Chapter 4: Risk Factors

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

4.1 Altered Plant Communities (Nonnative Grasses)

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

Nonnative grasses can compete with native grass species (which are used as food and cover by Sonoran desert tortoises) through competition for space, water, and nutrients, thereby affecting native plant species density and species composition within invaded areas (Stevens and Fehmi 2008, p. 383–384; Olsson et al. 2012a, entire; 2012b, pp. 10, 18–19; McDonald and McPherson
2011, pp. 1150, 1152; Franklin and Molina-Freaner 2010, p. 1664). This process is primarily driven by the timing and amount of precipitation. Tortoise food plants include herbs, grasses, woody plants, and succulents, which provide various levels of nutrition and assist with maintaining a tortoise’s hydration balance (or potassium excretion potential, PEP) (Oftedal 2002, entire). Cover plants, such as trees, shrubs, subshrubs, and cacti (succulents) serve as protective cover to lower predation risk (Avery and Neibergs 1997, p. 13; Grandmaison et al. 2010, p. 585). In addition, cover plants provide thermoregulation (regulating body temperature) when tortoises are active above ground during such activities as foraging, moving between shelter sites, dispersing, and seeking mates (Grandmaison et al. 2010, p. 585).

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

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

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

8 Note that about 6 percent of predicted potential Sonoran desert tortoise habitat is outside of the area covered by the REA SOD, therefore no data are available for those areas.
To assess the potential scope of nonnative grasses within the range of the Sonoran desert tortoise in Sonora, we considered the predicted potential habitats with the highest potential for concern as being those within the Plains of Sonora subdivision of Sonoran Desertscrub that have lower than a 5% slope. These areas are where the cultivation of buffelgrass is most likely to occur. Based on the way we categorized the predicted potential habitat, these areas of potential concern are within the predicted “moderately potential” habitat. These areas of potential concern (within the Plains of Sonora subdivision of Sonoran Desertscrub) represent about 2,800 sq mi (1.8 million ac, 725,000 ha), about 20% of all the predicted potential habitat in Sonora, Mexico (Figure 11).

Theoretically, the effects of nonnative grasses on individual tortoises discussed above may manifest in population-level effects, in terms of their resiliency, redundancy, and representation over time and space. However, such population-level effects have not been identified through long-term monitoring (even though some species of nonnative grass have occurred within monitoring plots for decades if not over a century), nor been documented in the literature. Population-level effects would only become discernable (with current research and monitoring methods) over an extremely long period of time (decades to centuries) due to the life history and longevity of the species. Adequate time periods are well-outside of both the existing period of monitoring and our ability to predict such population-level effects in the future.
Figure 9. Distribution of modeled invasive vegetation within the predicted potential habitat of the Sonoran desert tortoise in Arizona (based on REA SOD, Strittholt et al. 2012, pp. 89-92).
Figure 10. Proportion of the predicted potential Sonoran desert tortoise habitat in Arizona with modeled invasive vegetation (based on REA SOD).
Figure 11. Distribution of areas of concern for nonnative grasses and fire risk within the predicted potential habitat of the Sonoran desert tortoise in Sonora, Mexico (location of medium quality habitat within the Plains of Sonora biotic subregion).
4.2 Altered Fire Regime

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

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

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

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

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

To assess the potential scope of an altered fire regime within the range of the Sonoran desert tortoise in Arizona, we used an existing GIS analysis conducted as part of the REA SOD (Appendix B; Strittholt et al. 2012, pp. 92–96). This spatial analysis provided a predicted spatial occurrence area with high potential fire risk (Figure 12). The results indicate that about 23% of current predicted potential habitat in Arizona9 is in areas designated as high fire potential (Figure 13).

To assess the potential scope of nonnative grasses (and thus the potential for an altered fire regime) within the range of the Sonoran desert tortoise in Sonora, we considered the predicted potential habitats with the highest potential for concern to be those within the Plains of Sonora.
biotic subregion that have lower than a 5% slope. These areas are where the cultivation of buffelgrass is most likely to occur. Based on the way we categorized the predicted potential habitat, this area of concern is within the predicted medium potential habitat. This area within the Plains of Sonora biotic subregion represents about 20% of the entire predicted potential habitat in Sonora, Mexico (Figure 11).

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

**Key Assumption:** Our assessment assumes that any changes in future wildfire regimes from possible nonnative grass expansion and increased human fire starts are not likely to have significant impact on populations of Sonoran desert tortoises because fire suppression efforts will prevent high numbers of large-scale fires, and, when fires do burn large areas, the effects to the native vegetation community are limited by suppression efforts and natural recovery capabilities. Because of the uncertainty about the past, present, and future role of wildfire in the Sonoran Desert ecosystems and the ability for successful management suppression, we acknowledge the limitations in these assumptions.
Figure 12. Distribution of modeled areas with high fire potential within the predicted potential habitat of the Sonoran desert tortoise in Arizona (based on REA SOD).

Legend
- Analysis Area
- No Fire Data Available
- Urban Areas
- Potential Habitat within High Fire Potential
- High Fire Potential, No Potential Habitat
- Potential Habitat, No High Fire Potential
- Major Roads

Modeled Current High Fire Potential includes human and naturally caused occurrences.

