# 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.

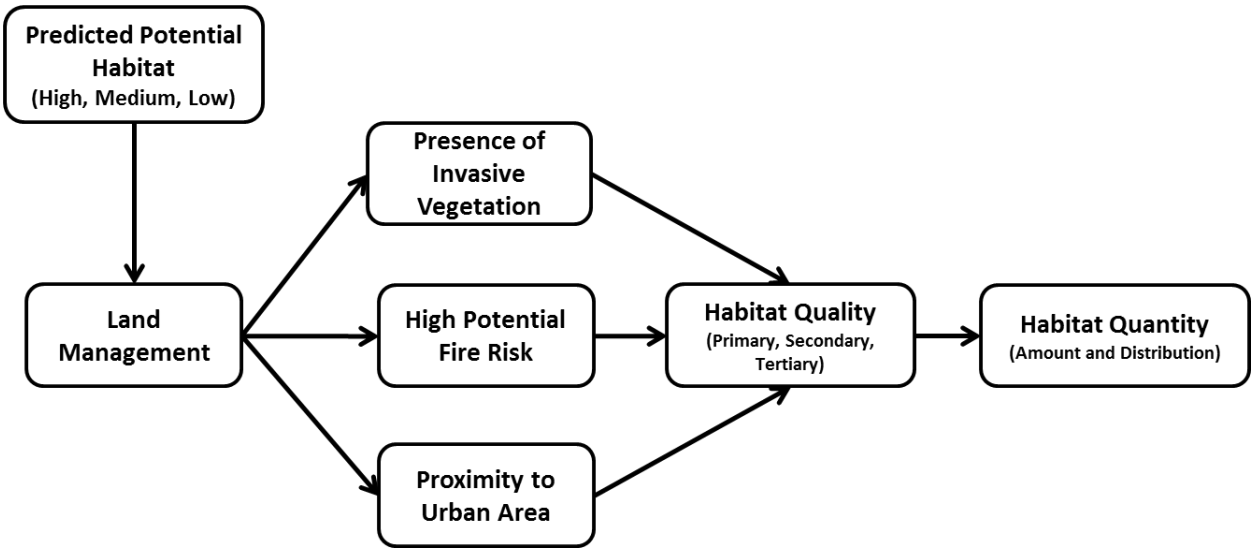



**Figure 20. Conceptual diagram illustrating the factors we used to generate a measure of habitat quality and quantity for the Sonoran desert tortoise.**

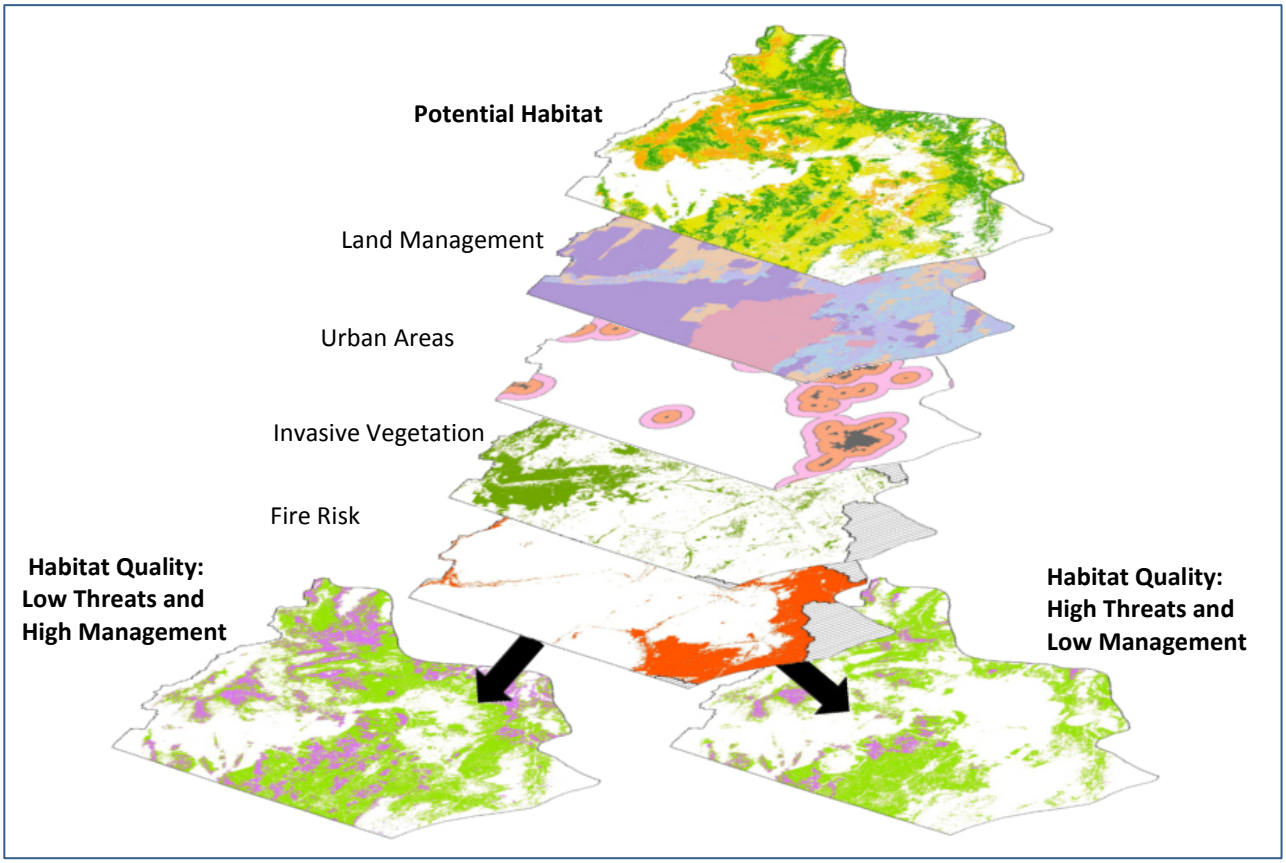



**Figure 21. Visualization of the union of five spatial information layers to produce habitat quality maps under two alternatives of current conditions for the Sonoran desert tortoise.**

