Appendix C
Habitat Suitability Models

In addition to vulnerability assessments described in **Appendix B**, another tool for projecting a species' potential response to climate change is a temperature-shifted habitat suitability model. The Mahalanobis distance statistic (D^2) (Clark et al. 1993; Rotenberry et al. 2002, 2006; Browning et al. 2005) is one of several habitat suitability modeling tools available, and consistently ranks well in its performance compared to other methods (Griffin et al. 2010; Liang et al. 2014). The Mahalanobis statistic was used in this science plan to model the distribution of suitable habitat of selected indicator species. For any location, the Mahalanobis statistic yields an index of its habitat similarity (HSI) to the multivariate mean of the habitat characteristics at the target species location (the calibration data set). Many geographic information system (GIS) modeling approaches use only species-presence data for the dependent variable as opposed to known absences which are much more difficult to verify. But the Mahalanobis approach avoids the uncertain assumption of correct identification of unoccupied habitats (Knick and Rotenberry 1998; Rotenberry et al. 2002; Browning et al. 2005) and arguably provides a more transparent view of how individual variables influence model outcomes by being partitioned into separate components (Dunn and Duncan 2000; Rotenberry et al. 2002, 2006). Partitioning is based on a principal-components analysis of the selected model variables in the calibration data set. Each of the partitions are additive, orthogonal variable combinations that incrementally explain more variance until the final partition (the full model) captures the full range of variance exhibited in the calibration data. Mahalanobis distances and their partitions with SAS code provided in Rotenberry et al. (2006) were calculated.

For the niche-modeling process, a GIS map of the study area was divided into 180 m × 180 m cells. Each cell was scored for underlying environmental variables. Cells containing a species observation were used to create a calibration data set from which each species' niche model was constructed. Once a model was created, it was used to calculate habitat suitability indices (HSIs) for the selected Mahalanobis distance partition for every other cell of the map data set. HSIs were rescaled to range from 0-1, with 0 being the most dissimilar and 1 being the most similar to the multivariate mean habitat characteristics based on the calibration data set, following Rotenberry et al. (2006). ArcGIS 9.3 (ESRI 2008) was used to provide a spatial model (niche map) of the similarity to the species mean for each cell. Identifying the model that best fits the distribution of observation records was a multi-step process. First, the median HSI values for each model partition were inspected to identify those partitions with the highest median values. From those partitions with the highest values, the mapped representations of the selected model partition were then examined to determine which partition best encompassed the observation points without including extensive additional areas known to be unoccupied. From these steps, the best performing current conditions niche model was selected and produced.

Habitat variables were selected based on expectations of their likely influence on the distribution of the vegetation within the Monument and surrounding region. Observations were obtained evenly across the full range of elevations and habitats that each species was known to occur based on ongoing surveys within the Monument and the surrounding landscape (C. Barrows, unpublished data sets); the more spatially unbiased and un-clustered the observations, the better the resulting model is at representing the distribution of suitable habitat (Phillips et al. 2009). Partitioned Mahalanobis D^2 models were constructed with different suites of abiotic variables derived from GIS layers readily available from internet sources in 2008: soils (Natural Resources Conservation Service 2008), ruggedness (Sappington et al. 2007; United States Geological Survey 2009), and climate (PRISM Climate Group 2004). Those variables included slope

(steepness, direction, and ruggedness); rockiness; fire history; percentage of sand, clay, and silt in the soil; water holding capacity of the soil; and mean maximum summer temperatures. Rainfall and summer temperature are strongly (negatively) correlated; hence, precipitation was not included. Given the large number of observations, any combination of variables deemed appropriate could be included in each species' niche model.

Using the best performing niche model based on current or recent environmental conditions, the model was then fitted onto new map data sets with shifted map-point values for summer maximum temperature and mean annual precipitation. Rather than use a downscaled Global Circulation Model (GCM) with uncertain error when applied to a complex topographic unit such as the Monument, a temperature gradient approach (Barrows and Murphy-Mariscal 2012) was used. To simplify the presentation of analyses here, only the 3°C shifted models are compared to the constructed current conditions models rather than showing the incremental increases of maximum summer temperatures by 1, 2 and 3°C. A +3°C shift approximates a maximum expected change from current conditions over this century (IPCC 2007) and so represents a potential "worst case" from which to assess the sensitivity of species to climate change. If the climate doesn't heat to a "worst case" scenario, shifts in suitable habitat, and so impacts to species, will likely be incrementally less than predicted for the modeled +3°C shift. For each model, the area of suitable habitat in hectares for HSI values ≥ 0.7 was calculated and the distribution of that suitable habitat was mapped. The selection of HSI values of ≥ 0.7 for model comparisons, while arbitrary, correspond to visually close fits between location data and niche model distributions.

For prioritizing species' risks using HSMs, two criteria were identified: 1) the proportional loss of each species' suitable habitat expected with a 3°C increase in a summer maximum-temperatures scenario, and 2) how much of the species' current habitat will continue to be suitable under that scenario. This second criterion addresses uncertainty associated with the ability of a species to shift its distribution at the same pace as the climate shifts. The current increasingly more rapid rate of climate change has been contrasted with what was thought to be more gradual rates during the past, which may have allowed species many generations to shift their distributions as they tracked preferred climate envelopes. A summary of the proportional loss of suitable habitat and the amount of climate refugia for each modeled species is shown below in **Table C1**. Habitat suitability models (maps) for individual species are also provided below. It is important to reiterate that these models are hypotheses that need to be validated or refuted, and improved as more data are collected.

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Table C1. Summary statistics for the 24 habitat suitability models constructed for selected species occurring within the Monument.[1]

	current elevation (m)	3C+ modeled elevation (m)	current modeled habitat extent (ha)	3C+ modeled habitat extent (ha)	% change	climate refugia extent (ha)	refugia as a % of 3C+ extent
Reptiles							
Banded rock lizard	595 ± 175	980 ± 182	17383	14029	19%	3245	24%
Chuckwalla	530 ± 267	894 ± 263	213600	111816	48%	59415	53%
Granite spiny lizard	1082 ± 340	1340 ± 311	56959	35970	39%	27912	78%
Western fence lizard	1260 ± 297	1681 ± 353	150867	62804	58%	43860	70%
Southern sagebrush lizard	2187 ± 246	2511 ± 205	18993	8206	57%	4620	56%
Desert spiny lizard	726 ± 315	1086 ± 295	243240	99782	59%	83589	84%
Yucca night lizard (spp complex)	993 ± 212	1195 ± 163	156051	86100	45%	45590	53%
Coast horned lizard	1188 ± 246	1515 ± 184	106505	38618	64%	8359	22%
Desert horned lizard	367 ± 258	646 ± 201	425470	244150	43%	192738	79%
Mojave desert tortoise	601 ± 212	876 ± 218	208089	54095	74%	40364	0
Plants							
Desert agave	731 ± 259	1015 ± 250	10822	7633	29%	4140	54%
Ocotillo	521 ± 173	930 ± 179	98859	63277	36%	12730	20%
Single-leaf pinyon pine	1335 ± 177	1459 ± 272	21449	9185	57%	269	3%
California barrel cactus	595 ± 193	924 ± 207	33780	20198	40%	6007	30%
White bursage	581 ± 289	918 ± 269	327655	164877	50%	86579	52%
Brittlebush	451 ± 281	703 ± 203	335207	140891	58%	85857	61%
Acton encelia	1076 ± 228	1271 ± 183	65545	30822	53%	1869	6%
Creosote bush	486 ± 354	654 ± 287	475658	266765	44%	237638	89%
Muller's oak	1331 ± 196	1480 ± 193	74474	15912	79%	6273	39%

	current elevation (m)	3C+ modeled elevation (m)	current modeled habitat extent (ha)	3C+ modeled habitat extent (ha)	% change	climate refugia extent (ha)	refugia as a % of 3C+ extent
Jojoba	881 ± 194	1055 ± 165	106103	67392	37%	22025	33%
California juniper	1167 ± 190	1350 ± 144	71329	38990	45%	11602	30%
Red shank	1389 ± 194	1779 ± 195	31240	7105	77%	2031	28%
Jeffrey pine	2050 ± 366	2417 ± 293	15429	6172	60%	2553	41%
Catclaw acacia	650 ± 225	934 ± 265	147316	93665	37%	61482	66%

[1]Species highlighted in red are those shown to be more at risk from projected levels of climate change as measured by the small percentage (≤ 30%) of their current suitable habitat that will remain as a climate refugia and a ≥ 50% decline in the amount of total future suitable habitat. For the desert tortoise, the calculation of refugia as a percentage of the future extent of suitable habitat is for the Monument only. Other desert tortoise refugia exist on lands to the north, such as in Joshua Tree National Park.

As indicated in **Appendix B**, results reveal strong parallels for those species for which both vulnerability assessments and habitat suitability models were prepared—models for pinyons, red shank, coast horned lizards, and desert tortoises all indicate high risk levels. Taken together, based on vulnerability assessments and habitat suitability models, additional species at higher risk include Peninsular bighorn sheep, Acton brittlebush, and bigberry manzanita.

