Species Status Assessment for the Sonoran Desert Tortoise

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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.

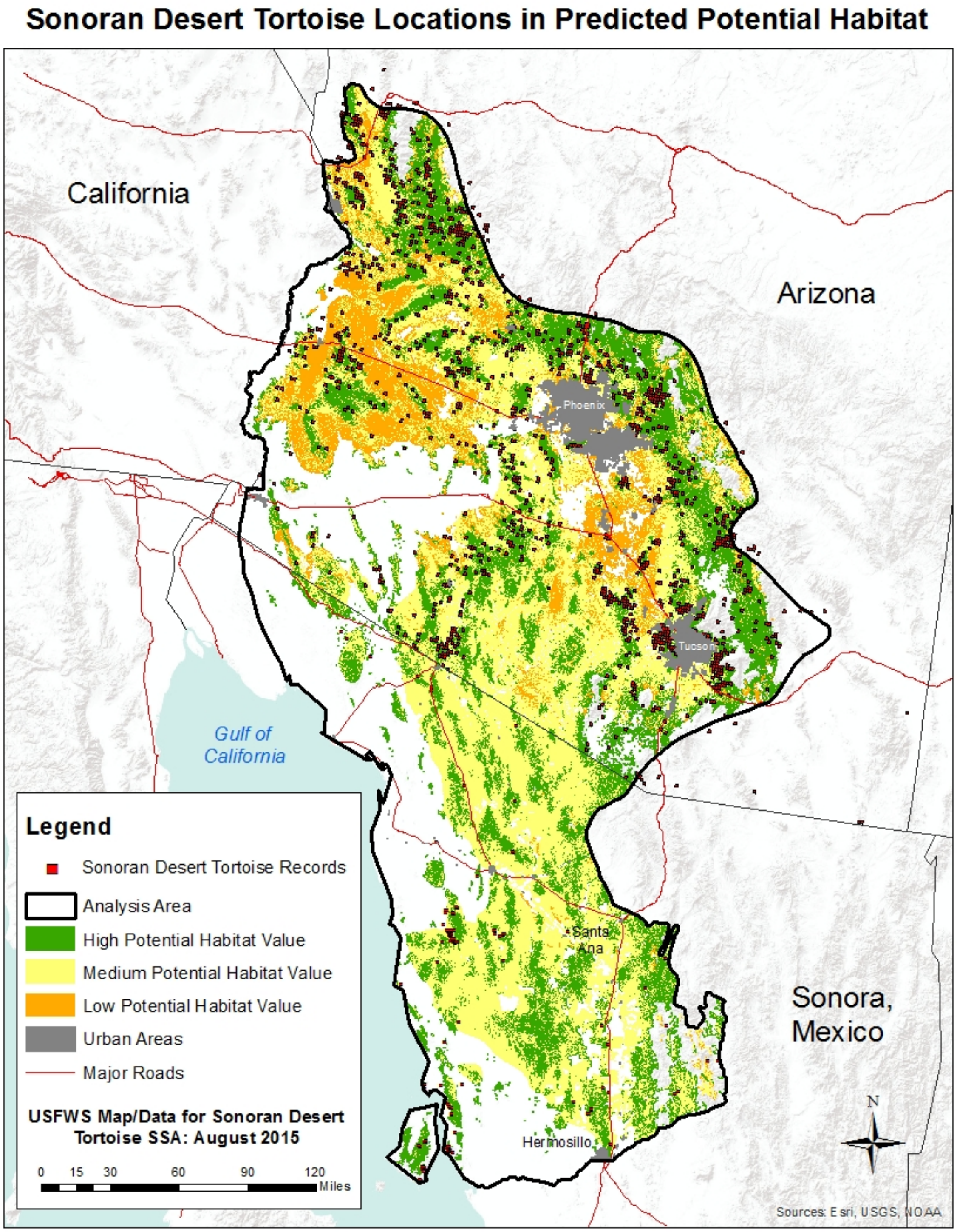

Figure ES-1. Predicted potential habitat for the Sonoran desert tortoise based on elevation, slope, and vegetation type with tortoise occurrence records identified.

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)

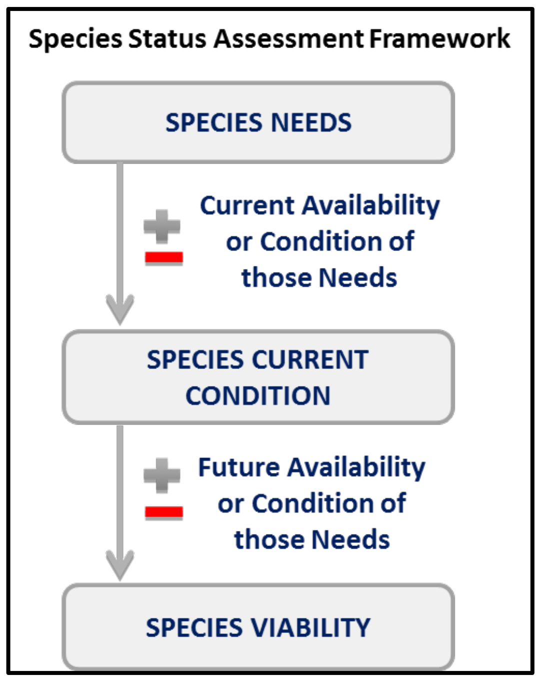
USFWS- U.S. Fish and Wildlife Service

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. <u>Introduction</u>.
2. <u>Species Biology and Needs</u>. The resource needs of individuals and a framework for what the species needs across its range for species viability;
3. <u>Predicted Potential Habitat</u>. The predicted rangewide potential habitat analysis;
4. <u>Risk Factors</u>. 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. <u>Current Conditions</u>. The species' current range, habitat conditions, and population estimates; and
6. <u>Future Conditions and Viability</u>. 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.

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[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.

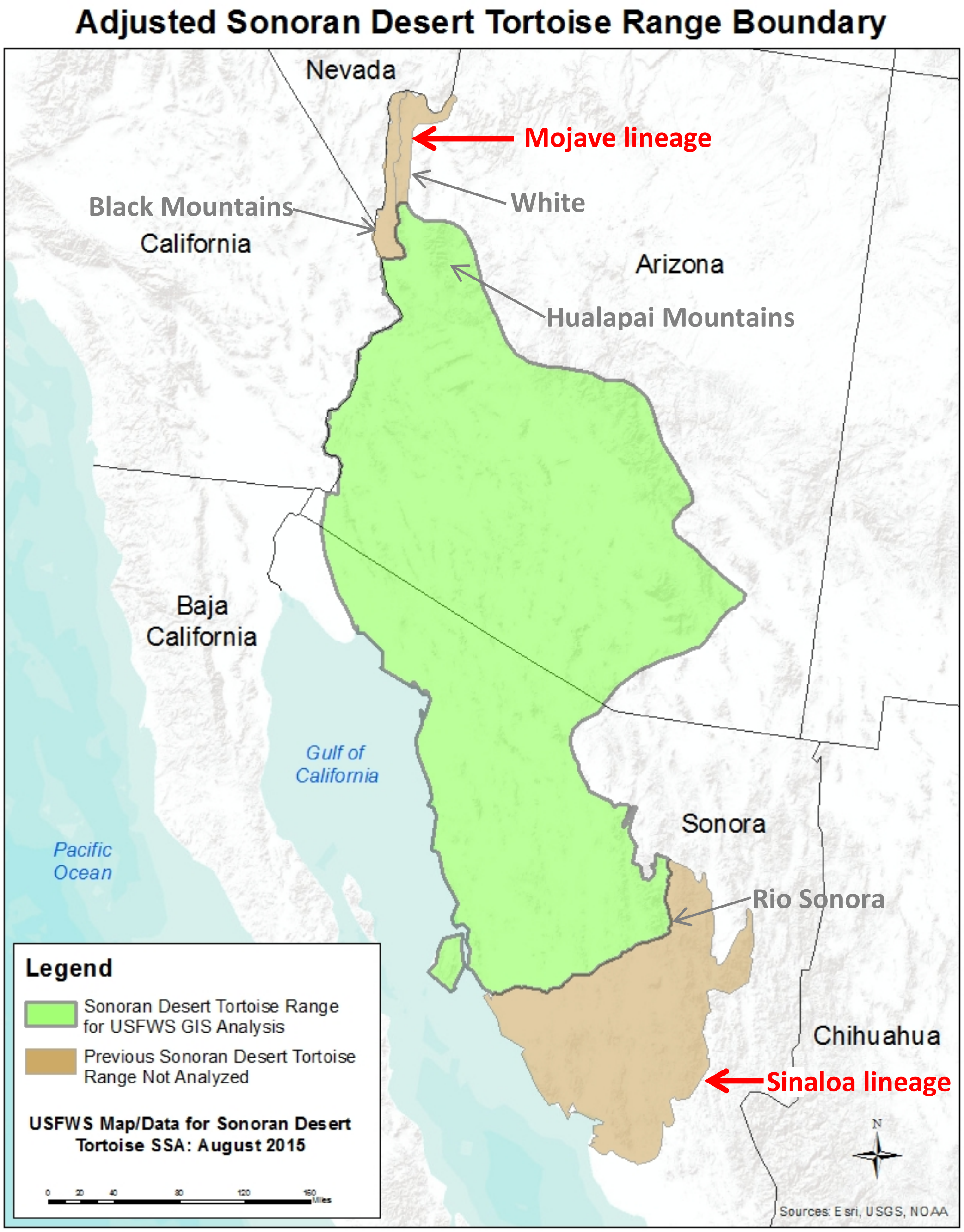


Figure 2. Our adjusted Sonoran desert tortoise range boundary highlighting areas that were previously included as portions of the Sonoran desert tortoise species range. Recent genetic analyses support that tortoises in the brown areas do not wholly represent the pure Sonoran desert tortoise genetic lineage 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.

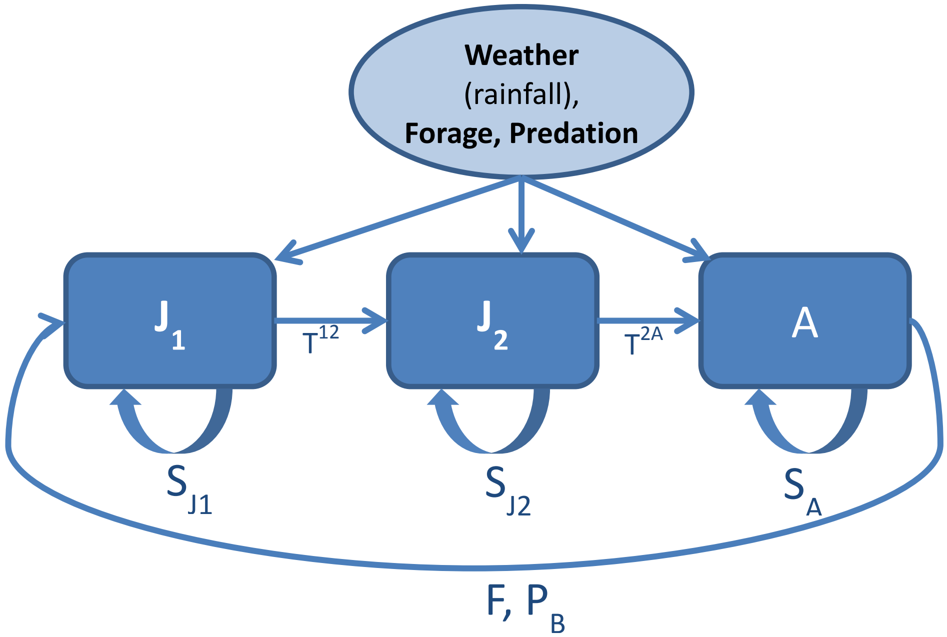
The young juvenile size class includes hatchlings and very small juveniles. Tortoises generally remain in this size class for approximately 5 years until their shells ossify (harden). Eggs hatch in September and October (Van Devender 2002, pp. 10–11; Averill-Murray 2002b, p. 295), following the end of 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).

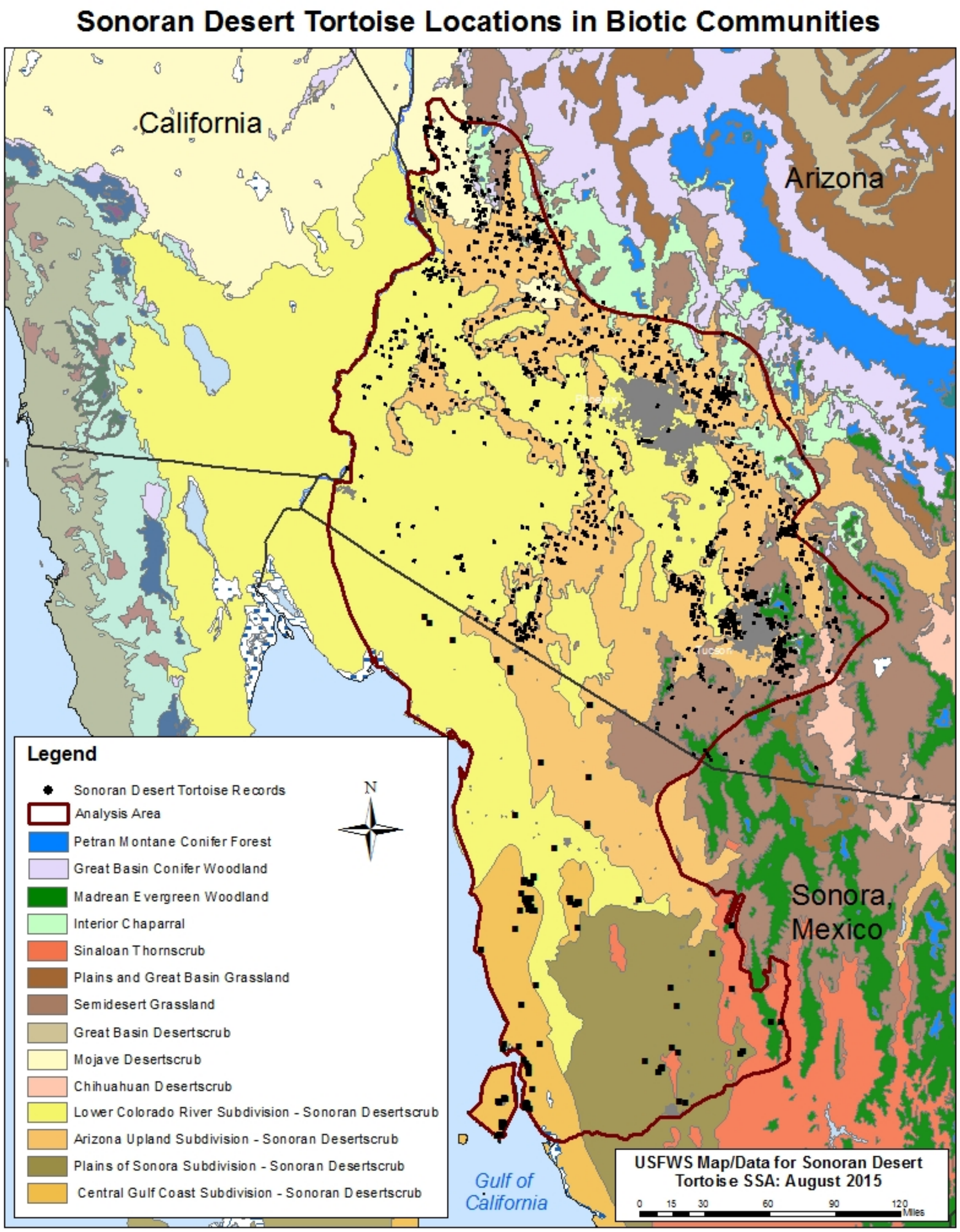


Figure 4. Biotic communities (from Brown 1994) within the Sonoran desert tortoise's range encompassing portions of Arizona and the Mexican State of Sonora with tortoise records identified. Species records for Mexico were obtained from field investigations, museums, literature, and photo-vouchers as provided 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.

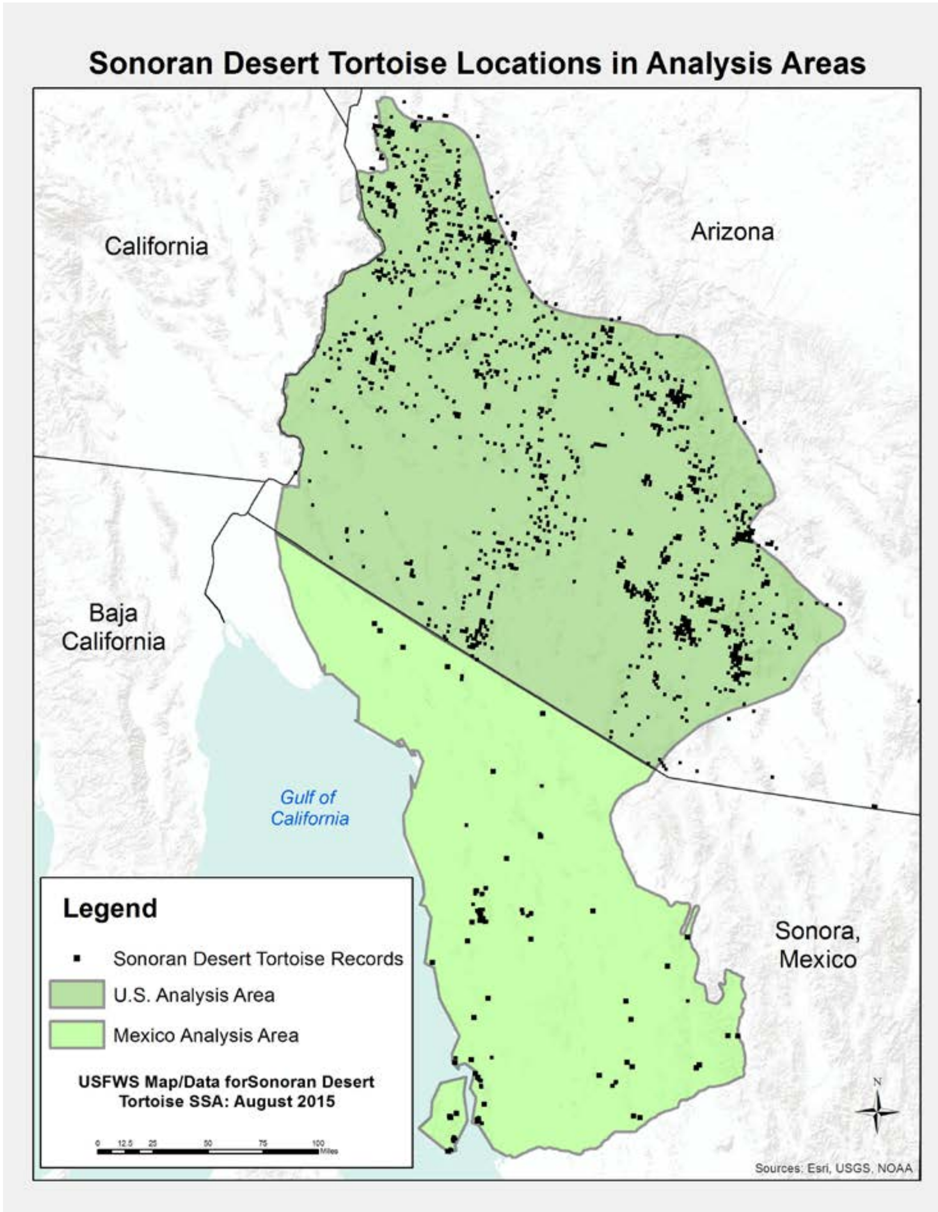


Figure 5. The extent of the U.S. and Mexico areas of analysis for the Sonoran desert tortoise with tortoise records identified. Species records for Mexico were obtained from field investigations, museums, literature, and photo-vouchers as provided by Rosen *et al*. (2014a, Figure 1.2). Records[4] for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

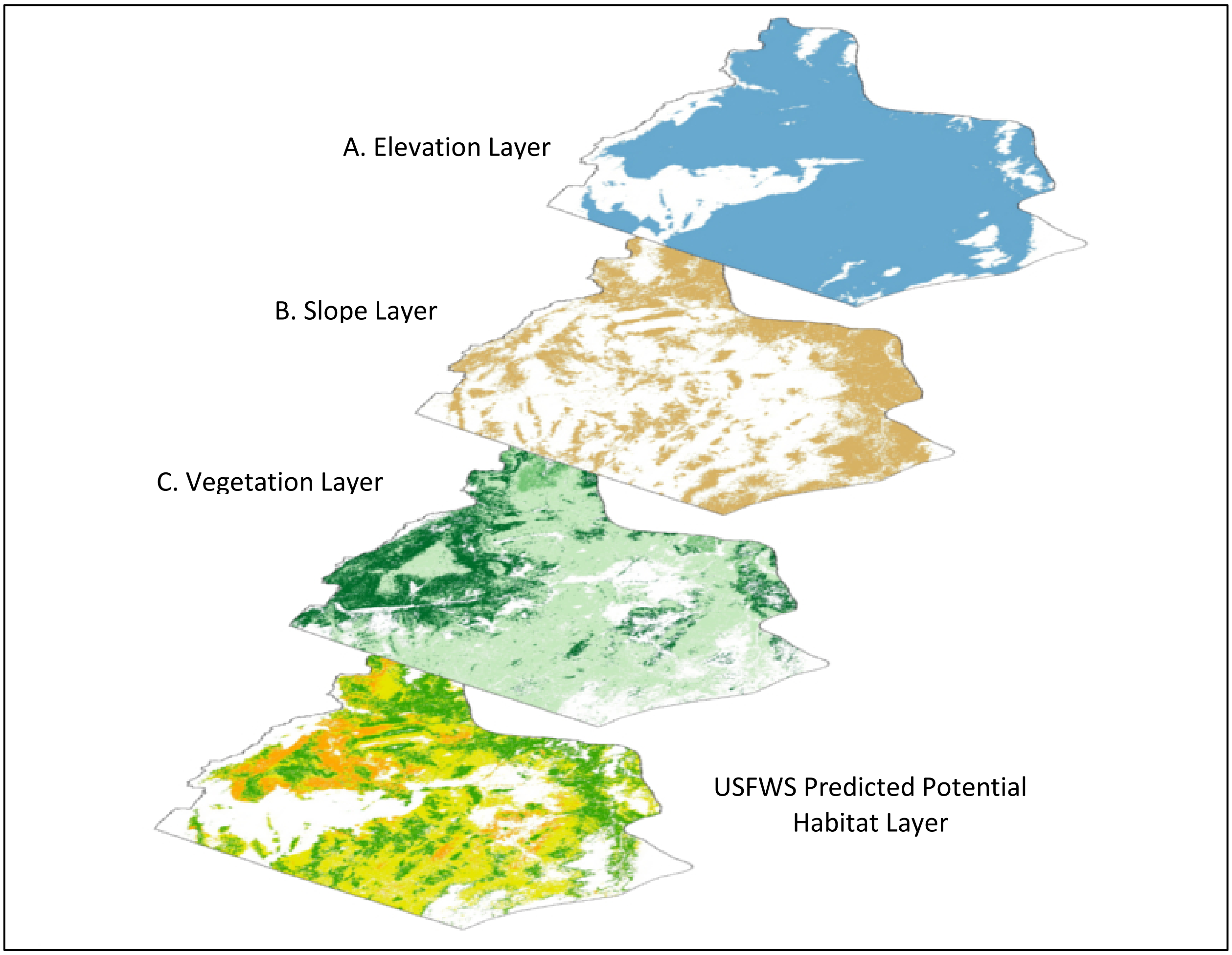


Figure 6. Visualization of the union of three data layers to produce predicted potential habitat map for the Sonoran desert tortoise.

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**

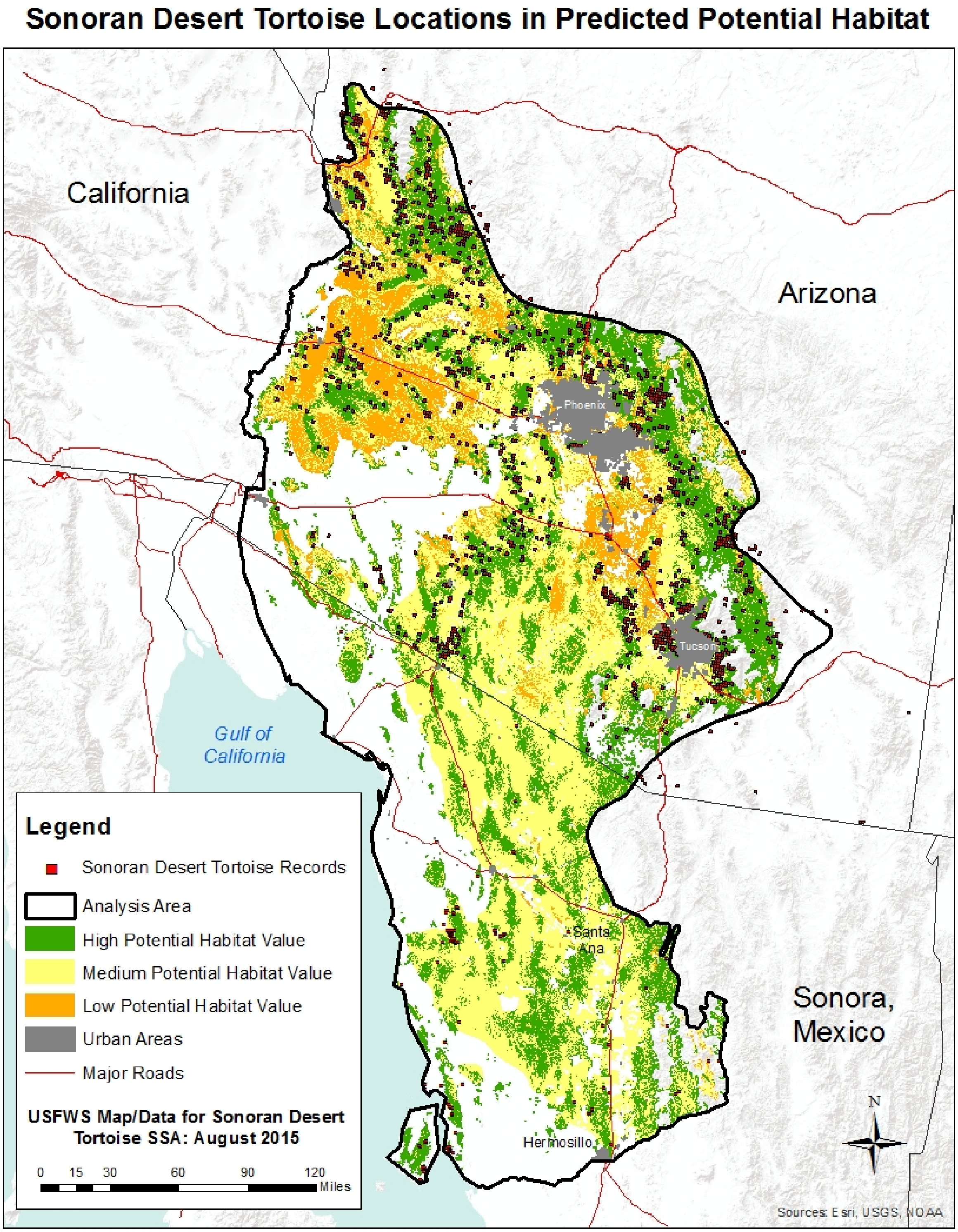


Figure 7. Predicted potential habitat for the Sonoran desert tortoise based on elevation, slope, and vegetation type with tortoise occurrence records identified.

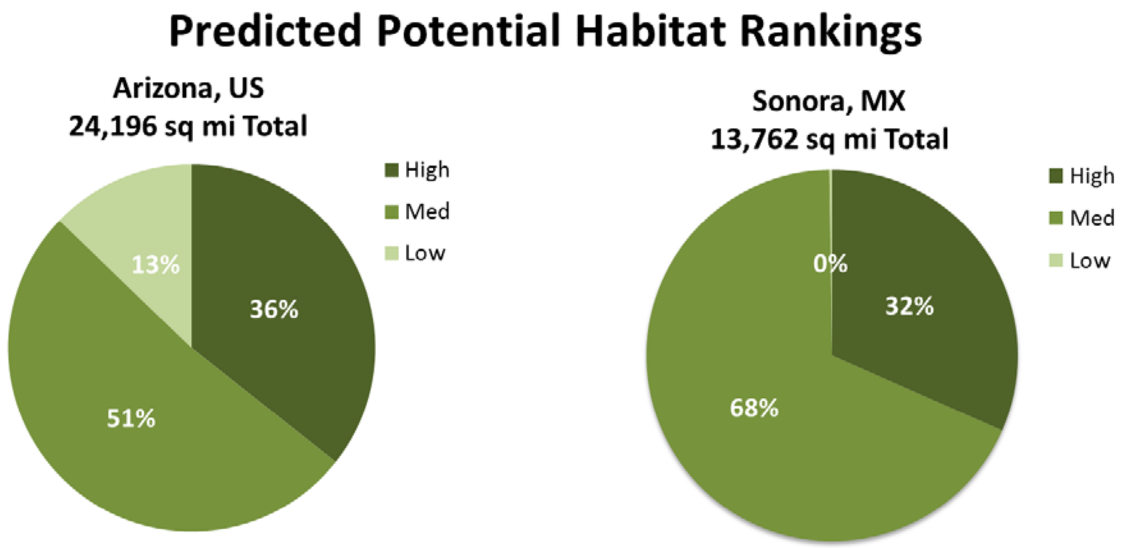


Figure 8. Summary of Sonoran desert tortoise potential habitat rankings in Arizona, U.S., and Sonora, MX, in square miles of high, medium, and low categories.

Chapter 4: Risk Factors

> **Note:** This chapter contains **summaries** of the risk factors. For further information and more citations from the literature supporting these summaries, see the tables in **Appendix C**.

The following discussion provides a summary of the factors that are affecting or could be affecting the current and future condition of the Sonoran desert tortoise throughout some or all of its range. The full analysis of these factors is outlined in the attached cause and effects tables (see Appendix C: Cause & Effects Tables) and the factors are further analyzed within our landscape analysis and population model (Chapters 5 and 6 and Appendix D). Although this is a rangewide analysis, the levels of information available for Arizona and Sonora, Mexico, remain significantly different. Where we have available data on any particular stressor for Mexico, we include it.

4.1 Altered Plant Communities (Nonnative Grasses)

Nonnative grasses including buffelgrass (*Pennisetum ciliare*), red brome (*Bromus rubrens*), Mediterranean grass (*Schismus* spp.), Saharan (or Asian) mustard (*Brassica tournefortii*), thistles (genera *Centaurea* and *Cirsium*), and natal grass (*Melinus repens*), have spread naturally on the landscape and in some cases have become naturalized in portions of the Sonoran desert tortoise's range (Bahre 1991, p. 155; D'Antonio and Vitousek 1992, pp. 65, 75; Brooks and Pyke 2001, p. 3, 5; Esque *et al*. 2002, p. 313; Van Devender 2002, p. 16; Abella 2010, p. 1249). Some of these may have been intentionally introduced for livestock or soil stabilizers, while others, including red brome and other Mediterranean species, may have been inadvertently introduced (Salo 2005, pp. 168–170). Additionally, other desert-adapted nonnative species have been introduced for landscaping purposes (Grissom 2015b, p. 1). We expect these nonnative species to persist in these areas into the future and likely increase in distribution (Olsson 2012a, entire). Of these species, red brome, buffelgrass, and Mediterranean grass may pose more of a concern for the Sonoran desert tortoise due to their overlap in distribution and habitat with the tortoise. In Arizona, most nonnative grasses are currently considered noxious weeds and are no longer used for the purposes described above; however, in Mexico, considerable acreage continues to be cleared for buffelgrass cultivation as livestock pasture (Franklin and Molina-Freaner 2010, p. 1664). Nonnative annuals such as red brome and Mediterranean grass have short-lived seed banks and. Jurand *et al*. (2013, pp. 71–72) found that red brome seed viability in the seed bank decreased significantly after two years in the Mojave Desert. Jurand *et al*. (2013, p. 72) also indicated that, there is potential for some brome species' seeds to last up to three years, but that brome species are susceptible to population crashes in years of severe drought. During a multi-year drought, these nonnative seeds may be outcompeted by native vegetation with long-lived seed banks; however, it is important to note that brome species are capable of producing a high number of seeds per plant (Jurand *et al*. 2013, p. 72), and even a tiny percentage of the seed bank surviving can have an observable effect in plant community composition.

Nonnative grasses can compete with native grass species (which are used as food and cover by Sonoran desert tortoises) through competition for space, water, and nutrients, thereby affecting native plant species density and species composition within invaded areas (Stevens and Fehmi 2008, p. 383–384; Olsson et al. 2012a, entire; 2012b, pp. 10, 18–19; McDonald and McPherson

2011, pp. 1150, 1152; Franklin and Molina-Freaner 2010, p. 1664). This process is primarily driven by the timing and amount of precipitation. Tortoise food plants include herbs, grasses, woody plants, and succulents, which provide various levels of nutrition and assist with maintaining a tortoise's hydration balance (or potassium excretion potential, PEP) (Oftedal 2002, entire). Cover plants, such as trees, shrubs, subshrubs, and cacti (succulents) serve as protective cover to lower predation risk (Avery and Neibergs 1997, p. 13; Grandmaison *et al.* 2010, p. 585). In addition, cover plants provide thermoregulation (regulating body temperature) when tortoises are active above ground during such activities as foraging, moving between shelter sites, dispersing, and seeking mates (Grandmaison *et al.* 2010, p. 585).

The effects of nonnative grasses on individual tortoises can vary over time, largely as a function of the density of nonnative grasses and depending on the availability of free-standing water for drinking by tortoises (different plant species may be more important when drinking water is not available). Effects can include (1) a reduction of forage availability, particularly of high-nutrition native plants; (2) a reduction in fitness of individual tortoises; and (3) an increase of time and energy spent in foraging activities, and, therefore, increased predation risk (Gray 2012, pp. 18, 47; Gray and Steidl 2015, p. 1986; Esque *et al*. 2003, p. 107; Rieder *et al*. 2010, p. 2436; Medica and Eckert 2007, p. 447; Hazard *et al*. 2010, pp. 139–145; Nagy *et al*. 1998, pp. 260, 263). Lower fitness due to inadequate nutrition may reduce reproductive potential in individuals, survival and recruitment of juveniles, and survival of adults. The effect of nonnative grasses on tortoise nutrition is somewhat ameliorated by the fact that tortoises can and do forage to some extent on nonnative grasses and forbs such as red brome, buffelgrass, and filaree (*Erodium cicutarium*) (Van Devender *et al*. 2002b, entire), which could make up for losses in species composition and biomass of native forage specis. Nonnative filaree has been demonstrated to provide significantly more nutritional value than some native forbs, including providing more digestible energy and crude protein, and about the same amount of digestible water (Nagy *et al*. 1998, p. 263–264). Buffelgrass in particular may impede movement of small tortoises if it occurs at high densities (Rieder *et al*. 2010, entire; Gray 2012, p. 48). A reduction in cover plants used by tortoises can limit thermoregulatory opportunities and reduce periods of potential surface activity, making individuals more susceptible to dehydration and malnutrition, as well as increase predation risk when the individuals are surface-active (Gray 2012, entire).

To assess the potential scope of nonnative grasses within the range of the Sonoran desert tortoise in Arizona, we use an existing GIS analysis conducted as part of the Rapid Ecological Assessment for the Sonoran Desert (REA SOD) completed by the U.S. Bureau of Land Management (BLM) (Appendix B; Strittholt *et al*. 2012, pp. 89–92). This spatial analysis provided a predicted spatial occurrence of invasive vegetation (Figure 9), including those nonnative grasses of concern in our assessment of the Sonoran desert tortoise[7]. The results indicate that about 15% of current predicted potential habitat in Arizona potentially has invasive vegetation[8] (Figure 10).

[7] We recognize the limitations of this dataset as Strittholt *et al*. (2012, p. 91) difficulties of mapping the distribution of major invasive vegetation species. Due to these difficulties, the actual extent of invasive vegetation, including the nonnative grasses of highest concern for the tortoise, may be underrepresented. However, this was the best available information on which to conduct our analysis.

[8] Note that about 6 percent of predicted potential Sonoran desert tortoise habitat is outside of the area covered by the REA SOD, therefore no data are available for those areas.

To assess the potential scope of nonnative grasses within the range of the Sonoran desert tortoise in Sonora, we considered the predicted potential habitats with the highest potential for concern as being those within the Plains of Sonora subdivision of Sonoran Desertscrub that have lower than a 5% slope. These areas are where the cultivation of buffelgrass is most likely to occur. Based on the way we categorized the predicted potential habitat, these areas of potential concern are within the predicted "moderately potential" habitat. These areas of potential concern (within the Plains of Sonora subdivision of Sonoran Desertscrub) represent about 2,800 sq mi (1.8 million ac, 725,000 ha), about 20% of all the predicted potential habitat in Sonora, Mexico (Figure 11).

Theoretically, the effects of nonnative grasses on individual tortoises discussed above may manifest in population-level effects, in terms of their resiliency, redundancy, and representation over time and space. However, such population-level effects have not been identified through long-term monitoring (even though some species of nonnative grass have occurred within monitoring plots for decades if not over a century), nor been documented in the literature. Population-level effects would only become discernable (with current research and monitoring methods) over an extremely long period of time (decades to centuries) due to the life history and longevity of the species. Adequate time periods are well-outside of both the existing period of monitoring and our ability to predict such population-level effects in the future.

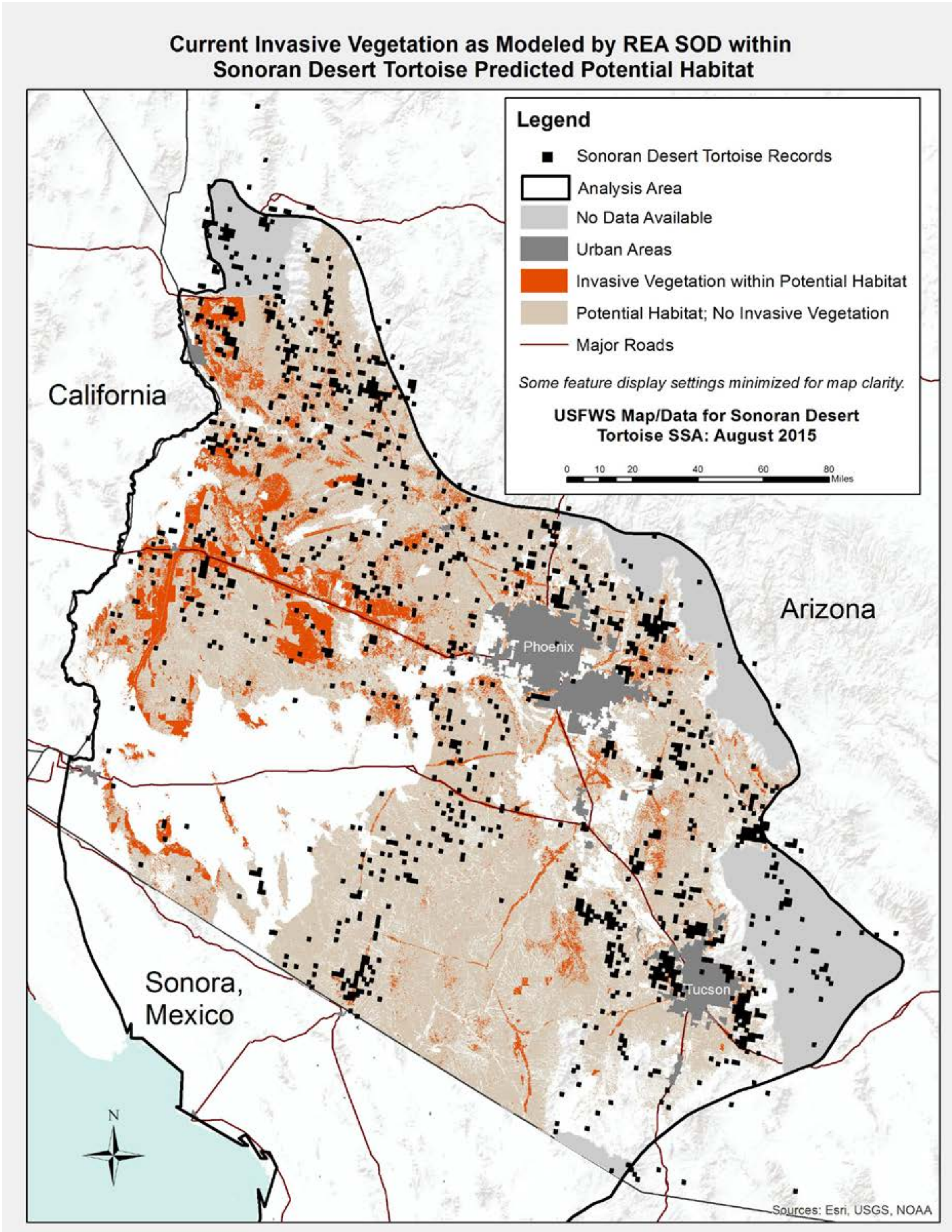


Figure 9. Distribution of modeled invasive vegetation within the predicted potential habitat of the Sonoran desert tortoise in Arizona (based on REA SOD, Strittholt *et al*. 2012, pp. 89-–92).

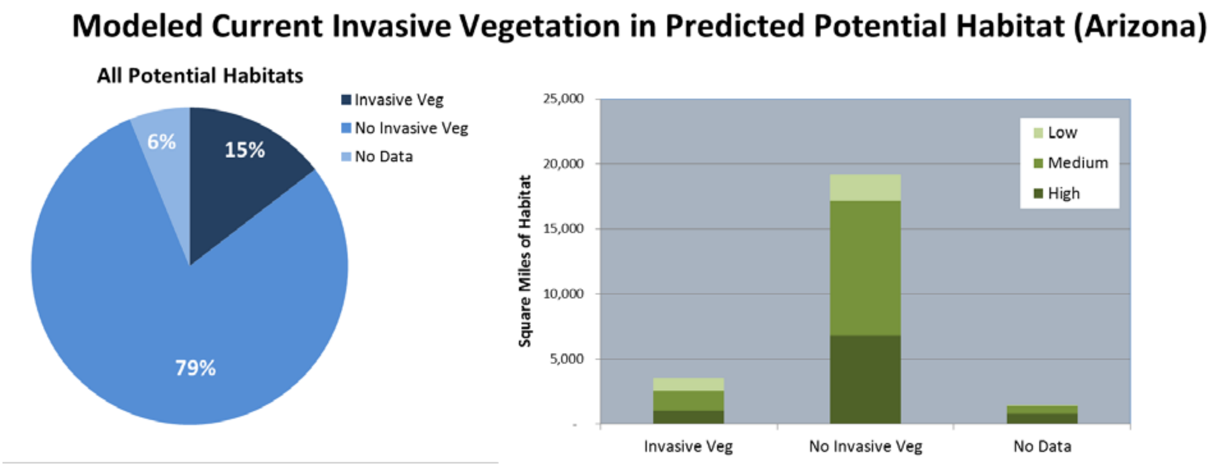


Figure 10. Proportion of the predicted potential Sonoran desert tortoise habitat in Arizona with modeled invasive vegetation (based on REA SOD).

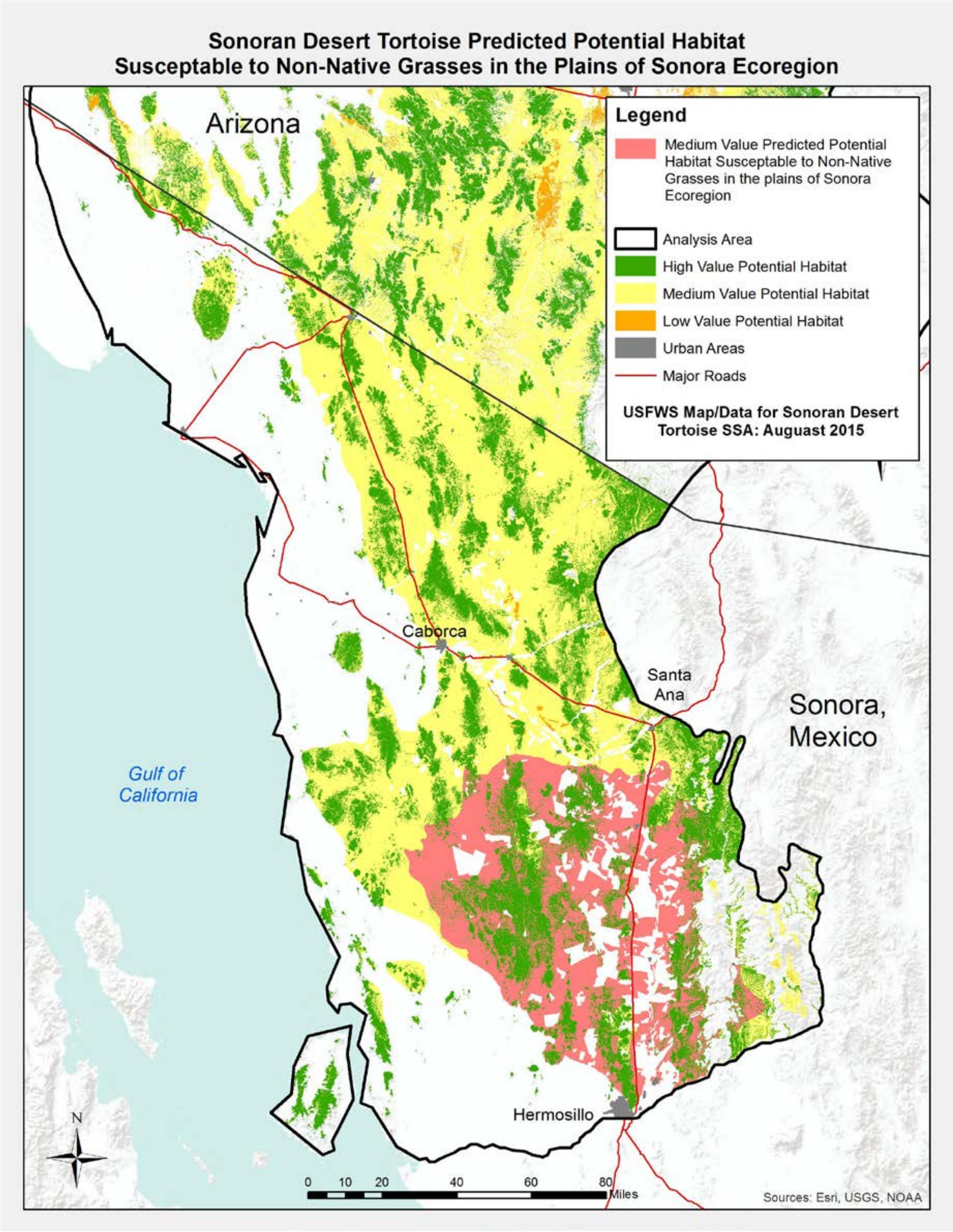


Figure 11. Distribution of areas of concern for nonnative grasses and fire risk within the predicted potential habitat of the Sonoran desert tortoise in Sonora, Mexico (location of medium quality habitat within the Plains of Sonora biotic subregion).

4.2 Altered Fire Regime

While wildfire can occur within wholly native desertscrub communities, particularly after two or more consecutive wet winters that result in a build-up of native annuals as fuel (McLaughlin and Bowers 1982, p. 247), wildfire was never a significant factor influencing the evolution of Mojave and Sonoran desertscrub communities (Esque *et al.* 2002, p. 312). In desertscrub communities that are free of nonnative grasses, wildfire has a long return interval and is rarely able to carry itself over a spatially significant area due to the extent of bare ground between vegetated patches. Consequently, native plants, in particular native cacti, trees, and shrubs, are ill-adapted to fire and generally fare very poorly in response to burns, although cacti still showed greater regeneration potential than trees or shrubs (Shryock *et al*. 2015, p. 33). In areas invaded by nonnative grasses, the density of fine fuels increases while open space between vegetation decreases, causing changes in fire behavior and, ultimately, in the fire regime; this has community-level effects of differing degrees that can last for several decades (Abella 2010, p. 1257). Abella (2010, p. 1273) also indicates that perennial plant cover post-fire in Mojave and Sonoran deserts can rebound to levels similar to undisturbed areas within 40 years and that both species richness and cover rebound more rapidly than species composition. Recent post-fire monitoring in Sonoran desert tortoise habitat indicates that topographically complex sites in central Arizona, invaded by red brome, require much less time than 40 years to meet the same pre-fire conditions than what has been documented in the Mojave Desert (Shryock *et al*. 2015, p. 35). Less is known about fire behavior in areas invaded by buffelgrass, but the higher biomass of buffelgrass (as compared to other nonnative grasses) and its higher burn temperatures (McDonald and McPherson 2013, entire) likely contribute to higher severity wildfires with commensurately lower survival of native plants. Lightning is the only natural ignition source for wildfire in desertscrub, whereas human-caused ignition sources are varied and considered to be the most frequent cause for wildfire starts, both currently and in recent history (Alfred *et al*. 2004, entire).

Nonnative forbs, such as Sahara mustard (*Brassica tournefortii*) (Dimmitt and Van Devender 2009, entire) and various thistle species (*Centaurea* and *Cirsium* species) are known to contribute to fires in many ecosystems (DiTomaso *et al*. 1999, entire; Lambert *et al*. 2010, entire). Although these nonnative forbs occur in Arizona, they are not typically found in the rocky habitat where Sonoran desert tortoises typically occupy (ASDM 2015, p. 2; DiTomaso *et al*. 1999, p. 233)

Direct, long-term effects of fire on Sonoran desert tortoise habitat can impact tortoise food availability, thermal refugia, and protection from predation (Esque *et al.* 2002, entire). Effects of wildfire and the post-burn recovery rate and potential has been shown to vary between Mojave and Sonoran desertscrub communities, particularly as influenced by environmental and abiotic factors (Abella 2010, entire; Shryock 2015, entire). Specifically, within the Arizona Upland Subdivision of Sonoran Desertscrub invaded by red brome, factors such as elevation, aspect, precipitation, and topographic heterogeneity can ameliorate the effects of a single burn to some degree (Shryock *et al*. 2015, pp. 34–35). Under certain conditions, Sonoran desert tortoise food plants can regrow in greater overall abundance than in unburned habitat (Shryock *et al*. 2015, p. 26); however, cover plants such as trees, shrubs, and cacti have been shown to fare poorly in response to wildfire, regardless of conditions or habitat characteristics, although cacti have been shown to recover faster, as described above.

Wildfires that occur in other subdivisions of Sonoran desertscrub, or in other biotic communities (e.g., Mojave Desertscrub), or areas invaded by nonnative grasses other than red brome, may have different effects on tortoise habitat. In Mexico, cultivated buffelgrass pastures are repeatedly burned to increase forage vigor for livestock use (Esque *et al.* 2002, p. 313). These pastures are primarily associated with the low valleys within the Plains of Sonora subdivision of Sonoran Desertscrub, geographically within the core of Sonoran desert tortoise distribution in Mexico, but generally outside habitat typically used by Sonoran desert tortoises. Tortoises generally do not occur in these lower valleys and may not be directly affected by burning pastures. Although most frequently documented in cultivated buffelgrass pasture in Sonora, repeated burns do occur in the same areas of native desert tortoise habitat over time, and baseline conditions of the vegetation community can be altered in such a manner that severe changes in species composition occur (also known as the grass-fire cycle) (D'Antonio and Vitousek 1992, p. 73).

Fire may also have direct effects on tortoises by killing individuals through incineration, elevating body temperature, poisoning from smoke inhalation, and asphyxiation. Potential post-fire indirect effects to individuals include nutrient deficiencies (see Esque *et al*. 2003, entire and references therein). Most wildfires in desertscrub communities occur during the spring and arid early summer (April-June) when relative humidity is low and ambient temperatures are high. This period of the year, particularly during April and May, is also important for adult female Sonoran desert tortoises to be surface active, consuming early annual growth as energy for subsequent egg development (Esque *et al.* 2002, p. 324). Therefore, adult female tortoises may be at elevated risk of injuries or death associated with wildfire. In general, the mobility of adult desert tortoises allows them to exploit microsites within a burn perimeter that support recovery of native forbs, grasses, and subshrubs, as well as use heterogeneous topography for thermal refugia, and, therefore, many adult tortoises may be able to persist in burned habitat (Shryock *et al*. 2015, p. 39). However, juvenile Sonoran desert tortoises have less mobility to explore the landscape, less access to some food plants because of their short stature, and less thermal inertia, which may pose greater challenges in burned habitat and which may make them more susceptible to effects from wildfire than adults (Shryock *et al*. 2015, p. 39).

To assess the potential scope of an altered fire regime within the range of the Sonoran desert tortoise in Arizona, we used an existing GIS analysis conducted as part of the REA SOD (Appendix B; Strittholt *et al*. 2012, pp. 92–96). This spatial analysis provided a predicted spatial occurrence area with high potential fire risk (Figure 12). The results indicate that about 23% of current predicted potential habitat in Arizona[9] is in areas designated as high fire potential (Figure 13).

To assess the potential scope of nonnative grasses (and thus the potential for an altered fire regime) within the range of the Sonoran desert tortoise in Sonora, we considered the predicted potential habitats with the highest potential for concern to be those within the Plains of Sonora

[9] Note that about 6 percent of predicted potential Sonoran desert tortoise habitat is outside of the area covered by the REA SOD, therefore no data are available for those areas.

biotic subregion that have lower than a 5% slope. These areas are where the cultivation of buffelgrass is most likely to occur. Based on the way we categorized the predicted potential habitat, this area of concern is within the predicted medium potential habitat. This area within the Plains of Sonora biotic subregion represents about 20% of the entire predicted potential habitat in Sonora, Mexico (Figure 11).

> **Key Assumption:** Our assessment assumes that any changes in future wildfire regimes from possible nonnative grass expansion and increased human fire starts are not likely to have significant impact on populations of Sonoran desert tortoises because fire suppression efforts will prevent high numbers of large-scale fires, and, when fires do burn large areas, the effects to the native vegetation community are limited by suppression efforts and natural recovery capabilities. Because of the uncertainty about the past, present, and future role of wildfire in the Sonoran Desert ecosystems and the ability for successful management suppression, we acknowledge the limitations in these assumptions.

Despite the fact that many wildfire ignitions occur annually in desertscrub communities within the range of the Sonoran desert tortoise, aggressive wildfire suppression policies are widely implemented by agencies and municipalities across the landscape in desertscrub communities. As a result of these policies, a very limited amount of tortoise habitat has burned in comparison to the total area considered potential habitat for Sonoran desert tortoises across their range. Fires set intentionally in Mexico to benefit buffelgrass pasture could potentially affect adjacent tortoise populations, but information is sparse in the literature, little research has been done on the effect of these fires on Sonoran desert tortoise habitat in Mexico, and many of these pastures occur in areas where tortoises are unlikely to occur based on their habitat preferences. We expect that aggressive wildfire suppression policies will remain in place in Arizona for the future and, therefore, do not expect this stressor to have an appreciable effect on Sonoran desert tortoises at the population-level, nor that it will affect the species' resiliency, redundancy, or representation. We also do not have information suggesting that the effects from wildfire in Mexico will change in the near future.