### *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.

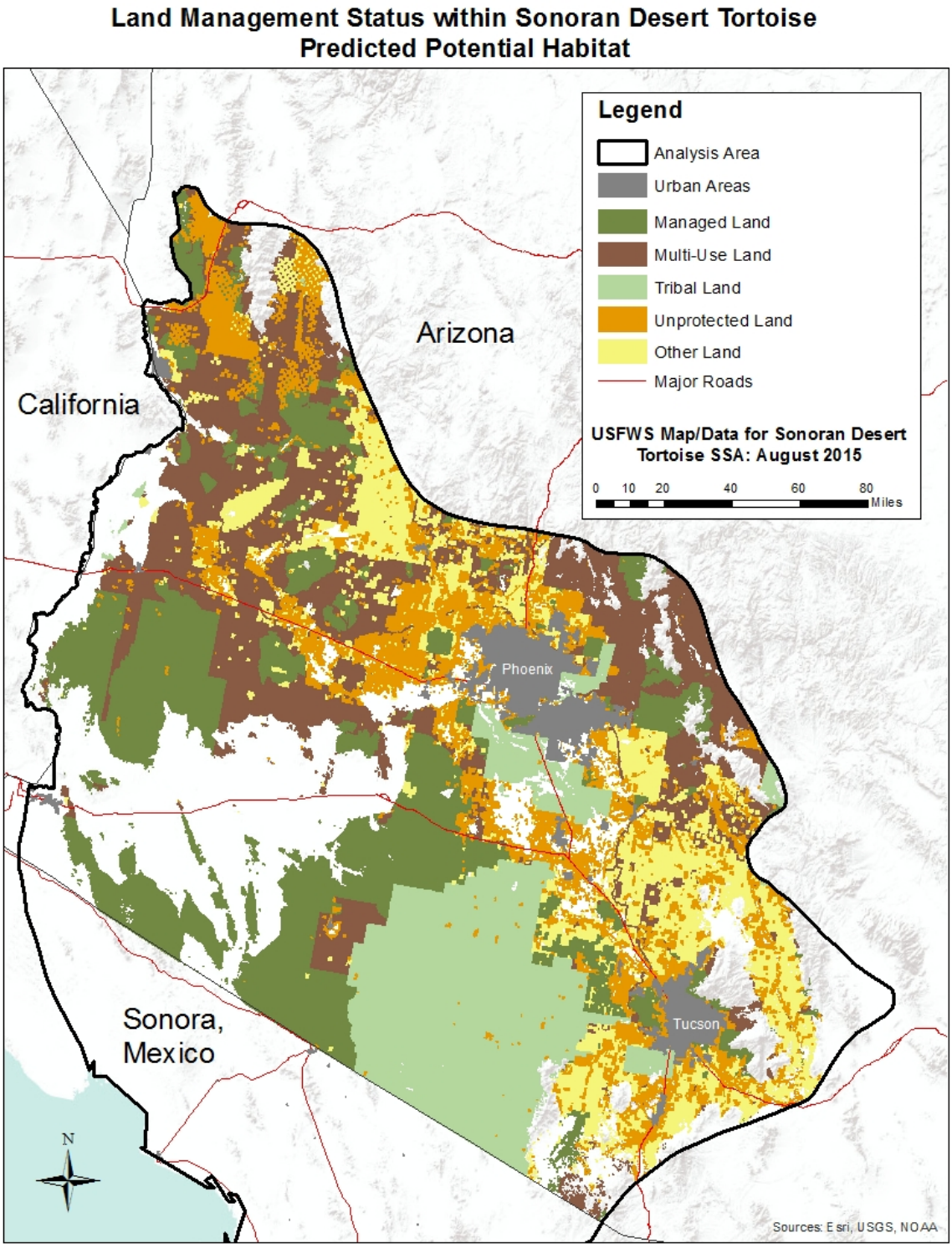



**Figure 22. Land management protected status within predicted potential habitat for the Sonoran desert tortoise in Arizona (see Appendix B for definition of categories).**

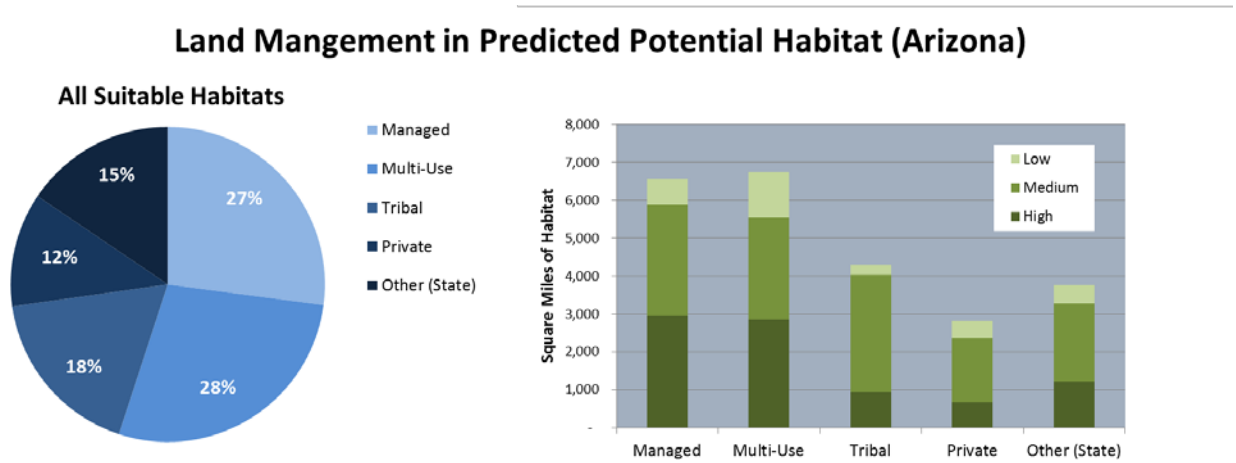



**Figure 23. Proportion of predicted potential habitats categorized by land management.**

### *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<br>b. Medium<br>c. Low | High | High | Med | Low | High | High | Med | Med | Low |
| **1. Land Management** | a. Managed<br>b. Multi-use<br>c. Tribal<br>d. Unprotected (Private)<br>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<br>b. Present<br>c. No data (6%) | all | all | all | all | a | b,c | a,c | b | all |
| **3. Fire Risk** | a. Not High Fire Potential<br>b. High Fire Potential<br>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<br>b. 10-20 km from city<br>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%** |

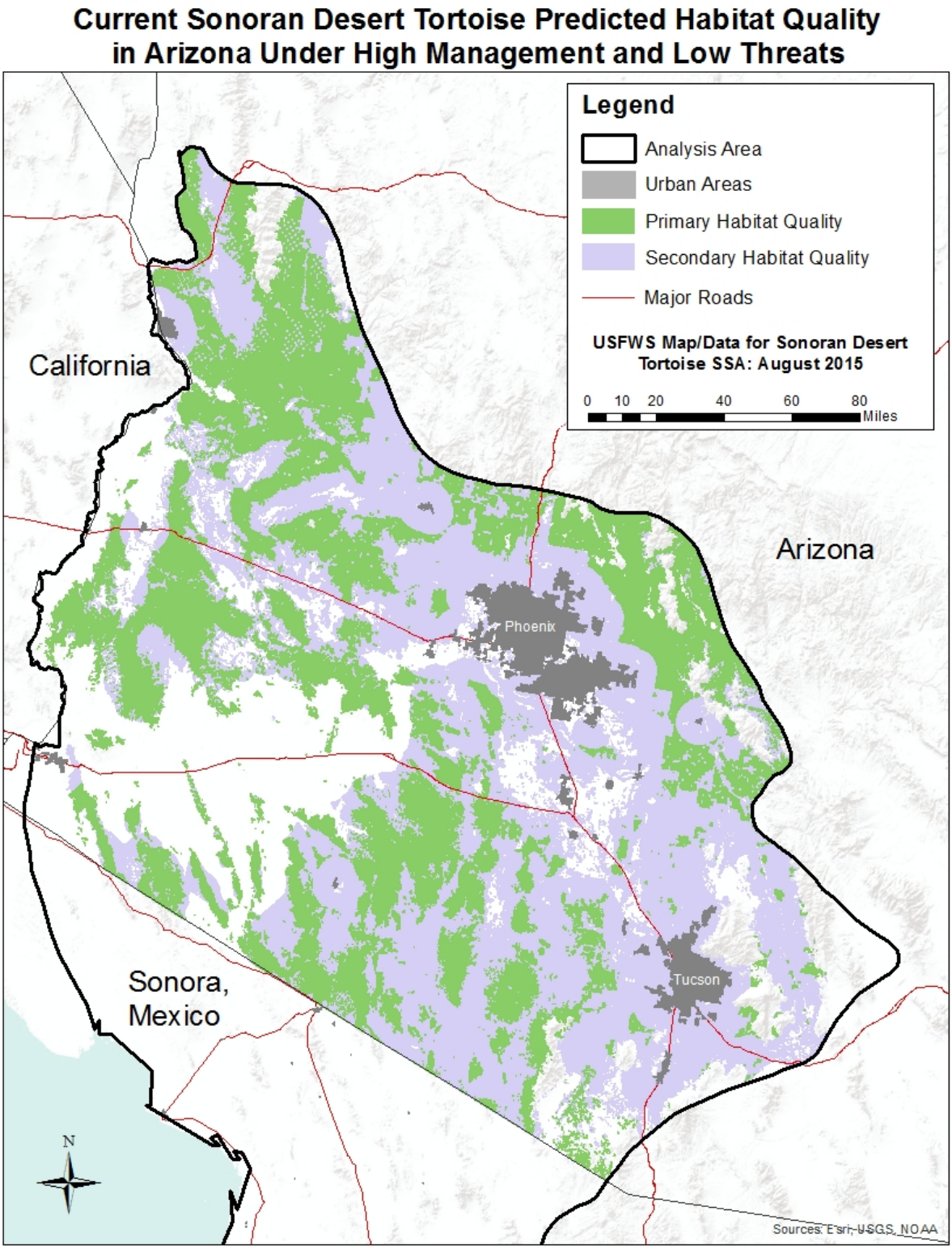



**Figure 24. Distribution of estimated primary and secondary habitat quality for the Sonoran desert tortoise in Arizona under High Management and Low Threats assumption.**