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Reptiles

Coast horned lizard, *Phrynosoma blainvillii*

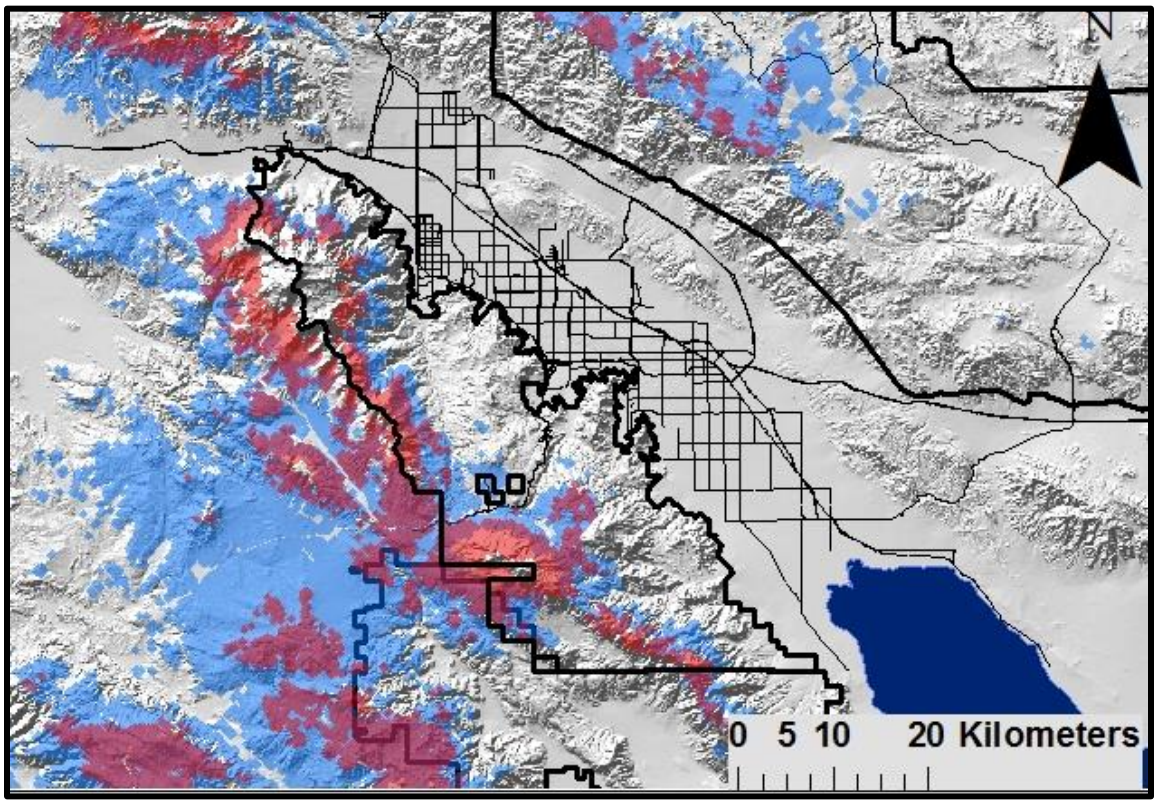

Figure 1. Habitat suitability model for coast horned lizards within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Desert horned lizard, *Phrynosoma platyrhinos*

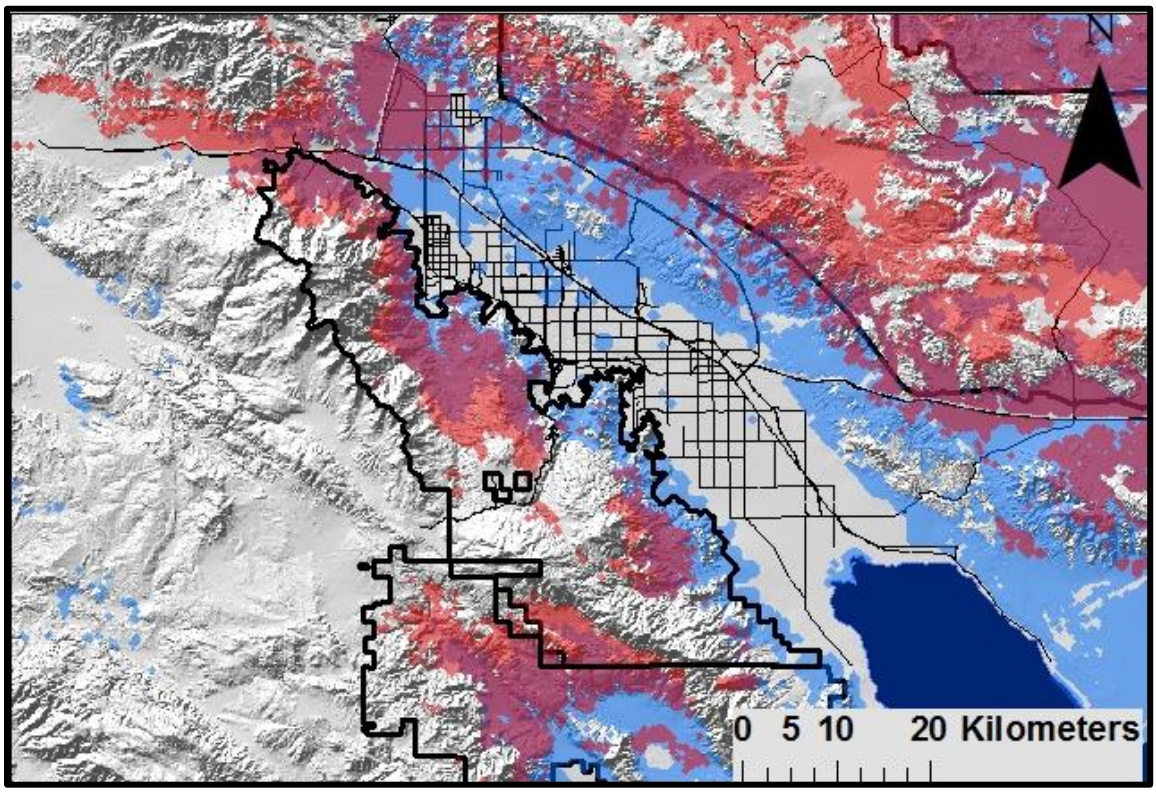

Figure 2. Habitat suitability model for desert horned lizards within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Banded rock lizard, *Petrosaurus mearnsi*

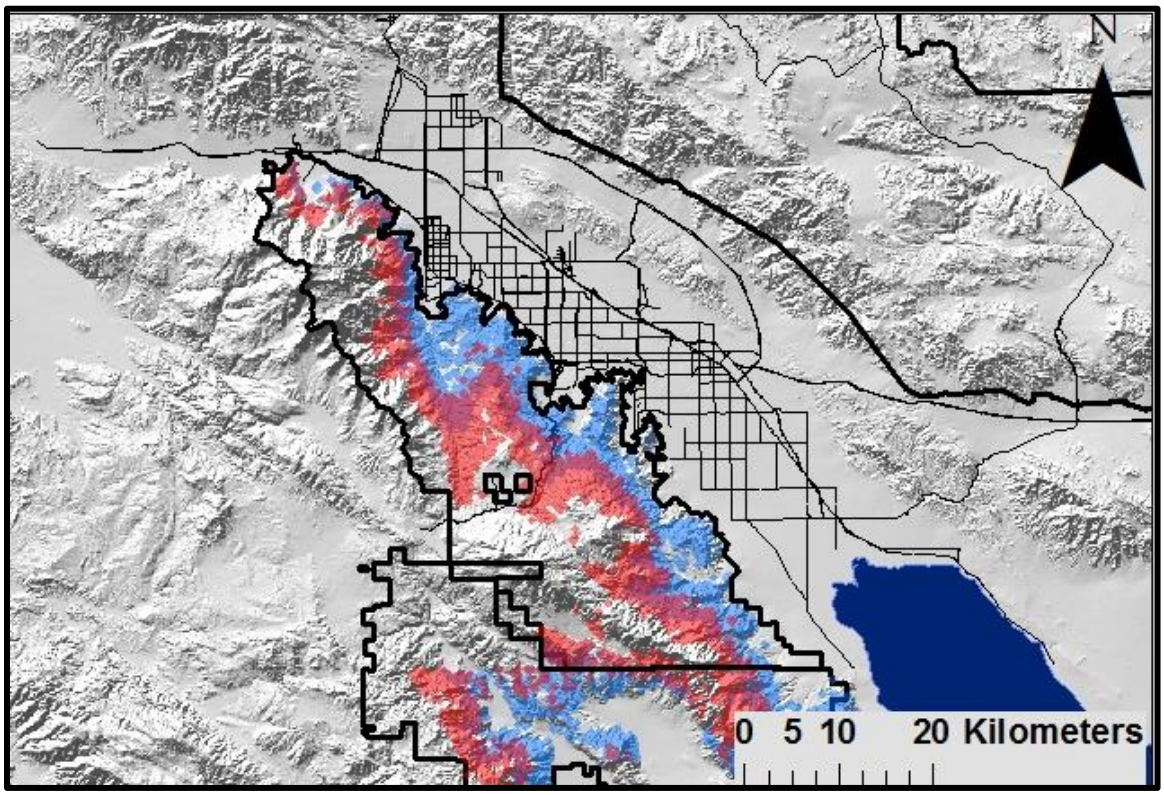

Figure 3. Habitat suitability model for banded rock lizards within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Chuckwalla, *Sauromalus ater*

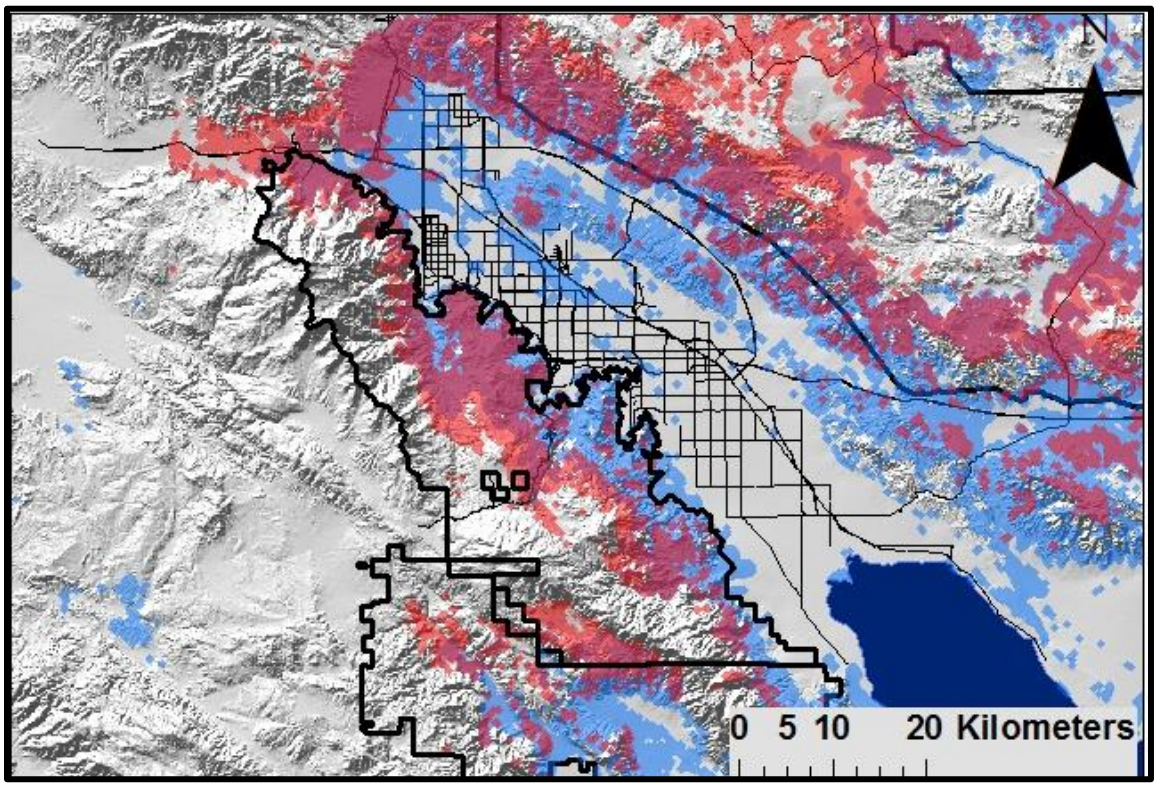

Figure 4. Habitat suitability model for chuckwallas within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Granite spiny lizard, *Sceloporus orcuttii*