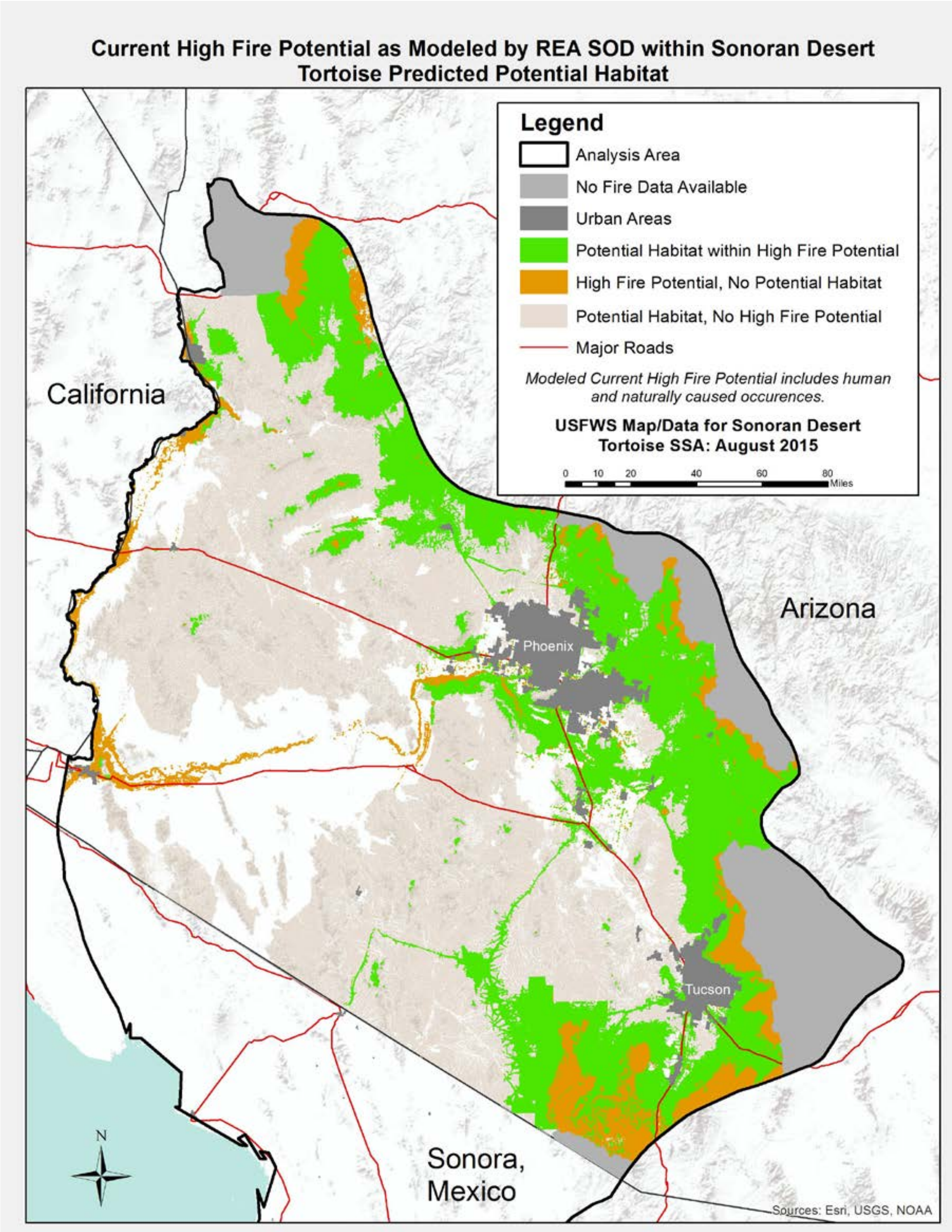


Figure 12. Distribution of modeled areas with high fire potential within the predicted potential habitat of the Sonoran desert tortoise in Arizona (based on REA SOD).

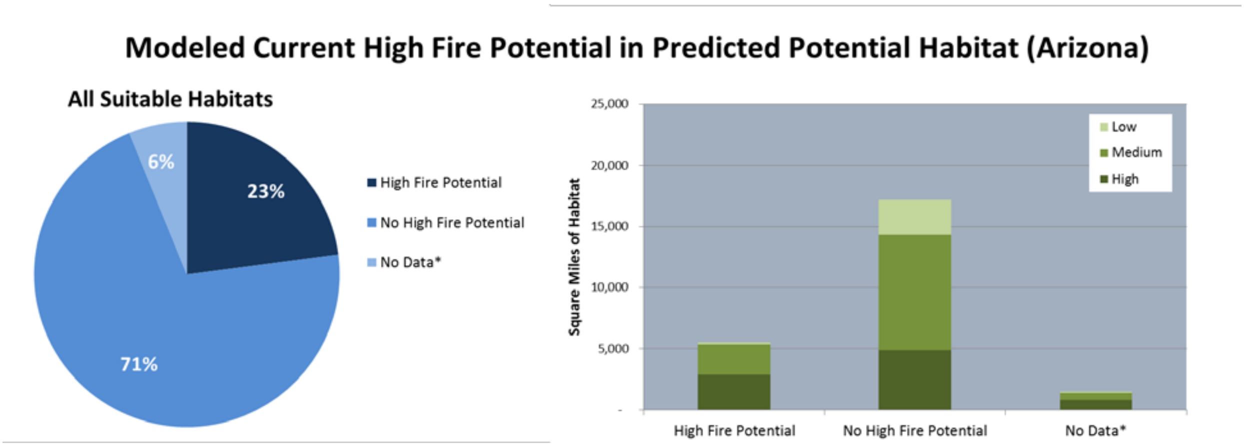


Figure 13. Proportion of the predicted potential Sonoran desert tortoise habitat in Arizona with modeled high fire potential (based on REA SOD).

4.3 Habitat Conversion

Over time and as the human population has grown within the range of the Sonoran desert tortoise, areas of urban and agricultural development have replaced natural habitat. When habitat is replaced by urban and agricultural development, forage plants, cover plants, and shelter sites used by Sonoran desert tortoises are removed, often permanently. The alteration or removal of these habitat features removes the ability for tortoises to adequately fulfill life history needs and can result in either immediate fatalities of individuals during construction or delayed fatalities from starvation, exposure, or predation should an individual survive the construction phase and/or be displaced from its home range. Additionally, habitat conversion also affects unaltered open space used by tortoises to establish home ranges and facilitate short-, medium-, and long-distance dispersal movements. At larger scales, urban development causes significant changes or removes habitat altogether, removing high potential habitat areas and making regional and landscape movements by tortoises challenging, if not impossible. Agricultural developments, while removing habitat characteristics needed to support several life history functions, still allow tortoises to move across them. In other words, agricultural areas may be more permeable for tortoise movements than urban developments. While some low-density urban developments may be permeable for tortoises, effects associated with urban development, such as human interactions and human presence on the landscape (collection, road fatalities, predation by dogs, etc. [see Section 4.6 Human Interactions (Urban Influences)]), may mean these areas are functionally impermeable.

Both urban and agricultural developments generally occur on flat, or nearly flat, terrain, typically in valley bottoms where tortoise densities are lowest or the species may be absent. Suburban housing developments, sometimes large-scale, can occur within lower bajadas, hillsides, and gently rolling hills where tortoises may establish home ranges. Examples of these types of developments in Arizona include Gold Canyon and Anthem near the Phoenix metropolitan area, and Dove Mountain, Oro Valley, and the Catalina Foothills areas near Tucson. Developments in these types of areas are expected to have a greater effect on tortoise populations than developments found in valley bottoms.

Urban and suburban development, one of the primary factors driving Arizona's economy, is expected to continue into the future (Gammage *et al*. 2008 entire; 2011 entire). Projected development is expected to occur primarily within a zone referred to as the Sun Corridor Megapolitan, driven primarily by its association with major transportation routes and other existing infrastructure. In a northward direction from the U.S.-Mexico border, this development zone occurs within the range of the Sonoran desert tortoise along Interstates (I)-19, I-10, and I-17 (Gammage *et al*. 2008 entire; 2011 entire). Additional suburban development zones are expected to occur along I-40 near Kingman and along State Route 93, which connects Wickenburg to Kingman, especially if the latter route is converted into an interstate (proposed I-11). The majority of projected development in Arizona is not anticipated to occur in potential tortoise habitat. However, we expect as much as 9% of potential tortoise habitat in Arizona could be developed within the next 50-100 years. In contrast, an estimated 73% of potential habitat should be protected from development due to land ownership and management. Water availability influenced by climate change and increased water withdrawals associated with ongoing urban and suburban development may ultimately limit urban/suburban development in Arizona.

The number of acres dedicated to irrigated agriculture has been on the decline in Arizona (U.S. Department of Agriculture 2009, p. 273). These areas are likely being converted into areas re-zoned for residential or commercial purposes or, rarely, left fallow for natural recovery. We predict that the observed trend associated with agricultural use will continue to decline in Arizona, unless farming practices or technology change, or a novel crop significantly influences market forces and reverses this trend.

Within the species' range in Sonora, Mexico, and according to recent reports, urban and agricultural development is also expected to continue into the future, but at a slower pace and smaller scale than Arizona. Hermosillo is the largest population center in Sonora (approximately 778,000 per the 2014 census) and could expand north and east which could potentially affect adjacent tortoise populations (Rosen *et al.* 2014a, pp. 22–23). Limited urban expansion could also be predicted for a small number of other communities within Sonora (Rosen *et al*. 2014a, pp. 22–23). With respect to agriculture in Sonora, the majority occurs on large river deltas which are not occupied by tortoises (Rosen *et al*. 2014a, pp. 22–23). Therefore, neither urban nor agricultural development is considered to be significantly affecting tortoise populations over a large area in Sonora currently, or into the future.

Rangewide, we did not find that the projected, potential footprint of urban or agricultural development is expected to affect a significant amount of potential habitat for tortoises, largely due to protections afforded by federally managed lands and the fact that much of urban development occurs within valley bottoms, in many cases on land previously used for irrigated agriculture. Population-level effects to Sonoran desert tortoises from habitat conversion have not been documented in the literature, and we do not anticipate effects to population resiliency, redundancy, or representation in the near future.

To assess the potential historical loss of habitat due to conversion to urban landscape, we calculated the amount of area currently designated as urban land within the range boundary of the Sonoran desert tortoise. About 1,279 sq mi (818,560 ac, 331,260 ha) of area is currently designated as urban in Arizona, representing approximately 5% of all predicted potential habitat (if all that land had been previously potential habitat, which it likely was not). In Mexico, about 53 sq mi (33,920 ac, 13,730 ha) of area is designated as urban representing less than 1% of predicted potential habitat. Even considering additional areas potentially lost historically due to agricultural or other development (which we have not quantified), historical habitat loss would appear to be relatively small.

To assess possible future habitat loss due to potential long-term urban growth in Arizona, we used a rudimentary spatial estimate of potential urban growth within areas that are not protected in some way from urban expansion (see Appendix D: Stochastic Simulation Model Report). Figure 14 shows a potential urban growth map in unprotected lands that could be susceptible to habitat conversion in the future[10]. In total for Arizona, we estimate about 9% of currently predicted potential habitat could be susceptible to future conversion to urban areas (Figure 15). Based on the low human population levels currently in potential habitat, we do not anticipate that urban expansion in Sonora, Mexico, is likely to result in a measureable loss of tortoise habitat in the near future.

[10] The urban projection map from which this habitat loss estimate was derived was published in 2008 as a possible 2040 projection. This estimate was done at the height of the economic expansion during the mid-2000's so we decided it would be unreasonable and over-estimating potential growth to use that urban growth projection as a 2040 estimate. We instead subjectively chose this projection to represent a potential future 60 years from the present.

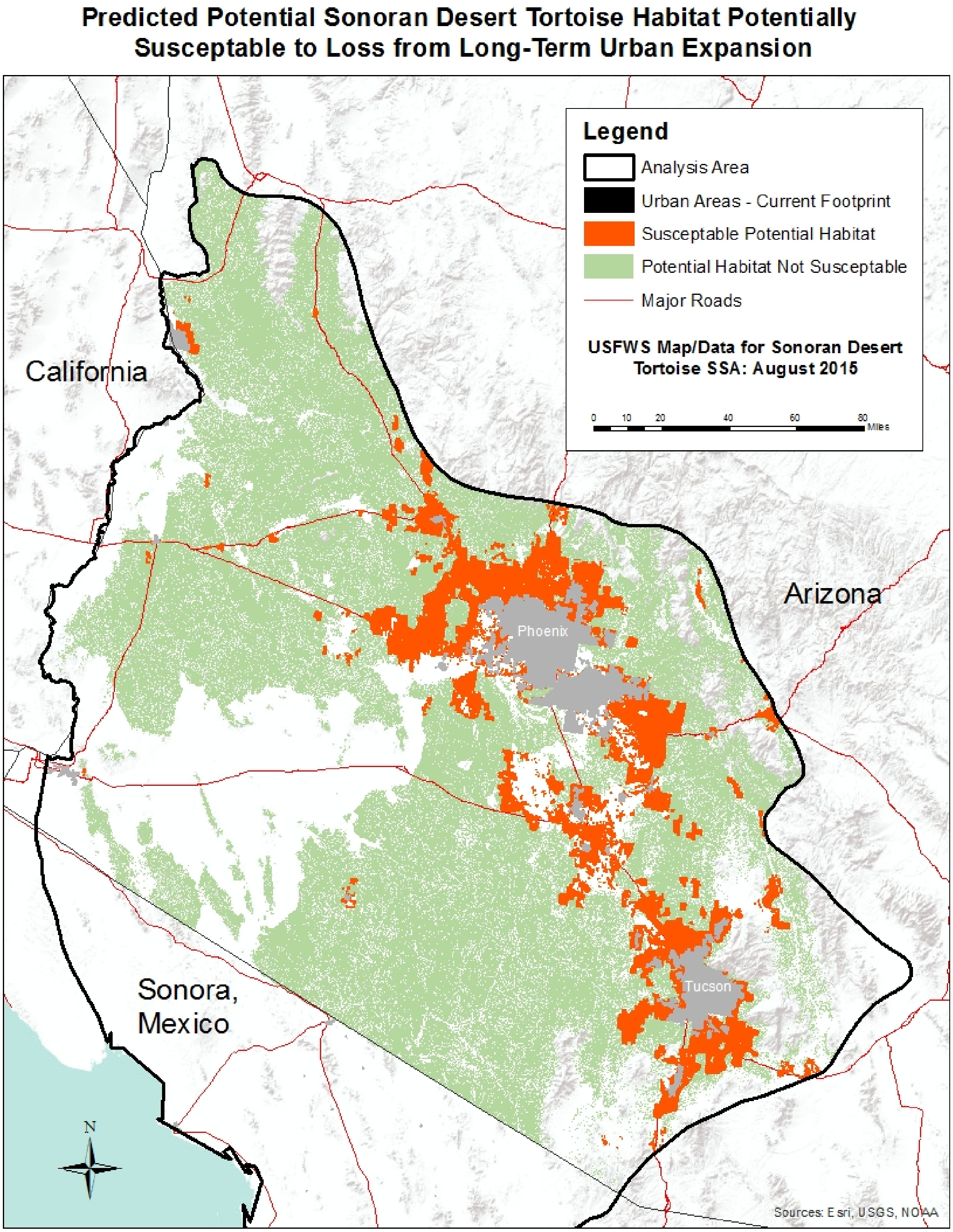


Figure 14. Possible future urban development within Arizona.

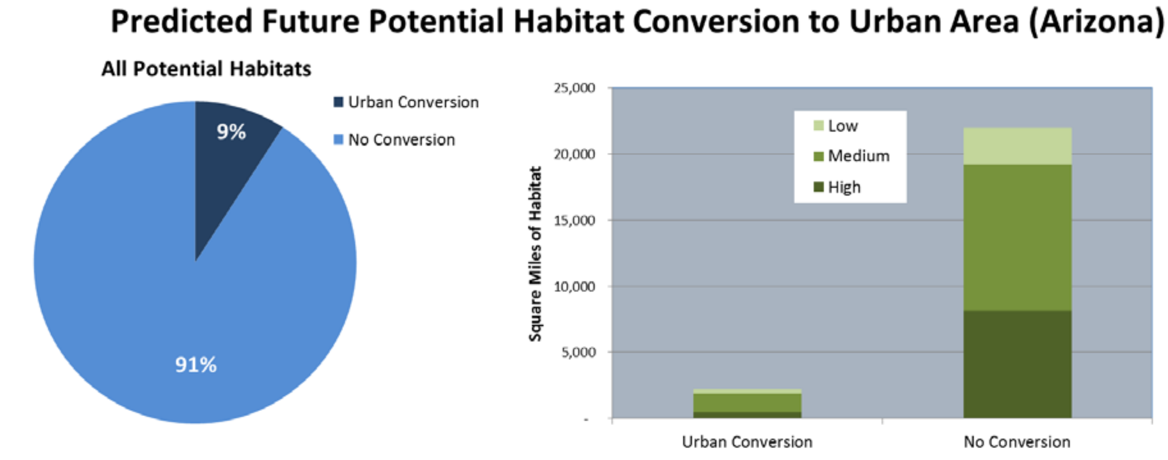


Figure 15. Proportion of the predicted potential Sonoran desert tortoise habitat in Arizona that may be susceptible to future conversion to urban areas.

4.4 Habitat Fragmentation

Habitat fragmentation is caused primarily by transportation infrastructure (e.g., roads, highways, interstates) as well as other forms of linear development such as canals, railroad tracks, and, in some sections along the U.S.-Mexico border, pedestrian fences constructed to control cross-border traffic. Considered permanent, these forms of development are largely ubiquitous (particularly roads) across the range of the tortoise and are necessary to facilitate the movement of commerce, people, and water. As one indicator of linear development, major roads within the range of the Sonoran desert tortoise are depicted in Figure 16. Where these forms of linear development occur within or adjacent to occupied Sonoran desert tortoise habitat, individual tortoises may be injured, killed, collected (biologically dead to the population), or physically unable to cross the development (Edwards *et al*. 2004, entire). Tortoises move within and outside their home ranges for different purposes depending on sex, age class, and size class. Tortoises will move to find preferred plant forage species that may be in season (Oftedal 2007, entire); to a different shelter site with a different exposure, depth, or substrate (Averill-Murray and Klug 2000, p. 62); or to search for potential mates (Averill-Murray *et al*. 2002a, pp. 139–144). Tortoises will also move to disperse outside of their home ranges, with distances ranging from a few hundred yards to several miles or more (Edwards *et al*. 2004, entire). When individuals are unable to successfully complete these movements within their home ranges or on the landscape, basic natural history functions can be compromised to varying degrees.

The relative permeability of linear development to tortoise movement varies widely, with some structures considered impassible (*i.e.*, some canals) and others easily traversed (*i.e.*, infrequently used roads). Therefore, effects of linear development on individual tortoises are not equal over space and time. Latch *et al*. (2011, entire) found that in Mojave desert tortoises, variables that influence population genetics and connectivity on local scales are different than those influencing these factors on regional scales. For example, not all roads have the same effect on tortoise movements. Road width, road type (e.g., rugged, improved gravel, paved), speed limits, traffic volume, availability of washes or other means of crossing under roads, and quality of tortoise habitat being transected have the greatest effect on tortoise injury and mortality rates. In most cases, only tortoises that are discovered dead on the road are reported (Lowery *et al*. 2011, p. 7, Grandmaison 2010b, p. 5), but tortoises that successfully cross are not. Telemetry research on the effects of roads on tortoises is limited, but suggests that depending on the type of road and frequency of traffic, tortoises may use a road to bask or to facilitate unobstructed movement (Grandmaison *et al*. 2010, p. 587) or in some cases, may refuse to cross a road (AGFD 2012b, pp. 19–46).

Principles in conservation genetics suggest that when connectivity between populations of a species is negatively affected or prevented outright, genetic diversity may be negatively affected over time (*i.e.*, genetic inbreeding or "bottlenecking") (Edwards *et al*. 2004, entire). By applying the FRAGGLE Model (spatial system dynamics model designed to calculate connectivity indices among populations) to gopher tortoise (*Gopherus polyphemus*) populations in Georgia, BenDor *et al*. (2009, entire) found that even minor habitat losses can result in disproportionate effects to population connectivity. In addition, should a stochastic event drastically reduce or effectively eliminate a given population that is isolated by linear development, natural recolonization from adjacent populations may be hampered or unlikely to occur (Edwards *et al*. 2004, p. 496). Population genetics of tortoises can best be understood by applying an "isolation by distance" model, meaning that genetic exchange among populations is likely positively correlated by proximity (or nearness) to the next population (Edwards *et al*. 2004, entire). While population-level impacts as a result of isolation of Sonoran desert tortoise populations may be occurring, there are no data available regarding the effects of linear development to tortoises at the population level (Edwards *et al*. 2004, p. 496). Because of the slow growth rates of tortoises and their long generation times (approximately 25 years), data collected from long-term monitoring plots using technologies and methodologies currently available would not be able to identify linear development as an influence even if impacts are occurring. These trends unfold on a multi-decadal scale, if not over centuries; given such timeframes, it is well outside our ability to predict with reasonable certainty any trends likely to occur in the near term future. We expect established principles in population genetics to guide long-term land use planning and development in coordination with local, state, and Federal agencies and conservation programs to account for the needs of the Sonoran desert tortoise in maintaining genetic connectivity. We did not further evaluate the potential effects of fragmentation.

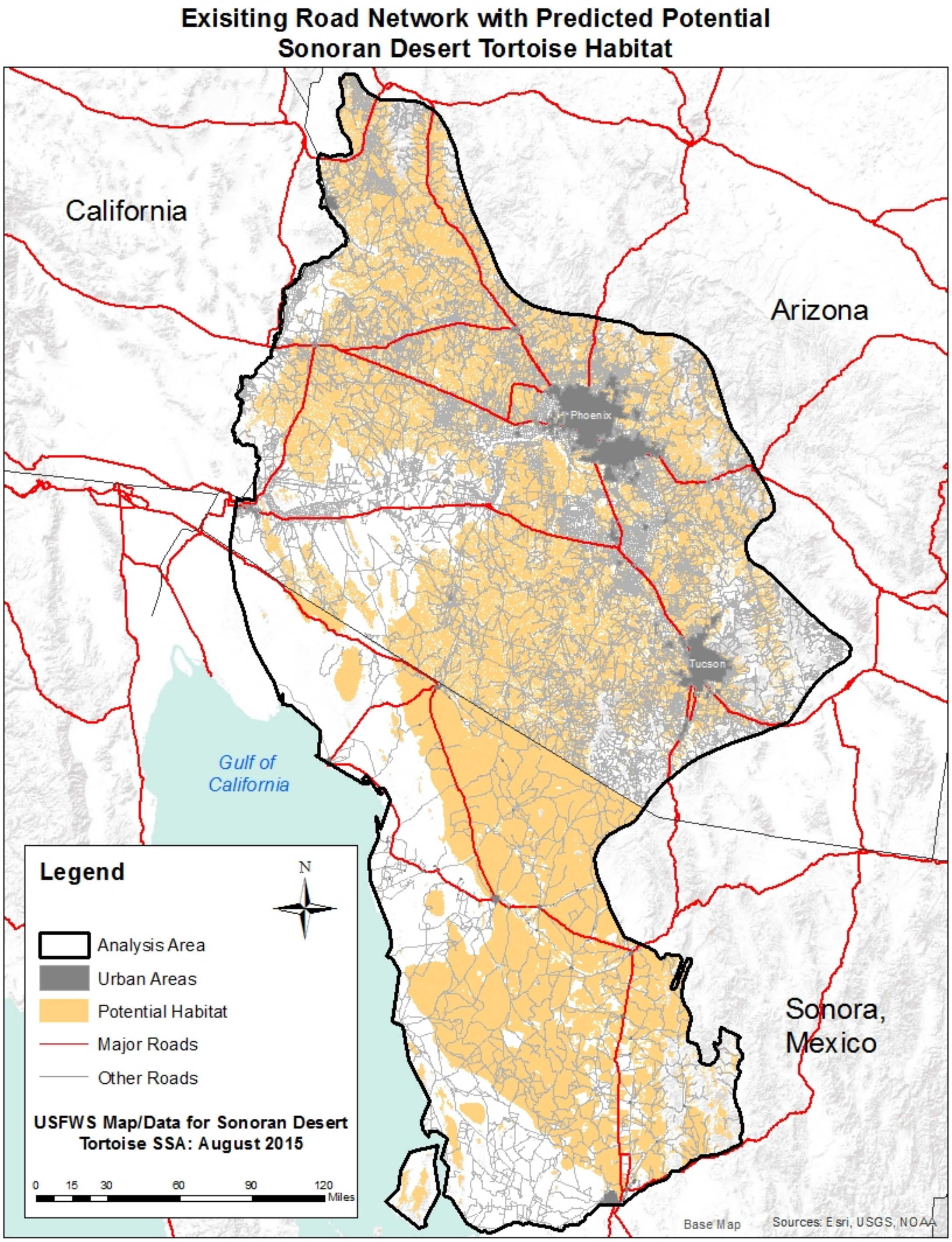


Figure 16. Roads within the range of the Sonoran desert tortoise.

4.5 Climate Change and Drought

There is unequivocal evidence that the earth's climate is warming based on observations of increases in average global air and ocean temperatures, widespread melting of glaciers and polar ice caps, and rising sea levels, with abundant evidence supporting predicted changes in temperature and precipitation in the southwestern deserts (IPCC 2007, entire; 2014, entire). Predicted temperature trends for the region encompassing the range of the Sonoran desert tortoise include warming trends during winter and spring, lowered frequency of freezing temperatures, longer freeze-free seasons, and higher minimum temperatures during the winters (Weiss and Overpeck 2005, p. 2075). In this same region, predictions of potential changes in precipitation due to climate change are less certain, but climate scientists largely agree that annual precipitation totals are likely to decrease as compared to historical averages (Seager *et al.* 2007, entire; Cook *et al.* 2015, p. 4). Climate models generally agree that winter and spring precipitation may be influenced by climate change, with predicted decreases in precipitation during these seasons. However, modeling results vary considerably with respect to how climate change could affect summer (monsoon) precipitation in Arizona and northern Mexico. While annual precipitation totals are predicted to decrease, summer precipitation totals may increase (IPCC 2007, p. 20), with wide fluctuation in scope and severity of summer precipitation events.

Sonoran desert tortoises evolved in arid conditions and have an array of physiological and behavioral tools to survive some degree of drought. However, because the principal effects of predicted climate change pertain to temperature and precipitation, the physiological ecology of Sonoran desert tortoises may be significantly compromised by changes in these climatic parameters, both directly and indirectly. Drought associated with climate change can affect tortoises directly by limiting the availability of free-standing water for drinking, either through a decrease in frequency of precipitation events or a decrease in precipitation totals per event. Availability of free-standing water is one of the strongest drivers of survivorship in Sonoran desert tortoises (Sullivan *et al.* 2014, entire). Drought can indirectly affect tortoises through a reduction in biomass of forage and cover plant species used for food, thermoregulation, and protective cover. Persistent drought and its effects on the tortoise's forage base can affect blood chemistry and water metabolism, reduce or eliminate the thymus and fat stores, and result in skeletal muscle and liver atrophy in desert tortoises (Berry *et al.* 2002b, pp. 443–446; Dickinson *et al.* 2002, pp. 251–252). Over time, drought and inadequate nutrition could result in lower growth rates, lower reproductive output, lower survivorship, and increased stress on bladder physiology. In Arizona, a reduction in average winter and spring precipitation is expected to disproportionately affect adult female Sonoran desert tortoises because they depend on spring annuals as a key source of energy for egg development (Averill-Murray and Klug 2000, pp. 65–66). In other subdivisions of Sonoran Desertscrub and habitat types found in Sonora, Mexico, relationships between winter and spring rainfall and annual plant responses are less clear.

Temperature increases associated with climate change directly affect Sonoran desert tortoises by dictating the length of time and frequency of when they can be surface active and engaged in life history functions. Increased temperatures may also affect sex-ratios during embryo development as this process has been confirmed to be temperature-dependent (Janzen 1994, p. 7488; Walther *et al.* 2002, pp. 393–394). Temperature increases can indirectly affect Sonoran desert tortoises by increasing evapotranspiration rates in plants which, in turn, increases the plants' water demands and, therefore, vulnerability to drought. These factors can ultimately contribute to an overall reduction in perennial and annual plant productivity and result in a reduction of the forage base and cover plants used by Sonoran desert tortoises.

Of the various stressors we have identified that could affect Sonoran desert tortoise populations, only drought has been found to have demonstrable effects to population trends over the existing period of study. Even short-term variability in precipitation can have sustained effects on Sonoran desert tortoises because of impacts to reproduction, recruitment, and annual survival. For example, research has shown that in populations that experience localized, prolonged drought conditions, annual adult survival can decrease by 10-20%, and abundance of adults can be reduced by as much as 50% or more in local instances (Zylstra *et al*. 2013, pp. 113–114). However, when drought conditions affecting these populations subsided, Sonoran desert tortoise numbers began to increase, reaching near pre-drought status, and the overall rate of change in population size was found to be greater than 1, indicating cumulative population growth over the range of the species in Arizona (Zylstra *et al.* 2013, pp. 112–114). If the magnitude and scope of drought should increase in the future as a result of climate change, effects to Sonoran desert tortoise survival rates could worsen. Current modeling suggests that adult survival rates could decrease by 3% during 2035-2060 as a result of climate change, as compared to the survival rates during 1987-2008 (Zylstra *et al*. 2013, p. 114). Sonoran desert tortoise populations that occur within the most arid portions of the species' range (western and southwestern Arizona and western-most Sonora, Mexico) presently exist at lower overall densities and may, therefore, be particularly vulnerable to the effects of drought. Modeling suggests that Sonoran desert tortoise populations adjacent to higher elevation habitat may slowly migrate into higher elevation areas or more northerly as habitat suitability for Sonoran desert tortoises shifts over time and space.

One estimate of the geographic scope of potential climate-related changes in the Sonoran Desert ecoregion was conducted by the REA SOD (Strittholt *et al.* 2012, pp. 126–152). This study showed a large portion of the Sonoran desert tortoise range having very high or moderately high long-term effects from climate change by 2060 (Figure 17). Our analysis of the future condition of the tortoise (Chapter 6: Future Conditions and Viability and Appendix D: Stochastic Simulation Model Report) incorporated the potential effects of climate change by estimating the annual proportion of the population of the tortoise that may be negatively affected by climate change and decreasing the survival rates in the simulation model by that proportion of the population. Altering the proportion of the population potentially affected over time under different scenarios allowed us to estimate a range of potential climate change effects.

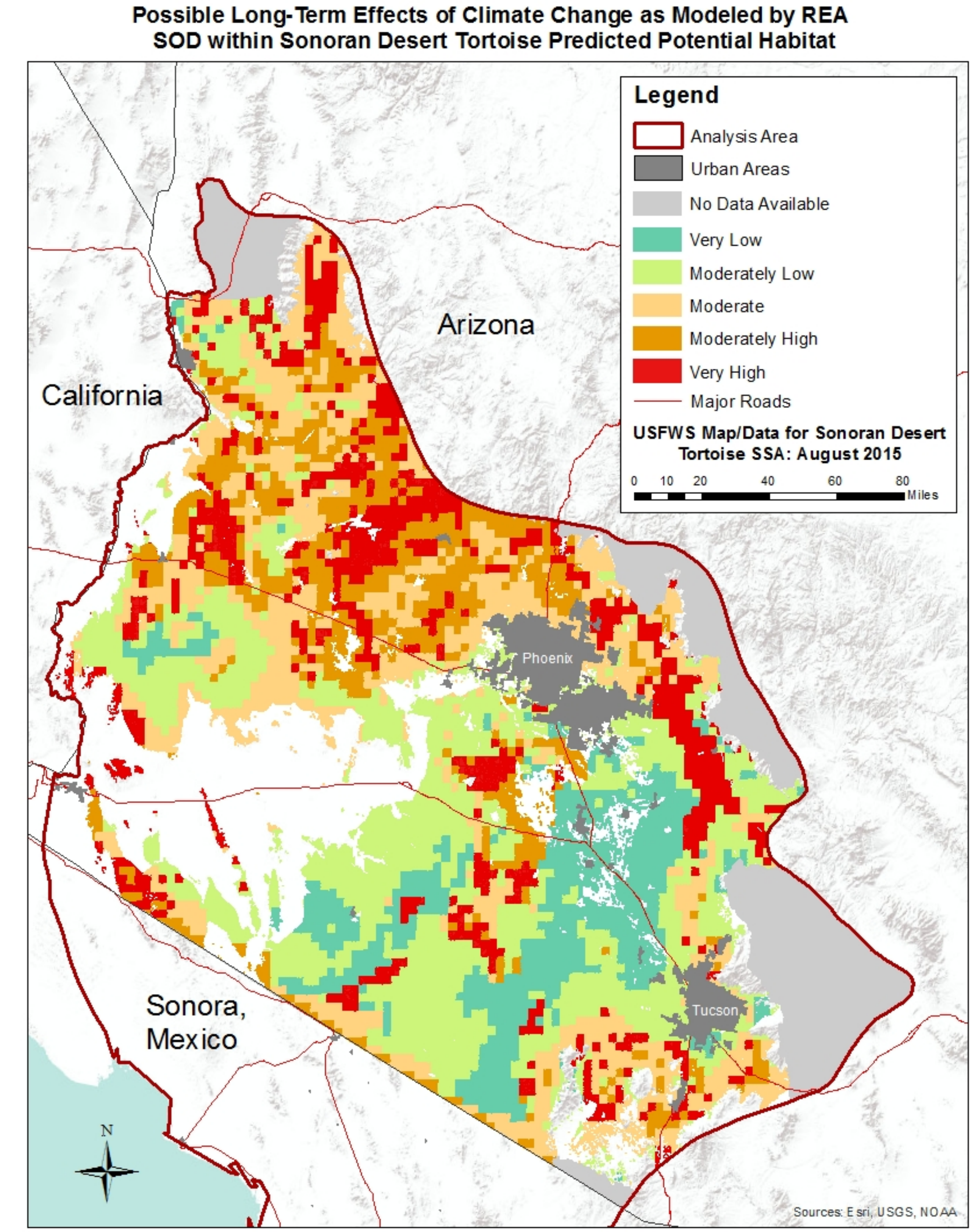


Figure 17. Project long-term effects of climate change by 2060 within predicted potential habitat of the Sonoran desert tortoise (based on REA SOD, Strittholt *et al.* 2012, pp. 126–152).

4.6 Human-Tortoise Interactions (Urban Influences)

Human population centers of varying sizes occur throughout the range of the Sonoran desert tortoise. These cities and towns are sources of people who inadvertently or purposefully interact with Sonoran desert tortoises while engaged in various activities within occupied tortoise habitat. These types of effects are difficult to quantify although the literature is clear they occur and act collectively as a stressor on Sonoran desert tortoises. Examples of activities that could lead to human interactions with tortoises (when in occupied tortoise habitat) include the use of vehicles (Lowery *et al*. 2011, entire), off-highway vehicles and off-road vehicles (Bury and Luckenback 2002, p. 257; Ouren *et al*. 2007, entire), or general recreation such as target shooting, hunting, hiking, rock crawling, trail bike riding, rock climbing/bouldering, and camping (Howland and Rorabaugh 2002, pp. 339–342; AGFD 2010, p. 9) . In addition, pet dogs that escape captivity or are intentionally abandoned can form feral packs which have been shown to molest Sonoran desert tortoises (Zylstra 2008, entire). These are all examples of inadvertent interactions that can have incidental effects on tortoises that are not otherwise the intent or purpose of the activity itself. Other forms of human interaction with tortoises are direct and intentional, such as collection of wild tortoises, release of captive tortoises into wild populations, or physically handling wild tortoises (Grandmaison and Frary 2012, entire). When a tortoise is picked-up and physically handled by a human, it may void its bladder (a defensive mechanism) which depletes a critical source of its metabolic water. Depending on the season of year and likelihood of precipitation, simply voiding the bladder could result in a dehydrated state, decline in reproductive energy, and eventually death of a tortoise (Grandmaison and Frary 2012, p. 266).

These types of human interactions with tortoises occur at highest frequency in the wild-urban interface zone (where urban development contacts open, undeveloped space) and are thought to attenuate with increasing distance from human population centers (Zystra *et al*. 2013, pp. 112–113). The likelihood of human interactions with Sonoran desert tortoises increases significantly with urban growth and the increase of highways, roads, and trails intersecting occupied tortoise habitat. Tortoises crossing roads can be seen by motorists who may do nothing, intentionally or unintentionally run over the tortoise, attempt to help the tortoise cross (by coaxing it to move or physically carrying it across the road), or collect the tortoise as a pet (Grandmaison and Frary 2012, entire). The larger and more conspicuous the tortoise is, the more likely it is to be noticed by motorists. Speed limits also influence the detection rate of tortoises along roads; slower speed limits generally correlate with higher detectability of tortoises and vice versa. Larger tortoises are more apt to be seen and, therefore, more likely prone to direct human interaction and less likely to be injured or killed by a vehicle. Smaller tortoises are less likely to be noticed and, therefore, less prone to direct human interaction, but more prone to injury or death from vehicles.

Effects of human interactions on tortoises are expected to only occur when tortoises are surface active. Generally speaking, Sonoran desert tortoises are sedentary and fossorial by nature, spending as much as 98% of their lives within their shelters to conserve energy and metabolic water reserves (Nagy and Medica 1986, p. 79). However, basic life history functions such as foraging, reproducing, and dispersing all require some level of surface activity. Adult female tortoises are most likely to be surface active during the spring and the summer rainy season. The peak surface activity period for all Sonoran desert tortoises, regardless of sex, age class, or size class, is the summer monsoon; however, all Sonoran desert tortoises will emerge from their shelters at any time of the year to drink free-standing water in response to precipitation (Averill-Murray and Klug 2000, entire; Sullivan *et al*. 2014, entire).

Population-level effects from human interactions with Sonoran desert tortoises are expected to be most severe when they occur to adult tortoises because adult survivorship is thought to be a primary determinant of population status; the investment of time and energy required to achieve reproductive status is high and the likelihood of any particular tortoise achieving adulthood is low (Howland and Rorabaugh 2002, p. 339; Zylstra *et al*. 2013, pp. 112–115; Campbell *et al.* 2014, pp. 2, 14). Further, negative effects to adult females are presumed to have a disproportionately larger effect on resident tortoise populations because an adult female tortoise may have many clutches of eggs over her lifetime (Van Devender 2002a, p. 11).

Population-level effects from human interactions have been demonstrated from current research. Adult survivorship has been shown to improve with increasing distance from urbanized areas; specifically, the odds of a Sonoran desert tortoise surviving one year increases 13% for each 6.2 mi (10 km) increase in distance from a city of at least 2,500 people (Zylstra *et al*. 2013, pp. 112-113). Effects from human interactions with Sonoran desert tortoises have not resulted in the documented extirpation of any known tortoise populations. However, in the case where tortoise populations exist at low densities, are already threatened by persistent drought, or occur adjacent to areas of very high human population densities with commensurate levels of outdoor recreation and visitation, loss of adult tortoises may have a population-level effect.

To assess the potential geographic scope of human interactions, we calculated the acreage of predicted potential habitat areas within 6.2-mi (10-km) rings of cities greater than 2,500 in population size. While the potential for human interactions exists beyond these areas, we assumed that the closer tortoises are to human population centers, the more likely that these interactions (and other urban edge effects) will occur. Figure 18 shows the areas around cities in 6.2-mi (10-km) and 12.4-mi (20-km) rings. Overall, 29% of predicted potential tortoise habitat occurs within 12.4 mi (20 km) of urban areas in Arizona and 9% does in Sonora (Figure 19).

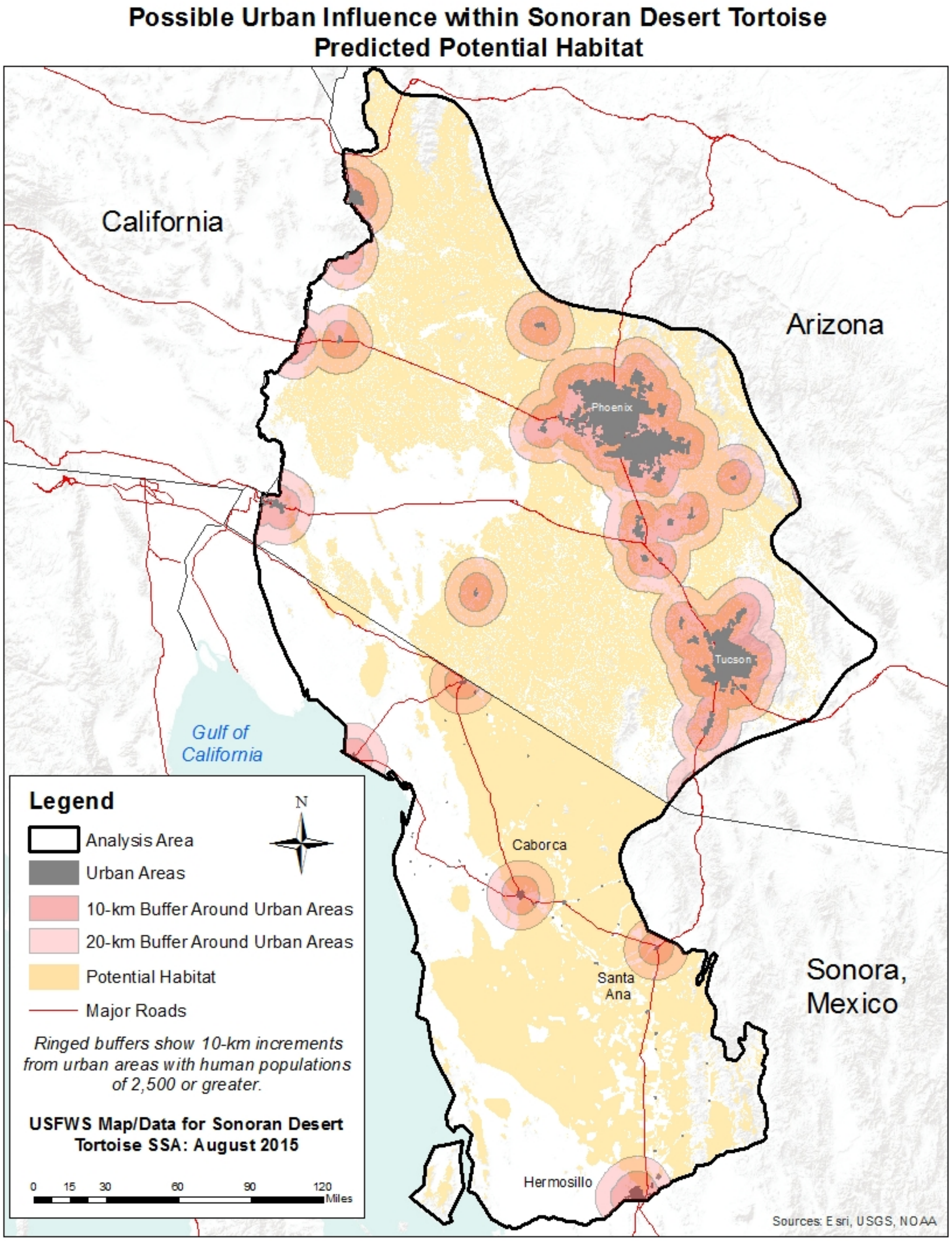


Figure 18. Distance from human population centers exhibited as ringed 10-kilometer buffers.

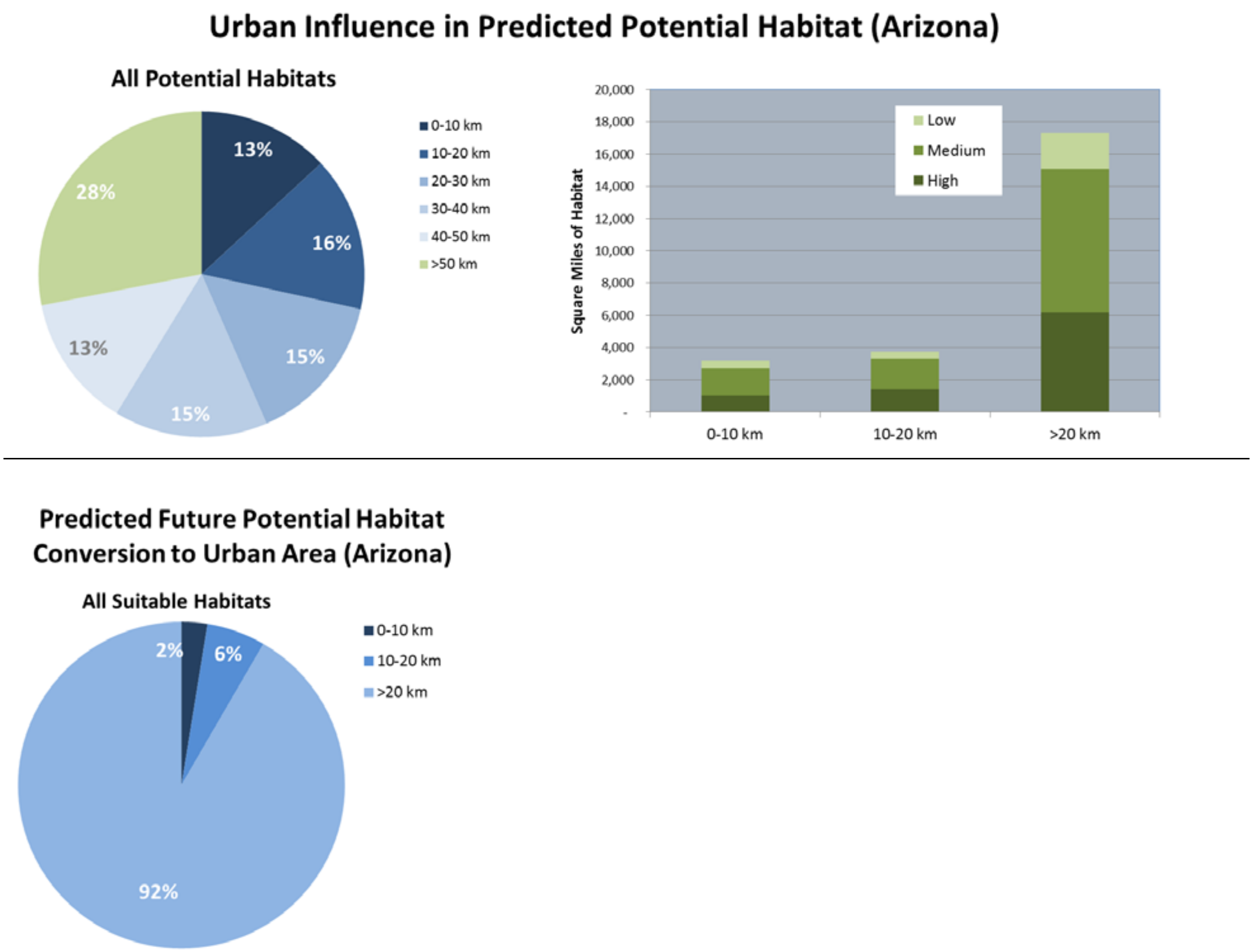


Figure 19. Proportion of the predicted potential Sonoran desert tortoise habitat in Arizona (top) and Sonora (bottom) that may be influenced by urban areas.

4.7 Conservation Measures

There are a number of conservation actions that have been implemented to minimize stressors and maintain or improve the status of the Sonoran desert tortoise, including most significantly a candidate conservation agreement (CCA; see AIDTT 2015, entire) with AGFD, BLM, Department of Defense, National Park Service, U.S. Fish and Wildlife Service, Bureau of Reclamation, Customs and Border Protection, U.S. Forest Service, Natural Resources Conservation Service, and Arizona Department of Transportation (collectively referred to as "Parties"). Candidate conservation agreements are formal, voluntary agreements between the Service and one or more parties to address the conservation needs of one or more candidate species or species likely to become candidates in the near future. Participants voluntarily commit to implement specific actions designed to remove or reduce threats to the covered species, so that listing may not be necessary. The CCA for the Sonoran desert tortoise was completed by the Parties in March 2015 and was signed by the final signatory, the Service, on

June 19, 2015. The CCA will be implemented on approximately 13,000 sq mi (8.3 million ac, 3.4 million ha) of Sonoran desert tortoise habitat in Arizona. This action area encompasses approximately 55% of the species' predicted potential habitat in Arizona and 34% of its predicted potential habitat rangewide.

The CCA is designed to encourage, facilitate, and direct effective tortoise conservation actions across multiple agencies and entities having the potential to directly influence species conservation in Arizona. Parties to the CCA identified existing tortoise conservation measures and efforts during the development of the agreement, while sharing conservation expertise and information across a broad range of organizations. This allows for an organized conservation approach that encourages coordinated actions and uniform reporting, integrates monitoring and research efforts with management, and supports ongoing conservation partnership formation.

Through implementation of the CCA, all Parties will participate in range-wide conservation and management of the Sonoran desert tortoise by assessing and directing conservation measures in Arizona. The CCA is designed to provide a comprehensive conservation framework for applying effective Sonoran desert tortoise conservation and management actions, such that:

- Sonoran desert tortoise populations and habitats are more effectively identified, inventoried, and conserved through time;
- The Parties can develop and implement conservation measures aimed at maintaining or enhancing Sonoran desert tortoise habitat and populations; and,
- The ability of the Parties to monitor the response of the species to conservation and management actions is enhanced as a result of the cooperative/comprehensive framework provided through the CCA.

The CCA includes many existing and new management actions intended to conserve and protect the desert tortoise and its habitat. Management actions in the CCA include, but are not limited to, reducing the spread of nonnative grasses, reducing or mitigating dispersal barriers, reducing the risk and impact of desert wildfires, reducing the impact of off-highway vehicles, population monitoring, and reducing illegal collection of tortoises. A complete list of the stressor-specific conservation measures can be found in Appendix A of the CCA (AIDTT 2015). The CCA provides for consideration of Sonoran desert tortoise habitat and is an important part of conserving the species. Implementation of these conservation actions will be evaluated through ongoing monitoring of useful metrics to document that committed activities are being completed in a timely and thorough fashion. In addition, the Parties' commitments to continue research at the existing Sonoran desert tortoise long-term monitoring plots throughout Arizona will increase the understanding of tortoise population trends and management needs.

In order to meet the objectives of this CCA, the Arizona Interagency Desert Tortoise Team (AIDTT) will manage, administer, and periodically review the implementation of species conservation outlined in the CCA. The AIDTT was formed in 1985 to coordinate research and management of Sonoran desert tortoise populations in Arizona. Co-chaired by representatives of AGFD and the Service, AIDTT cooperation is intended to: (1) ensure the perpetuation of the species and (2) prevent loss and improve quality of habitat in Arizona. As such, the AIDTT is uniquely qualified to manage and administer this program because its membership includes tortoise experts and land/resource managers from across the range of the Sonoran desert tortoise in Arizona.

Long-term management of tortoise populations and habitat, as outlined in the CCA, is an important contribution to the conservation of the Sonoran desert tortoise. The initial term of the CCA is 10 years. Thereafter, the Parties agree that the CCA will be extended for additional 5-year increments until long-term habitat and population conservation of the desert tortoise is achieved, as determined by the AIDTT.

4.8 Other Factors Considered

Because Sonoran desert tortoises are found so widely distributed, individual tortoises may be impacted by a wide variety of other stressors that were not discussed in detail in this SSA Report. We have evaluated these other stressors but not included discussion of them here because they are not thought to represent operative stressors on the species into the future. These other factors represent historical, but not future threats (e.g., conversion to agriculture), are not known to have measurable population level impacts (e.g., Upper Respiratory Tract Disease, Cutaneous Dyskeratosis, environmental contaminants, predation, grazing), are narrow in scope in context of the relatively wide range of the tortoise (e.g., off-highway vehicle use, trash, field research, undocumented human immigration), or some combination of the above.

Chapter 5: Current Conditions

In this chapter, we describe the current condition of the Sonoran desert tortoise through analysis of habitat distribution and population size across its range. We first review the historical information on the species' range. We then describe our geospatial analysis (see further explanation in Appendix B) that allows us to describe predicted potential habitat across the species' range. Using that information in addition to available data on stressors to the species, we then describe how we measured habitat quantity and quality throughout the species' range. We then describe how we used population densities and our habitat quality analysis to make estimates of population abundance for the U.S. and Mexico areas of analysis.

5.1 Current and Historic Range

The Sonoran desert tortoise occupies portions of western, northwestern, and southern Arizona in the United States, and the northern two-thirds of Sonora, Mexico. According to our GIS analysis, roughly 40% of the geographic range of the pure Sonoran desert tortoise genotype occurs in Mexico. The total area within the range of Sonoran desert tortoise in Arizona and Mexico is 65,938 sq mi (42 million ac, 17 million ha). This range includes 40,177 sq mi (26 million ac, 10 million ha) in the United States and 25,761 sq mi (16 million ac, 7 million ha) in Mexico.

The current range and distribution of the tortoise is largely the same as the historical range and distribution according to available data. In Arizona, no population extirpations or range reductions have been documented in the literature. Information on the historical versus current distribution of the tortoise in Mexico is less certain.

Note: Important terminology used in this SSA report.

Habitat Potential – predicted Sonoran desert tortoise habitat based solely on physical conditions (elevation, slope, and vegetation), measured as High, Medium, and Low.

Habitat Quality – predicted Sonoran desert tortoise habitat based on habitat potential plus additional factors that could be influencing habitat conditions such as stressors and land management, measured as Primary, Secondary, and Tertiary.

5.2 Habitat Quality Analysis: Arizona, U.S.

After generating our predicted potential habitat layer (see Chapter 3: Predicted Potential Habitat), we next classified the overall habitat quality of areas within the species range into three categories (primary, secondary, and tertiary) based on the potential habitat and the possibility for stressors to be present (Figure 20). Based on the outcome of our analysis of potential risk factors, we included factors in the habitat quality assessment that could have population-level effects to tortoises. We used four geospatial layers to capture those factors and quantify potential habitat conditions: land management, presence of nonnative vegetation, high fire risk potential, and proximity to urban areas. We used these four factors, representing possible stressors and conservation actions, to categorize all the areas within the species' range for the overall habitat quality identified as primary, secondary, or tertiary under two different alternatives (Figure 21). One assuming High Management and Low Threats, and a second alternative assuming Low Management and High Threats.

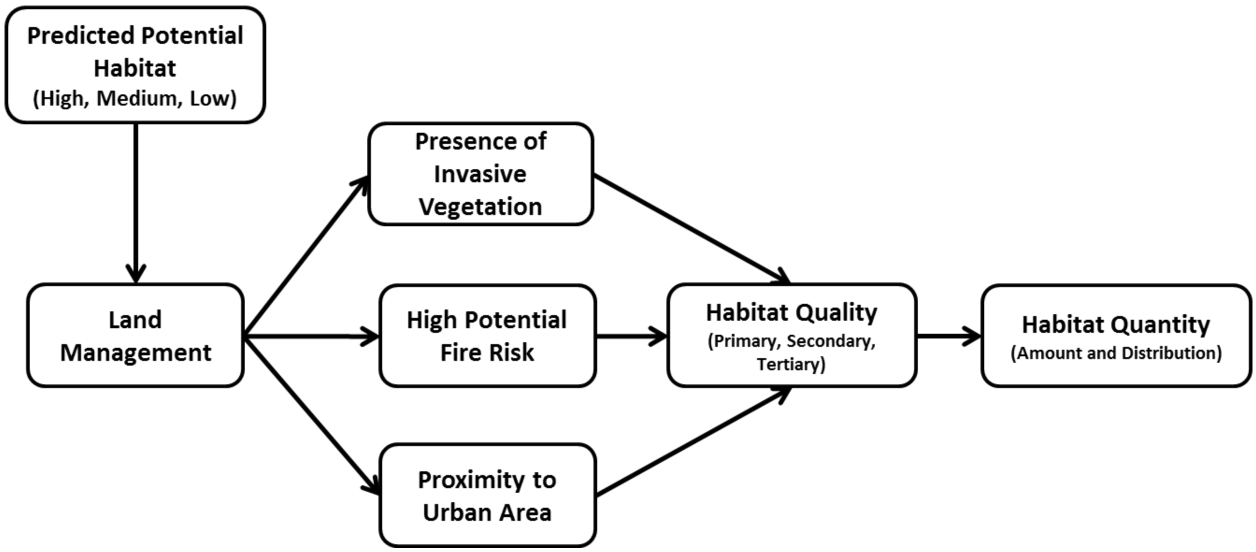


Figure 20. Conceptual diagram illustrating the factors we used to generate a measure of habitat quality and quantity for the Sonoran desert tortoise.