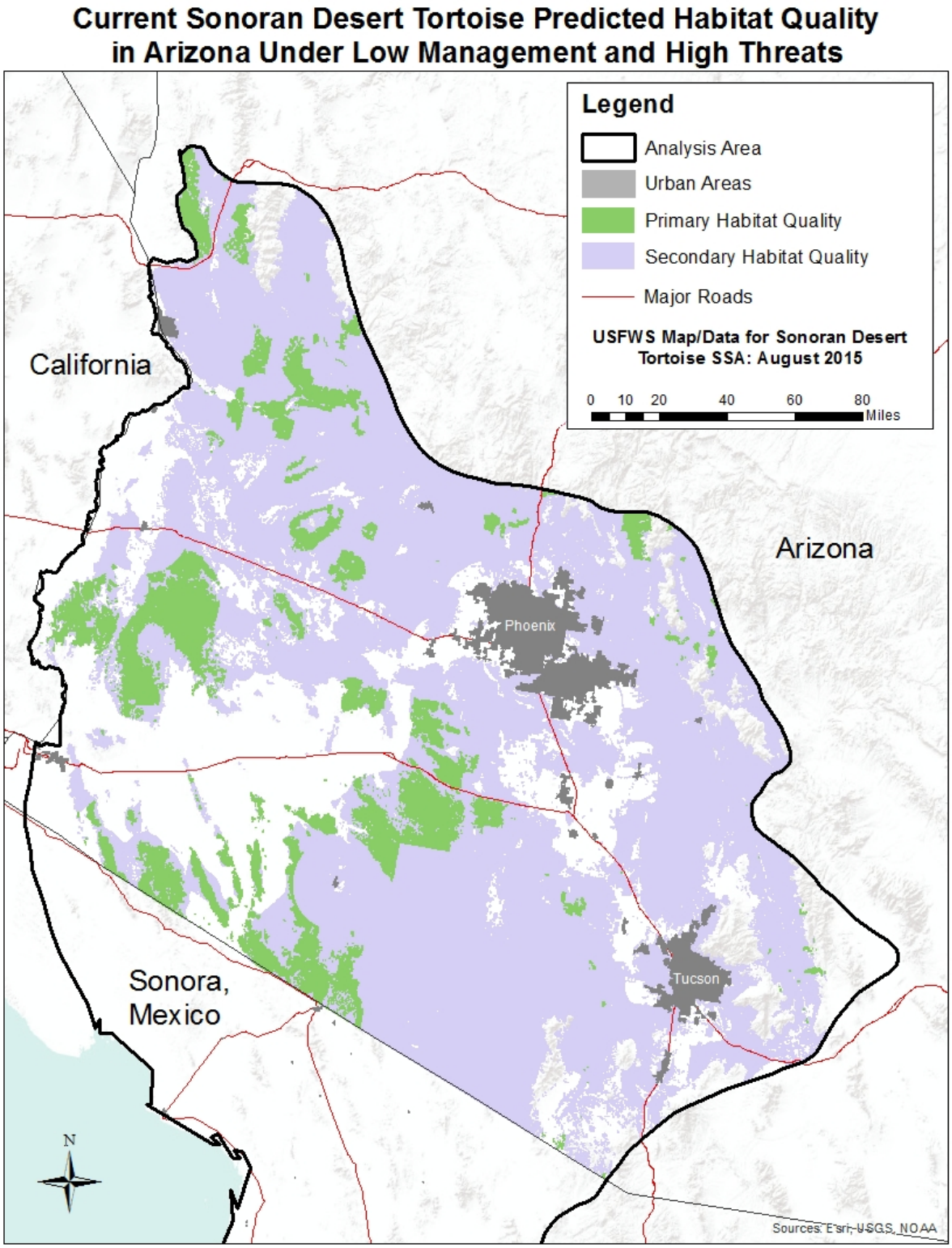



**Figure 25. Distribution of estimated primary and secondary habitat quality for the Sonoran desert tortoise in Arizona under Low Management and High Threats assumption.**

## 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.

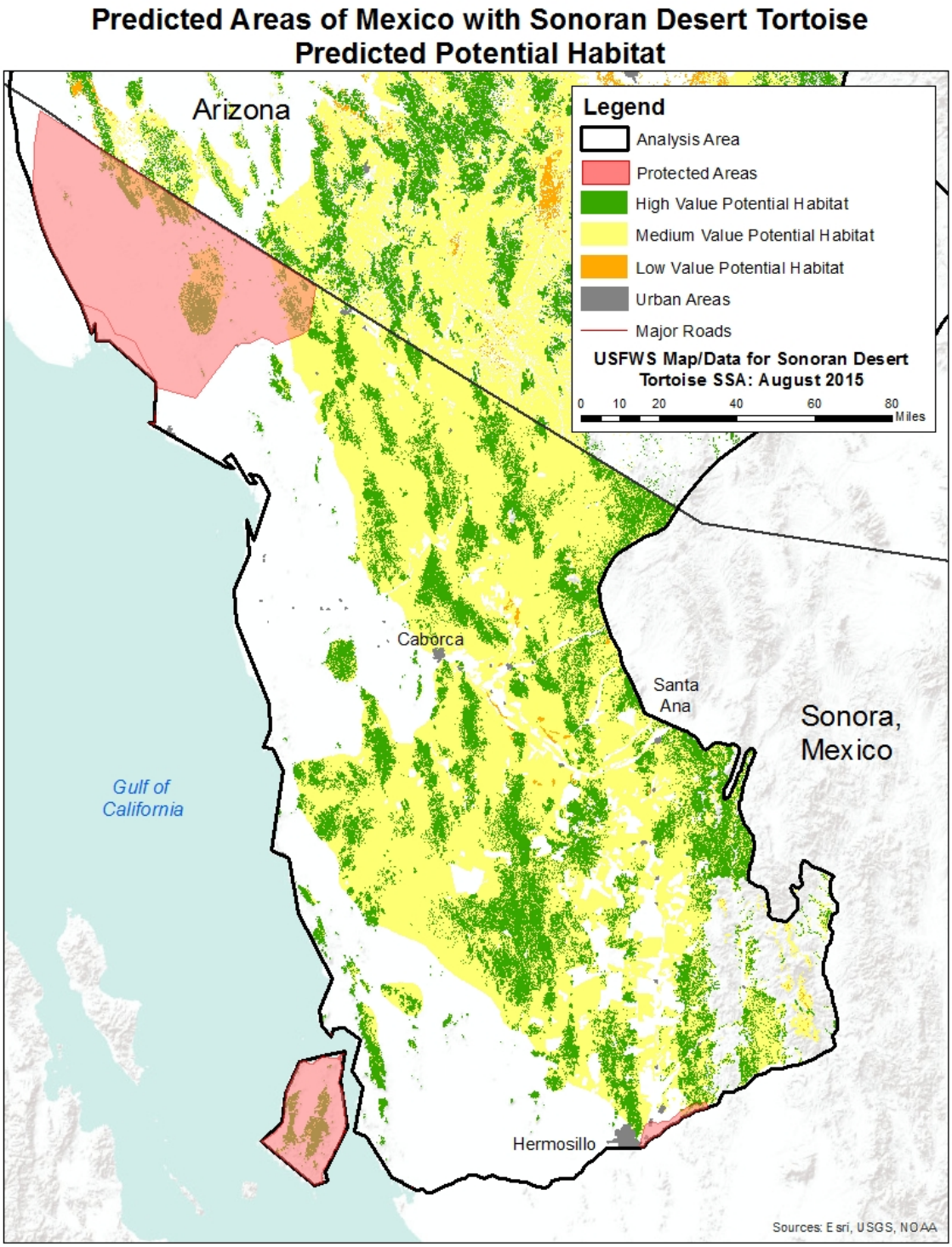



**Figure 26. Location of Mexican protected areas with predicted potential Sonoran desert tortoise habitat in Sonora, Mexico.**

**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<br>b. Medium<br>C. Low | High | High | Med | Low | High | High | Med | Med | Low |
| **1. Land Management** | a. Protected<br>b. Unprotected | a | b | a | a | -- | a | all | all | all |
| **2. Fire and Invasive Veg Risk** | a. Absent<br>b. Present | all | all | all | all | -- | all | a | b | all |
| **3. Urban Influence – Distance** | a. >20 km from >2,500 city<br>b. 10-20 km from city<br>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% |