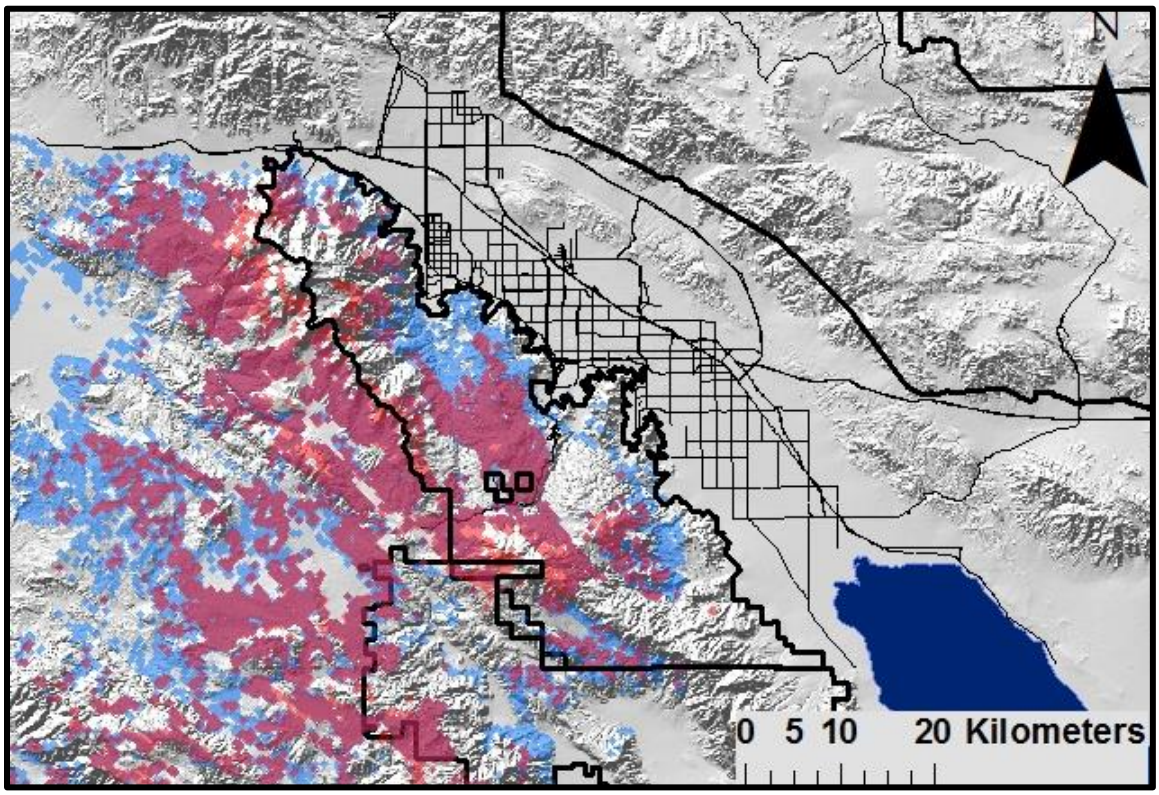

Figure 5. Habitat suitability model for granite spiny lizards within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Western fence lizard, *Sceloporus occidentalis*

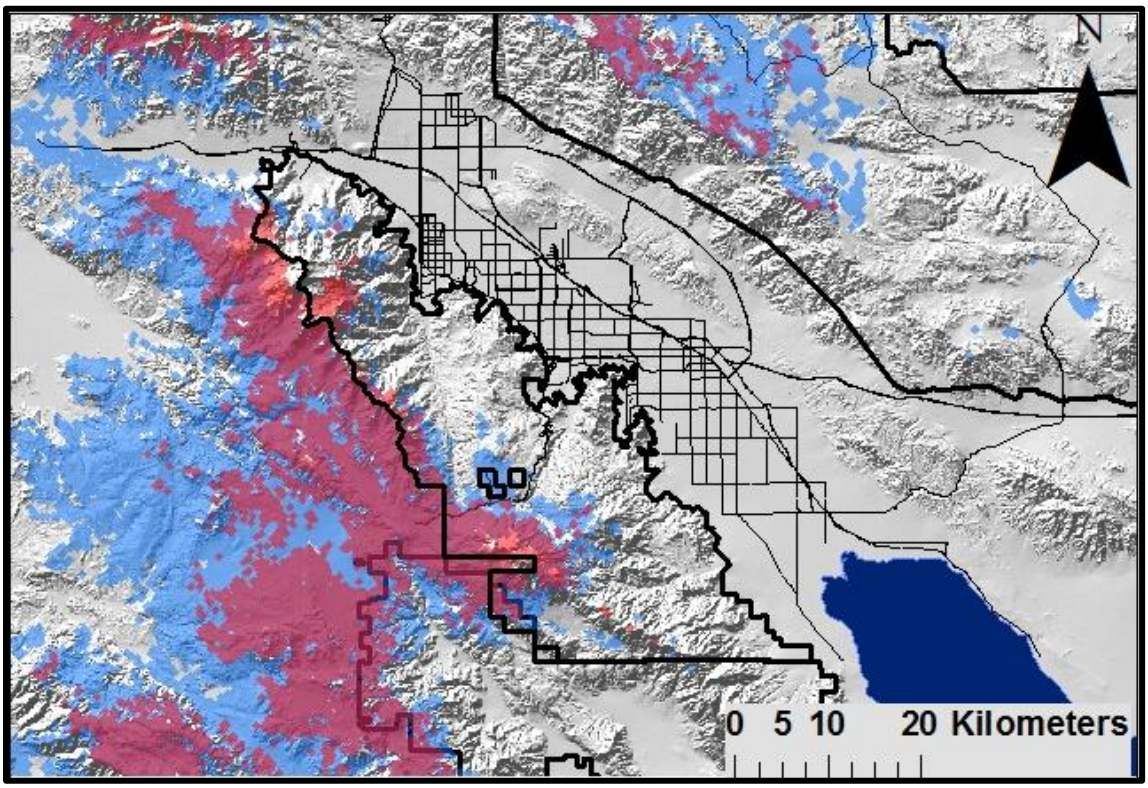

Figure 6. Habitat suitability model for western fence lizards within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Desert spiny lizard, *Sceloporus magister*

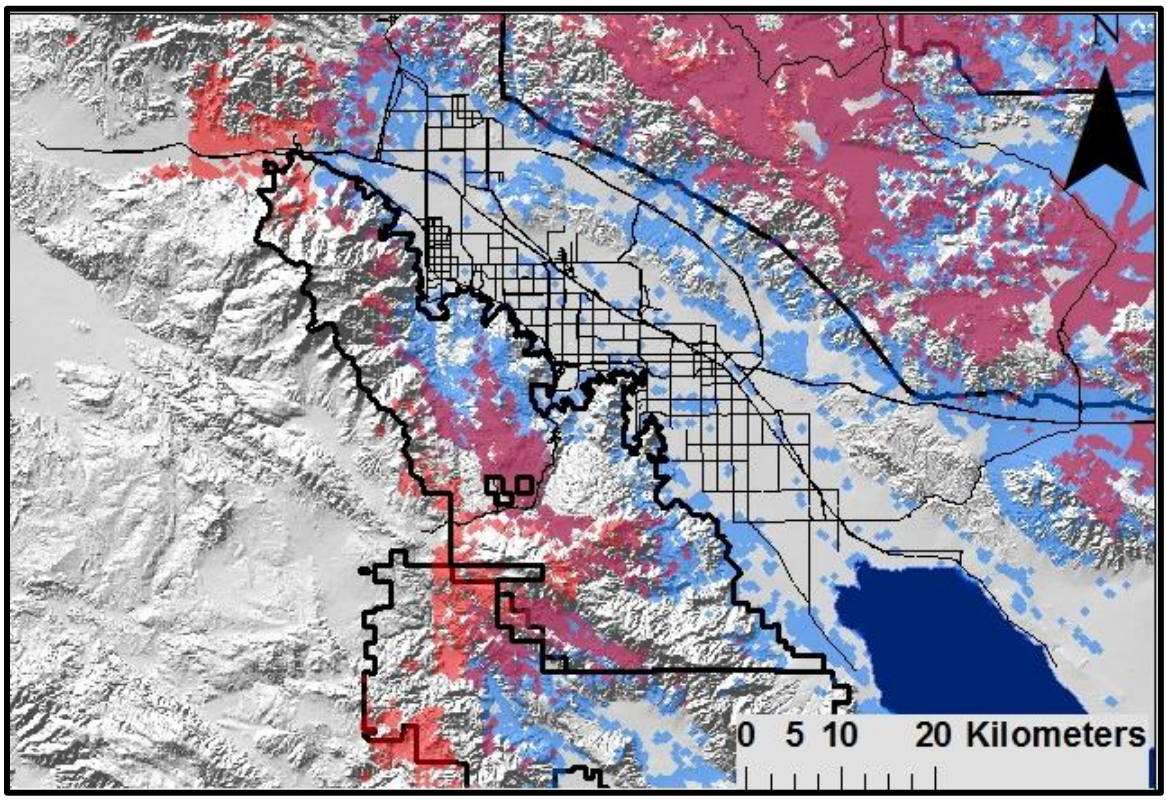

Figure 7. Habitat suitability model for desert spiny lizards within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Southern sagebrush lizard, *Sceloporus vandenburgianus*