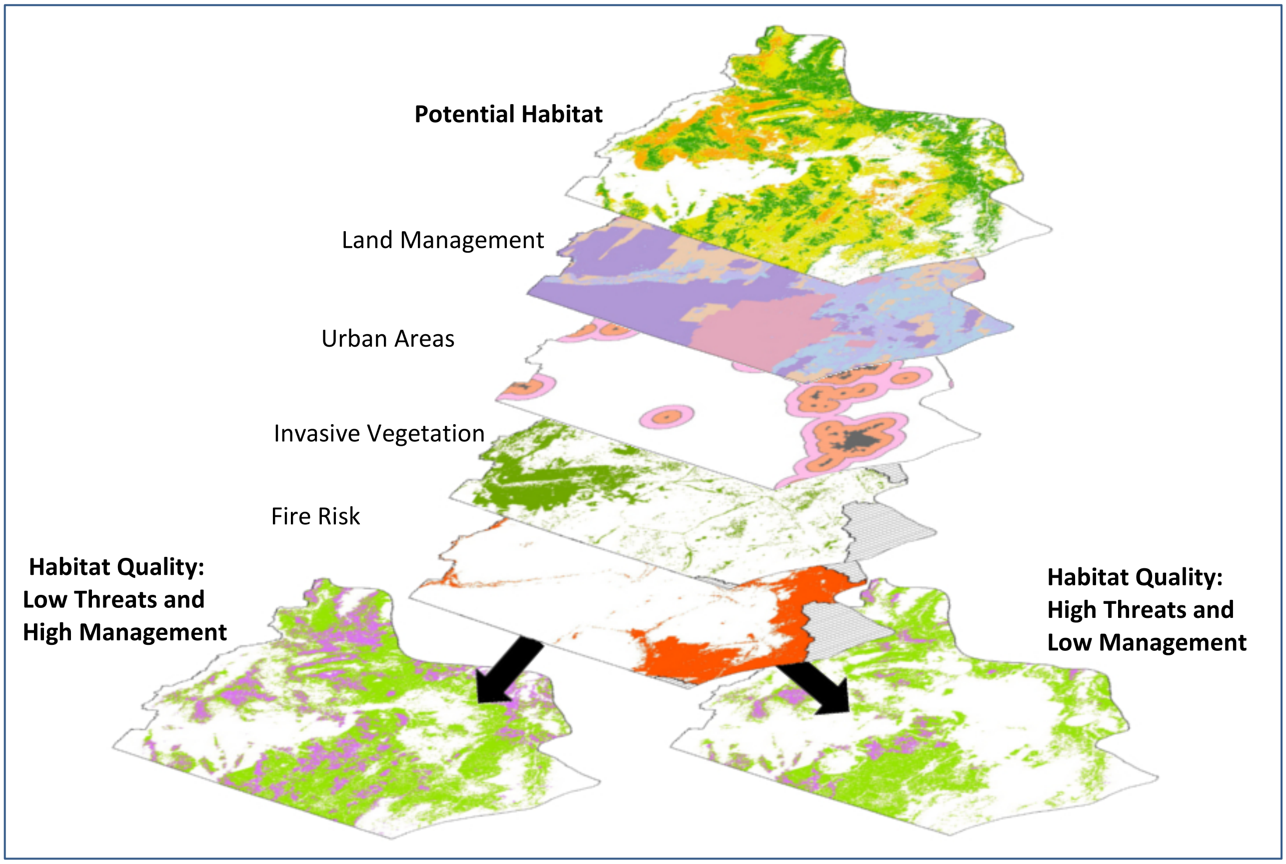


Figure 21. Visualization of the union of five spatial information layers to produce habitat quality maps under two alternatives of current conditions for the Sonoran desert tortoise.

5.2.1 Land Management

We assessed land management as an overall filter of habitat quality for the tortoise. We categorized land management into five categories (Table 2) based on land ownership (Managed, Multi-use, Tribal, Unprotected (Private), and Other (State)). See the GIS Report in Appendix B for an explanation of these categories. Those lands currently being "Managed" or protected for wildlife benefits that have high conservation value to the Sonoran desert tortoise and its habitat were considered to contribute most to habitat quality. We think that lands that are managed for wildlife benefits would reduce some potential stressors to the tortoise through actions including, but not limited to, limiting the spread of nonnative plants, controlling fire, minimizing interaction with humans, and limiting the alteration of the natural vegetation community and geological structures that form the basis of tortoise habitat needs. The areas identified as "Multi-use" include general conservation lands with at least an indirect benefit to wildlife and a moderate conservation value to the Sonoran desert tortoise. Tribal lands were treated the same as multi-use lands. "Unprotected" lands are primarily private lands with no indicated protection for wildlife or habitat, and "Other" lands are primary State of Arizona trust lands held for the purpose of generating funds. Using land management as a factor in characterizing habitat quality provides for a general measure of potential habitat conditions and management of stressors in a cumulative fashion. Spatial distribution of these land management assignments and the proportion of predicted potential habitats within each are provided in Figure 22 and Figure 23, respectively.

5.2.2 Nonnative Grasses

The potential effects of nonnative grasses were considered in our assessment of the current condition of tortoise habitat using a spatial distribution model that predicts the current occurrence of invasive vegetation (see Appendix B: GIS Analysis Report for a description of this spatial analysis using the BLM's REA SOD). We recognize that this spatial model predicts more than just the nonnative grasses that are of most concern for potential affects to the tortoise, so these data likely represent a larger and denser distribution of nonnative vegetation than may actually be of concern. This analysis also only predicts the presence or absence of invasive vegetation and not necessarily the density of the nonnative grasses of concern[11]. Because of the uncertainty related to the likelihood of population-level effects from nonnative grasses (see section 4.1 Altered Plant Communities (Nonnative Grasses)), we calculated the current conditions of tortoise habitat under conditions with and without consideration of the effects of nonnative grasses (Table 2).

5.2.3 Fire Risk

The potential effects of fire were considered in our assessment of the current condition of tortoise habitat using a spatial distribution model that estimates areas having high fire potential (see Appendix B: GIS Analysis Report) for a description of this spatial analysis using the REA SOD). These data identify areas with high probability of fire based on predictions of both human and naturally caused fire occurrence including landscape factors and the locations of fire occurrences. This assessment does not attempt to predict the outcome of any possible fire; however, it provides a useful estimate of where high potential for fire exists within the range of the tortoise. Because of the uncertainty related to the likelihood of population-level effects from fire (see section 4.2 Altered Fire Regime (Nonnative Grasses)), we calculated the current conditions of tortoise habitat under conditions with and without consideration of the effects of fire (Table 2).

[11] Note that these data from the REA SOD do not include about 6 percent of our tortoise habitat boundary.

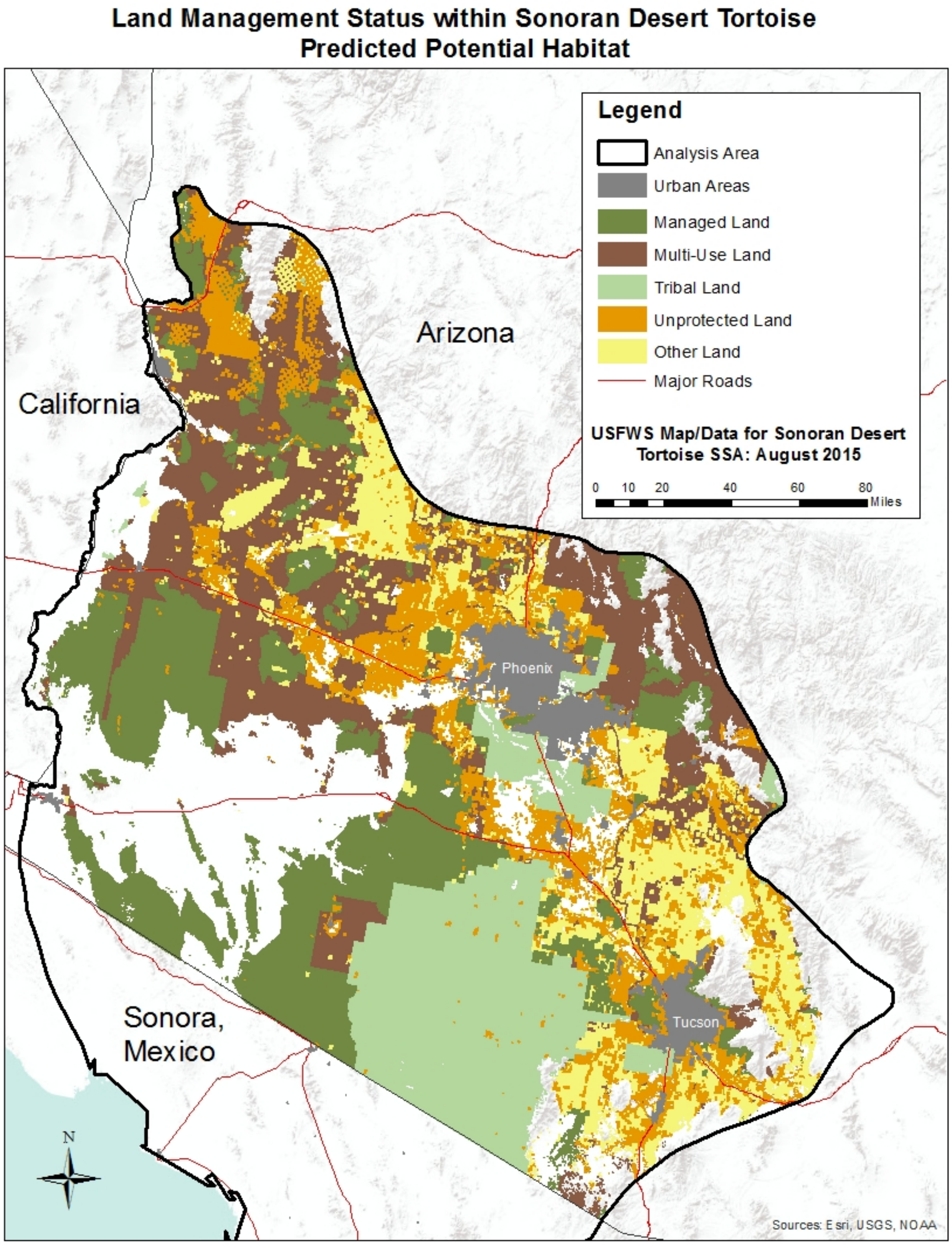


Figure 22. Land management protected status within predicted potential habitat for the Sonoran desert tortoise in Arizona (see Appendix B for definition of categories).

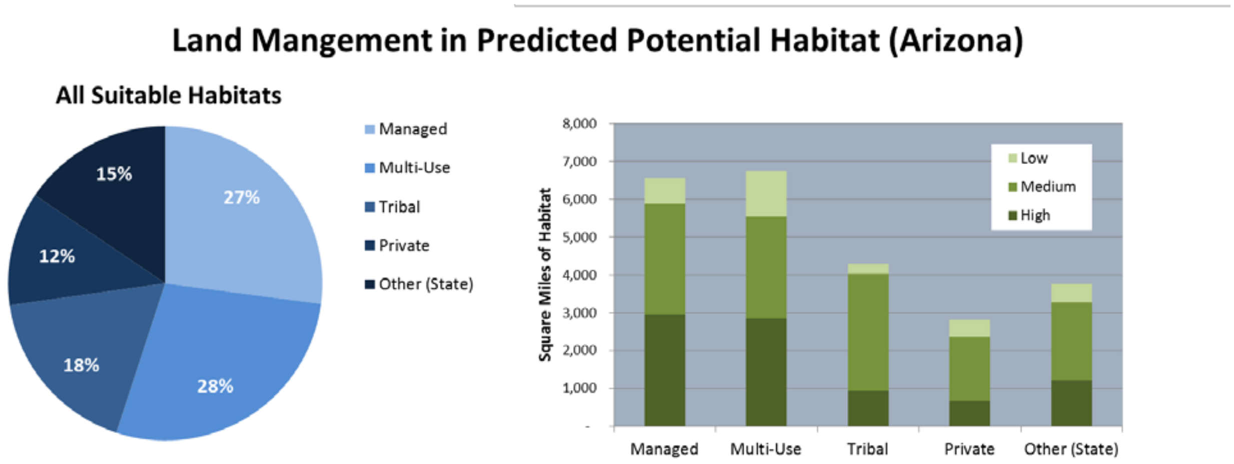


Figure 23. Proportion of predicted potential habitats categorized by land management.

5.2.4 Urban Influence

The potential effects of urban areas were considered in our assessment of the current condition of tortoise habitat by identifying areas nearby urban areas with at least 2,500 people (see Appendix B: GIS Analysis Report). We chose to use towns of at least 2,500 as a subjective threshold for the assessment based on our assumption that smaller towns with fewer people are less likely to have elevated impacts on tortoises due to a lesser opportunity of human interactions[12]. We calculated the amount of tortoise habitat within 6.2 and 12.4 mi (10 and 20 km) of cities of at least 2,500. Because of the uncertainty related to the likelihood of population-level effects from urban influences (see section 4.6 Human Interactions (Urban Influences)), we calculated the current conditions of tortoise habitat under conditions with possible effects within 6.2 mi (10 km) and within 12.4 (20 km) of a city (Table 2).

5.2.5 Summary: Current Condition of Habitat Quality and Quantity in Arizona

We quantified the overall current condition of tortoise habitat within the three habitat quality categories (primary, secondary, and tertiary) under two different assumptions[13] about the status of the habitat (Table 2). The first assumption was that there will be extensive (high) conservation management actions for the tortoise and that the potential for impacts from nonnative grasses, fire, and urban influences is relatively low (Table 2: **High Management and Low Threats**). Under this assumption we included as primary quality habitat all areas with high potential habitat that are under either managed, multi-use, or Tribal management and occur more than 6.2 mi (10 km) from a city. No adjustments were made for invasive vegetation or fire

[12] Zylstra *et al*. (2013, p. 110) provides the basis for consideration of this potential effect, however, they do not report the size of the city that they refer to in their study, only the "nearest incorporated city." So presumably they did not use a minimum in their analysis, but we thought very small towns with few people would have a more limited potential impact on tortoises.
[13] Note that in our viability analysis (Chapter 6) under different scenarios, these current conditions provide a basis for the four scenarios under current conditions. The first assumption here is reflected in scenarios Ac and Bc, and the second assumption here is reflected in scenarios Cc and Dc in the viability analysis.

concerns. The remaining high potential habitat was categorized as secondary habitat quality. All medium potential habitat was categorized as secondary habitat quality, and all low potential habitat was categorized as tertiary habitat quality. This analysis resulted in an estimated 6,090 sq mi (3.9 million ac, 1.6 million ha) of primary quality habitat (25%), 15,010 sq mi (9.6 million ac, 3.9 million ha) of secondary quality habitat (62%), and 3,100 sq mi (2.0 million ac, 803,000 ha) of tertiary quality habitat (13%) (Table 2). The spatial distributions of the primary and secondary quality habitats under this assumption are depicted in Figure 24.

The second assumption was that there will be lower conservation management actions for the tortoise and that the potential for impacts from nonnative grasses, fire, and urban influences is higher (Table 2: **Low Management and High Threats**). Under this assumption we included as primary quality habitat areas with all of the following conditions: high habitat potential, Managed lands, no invasive species, no high potential for fire risk, and beyond 12.4 mi (20 km) from a city. The remaining high potential habitat was categorized as secondary habitat quality. We also included as secondary quality habitat areas with all of the following conditions: medium potential habitat; Managed, Multi-use, or Tribal lands; no invasive species or no data; no high potential for fire risk or no data; and beyond 6.2 mi (10 km) from a city. The remaining medium potential habitat was categorized as tertiary habitat quality. All low potential habitat was also categorized as tertiary habitat quality. This analysis resulted in an estimated 1,820 sq mi (1.1 million ac, 471,000 ha) of primary quality habitat (8%), 15,870 sq mi (10 million ac, 4.1 million ha) of secondary quality habitat (75%), and 4,100 sq mi (2.6 million ac, 1.1 million ha) of tertiary quality habitat (17%) (Table 2). The spatial distributions of the primary and secondary quality habitats under this assumption are depicted in Figure 25.

We recognize that these habitat categories are only models of possible habitat conditions based on largely untested assumptions. For example, there has been no ground-truth effort or verification of this application of information. However, we think it represents a reasonable approach to estimating both quantitatively and spatially the potential habitat conditions for the Sonoran desert tortoise based on the best available information.

Table 2. Summary of habitat quality categories in Arizona, US, using spatial layers under two sets of current conditions.

Tortoise Habitat, Arizona, U.S.		Current Condition High Management and Low Threats Overall Habitat Quality				Current Condition Low Mangement and High Threats Overall Habitat Quality				
Spatial Layers	**Categories**	**Primary**	**Secondary**		**Tertiary**	**Primary**	**Secondary**		**Tertiary**	
Base: Habitat Suitability	a. High b. Medium c. Low	High	High	Med	Low	High	High	Med	Med	Low
1. Land Management	a. Managed b. Multi-use c. Tribal d. Unprotected (Private) e. Other (State)	a,b,c	d,e	all	all	a	b,c,d,e	a,b,c	d,e	all
2. Invasive Vegetation	a. Absent b. Present c. No data (6%)	all	all	all	all	a	b,c	a,c	b	all
3. Fire Risk	a. Not High Fire Potential b. High Fire Potential c. No data (6%)	all	all	all	all	a	b,c	a,c	b	all
4. Urban Influence – Distance	a. >20 km from >2,500 city b. 10-20 km from city c. 0-10 km from city	a,b	c	all	all	a	b,c	a,b	c	all
	Habitat Area (mi^2)	6,089	2,536	12,470	3,100	1,820	6,801	11,422	1,048	3,100
	Total Habitat (mi^2)	**6,090**	**15,010**		**3,100**	**1,820**	**18,270**		**4,100**	
	Percent of Total Habitat	**25%**	**62%**		**13%**	**8%**	**75%**		**17%**	

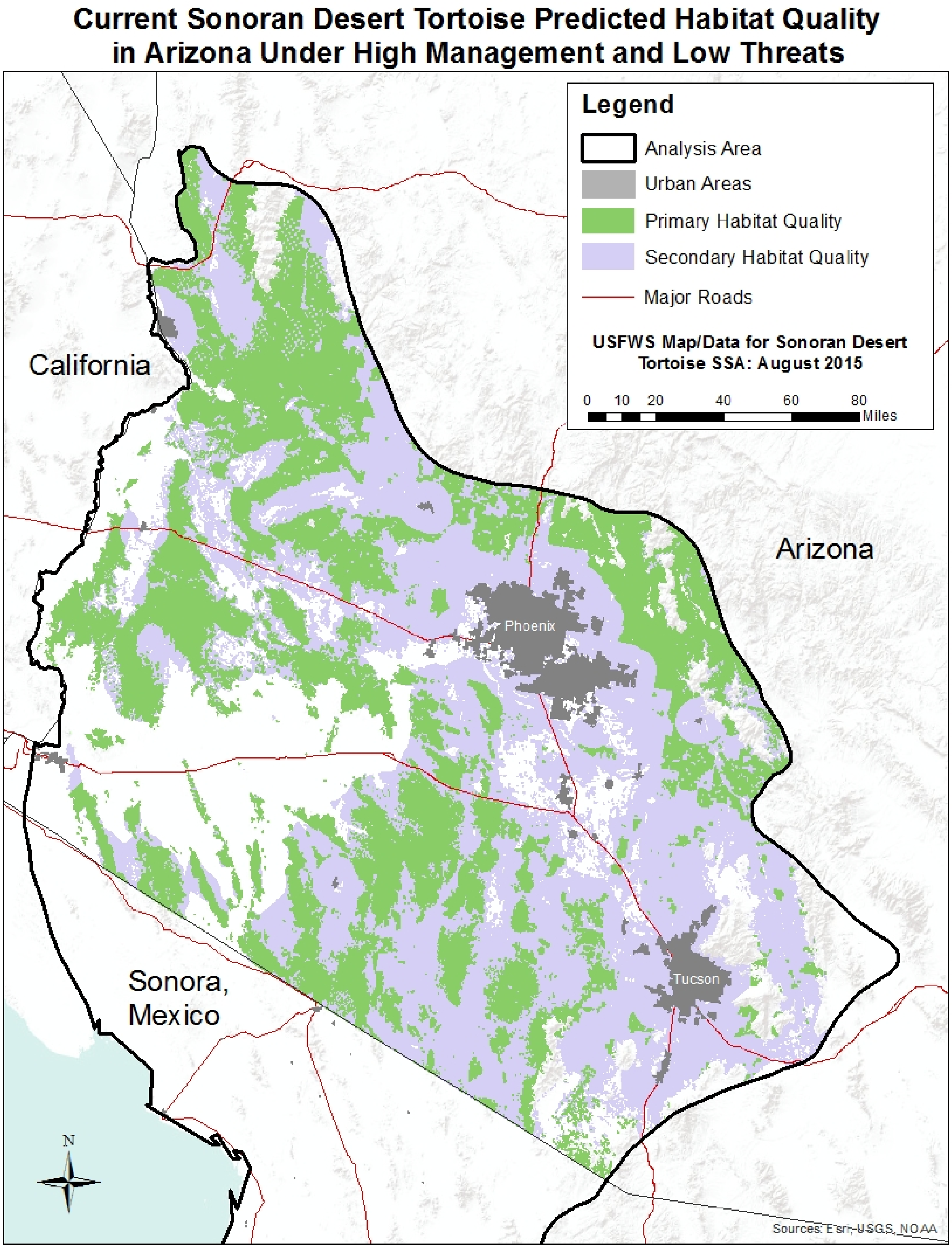


Figure 24. Distribution of estimated primary and secondary habitat quality for the Sonoran desert tortoise in Arizona under High Management and Low Threats assumption.

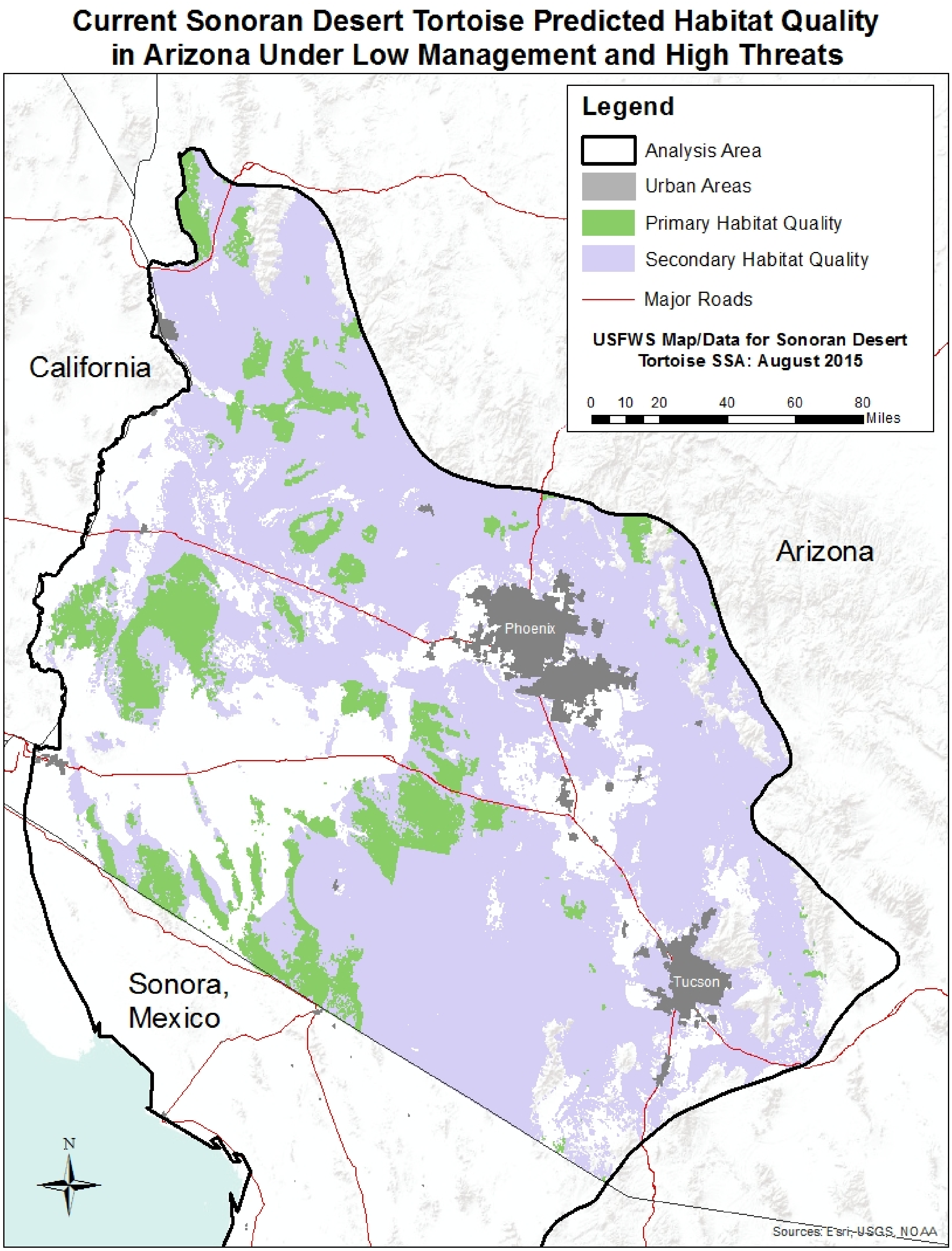


Figure 25. Distribution of estimated primary and secondary habitat quality for the Sonoran desert tortoise in Arizona under Low Management and High Threats assumption.

5.3 Habitat Quality Analysis: Sonora, MX

We followed the same basic approach for categorizing habitat in Sonora, Mexico; however, the information available and the conditions in Mexico are somewhat different. We used the same concept to categorize predicted potential habitat quality as primary, secondary, or tertiary considering the same four factors as we did in Arizona (Figure 20 and Figure 21).

5.3.1 Land Management

In Mexico, there are a few areas that are under some level of government conservation management, and we assumed there would be some benefits to the tortoise in these areas (Figure 26). We calculated that about 566 sq mi (362,000 ac, 147,000 ha) of predicted potential habitat in Sonora, about 4% of the total in Sonora, is within these protected areas. Although other non-governmental lands may be managed in such a way as to provide benefits to the Sonoran desert tortoise and its habitats, we did not have information to further distinguish land management in Mexico.

5.3.2 Nonnative Grasses & Fire Risk

There is not sufficient information available to model potential risks associated with nonnative grasses and fire in Sonora. However, as described in Section 4.1 above, we assume that the areas most susceptible to effects of nonnative grasses and fire are those areas within the Plains of Sonora at lower slopes because these areas are most likely to experience continued cultivation of buffelgrass (Figure 11). Overall about 2,800 sq mi (1.8 million ac, 725,000 ha), about 20% of the potential habitat in Sonora, of all predicted potential habitat is within the Plains of Sonora with low slopes.

5.3.3 Urban Influence

Consistent with the analysis in Arizona, we considered the potential effects of urban areas in Sonora. We calculated the amount of tortoise habitat within 6.2 and 12.4 mi (10 and 20 km) of cities of at least 2,500 (Figure 18). Because of the uncertainty related to the likelihood of population-level effects from urban influences (see Chapter 4), we calculated the current conditions of tortoise habitat under conditions with potential effects within 6.2 mi (10 km) and within 12.4 mi (20 km) of a city (Table 3).

5.3.4 Summary: Current Condition of Habitat Quality and Quantity in Sonora

Consistent with the analysis for Arizona, we quantified the overall current condition of tortoise habitat within the three habitat quality categories (primary, secondary, and tertiary) under two different assumptions[14] about the state of the habitat (Table 3). The first assumption was that there will be high conservation management actions for the tortoise and that the potential for impacts from nonnative grasses, fire, and urban influences is relatively low (Table 3: **High**

[14] Note that in our viability analysis (Chapter 6) under different scenarios, these current conditions provide a basis for the four scenarios under current conditions. The first assumption here is reflected in scenarios Ac and Bc, and the second assumption here is reflected in scenarios Cc and Dc in the viability analysis.

Management and Low Threats). Under this assumption, we included as primary quality habitat all areas with high habitat potential that are protected areas and occur more than 6.2 mi (10 km) from a city. No adjustments were made for invasive vegetation or fire concerns. The remaining high potential habitat was categorized as secondary habitat quality. All medium potential habitat was categorized as secondary habitat quality, and all low potential habitat was categorized as tertiary habitat quality. This analysis resulted in an estimated 330 sq mi (211,000 ac, 85,000 ha) of primary quality habitat (2% of potential habitat in Mexico), 13,400 sq mi (8.6 million ac, 3.5 million ha) of secondary quality habitat (98%), and 30 sq mi (19,000 ac, 8,000 ha) of tertiary quality habitat (0.2%) (Table 3). The spatial distributions of the primary and secondary quality habitats under this assumption are depicted in Figure 27.

The second assumption was that there will be lower conservation management actions for the tortoise and that the potential for impacts from nonnative grasses, fire, and urban influences is higher (Table 3: **Low Management and High Threats**). Under this assumption we included no areas as primary quality habitat because of the uncertainty related to benefits related to protected lands, so all high potential habitat was categorized as secondary habitat quality. We also included as secondary habitat quality areas with all of the following characteristics: medium habitat potential, any land protection status, no nonnative grasses or fire risk, and beyond 6.2 mi (10 km) from a city. The remaining medium potential habitat was categorized as tertiary habitat quality. All low potential habitat was also categorized as tertiary habitat quality. This analysis resulted in no primary quality habitat, 10,550 sq mi (6.8 million ac, 2.7 million ha) of secondary quality habitat (79% of potential habitat in Mexico), and 3,210 sq mi (2.0 million ac, 831,000 ha) of tertiary quality habitat (21%) (Table 3). The spatial distributions of the primary and secondary quality habitats under this assumption are depicted in Figure 28.

We recognize that these habitat categories are only models of possible habitat conditions based on largely untested assumptions. For example, there has been no ground-truth effort or verification of this application of information. However, we think it represents a reasonable approach to estimating both quantitatively and spatially the potential habitat conditions for the Sonoran desert tortoise based on the best available information.

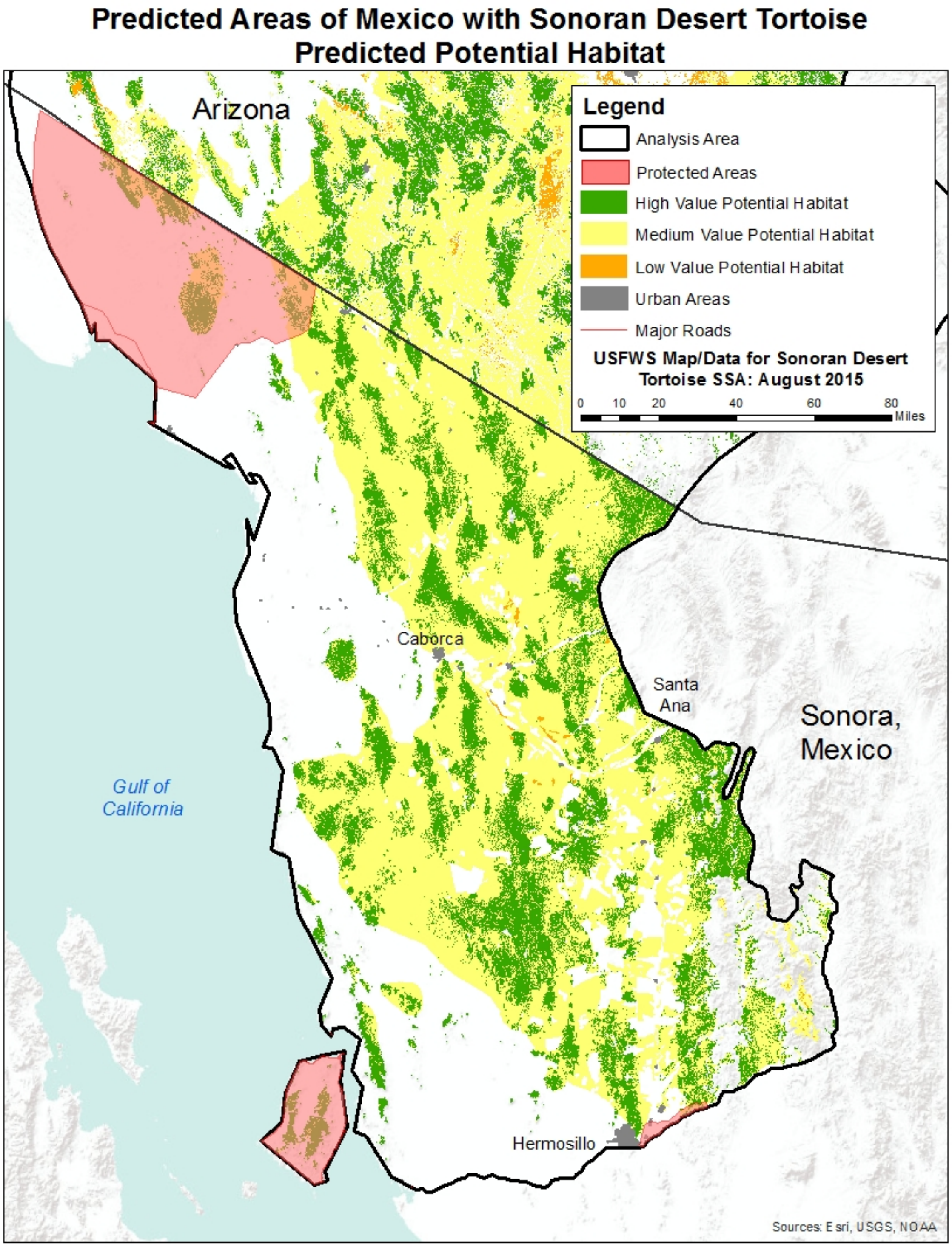


Figure 26. Location of Mexican protected areas with predicted potential Sonoran desert tortoise habitat in Sonora, Mexico.

Table 3. Summary of habitat quality categories in Sonora, MX, using spatial layers under two sets of current conditions.

Tortoise Habitat, Sonora, MX		Current & Future Conditions High Mgt and Low Threats				Current & Future Conditions Low Mgt and High Threats				
		Overall Habitat Quality				Overall Habitat Quality				
SPATIAL LAYERS	**POSSIBLE STATES**	**Primary**	**Secondary**		**Tertiary**	**Primary**	**Secondary**		**Tertiary**	
Base: Habitat Suitability	a. High b. Medium C. Low	High	High	Med	Low	High	High	Med	Med	Low
1. Land Management	a. Protected b. Unprotected	a	b	a	a	--	a	all	all	all
2. Fire and Invasive Veg Risk	a. Absent b. Present	all	all	all	all	--	all	a	b	all
3. Urban Influence – Distance	a. >20 km from >2,500 city b. 10-20 km from city C. 0-10 km from city	a,b	all	all	all	--	all	a,b	c	all
	Habitat Area (mi^2)	332	4,028	9,380	30	-	4,350	6,198	3,179	30
	Total Habitat (mi^2)	**330**	**13,400**		**30**	**-**	**10,550**		**3,210**	
	Percent of Total Habitat	2%	98%		0%	0%	79%		21%	

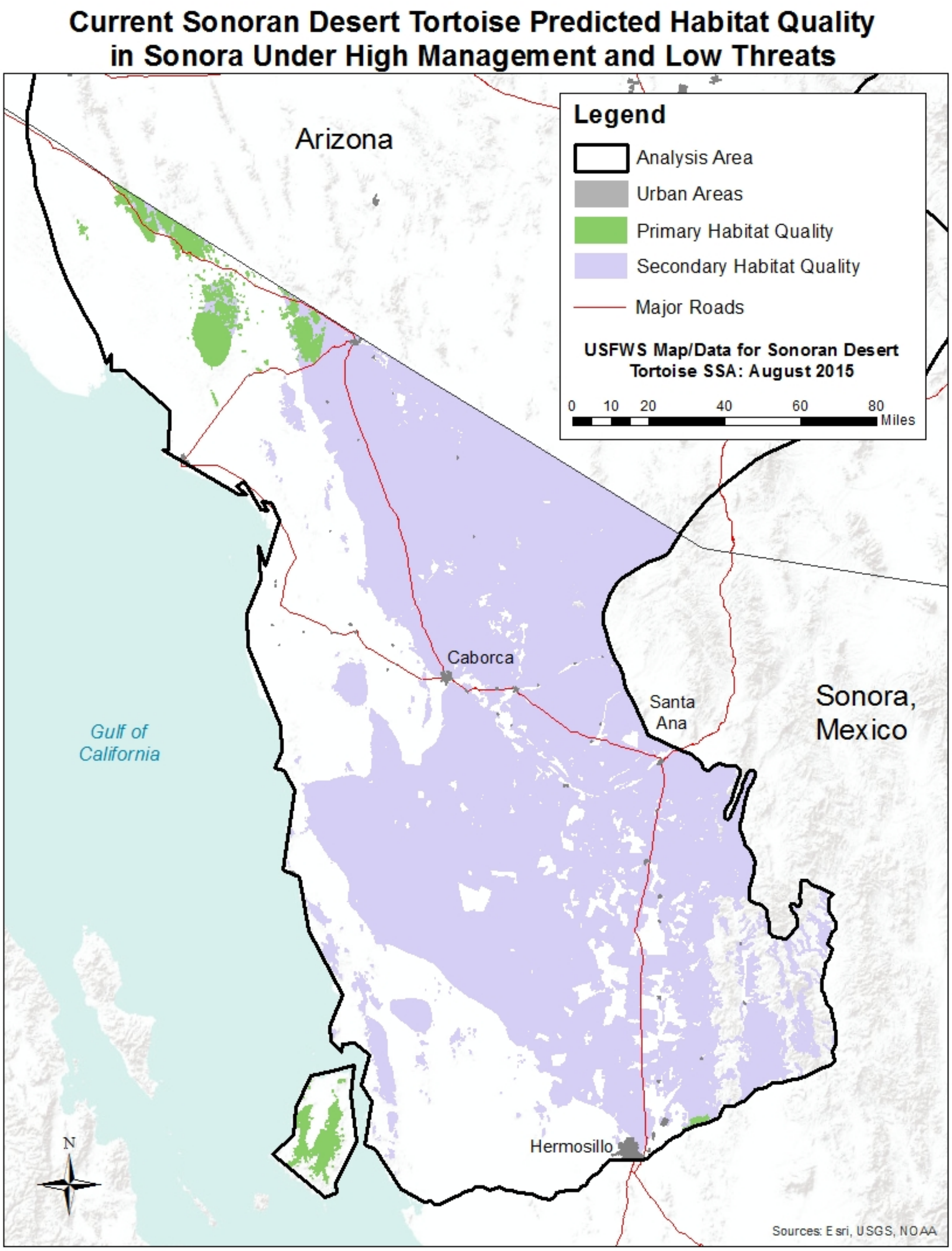


Figure 27. Distribution of estimated primary and secondary habitat quality for the Sonoran desert tortoise in Sonora under High Management and Low Threats assumption.

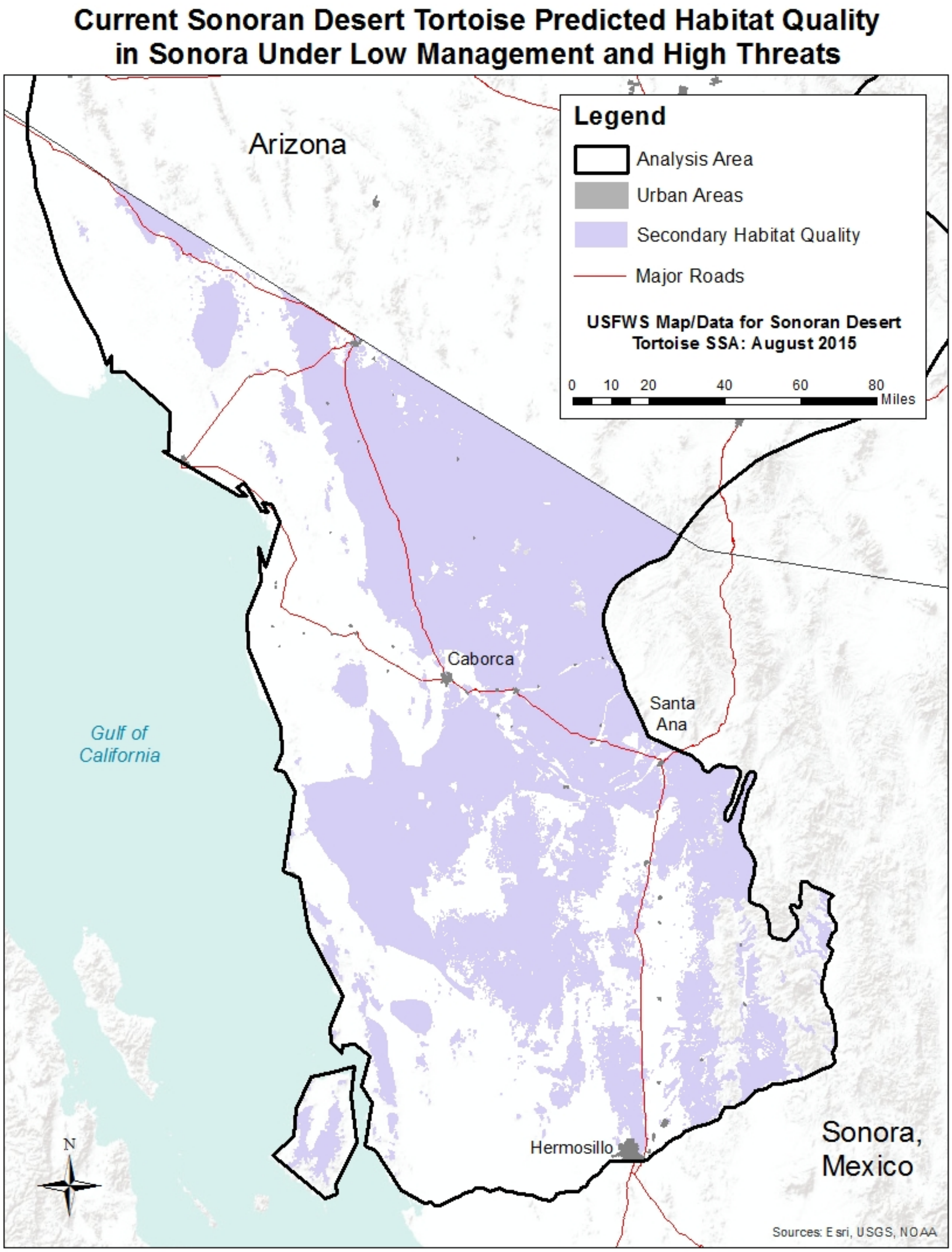


Figure 28. Distribution of estimated primary (none) and secondary habitat quality for the Sonoran desert tortoise in Arizona under Low Management and High Threats assumption.

5.4 Abundance Estimates

To further assess the current condition of the Sonoran desert tortoise we used our habitat quality and quantity summaries to calculate a rough estimate of the potential tortoise population sizes in Arizona and Sonora. To do this we extrapolated reported population density estimates in high and low quality habitats to our habitat categories (Figure 29), in other words we multiplied density estimates by the amount of area in each habitat quality category.

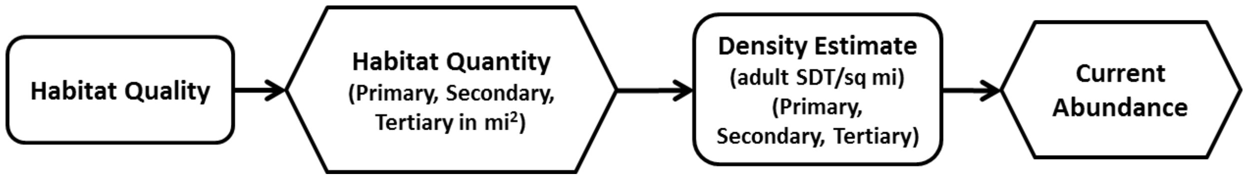


Figure 29. Conceptual model showing the process to estimate current abundance for the Sonoran desert tortoise.

We estimated the adult density of tortoises in primary (highest quality) habitats by using the mean estimate of tortoise densities at 16 long-term monitoring plots as reported by Zylstra and Steidl (2009, p. 43). All of these 16 monitoring plots are within areas we categorized as high potential habitat. The results were an estimate of 43.3 adults per square mile (Table 4). This density estimate has a large amount of variability (density estimates at specific sites range from 6.4 to 145.2 adult tortoises per square mile), but the mean represents the best available information for this estimate. For tertiary (lower) quality habitats we used an estimate of 5.2 adults per square mile based on research in low quality habitat surveyed in 2001 on the Ironwood Forest National Monument (Averill-Murray and Averill-Murray 2005, p. 69). We then estimated densities of 24.3 adults per square mile in secondary (medium) quality habitats as an intermediate approximation between the densities in primary and tertiary habitats. We used the same density estimates for Arizona and Mexico.

Key Assumption: Using Zylstra and Steidl (2009, p. 43) as our basis for the densities of Sonoran desert tortoises in our designation of primary quality habitats is a noteworthy assumption that is foundational to the rest of the analysis. Approximating related densities in secondary and tertiary quality habitats is another important assumption. Finally, extrapolating rangewide population estimates from these reported and approximated densities is a further extension of these assumptions. We recognize the limitations of these analyses, but we think they represent a helpful application of the best available information to the biological status of the Sonoran desert tortoise. We account for some of the uncertainties in this approach through the use of a range of scenarios and reporting of the confidence intervals in the results of the population model.

There is a large amount of uncertainty associated with these estimates, so we also calculated current population estimates under a range of assumptions (Table 5). We used a High and Low density estimate for each category of habitat quality. The densities presented above serve as the High density estimates. For the Low density estimate for primary quality habitat, we used the median of the long-term monitoring density data in primary quality habitat (25.2); for tertiary quality habitat, we used 50% of the estimate in tertiary quality habitat (2.6); and for secondary quality habitat, we used a midpoint between the estimates for primary and tertiary quality habitats (13.9) (see Table 5). When population densities are then summed across the three habitat quality categories, this approach resulted in four overall rangewide current population estimates ranging from 470,000 to 970,000 adult tortoises (Table 5).

Table 4. Density estimates at long-term plots in Arizona that were surveyed at least twice for desert tortoises between 1996 and 2006. Adapted from Zylstra and Steidl (2009, p. 43).

Monitoring Plot	adults/sq mi
Arrastra Mountains	25.2
Bonanza Wash	15.9
Buck Mountains	16.1
Eagletail Mountains	29.0
East Bajada	7.6
Granite Hills	57.5
Harcuvar Mountains	48.7
Harquahala Mountains	6.4
Hualapai Foothills	18.1
Little Shipp Wash	68.2
Maricopa Mountains	23.6
New Water Mountains	24.2
San Pedro Valley	39.4
Tortilla Mountains	145.2
West Silverbell Mountains	123.9
Wickenburg Mountains	36.7
Mean	**43.3**
Median	**25.2**
Sample Size	16

Table 5. Population estimates for the Sonoran desert tortoise in Arizona, Mexico, and rangewide, rounded to the nearest 10,000. Density is the estimated number of adult tortoises per square mile in each of the three Habitat Quality categories. Habitat Area is the total amount of calculated areas, in square miles, of habitat within the three Habitat Quality categories. Pop Est is the estimated tortoise abundance, which is the product of Density and Habitat.

Abundance Estimates			Quality Habitat: High Mgt & Low Threats			Quality Habitat: Low Mgt & High Threats		
Habitat Quality	Mean Density (adult/mi²)	Median Density (adult/mi²)	*Habitat Area (mi²)*	High Pop Est (adults)	Low Pop Est (adults)	*Habitat Area (mi²)*	High Pop Est (adults)	Low Pop Est (adults)
			ARIZONA, U.S.					
Primary	**43.3**	**25.2**	*6,090*	**263,697**	***153,468***	*1,820*	**78,806**	***45,864***
Secondary	**24.3**	**13.9**	*15,010*	**363,993**	***208,639***	*18,220*	**441,835**	***253,258***
Tertiary	**5.2**	**2.6**	*3,100*	**16,120**	***8,060***	*4,150*	**21,580**	***10,790***
US Total			*24,200*	**640,000**	**370,000**	*24,190*	**540,000**	***310,000***
			SONORA, MX					
Primary	**43.3**	**25.2**	-	-	***0***	-	-	***0***
Secondary	**24.3**	**13.9**	*13,730*	**332,953**	***190,847***	*10,900*	**264,325**	***151,510***
Tertiary	**5.2**	**2.6**	*30*	**156**	***78***	*2,860*	**14,872**	***7,436***
MX Totals			*13,760*	**330,000**	***190,000***	*13,760*	**280,000**	***160,000***
			RANGEWIDE					
Rangewide Totals			*37,960*	**970,000**	***560,000***	*37,950*	**820,000**	***470,000***

Chapter 6: Future Conditions and Viability

We have reviewed the ecological needs of the Sonoran desert tortoise, the current conditions of the species, and the risk factors and conservation actions that drive the condition of the species. We next turn to evaluating the potential future condition of the species to assess its viability. Because of the complexity of potential factors and the large range of the Sonoran desert tortoise, we developed several quantitative tools to assist us in characterizing the future habitat conditions and species responses in order to evaluate a range of plausible future scenarios. We used our spatial analysis of current conditions (habitat quantity and quality based on scope of potential stressors) in developing scenarios of future environmental conditions to forecast the risk of extinction of the species over time using a simulation model. This analysis informs our characterization of the future viability of the Sonoran desert tortoise.

6.1 Stochastic Simulation Model

The purpose of the stochastic simulation model is to use the relationship of potential environmental conditions (habitat quality and quantity) and species abundance to project the future risk of extinction of the Sonoran desert tortoise. After considering the potential causes and effects of stressors as they relate to quantity and quality of habitat and the possible impacts on vital rates, we constructed a simulation model with the following key parameters as inputs (described below): habitat quantity and quality, extent of drought, starting abundance (or population size), maximum abundance, and vital rates. The model outputs are median abundance, population growth rate, and the probability of quasi-extinction (Figure 30). We ran the model under a range of different scenarios representing key areas of uncertainty in the analysis. Below is a brief discussion of the model parameters. A more detailed explanation about how the simulation model incorporates these parameters is provided in Appendix D: Stochastic Simulation Model Report.

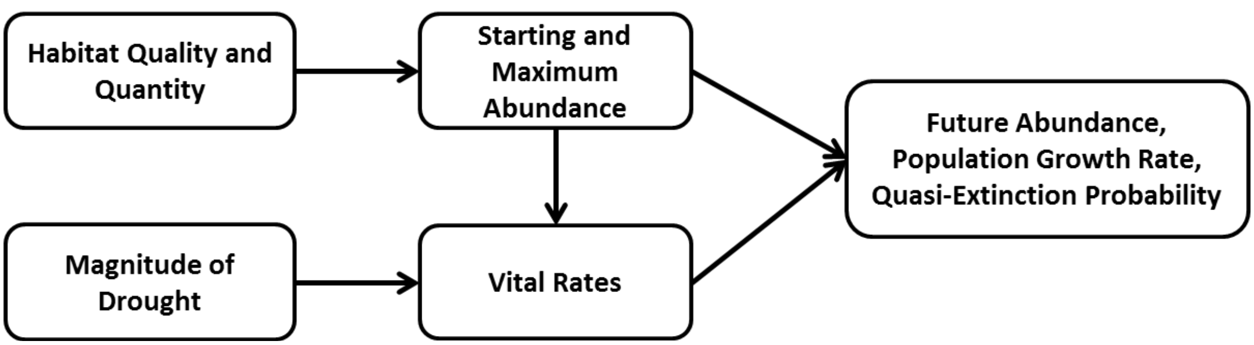


Figure 30. Overview diagram of the stochastic simulation model for the Sonoran desert tortoise. Inputs to the model included habitat quality and quantity and magnitude of drought. Habitat determined the starting and maximum abundance which influences vital rates, as does the magnitude of drought. The output of the model includes future abundance, population growth rate and quasi-extinction probability.

How does the simulation model work? Essentially the population simulation model takes a given starting abundance (estimated number of female tortoises) and calculates the future abundance over time by applying reproductive and survival rates (i.e., vital rates). These vital rates are the proportion of the total tortoises in a population that are surviving, being adding to the population through reproduction, or being removed from the population each year. For example, an adult survival rate of 0.9 means 90% of the adult tortoises are surviving from one year to the next and 10% are dying. By calculating the number of tortoises being added to the population through reproduction and taken away from the population through death each year, it allows us to project the change in the abundance of tortoises over time based on those vital rates. Because there is natural variation in reproduction and survival rates, as well as uncertainty about those rates, the vital rates are not single set numbers but are a range based on our understanding of the species.

The computer runs the model 1,000 times, and in each model run, or replicate, randomly selects different annual vital rates within the given ranges. Therefore, the model results will vary between replicates based on which vital rates were randomly selected.

Each model replicate calculates the annual abundance of tortoises for each year for 200 years into the future, and we can use the median abundance of these 1,000 replicates as our estimate of the future abundance of the tortoise. The change in the median abundance estimates over time results in a population growth rate, where 1.0 is stable (no change in abundance), less than 1.0 is declining, and greater than 1.0 is increasing. With 1,000 replicates of annual population growth rate we can calculate the average annual population growth rate.

Because of the variation and an uncertainty in survival and reproductive rates, some of the abundance projections of those 1,000 replicates of the model will fall below a quasi-extinction level. The quasi-extinction level is a threshold number of individuals that we established prior to the analysis. When the simulated abundance of a replicate drops below this threshold, we consider that replicate to be extinct. For example, if the population abundance falls below the quasi-extinction level in 10 of the 1,000 replicates over 100 years, then the quasi-extinction probability is 0.01 or 1% in 100 years. We ran the model independently for different scenarios (9 in the US and 9 in Mexico) and each scenario is replicated 1,000 times to produce the model results.

6.1.1 Habitat quantity and quality (Input)

We determined the starting habitat quantity and quality for the simulation model using the three categories of overall habitat quality within the species range (primary, secondary, and tertiary) based on the habitat potential and possibility for effects of stressors. More specifically, the habitat quality was determined by considering a combination of overall habitat potential (based on vegetation, elevation, and slope) (see Chapter 3: Predicted Potential Habitat) and the conditions of the habitat (based on land management, presence of invasive vegetation, high fire risk potential, and the proximity to urban areas) (see Chapter 5: Current Conditions). Habitat quality and quantity were used in calculating both starting abundance sizes and annual population ceiling (carrying capacity) (Figure 31).

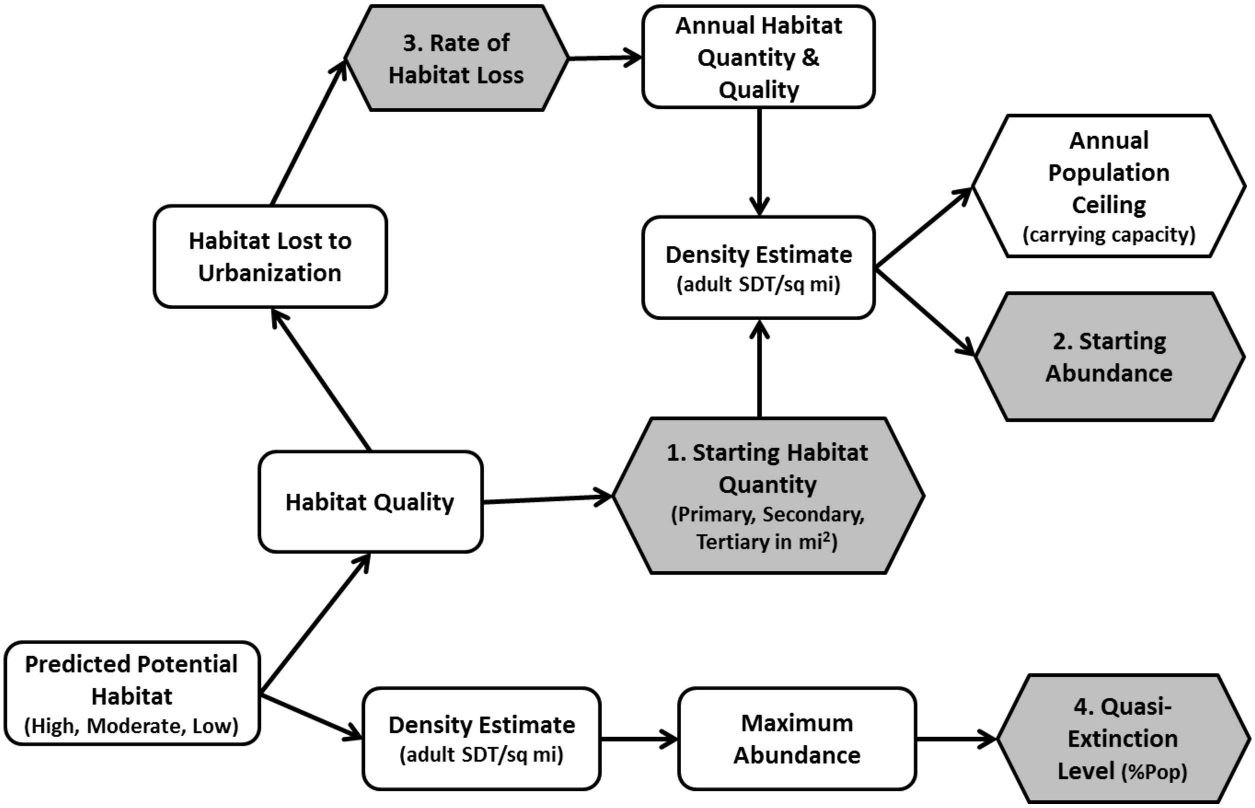


Figure 31. Derived inputs (shaded boxes) of the stochastic simulation model for the Sonoran desert tortoise.

6.1.2 Starting and Maximum Abundance (Input)

We used our density estimates of adult tortoises in the different habitat qualities (see section 5.4 Abundance Estimates) to derive the starting abundance (or population size), maximum abundance (which represents the carrying capacity or population ceiling for the model), and quasi-extinction level (see below) (Figure 31). For the starting abundance for the model simulations we multiplied the estimated habitat area of each of the three habitat quality categories by the population density estimates in those categories. However, the model uses half of this total number, as it is a female-only model and assumes a sex ratio of 1:1 (see Appendix D: Stochastic Simulation Model Report). For this evaluation, we assume the species is at carrying capacity[15] at the outset of the model and this population estimate serves as a ceiling or carrying capacity to limit overall population growth in the simulation for scenarios not involving future loss of habitats due to urbanization. For evaluating different scenarios we used mean (average)

[15] We recognize that it is an important assumption that the species is currently at carrying capacity based on the density of individuals in different levels of habitat quality. This is a conservative approach which limits the potential for future growth of the population. We do not have any relevant information that would better inform a different assumption.

estimated levels of population density as the "High" population estimate (see section 5.4 Abundance Estimates). As a conservative estimate for other scenarios we used these median (numerical mid-point) density estimates as a "Low" population estimate. The estimates for these low scenarios allow us to recognize and account for the large uncertainty associated with these density estimates. We rounded all of these estimates to the nearest 10,000 tortoises.