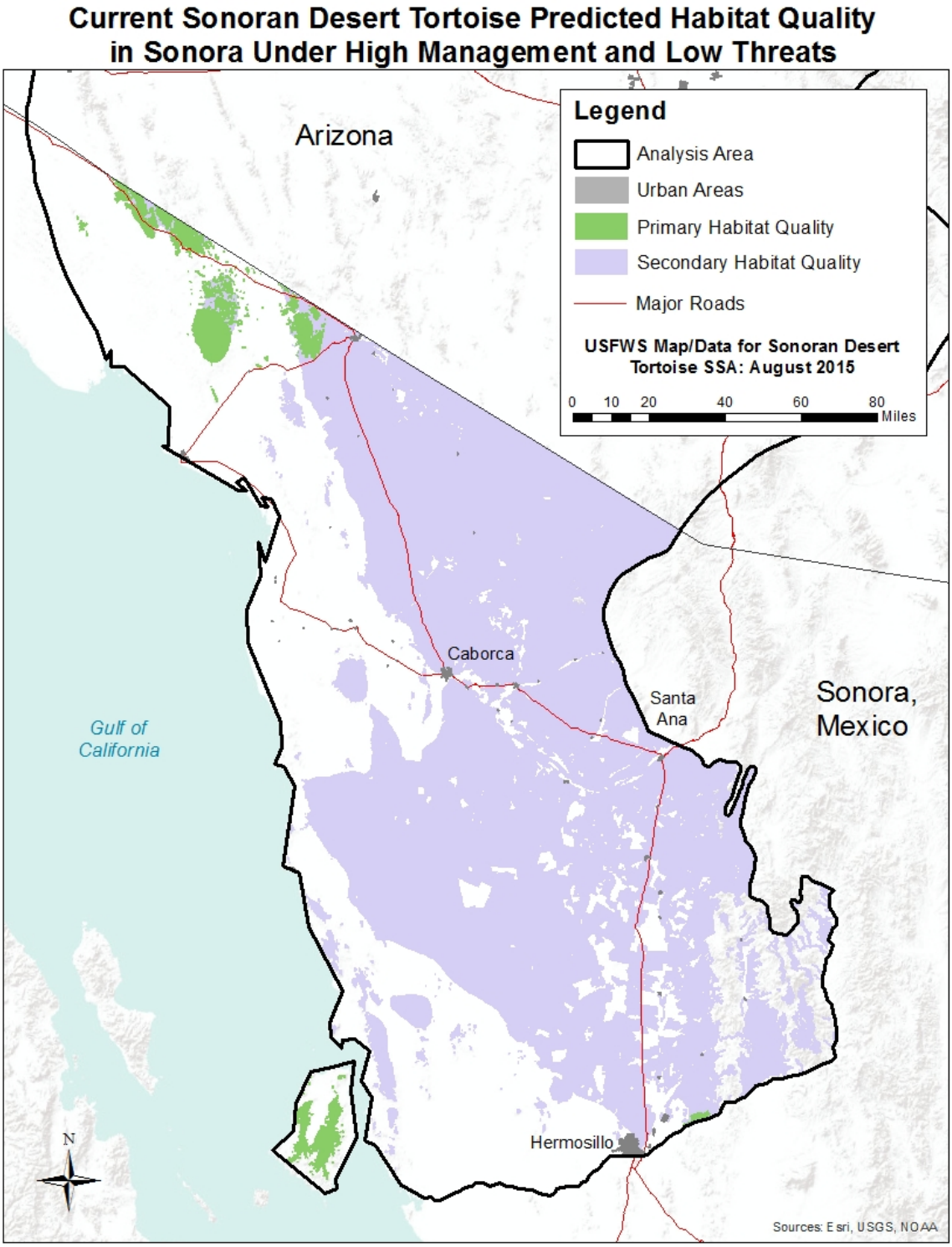



**Figure 27. Distribution of estimated primary and secondary habitat quality for the Sonoran desert tortoise in Sonora under High Management and Low Threats assumption.**

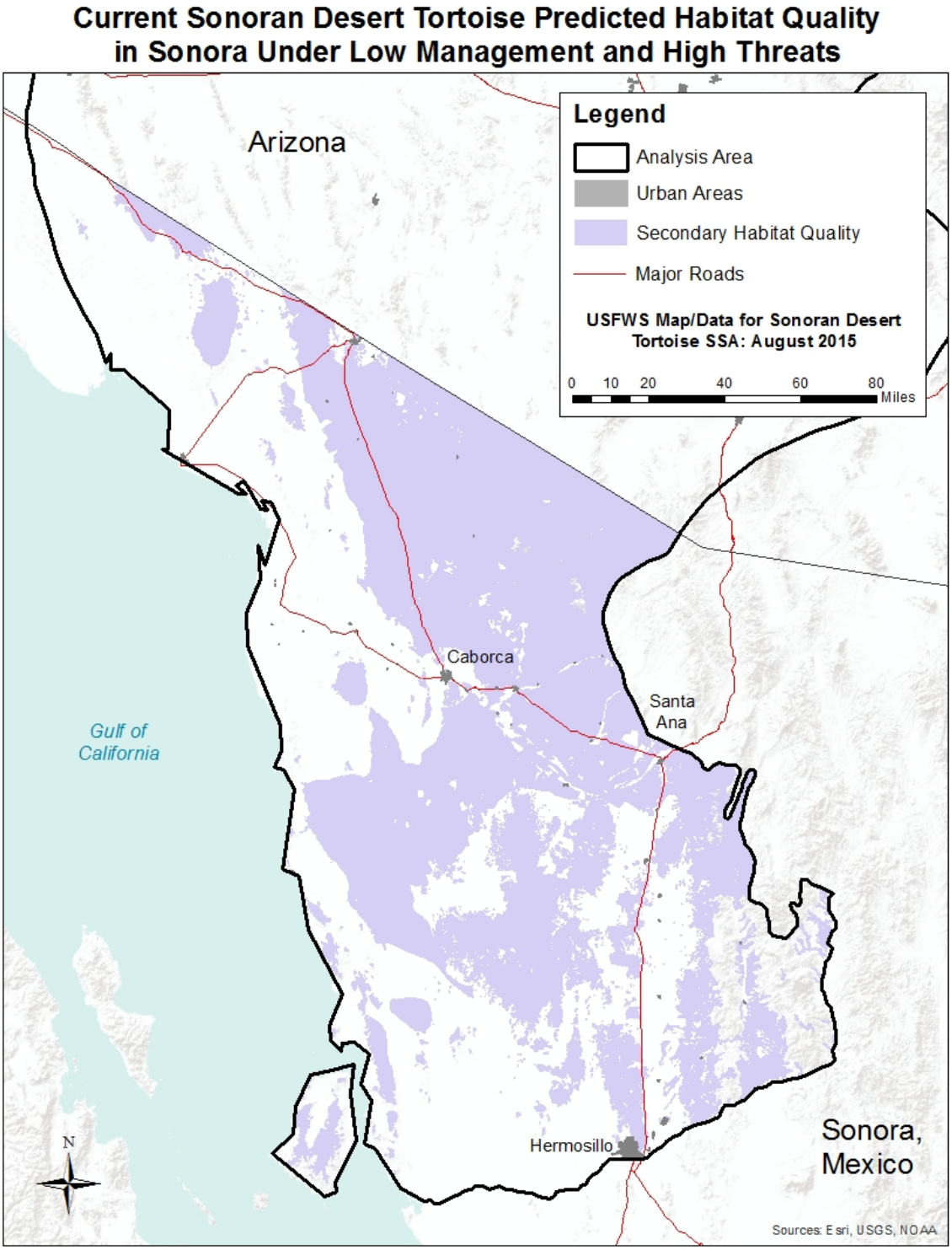



**Figure 28. Distribution of estimated primary (none) and secondary habitat quality for the Sonoran desert tortoise in Arizona under Low Management and High Threats assumption.**

## 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.

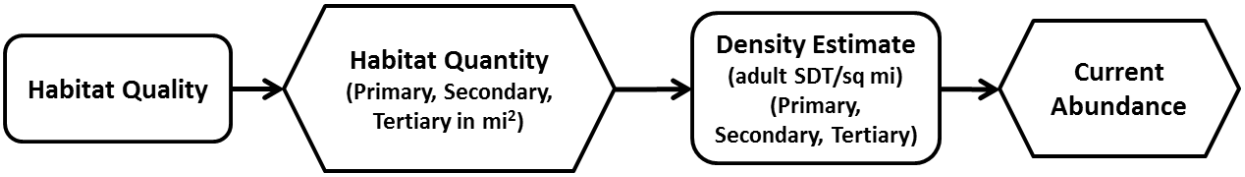



**Figure 29. Conceptual model showing the process to estimate current abundance for the Sonoran desert tortoise.**

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/mi$^2$) | Median Density (adult/mi$^2$) | *Habitat Area (mi$^2$)* | High Pop Est (adults) | Low Pop Est (adults) | *Habitat Area (mi$^2$)* | 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.