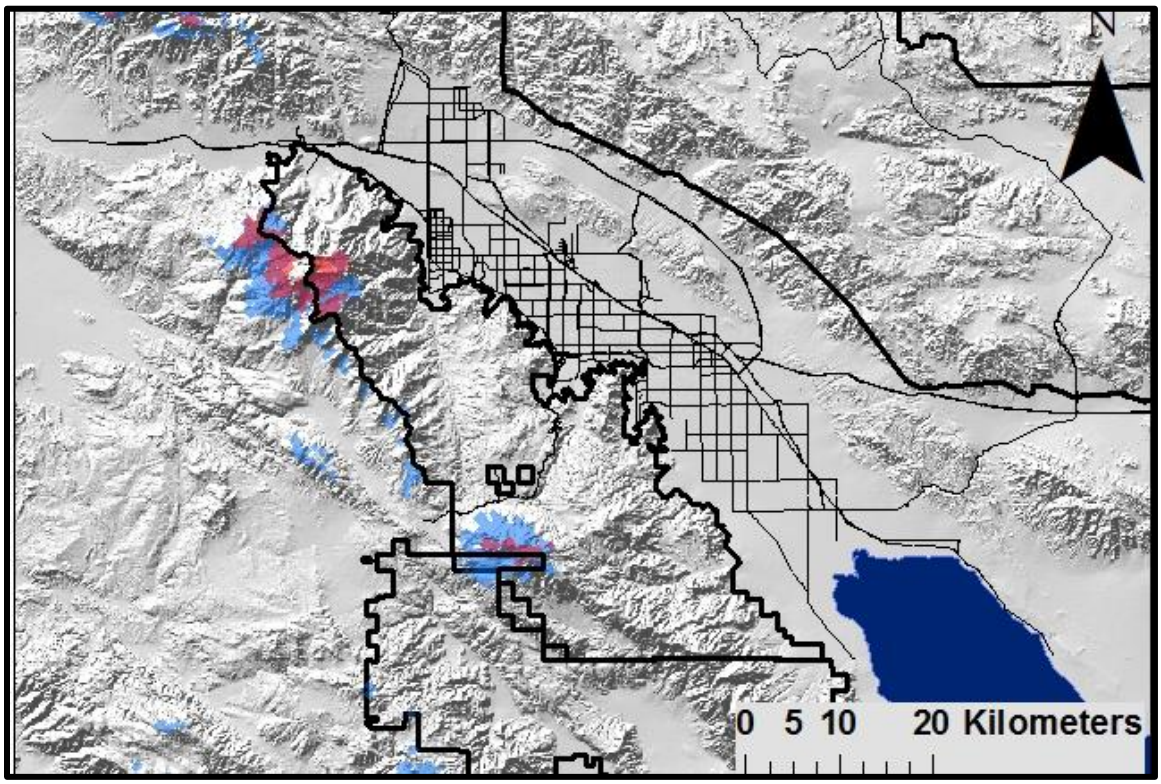

Figure 8. Habitat suitability model for southern sagebrush lizards within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Desert night lizard species complex, *Xantusia* spp.

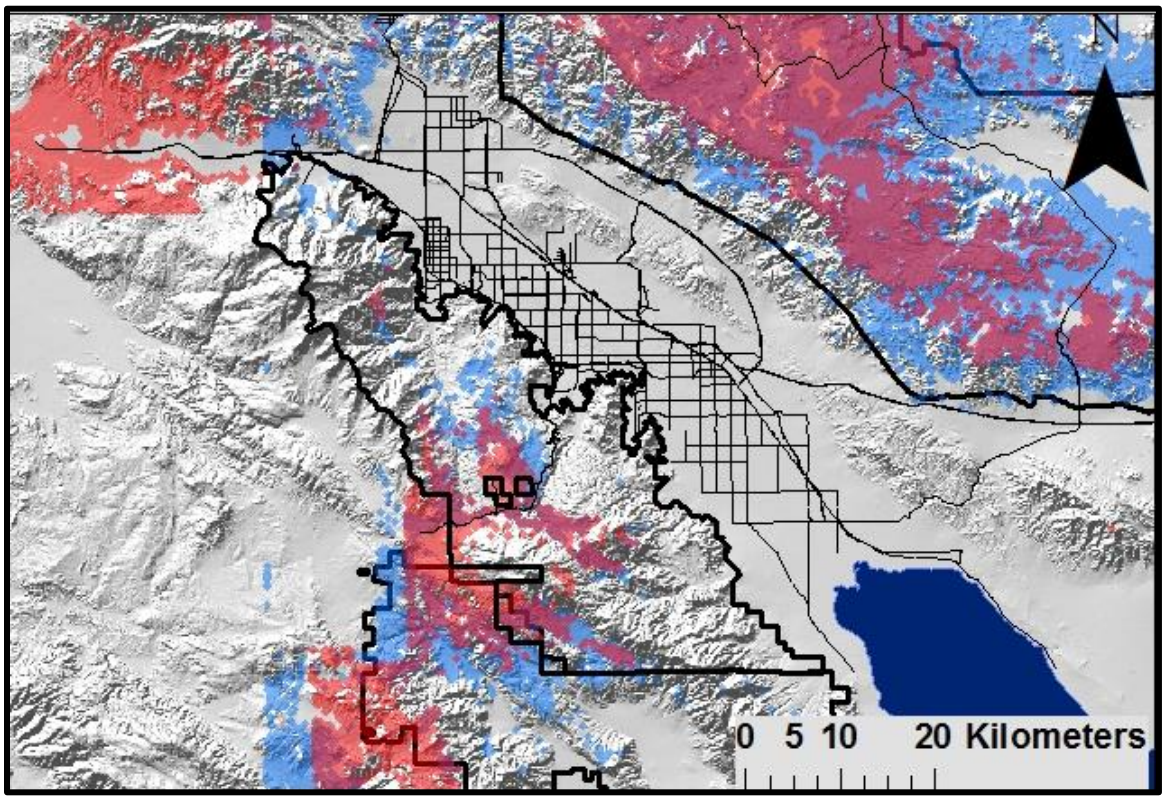

Figure 9. Habitat suitability model for the desert night lizard species complex within the project area. Within this modeled area, distributions for *Xantusia vigilis*, *X. wigginsii*, and up to one or more other, yet undescribed species are included. *X. vigilis* is generally restricted to the north of the Coachella Valley. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Mojave desert tortoise, *Gopherus agassizi*

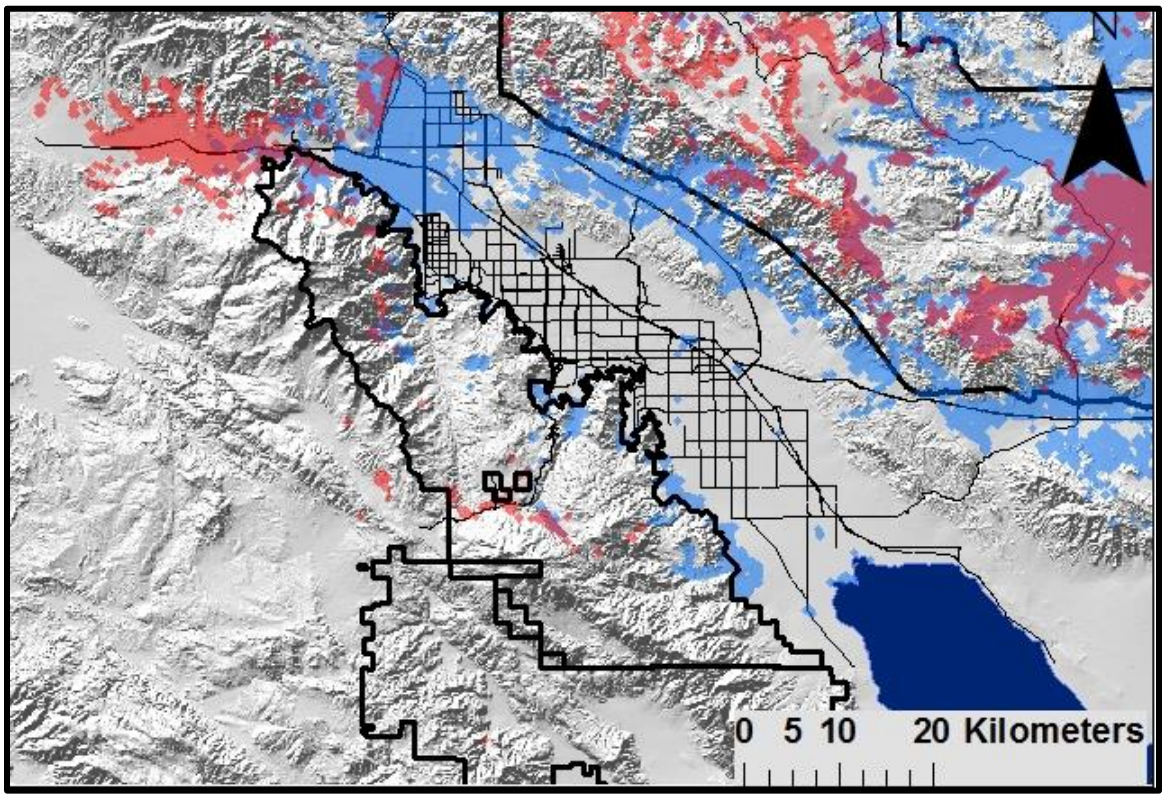

Figure 10. Habitat suitability model for desert tortoises within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Perennial/Woody Vegetation

Creosote bush, *Larrea tridentata*

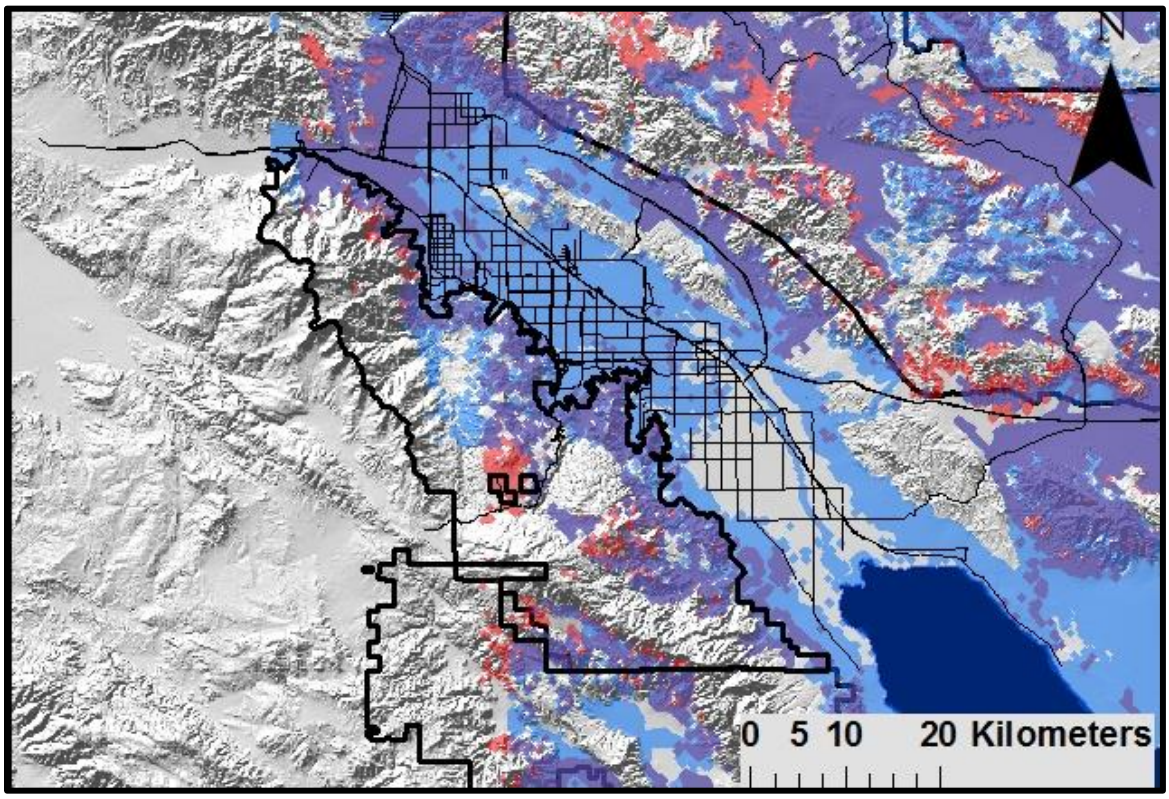

Figure 11. Habitat suitability model for creosote bush within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Jojoba, *Simmondsia chinensis*