6.1.3 Rate of Habitat Loss and Degradation (Input)

For future scenarios in Arizona where we considered a potential future loss of overall habitat due to urban development, we calculated an annual rate of habitat loss in each habitat quality category. We determined this rate using a spatial analysis joining our habitat areas within areas in Unprotected (Private) or Other (State) categories with areas around urban centers that have potential for urban development (see Appendix B: GIS Analysis Report). We assumed this amount of habitat could be lost over a period of about 60 years[16]. Using this method, the overall loss of potential habitat was about 9%. We calculated the annual rate of habitat loss in each category and the model recalculated a new population ceiling annually for the scenarios involving habitat loss.

In addition, for the future habitat conditions under low management and high threat scenarios, we also applied a 10% habitat degradation factor[17] for the 60-year period (Table 6). That is, we assumed that risks from nonnative grasses and fire may continue to spread and further degrade habitat conditions in the future. This factor was then extrapolated over the 200-year timeframe in the simulation model based on an annual rate of habitat change.

We did not project future habitat loss from urbanization or additional habitat degradation in Mexico because we had little information from which to draw such projections and also because urban expansion is unlikely to be a measurable contributor to potential habitat loss in this part of Mexico.

[16] The urban projection map from which this habitat loss estimate was derived was published in 2008 as a possible 2040 projection. This estimate was done at the height of the economic expansion during the mid-2000's so we decided it would be unreasonable and over-estimating potential growth to use that urban growth projection as a 2040 estimate. We instead subjectively chose this projection to represent a potential future 60 years from the present.

[17] This habitat degradation factor was a professional judgment about the scale of the potential for increasing risks for nonnative grasses and fire concerns. While the spatial expansion of nonnative grasses could exceed a 10% increase in 60 years, the overall level of habitat degradation is presumed to be on that scale (keeping in mind that the analysis of habitat conditions has already accounted for a 9% habitat loss and existing degradation of all areas at high risk of fire).

Table 6. Summary of habitat quality categories in Arizona, U.S., using spatial layers under two sets of future conditions.

Tortoise Habitat, Arizona, U.S.		Future Conditions Urban Growth, High Management and Low Threats Overall Habitat Quality				Future Conditions Urban Growth, Low Management and High Threats Overall Habitat Quality					
LAYERS	**POSSIBLE STATES**	**Primary**	**Secondary**		**Tertiary**	**Primary**	**Secondary**		**Tertiary**		
Base: Habitat Suitability	a. High b. Medium c. Low	HIGH	HIGH	MED	LOW	HIGH	HIGH	MED	HIGH	MED	LOW
Urban Growth Potential	a. Existing b. Full Conversion	b	b	b	b	b	b	b	b	b	b
1. Land Management	a. Managed b. Multi-use c. Tribal d. Unprotected (Private) e. Other (State)	a,b,c	d,e	all	all	a	b,c,d,e	a,b	all	all	all
2. Invasive Vegetation	a. Absent b. Present c. No data (6%)	all	all	all	all	a	b,c	a	all	b,c	all
3. Fire Risk	a. Not High Fire Potential b. High Fire Potential c. No data (6%)	all	all	all	all	a	b,c	a	all	b,c	all
4. Urban Influence – Distance	a. >20 km from >2,500 city b. 10-20 km from city c. 0-10 km from city	a,b	c	all	all	a	a,b	a	b,c	b,c	all
	Habitat Area (mi^2)	6,090	2,090	11,016		1,820	5,569	5,560	786	5,456	2,792
	10% "Degradation"	-	-	-	-	(182)	182	(1,113)			1,113
	Total Habitat (mi^2)	**6,090**		**13,110**	**2,790**	**1,640**		**10,200**			**10,140**
	Percent of Total Habitat	**24%**		**64%**	**13%**	**8%**		**41%**			**51%**

6.1.4 Extent of Drought (Input)

The pattern and extent of precipitation is a crucial variable that influences the abundance of tortoise populations. And we expect climate-related variables to change in the future due to global climate change. We considered the extent and effect of drought (generally periods of time with below average precipitation and moisture conditions below at least moderate drought levels[18]) as a key variable in the simulation model. While the other potential changes in environmental conditions influenced quantity and quality of habitat and were incorporated into the model by limiting the maximum population size, the extent of drought was incorporated as a direct influence on the survival and transition rates used in the model for all three life stages (Figure 30). Refer to Appendix D for the description of how drought was incorporated into the simulation model.

The simulation model incorporates three levels of potential increases in the extent of drought. The low climate change effects were considered in the current condition scenarios because we think that some effects of climate change are already very likely to occur due to atmospheric conditions that have already changed. This low climate change effect was estimated as a 10% increase in the average spatial extent of drought over historical levels. For the future climate change scenarios we considered a moderate (20% increase in average spatial extent of drought) and a high (30% increase in average spatial extent of drought) climate change impacts.

6.1.5 Vital Rates (Input)

We based our estimates for survival and transition rates at three life stages on published literature to the extent possible and varied the rates around mean estimates (see Appendix C).

6.1.6 Population Growth Rates, Abundance, and Risk of Quasi Extinction (Output)

The outputs of the simulation model include population growth rate, mean abundance over time (with 95% confidence intervals), and the probability of the population falling below a quasi-extinction threshold. The probability of quasi-extinction over time is based on running 1,000 simulations of the model with specific scenarios of input parameters and calculating the proportion of the simulations where the population size falls below a pre-determined abundance threshold. This probability (along with mean abundance) is profiled on an annual basis and plotted over time to describe the resiliency as one unit of analysis under a specific scenario of model inputs. Determining what the quasi-extinction threshold should be for this analysis for the tortoise is an important choice because it influences the nature of the resulting quasi-extinction probability profile. It is important not to consider absolute extinction as a threshold because population dynamics that change once populations get very small (Morris and Doaks 2002, p. 43) are not accounted for in our model. And with a long lived species such as the tortoise, a population can persist for a long time with just one or two individuals, but be functionally extinct because no breeding is occurring (e.g., the Pinta Island tortoise population in the Galapagos archipelago which persisted for decades with just one individual). Instead we chose to use higher quasi-extinction thresholds which more appropriately reflect the genetic and ecological

[18] We considered drought as conditions that scored below -1.99 on the Palmer Drought Severity Index over a 12-month period ending in December.

problems that could place the tortoise at an unacceptable risk of extinction were the population size to fall below that threshold.

Due to the high uncertainty about an appropriate level of a quasi-extinction threshold for the tortoise, our scenarios for the simulation model (described below) incorporated a low and high threshold as a percentage of the total maximum population estimate, or carrying capacity, under the baseline scenario. We chose to use 2% and 4% of the maximum population size for our range of scenarios to evaluate. Assuming a total estimate of tortoises under the baseline conditions of 350,000 females in Arizona, this would put the quasi-extinction levels at either 7,000 or 14,000 adult females (14,000 or 28,000 total adults), respectively, in Arizona[19] as the threshold below which the model would consider the population quasi extinct. Given a range of approximately 24,000 sq mi (15 million ac, 6 million ha) in Arizona, these quasi-extinction levels would represent densities of 0.6 and 1.2 total adult tortoises per square mile under the low and high thresholds, respectively. These would represent very low densities, probably below densities at which tortoises would be able to successfully find mates for sustaining reproduction. If the tortoise was to actually decline this drastically, it is probably more realistic to envision that there would likely be a relatively small number of populations remaining within the highest quality habitats. This would represent a severe, unacceptable reduction in the redundancy and representation for this species. So we used these levels as the metric for reasonable estimates by which we assessed the risk of quasi extinction to the range of the species in Arizona and Sonora.

6.1.7 Time Frame

Regarding the length of time for any modeled assessment of species status, it is important to strive to incorporate enough generations of a species to be able to detect potential population and species-level responses to changes in environmental conditions. For the Sonoran desert tortoise this is particularly challenging because it has such a relatively long life span and long time to maturity. We chose to run the simulation model over a 200-year time frame. This length of time represents about 8 generations for the tortoise (assuming a 25-year generation length), which is a relatively small number of generations to identify changes in population parameters. However, it is a relatively long time over which to forecast changes in environmental conditions. Population models are commonly extended for 50 or 100 years for species with shorter generation times. We doubled our timeframe for this simulation model as compared to common practices because of the longer generation time of the tortoise.

However, there are large uncertainties associated with forecasting human behaviors, land management practices, and climate change for this long of time frame. So, while the model can forecast quasi-extinction risk over this 200-year time period, we may use a shorter time period and, therefore, only a portion of the simulation model results in the application of the risk profiles in our decision-making under the Act.

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[19] For Sonora, Mexico, the baseline population estimate would be 190,000 females. A 2 percent and 4 percent quasi-extinction threshold there would put the quasi-extinction levels at either 4,000 or 8,000 adult females (8,000 or 16,000 total adults), respectively, in Sonora.

6.2 Scenarios: Arizona

In evaluating the potential viability of the tortoise, we considered a number of plausible future scenarios and assessed risks to the tortoise from those scenarios using the simulation model. These scenarios were developed to represent a range of current and future conditions in order to consider the potential responses by the tortoise to varying habitat and climatic conditions across its range in Arizona. The scenarios help us take into account a variety of key uncertainties in the information and in the analysis. Figure 32 diagrams the basic approach of how we constructed these scenarios. These nine scenarios varied in these four main parameters:

1) Population estimates and quasi-extinction levels (accounting for variability in tortoise density estimates and a varying approach evaluating species risk);
2) Habitat conditions (accounting for differences in the effects of potential risk factors and conservation efforts);
3) Future spatial drought extent (accounting for varying future climate change effects under Future Conditions); and
4) Habitat loss (from future effects of conversion of habitat to an urban environment).

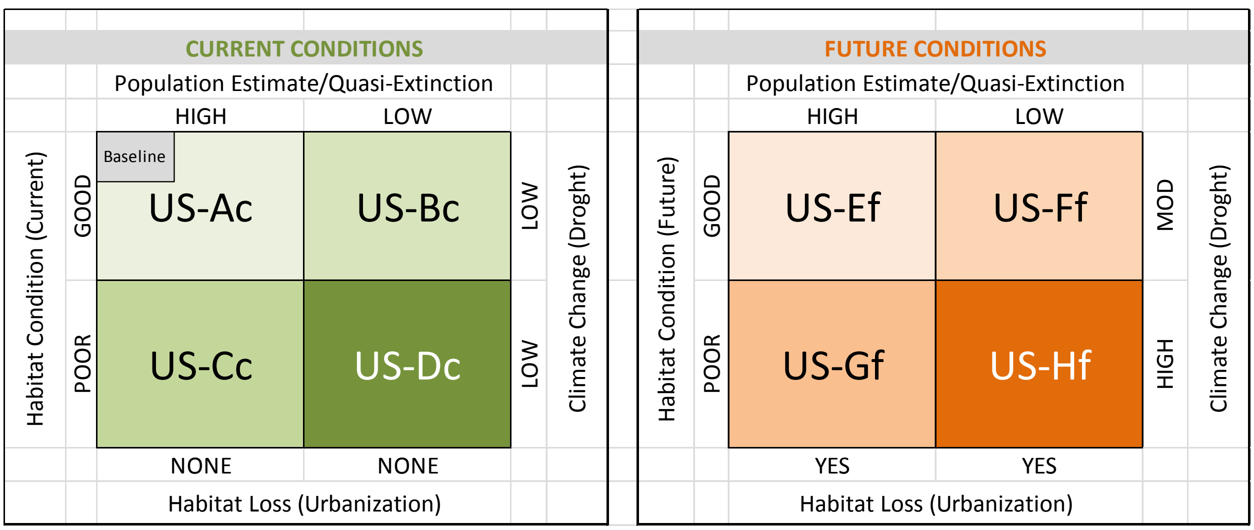


Figure 32. Diagram of the relative combination of parameters used in nine scenarios for the tortoise simulation model in Arizona, U.S. (Codes for each scenario are "US" for United States, "A" through "H" to number each scenario, and "c" for current conditions and "f" for future conditions.)

We conducted model simulations of a baseline scenario (Baseline), four scenarios with different combinations of variables under current conditions (labeled US-Ac, US-Bc, Us-Cc, and US-Dc) and four scenarios with different combinations of variables under possible future conditions (labeled US-Ef, US-Ff, US-Gf, and US-Hf). These scenarios are intended to include combinations of the different model inputs that span a range of likely possibilities for current and future habitat conditions under which we can evaluate the risk of extinction to the species and assess the species viability. The starting quality and quantity of habitat under both current and future conditions scenarios are the same as reported in Table 2 (Chapter 5: Current Conditions).

Future habitat conditions (assuming the conditions are reflective of an estimated 60 years in the future) are shown in Table 6. The difference is the calculated annual rate of habitat loss and degradation. Table 7 and Table 8 list the values associated with each of the nine scenarios in Arizona used as inputs to the simulation model, and we describe them generally below.

Table 7. Summary of scenarios under baseline and current conditions in Arizona, U.S.

BASELINE CONDITIONS						
Scenarios	Habitat Conditions	Starting Habitat (Sq Mi)	Habitat Conversion (annual rate)	Drought Extent	Starting Pop Size (adult females)	Quasi-Extinction (total females)
US-BASELINE	Quality	No Threats, No Mgt	None	No Climate Change	HIGH Density	2% of Max Pop Size
Baseline Conditions	Primary	8,630	0	historical drought extent	350,000 (Max Pop)	7,000
	Secondary	12,470	0			
	Tertiary	3,100	0			
CURRENT CONDITIONS						
Scenarios	Habitat Conditions	Starting Habitat (Sq Mi)	Habitat Conversion (annual rate)	Drought Extent	Starting Pop Size (adult females)	Quasi-Extinction (total females)
US-Ac	Quality	Low Threats, High Mgt	None	Low Climate Change	HIGH Density	2% of Max Pop Size
Current Condition, Best Case for SDT	Primary	6,090	0	historical drought extent +10%	320,000	7,000
	Secondary	15,010	0			
	Tertiary	3,100	0			
US-Bc	Quality	Low Threats, High Mgt	None	Low Climate Change	LOW Density	4% of Max Pop Size
Current Condition, Good Case for	Primary	6,090	0	historical drought extent +10%	190,000	14,000
	Secondary	15,010	0			
	Tertiary	3,100	0			
US-Cc	Quality	High Threats, Low Mgt	None	Low Climate Change	HIGH Density	2% of Max Pop Size
Current Condition, Poor Case for SDT	Primary	1,820	0	historical drought extent +10%	270,000	7,000
	Secondary	18,220	0			
	Tertiary	4,150	0			
US-Dc	Quality	High Threats, Low Mgt	None	Low Climate Change	LOW Density	4% of Max Pop Size
Current Condition, Worst Case SDT	Primary	1,820	0	historical drought extent +10%	150,000	14,000
	Secondary	18,220	0			
	Tertiary	4,150	0			

Table 8. Summary of scenarios under future conditions in Arizona, U.S.

FUTURE CONDITIONS						
Scenarios	Habitat Conditions	Starting Habitat (Sq Mi)	Habitat Conversion (annual rate)	Drought Extent	Starting Pop Size (adult females)	Quasi-Extinction (total females)
US-Ef	Quality	Low Threats, High Mgt	Urban Growth (9% habitat loss)	Moderate Climate Change	HIGH Density	2% of Max Pop Size
Future Condition, Best Case for SDT	Primary	6,090	-	historical drought extent +20%	320,000	7,000
	Secondary	15,010	(0.0021)			
	Tertiary	3,100	(0.0017)			
US-Ff	Quality	Low Threats, High Mgt	Urban Growth (9% habitat loss)	Moderate Climate Change	LOW Density	4% of Max Pop Size
Future Condition, Good Case for SDT	Primary	6,090	-	historical drought extent +20%	190,000	14,000
	Secondary	15,010	(0.0021)			
	Tertiary	3,100	(0.0017)			
US-Gf	Quality	High Threats, Low Mgt	Urban Growth (9% habitat loss)	High Climate Change	HIGH Density	2% of Max Pop Size
Future Condition, Poor Case for SDT	Primary	1,820	(0.0016)	historical drought extent +30%	270,000	7,000
	Secondary	18,220	(0.0073)			
	Tertiary	4,150	0.0241			
US-Hf	Quality	High Threats, Low Mgt	Urban Growth (9% habitat loss)	High Climate Change	LOW Density	4% of Max Pop Size
Future Condition, Worst Case for SDT	Primary	1,820	(0.0016)	historical drought extent +30%	150,000	14,000
	Secondary	18,220	(0.0073)			
	Tertiary	4,150	0.0241			

US-Baseline. This scenario is a baseline of habitat conditions that provides for no threats or management considerations (Table 7). Therefore the assessment of habitat potential correlates directly with the assessment of habitat quality, so high, moderate, and low potential habitat corresponds directly with primary, secondary, and tertiary habitat qualities, respectively. There is no loss of habitat due to conversion of habitat to urban areas. The extent of drought is based on the estimated historic drought extent. The starting population size uses the product of the high density estimates and the habitat potential area, and the quasi-extinction level is set at 2% of the maximum carrying capacity based solely on potential habitat. This is not a very realistic scenario because it assumes that the entire potential habitat has been unaffected by any stressors. It also assumes no change in the extent of drought. This is considered a baseline scenario and not a likely possible scenario for consideration in our decisions.

US-Ac – Current Condition, best case for tortoise. This scenario, US-Ac, is a relatively “best case”[20] scenario for tortoises under current habitat conditions. It uses habitat

[20] Throughout this report we use the terms best case and worse case in reference to our range of scenarios. These are intended to be relative terms compared with each of the scenarios considered in this analysis. There could be projections based on better or direr predictions of conditions for the tortoise, but our best case and worst case

conditions assuming no stressors from fire or nonnative grasses, and assumes there will be benefits from conservation actions (Table 7). So, the starting primary quality habitat includes all of the areas with high potential habitat that are in the managed and multi-use land categories and are beyond 6.2 mi (10 km) from the nearest urban area. The US-Ac scenario uses future drought conditions with only a small increase (10%) in the extent of drought in the future (in other words, low climate change effects). This scenario includes no additional loss of habitat from urban growth. The US-Ac scenario uses a relatively high value (320,000 adult females) for the starting and maximum population size and 2% of maximum carrying capacity as the quasi-extinction level.

<u>US-Bc – Current Condition, good case for tortoises</u>. This scenario, US-Bc, is a relatively "good case" scenario for tortoises under current habitat conditions. It uses habitat conditions assuming no stressors from fire or nonnative grasses, and assumes there will be benefits of conservation actions (Table 7). So, the starting primary quality habitat includes all of the areas with high potential habitat that are in the managed and multi-use land categories and are beyond 6.2 mi (10 km) from the nearest urban area. The US-Bc scenario uses future drought conditions with only a small increase (10%) in the extent of drought in the future (in other words, low climate change effects). This scenario includes no additional loss of habitat from urban growth. The US-Bc scenario uses a relatively low value (190,000 adult females) for the starting and maximum population size and 4% of maximum carrying capacity as the quasi-extinction level.

<u>US-Cc – Current Condition, poor case for tortoise</u>. This scenario, US-Cc, is a relatively "poor case" scenario for tortoises under current habitat conditions. It uses habitat conditions assuming there are impacts from fire and nonnative grasses, and assumes there will be little benefit from conservation actions (Table 7). So the starting primary quality habitat includes only the areas with high potential habitat that are in managed land categories with no high fire potential or nonnative grasses present and are beyond 12.4 mi (20 km) from the nearest urban area. The US-Cc scenario uses future drought conditions with only a small increase (10%) in the extent of drought in the future (in other words, low climate change effects). This scenario includes no additional loss of habitat from urban growth. The US-Cc scenario uses a relatively high value (270,000 adult females) for the starting and maximum population size and 2% of maximum carrying capacity as the quasi-extinction level.

<u>US-Dc – Current Condition, worst case for tortoise</u>. This scenario, US-Dc, is a relatively "worst case"[21] scenario for tortoises under current habitat conditions. It uses habitat conditions assuming there are impacts from fire and nonnative grasses, and assumes there will be little benefit from conservation actions (Table 7). So the starting primary quality habitat includes only the areas with high potential habitat that are in managed land categories with no high fire potential or nonnative grasses present and are beyond 12.4 mi (20 km) from the nearest urban area. The US-Dc scenario uses future drought conditions with only a small increase (10%) in the extent of drought in the future (in other words,

scenarios are intended to represent our understanding of good and very poor, but still plausible, conditions upon which to base our projections.

[21] Ibid.

low climate change effects). This scenario includes no additional loss of habitat from urban growth. The US-Dc scenario uses a relatively low value (150,000 adult females) for the starting and maximum population size and 4% of maximum carrying capacity as the quasi-extinction level.

<u>US-Ef – Future Condition, best case for tortoise</u>. This scenario, US-Ef, is a relatively "best case" scenario for tortoises under future habitat conditions. It uses habitat conditions assuming no stressors from fire or nonnative grasses, and assumes there will be benefits from conservation actions (Table 8). So the starting primary quality habitat includes all of the areas with high potential habitat that are in managed and multi-use land categories and are beyond 6.2 mi (10 km) from the nearest urban area. The US-Ef scenario uses future drought conditions with a relatively moderate increase (20%) in the extent of drought in the future (in other words, moderate climate change effects). This scenario includes additional loss of habitat from urban growth at an overall rate of about 9% loss per 60 years. The US-Ef scenario uses a relatively high value (320,000 adult females) for the starting and maximum population size and 2% of maximum carrying capacity as the quasi-extinction level.

<u>US-Ff – Future Condition, good case for tortoises</u>. This scenario, US-Ff, is a relatively "good case" scenario for tortoises under future habitat conditions. It uses habitat conditions assuming no stressors from fire or nonnative grasses, and assumes there will be benefits of conservation actions (Table 8). So the starting primary quality habitat includes all of the areas with high potential habitat that are in managed and multi-use land categories and are beyond 6.2 mi (10 km) from the nearest urban area. The US-Ff scenario uses future drought conditions with a relatively moderate increase (20%) in the extent of drought in the future (in other words, moderate climate change effects). This scenario includes additional loss of habitat from urban growth at an overall rate of about 9% loss per 60 years. The US-Ff scenario uses a relatively low value (190,000 adult females) for the starting and maximum population size and 4% of maximum carrying capacity as the quasi-extinction level.

<u>US-Gf – Future Condition, poor case for tortoise</u>. This scenario, US-Gf, is a relatively "poor case" scenario for tortoises under future habitat conditions. It uses habitat conditions assuming there are impacts from fire and nonnative grasses, and assumes there will be little benefit from conservation actions (Table 8). So the starting primary quality habitat includes only the areas with high potential habitat that are in managed land categories with no high fire potential or nonnative grasses present and are beyond 12.4 mi (20 km) from the nearest urban area. The US-Gf scenario uses future drought conditions with a relatively high increase (30%) in the extent of drought in the future (in other words, high climate change effects). This scenario includes additional loss of habitat from urban growth at an overall rate of about 9% loss per 60 years. The US-Gf scenario uses a relatively high value (270,000 adult females) for the starting and maximum population size and 2% of maximum carrying capacity as the quasi-extinction level.

<u>US-Hf – Future Condition, worst case for tortoise</u>. This scenario, US-Hf, is a relatively "worst case" scenario for tortoises under future habitat conditions. It uses habitat

conditions assuming there are impacts from fire and nonnative grasses, and assumes there will be little benefit from conservation actions (Table 8). So the starting primary quality habitat includes only the areas with high potential habitat that are in managed land categories with no high fire potential or nonnative grasses present and are beyond 12.4 mi (20 km) from the nearest urban area. The US-Hf scenario uses future drought conditions with a relatively high increase (30%) in the extent of drought in the future (in other words, high climate change effects). This scenario includes additional loss of habitat from urban growth at an overall rate of about 9% loss per 60 years. The US-Hf scenario uses a relatively low value (150,000 adult females) for the starting and maximum population size and 4% of maximum carrying capacity as the quasi-extinction level.

6.3 Scenarios: Mexico

For scenarios in the Mexico area of analysis, we followed the same basic methodology as for Arizona with some differences. The primary differences were how we categorized habitat conditions and our exclusion of future habitat loss due to urbanization. Mexican protected areas are treated like multi-use areas in Arizona. Concerns over potential effects of nonnative grasses and fire are limited to areas within the Plains of Sonora with less than 5% slope (see Section 5.3.2 for a discussion). Figure 33 diagrams the basic approach of how we constructed these nine scenarios with similar parameters used as the Arizona scenarios.

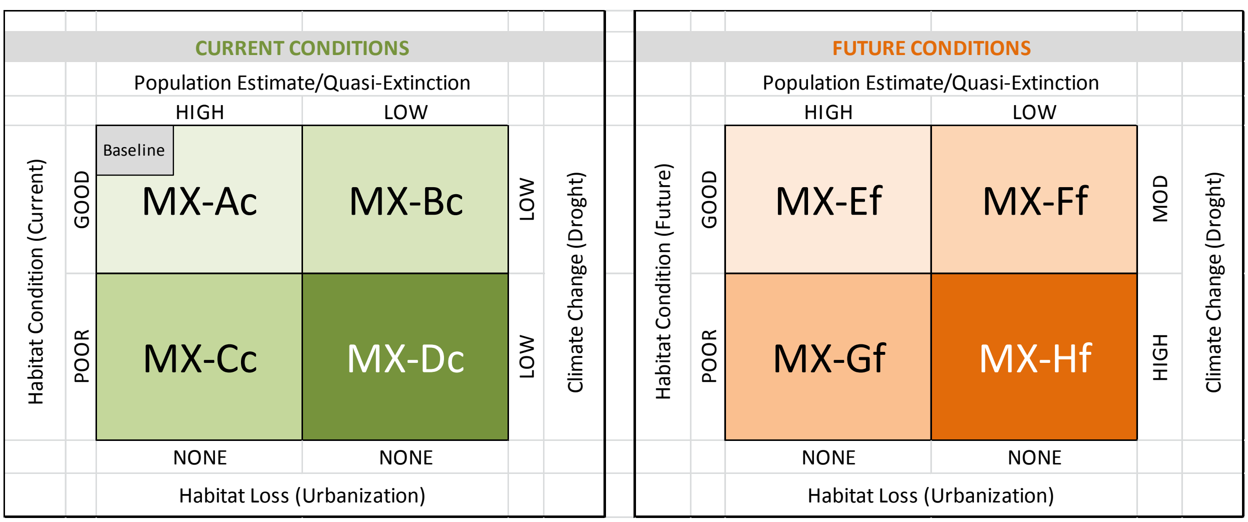


Figure 33. Diagram of the relative combination of parameters used in nine scenarios for the tortoise simulation model in Sonora, Mexico. (Codes for each scenario are "MX" for Mexico, "A" through "H" to number each scenario, and "c" for current conditions and "f" for future conditions.)

We conducted model simulations of a baseline scenario (Baseline), four scenarios with different combinations of variables under current conditions (labeled MX-Ac, MX-Bc, MX-Cc, and MX-Dc) and four scenarios with different combinations of variables under possible future conditions (labeled MX-Ef, MX-Ff, MX-Gf, and MX-Hf). These scenarios are intended to include combinations of the different model inputs that span a range of likely possibilities for current and future habitat conditions under which we can evaluate the risk of extinction to the species and assess the species viability. The starting quality and quantity of habitat under both current and future conditions scenarios are the same as reported in Table 3 (Chapter 5: Current Conditions). For future habitat conditions in Sonora, we assumed there would be no additional habitat loss or degradation in Mexico. Table 9 and Table 10 list the values associated with each of the nine scenarios in Arizona used as inputs to the simulation model, and we describe them generally below.

Table 9. Summary of scenarios under baseline and current conditions in Sonora, Mexico.

BASELINE CONDITIONS					
Scenarios (Sonora)	Habitat Conditions	Starting Habitat (Sq Mi)	Drought Extent	Starting Pop Size (adult females)	Quasi-Extinction (total females)
MX-BASELINE	Quality	No Threats	No Climate Change	HIGH Density	2% of Max Pop Size
Baseline Conditions	Primary Secondary Tertiary	4,350 9,380 30	historical drought extent	210,000	4,000

CURRENT CONDITIONS					
Scenarios (Sonora)	Habitat Conditions	Starting Habitat (Sq Mi)	Drought Extent	Starting Pop Size (adult females)	Quasi-Extinction (total females)
MX-Ac	Quality	LOW Threats	LOW Climate Change	HIGH Density	2% of Max Pop Size
Current Condition, Best Case for SDT	Primary Secondary Tertiary	320 13,400 30	historical drought extent +10%	170,000	4,000
MX-Bc	Quality	LOW Threats	LOW Climate Change	LOW Density	4% of Max Pop Size
Current Condition, Good Case for SDT	Primary Secondary Tertiary	320 13,400 30	historical drought extent +10%	100,000	8,000
MX-Cc	Quality	HIGH Threats	LOW Climate Change	HIGH Density	2% of Max Pop Size
Current Condition, Poor Case for SDT	Primary Secondary Tertiary	- 10,550 3,210	historical drought extent +10%	140,000	4,000
MX-Dc	Quality	HIGH Threats	LOW Climate Change	LOW Density	4% of Max Pop Size
Current Condition, Worst Case for SDT	Primary Secondary Tertiary	- 10,550 3,210	historical drought extent +10%	80,000	8,000

Table 10. Summary of scenarios under future conditions in Sonora, Mexico.

FUTURE CONDITIONS					
Scenarios (Sonora)	Habitat Conditions	Starting Habitat (Sq Mi)	Drought Extent	Starting Pop Size (adult females)	Quasi-Extinction (total females)
MX-Ef	Quality	LOW Threats	MODERATE Climate Change	HIGH Density	2% of Max Pop Size
Future Condition, Best Case for SDT	Primary Secondary Tertiary	320 13,400 30	historical drought extent +20%	170,000	4,000
MX-Ff	Quality	LOW Threats	MODERATE Climate Change	LOW Density	4% of Max Pop Size
Future Condition, Good Case for SDT	Primary Secondary Tertiary	320 13,400 30	historical drought extent +20%	100,000	8,000
MX-Gf	Quality	HIGH Threats	HIGH Climate Change	HIGH Density	2% of Max Pop Size
Future Condition, Poor Case for SDT	Primary Secondary Tertiary	- 10,550 3,210	historical drought extent +30%	140,000	4,000
MX-Hf	Quality	HIGH Threats	HIGH Climate Change	LOW Density	4% of Max Pop Size
Future Condition, Worst Case for SDT	Primary Secondary Tertiary	- 10,550 3,210	historical drought extent +30%	80,000	8,000

Baseline. This scenario is a baseline of habitat conditions that provides for no threats or management considerations (Table 9). Therefore the assessment of habitat potential correlates directly with the assessment of habitat quality, so high, moderate, and low potential habitat corresponds directly with primary, secondary, and tertiary habitat qualities, respectively. The extent of drought is based on the estimated historic drought extent (which was assumed to be the same as that used for Arizona). The starting population size uses the product of the high density estimates and the habitat potential area, and the quasi-extinction level is set at 2% of the maximum carrying capacity based solely on habitat potential. This is not a very realistic scenario because it assumes that the entire potential habitat has been unaffected by any stressors. It also assumes no change in the extent of drought. This is considered a baseline scenario and not a likely possible scenario for consideration in our decisions.

MX-Ac – Current Condition, best case for tortoise. This scenario, MX-Ac, is a relatively "best case" scenario for tortoises under current habitat conditions. It uses habitat conditions assuming no stressors from fire or nonnative grasses, and assumes there will be benefits from conservation actions on protected lands (Table 9). So, the starting primary quality habitat includes all of the areas with high potential habitat that are in the protected lands and are beyond 6.2 mi (10 km) from the nearest urban area. The MX-Ac scenario uses future drought conditions with only a small increase (10%) in the extent of drought in the future (in other words, low climate change effects). The MX-Ac scenario uses a relatively high value (170,000 adult females) for the starting and maximum population size and 2% of maximum carrying capacity as the quasi-extinction level.

MX-Bc – Current Condition, good case for tortoises. This scenario, MX-Bc, is a relatively "good case" scenario for tortoises under current habitat conditions. It uses habitat conditions assuming no stressors from fire or nonnative grasses, and assumes there will be benefits of conservation actions (Table 9). So, the starting primary quality habitat includes all of the areas with high potential habitat that are in the protected land categories and are beyond 6.2 mi (10 km) from the nearest urban area. The MX-Bc scenario uses future drought conditions with only a small increase (10%) in the extent of drought in the future (in other words, low climate change effects). The MX-Bc scenario uses a relatively low value (100,000 adult females) for the starting and maximum population size and 4% of maximum carrying capacity as the quasi-extinction level.

MX-Cc – Current Condition, poor case for tortoise. This scenario, MX-Cc, is a relatively "poor case" scenario for tortoises under current habitat conditions. It uses habitat conditions assuming there are impacts from fire and nonnative grasses (in the Plains of Sonora area), and assumes there will be little benefit from conservation actions in protected areas (Table 9). There is no starting primary quality habitat. Medium potential habitats are categorized as secondary quality if they have no nonnative grass and fire concerns and are beyond 6.2 mi (10 km) from an urban area, otherwise medium potential habitats were categorized as tertiary quality. The MX-Cc scenario uses future drought conditions with only a small increase (10%) in the extent of drought in the future (in other words, low climate change effects). The MX-Cc scenario uses a relatively high value (140,000 adult females) for the starting and maximum population size and 2% of maximum carrying capacity as the quasi-extinction level.

MX-Dc – Current Condition, worst case for tortoise. This scenario, MX-Dc, is a relatively "worst case" scenario for tortoises under current habitat conditions. It uses habitat conditions assuming there are impacts from fire and nonnative grasses (in the Plains of Sonora area), and assumes there will be little benefit from conservation actions in protected areas (Table 9). There is no starting primary quality habitat. Medium potential habitats are categorized as secondary quality if they have no nonnative grass and fire concerns and are beyond 6.2 mi (10 km) from an urban area, otherwise medium potential habitats were categorized as tertiary quality. The MX-Dc scenario uses future drought conditions with only a small increase (10%) in the extent of drought in the future (in other words, low climate change effects). This scenario includes no additional loss of habitat from urban growth. The MX-Dc scenario uses a relatively low value (150,000 adult females) for the starting and maximum population size and 2% of maximum carrying capacity as the quasi-extinction level.

<u>MX-Ef – Future Condition, best case for tortoise</u>. This scenario, MX-Ef, is a relatively "best case" scenario for tortoises under future habitat conditions. It uses habitat conditions assuming no stressors from fire or nonnative grasses, and assumes there will be benefits from conservation actions in protected areas (Table 10). So the starting primary quality habitat includes all of the areas with high potential habitat that are in protected areas and are beyond 6.2 mi (10 km) from the nearest urban area. The MX-Ef scenario uses future drought conditions with a relatively moderate increase (20%) in the extent of drought in the future (in other words, moderate climate change effects). The MX-Ef scenario uses a relatively high value (170,000 adult females) for the starting and maximum population size and 2% of maximum carrying capacity as the quasi-extinction level.

<u>MX-Ff – Future Condition, good case for tortoises</u>. This scenario, MX-Ff, is a relatively "good case" scenario for tortoises under future habitat conditions. It uses habitat conditions assuming no stressors from fire or nonnative grasses, and assumes there will be benefits of conservation actions in protected areas (Table 10). So the starting primary quality habitat includes all of the areas with high potential habitat that are in protected areas and are beyond 6.2 mi (10 km) from the nearest urban area. The MX-Ff scenario uses future drought conditions with a relatively moderate increase (20%) in the extent of drought in the future (in other words, moderate climate change effects). The MX-Ff scenario uses a relatively low value (100,000 adult females) for the starting and maximum population size and 4% of maximum carrying capacity as the quasi-extinction level.

<u>MX-Gf – Future Condition, poor case for tortoise</u>. This scenario, MX-Gf, is a relatively "poor case" scenario for tortoises under future habitat conditions. It uses habitat conditions assuming there are impacts from fire and nonnative grasses, and assumes there will be little benefit from conservation actions (Table 10). There is no starting primary quality habitat. Medium potential habitats are categorized as secondary quality if they have no nonnative grass and fire concerns and are beyond 6.2 mi (10 km) from an urban area, otherwise medium potential habitats were categorized as tertiary quality. The MX-Gf scenario uses future drought conditions with a relatively high increase (30%) in the extent of drought in the future (in other words, high climate change effects). The MX-Gf scenario uses a relatively high value (140,000 adult females) for the starting and maximum population size and 2% of maximum carrying capacity as the quasi-extinction level.

<u>MX-Hf – Future Condition, worst case for tortoise</u>. This scenario, MX-Hf, is a relatively "worst case" scenario for tortoises under future habitat conditions. It uses habitat conditions assuming there are impacts from fire and nonnative grasses, and assumes there will be little benefit from conservation actions (Table 10). There is no starting primary quality habitat. Medium potential habitats are categorized as secondary quality if they have no nonnative grass and fire concerns and are beyond 6.2 mi (10 km) from an urban

area, otherwise medium potential habitats were categorized as tertiary quality. The MX-Hf scenario uses future drought conditions with a relatively high increase (30%) in the extent of drought in the future (in other words, high climate change effects). The MX-Hf scenario uses a relatively low value (80,000 adult females) for the starting and maximum population size and 4% of maximum carrying capacity as the quasi-extinction level.

6.4 Viability Projections under Current Condition Scenarios

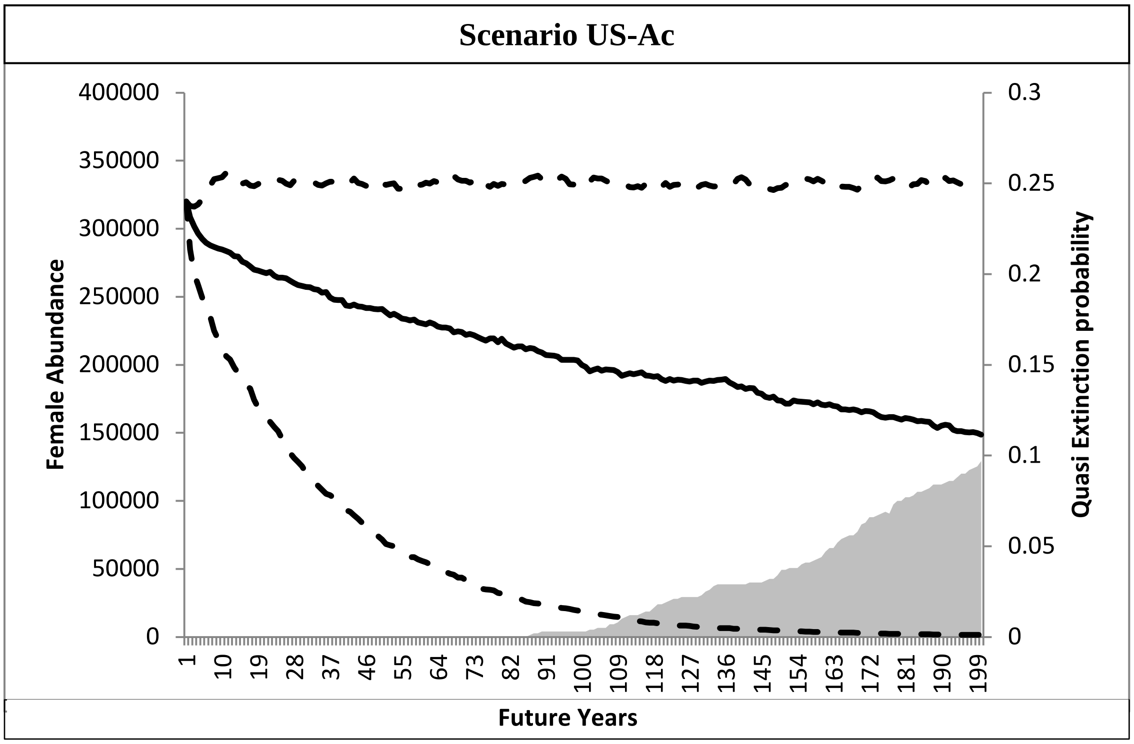
The four current condition scenarios provided a range of conditions based on habitat quality and population sizes to bracket our uncertainty about those parameters. Each of these scenarios had a low effect of climate change and no future habitat loss due to urbanization or habitat degradation. The full results of the analyses of future projections using simulation model for the Sonoran desert tortoise under the four current condition scenarios are reported in Table 11 and in Appendix D, Figures D-4.2 – 4.5 (Arizona, U.S.) and D-5.2 – 5.5 (Sonora, Mexico). These results show projected population growth rates, mean tortoise abundance, and quasi-extinction risk over the 200-year timeframe of analysis. Figure 34 is an example of the population simulation output for scenarios US-Ac and MX-Ac, the overall best cases for the tortoise. These results provide a measure of overall population resilience for the Arizona and Sonora analysis areas under current conditions.

All of the current condition scenarios have a population growth rate slightly less than one (λ = 0.9932 to 0.9969), indicating slow population declines, which are reflected in the declining mean abundances for all scenarios (Table 11). The risk of quasi extinction is heavily influenced by the quasi-extinction threshold we chose under different scenarios (2% of 4% of maximum population size). However, for all the current condition scenarios the probability of quasi extinction was 0.00 at 50 years. And the probability of quasi extinction at 100 years was less than 0.01 for all scenarios with a 2% abundance threshold and approximately 0.066 or less than for scenarios with 4% abundance threshold. In other words for either of the two analysis areas, there was less than 0.01 probability (< 1% chance) of falling below 2% of the maximum population at 100 years and less than 0.07 probability (< 7% chance) of falling below 4% of the maximum population at 100 years. The wide confidence intervals around the mean abundance estimates demonstrate the high variability in these results and that there is some chance of populations declining to near or below quasi-extinction levels. These results provide a measurement of the expected resiliency of Sonoran desert tortoise populations under our estimates of current environmental conditions based on predicted habitat quality and quantity.

Although the population simulation model is not spatially explicit at a scale smaller than the Arizona and Sonora areas of analysis, the spatial distribution of the primary and secondary quality habitats are shown in Figure 24 and Figure 25 (and quantified in Table 2) for Arizona and Figure 26 for Sonora (and quantified in Table 3). For the U.S. analysis area, assessing current potential habitat conditions resulted in a range of 8% to 25% of all potential tortoise habitat being in the primary quality category; 62% to 75% in secondary quality; and 13% to 17% 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% in secondary quality; and 0.2% to 21% in tertiary quality. These predicted distributions of habitat characterize the redundancy and representation of the Sonoran desert tortoise.

Table 11. Results of the population simulation model under different scenarios, where N_0 is the starting abundance of adult females (in thousands); λ_{200} is the median population growth rate over 200 years (*SE* is standard error); N_t is the median abundance of adult females (in thousands) at time *t*; and P_{Qet} is the probability of quasi extinction at time *t*.

				Results at 50 years		*Results at 75 years*		*Results at 100 years*		*Results at 200 years*	
	Scenario	N_0	λ_{200} (SE)	N_{50}	P_{Qe50}	N_{75}	P_{Qe75}	N_{100}	P_{Qe100}	N_{200}	P_{Qe200}
BASELINE	US-Base	350	0.9944 (0.004)	271	0.000	262	0.000	259	0.001	221	0.076
	MX-Base	210	0.9972 (0.007)	158	0.000	150	0.000	142	0.000	120	0.070
CURRENT CONDITIONS	US-Ac	320	0.9932 (0.003)	241	0.000	219	0.000	200	0.003	149	0.097
	MX-Ac	170	0.9969 (0.008	129	0.000	124	0.001	119	0.005	91	0.092
	US-Bc	190	0.9938 (0.003)	139	0.000	130	0.011	125	0.034	102	0.187
	MX-Bc	100	0.9961 (0.008)	72	0.000	67	0.006	62	0.037	46	0.220
	US-Cc	270	0.9935 (0.003)	204	0.000	191	0.000	174	0.005	138	0.107
	MX-Cc	140	0.9964 (0.007	100	0.000	96	0.000	89	0.006	68	0.116
	US-Dc	150	0.9939 (0.003)	115	0.000	108	0.008	103	0.043	80	0.224
	MX-Dc	80	0.9962 (0.008)	55	0.000	53	0.021	48	0.066	38	0.254
FUTURE CONDITIONS	US-Ef	320	0.9925 (0.003)	233	0.000	213	0.000	199	0.003	130	0.113
	MX-Ef	170	0.9948 (0.008)	116	0.000	103	0.001	96	0.003	61	0.126
	US-Ff	190	0.9928 (0.004)	133	0.001	124	0.011	114	0.041	90	0.205
	MX-Ff	100	0.9952 (0.008)	68	0.000	63	0.005	58	0.045	38	0.250
	US-Gf	270	0.9914 (0.003)	185	0.000	164	0.000	148	0.009	96	0.142
	MX-Gf	140	0.9950 (0.009)	96	0.000	86	0.002	79	0.010	52	0.131
	US-Hf	150	0.9915 (0.003)	104	0.000	91	0.015	79	0.068	51	0.275
	MX-Hf	80	0.9945 (0.009)	54	0.001	48	0.033	43	0.089	27	0.323



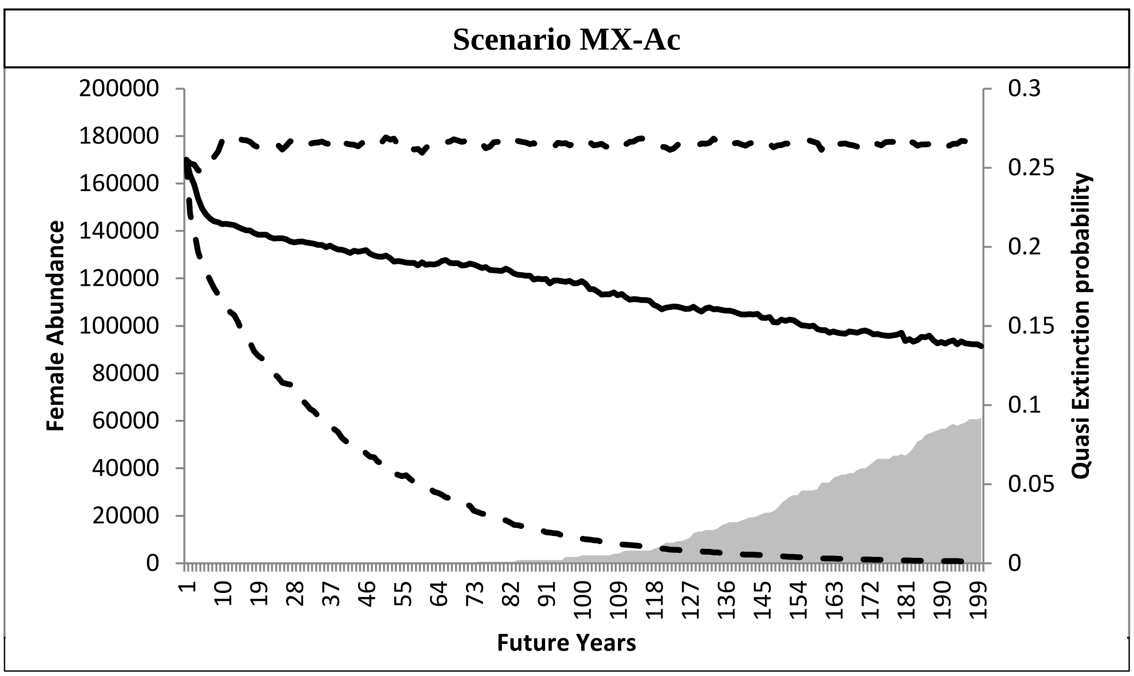


Figure 34. Plots of predicted median abundance (solid line, primary (left) axis) with 95% confidence interval (dashed lines, primary axis) and the probability of quasi extinction (shaded area, secondary (right) axis) for the best case current conditions scenarios in Arizona, U.S. (top, US-Ac) and Sonora, Mexico (bottom, MX-Ac).

6.5 Viability Projections under Future Condition Scenarios

The four future condition scenarios provided a range of conditions based on habitat quality and population sizes to bracket our uncertainty about those parameters. They also included a range of drought impacts due to climate change and a loss of habitat due to urban and suburban expansion along with a increasing habitat degradation. The full results of the analyses of future projections for the Sonoran desert tortoise under the four future condition scenarios are found in in Table 11and Appendix D, Figures D-4.6 – 4.9 (Arizona, U.S.) and D-5.6 – 5.9 (Sonora, Mexico). These results show projected population growth rates, mean tortoise abundance, and quasi-extinction risk over the 200-year timeframe of analysis. Figure 35 is an example of the population simulation output for scenarios US-Hf and MX-Hf, the overall worst cases for the tortoise.

All of the future condition scenarios have a population growth of slightly less than one (λ = 0.9914 to 0.9952), indicating slow population declines, which are reflected in the declining mean abundances for all scenarios. 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. At 75 years, the risks increased, ranging from 0 in some scenarios to as high as 0.033 probability of quasi extinction (a 3.3% risk of quasi extinction in 75 years) in the worst case future scenario for the Mexico analysis area. Only the worst case scenarios resulted in more 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 range from 0.003 to 0.089 probability of quasi extinction. At 200 years, the range of quasi extinction under future scenarios is 0.113 to 0.323. These results provide a measurement of the expected resiliency of Sonoran desert tortoise populations under our estimates of future environmental conditions based on predicted habitat quality and quantity.

Although the population simulation model is not spatially explicit at a scale smaller than the Arizona and Sonora areas of analysis, the spatial distribution of the primary and secondary quality habitats projected under future conditions in Arizona are shown in Figure 36 and Figure 37 for Arizona (and quantified in Table 6). For Sonora, we did not expect measurable habitat loss from urbanization or ongoing degradation of habitat quality, therefore the future habitat projections are the same as current conditions, represented in Figure 27 and Figure 28 (and quantified in Table 3). Under worst case future scenarios that include low management, high threats, habitat loss, and habitat degradation, Arizona is projected (considering a 60-year future condition) to maintain 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. These predicted distributions of habitat characterize the projected future redundancy and representation of the Sonoran desert tortoise.

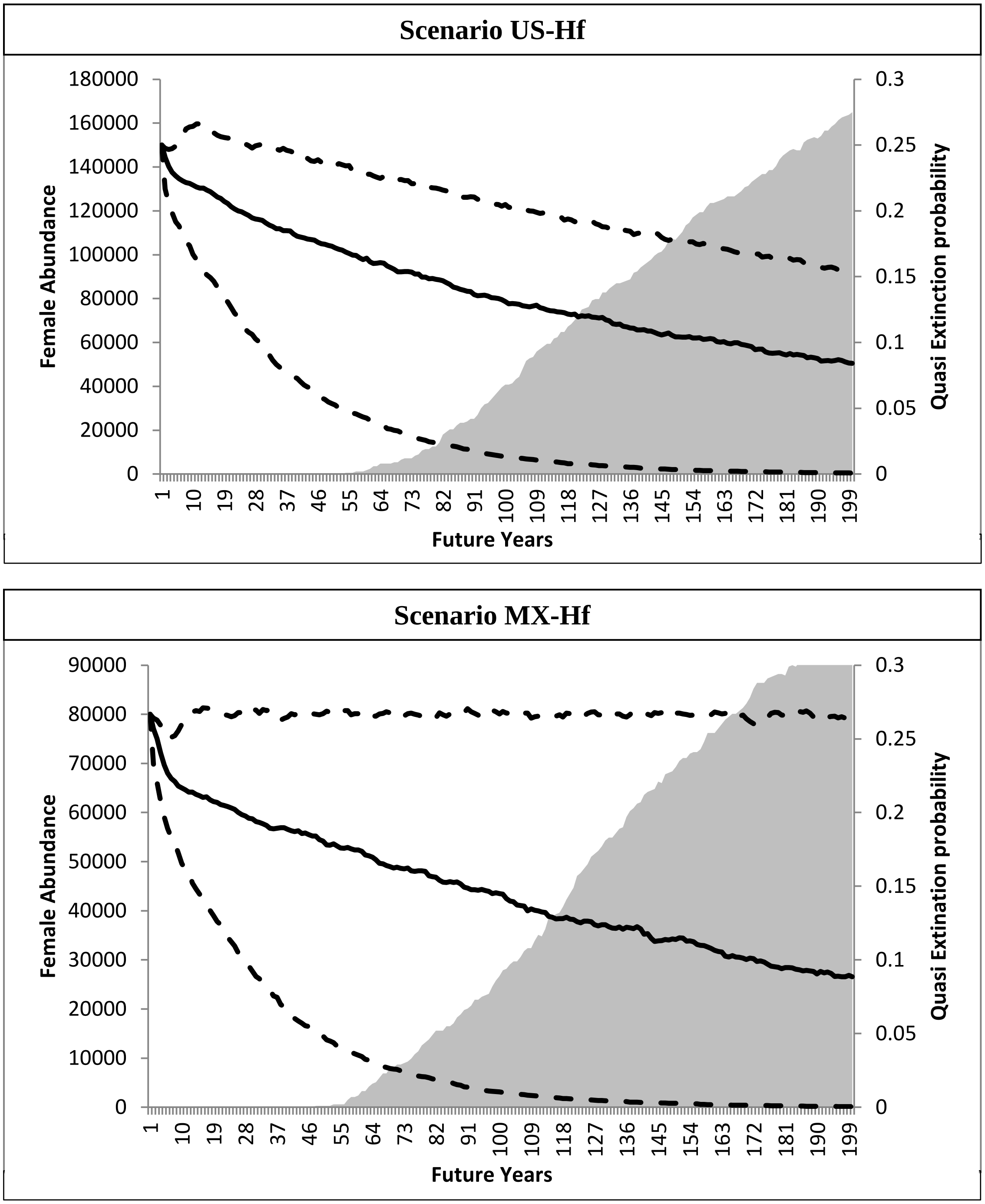


Figure 35. Plots of predicted median abundance (solid line, primary (left) axis) with 95% confidence interval (dashed lines, primary axis) and the probability of quasi extinction (shaded area, secondary (right) axis) for the worst case future conditions scenarios in Arizona, U.S. (top, US-Hf) and Sonora, Mexico (bottom, MX-Hf).

Future Sonoran Desert Tortoise Predicted Habitat Quality in Arizona Under Scenarios E and F

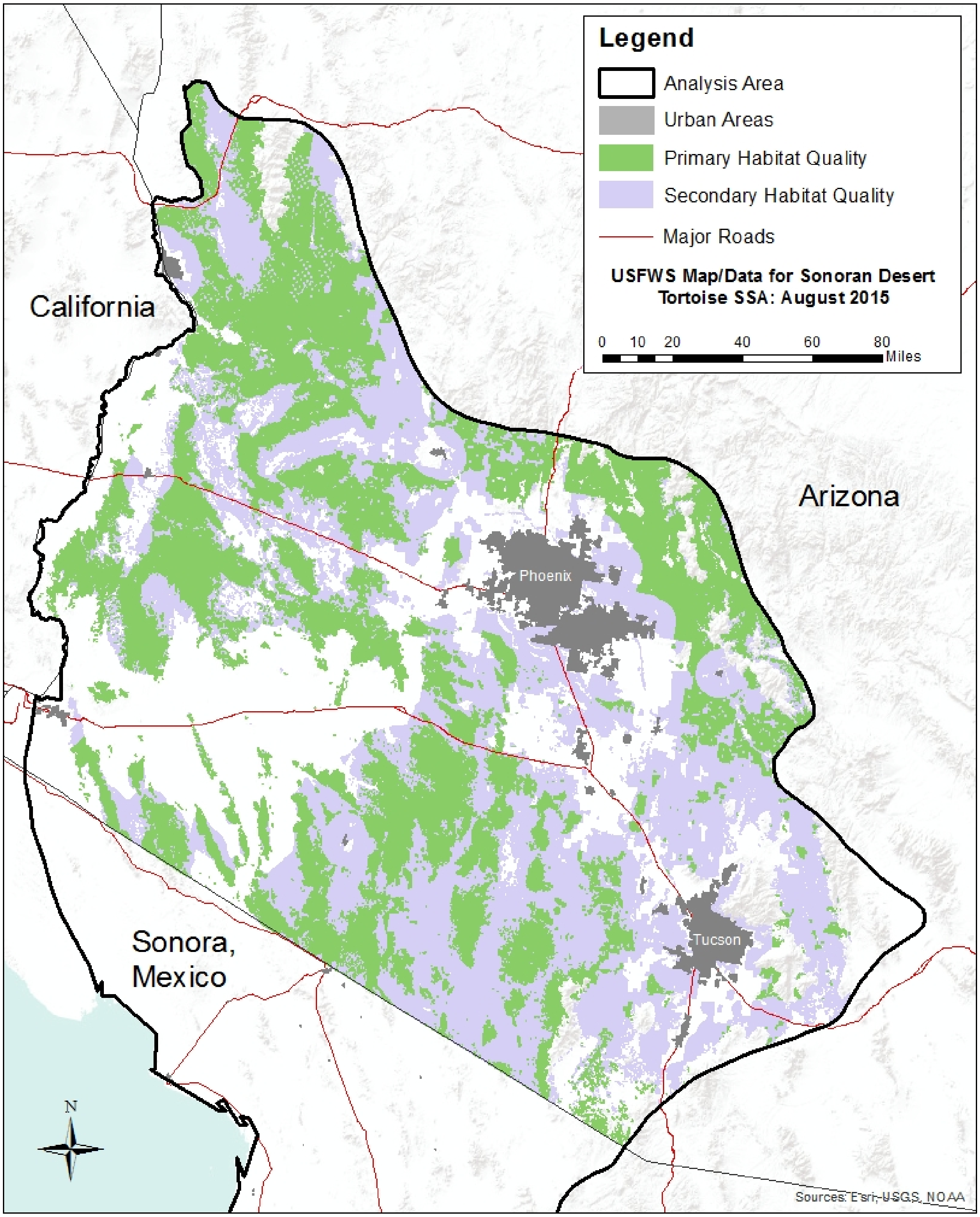


Figure 36. Primary and secondary habitat quality distribution under future condition scenarios US-Ef and US-Ff in approximately 60 years in Arizona.