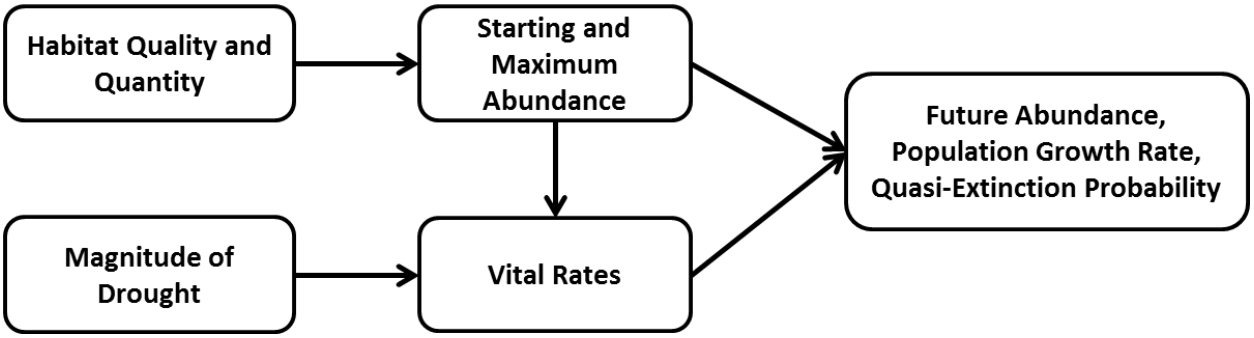



**Figure 30. Overview diagram of the stochastic simulation model for the Sonoran desert tortoise. Inputs to the model included habitat quality and quantity and magnitude of drought. Habitat determined the starting and maximum abundance which influences vital rates, as does the magnitude of drought. The 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).

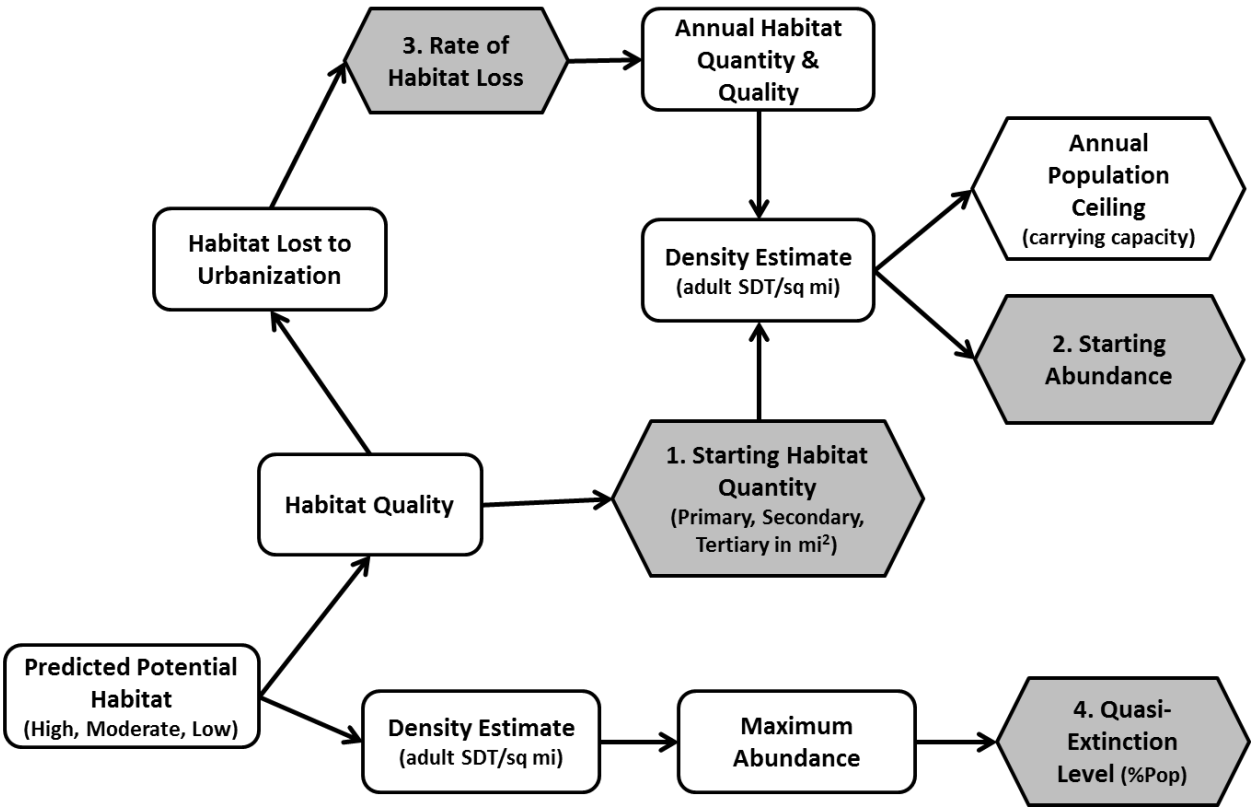



**Figure 31. Derived inputs (shaded boxes) of the stochastic simulation model for the Sonoran desert tortoise.**

### *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<br>b. Medium<br>c. Low | HIGH | HIGH | MED | LOW | HIGH | HIGH | MED | HIGH | MED | LOW |
| Urban Growth Potential | a. Existing<br>b. Full Conversion | b | b | b | b | b | b | b | b | b | b |
| 1. Land Management | a. Managed<br>b. Multi-use<br>c. Tribal<br>d. Unprotected (Private)<br>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<br>b. Present<br>c. No data (6%) | all | all | all | all | a | b,c | a | all | b,c | all |
| 3. Fire Risk | a. Not High Fire Potential<br>b. High Fire Potential<br>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<br>b. 10-20 km from city<br>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.

[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).

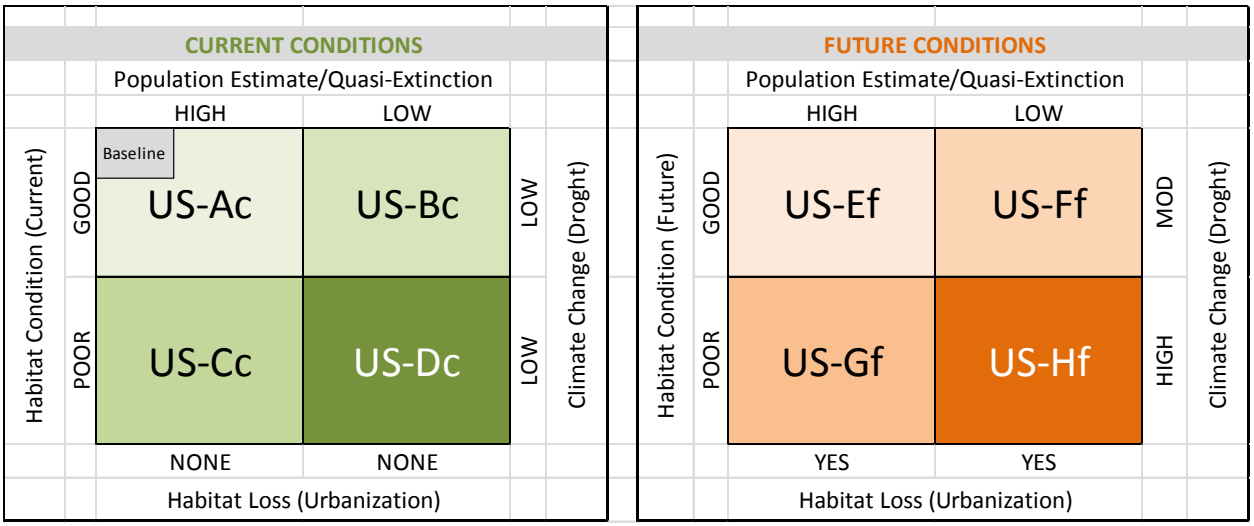



**Figure 32. Diagram of the relative combination of parameters used in nine scenarios for the tortoise simulation model in Arizona, U.S. (Codes for each scenario are "US" for United States, "A" through "H" to number each scenario, and "c" for current conditions and "f" for future conditions.)**