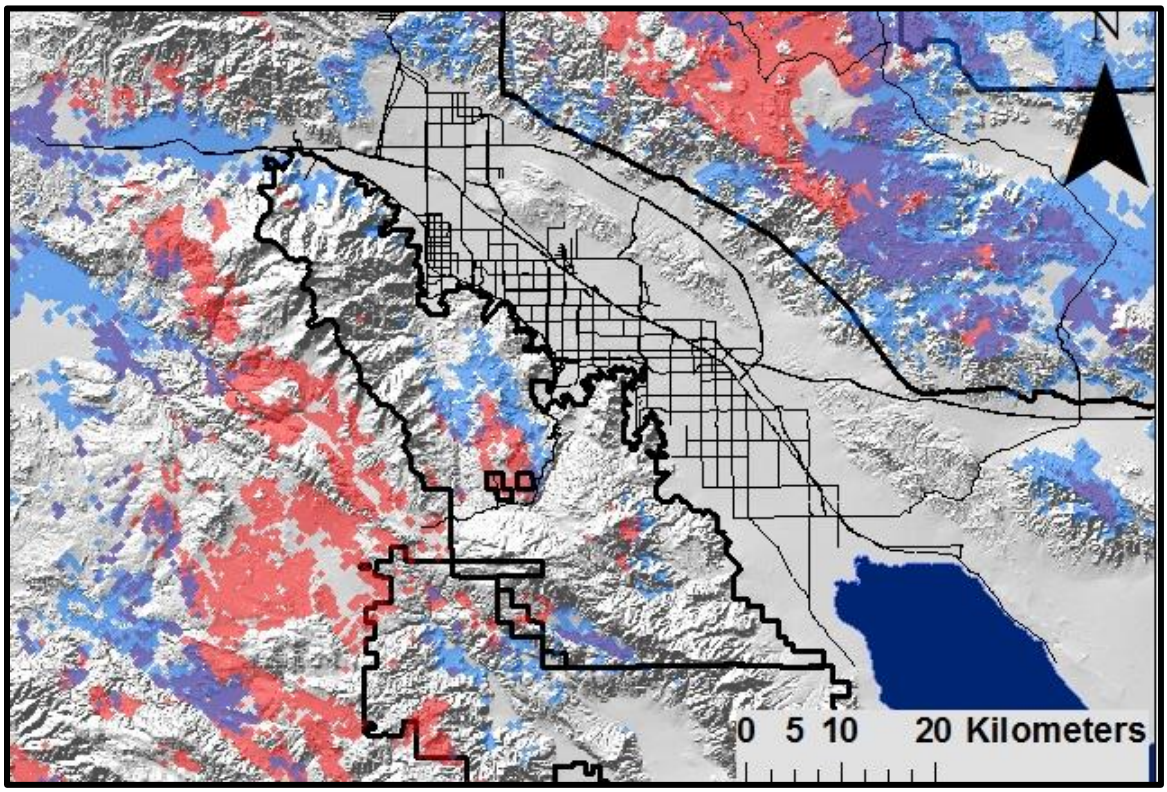

Figure 12. Habitat suitability model for jojoba within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Muller's oak, *Quercus cornelius-mulleri*

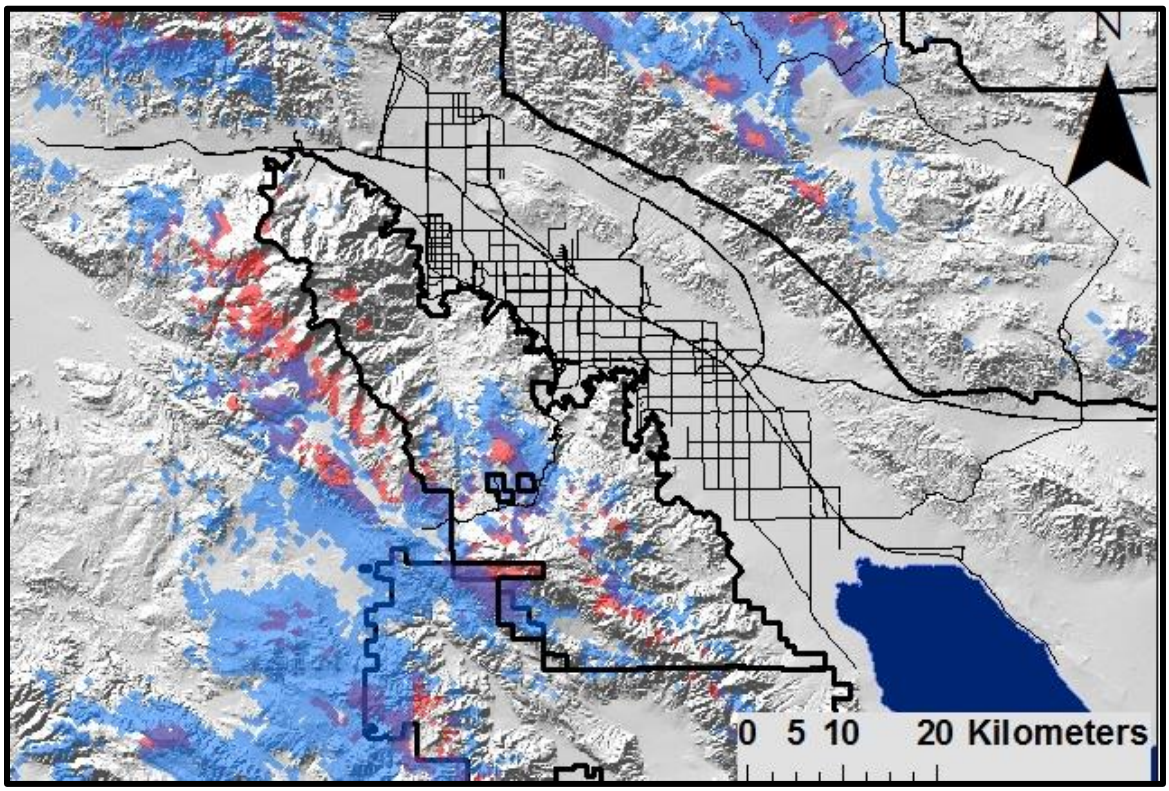

Figure 13. Habitat suitability model for Muller's oak within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

California juniper, *Juniperus californica*

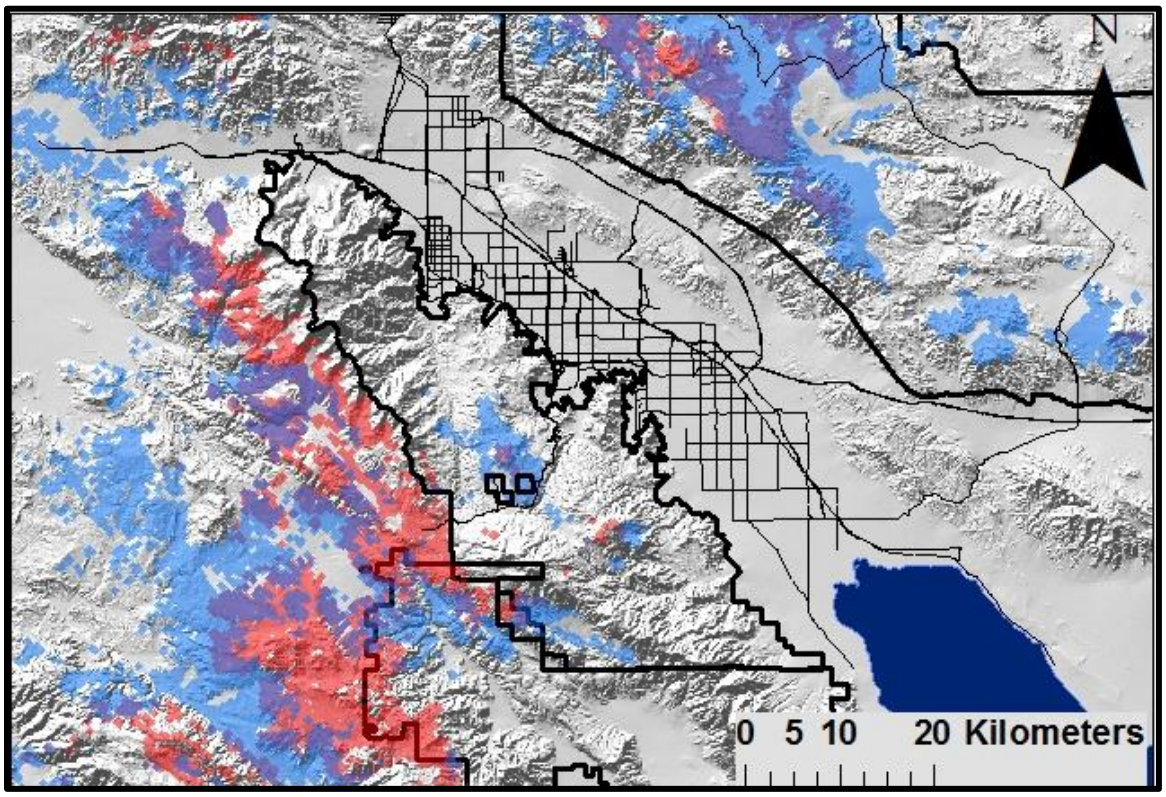

Figure 14. Habitat suitability model for California juniper within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