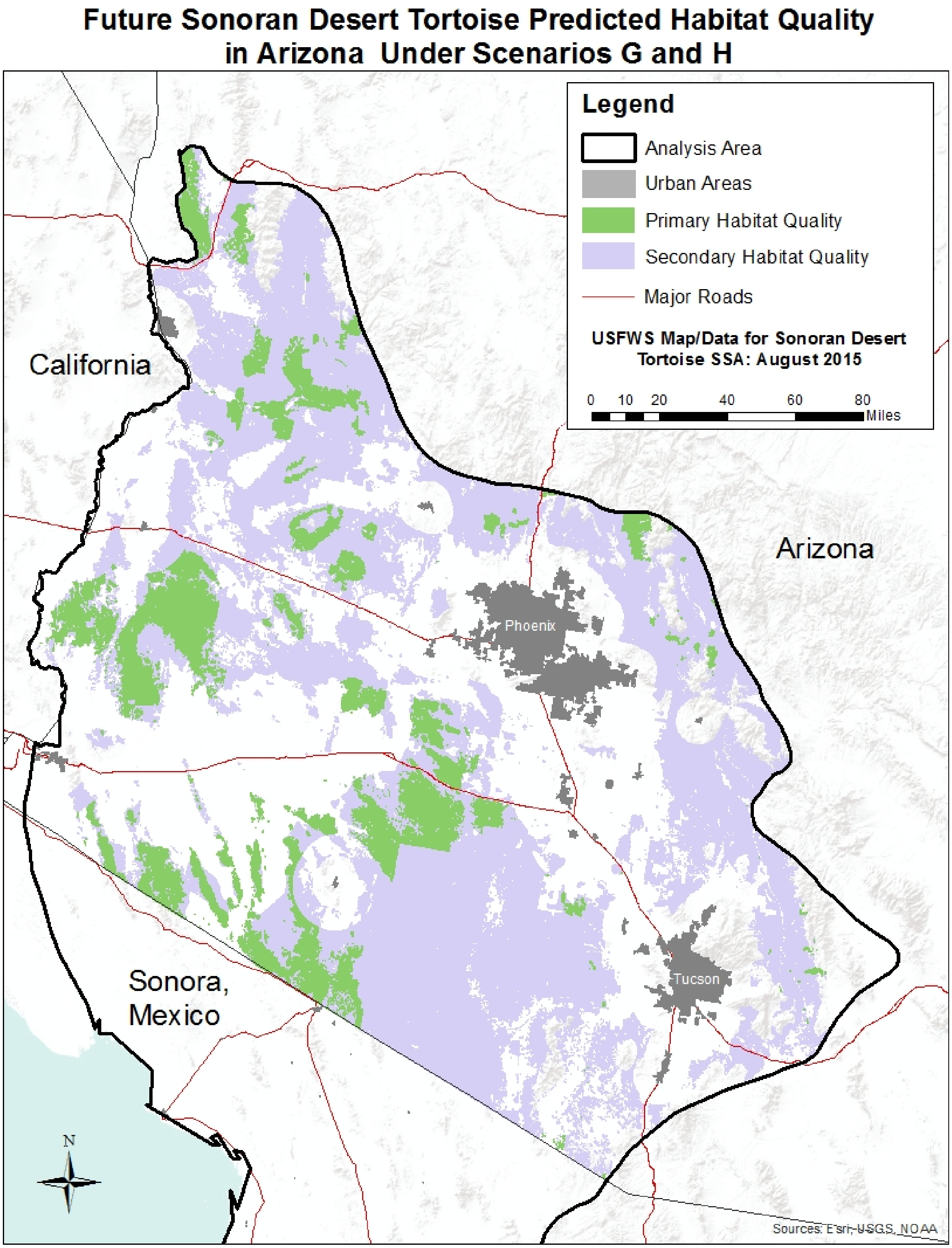


Figure 37. Primary and secondary habitat quality distribution under future condition scenarios US-Gf and US-Hf in approximately 60 years in Arizona.

6.6 Conclusions Viability and Species Risk

We estimated that the Sonoran desert tortoise currently ranges across an area of up to 38,000 sq mi (24.3 million ac, 9.8 million ha) in Arizona, U.S., and Sonora, Mexico, with a total adult population in the range of 470,000 to 970,000. It does not appear that the overall range of the species has changed measurably from historical conditions, although some habitat has certainly been lost and some have been degraded due to various anthropogenic activities.

We reviewed a number of potential factors that could be affecting the species. While many of these factors could be having effects on individual tortoises, they have not been shown to have population-level effects on the species. Other factors may have population-level effects, but, because of the long-life span, abundance, and wide range of the Sonoran desert tortoise, these changes 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. Because of the high uncertainty of many of these factors, and the potential for cumulative effects, we analyzed current and future conditions under scenarios with high management and low threats, and low management and high threats, to assess a range of possible conditions.

As a means of quantifying and spatially projecting future conditions of the habitat of the Sonoran desert tortoise, we developed a habitat-based geospatial system to reflect potential current and future habitat conditions. These habitat analyses served as the basis to estimate population sizes and to conduct a simulation model to project future abundance and risks of quasi extinction to the tortoise. Although the simulation model is not spatially explicit at a smaller scale than the Arizona and Sonora 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. We projected future species responses to two levels of climate change represented as increases in the mean annual extent of tortoises exposed to drought.

For the Sonoran desert tortoise to maintain viability, it needs to have resilient populations, capable of withstanding stochastic events and preventing local extirpations. The populations need to be spread across its range in a way that reduces the chance that a catastrophic event is likely to lead to species extinction. And the species needs to maintain ecological and genetic diversity in way that preserves its adaptive capacity. Our analysis of the future environmental conditions (habitat quantity and quality) provides an indirect measure of these three concepts.

Population resiliency is estimated in our analysis through the population simulation model, projecting future median abundance, population growth rates, and probabilities of the population falling below a preselected quasi-extinction level. These projections of risk in terms of species abundance are largely influenced by the starting population size estimates and the quasi-extinction thresholds. However, the future scenarios are also influenced by the potential for climate change to result in an increase in the magnitude of droughts (see Table D-1, Appendix D). Because of the relatively large current estimated population sizes and the long life span of these tortoises, our simulation model suggests no real risks of quasi extinction in the next 50 years of either the Arizona or Sonora areas of analysis under any scenarios even though slow population declines are projected. When we look to 100 years and beyond to 200 years, our simulation model suggests the risks of quasi extinction begin to increase to near 0.05 probability at 100 years and exceeding 0.2 probability for some scenarios at 200 years.

We measured the redundancy (distribution of tortoise populations) and representation (diversity) indirectly through projecting the likely quality and quantity of habitat spatial 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 (considering a 60-year future condition) maintains about 11,800 sq mi (7.6 million ac, 3.1 million ha) of habitat would remain in Arizona in either primary or secondary habitat quality (Table 6). Other scenarios project more favorable conditions. The habitat quality under the worst case future (60-year) condition is projected to be distributed across the species range in both Sonora and Arizona (Figure 28 and Figure 37, respectively), although in Arizona the habitat for this scenario is quite reduced compared to more favorable scenarios (Figure 36) or current conditions (Figure 24 and Figure 25).

6.7 Uncertainty, Assumptions, and Models

Uncertainty is an inherent part of any biological analysis of the status of a species. We developed this SSA based on the best available scientific information for the Sonoran desert tortoise; however, although voluminous in comparison to other species, there is much that remains unknown. 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 one projects farther and farther into the future. Some of the most critical unknowns are related to trying to predict how much environmental change is likely to occur in the future, and what is the likely response of the species to be to these changes? In the face of these and other uncertainties, we are required to make decisions about the species with the best information we have.

We addressed some of the unknowns and uncertainties by making reasonable assumptions about the species and its ecosystem based on other, similar species or systems, or basic ecological knowledge. We have attempted to explain and highlight many of the key assumptions that we have made as part of the analytical process documented in this SSA report. Two additional ways that we dealt with critical uncertainties were through using scenarios and predictive models. With those tools, whenever a key uncertainty exists, such as, "What is the current abundance of tortoises in Arizona?," we can consider a range of plausible possibilities. In the case of tortoise abundance, we considered two alternative densities and two alternative amounts of habitat to provide a range of four possible abundance estimates. Similarly, in the instance of, "How will future habitat conditions change?," we included different levels of habitat quality to use in our analysis to evaluate a range of possibilities. For the overall analysis, we used nine different scenarios in both the US and Mexican analysis areas in an effort to capture a range of results for the risk to the species.

Another way we explicitly dealt with uncertainties in this analysis of a complex system was to use models to help us simplify the information. In general, quantitative models are useful if they help us make better decisions by incorporating large amounts of information and explicitly showing our assumptions (Starfield 1997, pp. 261–263). The two primary modeling systems we incorporated were the geospatial habitat analysis of both current and future conditions and the population simulation model to project the future changes in abundance of the tortoise under different scenarios of habitat conditions and incorporating the effects of increasing magnitude of drought associated with climate change. While these models can output seemingly very specific quantitative results, they are only a simulation and by no means are intended to predict the future with a high degree of certainty. For example, the actual amount of potential habitat or number of tortoises on the landscape, both currently and in the future, are most likely different than what we report here (note that we round the abundance of tortoises to the nearest 10,000). However, the models are built on our understanding of the ecological system that supports the tortoises and the influences in that system. Therefore, the models represent our best understanding of these systems and the plausible implications of changing environmental conditions in the future in terms of the future risk of extinction to the tortoise. The models give us, not a precise prediction, but rather the range of likely expected future status of the tortoise populations given what we currently know, and do not know, about the species and the environmental conditions.

Appendix A: Glossary

Admixture- the mixing of genetic material from two different species

Annual- having a yearly periodicity; living for one year

Bajada- a broad alluvial slope extending from the base of a mountain range out into a basin and formed by coalescence of separate alluvial fans

Biotic community- a group of interacting species coexisting in a particular habitat

Carapace- the hard upper part of the shell

Climate- prevailing mean weather conditions and their variability for a given area over a long period of time

Climate change- a change in one or more measures of climate that persists over time, whether caused by natural variability, human activity, or both

Cumulative effects- when several seemingly separate effects combine to have an effect greater than their individual effects

Drought- a prolonged period of abnormally low precipitation

Ecological diversity- the variation in the types of environmental settings inhabited by an organism

Extinction- the state or process of a species, family, or larger group disappearing from its entire range

Extirpation–the loss of a population or a species from a particular geographic region

Fallow- land that has undergone plowing and harrowing and has been left unseeded for one or more growing seasons

Fecundity- the potential reproductive capacity of an organism or population

Forage- to search for food or the food, itself

Fragmentation- the state of being broken into separate parts

Genetic diversity (genetic variability)- the genetic measure of a tendency of individual organisms of the same species to differ from one another

Geophagous- to 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

Gular shields- large, extended scales underneath the throat of male tortoises

Invasive species- a species that is not native to an ecosystem and which causes, or is likely to cause, economic or environmental harm or harm to human health

Introgression- the entry or introduction of a gene from one gene complex into another (as by hybridization)

Morphological- referring to the structure or form of an organism

Microsite- a small geographical area which exhibits markedly different ecological characteristic from the surrounding area.

Nonnative- originating in a different region and acclimated to a new environment

Ossify- to harden into bone

Potassium Excretion Potential (PEP)- an index of water, nitrogen, and potassium levels in a plant that affects a tortoise's ability to efficiently excrete potassium

Plastron- the hard bottom or ventral part of the shell

Quasi-Extinction- the probability of abundance declining to less than a pre-determined abundance threshold

Redundancy- the ability of a species to withstand catastrophic events

Refugia- an area in which animals may escape from or avoid a predator or environmental conditions

Representation- the ability of a species to adapt to changing environmental conditions

Reproductive effort- the resources an organism devotes to reproduction, often simply measured as the number of offspring produced

Resiliency- the ability of a species to withstand stochastic events

Source- the human-produced or natural origins of a stressor; the mechanism of an impact or benefit to a species

Stochastic events- arising from random factors such as weather, flooding, or fire

Stressor- Any physical, chemical, or biological alteration of the environment that can lead to an adverse response by individuals or populations of a species

Taxon- a group of organisms classified by their natural relationships or genetics

Taxonomic- pertaining to the classification of animals and plants.

Thermoregulation- the process by which body temperature is established and maintained

Viability- viability is not a specific state, but rather a continuous measure of the likelihood that the species will sustain populations over time.

Appendix B: GIS Analysis Report

Developing GIS Data Layers and Analysis for Sonoran Desert Tortoise (*Gopherus morafkai)* Species Status Assessment (SSA) September 2015

Introduction

Background Information

The Sonoran desert tortoise (*Gopherus morafkai;* hereafter SDT) is a species of gopher tortoise native to portions of Arizona and northwestern Mexico. Sonoran desert tortoises occur in eight distinct biotic communities but primarily on rocky (often granitic rock), steep slopes, bajadas (lower mountain slopes and alluvial fans) and in paloverde-mixed cacti associations, within the Arizona Upland and Lower Colorado River subdivisions of Sonoran desertscrub vegetation types. Valley bottoms and washes may be used for dispersal. Approximately 95% of all observed tortoise occurrences range between 900 to 4,200 feet (274 to 1,280 m) in elevation (Zylstra and Steidl 2009, p. 8).

Purpose

This study provides geographic/spatial data and models showing the location and extent of USFWS-defined predicted potential habitat of the Sonoran desert tortoise and associated threats based on specific spatial criteria.

Analysis Area

The extent of the GIS work and spatial modeling is a variation of the SDT distribution boundary developed by the Arizona Interagency Desert Tortoise Team, adopted from recent genetic research (Edwards *et al*. 2015, Edwards 2015). This boundary represents only our area of analysis. Actual tortoise distribution may go beyond this area. As explained in the Species Status Report for the Sonoran Desert Tortoise (SSA Report), in the northern part of the study area, a genetic contact zone in and near the Black Mountains was removed to exclude what are now considered to be Mojave desert tortoises, and the southern part of the study area (a genetic contact zone) was reduced to exclude what are now considered to be a separate Sinaloan lineage of desert tortoises (see Figure B-1.). All spatial data layers will be “clipped” to this boundary for area calculations and analysis.

Data Limitations

All source datasets used were developed by entities outside the USFWS. All datasets used are publicly available. The quality and accuracy of these data (ecological and spatial) may vary. Remotely sensed data products and large national datasets may contain inherent errors of omission and commission. Current landcover/landuse status may differ from the data displayed in the analysis. Actual, on-the-ground, quality and/or condition of mapped covertypes is not addressed. No field verification or reviews of ancillary datasets/aerial imagery were done to verify the accuracy of the data. Raster data has a minimum spatial resolution of 30 meters. This dataset, analysis, and all maps/products created from it are subject to change.

Projections and Transformations

For this project, all data was projected into North American Albers Equal Area Conic, North American Datum (NAD) 1983. Typically, the raster datasets are downloaded in WGS 84, or other geographic coordinate systems. Re-projecting to Albers does slightly alter the shape of the pixels, but the change is nearly proportional, so there is negligible effect to the acreage of each pixel.

GIS Platform

All GIS analysis and mapping work was done using ArcGIS 10.1 and 10.2.

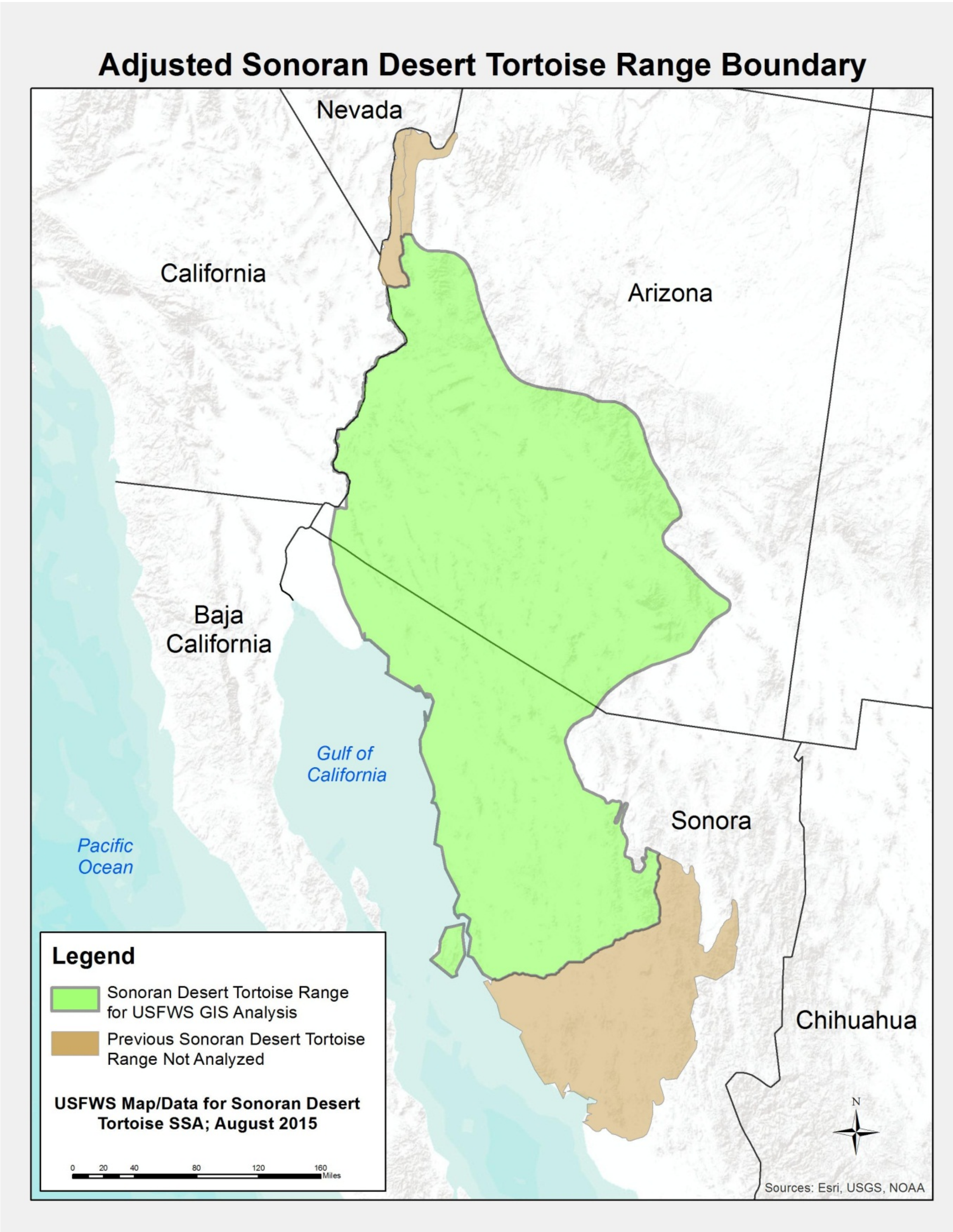


Figure B-1. SDT Distribution Boundary and USFWS Analysis Area.

Potential Habitat Analysis

For this GIS analysis, potential habitat for SDT is defined by a specific spatial relationship derived from available/public datasets. This spatial analysis is designed to provide a landscape-scale depiction of the relationship between several different spatial data layers that are relevant to SDT habitat. No attempt is being made to define or describe actual, on-the-ground SDT habitat. We recognize that this is a very course 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.

Data Sources

The primary data sources for the analysis include;

1. **Landcover (U.S.):** USGS LANDFIRE 2012, Existing Vegetation Type (EVT) raster data. This is a detailed national dataset, which can be downloaded off the USGS LANDFIRE website. This dataset is useful for identifying detailed grassland, shrub, and forested vegetative communities. The data is collected at a 30-meter spatial resolution.
2. **Landcover (Mexico):** The National Institute of Statistics and Geography (Instituto Nacional de Estadística y Geografía-INEGI) has produced a 1993 (Serie II) and 2001 (Serie III) 1:250,000 scale Uso de Suelo (Land Use) vector (polygon) digital map. INEGI's landuse/landcover datasets, Serie II and Serie III were also derived using Landsat imagery, but were created utilizing manual methods. Landuse/landcover types were visually interpreted from the Landsat imagery. Polygons were digitized to delineate LULC types and then verified with fieldwork.
3. **Elevation:** USGS National Elevation Dataset (NED) 2009 is a national raster dataset which can be downloaded from the National Map. The data is collected at a 30-meter resolution. This elevation data was available for both the U.S. and Mexico.

Habitat Criteria

For this spatial model, three criteria were used to predict potential habitat for SDT. These criteria were derived from the two data sources mentioned above. These criteria were determined through literature research and discussions with USFWS biologists.

A. **Elevation range:** Elevations from 274 meters to 1280 meters were extracted and used as a template for selecting the other criteria. Elevations below and above the range were not considered as suitable habitat. NOTE: Some Sonoran desert tortoises do occur at lower elevations in Mexico (Rosen *et al*. 2014e). In order to meet deadlines, and save geoprocessing time, one elevation model was used for the entire study area.

B. **Slope angle:** Slope was used as a general representation of ruggedness, helping to focus potential habitat identification in and around mountainous areas. Areas with slope angles of 5% or greater were considered either medium or high suitability. Areas with slope angles below 5% were considered either medium or low suitability. Slope is calculated, in the ArcMap Spatial Analyst tool. Higher and lower slope percentages were also examined (2.5% and 10%). Because of the low resolution of the source elevation data, little difference was observed between the three slope values.

C. **Landcover/Vegetation:** Specific vegetation covertypes were extracted from the LANDFIRE landcover data and INEGI landcover data, which were considered to have some relative association to SDT. These covertypes were classified as High Value, Medium Value, or Low Value based on the vegetation composition and landscape position identified in the class name (see Tables 1 & 2 for vegetation covertypes used). Covertypes were chosen based on their ecological description in relation to potential tortoise habitat. Many of these covertypes have only a small percentage of coverage within their respective classes (see Table 1.), but were left in the study, since there was some presence of occurrence.

"Union" Geoprocessing Tool

To analyze the relationship of these different layers, the Union geoprocessing tool was used. Union calculates the geometric union of any number of feature classes and feature layers (Figure B-2.). All input feature classes or feature layers must be polygons. The output feature class will contain polygons representing the geometric union of all the inputs as well as all the fields from all the input feature classes. See below for examples of how attribute values are assigned to the output features (Esri, Inc.).

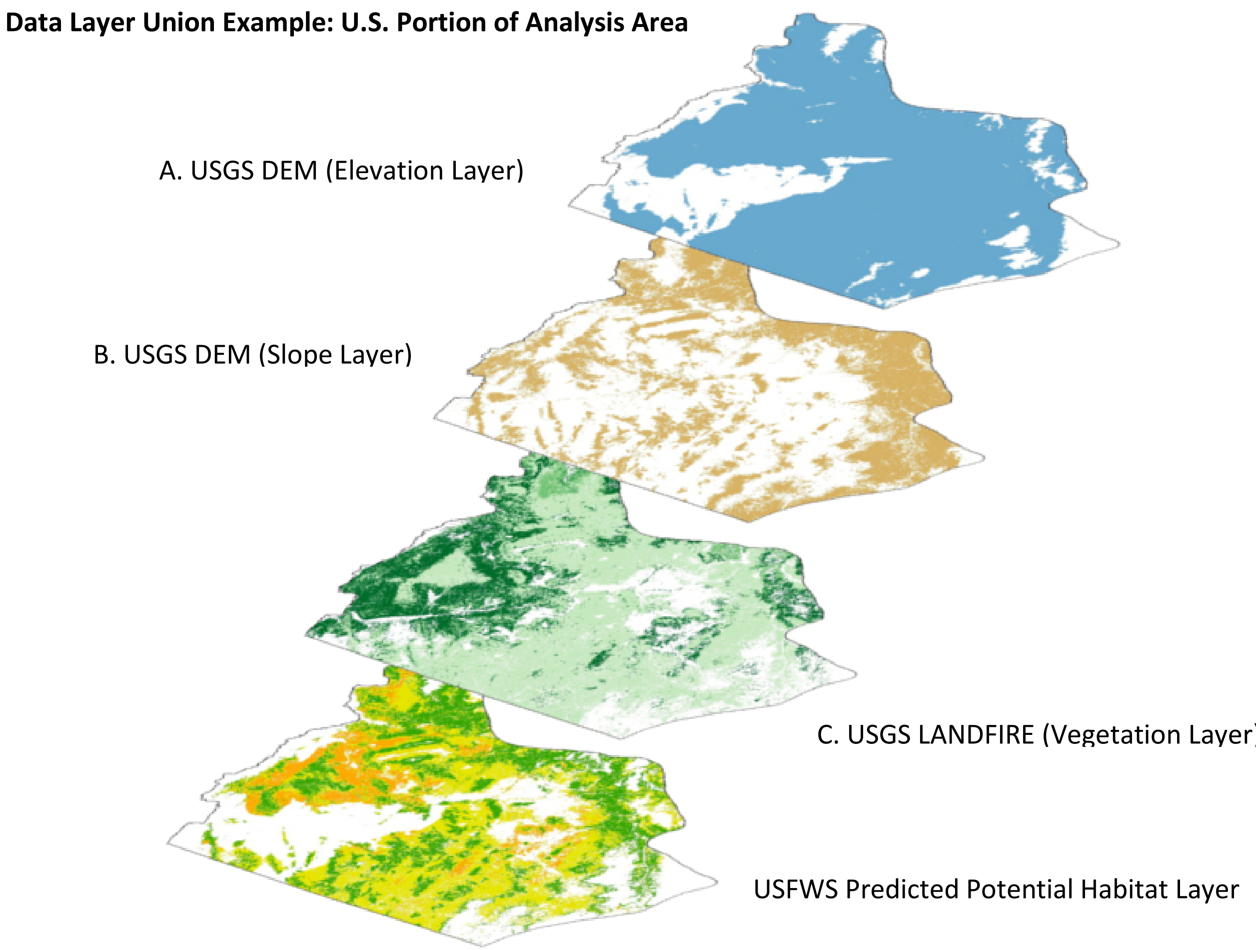


Figure B-2. Visualization of the union process.

Union does the following:

- Determines the spatial reference for processing. This will also be the output spatial reference. For details on how this is done, see Spatial Reference. All the input feature classes are projected (on the fly) into this spatial reference.
- Cracks and clusters the features. Cracking inserts vertices at the intersection of feature edges; clustering snaps together vertices that are within the x,y tolerance.
- Discovers geometric relationships (overlap) between features from all feature classes.
- Writes the new features to the output.

As mentioned above, this process does slightly alter the shapes of the new (unioned) polygons created, which can slightly alter the calculated acreages of the polygons (relative to pre-union acreage). This change is negligible, usually much less than one percent.

Ranking

Potential habitat was given a relative ranking based on how the spatial data, with the three geographic parameters (elevation range, slope, and vegetation cover type), related to one and other (High, Medium, and Low; explained further below). This ranking is based on this relative spatial relationship only and not an expression of true, on-the-ground, potential habitat quality.

Spatial Analysis

All High, Medium and Low Value landcover/vegetation cover types were dissolved (geoprocessing tool) together based on their rank (High, Med., Low). This process removes the individual/original classification, creating fewer polygons, which saves time in future geoprocessing exercises. The spatial data model was constructed by unioning the elevation, slope and the dissolved landcover layers into one large layer. This provides a "wall-to-wall" coverage within the SDT distribution area, carrying attributes from each of the elevation, slope and vegetation classes for each polygon. Within the data table of this "unioned" feature class, each polygon will have a numeric value representing the presence/absence of the three primary criteria;

Vegetation: All polygons will have the following "VegRank" attribute (Tables B-1 and B-2):

100=High Value
200=Med. Value
300=Low Value
0=no value

Elevation: All polygons will have the following "ElevRank" attribute:

10=Falls within the 274 m to 1,280 m range.
0=Outside of the 274 m to 1,280 m range.

Slope: All polygons will have the following "SlpRank" attribute:

1=5% slope or greater.
0=Less than 5% slope.

Every polygon will have a total rank (TotalRnk) based on the vegetation, elevation and slope attributes added together. Below is a chart showing the numerical rankings for all potential habitat identified.

Total (Habitat) Rank	Numeric Value (TotalRnk)
High	111 (100+10+1 = High veg, in elev. range, 5%+ slope)
Medium	110 (100+10=0 = High veg, in elev. range, less than 5% slope)
High	211 (200+10+1 = Med. veg, in elev. range, 5%+ slope)
Medium	210 (200+10+0 = Med. veg, in elev. range, less than 5% slope)
Medium	311 (300+10+1 = Low veg, in elev. range, 5%+ slope)
Low	310 (300+10+0 = Low veg, in elev. range, less than 5% slope)

Numerical values that fall outside of the above chart will have no potential habitat value in this analysis.

Table B-1. Landfire (2012) Cove rtypes for predicted potential habitat in Arizona.

Notes:

1. All Human development/impact cover types were not included.

2. Forested cover types were not included.

3. Cover types thought to be beyond the geographic range/area of the SDT were not considered.

High Value Cover Types	***Percentage of Type within each Value****
Sonoran Paloverde-Mixed Cacti Desert Scrub	96.8%
Sonoran Mid-Elevation Desert Scrub	3.0%
Sonoran Granite Outcrop Desert Scrub	0.2%
Medium Value Cover Types	
Mojave Mid-Elevation Mixed Desert Scrub	44.0%
Inter-Mountain Basins Semi-Desert Grassland	24.3%
North American Warm Desert Sparsely Vegetated Systems (I & II)	15.7%
Sonora-Mojave Semi-Desert Chaparral	9.3%
Madrean Oriental Chaparral	3.7%
Inter-Mountain Basins Semi-Desert Shrub-Steppe	1.6%
Coleogyne ramosissima Shrubland Alliance	1.4%
Low Value Cover Types	
Sonora-Mojave Creosotebush-White Bursage Desert Scrub	87.0%
Mogollon Chaparral	8.3%
Quercus turbinella Shrubland Alliance	4.2%
Inter-Mountain Basins Big Sagebrush Shrubland	0.3%
Southern Rocky Mountain Montane-Subalpine Grassland	0.3%
Quercus gambelii Shrubland Alliance	0.1%
Inter-Mountain Basins Sparsely Vegetated Systems	<0.1%
Colorado Plateau Blackbrush-Mormon-tea Shrubland	<0.1%
Rocky Mountain Lower Montane-Foothill Shrubland	<0.1%
Rocky Mountain Gambel Oak-Mixed Montane Shrubland	<0.1%
Cercocarpus montanus Shrubland Alliance	<0.1%

* Percentages calculated from original raster data pixel count.

Table B-2. Mexico INEGI Landcover data; Cover types for predicted potential habitat in Mexico.

High Value Cover Types	***Percentage of Type within each Value***
Desert Scrub/Shrub (Tiny leaves)	60%
Desert Scrub, Sarcocaule Scrub (copal, matacora, ocotillo)	17%
Thorny Shrub Mix/Mesquite Xeric (Huisache/Palo Verde/Acacia Mix)	12%
Secondary Scrub/Shrub (Desert scrub, tiny leaves)	3%
Desert Scrub, Crasicaule Thicket (Large Cactus/Sahuaro)	<1%
Desert Scrub, Mixed (Mixed Cactus)	<1%
Secondary Scrub/Shrub (Thorny scrub mix, mesquite, xeric)	<1%
Secondary Scrub/Shrub (Desert scrub, cactus)	<1%
Medium Value Cover Types	
Managed Pasture ("Induced" Grassland)	3%
Natural Grassland	2%
Desert Scrub/Shrub (Rosette leaves/agaves on gravely slopes)	<1%
Mesquite Forest	<1%
Secondary Grassland	<1%
Low Value Cover Types	
Oak Forest	<1%
Secondary Scrub/Shrub (Oak Scrub)	<1%
Unvegetated/Non-vegetated	<1%

General Results

Below are the calculated areas (Table B-3.) and distribution (Figure B-3.) for all potential SDT habitat the U.S. and Mexico.

Table B-3. Calculated areas for Potential Habitat Rankings within Study Area

U.S. Portion		
Totals	Acres	Square Miles
Study Area	25,713,643	40,178
High Value	5,519,789	8,625
Med. Value	7,983,153	12,474
Low Value	1,982,148	3,097
Total	15,485,090	24,196
Remainder/ No Habitat	10,228,554	15,982
Mexico Portion		
Totals	Acres	Square Miles
Study Area	16,486,776	25,761
High Value	2,783,968	4,350
Med. Value	6,001,091	9,377
Low Value	21,838	34
Total	8,806,897	13,761
Remainder/No Habitat	7,679,879	12,000
U.S. and Mexico Combined		
Totals	Acres	Square Miles
Study Area	42,200,419	65,939
High Value	8,303,757	12,975
Med. Value	13,984,244	21,851
Low Value	2,003,986	3,131
Total	24,291,987	37,957
Remainder/No Habitat	17,908,433	27,982

Notes:

Percent of Study Area in U.S. = 61%, in Mexico = 39%
Percent of Study Area identified as potential habitat = 58%
Percent of Study Area identified as High Value potential habitat = 20%
Percent of Study Area identified as Medium Value potential habitat = 33%
Percent of Study Area identified as Low Value potential habitat = 5%
Percent of potential habitat in U.S. = 64%
Percent of potential habitat in Mexico = 36%

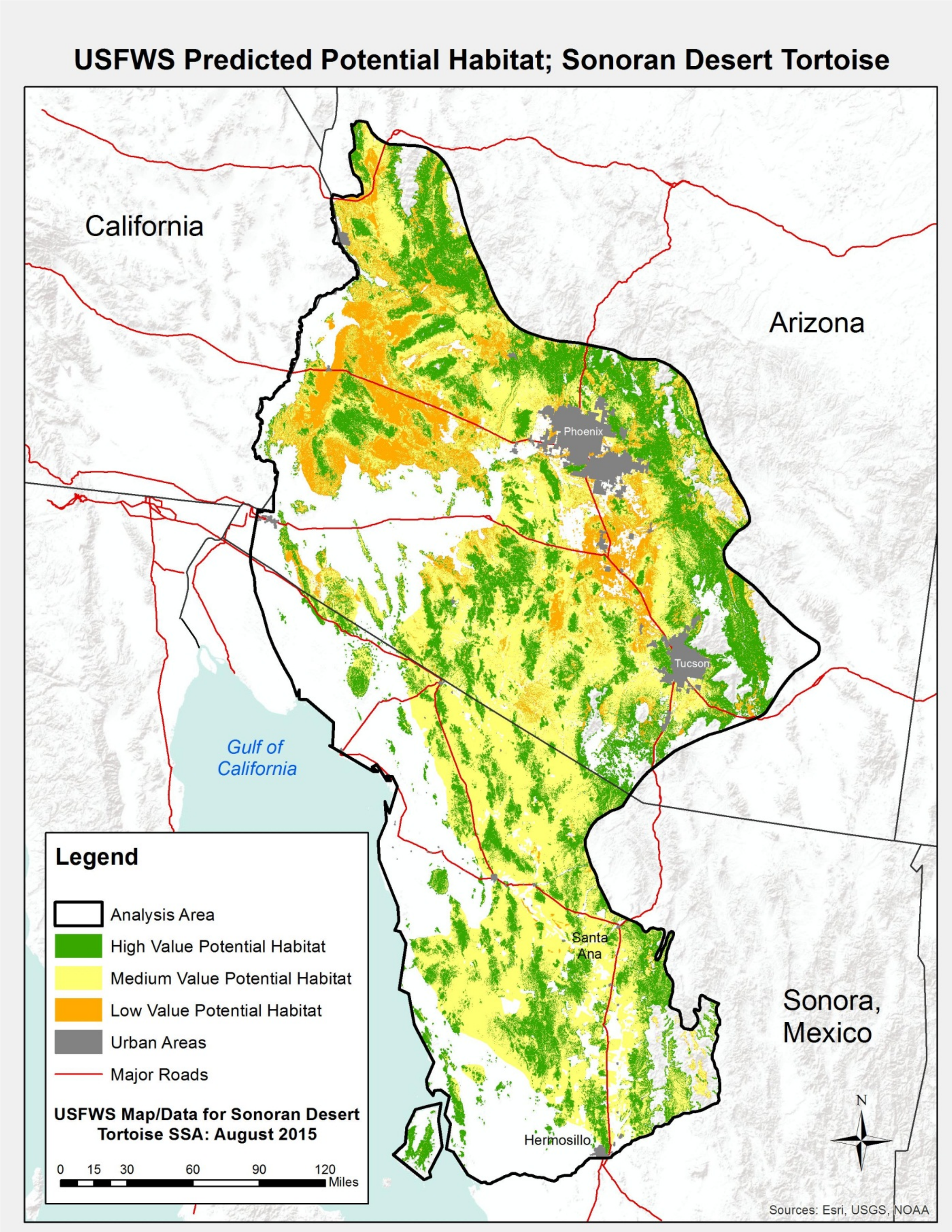


Figure B-3. Predicted potential Sonoran desert tortoise habitat from GIS analysis.

Evaluation of Potential Habitat Analysis with Available Observation Data

We attempted to evaluate the accuracy of the potential habitat analysis by overlaying SDT observation records provided by Arizona Game & Fish Department (AGFD)[1] with the potential habitat layer. However, the observation records were comprised of 4-square-kilometer polygonal plots rather than point data, making interactions with the 30-m resolution potential habitat data not possible because most of the observation data overlapped multiple potential habitat categories. Therefore, it was not possible to compare the observation data within potential habitat categories. The spatial relationship was simplified to look at plots that intersected the habitat layer, or did not (see Figure B-4.). The AGFD database contained a total of 2,000 species records from Arizona. The USFWS SDT analysis contained 1,734 of those records (some are in north of the analysis area that we considered Mojave desert tortoises). Of the 1,734 records within the analysis, 1,708 (98.5%) intersected the potential habitat layer.

[1] In addition, We note that the observational data provided by AGFD was collected over a large temporal range (1930's – 2014) by a variety of different sources, with different confidence levels, and general Native American lands were not included. Finally a large proportion of the data come from a relatively small number of long-term monitoring plots purposefully located in areas with good tortoise habitat and known to contain tortoises.

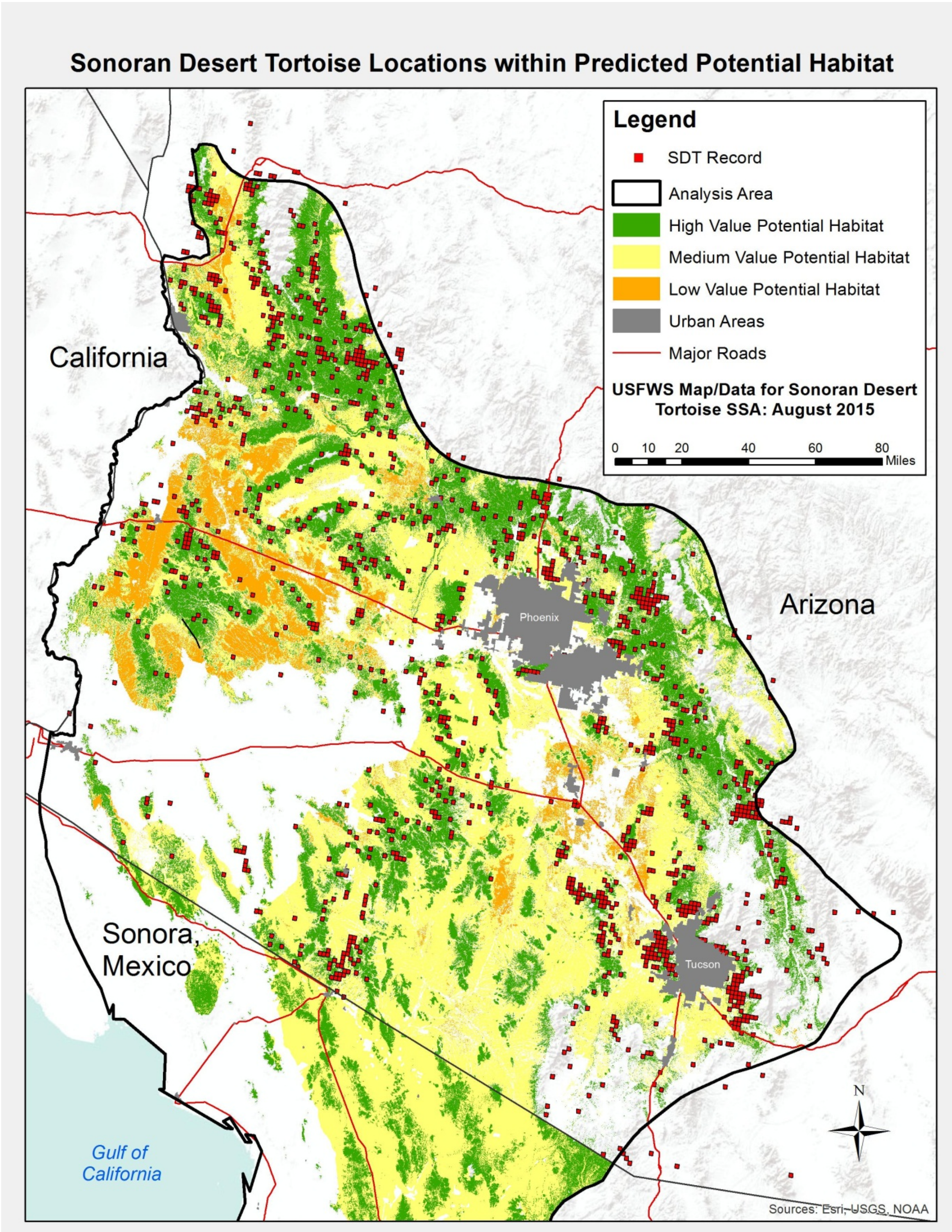


Figure B-4. AGFD Plots with USFWS potential habitat.

Protection Status & Threats Analysis

We developed a spatial representation of existing level of protection and potential threats related to the SDT. These data were collected from a variety of sources to conduct spatial analysis in relation to the potential habitat layers. To accomplish this, the union data processing technique was used to perform the analysis. As previously described, this union process combines the "overlaps" the different threat layers with the potential habitat layer. This overlap will show where the layers intersect, which can be calculated and displayed, indicating the portions of the potential habitat potentially susceptible to the threat. The majority of the threat data layers were only available for the U.S. portion of the Study Area. Some modeling based on available data layers for Mexico will be discussed below.

Data Sources
Spatial datasets were collected from the sources listed below. All datasets are publicly available, most are downloadable from the internet.

Conservation Biology Institute (CBI); Protected Areas Database, U.S., CBI Edition, v2
Land Ownership, U.S. (no ownership data available for Mexico)
U.S. Census Bureau, TIGER Data, 2012
Roads, major rivers, canals and drainages, for U.S.
ESRI, Inc. StreetMap and world datasets for ArcGIS 10.x
Road network, U.S., major roads Mexico
Department of Interior, Bureau of Land Management, Rapid Ecological Assessment (REA) SOD, 2010.
REA data was developed for Sonoran Desert ecoregion. Only data within Arizona was used.
Fire Occurrence: Current High Potential of Human and Naturally Caused Fire Occurrence
Invasive Vegetation: Invasive Upland Vegetation Species Current Predicted Distribution
Urban Footprint, U.S.: Urban Areas (U.S. Census Bureau)
Climate Change Effects: Long-Term Potential for Climate Change (4-km grid)
Instituto Nacional de Estadística y Geografía-INEGI (The National Institute of Statistics and Geography): Detailed road network for Mexico, and urban áreas data (extracted from landcover data).
World Database on Protected Areas (WDPA): Source for Protected Areas, Mexico.

Land ownership/Management and Protection Status/Urban Growth
Protected Areas Database, U.S., CBI Edition, v2: Though the union process, the CBI land ownership data was used to give each potential habitat polygon an ownership designation. Also, each ownership designation was given a management, or protection status descriptor, developed by USFWS biologists, to further describe the types, or levels, of protection occurring for that specific polygon. It was important to get a sense of not only areas there are considered protected by local, state or federal jurisdiction, but also to quantify areas where urban growth/development could occur in the long-term future.

<u>Ownership Designations:</u>
Federal Government: Owned by a Federal agency (NPS, USFS, BLM, etc.)
State Government: Owned by state of Arizona agency (parks, historic areas, trust lands etc.)
Local Governments: Owned by county or municipal governments (parks, open spaces, facilities, etc.)
Private: Owned by private citizens or entities.

Private Conservation: Owned by non-governmental conservation entities (TNC, etc.)
Tribal: Sovereign or trust Native American territories.
None: Ownership information not available.

Protection Status:

Managed: Land managed for wildlife habitat or low impact human activity (wilderness areas, wildlife management areas, preserves, some parks and monuments).
Multi-Use: Public land owned by public agencies (vast majority is Federal ownership), which allow more intrusive human activities (motorized vehicles, resource extraction, grazing, etc.) but provide some wildlife management benefits in addition to other uses. Also, includes Tribal/Native American lands.
Unprotected: Private lands with no indicated protection for wildlife or habitat.
Other: State Trust lands. Lands held by the state for the purpose of generating funds through leases, etc.
None: No protection status designated.

A similar, but simpler process was used for Mexico. Using the World Database on Protected Areas (WDPA) protected vs. unprotected areas for the Mexican portion of the Study Area were designated. Similar to the U.S. portion, the SSA report will describe and quantify the protection status for the entire predicted potential habitat within the Mexican portion. No urban growth potential was done for the Mexican portion.

Long-Term Urban Growth Potential (U.S. only)

This data was also used to provide a rough estimated projection of urban growth potential for the U.S./Arizona portion of the Study Area. The *Unprotected* and *Other* protection status features were extracted from the source ownership data. These layers, as compared with the other protection status layers, have the highest potential for future development. To further focus the relative usefulness of these layers, a “high growth potential” subset was extracted from the *Unprotected* and *Other* categories, to indicate where these areas might occur. Population growth projection maps created by the Maricopa Association of Governments (MAG 2013) were used as a guide for enhancing the CBI data layers. It should be noted that the MAG source maps were for display purposes only, and this data was not available for this analysis. High growth potential subsections of the *Unprotected* and *Other* data layers were estimated visually. This information may differ from MAG’s actual growth projection data. The SSA report discusses the impacts to predicted potential habitat generated by this spatial analysis.

The SSA report will describe and quantify the ownership and protection status for the entire predicted potential habitat within the U.S./Arizona portion of the study area.

Using Multiple Layers of Bureau of Land Management, Rapid Ecological Assessment SOD, 2010

The publicly available data layers created for the BLM Rapid Ecological Assessment program provided the basis for several of the threats spatial analysis. It should be noted that most of these data layer layers are, themselves, spatial models with limitations. However, they were the best available data sources to examine the relationships and potential effects of possible threats to our predicted potential habitat. Each of the data layers used for the analysis is listed below, brief analysis descriptions and excerpts from the metadata providing basic information on the development of that layer.

Urban Influence, U.S./Mexico;

The urban footprint dataset was used to develop an "urban influence" model, by creating a 10-km ringed buffer around urban areas with a human population of 2,500 or greater. This ringed buffer data was then, "unioned" with the potential habitat data to calculate areas of potential habitat within each 10 km rings.

Fire Occurrence: Current High Potential of Human and Naturally Caused Fire Occurrence;

This dataset shows the combination of high probability areas from two Maxent models that predict human and naturally caused fire occurrence. The data was "unioned" with the potential habitat data to calculate areas of potential habitat which could potentially fall within a fire risk scenario.

Caution should be exercised in interpreting this dataset, as it is based on an association between landscape factors and the locations of fire occurrences. This dataset does not provide information about the likely outcome of a fire. See the human and naturally caused fire occurrence datasets for more information and limitations (Department of Interior 2010).

Invasive Vegetation: Invasive Upland Vegetation Species Current Predicted Distribution:

This dataset depicts the current predicted distribution of major invasive vegetation species in the Sonoran Desert Ecoregion. The data was "unioned" with the potential habitat data to calculate areas of potential habitat which could potentially be threatened by the spread of predicted invasive vegetation.

This dataset is the combination of invasive vegetation mapped by LANDFIRE Existing Vegetation Type (v1.1), LANDFIRE Succession Classes (v1.0), NatureServe National Landcover (v27), Integrated Landscape Assessment Project current vegetation cover (draft), Tamarisk probability model (Jarnevich *et al*. 2011), Sahara mustard MaxEnt model developed for this REA(CBI 2011), and Tamarisk distribution lines (1965). Data used to create this dataset range from 1965 to 2011, some of which used imagery and plot data that are somewhat older (e.g., LANDFIRE used imagery 1999-2003). However, since sources were used in an additive fashion, this dataset can be taken to represent current predicted status around 2000 to present. This dataset is the result of several disparate predictions, each of which has inherent biases and data quality limitations. Care should be exercised in interpretation of this dataset. It is not appropriate to assume that this dataset has high spatial accuracy at local scales; rather, it can be taken as a rough measure of where invasive vegetation species are likely to occur at the ecoregion scale (Department of Interior 2010).

Climate Change Effects: Long-Term Potential For Climate Change (4 KM grid);

This dataset provides an estimate of areas of higher and lower potential for climate change impacts. The data was "unioned" with the potential habitat data to calculate areas of potential habitat which could fall within the various climate change risk categories identified in the data. The REA climate change data is the result of a fuzzy model that integrates changes in precipitation, runoff, potential natural vegetation, and summer and winter temperature. Normalized summer and winter temperature differences (change in temperature between 1968-1999 and 2045-2060 divided by standard deviation of PRISM temperature for 1968-1999) were converted to fuzzy values and the maximum value extracted. This was averaged with fuzzy values for change in runoff and normalized change in annual precipitation. This value was then combined with areas of potential natural vegetation change and the maximum value extracted to provide the final estimate of potential for climate change impacts. Caution should be exercised in interpreting this dataset. It provides one possible estimate of climate change impacts based on integration of statistically resampled regional climate projections based on boundary conditions from a single global climate model (ECHAM5) compared to current conditions (PRISM). It was not feasible in the scope of this REA to perform this analysis for other available climate projections; however, comparison of results across projections may provide additional insights as to the variability in areas of potential climate impacts. Please note that this dataset does not account for uncertainty of climate projections; this uncertainty is a combination of assumptions inherent in the model construction as well as spatial variability of climate observations over heterogenous landscapes (e.g., sparse weather stations recording past/current climate conditions, unevenly distributed across highly variable terrain). Also note that the impacts of climate change are likely to be highly specific to particular species and ecosystems. The factors integrated into this dataset are intended to provide an overall estimate across species and ecosystems. Additional analyses (outside the scope of this REA) would be required to address species-specific impacts due to climate (Department of Interior 2010).

Fragmentation/Human Footprint (Display Only)

The linear features (roads only) from the U.S. Census Bureau, TIGER data and the Instituto Nacional de Estadística y Geografía (INEGI) were used to depict a landscape-scale road network and indicate a "human footprint" representation for map displays used in SSA discussions. These data were not used for analysis.

Plains of Sonora, Mexico

The Plains of Sonora is a physiographic biotic subregion in the southern part of the Mexican portion of the Study Area (Brown, 1994). Since little spatial data was available to look at threats in Mexico, this area was used to assess the potential scope of the effects of non-native grasses and fire risk in low slope areas. A variety of literature has shown that these low slope grasslands are susceptible to fire occurrence and invasion of non-native grasses. For the spatial analysis, medium potential habitat areas (which primarily are determined with various vegetation types and less than 5% slope), were identified as susceptible. A more detailed description and analysis will be outlined in the SSA Report.

Results

All results and area calculations for all of the ownership/protection status and the threats analysis are discussed in the SSA Report. Descriptions of how the various data layers were used in the analysis are discussed below.

Conclusion

This report is a brief summation of the GIS data analysis (data layer usage and geoprocessing techniques) devised to help provide a spatial understanding of the location and extent of potentially suitable habitat for SDT and to analyze how specific threats may affect these areas. The larger SSA report will provide a more detailed discussion on the actual results and summaries of the various threat analysis scenarios.

Literature Cited

References are provided in Appendix E of the SDT SSA Report.

Data Websites/References

Arizona Game and Fish Department, Heritage Data Management System; Source for location monitoring plots; http://www.azgfd.gov/w_c/edits/species_concern.shtml

Conservation Biology Institute (CBI), U.S. Protected Areas Database (PAD-US CBI Edition, v2): Source for land ownership data, U.S. only; http://consbio.org/products/projects/pad-us-cbi-edition

Department of Interior, Bureau of Land Management, Rapid Ecological Assessment (REA) Sonoran Desert (SOD), 2010: Source for multiple threats datasets;
http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas/dataportal.html

Environmental Research Systems Institute, Inc. (esri); ArcGIS 10.1; Source of GIS platform, data layers and geoprocessing tools;
http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//001z00000003000000.htm
http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//00080000000s000000

Instituto Nacional de Estadistica Y Geografia (INEGI): Source for landcover and roads data, Mexico;
http://www.inegi.org.mx/

Maricopa Association of Governments (MAG): Population Growth and Arizona State Lands, Joint Planning Advisory Council, December, 2013 (Powerpoint presentation converted to PDF).

The Nature Conservancy: Digital representation of Brown and Lowe's "Biotic Communities of the Southwest" map (1979) developed by The Nature Conservancy in Arizona (2004). see www.azconservation.org for limitations.

U.S. Census Bureau,TIGER Products: Source for roads data layer;
https://www.census.gov/geo/maps-data/data/tiger.html

U.S. Geological Survey, LANDFIRE Existing Vegetation Type: Source for landcover data, U.S.;
http://www.landfire.gov/

U.S. Geological Survey, National Elevation Dataset (via The National Map): Source for Elevation data, U.S. and Mexico; http://ned.usgs.gov/#

World Database on Protected Areas (WDPA): Source for Protected Areas, Mexico;
http://www.protectedplanet.net/

Appendix C: Cause & Effects Tables

Template for Cause and Effects Evaluation

THEME: ?			
[ESA Factor(s): ?]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	*What is the ultimate source of the actions causing the stressor?*	See next page for confidences to apply at each step.	Literature Citations, with page numbers , for each step.
- Activity(ies)	*What is actually happening on the ground as a result of the action?*		
STRESSOR(S)	*What are the changes in evironmental conditions on the ground that may be affecting the species?*		
- Affected Resource(s)	*What are the resources that are needed by the species that are being affected by this stressor?*		
- Exposure of Stressor(s)	*Overlap in time and space. When and where does the stressor overlap with the resource need of the species (life history and habitat needs)?*		
- Immediacy of Stressor(s)	*What's the timing and frequency of the stressors? Are the stressors happening in the past, present, and/or future?*		
Changes in Resource(s)	*Specifically, how has(is) the resource changed(ing)?*		
Response to Stressors: - INDIVIDUALS	*What are the effects on individuals of the species to the stressor? (May be by life stage)*		
POPULATION & SPECIES RESPONSES	*[Following analysis will determine how do individual effects translate to population and species-level responses? And what is the magnitude of this stressor in terms of species viability?]*		
Effects of Stressors: - POPULATIONS [RESILIENCY]	*What are the effects on population characteristics (lower reproductive rates, reduced population growth rate, changes in distribution, etc)?*		
- SCOPE	*What is the geographic extent of the stressor relative to the range of the species/populations? In other words, this stressor effects what proportion of the rangewide populations?*		
Effects of Stressors: - SPECIES (Rangwide) [REDUNDANCY]	*What are the expected future changes to the number of populations and their distribution across the species' range?*		
Effects of Stressors: - SPECIES (Rangwide) [REPRESENTATION]	*What changes to the genetic or ecology diversity in the species might occur as a result of any lost populations?*		

This table of Confidence Terminology explains what we mean when we characterize our confidence levels in the cause and effects tables on the following pages.