USFWS Map/Data for Sonoran Desert Tortoise SSA: August 2015

Sources: Ein, USGS, NOAA
4.3 Habitat Conversion

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

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

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

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

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

Rangewide, we did not find that the projected, potential footprint of urban or agricultural development is expected to affect a significant amount of potential habitat for tortoises, largely due to protections afforded by federally managed lands and the fact that much of urban development occurs within valley bottoms, in many cases on land previously used for irrigated agriculture. Population-level effects to Sonoran desert tortoises from habitat conversion have not been documented in the literature, and we do not anticipate effects to population resiliency, redundancy, or representation in the near future.
To assess the potential historical loss of habitat due to conversion to urban landscape, we calculated the amount of area currently designated as urban land within the range boundary of the Sonoran desert tortoise. About 1,279 sq mi (818,560 ac, 331,260 ha) of area is currently designated as urban in Arizona, representing approximately 5% of all predicted potential habitat (if all that land had been previously potential habitat, which it likely was not). In Mexico, about 53 sq mi (33,920 ac, 13,730 ha) of area is designated as urban representing less than 1% of predicted potential habitat. Even considering additional areas potentially lost historically due to agricultural or other development (which we have not quantified), historical habitat loss would appear to be relatively small.

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

---

10 The urban projection map from which this habitat loss estimate was derived was published in 2008 as a possible 2040 projection. This estimate was done at the height of the economic expansion during the mid-2000’s so we decided it would be unreasonable and over-estimating potential growth to use that urban growth projection as a 2040 estimate. We instead subjectively chose this projection to represent a potential future 60 years from the present.
Figure 14. Possible future urban development within Arizona.
Figure 15. Proportion of the predicted potential Sonoran desert tortoise habitat in Arizona that may be susceptible to future conversion to urban areas.

4.4 Habitat Fragmentation

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

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

Principles in conservation genetics suggest that when connectivity between populations of a species is negatively affected or prevented outright, genetic diversity may be negatively affected over time (i.e., genetic inbreeding or “bottlenecking”) (Edwards et al. 2004, entire). By applying the FRAGGLE Model (spatial system dynamics model designed to calculate connectivity indices among populations) to gopher tortoise (Gopherus polyphemus) populations in Georgia, BenDor et al. (2009, entire) found that even minor habitat losses can result in disproportionate effects to population connectivity. In addition, should a stochastic event drastically reduce or effectively eliminate a given population that is isolated by linear development, natural recolonization from adjacent populations may be hampered or unlikely to occur (Edwards et al. 2004, p. 496). Population genetics of tortoises can best be understood by applying an “isolation by distance” model, meaning that genetic exchange among populations is likely positively correlated by proximity (or nearness) to the next population (Edwards et al. 2004, entire). While population-level impacts as a result of isolation of Sonoran desert tortoise populations may be occurring, there are no data available regarding the effects of linear development to tortoises at the population level (Edwards et al. 2004, p. 496). Because of the slow growth rates of tortoises and their long generation times (approximately 25 years), data collected from long-term monitoring plots using technologies and methodologies currently available would not be able to identify linear development as an influence even if impacts are occurring. These trends unfold on a multi-decadal scale, if not over centuries; given such timeframes, it is well outside our ability to predict with reasonable certainty any trends likely to occur in the near term future. We expect established principles in population genetics to guide long-term land use planning and development in coordination with local, state, and Federal agencies and conservation programs to account for the needs of the Sonoran desert tortoise in maintaining genetic connectivity. We did not further evaluate the potential effects of fragmentation.
Figure 16. Roads within the range of the Sonoran desert tortoise.
4.5 Climate Change and Drought

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

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

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

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

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

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

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

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

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

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

To assess the potential geographic scope of human interactions, we calculated the acreage of predicted potential habitat areas within 6.2-mi (10-km) rings of cities greater than 2,500 in population size. While the potential for human interactions exists beyond these areas, we assumed that the closer tortoises are to human population centers, the more likely that these interactions (and other urban edge effects) will occur. Figure 18 shows the areas around cities in 6.2-mi (10-km) and 12.4-mi (20-km) rings. Overall, 29% of predicted potential tortoise habitat occurs within 12.4 mi (20 km) of urban areas in Arizona and 9% does in Sonora (Figure 19).
Figure 18. Distance from human population centers exhibited as ringed 10-kilometer buffers.
There are a number of conservation actions that have been implemented to minimize stressors and maintain or improve the status of the Sonoran desert tortoise, including most significantly a candidate conservation agreement (CCA; see AIDTT 2015, entire) with AGFD, BLM, Department of Defense, National Park Service, U.S. Fish and Wildlife Service, Bureau of Reclamation, Customs and Border Protection, U.S. Forest Service, Natural Resources Conservation Service, and Arizona Department of Transportation (collectively referred to as “Parties”). Candidate conservation agreements are formal, voluntary agreements between the Service and one or more parties to address the conservation needs of one or more candidate species or species likely to become candidates in the near future. Participants voluntarily commit to implement specific actions designed to remove or reduce threats to the covered species, so that listing may not be necessary. The CCA for the Sonoran desert tortoise was completed by the Parties in March 2015 and was signed by the final signatory, the Service, on
June 19, 2015. The CCA will be implemented on approximately 13,000 sq mi (8.3 million ac, 3.4 million ha) of Sonoran desert tortoise habitat in Arizona. This action area encompasses approximately 55% of the species’ predicted potential habitat in Arizona and 34% of its predicted potential habitat rangewide.

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

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

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

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

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

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

4.8 Other Factors Considered

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