California barrel cactus, *Ferocactus cylindraceus*

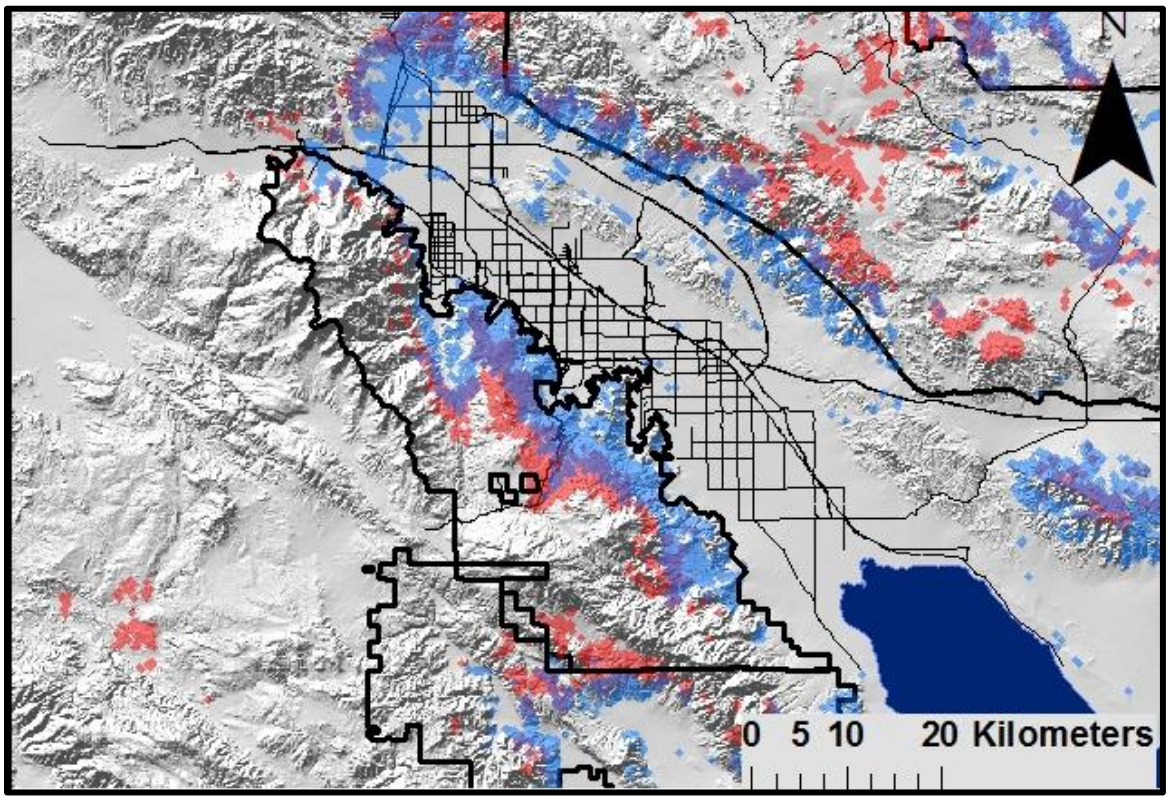

Figure 15. Habitat suitability model for California barrel cactus within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Single-leaf pinyon pine, *Pinus monopylla*

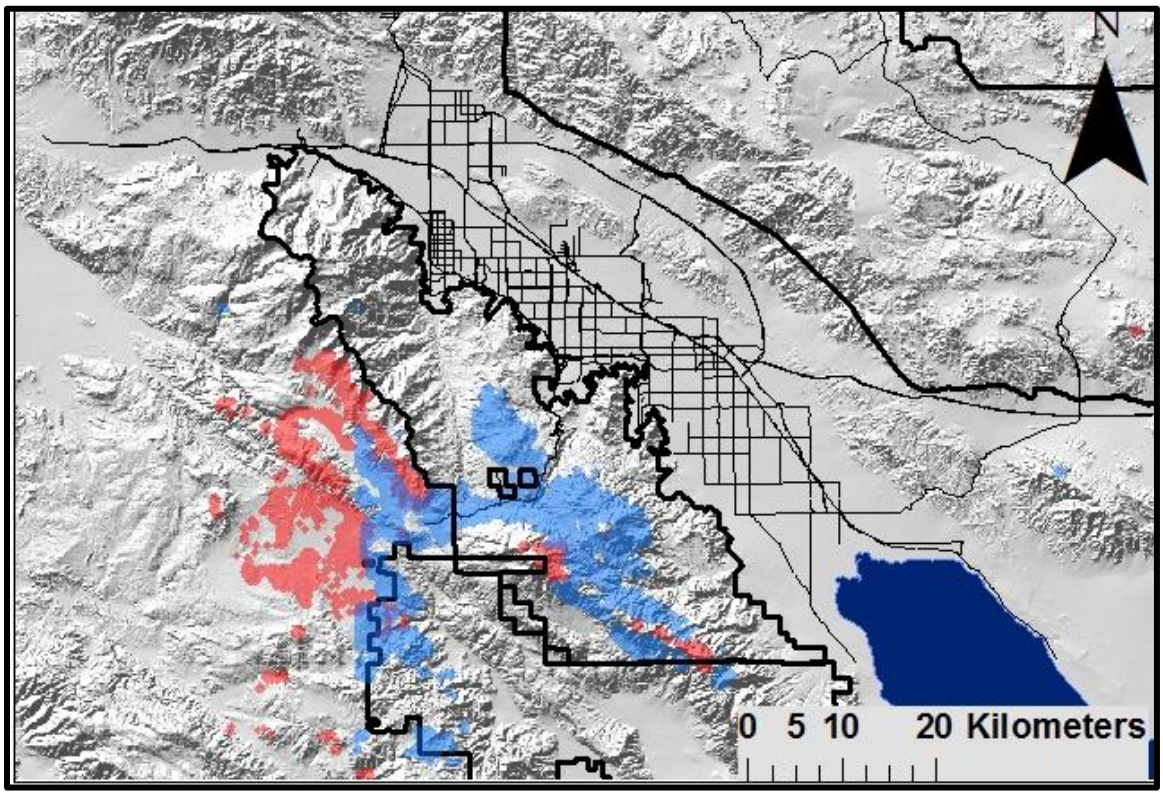

Figure 16. Habitat suitability model for single-leaf pinyon pines within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Ocotillo, *Fouquieria splendens*

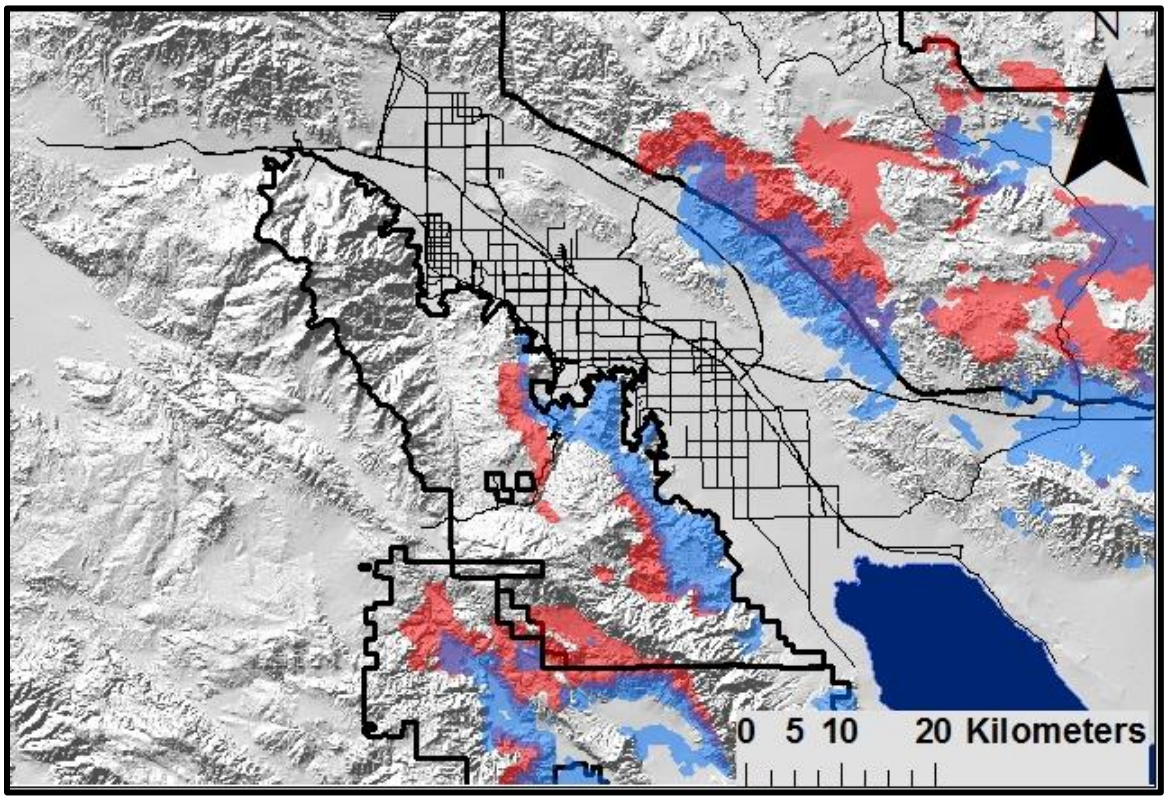

Figure 17. Habitat suitability model for ocotillo within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Desert agave, *Agave deserti*