Confidence Terminology	Explanation
Highly Confident	We are more than **90% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by documented accounts or research and/or strongly consistent with accepted conservation biology principles.
Moderately Confident	We are **70 to 90% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by some available information and/or consistent with accepted conservation biology principles.
Somewhat Confident	We are **50 to 70% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by some available information and/or consistent with accepted conservation biology principles.
Low Confidence	We are less than **50% sure** that this relationship or assumption accurately reflects the reality in the wild, as there is little or no supporting available information and/or uncertainty consistency with accepted conservation biology principles. Indicates areas of high uncertainty.

THEME: Altered Native Plant Communities/Nonnative Grasses			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Nonnative grasses, primarily buffelgrass, red brome, and *Schismus* spp. (Mediterranean grass), of African and Mediterranean natural origin, have been invading desertscrub habitats, expanding their distribution within the range of the tortoise, limited only by each species' ecological parameters for survival and ongoing management actions.	**Highly confident** that nonnative grasses have become established at various densities and have continued to spread throughout the range of the tortoise over time.	Stevens and Falk 2009, p. 420; Bahre 1991, p. 155; D'Antonio and Vitousek 1992, pp. 65, 75; Brooks 1999, p. 13; Brooks 2001, p. 4; Brooks and Pyke 2001, p. 3, 5; Brooks and Esque 2002, p. 337; Esque *et al*. 2002, p. 313; Van Devender 2002, p. 16; Brooks and Matchett 2006, p. 148; DeFalco 2007a, p. 1; Zouhar *et al*. 2008, p. 157; Abella 2010, p. 1249; AGFD 2010a, p. 13; Strittholt *et al*. 2012, pp. 89-92; AIDTT 2015, Appendix A
- Activity(ies)	Historically, some of these plants were purposely introduced for soil stabilization and livestock forage in Arizona, while others were inadvertently introduced. In Mexico, land continues to be cleared for buffelgrass cultivation as livestock pasture. Any activity that results in soil disturbance potentially provides conditions for nonnative grass invasion, although they can invade undisturbed habitats, too. Vehicles, in particular, disperse seeds along roadways and trails. In Arizona, these plants are now considered noxious weeds in many areas, are no longer intentionally planted, and are actively managed against (remove and control introduction and spread) as agency resources allow (see Appendix A of "Sonoran Desert Tortoise Candidate Conservation Agreement"). Fire is an activity that results in disturbance and can result in invasion by nonnative species in burned areas (see discussion under Altered Fire Regime).	**Highly confident** of historical and current land activities that result(ed) in the establishment and spread of nonnative grasses on the landscape.	D'Antonio and Vitousek 1992, p. 65; Bahre 1991, p.156-158; Stevens and Falk 2009, p. 420; Franklin and Molina-Freaner 2010, p. 1664; Walker and Pavlakovich-Kochi 2003, p. 14; Franklin *et al*. 2006, entire; Búrquez-Montijo *et al*. 2002, p. 133; Arriaga *et al*. 2004, p. 1505; Taylor *et al*. 2012, p. 4; Esque *et al*. 2002, p. 313; Bean 2015; AIDTT 2015, Appendix A; McDonald and McPherson 2013, p. 26; Salo 2005, pp. 168-170
STRESSOR(S)	Nonnative grasses crowd out native plants through competition for space, water, and nutrients. Based on the ecological and climatic conditions present, nonnative plant species can completely replace native plants and shift the community composition, especially with multiple burns (see discussion under Altered Fire Regimes). As a result, the stressors include presence of nonnative species and reduction or elimination of native species.	**Highly Confident** of the potential for competitive pressure of nonnative grasses on native plant species and variability over time and space based on ecological and climatic conditions present.	Stevens and Fehmi 2008, p. 383-384; Olsson *et al*. 2012a, entire; 2012b, pp. 10, 18-19; McDonald and McPherson 2011, pp. 1150, 1152; Franklin and Molina-Freaner 2010, p. 1664; Gray and Steidl 2015, p. 1982, Table 2
- Affected Resource(s)	Native forage and cover plant species used by tortoises are affected. Tortoises are chiefly herbivorous and forage on a wide variety of native herbs, grasses, woody plants, and succulents. Tortoises also use tree, shrub, subshrub, and cactus species as protective cover and for thermoregulation when active above ground during such activities as foraging, basking, and reproductive behaviors. Nonnative grasses are also used as forage by tortoises, ranging in nutritional potential depending on plant species and age class of tortoises using them. Of the nonnative plant species, only red brome, *Schismus*, and *Erodium cicutarium* (redstem filaree) are frequently eaten and considered relatively important nonnative species in their diet, although sharp seeds (particularly from red brome and cheatgrass) can get lodged between the tortoises' upper and lower jaw and become a source of infection. Navigation of tortoises through habitat invaded by buffelgrass may be negatively affected, especially for tortoises in the hatchling and juvenile size classes. Tortoises have been shown to avoid habitat with dense stands of nonnative grasses, particularly buffelgrass.	**Highly confident** that nonnative grasses can negatively affect the quantity and distribution of native forage and cover plant species used by tortoises within their home range. **Moderately confident** that buffelgrass can negatively affect mobility of tortoises and can lead to avoidance of habitat patches where nonnative grass reaches high density.	Ogden 1993, pp. 1–8; Van Devender *et al.* 2002; pp. 175–176, 183; 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, Gray 2012, pp. 18, 47-48; Esque *et al*. 2003, p. 107; DeFalco 2006, p. 5; McLuckie *et al*. 2007, p. 8; Rieder *et al*. 2010, p. 2436; Medica and Eckert 2007, p. 447; Hazard *et al*. 2010, pp. 139–145; Nagy *et al*. 1998, pp. 260, 263
- Exposure of Stressor(s)	Tortoise exposure to effects from nonnative grasses is generally broad over space and time as they generally occur in the specific habitats used by all life stages of tortoises. Management actions on the landscape can reduce the exposure of tortoises to the effects of the stressors.	**Moderately confident** in tortoise exposure to effects of nonnative grasses.	D'Antonio and Vitousek 1992, p. 65; Bahre 1991, p.156-158; Stevens and Falk 2009, p. 420; Thomas and Guertin 2007, Appendices I and II; Gade 2015; Rogstad 2008, p. 9; Zylstra and Swann 2009, p. 16; USNPS 2014, pp. 7-8; Van Devender and Dimmitt 2006 pp. 3, 6, 10; Burquez-Montijo *et. al*. 2002, p. 138–139; AIDTT 2015, Appendix A

THEME: Altered Native Plant Communities/Nonnative Grasses			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
- Immediacy of Stressor(s)	To varying degrees, nonnative grasses are considered a stressor to tortoises in the past, present, and future.	**Highly confident** in the history of nonnative grass invasion and potential for continued invasion in the future.	D'Antonio and Vitousek 1992, p. 65; Bahre 1991, p.156-158; Stevens and Falk 2009, p. 420; Thomas and Guertin 2007, Appendices I and II; Rogstad 2008, p. 39; Tim Hughes, USBLM pers. comm., 2015; OPCNM 2011, p. 22; 2014, p. 36; Zylstra and Swann 2009, p. 16; Edwards and Leung 2009, p. 327; Bean 2015, entire; Gade 2015, entire; AIDTT 2015, Appendix A
Changes in Resource(s)	Nonnative grasses can crowd out (compete with) native forage and cover plant species through competition for space, water, and nutrients affecting native plant species density and species composition within invaded areas. Competitive pressure varies by species involved, habitat setting, precipitation patterns and amounts, and other environmental and climatic conditions. In highly invaded habitat areas, less native plant cover, lower native plant diversity, lessened availability of high-PEP plant species important for regulating hydration levels in tortoises, lower regeneration of shelter plant species (shrubs and trees) are expected.	**Moderately confident** that in habitat areas affected by high-density nonnative grass invasions, negative effects to tortoise plant forage and cover species can be expected but largely contingent on environmental and climatic variability which changes over time and space. Confidence fluctuates over time and space from high (with conditions favoring nonnative plant species) to low (with conditions that favor native plant species).	Oftedal 2002, entire; Stevens and Fehmi 2009, p. 383-384; Olsson *et al*. 2012a, entire; 2012b, pp. 10, 18-19; McDonald and McPherson 2011, pp. 1150, 1152; Franklin and Molina-Freaner 2010, p. 1664; Gray and Steidl 2015, p. 1982, Table 2
Response to Stressors: **- INDIVIDUALS**	The response of individuals to these stressors will depend on timing and extent of annual rainfall. In high rainfall years, opportunities for hydration increase and the relative degree of nutrition in the tortoises forage base may not be as important which may lessen the effect on a tortoise's annual reproduction and survival in areas invaded by nonnative grasses. During dry years, lower native plant diversity and density will exacerbate effects of nonnative grasses (which tend to out-compete natives during periods of stress) by limiting the availability of high PEP plant species which affects a tortoises' ability to manage its water balance via physiological constraints. Nonnative annuals such as red brome and *Schismus* spp. have short-lived seed banks and may be reduced in density during dry years. Nonnative grasses can reduce forage capacity of high-nutrition native plants in invaded areas; reduced forage quality and quantity can reduce fitness of individual tortoises at all life stages; and increased time and energy spent in foraging activities could increase predation risk. Lower fitness due to lower nutrition may reduce reproductive potential in individuals, survival and recruitment of juveniles, and survival of adults. The effect of nonnative grasses on tortoise nutrition is somewhat ameliorated by the fact that tortoises can and do forage to some extent on nonnative grasses which could make up for losses in species composition and biomass of native species. Most of these nonnative forage species are a high source of energy and considered highly nutritious to adult tortoises. Nonnative grasses, especially buffelgrass, may impede movement if grasses are at peak densities. Reduced canopy cover can increase body temperatures and reduce periods of surface activity, making individuals more susceptible to dehydration and predation.	**Highly confident** that effects to individuals described will occur in areas densely invaded by nonnative grasses. **Somewhat confident** that effects to individuals described will occur in areas moderately invaded by nonnative grasses. **Low confidence** that effects to individuals described will occur in areas sparsely invaded by nonnative grasses.	Ogden 1993, pp. 1–8; Van Devender *et al*. 2002; pp. 175–176, 183; Oftedal 2007, p. 21; Ernst and Lovich 2009, p. 562; Meyer *et al*. 2010, pp. 28–29, 44–48, Gray 2012, pp. 18, 47; Gray and Steidl 2015, p. 1986; Esque *et al*. 2003, p. 107; DeFalco *et al*. 2006, p. 5; McLuckie *et al*. 2007, p. 8; Rieder *et al*. 2010, p. 2436; Medica and Eckert 2007, p. 447; Hazard *et al*. 2010, pp. 139–145; Nagy *et al*. 1998, pp. 260, 263; Olsson *et al*. 2012a, entire

THEME: Altered Native Plant Communities/Nonnative Grasses			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	The literature has focused on effects of nonnative grasses on individual tortoises; literature documenting population-level effects has thus far not been identified, even though these nonnative grasses have occurred within long-term monitoring plots for decades and in some cases, over a century. Theoretically, lower annual survival of juveniles and adults and lower reproductive output over time could reduce population sizes and lower overall population resiliency, but these population-level effects have not been identified through long-term monitoring, documented in the literature, or have otherwise not been identified in our review of existing literature. Population-level effects would only become discernable (via current research methods) over an extremely long period of time (decades to centuries) due to the life history and longevity of the species which is well-outside both the existing period of monitoring and our ability to predict such population-level effects in the foreseeable future. This stressor may increase the species' susceptibility to other stressors in areas heavily invaded by nonnative grasses.	**Low confidence** in potential population-level effects because of a lack of research and observation from the sampling of long-term monitoring plots.	
- SCOPE	One or more species of nonnative grass occurs across most of the range of the species; becoming naturalized in some regions. Density of nonnative grasses likely varies considerably in time and space depending on ecological, environmental, and climatic variables. Some species, such as red brome in Arizona, has become naturalized in multiple terrain types on the landscape; both in Sonoran and Mojave desertscrub communities. Buffelgrass is constrained to Sonoran desertscrub; largely distributed in southern Arizona and northern Sonora where it occurs primarily along roadways, within washes, disturbed sites, with a scattered distribution of individual patches on steep, south-facing rocky slopes -apparently by wind-dispersed seeds. In addition to the land area subjected to the deliberate cultivation of buffelgrass in Sonora, estimates state that buffelgrass has naturally colonized two-thirds of the state. Cultivated buffelgrass pastures are most associated with the low valleys within the Plains of Sonora subdivision of Sonoran Desertscrub. While the Plains of Sonora is within the geographic core of the Sonoran desert tortoise's distribution in Mexico, the species is not expected to occur in the lower valleys that comprise most of the Plains of Sonora. Preliminary GIS results: Of the approximately 24,000 square miles of suitable tortoise habitat in Arizona, approximately 15% is currently modeled to have nonnative grasses. Land managers in Arizona, particularly Federal agencies, have been implementing conservation measures to reduce the spread of nonnative grasses and restore native vegetation. Outside of federally-managed land, nonnative grasses may or may not be managed. The effectiveness of these efforts depends in part on the agency resources that are available. Outside of designated conservation areas, management against nonnative grasses is largely non-existent in Mexico.	**Moderately Confident** in the distribution of nonnatives **Moderately Confident** that management against nonnative grasses will continue into the future on Federal lands. **Low confidence** that nonnative grasses will be adequately managed on non-federal lands in the foreseeable future.	Strittholt *et al*. 2012, pp. 89-92; Thomas and Guertin 2007, Appendices I and II; Van Devender and Dimmitt 2006, entire; D'Antonio and Vitousek 1992, p. 65; Bahre 1991, p.156-158; Stevens and Falk 2009, p. 420; Stevens and Fehmi 2009 p. 379; Olsson *et al*. 2012a, p. 137; Búrquez-Montijo *et al*. 2002, p. 136, Figure 8.3; Rogstad 2008, p. 39; Tim Hughes, USBLM pers. comm., 2015; OPCNM 2011, p. 22; 2014, p. 36; Zylstra and Swann 2009, p. 16; Edwards and Leung 2009, p. 327; Bean 2015, entire; Gade 2015, entire; AIDTT 2015, Appendix A; Grissom 2015b, p. 3; Van Devender et al. 2009; p. 91

THEME: Altered Native Plant Communities/Nonnative Grasses			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
- Scope (Conservation Efforts)	Conservation actions that include measures to reduce the likelihood of invasion of nonnative grasses into new areas, slow the invasion process, or rehabilitate invaded areas can reduce the effects of nonnative grasses on native vegetation. The Federal agencies that manage lands within the range of the SDT have management and implementation plans in place to address invasive species management. Below we summarize a few of these management efforts, but a complete list of actions that signatories to the CCA are taking to address this stressor can be found in Appendix A of the CCA. Buffelgrass control is the resource management priority at Saguaro National Park and Organ Pipe Cactus National Monument. Since 2007, the NPS has been treating between 160 and 650 acres per year with chemical and mechanical control. Herbicide treatments appear to be particularly promising for buffelgrass control. Most recently, Saguaro National Park has incorporated aerial herbicide delivery to control its spread in remote areas of the park and Organ Pipe Cactus National Monument has been extremely successful in controlling buffelgrass through follow-up treatments and a large volunteer effort. The BLM has treated 18 percent (475 acres) of buffelgrass-invaded habitat identified on their lands and is committed to continuing nonnative plant removal efforts, especially in SDT habitat. The USFS requires any seed mix used for re-vegetation be weed free and integrates measures into their multiple-use planning to minimize actions that could increase the spread of invasive species. The Coronado National Forest is committed to suppressing or eradicating buffelgrass on 1,000 to 1,500 acres of Sonoran Desert every year using herbicides and manual methods. The Tonto National Forest has also committed to working with partners to control or eradicate invasive plant species, especially buffelgrass, on their lands. Both the Department of Defense and FWS area also working with partners to remove and control the spread of nonnative plants on their lands and are committed to continuing these management efforts into the future. The Arizona Department of Transportation implements mitigation measures to prevent the establishment of nonnative grasses within rights-of-way and easements during periods of construction by using native seed mixes for reestablishment of disturbed areas and a state-wide herbicide treatment program for roadside areas. This action is important because roads (and other disturbed areas) can be a source of invasive species to SDT habitat and this action can ensure that these grasses never get a foot-hold.		AIDTT 2015, entire; McDonald and McPherson 2013, pp. 35-36
Effects of Stressors: **- SPECIES (Rangwide)** **[REDUNDANCY]**	The literature has focused on effects of nonnative grasses on individual tortoises; literature documenting population-level effects has thus far not been identified, even though these nonnative grasses have occurred within long-term monitoring plots for decades and in some cases, over a century. Theoretically, lower annual survival of juveniles and adults and lower reproductive output over time could reduce population sizes and lower overall population resiliency, but these population-level effects have not been identified through long-term monitoring, documented in the literature, or have otherwise not been identified in our review of existing literature. Population-level effects would only become discernable (via current research methods) over an extremely long period of time (decades to centuries) due to the life history and longevity of the species which is well-outside both the existing period of monitoring and our ability to predict such population-level effects in the foreseeable future. This stressor may increase the species' susceptibility to other stressors in areas heavily invaded by nonnative grasses.		
Effects of Stressors: **- SPECIES (Rangwide)** **[REPRESENTATION]**	The literature has focused on effects of nonnative grasses on individual tortoises; literature documenting population-level effects has thus far not been identified, even though these nonnative grasses have occurred within long-term monitoring plots for decades and in some cases, over a century. Theoretically, lower annual survival of juveniles and adults and lower reproductive output over time could reduce population sizes and lower overall population resiliency, but these population-level effects have not been identified through long-term monitoring, documented in the literature, or have otherwise not been identified in our review of existing literature. Population-level effects would only become discernable (via current research methods) over an extremely long period of time (decades to centuries) due to the life history and longevity of the species which is well-outside both the existing period of monitoring and our ability to predict such population-level effects in the foreseeable future. This stressor may increase the species' susceptibility to other stressors in areas heavily invaded by nonnative grasses.		

THEME: Altered Fire Regime			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Introduction and invasion of nonnative plants, which include *Pennisetum ciliare* (buffelgrass), *Bromus rubrens* (red brome), *Schismus* spp. (Mediterranean grass), *Brassica tournefortii* (Saharan (or Asian) mustard), genera *Centaurea* and *Cirsium* (thistles), and *Melinus repens* (natal grass). Buffelgrass, red brome, and Mediterranean grass are the nonnative plants most likely to affect the Sonoran desert tortoise and its habitat via this stressor. Nonnative grasses carry fire, and therefore can alter the ecosystem by increasing the frequency, duration, and magnitude of wildfires in a region that otherwise evolved in the absence of fire.	**Highly confident** that nonnative plants are widely considered to be the source of altered fire regimes in desertscrub communities; fire is uncommon in native desert ecosystems; and key cover species are not fire adapted	Bahre 1991, pp. 125, 155; D'Antonio and Vitousek 1992, pp. 65, 75; Brooks 1999, p. 13; Brooks 2001, p. 4; Brooks and Pyke 2001, p. 3, 5; Brooks and Esque 2002, p. 337; Esque *et al*. 2002, p. 313; Van Devender 2002, p. 16; Brooks and Matchett 2006, p. 148; DeFalco 2007a, p. 1; Zouhar *et al*. 2008, p. 157; Abella 2010, p. 1249; AGFD 2010a, p. 13
- Activity(ies)	Wildfire in desert ecosystems can spread in entirely native, uninvaded desertscrub communities when two consecutive winters with above average precipitation create a substantial increase in annual plant production and source of fine fuels. However, in an ecological context, wildfire has a long return interval and was never an influential factor in Mojave or Sonoran desertscrub ecosystems because, while natural ignitions did occur, the amount and spatial orientation of fuels that could theoretically carry fire was not generally present due to the extent of bare ground between vegetated patches. In areas invaded by nonnative grasses, fine fuels tend to be more continuous and the amount of bare ground between vegetated patches has decreased resulting in increased fire potential. Nonnative grasses of concern are also fire-adapted, meaning that should fire occur repeatedly over time in the same area (rarely observed), negatively-affected native plant species may be quickly out-competed by positively-affected nonnative grasses, potentially resulting a grass/fire cycle and ultimately, type-conversion of habitat. Ignition sources include natural sources such as lightening (particularly during the late spring and arid fore-summer months when "dry" thunderstorms occur in the Sonoran Desert) and anthropogenic sources such as parking vehicles over dry vegetation, fireworks, discarded cigarettes, backcountry recreationists, and trash burning. Such human-caused wildfires in desertscrub are most common near urban developments, major roadways, and in areas where off-highway vehicle use is uncontrolled. Fires are set intentionally in Mexico to improve the vigor of buffelgrass fields.	**Highly confident** that nonnative grasses can change the fire regime of an area. **Moderately confident** that successive wildfires over the same area can result in a grass/fire cycle and eventual type-conversion of habitat. **Highly confident** in description of potential ignition sources.	D'Antonio and Vitousek 1992, p. 73; Esque 2007, p. 2; Brooks 1999, p. 13; Alford *et al*. 2004, entire; McLaughlin and Bowers 1982, p. 247
STRESSOR(S)	Increased fire in desert ecosystems has the potential to increase the direct exposure of tortoises to fire as well as alter native vegetation communities. Nonnative grasses, particularly buffelgrass, can create wildfires with longer flame lengths, more rapid rates of spread, higher temperatures, and higher mortality of native flora. Such fires in desertscrub habitat can char the ground surface and affect the subsequent plant cover and species composition, potentially favoring nonnative grasses. The ecological effects of wildfire in dense, buffelgrass-invaded, Sonoran desertscrub have not been observed on a broad scale due to aggressive fire suppression policies and limited distribution in areas away from roads. However, effects are modeled to be potentially more severe based on the unique physical characteristics of buffelgrass which affect fire behavior, versus other common nonnative grasses. Should repeated burns occur in areas invaded by fire-adapted nonnative grasses, baseline conditions of the vegetation community could be altered in such a manner that severe changes in species composition could be expected (grass-fire cycle).	**Moderately confident** of the general effects of wildfire in desertscrub communities and anticipated effects on habitat affected by multiple burns.	Esque 2007, p. 2; Woodbury and Hardy 1948, p. 194; Brooks *et al*. 1999, p. 40; Brooks and Esque 2002, p. 335; Esque *et al*. 2003, p. 105; McLuckie *et al*. 2007, p. 7; Shryock *et al*. 2015, pp. 14–15, 20-21, 26, 36; Abella 2010, p. 1270; McDonald and McPherson 2011, p. 1152; 2013, entire; Grissom 2015a, pp. 2-4
- Affected Resource(s)	The native vegetative community of the Sonoran desert tortoise is affected, specifically forage plants which provide necessary nourishment for reproduction and survival and cover plants which provide for thermoregulatory needs and aid in protection against predators while tortoises are surface active. The degree of effect on these resources can range from negligible to severe, influenced by a multitude of factors.	**Highly confident** that forage and cover plant species are the resources most affected by wildfire.	Averill-Murray *et al.* 2002a; Bury *et al*. 2002, p. 100; Lutz *et al*. 2005, p. 22; Grandmaison *et al*. 2010, p. 582; Shryock *et al*. 2015, pp. 14–15, 20-21, 26

THEME: Altered Fire Regime			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
- Exposure of Stressor(s)	Wildfires in desertscrub that are naturally caused are most-likely to occur during late spring-early summer (May-June) when relative humidity is low and ambient temperatures are high; when "dry" thunderstorms with lightening strikes occur. Human-caused wildfire is likely to also occur during the spring (March - May) due to pleasant conditions for outdoor activities and conditions with low relative humidity and high(er) ambient temperatures. This period generally coincides with the period when reproductive female tortoises may be surface active from March through early May if suitable temperature conditions persist. However, documentation of wildfire-associated fatalities has been low. Wildfires caused by lightning strikes may also occur during the monsoon when tortoises of all age and size classes may be surface active, however higher relative humidity, moisture level of fuels, and ensuing precipitation generally prevent these fires from spreading naturally in a significant manner. In Mexico, cultivated buffelgrass pastures are repeatedly burned to increase vigor for livestock use. These pastures are most associated with the low valleys within the Plains of Sonora subdivision of Sonoran Desertscrub. While the Plains of Sonora is within the geographic core of Sonoran desert tortoise distribution in Mexico, the species is not expected to occur in the lower valleys as compared to bajada and hillside habitat and may not be directly affected by burning pastures.	**Moderately confident** about when human-caused and lightning-caused wildfires are most likely to occur. **Highly confident** that reproductive females tortoises are potentially disproportionately affected by spring and early summer wildfires as compared to other age- and size-classes of tortoises. **Low confidence** that induced fires in buffelgrass pasture in Mexico are having a significant effect on adjacent tortoise habitat due to limited data.	Averill-Murray *et al*. 2002a, p. 138; Brooks and Pyke 2001, p. 5; Esque *et al*. 2002, pp. 312-313, 321; Zouhar *et al*. 2008, pp. 155, 160; Rorabaugh 2010, p. 181; Alford *et al*. 2004, p. 452, Figure 1; Strittholt *et al*. 2012, pp. 92-96; USBLM 2010, p. 9; Esque *et al*. 2003, pp. 106-107
- Immediacy of Stressor(s)	Wildfire in desertscrub is a recent phenomenon in an evolutionary context. Up until several decades ago, wildfires were only expected to occur in areas that received successive winter rains over a period of two to three years, leading to a build-up in native annuals as a fuel load. Over time and into the future, if the distribution and density of nonnative grass expand on the landscape, the frequency of ignitions and potentially the size of wildfires may increase (depending on location, terrain, and fuel load). Although occasional large fires could still happen, fire suppression policies are expected to minimize the severity and scope of wildfire in Arizona into the future.	**Moderately confident** in the scope and frequency of potential wildfires into the future.	Brooks and Pyke 2001, p. 5; Esque *et al.* 2002, p. 312; Zouhar *et al.* 2008, pp. 155, 160; Rorabaugh 2010, p. 181; Alford *et al*. 2004, p. 452, Figure 1; McLaughlin and Bowers 1982, p. 247; AIDTT 2015, Appendix A
Changes in Resource(s)	Forage Plants: The degree of effects can vary considerably over a burned area due to fire behavior and abiotic factors in some habitat types. For example, elevation, precipitation, aspect, slope, habitat heterogeneity, etc. affect a given burned area's recovery response in Arizona Upland Sonoran Desertscrub habitat invaded by red brome. Topographic heterogeneity within a burn perimeter can create patches of relatively unaffected habitat, creating a mosaic of different vegetation community conditions and leaving some forage potential for tortoises to exploit and continue to occupy that habitat. In addition, the bimodal precipitation pattern that is characteristic of the Sonoran Desert, tends to favor a more rapid recovery of vegetation, post-burn as compared to the Mojave Desert, for example. In Arizona Upland Sonoran Desertscrub invaded by red brome that has burned once, forage plant species have been shown to have greater overall abundance and plant cover within the first decade post-burn than in unburned reference sites. The rate of post-burn recovery of habitat is expected to be largely precipitation-driven, and may be accelerated during above-average precipitation years and restricted during years of drought. Although fire influences soil physical and chemical properties, soils may still remain intact after fire. Roots and seeds are not necessarily entirely removed by fire and these residual propagules may enhance plant reestablishment on fires. After disturbances such as fire that do not physically remove or heavily compact soils, perennial plant cover in these areas can rebound, in some instances, to levels similar to undisturbed areas within 40 years whereas species composition can take longer to recover in certain areas and environmental scenarios. Cover Plants: Plant types such as shrubs, cactus, and trees provide surface-active tortoises with protective cover to avoid potential predators as well as create a wide degree of thermoregulatory regimes over their home range to allow them to maintain preferred body temperatures and extend the period of time spent foraging, searching for mates, moving between known shelter sites, and other behaviors. Plants used as cover by tortoises have been found to be the most affected by wildfire and recover very slowly; however, some cacti in Arizona Upland Sonoran Desertscrub have been documented to show greater regeneration potential than shrubs or trees, particularly with higher annual precipitation. The number, location, or condition of subterranean shelter sites are not expected to be affected by wildfire and, thus, would continue to provide sufficient cover for tortoises.	**Somewhat confident** in the analysis pertaining to the effect of wildfire on plant forage species because of the large number of environmental and abiotic variables and habitat characteristics that collectively, positively or negatively influence both the degree of damage caused by fire and the recovery rate and condition of burned habitat. The effect of each fire is unique to the area burned and the variables of influence. **Highly confident** in the effect of wildfire on cover plants; universally supported in the nonnative grass/wildfire literature.	Esque 2007, p. 2; Woodbury and Hardy 1948, p. 194; Brooks *et al*. 1999, p. 40; Brooks and Esque 2002, p. 335; Esque *et al*. 2003, p. 105; McLuckie et al. 2007, p. 7; Shryock *et al*. 2015, pp. 14–15, 20-21, 26, 33,36; Abella 2010, p. 1270-1273; McDonald and McPherson 2011, p. 1152; Grissom 2015a, pp. 2-4

THEME: Altered Fire Regime			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
Response to Stressors: - INDIVIDUALS	Fire may kill a desert tortoise by incineration, elevating body temperature, poisoning from smoke inhalation, asphyxiation, and nutrient deficiencies in post-fire foraging. Survival rates of Sonoran desert tortoises are contingent upon several factors, including fire behavior, fire intensity, weather, soil type, substrate, vegetation, tortoise activity, and shelter depth. Season of wildfire will have varying effects to age classes and sexes of tortoises. Spring - early summer wildfires may affect reproductive females that are surface active and foraging to gain nutrients for subsequent egg development; however, we have limited data documenting fatalities associated with wildfires. Monsoon wildfires occur when all age classes are expected to be most active. Wildfires at any time could affect any age or sex tortoise that is occupying a shallow shelter. Multiple wildfires in the same area may exacerbate all effects; however, the specific, long-term effects of multiple fires on Sonoran Desert vegetation and tortoises are little understood. Forage and cover plant species used by tortoises may be affected differently. Forage plant species may be temporarily reduced in abundance or diversity, but may also rebound more quickly. A reduction of forage potential could lead to lower nutrition, lower growth rates, lower fecundity, and lower survivorship. Cover plant species are generally considered to be negatively affected for the long term. A reduction of cover plants can, depending on availability of other structural features, reduces the potential for tortoises to be surface active by altering their thermoregulatory abilities and increasing predation risk. Characteristics of the Sonoran Desert invaded by red brome such as heterogeneous topography (incised washes, boulder fields, cliff faces, etc.) and elevated precipitation, provide microsites that are favorable to recovery of numerous forbs, grasses, and subshrubs, particularly at higher elevations or on north-facing slopes, allowing post-fire recovery to occur at a much faster pace than typically observed in Mojave desertscrub (where much of the existing literature pertains). These factors likely enable adult tortoises to continue to use burned habitat, exploiting the increased availability of food plants and the thermal refugia afforded by heterogeneous topography. However, hatchling ~~juvenile~~ Sonoran desert tortoises have less mobility to explore the landscape, less access to food plants by their short stature, and less thermal inertia which may pose greater challenges in burned habitat which may make them more susceptible to effects of wildfire than adults.	**Moderately confident** in assessment of effects to individual tortoises as effects from wildfire are highly variable and influenced by a wide array of environmental and abiotic factors.	Esque 2007, p. 2; Woodbury and Hardy 1948, p. 194; Brooks et al. 1999, p. 40; Brooks and Esque 2002, p. 335; Esque *et al*. 2003, p. 105-107; McLuckie *et al*. 2007, p. 7; Shryock *et al*. 2015, pp. 35-36, 39
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	Literature documenting long-term population level effects to tortoises as a result of fire impacts does not exist. Theoretically, a low to moderate loss of individuals within a population biased towards reproductive females can be significant for a long-lived species with low reproductive capacity. The loss of reproductive females could cause declines in reproductive rates and population growth rates. Alternatively, that loss could be offset by subsequent years of increased recruitment. Nonetheless, research has not demonstrated population-level effects from wildfire.	**Low confidence** that population level effects from wildfire are expected because of a lack of research and the amount of time required to detect potentially subtle trends in tortoise populations.	Esque *et al*. 2003, p. 107

THEME: Altered Fire Regime			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
- SCOPE	The acreage of desertscrub in Arizona that has burned historically is very small, in context of the range-wide distribution of the species. However, the area invaded by one or more of the most invasive, fire-prone, nonnative grasses is much larger. Ignition is required for a wildfire. Naturally-caused fires (e.g., lightning strikes) are influenced by summer temperature, elevation, winter precipitation, and distance to major rivers. Human-caused ignitions are the most common type of ignition historically and are likely to increase into the future based on human population growth predictions. Human caused fires are influenced by distance to highways, distance to urban areas, distance to major rivers, and winter precipitation. Ignition potential from human activity occurs year-round but does not necessarily result in an ensuing wildfire unless fuel loads, fuel moisture, and climatic conditions are favorable. The total number of ignitions on BLM land in Arizona from 1990-2008 was 854 (total area within fire perimeters were reported as 164,801 acres). Since the 1980s, within Sonoran desertscrub on the Tonto National Forest, the number of fires ranges from below 50 to over 200 per year. Over the last 30 years there have been 21,310 human-caused fires and 1,324 naturally-caused fires in Sonoran desertscrub within Arizona. It is important to note that, with all of these fires, we do not have data regarding the size of each fire and how much area within the burn perimeter actually burned. We assume, based on previous post-fire monitoring data that unburned islands of habitat occurred within these areas and the fires did not result in 100 percent loss of Sonoran Desert vegetation and that most of the fires reported were relatively small in size. Preliminary GIS results: Of the approximately 24,000 square miles of suitable tortoise habitat in Arizona, approximately 23% currently occurs within areas deemed to be at a high fire risk from either natural or human causes. Fires intentionally set in Mexico to improve the condition of buffelgrass pasture have the potential to affect adjacent tortoise populations but information is sparse in the literature and little research has been done on the effect of these fires on Sonoran desert tortoise habitat in Mexico. Additionally, many of these pastures occur in areas outside of tortoise habitat, as described above.	**Moderately confident** that future ignitions could increase in frequency in combination with a growing human population. **Moderately confident** that the area burned in Arizona should remain comparatively insignificant in a range-wide context **Low confidence** in our ability to accurately assess the potential risk of fire in Mexico to resident tortoises or their status in that county.	Strittholt *et al*. 2012, pp. 92-96; Alford *et al*. 2004 (entire); Esque *et al*. 2002, pp. 313, 321; USBLM 2010, p. 9
- Scope (Conservation Efforts)	Regardless of ignition frequency or location, wildfire in Sonoran desertscrub within Arizona is aggressively suppressed which has resulted in very few acres burned over time in comparison to the overall acreage on nonnative plant species within the range of the tortoise. Logistics, terrain, access, number of fires burning, and resources available all dictate the response to wildfire and affect the amount of habitat burned. Only in extremely rugged and remote terrain would a wildfire be expected to become significantly large, which has occurred in the past on an infrequent basis. We expect such suppression policies to continue into the future, limiting the spatial potential for wildfire to affect tortoise habitat in Arizona. Preliminary GIS results: Of the approximately 24,000 square miles of suitable tortoise habitat in Arizona, approximately 55% currently occurs within managed or multi-use government-owned properties.	**Moderately confident** that while potential ignition sources are many and varied, fire suppression policies in Arizona are expected to limit the area burned by wildfire.	AIDTT 2015, Appendix A
Effects of Stressors: - SPECIES (Rangwide) [REDUNDANCY]	One or more wildfires in desertscrub habitat that is invaded by nonnative grasses could begin to change the suitability of habitat for tortoises through the grass/fire cycle and slowly contribute to lowered survivorship and potentially population level effects if adult female tortoises are disproportionately affected. However, aggressive fire suppression policies in Arizona limit the potential for this scenario to occur. Fires intentionally set in Mexico to improve the condition of buffelgrass pasture have the potential to affect adjacent tortoise populations but most of these pastures occur outside of tortoise habitat (per above) and information is sparse in the literature and little research has been done on the effect of these fires on Sonoran desert tortoise habitat in Mexico.	**Moderately confident** that the area burned in Arizona should remain comparatively insignificant in a range-wide context and therefore will have an insignificant effect at the species level. **Low confidence** in our ability to accurately assess the potential risk of fire in Mexico to resident tortoise populations or their status in that country.	Esque *et al*. 2002, pp.313, 321

THEME: Altered Fire Regime			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
Effects of Stressors: - SPECIES (Rangwide) [REPRESENTATION]	One or more wildfires in desertscrub habitat that is invaded by nonnative grasses could begin to change the suitability of habitat for tortoises through the grass/fire cycle and slowly contribute to lowered survivorship and potentially population level effects if adult female tortoises are disproportionately affected. However, aggressive fire suppression policies in Arizona limit the potential for this scenario to occur. Fires intentionally set in Mexico to improve the condition of buffelgrass pasture have the potential to affect adjacent tortoise populations but most of these pastures occur outside of tortoise habitat (per above) and information is sparse in the literature and little research has been done on the effect of these fires on Sonoran desert tortoise habitat in Mexico.	**Moderately confident** that the area burned in Arizona should remain comparatively insignificant in a range-wide context and therefore will have an insignificant effect at the species level. **Low confidence** in our ability to accurately assess the potential risk of fire in Mexico to resident tortoise populations or their status in that country.	Esque *et al*. 2002, pp.313, 321

THEME: Habitat Conversion			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Conversion of habitat from urban expansion and irrigated agriculture.	**Highly Confident** that urban growth and associated infrastructure will continue. **Low Confidence** that irrigated agricultural areas will expand.	SSDAN; 2000, entire; Gammage *et al*. 2011, p. 10; Pinal County Comprehensive Plan 2009, p. 109; Howland and Rorabaugh 2002, entire; Stoleson *et al*. 2005, pp. 54, 60; U.S. Census Bureau 2005, p. 1; USDA 2009, p. 7
- Activity(ies)	Habitat is being graded and covered by pavement or converted to urban landscaping or (much less frequently) into irrigated, commercial agriculture.	**Highly Confident**	Gammage et al. 2008 entire, 2011 entire, USDA 2009, p. 7; Stoleson *et al*. 2005, pp. 54, 60
STRESSOR(S)	Complete removal of habitat including forage plants, cover plants, and shelter sites. Human activities related to conversion (e.g., clearing, construction).	**Highly Confident**	Howland and Rorabaugh 2002, pp. 335-336
- Affected Resource(s)	Vegetation used as forage and cover; shelter sites used for extended dormancy and nesting; uninterrupted open space to establish home ranges and facilitate short-, medium-, and long-distance dispersal movements. Generally urban development causes significant changes to habitat (usually removes it entirely) making regional and landscape movements challenging if not impossible. Generally, agricultural development, however, may still allow for these movements even though the habitat is no longer suitable for occupation of tortoises; depending on size and extent of agricultural area.	**Highly Confident**	Ogden 1993, pp. 1–8; Van Devender *et al*. 2002; pp. 175–176; Oftedal 2007, p. 21; Ernst and Lovich 2009, p. 562; Meyer et al. 2010, pp. 28–29, 44–48; Averill-Murray and Klug 2000, p. 69; Averill-Murray *et al*. 2002b, p. 126, Riedle 2015a; 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
- Exposure of Stressor(s)	Commercial, residential, and agricultural development is mostly associated with valley bottoms and areas with limited slope. A lesser degree of residential development has occurred and is expected to continue within the upper bajadas and steeper slopes adjacent to development zones. Increased residential development has occurred within the lower bajadas and rolling hills above 1,300 feet elevation (e.g., large-scale communities such as Gold Canyon, Anthem, Dove Mountain) and is expected to continue into the future, adjacent to development zones. These building sites, if zoned for residential construction, are highly desirable as home-building sites for their view sheds. The Catalina Foothills and Oro Valley areas within greater Tucson are excellent examples of this type of development. Generally, Federally managed lands are protected from conversion to urban or industrial agriculture uses unless selected for disposal. Lands managed by the State Land Department and private lands may be developed at any time depending on market value and proximity to existing urban infrastructure. All life-history needs of the tortoise are negatively impacted by development where there is overlap with occupied habitat, although the degree of effects depends on the nature and density of the development.	**Highly Confident**	SSDAN; 2000, entire; Gammage *et al*. 2008 (entire), 2011, (entire); Pinal County Comprehensive Plan 2009, p. 109
- Immediacy of Stressor(s)	The Arizona economy has been and is expected to continue to be largely driven by the construction and development sectors. Loss of habitat has been occurring for decades and is expected to continue into the future as the human population continues to grow at changing rates over time. Regional, widespread megadrought or unfavorable economic conditions may ultimately limit development and population growth regionally. Land that is developed for commercial or residentail purposes is considered permanently lost as tortoise habitat. Land that is converted to commercial agriculture uses may ultimately be abandoned and return to a semi-natural state but is more likely to be converted into urban or residential uses if not used for agriculture. Similar trends pertaining to human population growth and urban development could be expected in Sonora, Mexico, perhaps at a slower pace and smaller scale. However, irrigated agricultural development in Sonora is not expected to be a significant stressor to Sonoran desert tortoise habitat in Mexico as most of the development occurs along large, flat river deltas which are not considered to be suitable for Sonoran desert tortoises.	**Highly confident** that some development will continue within the range of the tortoise. **Somewhat confident** on growth predictions based on extenuating factors such as water supply and market forces. **Moderately confident** that urban growth will continue in Mexico within the range of the tortoise **Low confidence** on our ability to accurately predict growth and development potential in Sonora, Mexico.	SSDAN; 2000, entire; Gammage *et al*. 2008 (entire), 2011 (entire); Pinal County Comprehensive Plan 2009, p. 109; Cook *et al*. 2015, p. 4; Stoleson *et al*. 2005, p. 54, 59-60; Rosen *et al*. 2014a, p. 23

THEME: Habitat Conversion			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
Changes in Resource(s)	Habitat fully converted to urban development is no longer usable by tortoises. The amount of suitable habitat continues to be reduced over time. There is no expectation that land used for urban development will again become suitable for Sonoran desert tortoises. In Airzona, land that is converted to commercial agriculture uses may ultimately be abandoned and return to a semi-natural state but is more likely to be converted into urban or residential uses if not used for agriculture. Time required for recovery of habitat after abandonment of agricultural lands can be on the order of decades. The presence of nonnative species such as buffelgrass, cheatgrass, or red brome in disturbed Mojave or Sonoran desertscrub may further limit post-disturbance recovery. Other factors such as the amount of soil removed or the degree of soil compaction influence regeneration of habitat and are extremely variable.	**Highly confident** that areas developed for urban uses are lost entirely for tortoises into the future. **Low confidence** that land converted for commercial or irrigated agriculture will ever become suitable habitat for tortoises in the future.	Abella 2010, pp. 1270-1271, 1273; Brown and Minnich 1986, p. 411; Brooks 1999, p. 18
Response to Stressors: - INDIVIDUALS	Loss of forage plants, cover plants, and sheltering sites removes the ability for the species to adequately fulfill natural history needs and results in either immediate fatalities of individuals during construction or delayed fatalities from starvation, exposure, or predation should an individual survive the construction phase and/or be displaced from its home range.	**Highly confident** that a tortoise in harm's way from a construction or development project is unlikely to survive immediate, direct or delayed, indirect effects.	Howland and Rorabaugh 2002, pp. 335-336
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	Not all losses to Sonoran desert tortoise habitat have equal effects to tortoise populations. For example, the loss of primary (or "core") Sonoran desert tortoise habitat (within or adjacent to boulder-strewn bajadas) would have a disproportionately greater impact to a Sonoran desert tortoise population than a loss of similar size within the flat, creosote-bursage community found in valley floors or similar types of valley bottoms in Mexico (considered dispersal or "secondary" habitat). Both types of habitat are used by the Sonoran desert tortoise, but the latter is considered to have an exceptionally low density of tortoises; serving rather as a potential dispersal corridor during medium- to long-distance dispersal movements on rare occasion. While not as vital to the species as primary habitat (where home ranges are developed), dispersal habitat functions to an unknown degree in facilitating connectivity of populations over time; providing for exchange of genetic material among populations, and providing a potential source of individuals in the event of a localized, stochastic decline within a given population. The majority of habitat conversion within the range of the species has occurred and is expected to continue to occur within dispersal, or secondary, habitat and therefore has not directly resulted in the loss of any known tortoise populations. Indirect effects to populations from development adjacent to core, or primary, habitat could be occurring but require multiple decades, if not centuries, of monitoring to detect trends within populations. If the direct loss of habitat due to urban expansion is within high quality habitat areas and is large enough in area, population effects are likely to occur in the future.	**Moderately confident** that habitat conversion is not expected to affect the resiliency of tortoise populations range-wide.	Edwards *et al*. 2004, entire; Zylstra *et al*. 2013, entire
- SCOPE	Within Arizona, future urban development is projected to be the most significant along the Sun Corridor Megapolitain area following I-19, I-10, and I-17, with additional development along I-40 near Kingman and along major state highways over the next 50 to 100 years. The I-11 corridor is planned to replace existing State Route 93, although the project appears to advance in a sporadic manner. If I-11 is completed, it would be conceivable that non-federal lands along its route would be developed over time. Currently, development in Arizona has replaced some historical tortoise habitat and projections (from preliminary GIS analysis) suggest as much as 9 percent of suitable tortoise habitat could be developed over the next 50 to 100 years. About 73% of currently suitable tortoise habitat in Arizona is likely not to be developed due to land ownership and management (government and tribal lands). Acres of agricultural development have been documented as decreasing over time and are not expected to significantly influence tortoise populations in the future in Arizona, unless a new type of crop significantly influences market forces and reverses this trend. In Sonora, Mexico, Hermosillo is the largest developed city that in the next several decades could expand north and east, potentially affecting tortoise populations. Small communities such as Sonoyta, Pitiquito, Benjamin Hill, Punta Chueca, Kino Bay, Moctezuma, and San Carlos could see expansion over time; however, we do not know what the growth of these areas wil be. Although in general, future development in Mexico is not currently seen as a significant stressor to tortoise populations over a significant area.	**Highly confident** that urban development has replaced some historical tortoise habitat in Arizona. **Somewhat confident** about the extent of future urban expansion. **Highly Confident** that urban development will not occur or will occur on a very small portion of Federal lands within the range of the tortoise. **Somewhat confident** about potential growth projections in Mexico.	SSDAN; 2000, entire; Gammage *et al*. 2011, p. 10; Pinal County Comprehensive Plan 2009, p. 109; Rosen *et al*. 2014a, pp. 22-23; USDA 2009, p. 7

THEME: Habitat Conversion			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
Effects of Stressors: - SPECIES (Rangwide) [REDUNDANCY]	In the case of moderate to extreme projected growth and development scenarios, the number of tortoise populations could begin to decline. The rate of decline would be influenced by the scope and magnitude of the habitat conversion over time. This time scale may be on the order of decades to centuries.	**Low confidence**	Edwards *et al*. 2004, entire; Zylstra *et al*. 2013, entire
Effects of Stressors: - SPECIES (Rangwide) [REPRESENTATION]	The effect of lost populations as a result of habitat conversion, in a range-wide context, depends on where populations are lost. Genetic connectivity and dispersal characteristics fit the isolation by distance model. Where habitat conversion interrupts connectivity between populations, the loss of fragmented populations may reduce genetic representation over time. These impacts, however, function at a time scale which far exceeds our ability to accurately predict such a range-wide impact.	**Low confidence** that representation of important genotypes among populations could decline as a result of habitat conversion.	Edwards *et al*. 2004, entire; Howland and Rorabaugh 2002, entire

THEME: Habitat Fragmentation			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Transportation infrastructure (roads, highways, interstates), canals, railroad tracks; international border pedestrian fences; other linear development that reduces or impedes movement of tortoises.	**Highly confident** that these linear developments can either completely preclude crossing of tortoises or reduce the percentage of tortoises that successfully cross.	Edwards *et al*. 2004, entire; Foreman 2000, p. 33-34; Audsley 2010, p. 5; Sferra 2010, pers. comm.
- Activity(ies)	The ground surface is becoming altered in an expanding network of linear development to convey vehicular traffic (roads), railroad commerce (tracks), and water for domestic, industrial, and agricultural purposes (canals). Border security infrastructure construction and maintenance (fences).	**Highly Confident**	Foreman 2000, p. 33-34
STRESSOR(S)	Tortoises move within and outside their home ranges for a variety of natural history functions including foraging for desired plant species in various areas, searching for mates; selecting, constructing, and seasonally rotating through shelter sites; and short-, medium-, and long-distance dispersal. Linear developments affect a tortoise's ability to freely move on the landscape and become a source of mortality within an area, depending on the type and scale of the linear development.	**Highly confident** that tortoises require the ability to move within and outside of their home ranges for a variety of life history functions. **Moderately confident** that linear development negatively affects an individual tortoises' ability to move in areas where linear development transects occupied home ranges.	Fahrig and Rytwinski 2009, p. 1; Boarman and Sazaki 2006, p. 99; Averill-Murray and Klug 2000, p. 69; Averill-Murray *et al*. 2002b, p. 126, Riedle 2015a; Ogden 1993, pp. 1–8; Van Devender *et al*. 2002; pp. 175–176; Oftedal 2007, p. 21; Ernst and Lovich 2009, p. 562; Meyer *et al*. 2010, pp. 28–29, 44–48; Lowery *et al*. 2011, p. 7, Grandmaison 2010b, p. 5
- Affected Resource(s)	Navigable ground surface.	**Highly Confident**	Zylstra and Swann 2009, p. 10; Edwards *et al*. 2004, entire
- Exposure of Stressor(s)	Once a linear development such as a paved road (arterial, highway, interstate), canal, or railroad bed is constructed, the development is considered permanent. Exposure to this stressor occurs whenever a tortoise needs to move within or outside its home range where that movement is impeded or restricted by a form of linear development.	**Highly Confident**	Foreman 2000, entire
- Immediacy of Stressor(s)	Current, ongoing, and increasing into the future. Over time, the density and scope of linear development has increased to keep pace with growing human population demands. Currently, some form of linear development occurs over most of the range of the species at various scales and densities. The forms of linear development we have identified are considered permanent and therefore are expected to cause effects as long as occupied tortoise habitat overlaps with the linear development.	**Highly Confident**	Foreman 2000, entire; Edwards *et al*. 2004, entire
Changes in Resource(s)	In some areas, the ease of tortoise movement within and outside of home ranges has changed over time. Resident tortoises may or may not be able to successfully perform certain natural history functions depending on the location and type of linear development.	**Highly Confident**	Foreman 2000, entire; Edwards *et al*. 2004, entire; Fahrig and Rytwinski 2009, p. 1; Boarman and Sazaki 2006, p. 99

THEME: Habitat Fragmentation			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
Response to Stressors: **- INDIVIDUALS**	Individuals attempting to cross linear developments may be injured or killed by vehicular strikes, drowning, etc., or may simply be physically unable to cross the linear development. There are data documenting tortoise road fatality but not data documenting the frequency with which tortoises may cross a development successfully and unharmed; therefore, it is possible that some tortoises are successfully crossing these developments. The limited number of telemetry studies on tortoises showed they either did not cross any roads, made short-intermediate movements, or their signals were lost. Effects of linear development on individual tortoises are not equal. Regarding roads, highways, etc., we expect road width, road type (rugged, improved gravel, paved), speed limits, traffic volume, availability of washes traversing underneath roads, and quality of tortoise habitat being transected have the greatest effect on tortoise injury/mortality rates. Tortoises crossing roads that require slow(er) rates of speed have a higher likelihood of being noticed because drivers are more attentive. In these situations, the likelihood of collection or handling is greater. The larger the tortoise, the more likely it is to be seen. Tortoises crossing paved roads with higher speed limits may be less prone to being noticed and more prone to being injured or killed from a vehicle strike. Roads are an example of linear development that may allow an unknown percentage of tortoises to successfully cross whereas canals are largely considered impassible and may act as a sink to dispersing tortoises. Conservation measures such as tortoise fencing have been implemented along some forms of linear development. However, ongoing maintenance of these structures has not occurred and numerous breaches continue to exist. We are uncertain what effect these structures have had on limiting road fatality of neighboring tortoise populations. Other conservation measures such as implementation of reduced speed limits, education, and construction of tortoise-friendly culverts and underpasses, etc. are being considered for future development on many Federal lands. In addition there are efforts in place on Federal lands (*e.g*,. BLM, FWS, NPS) to restore connectivity between high value habitat where it has been modified.	**Highly confident** that some unknown number of tortoises are killed on the road, or by other forms of linear development, every year throughout their range and that various characteristics associated with specific linear developments influence permeability and injury/mortality rates within occupied habitat.	Boarman and Sazaki 2006, entire; Hoff and Marlow 2002, pp. 451-454; Boarman *et al*. 1997, p. 57; Forman and Alexander 1998, p. 213; Boarman 2002, pp. 54–55; Boarman and Sazaki 2006, p. 98; Dieringer 2010, p. 1; Grandmaison 2010, p. 5; Lowery *et al*. 2011, p. 7; USBLM 2007, p. 17; 2010b, p. 119; 2010a, pp. 31-32; 2012e, pp. 74-82; Gade 2015, entire; Leavitt and Hoffman 2014, entire; Grandmaison 2010b, entire; Grandmaison and Frary 2012, entire; AIDTT 2015, Appendix A
POPULATION & SPECIES RESPONSES			
Effects of Stressors: **- POPULATIONS** **[RESILIENCY]**	While available data suggest that some rate of tortoise injury or fatality may be associated with linear development there are no data available which document population-level effects on population resiliency from this stressor. Theoretically, the resiliency of populations may be impacted if movements within a population or between populations are limited by linear developments. Effects could take many forms including reduced reproduction if juveniles are unable to disperse or adult males and females are unable to find each other; or reduced survival of individuals if access to ephemeral food sources is affected. However, no data are available that have connected effects of linear development to tortoises at the population level. Effects from linear development at the population level may be occurring but will not be measureable for many decades, if not centuries.	**Low confidence** that tortoise population resiliency is being negatively affected by linear development.	Boarman and Sazaki 1996, p. 1; Boarman *et al*. 1997, p. 57; Boarman 2002, pp. 54–55; Boarman and Sazaki 2006, p. 98; Dieringer 2010, p. 1; Saunders *et al*. 1991, pp. 23–24; Forman and Alexander 1998, entire; Seiler 2001, p. 3; Forman 2000, entire; Averill-Murray and Klug 2000, p. 68; Howland and Rorabaugh 2002, p. 335; Edwards *et al*. 2004, p. 496; van Riper 2014, pp. 13, 83–85; Friggins *et al*. 2012, p. 9, Figure 1-4; Notaro *et al*. 2012, p. 1378
- SCOPE	Linear development occurs within most portions of the species' range-wide distribution but varies significantly in effect to resident or nearby tortoise populations depending on the type of linear development and other characteristics. Most forms of major linear development (interstate highways, canals, railroad beds, etc.) occur on flat or gently sloping terrain, with some exceptions. In these situations, only moderate- to low-suitability habitat is affected. Some linear developments in tortoise habitat also have washes that can act as underpasses, allowing for permeability of some of these linear developments.	**Moderately confident** that linear development has occurred throughout most of the range of the species.	Strittholt *et al*. 2014, p. 159; Rosen *et al*. 2014a, pp. 20-21

