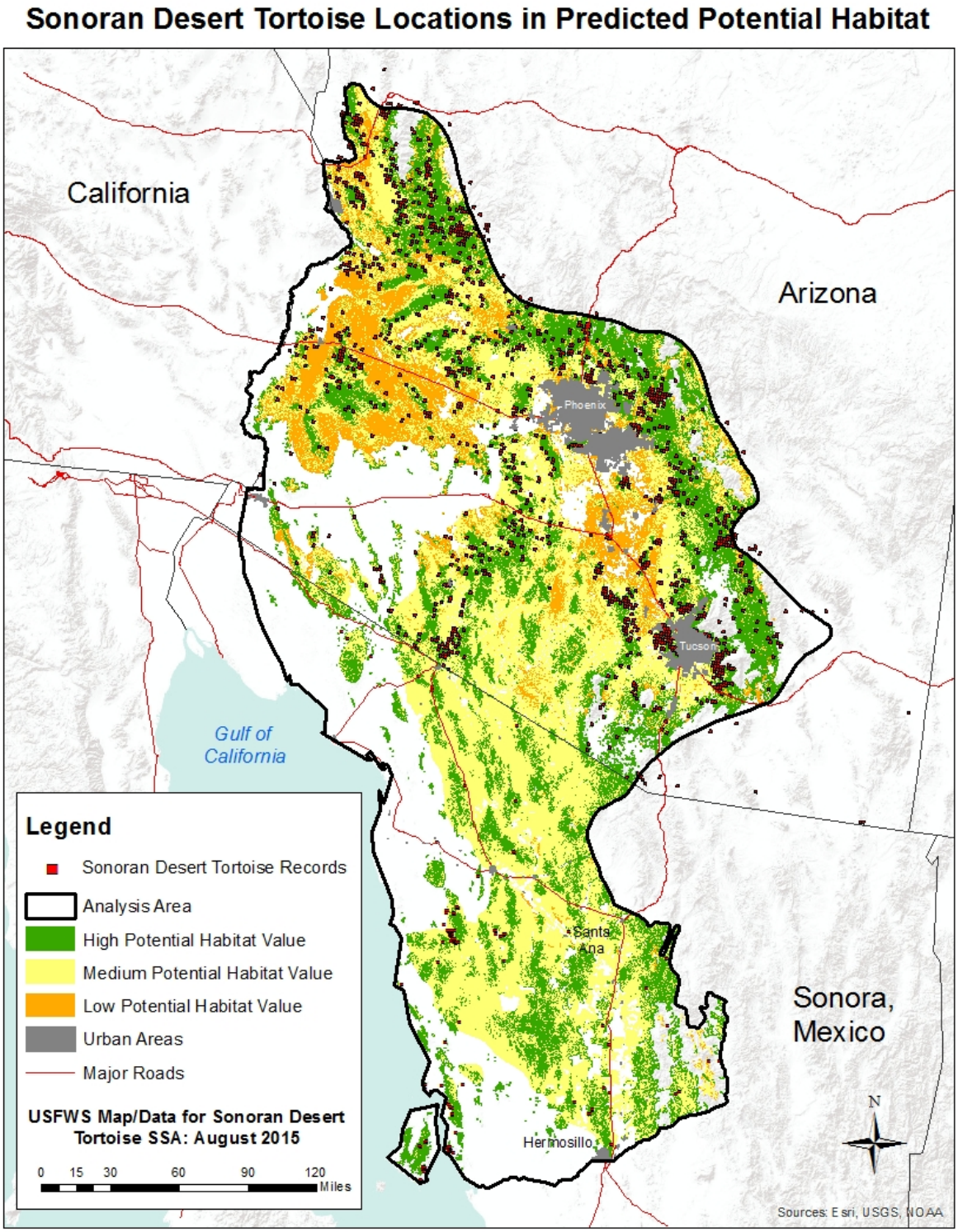


Figure 7. Predicted potential habitat for the Sonoran desert tortoise based on elevation, slope, and vegetation type with tortoise occurrence records identified.

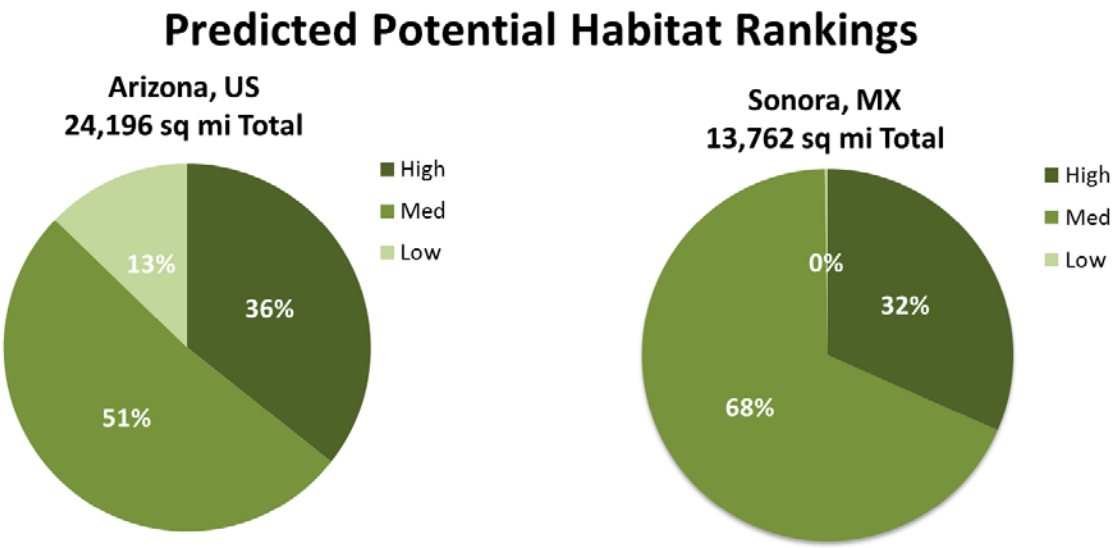


Figure 8. Summary of Sonoran desert tortoise potential habitat rankings in Arizona, U.S., and Sonora, MX, in square miles of high, medium, and low categories.