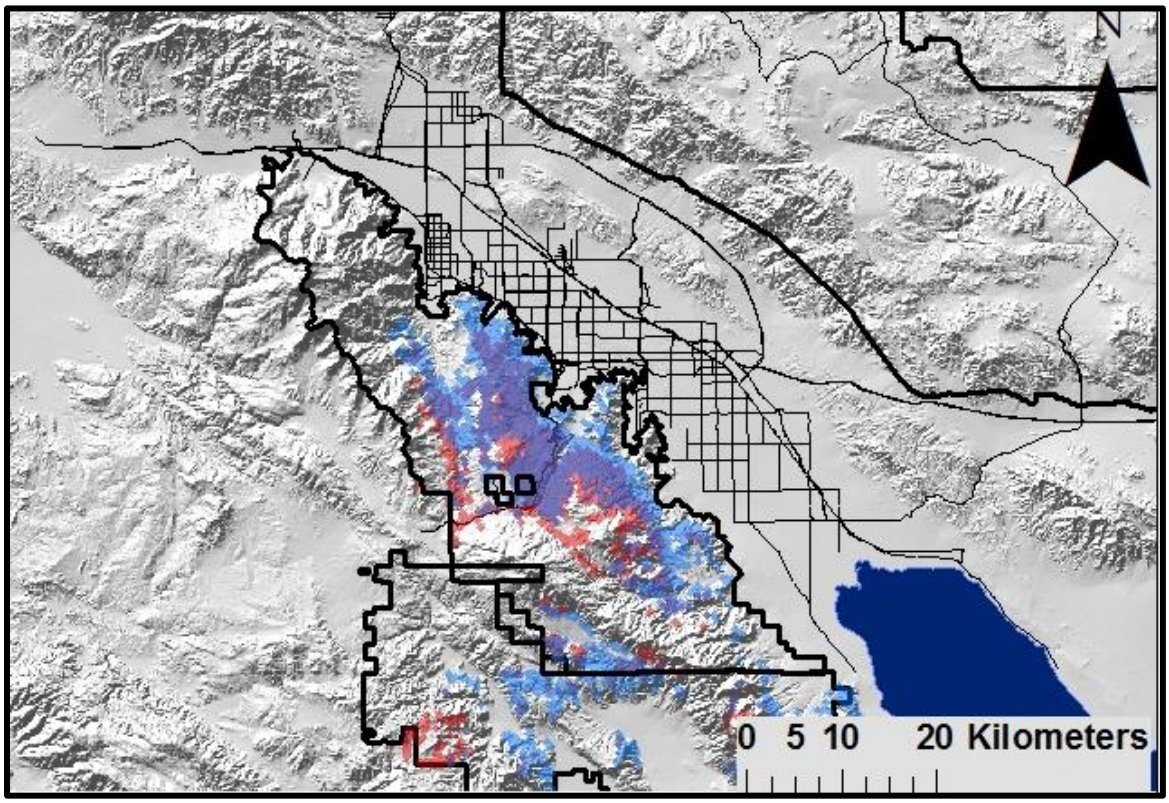

Figure 18. Habitat suitability model for desert agave within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Red shank, *Adenostoma sparsifolium*

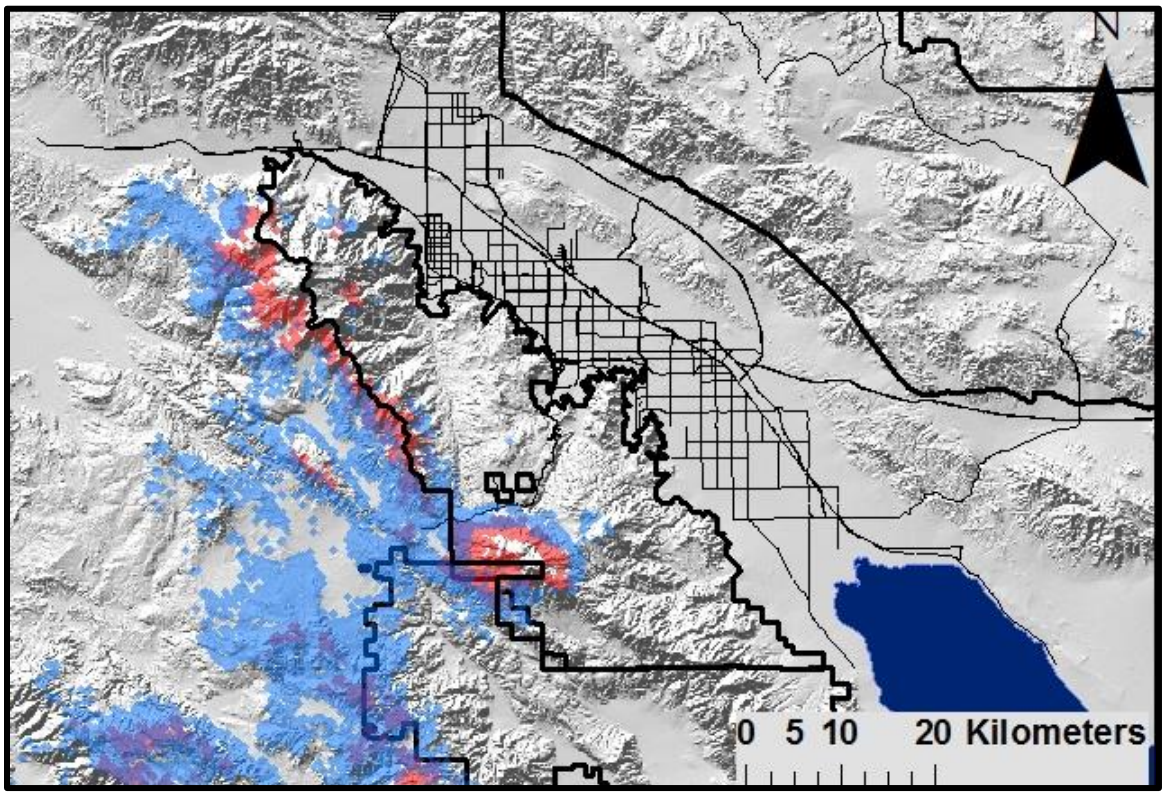

Figure 19. Habitat suitability model for red shank/ribbonwood within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Jeffrey pine, *Pinus jeffreyi*

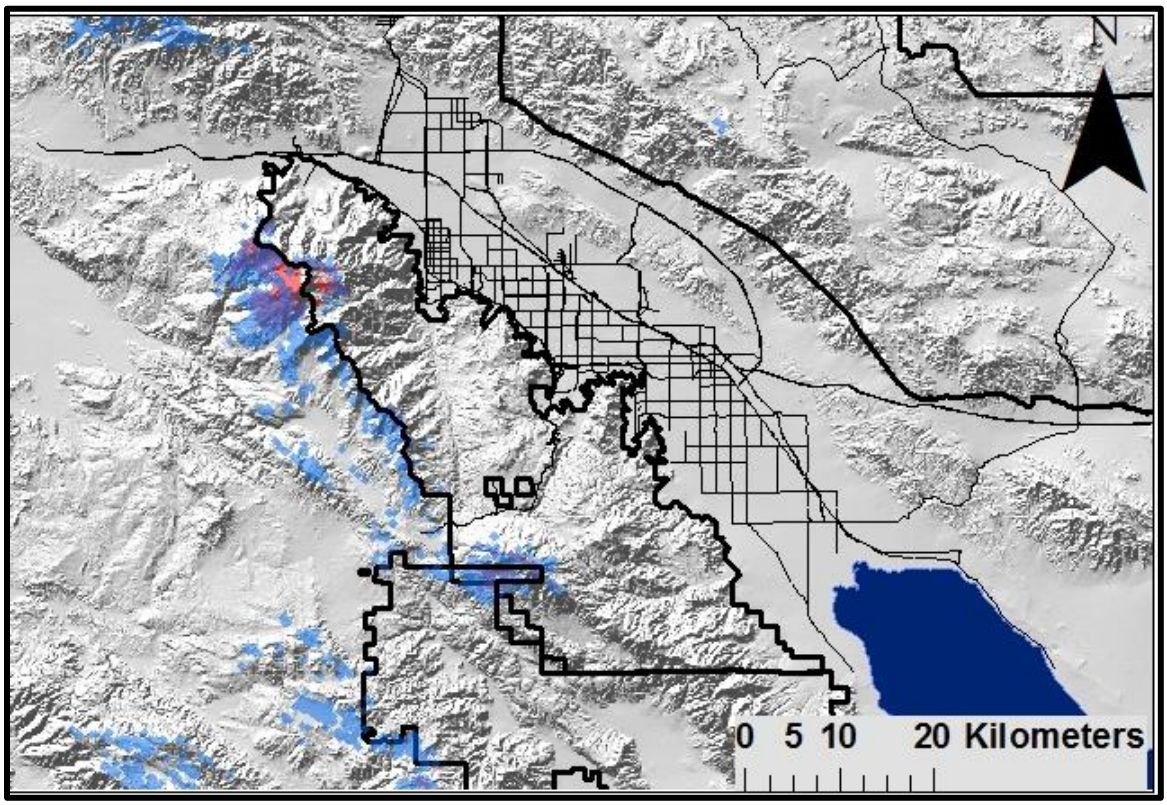

Figure 20. Habitat suitability model for Jeffrey pine within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Catclaw acacia, *Senegalia greggii*

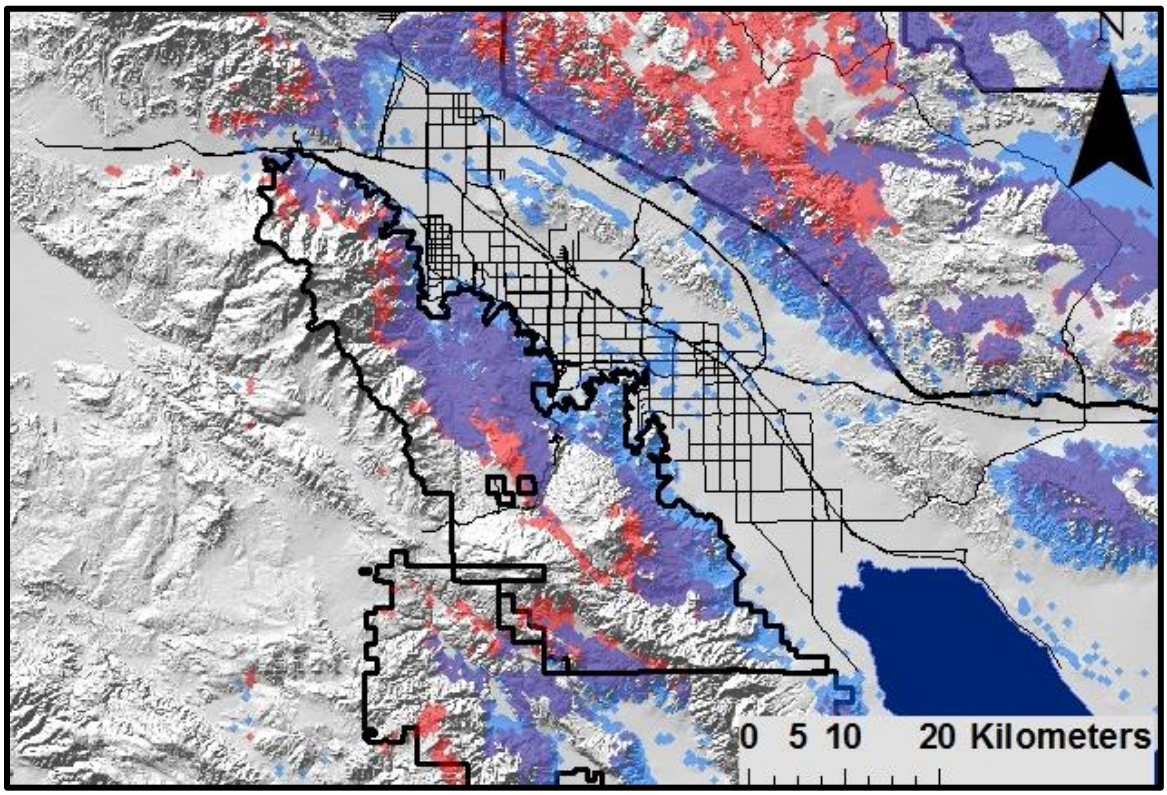

Figure 21. Habitat suitability model for catclaw acacia within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