THEME: Habitat Fragmentation			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
Effects of Stressors: - SPECIES (Rangwide) [REDUNDANCY]	While available data suggest that some rate of tortoise injury or fatality may be associated with linear development there are no data available which document population-level effects on population redundancy from this stressor. Theoretically, if linear development severs connectivity between populations, redundancy could be affected through a reduction or elimination of population rescue (i.e., tortoises moving in from adjacent populations to repopulate an area that has been extirpated); however, as noted above, some of these linear developments are bisected by washes, which can help maintain connectivity. Population impacts may be occurring; however, no data are available that have connected effects of linear development to tortoises at the population level. Effects from linear development at the population level may be occurring but will not be measureable for many decades, if not centuries.	**Low confidence** that tortoise population redundancy is being negatively affected by linear development.	Spang *et al.* 1988, p. 9; Averill-Murray and Klug 2000, p. 68; Edwards *et al.* 2004, p. 486; Averill-Murray and Averill-Murray 2005, p. 71; Saunders *et al*. 1991, pp. 23–24; Forman and Alexander 1998, entire; Seiler 2001, p. 3; Forman 2000, entire; Howland and Rorabaugh 2002, p. 335; Edwards *et al*. 2004, p. 496
Effects of Stressors: - SPECIES (Rangwide) [REPRESENTATION]	Theoretically, if connectivity among populations is affected above a certain (unknown) threshhold, then genetic representation could be degraded over space and time. Special genetic evolutionary traits that may be particularly useful in the future, such as being adapted to naturally hyper-arid zones, may not be allowed to provide potential genetic safeguards to the species as a whole under future climatic conditions. For Sonoran desert tortoises, the concept of genetic isolation is primarily a factor of geographic distance. Research has found relatively high levels of polymorphism and heterozygosity and no evidence of recent loss of genetic diversity, i.e., no evidence of genetic bottlenecking that could result from the lack of mixing (gene exchange) among those Sonoran desert tortoise populations. However, the small sample size and number of alleles (genetic markers) used in the analysis might limit the ability to detect a bottleneck and long generation times, approximately 25 years, combined with relatively recent urban development makes it difficult to assess genetic effects of fragmentation on tortoise populations. Consequently, we would not be able to detect population-level effects from linear development on tortoise genetics for many decades if not centuries which is well-outside our ability to accurately predict.	**Low confidence** that tortoise population representation is being negatively affected by linear development.	Edwards *et al.* 2004, p. 486; Van Devender 2002, p. 16; Spang *et al*. 1988, p. 9; Averill-Murray and Klug 2000, p. 68; Edwards *et al*. 2004, p. 486; Averill-Murray and Averill-Murray 2005, p. 71; Saunders *et al*. 1991, pp. 23–24; Forman and Alexander 1998, entire; Seiler 2001, p. 3; Forman 2000, entire; Howland and Rorabaugh 2002, p. 335; Edwards *et al*. 2004, p. 496

THEME: Human-Tortoise Interactions			
[ESA Factor(s): E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Human population centers within the range of the tortoise; urban-wildland edge effects such as feral dogs; collection of wild tortoises as pets (Arizona and Mexico) and for food (Mexico) and release of captive tortoise; use of vehicles, OHVs, and ORVs in occupied tortoise habitat; general recreational activities (shooting, hiking, rock crawling, trail bike riding, rock climbing/bouldering, camping) in occupied tortoise habitat.	**Highly confident** that regional cities and towns are largely the source of people that inadvertently or purposefully interact with wild tortoises while involved with outdoor activities.	Sacco, pers. comm., 2007; Simmons, pers. comm., 2012; USBLM 2001, p. 1; Ouren *et al*. 2007, entire; AIDTT 2000, p. 10; Sullivan 2014, entire; Howland and Rorabaugh 2002, p. 340; Grandmaison and Frary 2010, pp. 264–265; Zylstra and Swann 2009, pp. 14-15; AGFD 2010a, pp. 9, 11-12; Jones 2008, p. 66; Hart *et al*. 1992, p. 120; AGFD 2010a, p. 9; Jones 2010, pers. comm.; AGFD 2014, p. 1; Berry 1986b, pp. 129-130; Zylstra *et al*. 2013, p.113; Averill-Murray and Swann 2002, p. 1; Bury *et al*. 2002, p. 102; Fritts and Jennings 1994, p. 52
- Activity(ies)	Activities resulting in stressors to the tortoise are associated with human use or presence in tortoise habitats, including recreation, travel, collection, and feral dogs. Correlated with proximity to urban areas.	**Highly confident** that collectively, negative effects to tortoises occur from these activities. **Low confidence** that any single activity on a single occasion will result in an effect to tortoise(s).	Sacco, pers. comm., 2007; Simmons, pers. comm., 2012; USBLM 2001, p. 1; Ouren *et al*. 2007, entire; Kessler 2014; Willard 2014; AIDTT 2000, p. 10; Sullivan 2014, entire; Howland and Rorabaugh 2002, p. 340; Grandmaison and Frary 2010, pp. 264–265; Zylstra and Swann 2009, pp. 14-15; AGFD 2010a, pp. 9, 11-12; Jones 2008, p. 66; Hart *et al*. 1992, p. 120; AGFD 2010a, p. 9; Jones 2010, pers. comm.; AGFD 2014, p. 1; Berry 1986b, pp. 129-130; Zylstra *et al*. 2013, p.113
STRESSOR(S)	Collection and disturbance. Above-normal rates of harassment (resulting in bladder voiding) and predation on individual tortoises within the urban-wildland interface, ~~or~~ within occupied habitat that is frequently visited by people from human population centers, or where vehicular access occurs. Tortoises are often documented as walking, resting, basking, and feeding on dirt roads and trails that occur within their home ranges which may increase the potential of tortoises being noticed (and therefore potentially handled or collected) or struck by a vehicle, and therefore may be especially susceptible to this form of stressor. Release of non-genetically pure, captive tortoises into wild populations can comprise genetic integrity of wild populations.	**Highly Confident** that tortoise injury or fatality occurs via stated mechanisms based on physical, genetic, or photographic evidence for each type of interaction. **Low confidence** on exactly how frequently these mechanisms act on individual tortoises or how many have been affected, or could be affected, over time.	Grandmaison *et al.* 2010, p. 587; Sullivan 2014; Sullivan *et al*. 2014, pp. 116–118; Boarman and Sazaki 1996, p. 1; 2006, p.98; Boarman *et al*. 1997, p. 57; Forman and Alexander 1998, p. 213; Boarman 2002, pp. 54–55; Dieringer 2010, p. 1; Bury et al. 2002, p. 103; Grandmaison and Frary 2010, pp. 264–265; Averill-Murray 2002a, pp. 430, 433–434; Hart *et al*. 1992, p. 120; AGFD 2010a, p. 9; Jones 2010, pers. comm.; AGFD 2014, p. 1; Averill-Murray and Swann 2002, p. 1; Edwards *et al*. 2010, p. 804; Zylstra 2008, p. 12; AGFD 2010a, p. 12; Berry 1986b, pp. 129-130; Zylstra *et al*. 2013, p.113
- Affected Resource(s)	N/A - these are primarily direct effects on individual tortoises.		
- Exposure of Stressor(s)	Effects primarily occur when tortoises may be surface active; adult females in spring; either sex and all age classes during monsoon and during/after any precipitation at any time of year. Likelihood of exposure to these stressors is attenuated by the fact that tortoises may spend up to 98% of their time in their shelters. Exposure risk is likely to be highest during the spring (female tortoise activity) and in response to precipitation (all tortoises; winter and monsoon). Cool weather associated with precipitation is widely considered optimal for OHV use in the Sonoran Desert due to comfortable temperatures, softened soil, and dust-free conditions; tortoises are also surface active during these periods for rehydration purposes and may be more vulnerable to fatality associated with elevated OHV use within washes (particularly hatchlings and small juveniles that are likely to go unnoticed by riders). Sonoran desert tortoises have often been found walking, resting, basking, and feeding on dirt roads and trails that occur within their home ranges which increases the potential of tortoises being noticed by humans or struck by a vehicle. Adult tortoises are more visibly conspicuous than juveniles or hatchlings and may be disproportionately affected by these activities. Collection of wild tortoises and release of captive tortoises into wild populations may occur at any time and is most likely to occur in habitat adjacent or near to human population centers. In addition, effects from dogs primarily occur in proximity to human populations centers, but can also occur some distance from urban areas as a result of feral dogs.	**Somewhat confident** in description of when certain sexes or age groups of tortoises are most likely to interact with humans. **Somewhat confident** in description of where tortoises are most likely to interact with humans.	Sullivan 2014; Grandmaison *et al*. 2010, p. 587; Sullivan *et al*. 2014, pp. 116–118; Nagy and Medica 1986, p. 79; AIDTT 2000, pp. 9-10
- Immediacy of Stressor(s)	Current and ongoing. Growing human populations over time have resulted in increasing demand for human access to wild areas including occupied Sonoran desert tortoise habitat. Some forms of recreation are increasing in frequency (OHV/ORV use, driving on roads, target shooting) while others may be stable or decrease in frequency over time (hiking, camping). Roads act as the primary avenue for human-tortoise interactions, and we consider all roads (other than primitive, two-track routes) to be permanent on the landscape.	**Highly confident** that over time, as human population grows and urban areas expand into the landscape, the incidence of human-tortoise interactions and the amount of tortoise habitat affected by urban-wildland interface effects will increase.	SSDAN; 2000, entire; Gammage *et al*. 2011, p. 10; Pinal County Comprehensive Plan 2009, p. 109; Howland and Rorabaugh 2002, entire
Changes in Resource(s)	N/A		

THEME: Human-Tortoise Interactions			
[ESA Factor(s): E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
Response to Stressors: - INDIVIDUALS	Injury, fatality (= collection), dehydration.	**Highly confident** that these effects to individual tortoises occur through associations with this stressor as documented in the literature. **Low confidence** that these effects occur in every instance, a majority of instances, some of the time, or infrequently. Frequency difficult to ascertain.	Grandmaison *et al.* 2010, p. 587; Sullivan 2014, entire; Sullivan *et al*. 2014, pp. 116–118; Boarman and Sazaki 1996, p. 1; 2006, p.98; Boarman et al. 1997, p. 57; Forman and Alexander 1998, p. 213; Boarman 2002, pp. 54–55; Dieringer 2010, p. 1; Bury *et al*. 2002, p. 103; Grandmaison and Frary 2010, pp. 264–265; Averill-Murray 2002a, pp. 430, 433–434; Hart *et al*. 1992, p. 120; AGFD 2010a, pp. 9, 11-12; Jones 2008, p. 66; 2010, pers. comm.; AGFD 2014, p. 1; Averill-Murray and Swann 2002, p. 1; Edwards *et al*. 2010, p. 804; Berry 1986b, pp. 129-130
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	Population-level effects from these activities are expected to be most severe when they occur to adult tortoises because adult survivorship is thought to be a primary determinant of population status. Adult survivorship has been shown to improve with increasing distance from urbanized areas, specifically, that the odds of a Sonoran desert tortoise surviving one year increases 13 percent for each 10-km (6.2-mi) increase in distance from a city.	**Moderately Confident**	Howland and Rorabaugh 2002, pp. 339-342; Zylstra *et al*. 2013, p. 113-114.
- SCOPE	Access and visitation potential into occupied habitat is driven by proximity to urban areas. Wherever roads or trails provide access, these activities could occur. Visitation into occupied tortoise habitat and likelihood of predation from feral dogs are also strongly influenced by proximity to populated human areas. Along the international border with Mexico, road density and use has been growing rapidly for interdiction purposes. Preliminary GIS results: Of the approximately 24,000 square miles of suitable tortoise habitat in Arizona, approximately 13% currently occurs within 10 km of a city with a population of at least 2,500 people and another 15% occurs within 20 km. Preliminary GIS results: Road density expressed as intactness (low intactness is correlated with high road density) can be a surrogate measure for habitat access. Range-wide, approximately 11 percent of tortoise habitat is categorized as having low intactness, 16 percent as having moderately low intactness, 24 percent as having moderately high intactness, and 49 percent as having high intactness (percentages rounded to nearest whole number). Tortoise habitat in Arizona has lower general intactness (higher road density per unit area) than Mexico. Sonoran desert tortoises are rarely viewed as a food source in Mexico, and there's little to no evidence that human consumption of tortoises remains a common practice or occurs at all.	**Moderately confident** in description of spatial relationship of stressor to tortoises. **Highly confident** in description of relative percentages of intactness of tortoise habitat.	Averill-Murray and Swann 2002, p. 1; Sayre and Knight 2010, p. 347; Sferra 2010, pers. comm.; USGAO 2009, entire; USBLM 2012d, p.58; 2012c, p. 111; 2013b, p. 80; 2007, p. 83, 85, 115; 2014, p. 1; USNPS 2006, entire; Rosen *et al*. 2014a, p. 20
- SCOPE (Conservation Efforts)	Several, existing conservation measures likely act to reduce effects of human-urban interactions with tortoises. For example, agencies have committed to enforcing regulations and policies that address the presence of feral dogs on their lands, restrict where dogs may be present, or prohibit dogs entirely. Other examples include regulations, policies, and training of staff which include identification of and enforcement against illegal release of captive tortoises. Travel management planning is being undertaken by several agencies. Through this process, illegal routes are either closed or made legal, and all routes (legal or not) are identified and mapped to better facilitate landscape-level management of OHV/ORV use. Additionally, many areas will have OHV access restricted to existing roads and routes. Off-road travel will not be allowed in many of these areas.		See Candidate Conservation Agreement

THEME: Human-Tortoise Interactions			
[ESA Factor(s): E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
Effects of Stressors: - SPECIES (Rangwide) [REDUNDANCY]	It is unlikely that this stressor alone could affect population redundancy, except for the case where populations exist at low densities, are already threatened by persistent drought, or occur adjacent areas of very high human population densities and commensurate levels of outdoor recreation and visitation. In these examples, loss of adult tortoises may have a population level effect. Based on available information, no tortoise population has been extirpated by this stressor.	**Somewhat Confident** that isolated populations, if under drought stress, may be vulnerable to the effects of human-urban interactions where located near dense, human-populated areas. **High confidence** that this stressor does not uniformly affect tortoises across the geographic extent of their range. **Low Confidence** that this stressor has an appreciable effect on a range-wide scale as this stressor is much less significant in scope and magnitude in Mexico where approximately 40 percent of the species' range occurs.	Averill-Murray and Swann 2002, p. 7, Zylstra *et al* . 2013, p. 113, Zylstra 2008, p. 12; Zylstra and Swann 2009, pp. 14-15; AGFD 2010, pp. 11-12
Effects of Stressors: - SPECIES (Rangwide) [REPRESENTATION]	Low density populations in western and southwestern Arizona and in the Central Gulf Coast subdivsion of the Sonoran Desert in Mexico are generally not exposed to significant human interaction and we don't expect this stressor to significantly influence representation of the species across its range. This potential stressor does not act uniformly across the species range, rather, occurs in varying degrees over space and time, positively correlated with distance to human population centers and degree of access.	**Low confidence** that populations that occur in the most arid portions of the species' range possess unique attributes that make them more resistant to drought stress than populations in other areas of the species' range. **High confidence** that this stressor does not uniformly affect tortoises across the geographic extent of their range. **Low Confidence** that this stressor has an appreciable effect on a range-wide scale as this stressor is much less significant in scope and magnitude in Mexico where approximately 40 percent of the species' range occurs.	Averill-Murray and Swann 2002, p. 7, Zylstra *et al* . 2013, p. 113, Zylstra 2008, p. 12; Zylstra and Swann 2009, pp. 14-15; AGFD 2010, pp. 11-12

THEME: Climate Change-Drought			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Global Climate Change	**Highly Confident** that drought will be more severe in Sonoran desert as a result of climate change over the next 50 to 100 years.	IPCC 2007, entire; 2014, entire
- Activity(ies)	Global climate change is caused by the increase in carbon emissions from numerous activities.		See IPCC publications
STRESSOR(S)	Long-term climate change may alter tortoise habitats through causing more extended droughts and decreased precipitation. Summaries of expected changes: (1) Warmer and fewer cold days and nights over most land areas, (2) warmer and more frequent hot days and nights over most land areas, (3) more frequent warm spells, heat waves, or both over most land areas, (4) changes in precipitation patterns favoring an increased frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) over most areas, and (5) an increase in the area affected by droughts Predicted temperature trends for the Sonoran Ecoregion: (1) Widespread warming trends in winter and spring, (2) decreased frequency of freezing temperatures, (3) lengthening of the freeze-free season, and (4) increased minimum temperatures per winter year Predicted trends in precipitation: (1) Spring time drying, (2) increased precipitation, (3) summer and winter decline in precipitation in short-term (2015-2030), (4) long term (2045-2060) summer precipitation declines will be smaller compared to historic levels; (5) 9 to 12 percent decrease in annual precipitation. Other modeling found that annual precipitation levels in the southern Colorado River Basin could increase during the 2020s, but decrease through the 2050s, with continued decreases through the 2070s. Reduced/altered vegetation cover and reduced vegetation biomass. Reduced or altered abundance or availability of water for drinking. These effects are primarily precipitation-driven. Precipitation is likely the most important ecological variable driving tortoise population trends over time and existing models for precipitation can not reliably predict changes in magnitude, timing, or frequency of precipitation, especially regarding summer rain which is critical for tortoises because of its contribution to the plant community.	**Highly confident** that precipitation is the most important ecological variable affecting tortoise population trends over time. **Low confidence** that current models can accurately predict potential changes in monsoon precipitation due to climate change. **Moderately confident** that total annual precipitation within or throughout the range of the tortoise will be reduced due to climate change. Moderately confident - that total annual precipitation will decrease as a result of climate change. Over what timeframe? **Low confidence** about what predicted changes there may be to monsoon precipitation. Models strongly suggest less total precipitation but largely do not agree whether winter or summer rain cycles will be effected similarly.	IPCC 2007, p. 7; 2014, pp. 39-43; Cook *et al*. 2015, p. 4; Christensen *et al*. 2007, pp. 887-888; Weiss and Overpeck 2005, p. 2075; Notaro *et al*. 2012, pp. 1370, 1379–1380; Weltzin *et al*. 2003, p. 942; Seager *et al*. 2007, entire; Solomon *et al*. 2009, p. 1707; USBOR 2011, p. 56; Hereford *et al.* 2006, p. 25; McAuliffe and Hamerlynck 2010, p. 885; Strittholt *et al*., 2012, p. 11; Van Devender 2002, p. 10; Zylstra *et al*. 2013, pp. 113-114
- Affected Resource(s)	Forage plants; water availability	**Highly confident** that climate change driven drought will affect the amount and diversity of forage plant species and affect the frequency and amount of precipitation which ultimately affects the overall availability of surface water for drinking by tortoises.	Averill-Murray *et al*. 2002a, pp. 140, 146; Ernst and Lovich 2009, p. 545; Martin and Van Devender 2002, p. 31

THEME: Climate Change-Drought			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
- Exposure of Stressor(s)	Climate models over the next 50 to 100 years generally agree that winter and spring precipitation may be influenced by climate change; model results regarding the influence of climate change on monsoon precipitation are less certain as monsoons are more difficult to model. Temperature changes occur year-round and may affect when and how long tortoises are surface active, depending on age class (smaller tortoises are more vulnerable to temperature effects). Tortoises of either sex or any age class come out to drink free-standing water in response to precipitation at any time of the year. Winter precipitation drives spring annual growth which is important for reproductive female tortoises to increase energy reserves for egg development; this relationship is less certain in Sonora where other Sonoran desertscrub subdivisions occur. Adult female tortoises may be disproportionately affected by changes in the quantity and quality of spring forage.	**Moderately confident** that climate change may decrease the amount of of winter and spring precipitation. **Low confidence** that monsoon precipitation will decrease due to climate change effects (models in disagreement). **Moderately confident** that changes in temperature associated with climate change will occur throughout the year. **Highly confident** that tortoises of either sex or any age class emerge to drink free-standing water as it becomes available at any time of the year. **Highly confident** that changes to winter precipitation will affect spring growth of annuals in Arizona and may disproportionately affect adult female tortoises which are largely the only sex and age class of tortoises know to be more regularly surface active during the spring. **Somewhat confident** that changes to winter precipitation will affect spring growth of annuals in Sonora and may disproportionately affect adult female tortoises which are largely the only sex and age class of tortoises know to be more regularly surface active during the spring.	IPCC 2007, p. 7; 2014, pp. 39-43; Cook *et al* . 2015, p. 4; Christensen *et al* . 2007, pp. 887-888; Weiss and Overpeck 2005, p. 2075; Notaro *et al* . 2012, pp. 1370, 1379–1380; Weltzin *et al* . 2003, p. 942; Strittholt *et al* . 2012, entire; Seager *et al* . 2007, entire; Solomon *et al* . 2009, p. 1707; USBOR 2011, p. 56; Shryock *et al* . 2015, p. 39; Sullivan *et al* . 2014, pp. 116–118; Averill-Murray and Klug 2000, p. 66; Bailey *et al* . 1995, p. 367; Esque *et al* . 2002, p. 324

THEME: Climate Change-Drought			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
- Immediacy of Stressor(s)	Climate change is occurring currently and is expected to continue into the future.	**Highly Confident**	IPCC 2007, p. 7; 2014, pp. 39-43; Cook *et al*. 2015, p. 4; Christensen *et al*. 2007, pp. 887-888; Weiss and Overpeck 2005, p. 2075; Notaro *et al*. 2012, pp. 1370, 1379–1380; Weltzin *et al*. 2003, p. 942;
Changes in Resource(s)	Decreasing annual precipitation (predicted declines in winter precipitation); summer rain less predictable (few storms of little rain or frequent storms of severe nature and significant flooding). Decreasing annual precipitation may affect the germination of annuals or regrowth of perennials. Decreased precipitation will reduce the frequency of access to free-standing water by tortoises for drinking.	**Moderately confident** that climate change may decrease the amount of winter and spring precipitation. **Low confidence** that monsoon precipitation will decrease due to climate change effects (models in disagreement). **Highly confident** that decreasing annual precipitation will reduce the frequency of when tortoises of either sex or any age class can emerge to drink free-standing water. **Moderately confident** that a decrease in annual precipitation will affect the forage base of tortoises.	IPCC 2007, p. 7; 2014, pp. 39-43; Cook *et al*. 2015, p. 4; Christensen *et al*. 2007, pp. 887-888; Weiss and Overpeck 2005, p. 2075; Notaro *et al*. 2012, pp. 1370, 1379–1380; Weltzin *et al*. 2003, p. 942; Sullivan *et al*. 2014, pp. 116–118; Oftedal 2002, p. 199; van Riper 2014, pp. 83-85

THEME: Climate Change-Drought			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
Response to Stressors: - INDIVIDUALS	Desert tortoises evolved in arid conditions, and possess numerous physiological and behavioral adaptations to survive some degree of drought. Individuals may suffer from drought stress if precipitation does not occur at a high enough frequency to provide drinking opportunities. Timing and amount of precipitation affects the forage base positively or negatively depending on the photosynthetic pathway of plant species. Persistent drought, and subsequent changes in the tortoise forage base, can affect blood chemistry and water metabolism, reduce or eliminate the thymus and fat stores, and result in skeletal muscle and liver atrophy in desert tortoises. Prolonged drought conditions would force the tortoise to eat less-armored cacti and whatever nonwoody senescent material that have not disintegrated or been blown away. Prolonged drought coupled with low nutrition forage would mean lower growth rates, lower reproductive output, lower survivorship, and increased stress on bladder physiology. In years of low winter rainfall, winter annuals do not germinate which may affect the amount and diversity of forage species during the spring. However some species of small weedy annuals as well as herbaceous perennials do germinate offering some foraging opportunities. In years of high summer rainfall, characterized as highly localized events, a vast diversity of summer annuals and herbaceous perennials respond favorably offering good forage in areas that receive high precipitation. Rising average annual temperatures could affect sex-ratios during embryo development; biasing in favor of females. Minor increases in temperatures could have a beneficial effect on tortoise populations as a single male can fertilize numerous females.	**Highly confident** that tortoises evolved in arid conditions and possess numerous physiological and behavioral adaptations to survive some degree of drought. **Highly confident** that decreasing annual precipitation would reduce the number of opportunities tortoises have to drink free-standing water which may induce drought stress. **Moderately confident** on described physical effects of drought stress on individual tortoises; many variables involved. **Moderately confident** that the season, frequency, and amount of precipitation could be influenced by climate change and in turn, affect the forage base of tortoises both positively and negatively. **Somewhat confident** that predicted rises in air temperatures associated with climate change could have an effect on sex determination of tortoise embryos resulting in a sex bias within affected regions of their distribution.	Schmidt-Nelson and Bently 1966, p. 911; Peterson 1996b, p. 1325; Christopher 1999, p. 365; Duda *et al*. 1999, p. 1188; AIDTT 2000, p. 4; Berry *et al*. 2002b, pp. 443–446; Dickinson *et al*. 2002, pp. 251–252; Oftedal 2002, pp. 199-200; Walther *et al*. 2002, pp. 393–394; Hereford *et al*. 2006, p. 25; Peterson 1996a, p. 1831; Zylstra, *et al*. 2013, p.114; Averill-Murray *et al*. 2002a, p. 146; Ernst and Lovich 2009, p. 545

THEME: Climate Change-Drought			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	Drought could result in demonstrable population declines over a short period of time. Even short-term variations in rainfall can have prolonged effects on a long-lived species because of impacts to reproduction, recruitment, and annual survival. In populations that have already experienced localized but prolonged drought adult Sonoran desert tortoise survival decreased 10-20 percent, and abundance of adults was reduced by ≥50 percent. Despite the declines, annual survival has since increased in these populations and the rate of change in population size was found to be greater than 1 indicating cumulative population growth over the range of the species in Arizona. Climate change scenarios project that drought severity and frequency will increase during 2035-2060, which is predicted to reduce adult annual survival by 3 percent during that time period, compared to the survival during 1987-2008. Tortoise mortality statistics from Mexico were positively correlated with temperature and negatively correlated with elevation and precipitation. There is concern that Sonoran desert tortoise adaptation processes will not be able to keep pace with the relatively fast-paced changes predicted as a result of climate change in the near- or mid-term. Considering the generation times of Sonoran desert tortoises and the observed rate of increase in global temperatures, the "evolutionary adaptation of tortoise physiology and behavior is a remote possibility." Tortoises in general have historically been found to be "weak dispersers" at large scales. In the case of Sonoran desert tortoises, steep transitions to northern, higher-elevation habitat may hamper the species' movement into these regions and resultant temperature regimes in these new areas may still be colder than what is physiologically-suitable, even under the effect of climate change. However, other responses of the Sonoran desert tortoise to climate change are possible such as (1) changing behavior in response to climatic stress or population declines, or (2) density-dependent factors allowing population persistence at lower abundance. With respect to the former, it is possible that increasing drought coupled with increasing temperatures may select for a behavioral shift in shelter site use in Sonoran desert tortoises, favoring the more humidity and temperature buffered earthen burrows over the less-buffered rock shelter sites. The most arid portions of the species current range include western and southwestern Arizona and in the Central Gulf Coast subdivision of Sonoran Desert in Mexico. Populations that currently occur in these most arid portions of the range are already at lowered densities and are considered to have added vulnerability to climate change-induced drought, could be significantly affected, and may become locally extirpated should multi-year drought conditions of sufficient magnitude become realized. Other populations to the east and northeast may be able to migrate to higher elevation habitat that may simultaneously by converting into desertscrub, to counter general trends of warming and drying. The ability (speed) of the species to evolve/migrate in keeping-up with predicted habitat shifts in response to climate change may significantly influence the viability of the species over time.	**Moderately confident** that drought associated with climate change could negatively affect adult survival rates within tortoise populations which is a fundamental driver in overall population resiliency over time, potentially leading to extirpation at the local population level should drought conditions persist for multiple years in the same area. **Low confidence** in predicting potential shifts in behavioral/evolutionary responses of tortoises to climate change. **Moderate confidence** that tortoise populations in the most arid portions of the species range may have higher vulnerability of local extirpation from drought-related climate change than populations that occur in less-arid portions of the range. **Somewhat confident** that tortoise populations along the eastern and northeastern portion of its range may be able to mitigate climate change effects by migrating up in elevation and latitude.	van Riper 2014, pp. 13, 83–85; Friggins *et al*. 2012, p. 9, Figure 1-4; Notaro *et al*. 2012, p. 1378; Weiss and Overpeck 2005, p. 2075; Galbraith and Price 2009, p. 80; Zylstra, *et al*. 2013, pp.113-114; Skelly *et al*. 2007, pp. 1353–1355; Rosen *et al*. 2014a, pp. 37-38; 2014b, p. 56; 2014c, p. 88; USGS 2005, entire

THEME: Climate Change-Drought			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
- SCOPE	Range-wide exposure to effects of climate change with regional variability in magnitude over space and time.	**Highly Confident**	Seager *et al.* 2007, entire; Solomon et al. 2009, p. 1707; Overpeck and Udall 2010, p. 1642
Effects of Stressors: - SPECIES (Rangwide) [REDUNDANCY]	Increasing drought severity or extent could result in demonstrable population effects over the next 100 years and beyond. Climate change-driven drought increases could affect the persistence of some tortoise populations in the most arid portions of their range (western and southwestern Arizona and in the Central Coast subdivsion of the Sonoran Desert in Mexico) where connectivity is already challenged by expansive areas of very low habitat suitability which could affect species redundancy. Increased drought severity projected for the period between 2035-2060 may cause the rate of population change in Sonoran desert tortoises to decrease 3%, from 1.08 to 1.05. Populations that can migrate to higher elevation habitats or more northerly latitudes may be able to remain viable under changing climate conditions.	**Moderately confident** that drought associated with climate change could negatively affect adult survival rates within tortoise populations which is a fundamental driver in overall population viability over time, potentially leading to extirpation at the local population level and potential effects to species redundancy, should drought conditions persist for multiple years in the same area. **Moderate confidence** that tortoise populations in the most arid portions of the species range may have higher vulnerability of local extirpation from drought-related climate change than populations that occur in less-arid portions of the range. **Somewhat confident** that tortoise populations along the eastern and northeastern protion of its range may be able to mitigate climate change effects by migrating up in elevation and latitude.	van Riper 2014, pp. 13, 83–85; Friggins *et al*. 2012, p. 9, Figure 1-4; Notaro *et al*. 2012, p. 1378; Zylstra *et al*. 2013, p.114

THEME: Climate Change-Drought			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
Effects of Stressors: - SPECIES (Rangwide) [REPRESENTATION]	Increasing drought severity or extent could result in demonstrable population effects over the next 100 years and beyond. Increased regional drought severity could affect the persistence of some tortoise populations particularly in the most arid portions of their range where connectivity is already challenged by expansive areas of very low habitat suitability. Populations that can migrate to higher elevation habitats may be able to remain viable under changing climate conditions. The latter example of populations are expected to retain some level of genetic connectivity with each other depending on the effect of linear development at local-regional scales.	**Moderately confident** that drought associated with climate change could negatively affect adult survival rates within tortoise populations which is a fundamental driver in overall population viability over time, potentially leading to extirpation at the local population level and potential effects to species redundancy, should drought conditions persist for multiple years in the same area. **Moderate confidence** that tortoise populations in the most arid portions of the species range may have higher vulnerability of local extirpation from drought-related climate change than populations that occur in less-arid portions of the range. **Somewhat confident** that tortoise populations along the eastern and northeastern portion of its range may be able to mitigate climate change effects by migrating up in elevation and latitude.	Zylstra *et al*. 2013, pp.114-115

Appendix D: Stochastic Simulation Model Report

Sonoran Desert Tortoise Stochastic Simulation Model for Species Status Assessment

Summary

We built a demographic population viability model to represent Sonoran desert tortoise (SDT) populations in Arizona and Mexico. The model was based on the best available demographic data and published analyses, and it included parametric uncertainty and environmental variation as sources of stochasticity in the projections. The model predicts the probability of quasi extinction (i.e., the probability of abundance declining to less than a pre-determined abundance threshold) at 50, 75, 100, and 200 years under current habitat and environmental conditions and possible future scenarios. We also incorporated a framework to evaluate a wide array of future possible conditions and estimate the relationship between those varied future conditions and quasi-extinction probability through regression analysis of the model output. For the purposes of this model and as part of the species status assessment, we are treating the species as two large populations, one in Arizona, U.S., and one in Sonora, Mexico.

Life Cycle Model Structure

We built a female-only, stage-structured matrix model to reflect the Sonoran desert tortoise life cycle (Figure D-1). The conceptual model of the tortoise's life cycle was elicited from taxa experts, based on published literature (Van Devender 2002, entire; Rostal *et al.* 2014, entire) and based on Mojave desert tortoise population models (Darst *et al*. 2013). The life cycle diagram presents three main life stages (Adults, small juveniles (J_1) and large juveniles (J_2)). Small juveniles, once hatched, can survive each year and remain in the small juvenile age class for approximately 5 years. Little is known about the habits or survival rates of small juveniles because they are very hard to detect and study. However, this life stage, given its size (<40mm), is likely the most susceptible to predation and other causes of mortality (McCoy *et al*. 2014). Larger juveniles remain in that age class for 10 or 12 years (until approximately the age of 15) and then transition into the breeding adult age class. Survival rates of newly hatched tortoises in their first year are very low. McCoy *et al*. (2014), suggest that, for North American tortoises in general, first year survival is as low as 10% and it increases about 1-2% annually thereafter, until the animals are in the subadult or large juvenile stage. Adults have very high survival rates, 0.93 – 0.98 annually (Zylstra *et al.* 2013) and can live for many years as adults. Approximately 52% of females will breed in any given years and the females lay small clutches of approximately 5 eggs (~2.5 female eggs per female; Campbell *et al.* 2014, p. 2), but many nests fail before hatching (McCoy *et al.* 2014).

In our simulation model we set mean annual survival ($\bar{S}^{A}$) to 0.95 (SD = 0.009), based on the results of Zylstra *et al*. (2013). We created a probability of breeding parameter (P_b) with mean of 0.52 (SD = 0.06) and a fecundity or clutch size parameter with mean of 2.5 eggs per female (SD = 0.5; Campbell *et al.* 2014). Zylstra *et al*. (2013) estimated annual survival of large juveniles ($\bar{S}^{J2}$) to average 0.77 (SD = 0.032), but they had limited data for these parameter estimates. Small juvenile survival rates were largely unknown because of the difficulties in studying the early life stages. Experts agreed that generation time for Sonoran Desert Tortoises is approximately 25 years. When combined with the well-studied adult survival and fecundity rates we used the PopBio package (Stubben and Milligan 2007) in program R (R core development team 2013) to test different values for the lesser known parameters ($\bar{S}^{J1}$, $\bar{S}^{J2}$, $\bar{T}^{12}$, $\bar{T}^{2A}$) to see what values led to the estimated 25 year generation time. The "generation.time" function calculates the expected average time between generations, defined as the average age at which a female produces her median off spring (Morris and Doak 2002, Stubben and Milligan 2007). With this approach we adjusted mean parameter values in the, model and set mean small juvenile survival ($\bar{S}^{J1}$) at 0.006 (SD = 0.00012), and small to large juvenile transition ($\bar{T}^{12}$) at 0.083 (SD = 0.00032). In our model the $\bar{S}^{J1}$ parameter is very low, but it includes nest survival (hatching probability) and the very low survival rates of the first few years of life (McCoy *et al*. 2014). We set large juvenile survival and large juvenile to adult transition ($\bar{T}^{2A}$) to sum to the Zylstra *et al*. (2013) annual survival estimate of 0.77. Mean large juvenile survival ($\bar{S}^{J2}$) was set to 0.67 and the transition rate to adulthood (($\bar{T}^{2A}$) was set to 0.1. With these parameters we constructed a projection matrix as follows:

$$\begin{bmatrix} N_{t+1}^{J1} \\ N_{t+1}^{J2} \\ N_{t+1}^{A} \end{bmatrix} = \begin{bmatrix} S_t^{J1} & 0 & (F_t * P_b) \\ T_t^{12} & S_t^{J2} & 0 \\ 0 & T_t^{2A} & S_t^{A} \end{bmatrix} * \begin{bmatrix} N_t^{J1} \\ N_t^{J2} \\ N_t^{A} \end{bmatrix}$$

We incorporated the projection into a stochastic simulation model that replicated the population many times and projected the population a set number of years into the future. In the model survival rates, inter-size class transition rates, and proportion of females that breed were drawn from beta distribution derived from the mean and standard deviations described above, while fecundity rates were drawn from a log normal distribution. We used the methods described by McGowan *et al*. (2011) to incorporate parametric uncertainty into the adult survival parameters since population growth is most sensitive to that parameter. This involves using the replication loop of the model to pick an average adult survival rate for the population that serves as the mean value for each year in that replicate of the population. Under this approach each replicate of the population projection has a different mean value of adult survival and those values are drawn from a beta distribution based on the empirically estimated mean and sampling variance. The model output mean population growth rate, abundance, and the proportion of replicates that went quasi extinct. We used two different thresholds for quasi extinction, 2% and 4% (~7,000 and 12,000 adult females in Arizona, respectively; and ~4,000 and 8,000 adult females in Sonora, respectively) of the maximum possible population size, to allow decision makers to see the implications of choosing an extinction threshold, and allow them to provide input on their risk tolerance.

Conceptual Model of SDT Ecology and Stressors

At a November 2014 meeting and workshop of tortoise experts, we elicited a conceptual model of Sonoran desert tortoise ecology and sought to identify ecological stressors to individuals and the population. We used previous *Federal Register* publications on the Sonoran desert tortoise for review and to guide a subsequent, expanded, and updated review of the available scientific literature to identify potential threats to explore and evaluate, and used basic concepts of conceptual modeling as a guide for developing the diagrams. At the workshop we explored the possible effects of nonnative grasses (primarily red brome [*Bromus* spp.] and buffelgrass [*Pennisetum ciliare*]) on SDT habitat and nutrition and how those issues could affect demographics of SDT. Experts generally agreed that nonnative grass species can at some level reduce forage quality that might affect tortoise nutrition (Nagy *et al.* 1998, pp. 260, 263; Hazard *et al.* 2010, pp. 139–145; Gray 2012, p. 18), and therefore breeding probability, clutch sizes, and growth rates of tortoises (i.e., transition probabilities between age classes; Figure D-2). Some nonnative grasses (*Schismus* spp.) have limited nutritional value to tortoises (Nagy *et al*. 1998, Hazard *et al*. 2010). Experts suggested that, at the spatial scale of our defined populations, wildfire in the desert may not be a significant direct mortality issue (but note exceptions such as Esque *et al.* 2003, pp. 105–107). Historically, fire suppression policies have been implemented widely, however, multiple fires in areas invaded by these fire-adapted nonnative grasses may perpetuate conversion of desert scrub into desert grassland (D'Antonio and Vitousek 1992, p. 73) (Figure D-2), which may lower habitat quality. Wildfire is expected to have a lesser effect on SDT compared to Mojave desert tortoise because of the differences in habitat preferences between the two species.

Experts also generally agreed that crop agriculture and grazing (AIDTT 2000, p. 9; Oftedal 2007, p. 26) had minimal direct effects on individual SDT (especially compared to Mojave desert tortoise) because they often inhabit steep, rocky, upland areas, where crop agriculture does not occur and grazing pressure is generally low. However, grazing and agriculture can facilitate encroachment by nonnative grass that can also reduce habitat quality and affect demography (Figure D-2). Experts identified urbanization as a key component of habitat loss for SDT populations and also believed that urbanization can lead to direct effects on tortoise survival through various mechanisms such as roadway strikes (AGFD 2012b, Table B.1), collection of wild tortoises (Grandmaison and Frary 2012, pp. 264–265), release of captive tortoises (Jones 2008, pp. 36–37; Edwards *et al.* 2010, pp. 801–807), feral dog predation (Jones 2008, p. 66), off-road vehicle use (Boarman 2002, pp. 43–51; Ouren *et al.* 2007, pp. 5, 11; USGAO 2009, pp. 10, 13), etc. (Figure D-2). However, the magnitude, frequency, and spatial extent of these direct effects on survival have not been effectively measured.

Experts identified climate change as a major factor in SDT population viability. Some researchers have concluded recently that the Sonoran Desert scrub habitat might expand under some climate change scenarios, thus benefitting SDT (Van Riper *et al*. 2014). However, other researchers expect climate change to impact tortoises primarily though drought (Seagar *et al*. 2007, entire; IPCC 2014, pp. 1456–1457); to a lesser extent it could affect sex ratios at the population level (Janzen 1994, p. 7488) as atmospheric temperatures can affect nest temperatures that determines sex of developing eggs. Climate change could also affect forage quality by the timing and intensity of seasonal monsoons that in turn could affect the annual probability of breeding, clutch size, and life-stage transitions (via juvenile growth rates). Climate change, via drought frequency and magnitude, might also affect survival rates of juvenile and adult tortoise, as Zylstra *et al.* (2013, p. 113) reported a 0.1 to 0.15 decline in annual survival for marked tortoise during periods of drought.

The process of developing a conceptual modeling was very informative and identified a number of issues to explore with respect to SDT population viability, many of which are highly uncertain or lack data to formalize a functional relationship beyond conceptual linkages. Through that process, however, we identified two key factors with high potential to affect tortoise populations in the future: drought and habitat availability (Figure D-4). Many of the threats identified in the literature and in the conceptual modeling workshop were thought to affect SDT populations via habitat quantity and quality, and climate change-induced drought could have major implications for annual survival of tortoises. We incorporated these two factors into our simulation model and explored the effects of each on population viability (Figure D-4).

Environmental Parameters

First, to model the effects of limiting habitat quantity and quality on the population, we created a ceiling-type density-dependence function in the model, whereby if the population exceeded an established maximum population size, the proportion of females that breed declined to zero. Ceiling-type density dependent functions are not usually realistic, e.g., all of the females in the population failing to breed in a single year is a severe effect, but ultimately it has the same effect as reducing the Pb parameter to 80% or 50% of normal rate but it just impacts the population faster when all of them fail to breed. Ceiling type density dependent functions lack biological detail but are commonly used in population viability modeling when the functional form of density dependence in the population is unknown. In addition, they are useful for capturing effects of density dependence without speculating on the mathematical formulation of density on demographic rates (Lande 1993, entire, Middleton *et al.* 1995, entire, Morris and Doak 2002, entire). The maximum population size in a given simulation was determined by the amount (mi^2) of habitat in good, medium and low condition (referred to as primary, secondary, and tertiary habitat quality) multiplied by an average expected density for each of those conditions. Using data from long-term monitoring plots (Averill-Murray *et al*. 2002b, Table 6.1; Zylstra *et al*. 2013, Table 1) we estimated densities of 43.3 tortoises per mi^2 in areas of primary habitat, 24.3 in secondary habitat, and 5.2 in tertiary habitat [see SSA Report Chapter 5 for description of habitat qualities and for population density estimates]. The model calculated maximum population size as follows:

$$Pop_{max} = (D_P \times A_P) + (D_S \times A_S) + (D_T \times A_T)$$

Where *D* was the density in primary (subscript *p*), secondary (subscript *s*) and tertiary (subscript *t*) and A is the area of habitat (in square miles).

We conducted two primary sets of simulations with this habitat-derived ceiling type density dependent function. We could set specific habitat quality amounts derived from GIS analyses and model specific habitat scenarios. We also allowed the ceiling threshold to be reduced annually within a simulation, to represent habitat loss or degradation over time. In our model we could also establish a maximum habitat area (drawn at random from 120% of current to 20% of current total) and then assigned habitat into the three quality classes by multiplying the total by three randomly generated proportions that summed to 1.0. With this approach we could explore the effect of differing amounts of habitat on the probability of extinction through regression analyses (described in detail below).

Second, we included a drought effect on survival of all age classes in our model. We drew a random value from a beta distribution derived from historic drought data (annual proportion of Arizona counties exposed to moderate to severe drought from 1900-2000), which determined the proportion of the population exposed to drought in any specific year. Annual survival for adults and juveniles exposed to drought was reduced to approximate the results reported in Zysltra *et al.* (2013, p. 113). For the projection model, survival became the weighted average of the animals exposed and not exposed to drought, for example:

$$S_t^{A,d} = \left(P_{drought} \times S_t^A \times DE_t\right) + \left(\left(1 - P_{drought}\right) \times S_t^A\right)$$

Where $P_{drought}$ is the proportion of the population exposed to drought and $S_t^{A,d}$ is the survival rate of adults for the full population, given the proportion that was exposed to drought. DE_t is the drought effect in a specific year which was modeled as a uniform random number between 0.8 and 0.99 (i.e., a 1% to 20% reduction in survival), to represent differing drought severity from year to year. Some droughts have low severity and do not effect survival very much and others, especially multi-year droughts, can have much greater survival consequences. With this framework we can model a wide array of droughts of different magnitudes and spatial extents to account for possible impacts of climate change as related to drought, and we can examine the effect of drought spatial magnitude on extinction probability.

Model Outputs

We used the model described above to run a set of 18 predetermined habitat, population and climate-based scenarios (9 each for Arizona and Sonora, see SSA Report for an explanation of the scenarios). The model used a thousand replications to project population outcomes 200 years into the future under each scenario and tracked adult age class population size, population growth rate (rate of annual change) and whether the population fell below the quasi-extinction threshold in each year.

Extinction sensitivity to drought and habitat loss

We also used an analysis similar to McGowan *et al.* (2014) to build a triple loop simulation model (Figure D-3) that allowed us to simulate thousands of replicates with a wide variety of habitat, drought, and population size scenarios to examine the functional form of the relationship of those factors to extinction probability. In the outer most loop of the model we selected 1,000 maximum total habitat and the mean proportions in each quality category. The minimum possible values for total habitat was 20% of the current amount and the maximum was set at 120% of the current amount, derived from a separate GIS analysis of available habitat in Arizona and Sonora. We also selected 1,000 values for increasing the mean of the proportion of the population exposed to droughts from a uniform distribution between 0.1 and 2.0 (representing between a 10% and 200% increase in the mean, i.e. mean population exposed to drought between 0.11 and 0.3 proportion of population). Furthermore, we randomly selected 1,000 random starting population sizes between 75,000 and 500,000 females. In the second loop (Figure D-3) the model replicated the population 1,000 times for each of the 1,000 sets of values passed forward from the outermost loop. In that second loop our model selected the mean values for the demographic parameters based on the statistical distributions described previously for each of the 1,000 replicates and those values were passed into the interior loop, also known as the annual loop. The model projected the population 200 years into the future and tracked adult age class population size, population growth rate (rate of annual change) and whether the population fell below the quasi-extinction threshold in each year. For each of the 1,000 replicates in the secondary loop we saved the proportion of replicates that went quasi extinct at 25 years, 50 years, 100 years and 200 years into the future, alongside the maximum abundance values, the initial population size and mean proportion affected by drought for that set of replicates. At the end of the simulation we had 1,000 lines of data matching extinction probability at 25, 50, 100 and 200 years with maximum abundance, initial abundance and proportion exposed to drought. We used those data to assess binomial regression models of extinction probability with maximum abundance, initial abundance and proportion exposed to drought as covariates in the models. Using AIC model selection criteria, we evaluated and compared multiple models of quasi extinction; models had one, two, or three covariates of mean drought, starting population size and/or max population size. The regression parameters in those models tell the relative probable effect of each covariate on the probability of quasi extinction and whether the covariate has a positive or negative association with probability of extinction.

This analysis is akin to a sensitivity analysis. With the regression parameters we can also predict the probability of quasi extinction for specified sets of covariate values. We used the regression parameters to generate table of expected quasi-extinction probability under varying conditions. McGowan *et al.* (2014) used this approach to identify the conditions under which risk was acceptably low in order to identify recovery criteria for a threatened population of piping plovers.

<u>Modeling Results</u>

Table D-1 lists results of all the model runs with projected population growth rates, and mean tortoise abundance and quasi-extinction risk at 50, 75, 100, and 200 years.

Current conditions

We ran a set of baseline conditions and four scenarios each for Arizona, U.S. (Figures D-4.1-4.5), and Sonora, Mexico (Figures D-5.1-5.5), that capture current conditions given our uncertainty regarding population density and starting population size. The Baseline scenario represents the best possible case with no climate change related effects on drought and survival and all habitats in the best possible condition. The other four scenarios in Arizona and Sonora project current conditions into the future (see prior description in viability section of SSA Report). In all scenarios the population declined over time with mean population growth rates slightly negative ($\lambda \approx 0.996$). Probability of quasi extinction varied among scenario but largely because we used two different quasi extinction thresholds (2% and 4% of maximum population size) to allow decision makers to the see the consequences of picking a quasi-extinction threshold. Under all "current conditions" scenarios for both Mexico and Arizona probability of quasi extinction was 0.00 at 50 years and at 100 years was less than 0.01 for scenarios with a 2%

abundance threshold and approximately 0.05 for scenarios with 4% abundance threshold. In other words, there was less than 0.01 probability of falling below 2% of the maximum population and approximately 0.05 probability of falling below 4% of the maximum population 100 years into the future.

All scenarios (current and future; see below) exhibited steep declines initially, but those declines are a mathematical artifact of setting the initial population size equal to the population ceiling in the simulations. When the population starts at the carrying capacity the median abundance will initially decline because some proportion of the 1,000 replicates will decline and those that don't decline cannot exceed the maximum population ceiling, therefore, the median which is a representation of the "middle trajectory," will decrease. These results do not mean that we will expect to see immediate rapid decline in the population before growth rates stabilize after 10 or so years.

Future conditions

The future scenario simulations added increased potential for drought (i.e., climate change effects) and annual habitat loss rates to mimic the effects of urbanization, wildfire and exotic vegetation encroachment on habitat carrying capacity. We ran four future scenarios each for Arizona (Figures D-4.6-4.9) and for Sonora (Figures D-5.6-5.9). The simulations showed a decline in the median abundance and faster declines than the "current conditions" scenarios. Mean population growth in Arizona was approximately 0.992, meaning, on average populations declined by approximately 0.8% annually and was 0.9945 in Sonora. Quasi-extinction probabilities were higher than the "current conditions" scenarios, but were still very dependent on whether a 2% or 4% of the initial population was used as the quasi-extinction threshold. For the Arizona population, under the worst climate change and habitat loss scenario we simulated (Figure D-4.9), the probability of quasi extinction was still 0.00 at 50 years and was 0.068 at 100 years. The worst case scenario for Sonora (Figure D-5.9) had a probability of quasi extinction of 0.00 at 50 years and 0.09 at 100 years.

Full simulation and regression modeling results

A regression model with maximum population size (*MaxPop*), initial female abundance (*NAI*) and mean drought exposure (*MDR*) as the independent variables and quasi-extinction probability as the dependent variable was the best model to explain variation in quasi-extinction probability at 200 years at 100. At 50 years, the regression model explained less of the variation in extinction probability but that is most likely because a smaller proportion of the population trajectories went quasi extinct; at 25 years none of the simulated populations surpassed the quasi-extinction threshold so no regression model converged on beta parameter estimates. We tested regression models with drought as the only covariate, and while these models performed well, the AIC model selection analysis indicated that adding initial abundance and maximum population size improved model fit. The regression equation for 200 years was:

$$P_{Qe200} = -3.019 + (14.13\ x\ MDR) - (1.588e^{-6} x\ NAI) - (1.145e^{-6} x\ MaxPop).$$

The regression parameters indicate that drought has a relatively very large and positive effect of quasi-extinction probability and initial population size and maximum population size have a smaller but significantly negative effects on quasi extinction ($p<<0.01$). The regression equation for 100 years was:

$$P_{Qe100} = -5.602 + (18.42\ x\ MDR) - (5.363e^{-6} x\ NAI) - (1.797e^{-6} x\ MaxPop).$$

The regression equation for 50 years was:

$$P_{Qe50} = -10.68 + (2.894\ x\ MDR) - (3.429e^{-5} x\ NAI) - (2.155e^{-6} x\ MaxPop).$$

Generally, as time horizon on the simulation shortened the strong positive effect of drought on quasi-extinction probability and the weaker but significant effect of NAI and MDR remained.

With the regression parameter estimates (intercept and slope terms) we constructed tables demonstrating the changing expected probability of quasi extinction under varying drought, and initial abundance conditions, along with approximately our current habitat limited maximum population size (e.g., Tables D-2 and D-3). The tables enable us to visualize more effectively the relationship between these variables. The tables are similar to the tables used in McGowan *et al.* (2014) to assess recovery criteria for piping plovers in the Northern Great Plains. We can also use the regression equation to calculate the expected quasi-extinction probability for any combination of values for the independent variables. Under this analysis, at 50 there is very low probability of quasi extinction (falling below fewer than 6,000 females) regardless of starting population size or drought magnitude. At 100 years quasi-extinction probability gets as high as 0.349 when, on average, 30% of the population is exposed to drought and there are only 100,000 females in the population initially. Whereas with, on average, 15% of the population exposed to drought and an initial abundance of 150,000 females, quasi-extinction probability at 100 years was 0.025. These tables essentially allow us to evaluate numerous scenarios within the range of possible future variation simultaneously.

Table D-1: Results of the population simulation model under different scenarios, where N_0 is the starting abundance of adult females (in thousands); λ_{200} is the median population growth rate over 200 years (*SE* is standard error); N_t is the median abundance of adult females (in thousands) at time *t*; and P_{Qet} is the probability of quasi extinction at time *t*.

			Results at 50 years		*Results at 75 years*		*Results at 100 years*		*Results at 200 years*	
Scenario	**N_0**	**λ_{200} (SE)**	**N_{50}**	**P_{Qe50}**	**N_{75}**	**P_{Qe75}**	**N_{100}**	**P_{Qe100}**	**N_{200}**	**P_{Qe200}**
US-Base	350	0.9944 (0.004)	271	0.000	262	0	259	0.001	221	0.076
MX-Base	210	0.9972 (0.007)	158	0.000	150	0	142	0	120	0.07
US-Ac	320	0.9932 (0.003)	241	0.000	219	0	200	0.003	149	0.097
MX-Ac	170	0.9969 (0.008	129	0.000	124	0.001	119	0.005	91	0.092
US-Bc	190	0.9938 (0.003)	139	0.000	130	0.011	125	0.034	102	0.187
MX-Bc	100	0.9961 (0.008)	72	0.000	67	0.006	62	0.037	46	0.22
US-Cc	270	0.9935 (.003)	204	0.000	191	0	174	0.005	138	0.107
MX-Cc	140	0.9964 (0.007	100	0.000	96	0	89	0.006	68	0.116
US-Dc	150	0.9939 (0.003)	115	0.000	108	0.008	103	0.043	80	0.224
MX-Dc	80	0.9962 (0.008)	55	0.000	53	0.021	48	0.066	38	0.254
US-Ef	320	0.9925 (0.003)	233	0.000	213	0	199	0.003	130	0.113
MX-Ef	170	0.9948 (0.008)	116	0.000	103	0.001	96	0.003	61	0.126
US-Ff	190	0.9928 (0.004)	133	0.001	124	0.011	114	0.041	90	0.205
MX-Ff	100	0.9952 (0.008)	68	0.000	63	0.005	58	0.045	38	0.25
US-Gf	270	0.9914 (0.003)	185	0.000	164	0	148	0.009	96	0.142
MX-Gf	140	0.9950 (0.009)	96	0.000	86	0.002	79	0.01	52	0.131
US-Hf	150	0.9915 (0.003)	104	0.000	91	0.015	79	0.068	51	0.275
MX-Hf	80	0.9945 (.009)	54	0.001	48	0.033	43	0.089	27	0.323

Table D-2: Quasi-extinction probability at 100 years, given 350,000 females as the maximum population size and varying values for initial female abundance and mean drought exposure.

100 years	Max pop = 350,000 females						
	Starting population size						
Magnitude of drought	100000	150000	200000	250000	300000	350000	400000
0.10	0.013	0.010	0.008	0.006	0.005	0.004	0.003
0.15	0.033	0.025	0.019	0.015	0.011	0.009	0.007
0.20	0.078	0.061	0.047	0.037	0.028	0.022	0.017
0.25	0.176	0.141	0.111	0.087	0.068	0.053	0.041
0.30	0.349	0.291	0.239	0.194	0.155	0.123	0.097

Table D-3: Quasi-extinction probability at 50 years, given 350,000 females as the maximum population size and varying values for initial female abundance and mean drought exposure.

50 years	Max pop = 350,000 females						
	Starting population size						
Magnitude of drought	100000	150000	200000	250000	300000	350000	400000
0.10	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.15	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.20	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.25	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.30	0.001	0.000	0.000	0.000	0.000	0.000	0.000

Figure D-1: Life cycle diagram of Sonoran Desert Tortoise. Adults (A) produce hatchlings (J_1) and which can survive (S_{J1}) and after approximately 5 years become older juveniles (J_2) which can survive (S_{J2}) and after an additional 10-12 become adults.