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<br>Secondary<br>Tertiary | 8,630<br>12,470<br>3,100 | 0<br>0<br>0 | historical drought extent | 350,000<br>(Max Pop) | 7,000 |
| | | | | | | |
| **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<br>Secondary<br>Tertiary | 6,090<br>15,010<br>3,100 | 0<br>0<br>0 | historical drought extent +10% | 320,000 | 7,000 |
| US-Bc | Quality | Low Threats, High Mgt | None | Low Climate Change | LOW Density | 4% of Max Pop Size |
| Current Condition, Good Case for | Primary<br>Secondary<br>Tertiary | 6,090<br>15,010<br>3,100 | 0<br>0<br>0 | historical drought extent +10% | 190,000 | 14,000 |
| 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<br>Secondary<br>Tertiary | 1,820<br>18,220<br>4,150 | 0<br>0<br>0 | historical drought extent +10% | 270,000 | 7,000 |
| US-Dc | Quality | High Threats, Low Mgt | None | Low Climate Change | LOW Density | 4% of Max Pop Size |
| Current Condition, Worst Case SDT | Primary<br>Secondary<br>Tertiary | 1,820<br>18,220<br>4,150 | 0<br>0<br>0 | historical drought extent +10% | 150,000 | 14,000 |

**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<br>Secondary<br>Tertiary | 6,090<br>15,010<br>3,100 | -<br>(0.0021)<br>(0.0017) | historical drought extent +20% | 320,000 | 7,000 |
| 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<br>Secondary<br>Tertiary | 6,090<br>15,010<br>3,100 | -<br>(0.0021)<br>(0.0017) | historical drought extent +20% | 190,000 | 14,000 |
| 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<br>Secondary<br>Tertiary | 1,820<br>18,220<br>4,150 | (0.0016)<br>(0.0073)<br>0.0241 | historical drought extent +30% | 270,000 | 7,000 |
| 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<br>Secondary<br>Tertiary | 1,820<br>18,220<br>4,150 | (0.0016)<br>(0.0073)<br>0.0241 | historical drought extent +30% | 150,000 | 14,000 |

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.

US-Bc – Current Condition, good case for tortoises. 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.

US-Cc – Current Condition, poor case for tortoise. 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.

US-Dc – Current Condition, worst case for tortoise. 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.

US-Ef – Future Condition, best case for tortoise. 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.

US-Ff – Future Condition, good case for tortoises. 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.

US-Gf – Future Condition, poor case for tortoise. 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.

US-Hf – Future Condition, worst case for tortoise. 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.

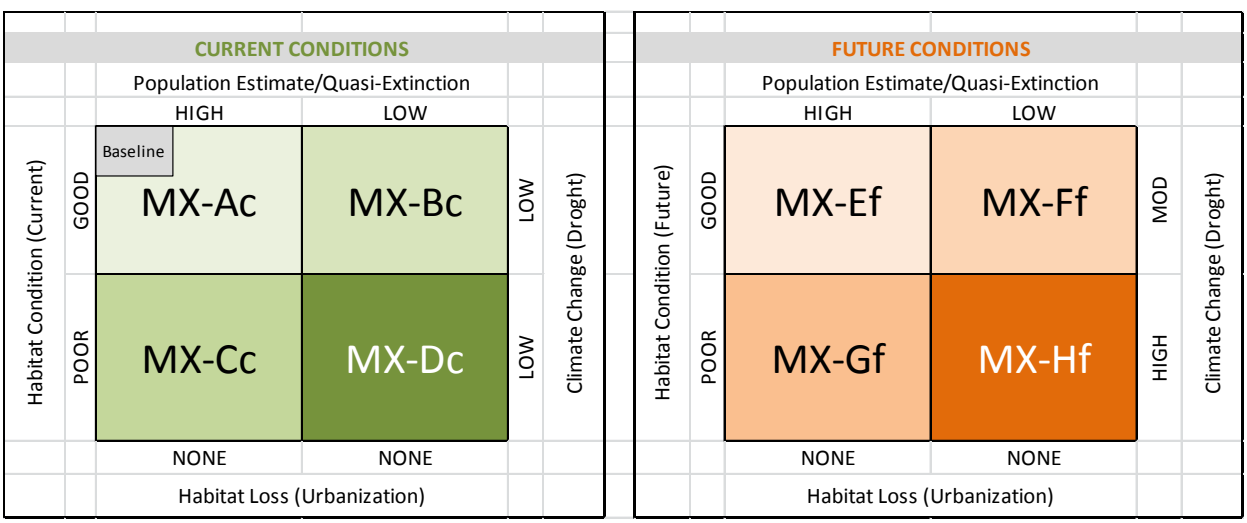



**Figure 33. Diagram of the relative combination of parameters used in nine scenarios for the tortoise simulation model in Sonora, Mexico. (Codes for each scenario are "MX" for Mexico, "A" through "H" to number each scenario, and "c" for current conditions and "f" for future conditions.)**

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<br>Secondary<br>Tertiary | 4,350<br>9,380<br>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<br>Secondary<br>Tertiary | 320<br>13,400<br>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<br>Secondary<br>Tertiary | 320<br>13,400<br>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<br>Secondary<br>Tertiary | -<br>10,550<br>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<br>Secondary<br>Tertiary | -<br>10,550<br>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<br>Secondary<br>Tertiary | 320<br>13,400<br>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<br>Secondary<br>Tertiary | 320<br>13,400<br>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<br>Secondary<br>Tertiary | -<br>10,550<br>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<br>Secondary<br>Tertiary | -<br>10,550<br>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.

MX-Ef – Future Condition, best case for tortoise. 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.

MX-Ff – Future Condition, good case for tortoises. 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.

MX-Gf – Future Condition, poor case for tortoise. 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.

MX-Hf – Future Condition, worst case for tortoise. 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