White bursage, *Ambrosia dumosa*

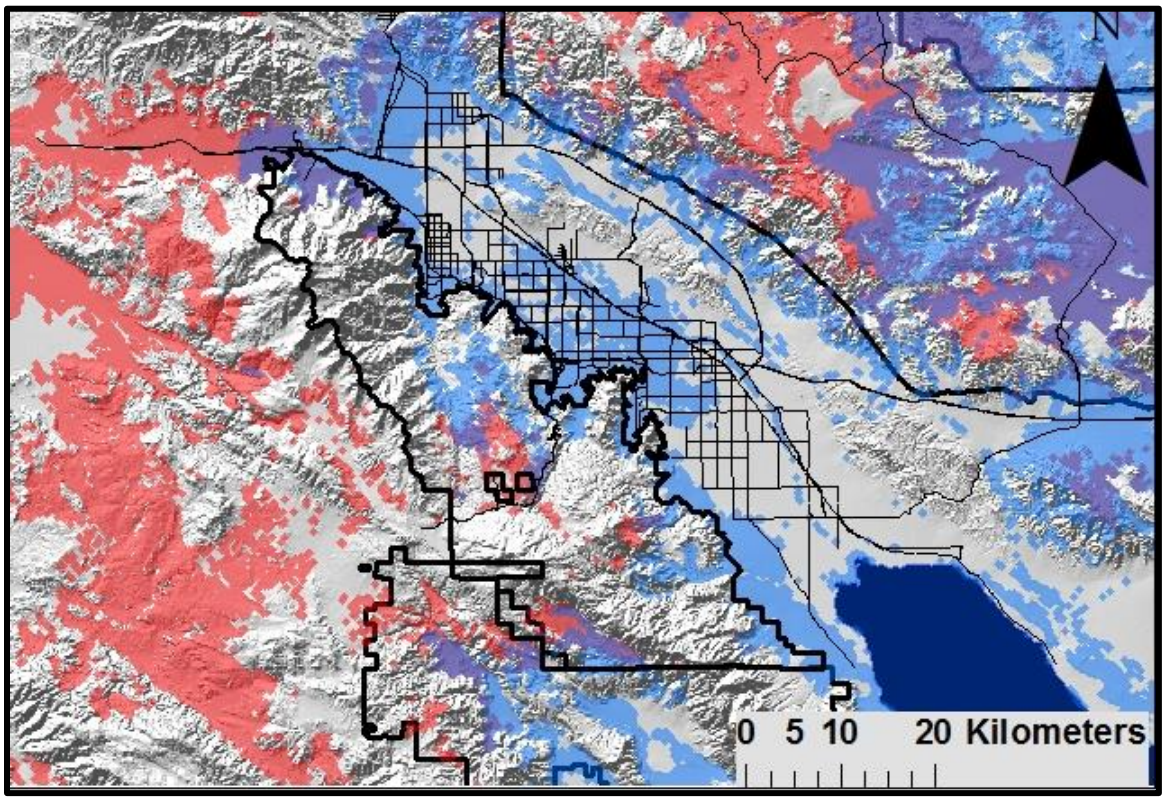

Figure 22. Habitat suitability model for white bursage/burro bush within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Acton encelia, *Encelia actonii*

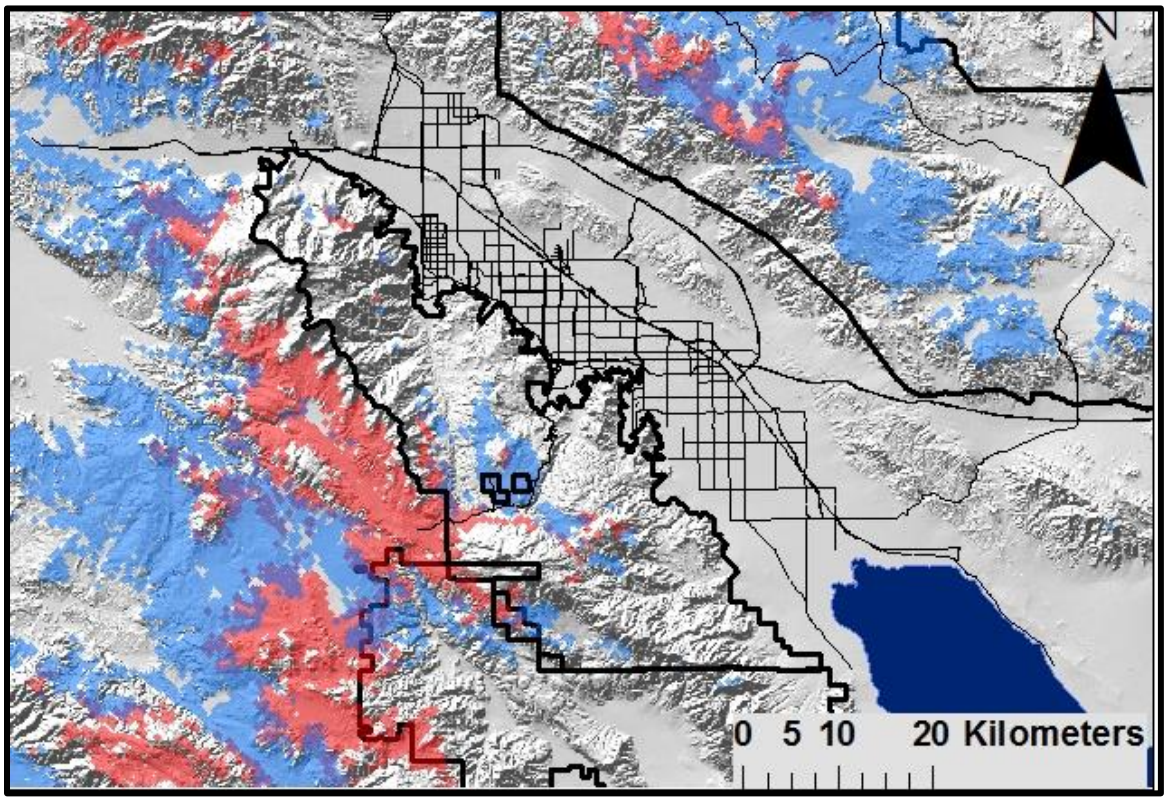

Figure 23. Habitat suitability model for Acton encelia within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

Brittlebush, *Encelia farinosa*

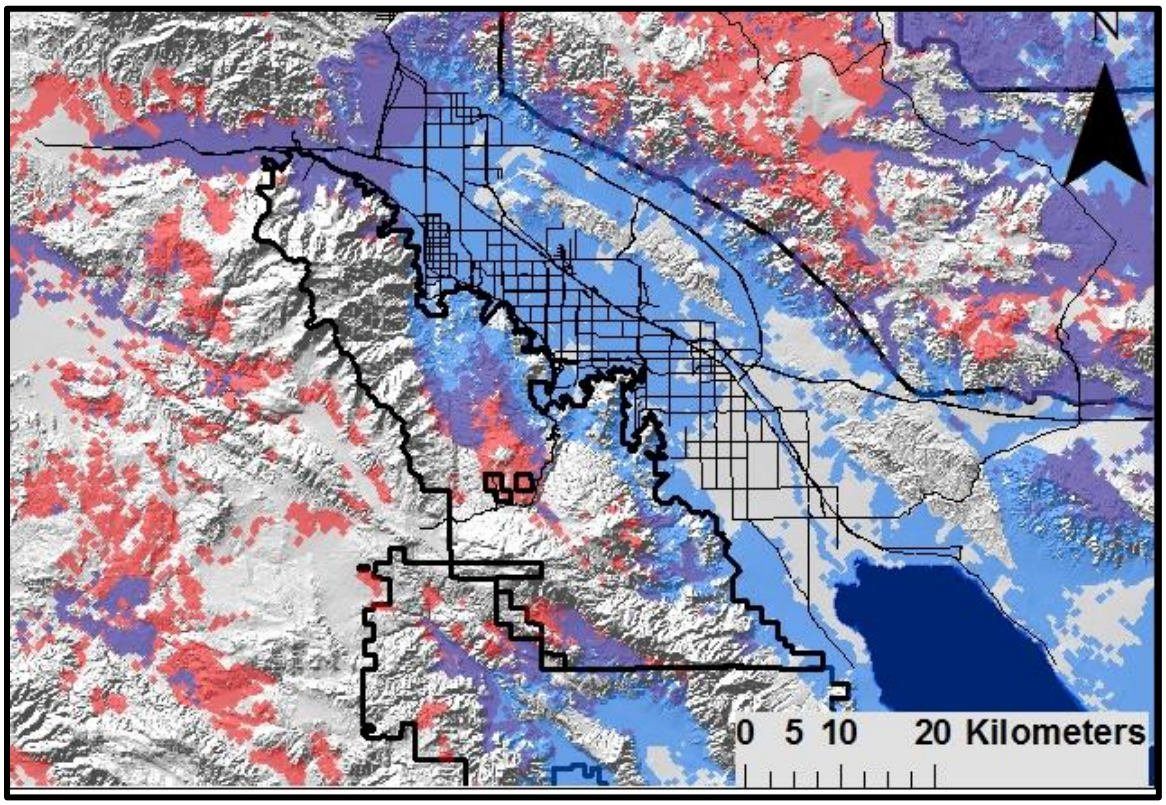

Figure 24. Habitat suitability model for brittlebush within the project area. Blue shaded areas represent modeled suitable habitat under current or recent historic conditions. Red shaded areas represent modeled suitable habitat under a summer temperature increase of 3°C. Purple shaded areas indicate where the two models overlap and so constitute areas of climate refugia for this species.

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