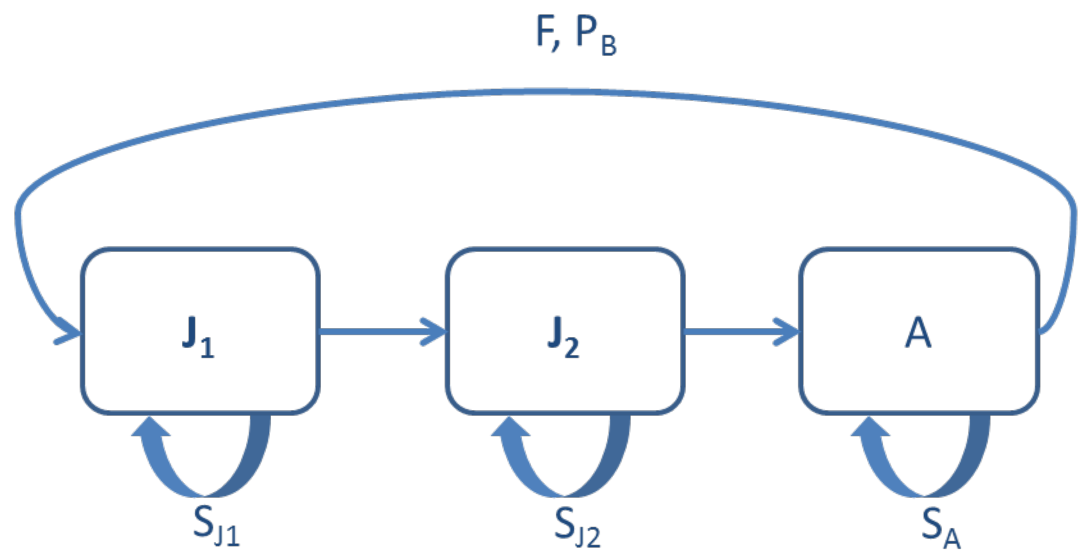


Figure D-2: Screen capture of a prototype conceptual model in Netica depicting Sonoran desert tortoise population dynamics and ecological interactions

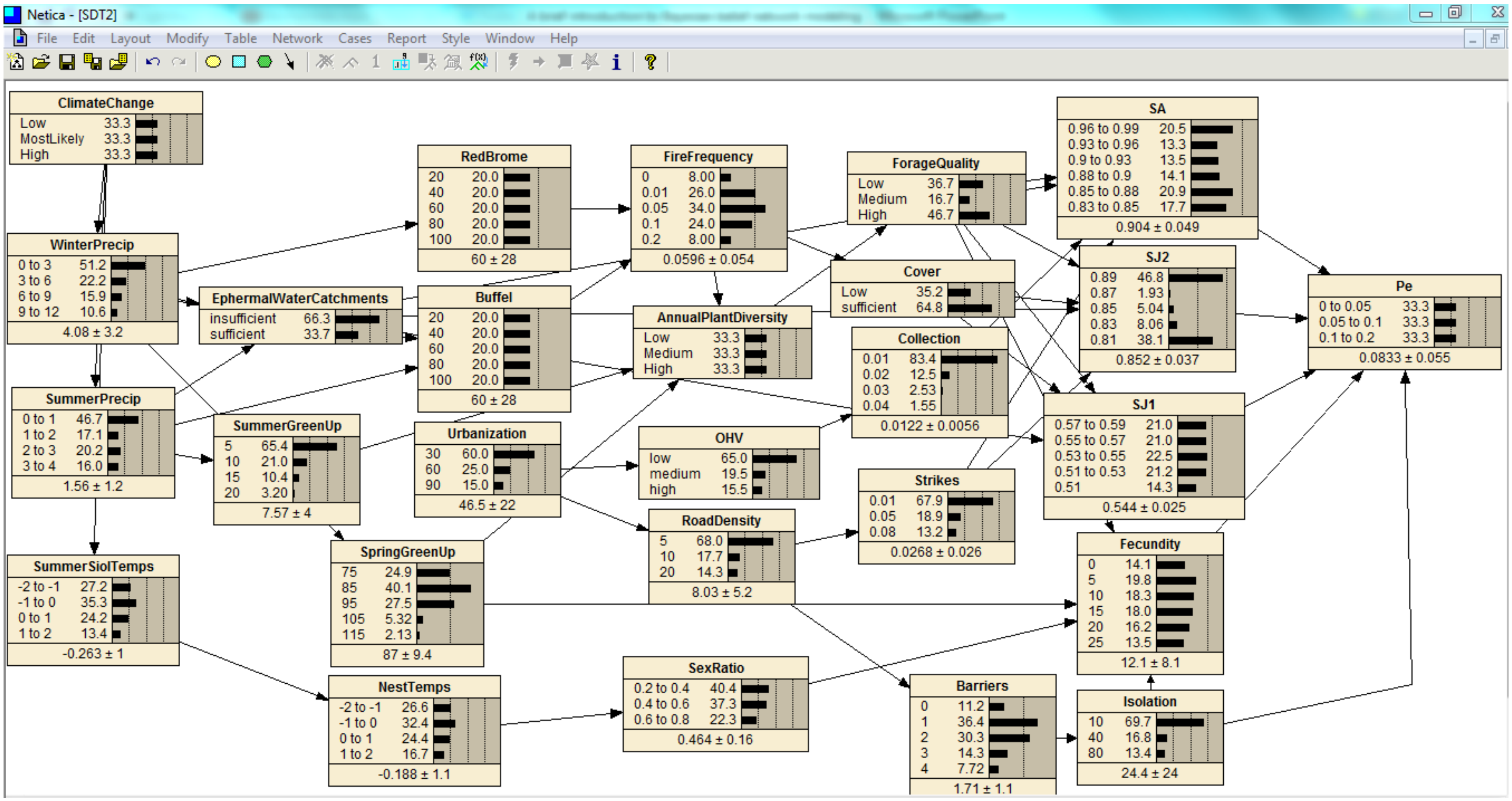


Figure D-3: Demonstration of the triple loop structure used in the Sonoran desert tortoise simulation model to generate 1000 probabilities of extinction with 1000 initial population sizes, habitat inputs and proportion of the population exposed to drought.

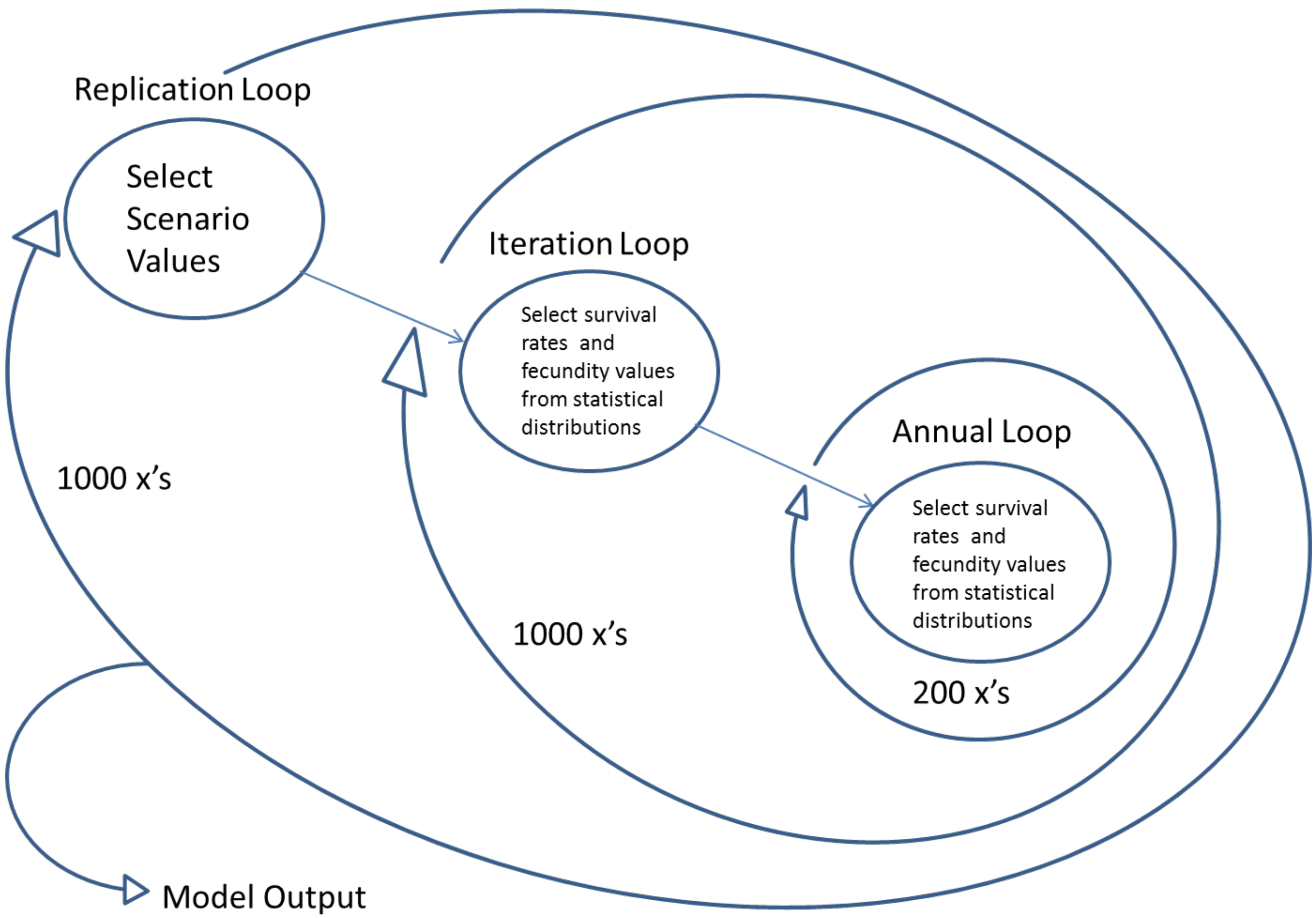


Figure D-4: Plots of predicted median abundance (solid line, primary (left) axis) with 95% confidence interval (dashed lines, primary axis) and the probability of quasi extinction (shaded area, secondary (right) axis) for the baseline (4.1), four "current conditions" scenarios (4.2 - 4.5) and four future conditions scenarios (4.6 - 4.9) in Arizona, U.S. See Draft SDT SSA Report for description of scenarios.

Figure 4.1 Arizona, Baseline

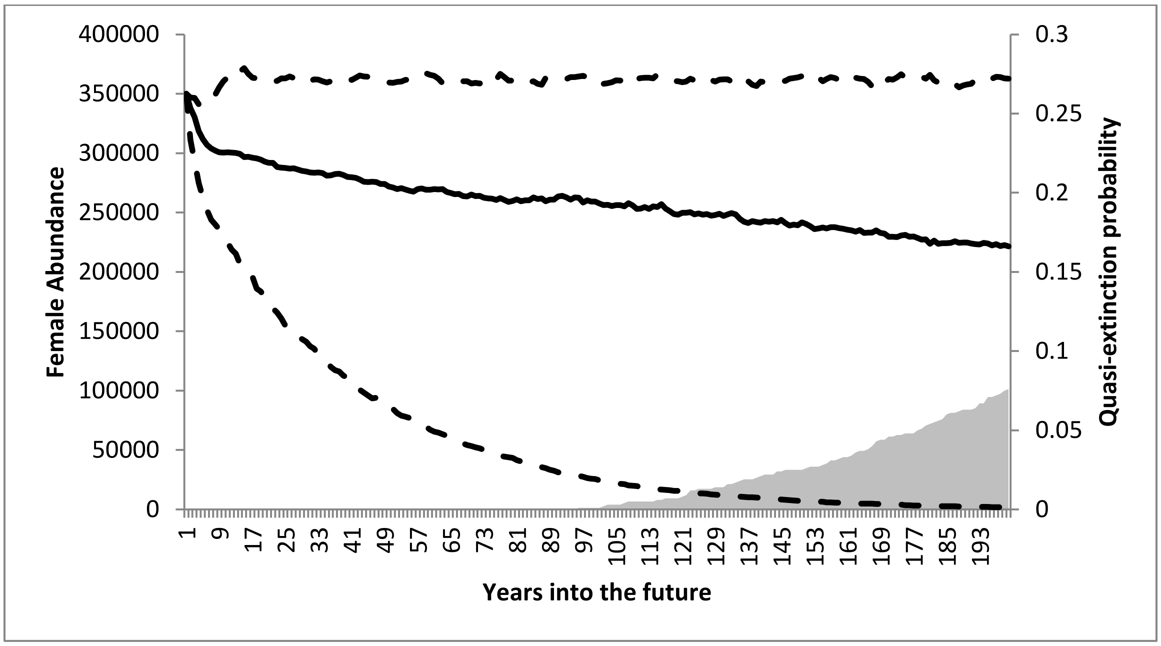


Figure 4.2 US-Ac

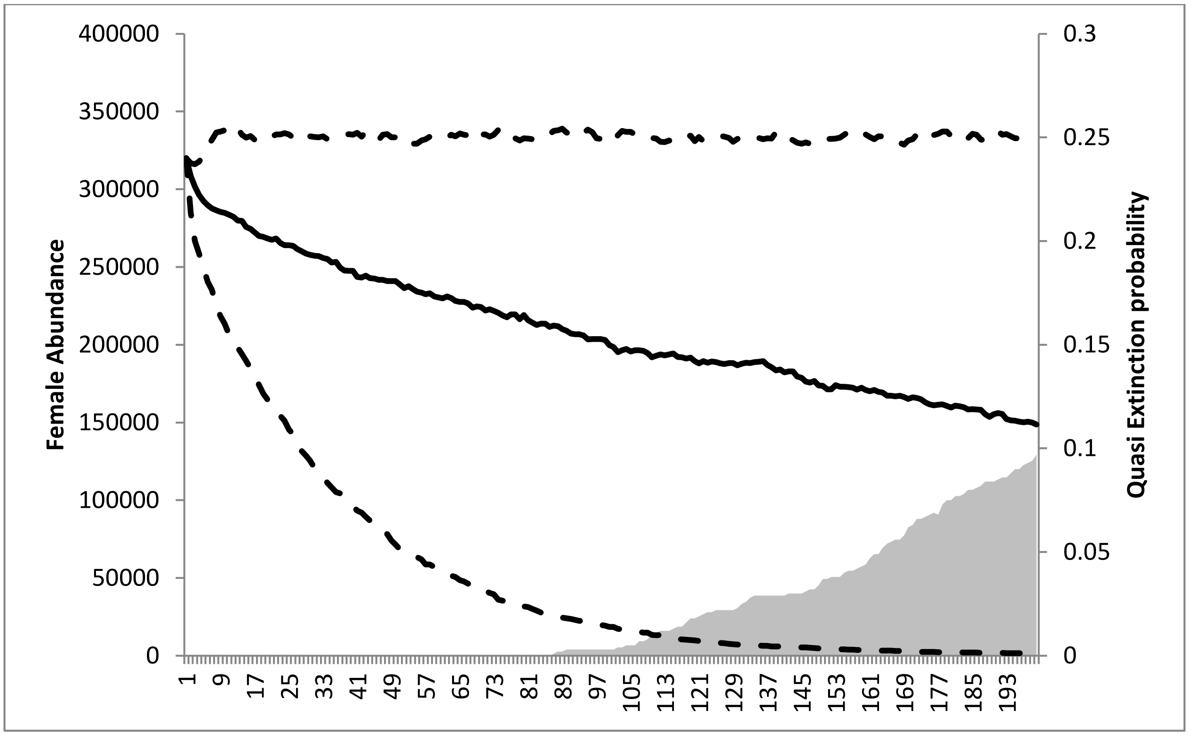


Figure 4.3 US-Bc

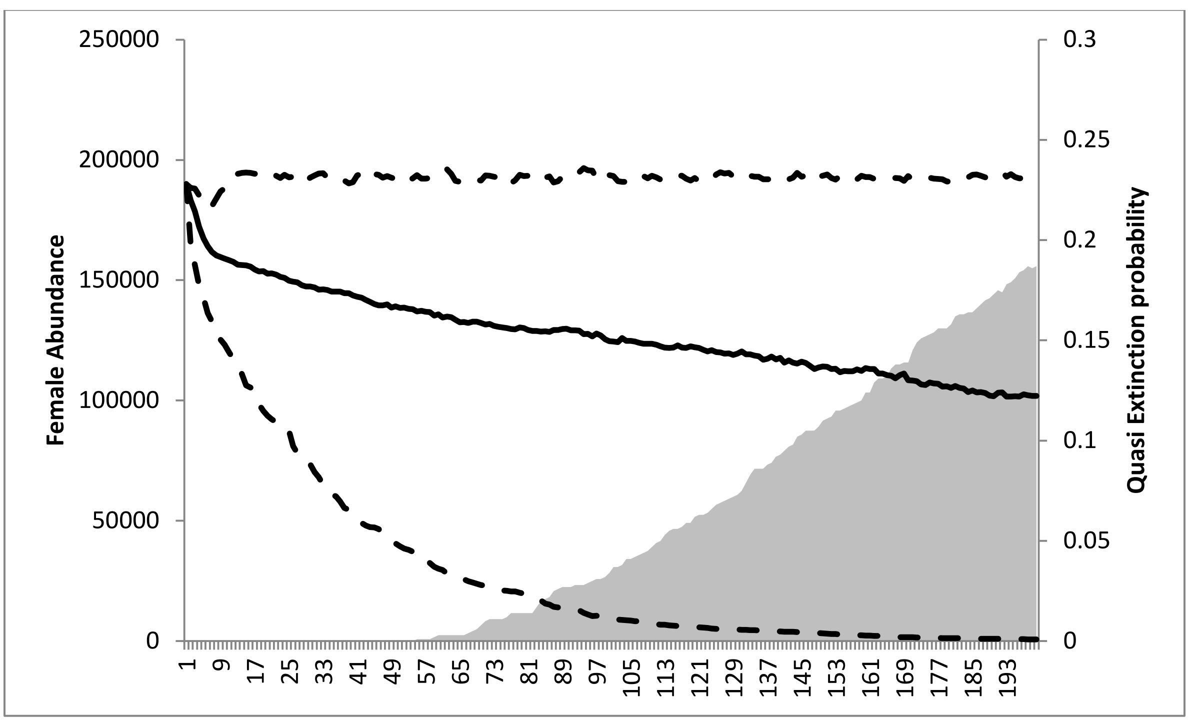


Figure 4.4 US-Cc

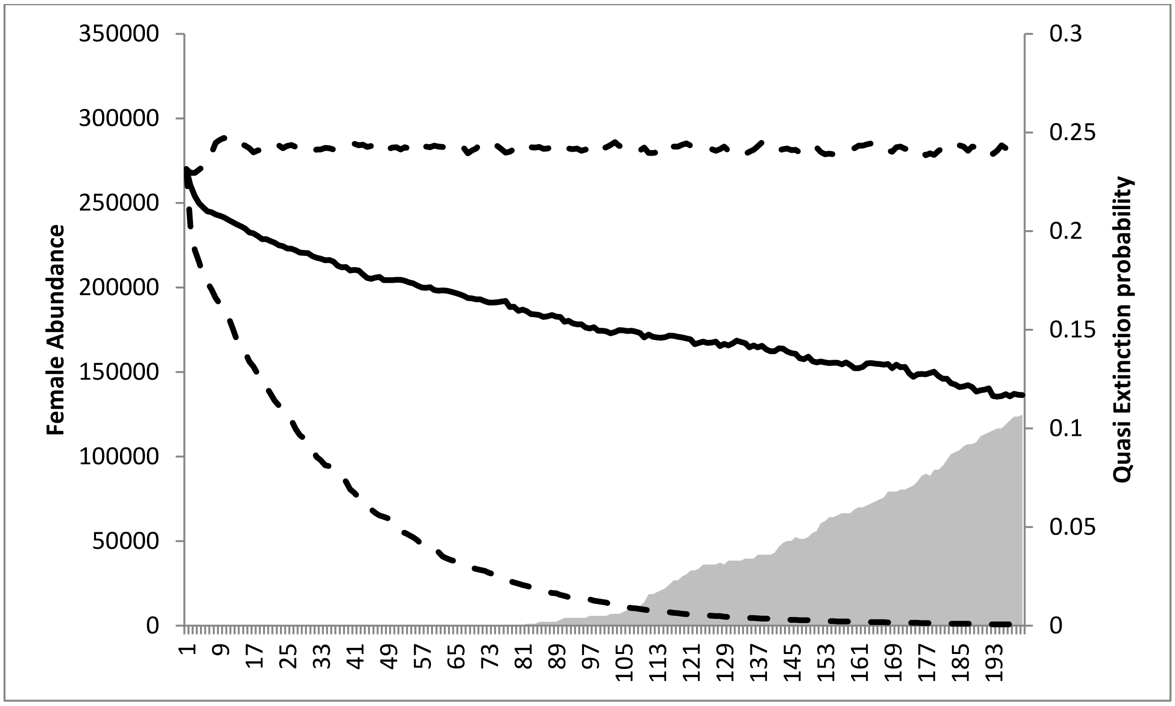


Figure 4.5 US-Dc

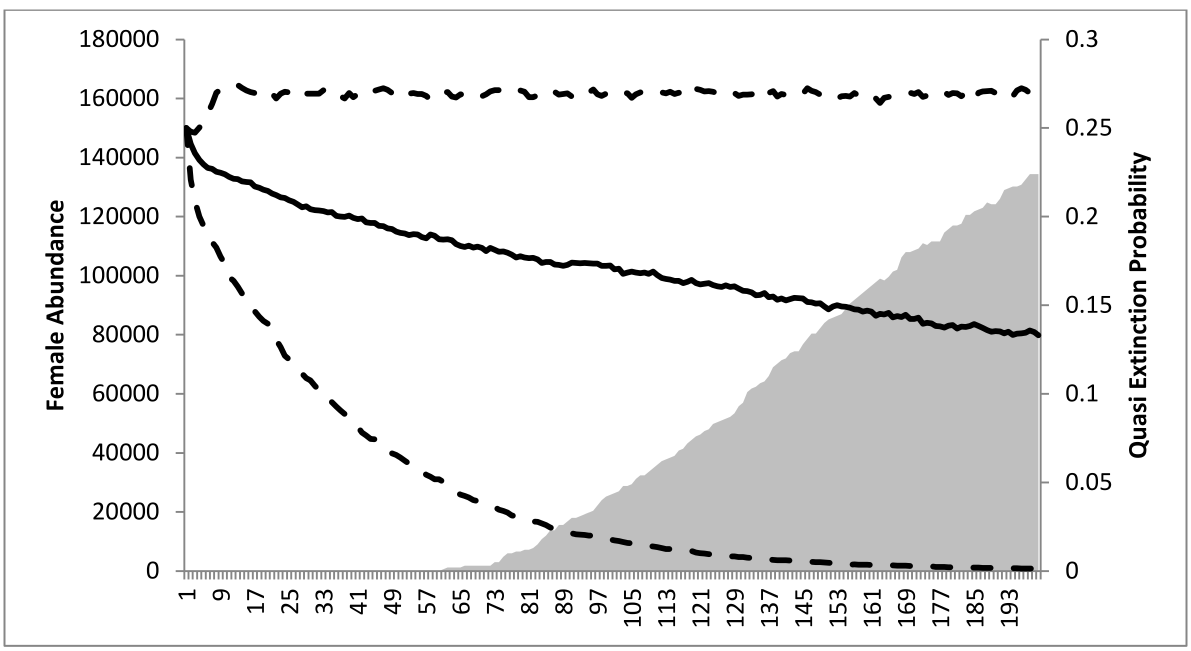


Figure 4.6 US-Ef

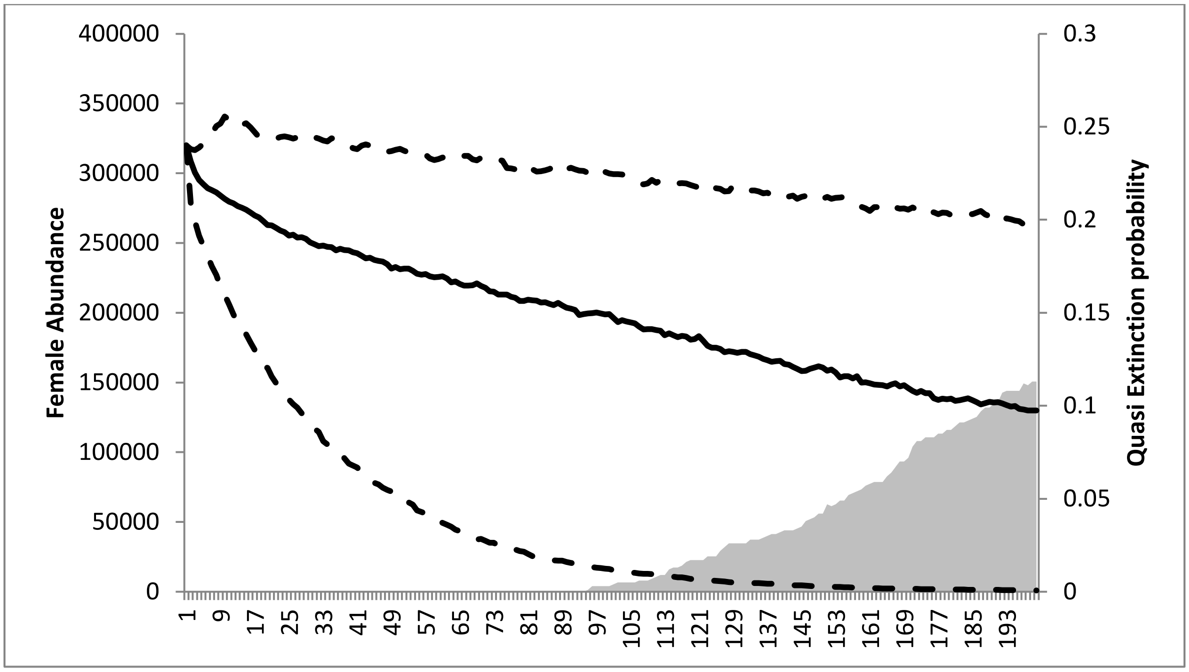


Figure 4.7 US-Ff

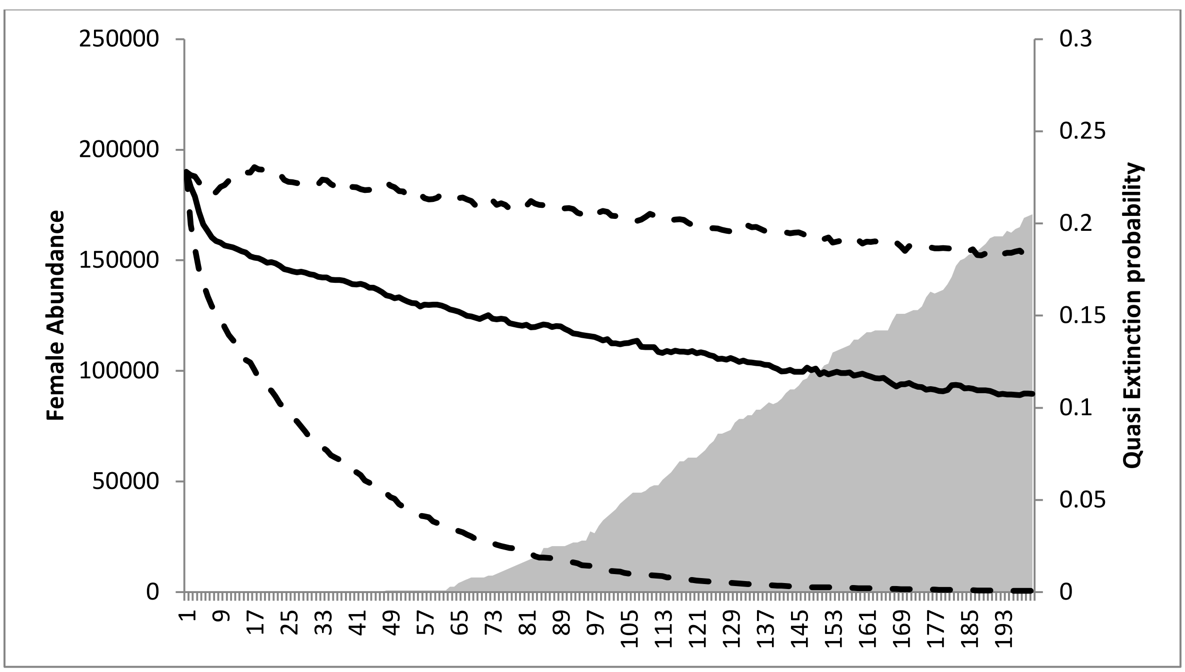


Figure 4.8 US-Gf

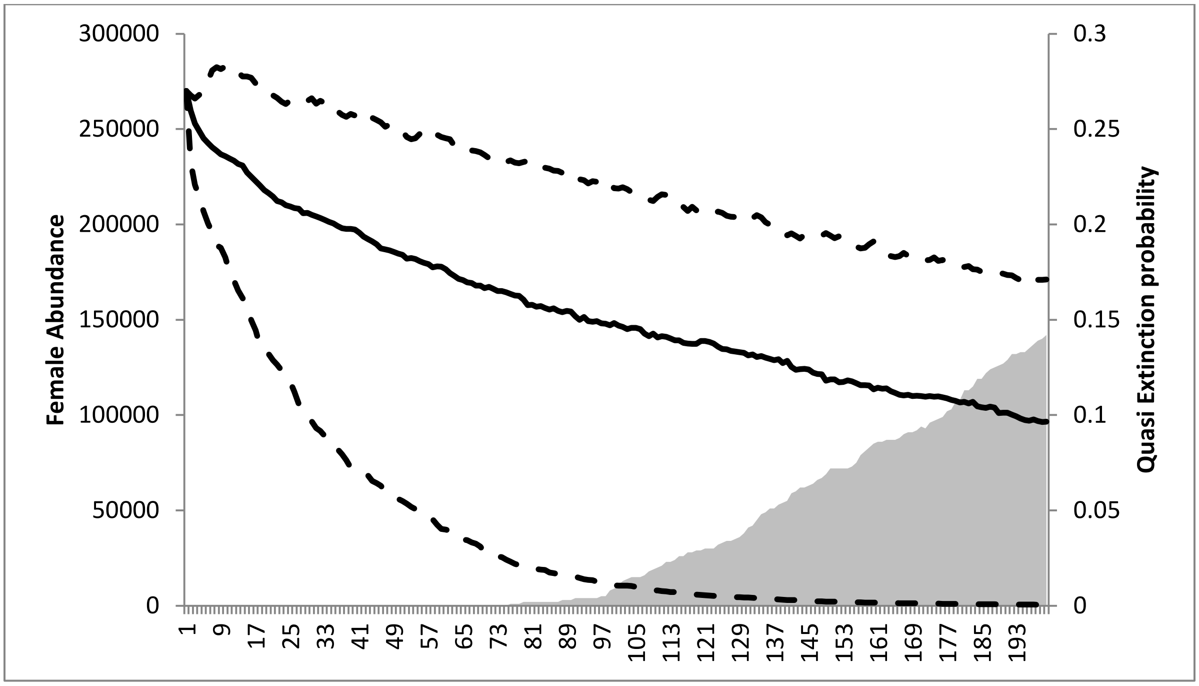


Figure 4.9 US-Hf

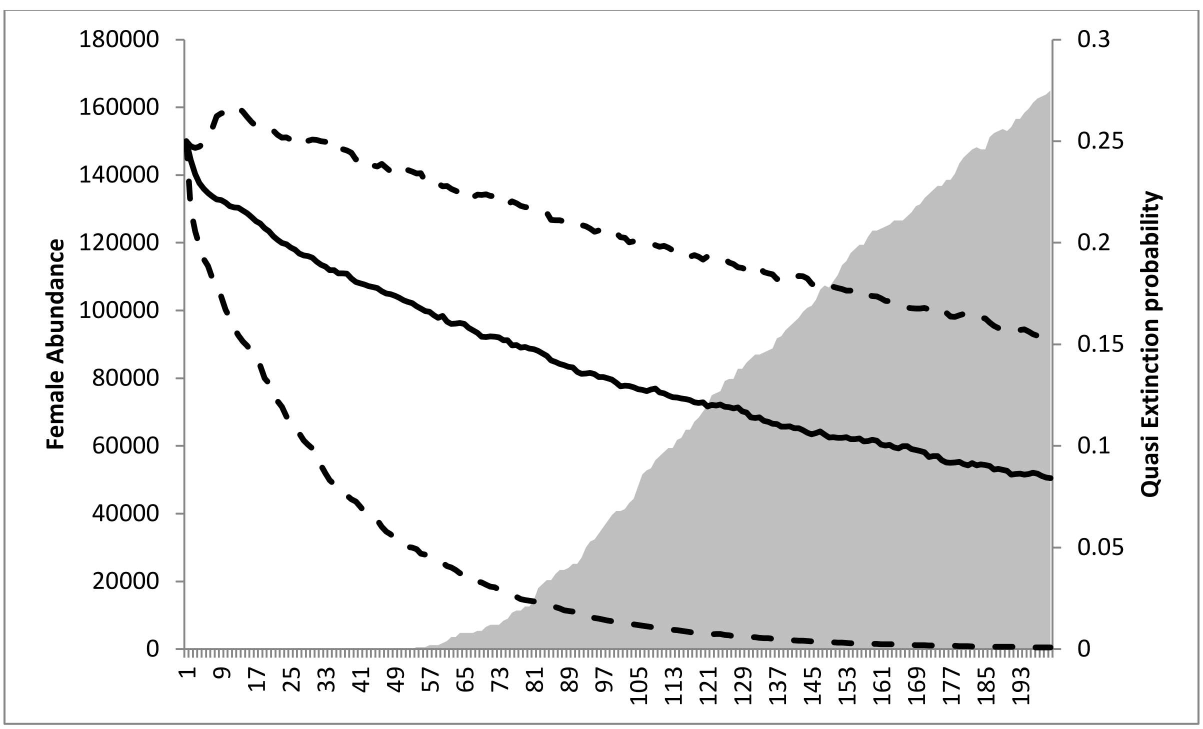


Figure D-5: Plots of predicted median abundance (solid line, primary (left) axis) with 95% confidence interval (dashed lines, primary axis) and the probability of quasi extinction (shaded area, secondary (right) axis) for the baseline (5.1), four "current conditions" scenarios (5.2 – 5.5) and four future conditions scenarios (5.6 – 5.9) in Sonora, Mexico. See Draft SDT SSA Report for description of scenarios.

Figure 5.1 Sonora, Baseline

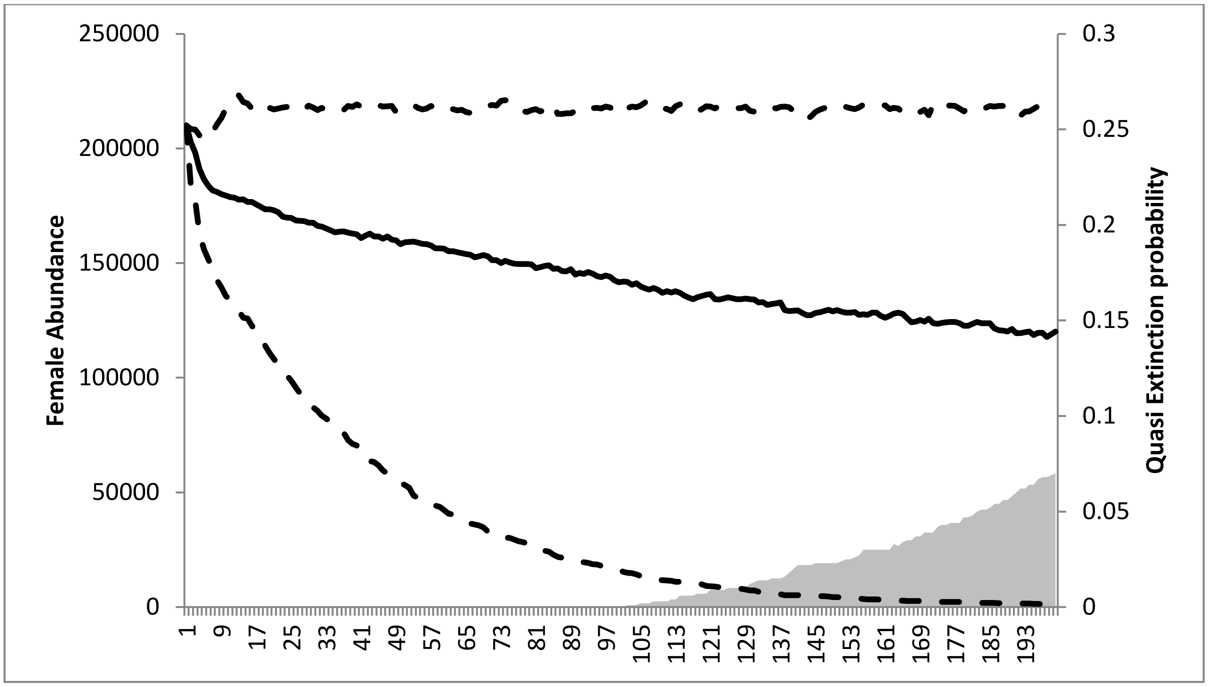


Figure 5.2 MX-Ac

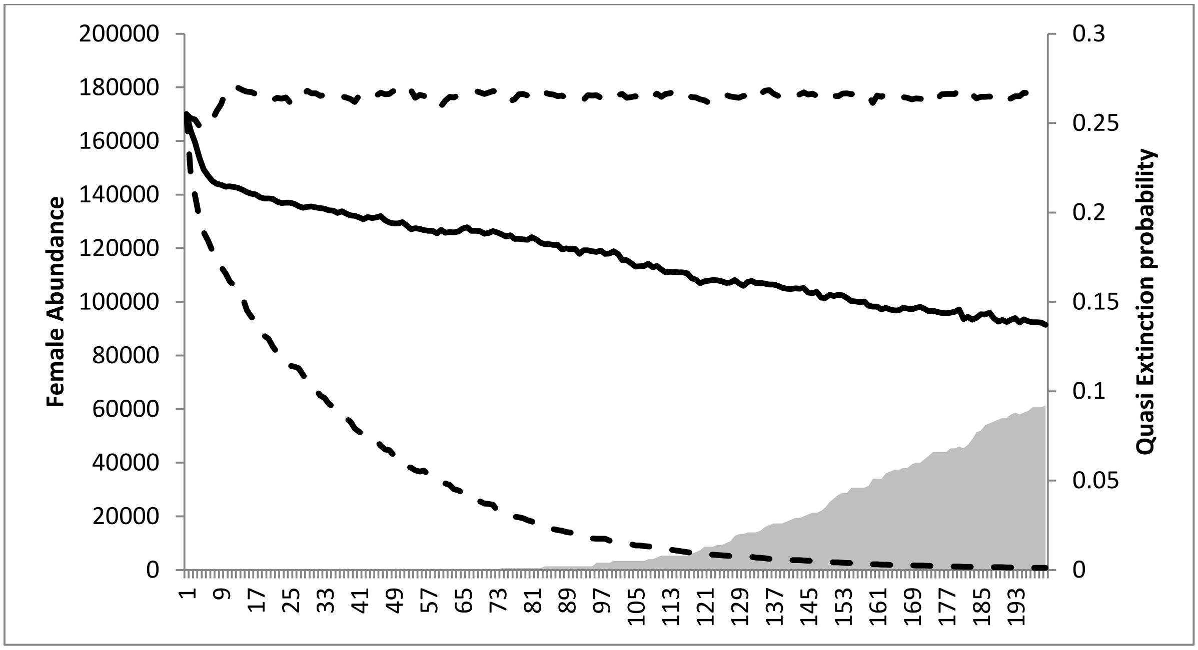


Figure 5.3 MX-Bc

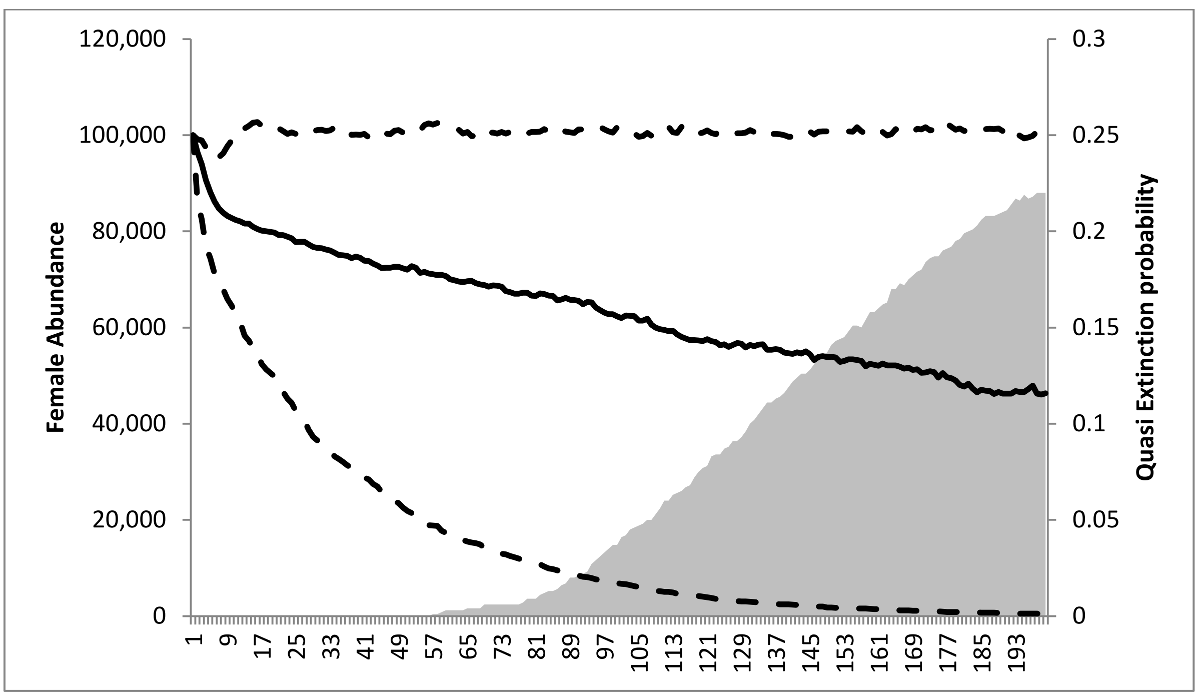


Figure 5.4 MX-Cc

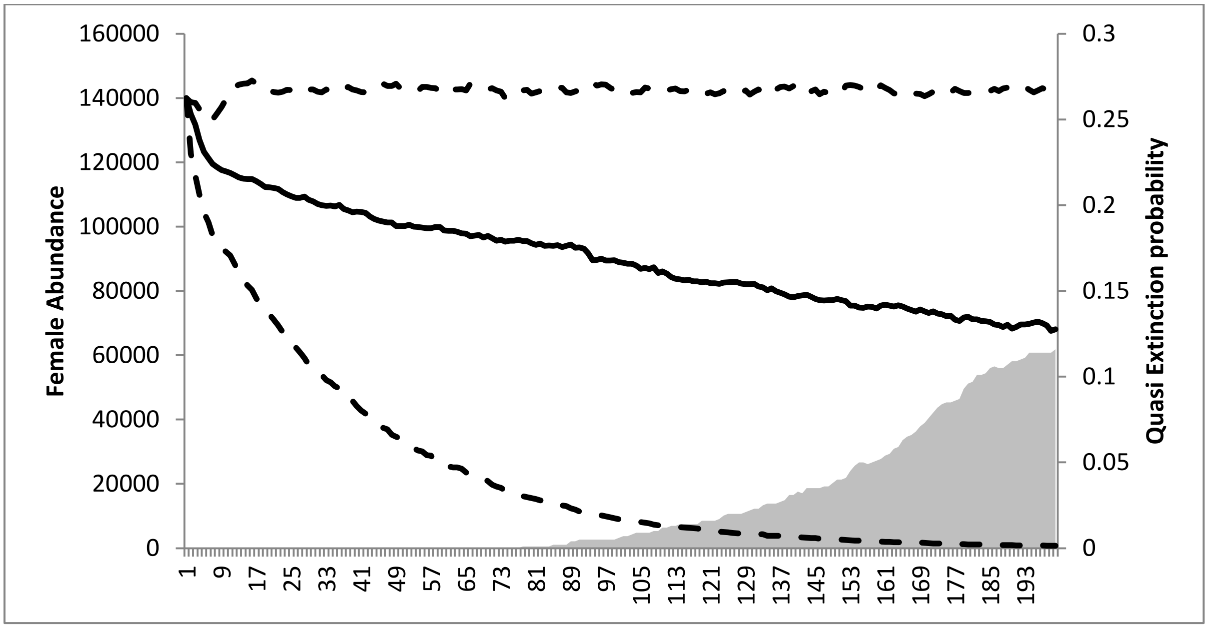


Figure 5.5 MX-Dc

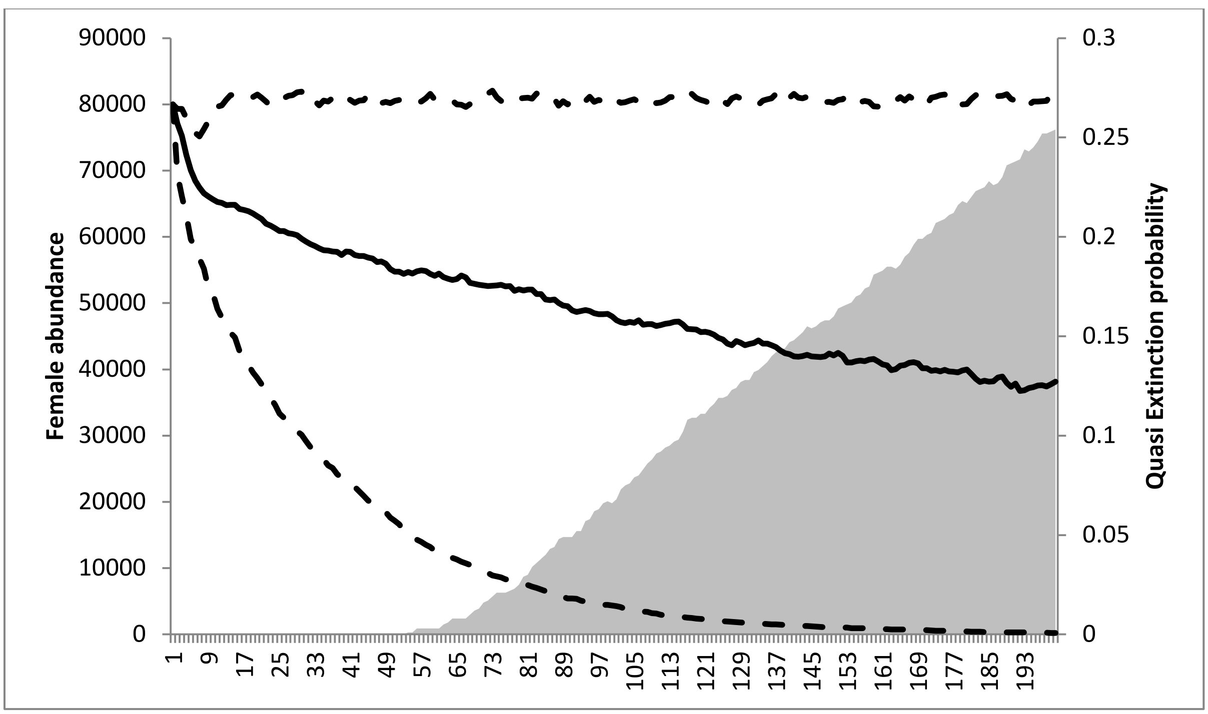


Figure 5.6 MX-Ef

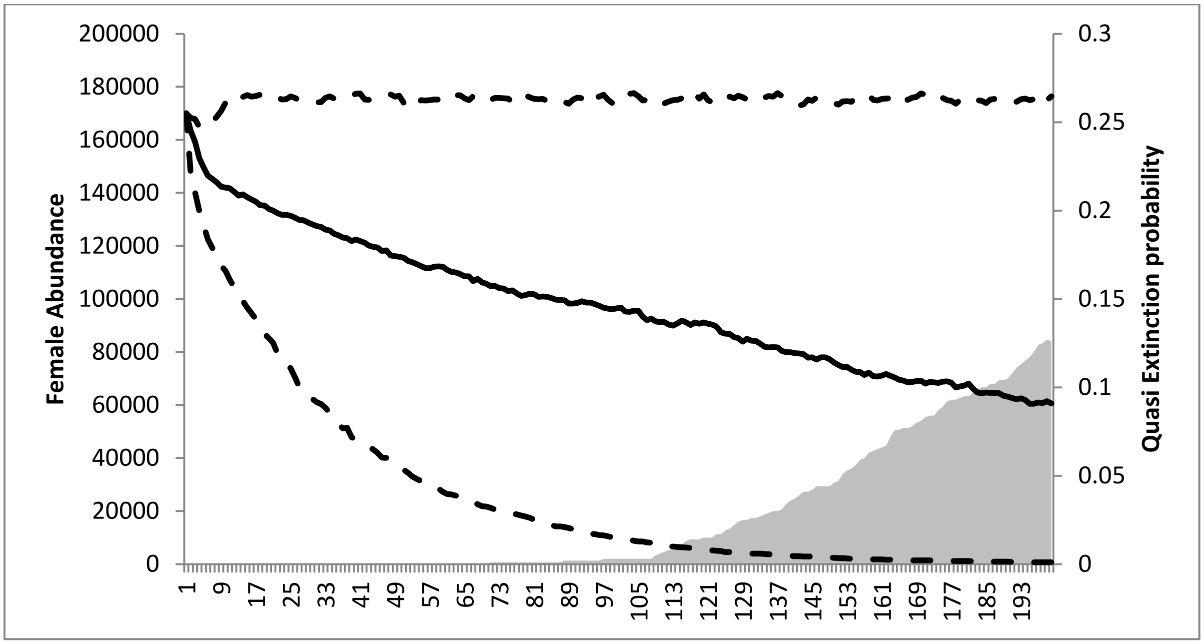


Figure 5.7 MX-Ff

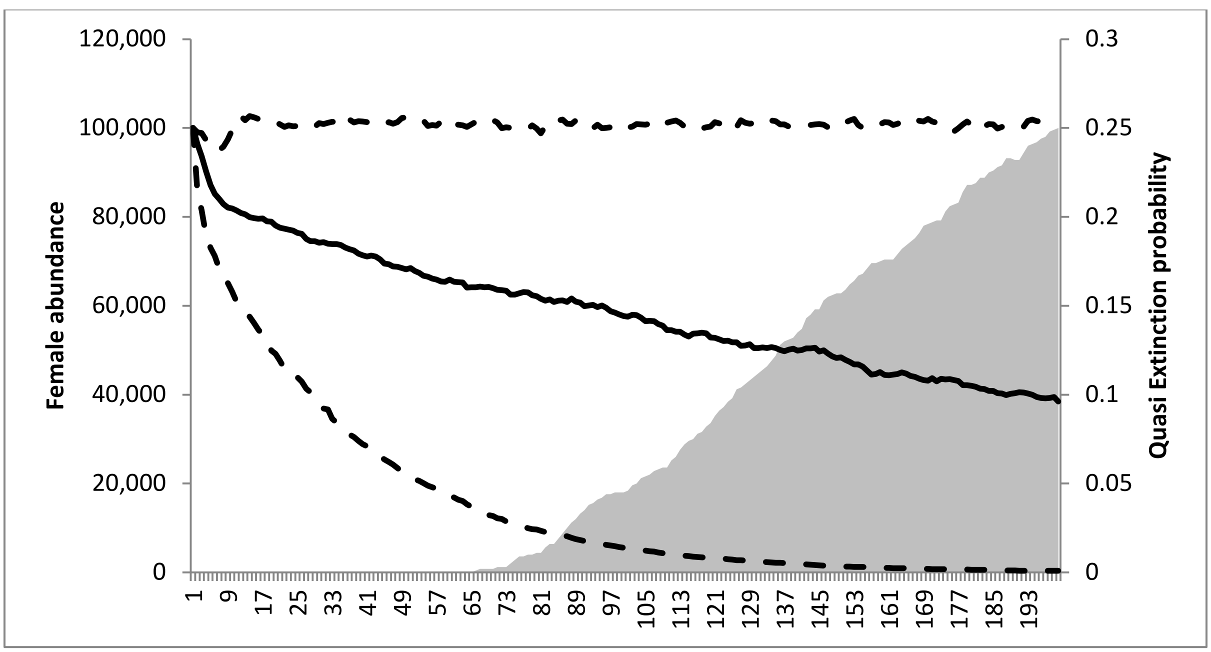


Figure 5.8 MX-Gf

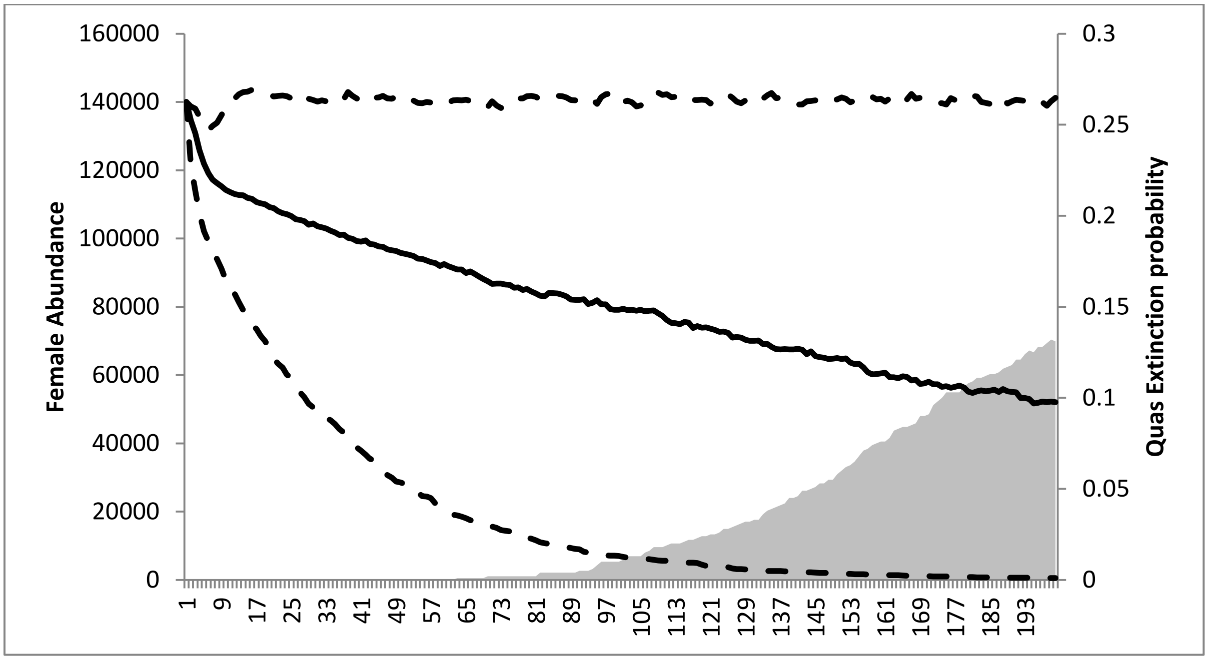
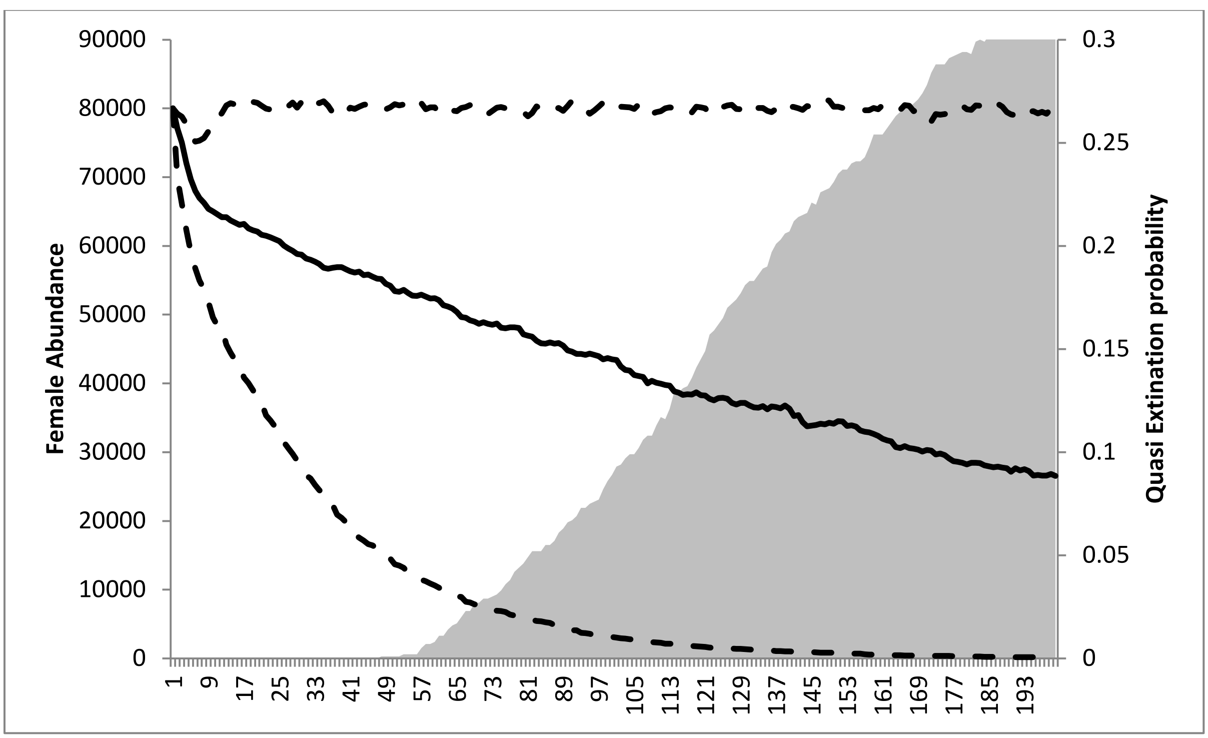


Figure 5.9 MX-Hf



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