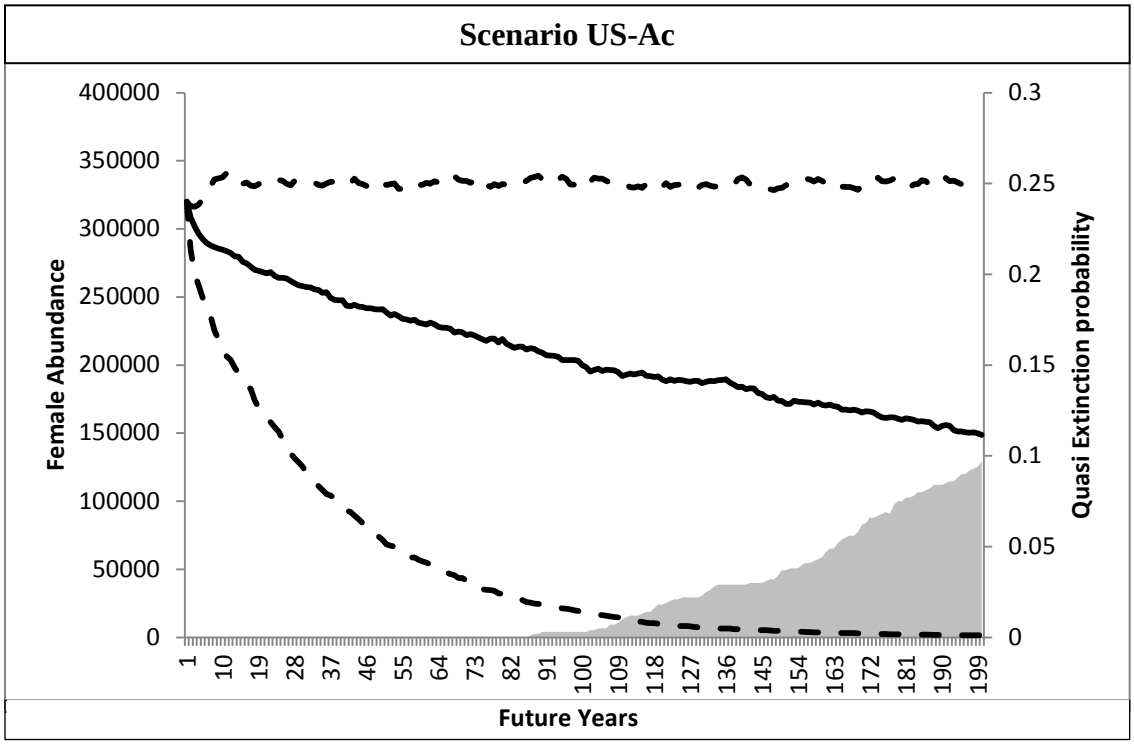
The four current condition scenarios provided a range of conditions based on habitat quality and population sizes to bracket our uncertainty about those parameters. Each of these scenarios had a low effect of climate change and no future habitat loss due to urbanization or habitat degradation. The full 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 ($\lambda$ = 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); $\lambda_{200}$ 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** | $N_0$ | $\lambda_{200}$ (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 |



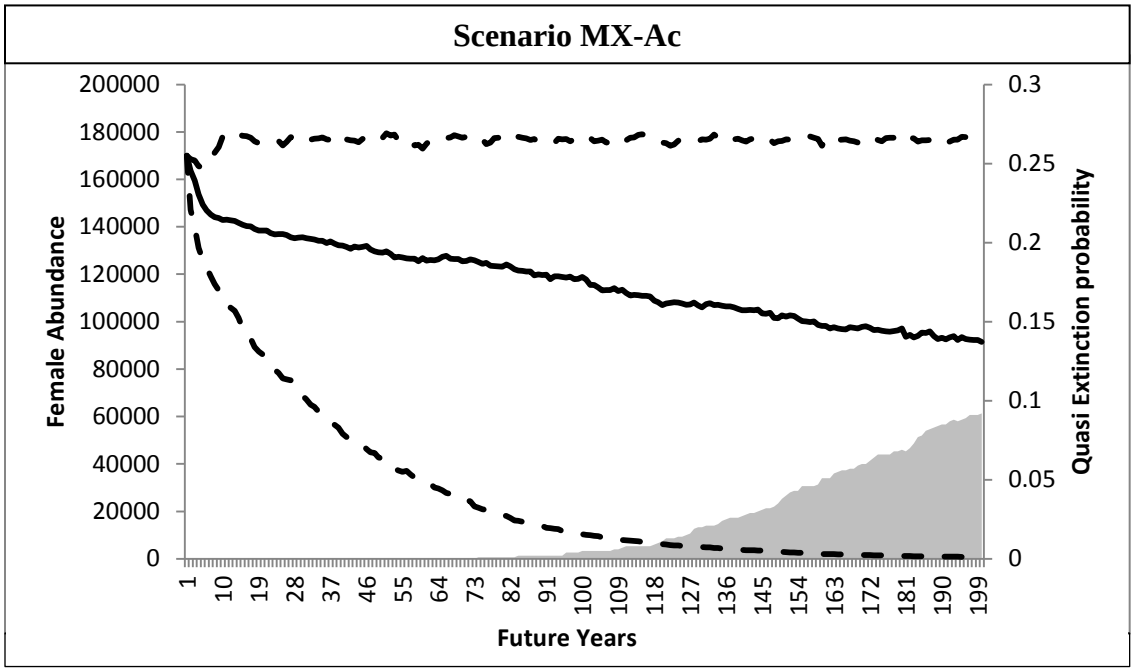




**Figure 34. Plots of predicted median abundance (solid line, primary (left) axis) with 95% confidence interval (dashed lines, primary axis) and the probability of quasi extinction (shaded area, secondary (right) axis) for the best case current conditions scenarios in Arizona, U.S. (top, US-Ac) and Sonora,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

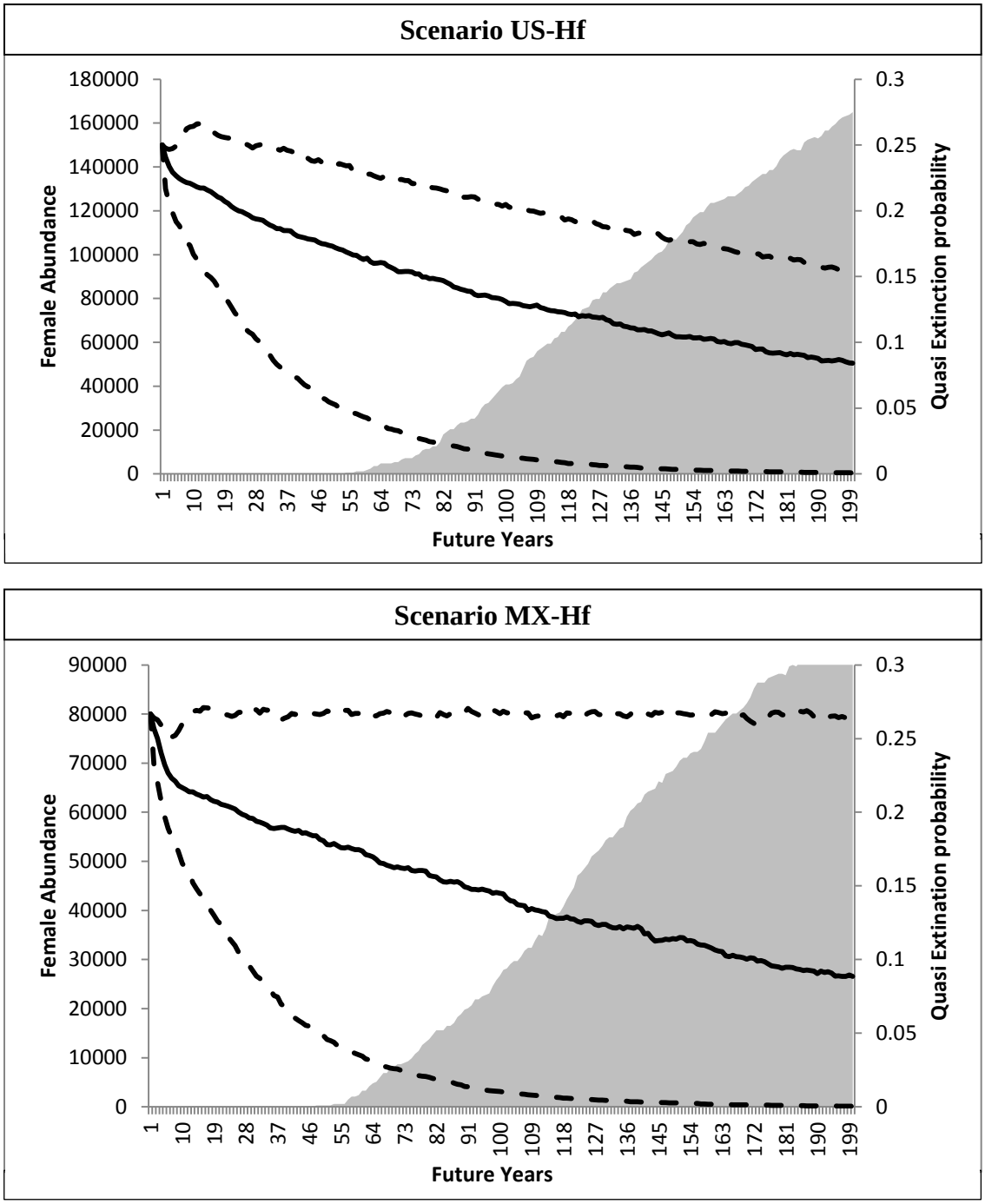



**Figure 35. Plots of predicted median abundance (solid line, primary (left) axis) with 95% confidence interval (dashed lines, primary axis) and the probability of quasi extinction (shaded area, secondary (right) axis) for the worst case future conditions scenarios in Arizona, U.S. (top, US-Hf) and Sonora,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

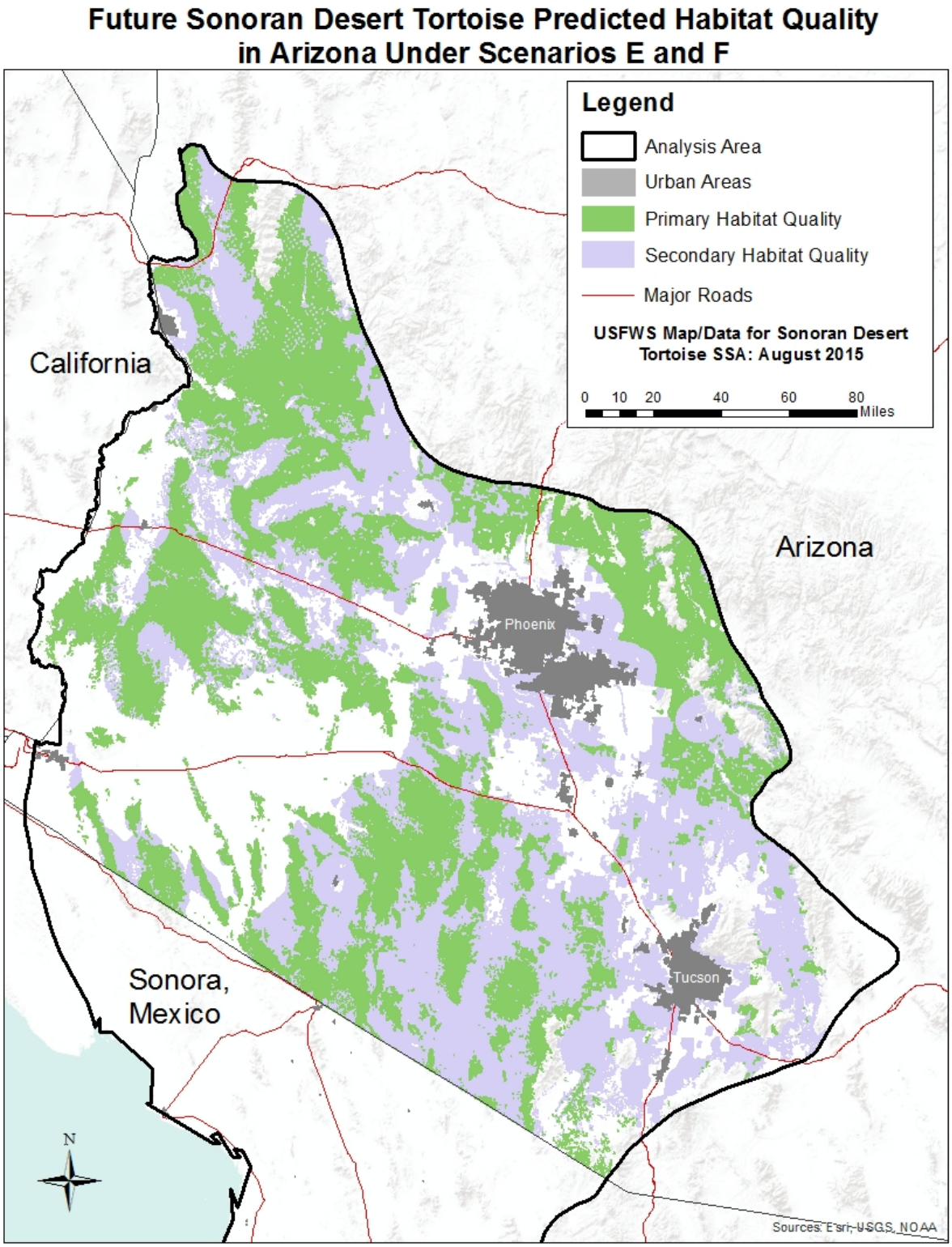



**Figure 36. Primary and secondary habitat quality distribution under future condition scenarios US-Ef and US-Ff in approximately 60 years in Arizona.**

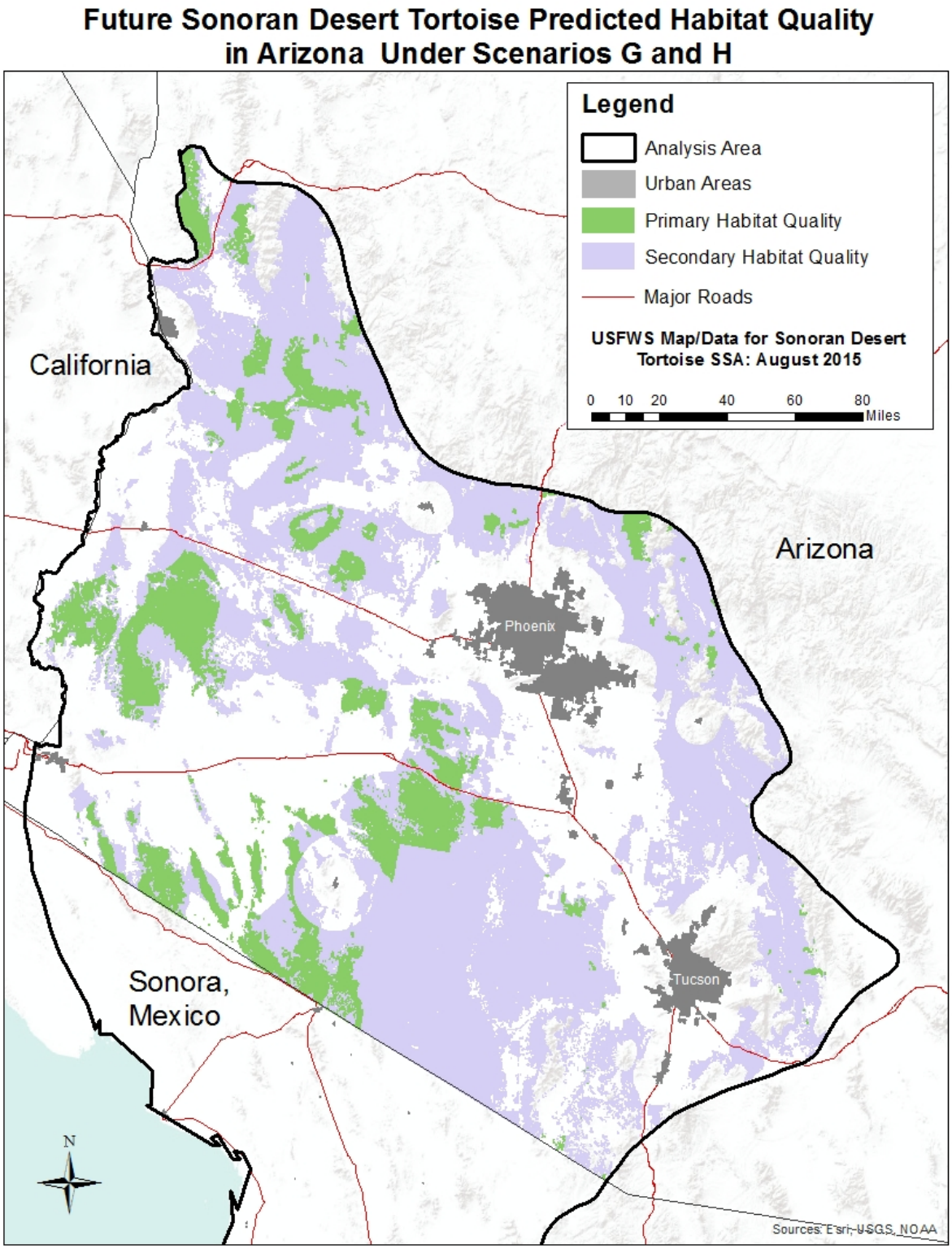



**Figure 37. Primary and secondary habitat quality distribution under future condition scenarios US-Gf and US-Hf in approximately 60 years in Arizona.**

## 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.