CONSERVATION OF SAN JOAQUIN ANTELOPE SQUIRRELS (*AMMOSPERMOPHILUS NELSONI*): ECOLOGICAL ASSOCIATIONS, HABITAT SUITABILITY, AND CONSERVATION STRATEGIES

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EXECUTIVE SUMMARY

San Joaquin antelope squirrels (*Ammospermophilus nelsoni*: SJAS) are endemic to the San Joaquin desert region in central California. SJAS once were widely distributed in arid shrubland and grassland habitats in the western and southern portions of the San Joaquin Valley from western Merced County down to Kern County and also on the Carrizo Plain and Cuyama Valley. Conversion of natural lands to agricultural, urban, and industrial uses has substantially reduced the available habitat for this species.

We conducted surveys at 326 locations from December 2017 to May 2019. We used automated camera stations to detect SJAS at each site, and we also collected habitat attribute data including information on topography, shrubs, ground cover, co-occurring animal species, and habitat disturbances. We detected SJAS at 160 locations. Locations where SJAS were detected typically were in arid shrub scrub areas or grasslands. If shrubs were present, they commonly were saltbush (*Atriplex polycarpa* or *A. spinifera*) or jointfir (*Ephedra* spp.). The ground cover was generally sparse and Arabian grass was commonly present. Conversely, SJAS were rarely found in locations with alkali sink habitat where iodine bush (*Allenrolfea occidentalis*), sinkweek (*Sueada* spp.), alkali goldenbush (*Isocoma acradenia*), and wild barley (*Hordeum* spp.) were common dominants. SJAS were found in areas ranging topographically from flat to moderate slopes. SJAS presence was not affected by nearby oil field activities or grazing.

SJAS frequently were found in association with kangaroo rats (*Dipodomys* spp.) and kangaroo rat burrows were abundant in areas with SJAS. SJAS likely occupy and modify kangaroo rat burrows and kangaroo rat burrows may be important for thermal and escape cover in areas with few or no shrubs. SJAS were negatively associated with the presence of California ground squirrels (*Otospermophilus beecheyi*). This could have been a function of differing habitat preferences or displacement by this larger competitor.

We modeled habitat suitability for SJAS based on the results of our surveys and the attribute data above. Thus, the primary model inputs were current land uses, vegetation community, and percent bare ground. Model results estimated that 5,931 km^2 of high or moderately high suitability habitat was still present within the historical range of SJAS along with an additional 4,753 km^2 of moderately low or low quality habitat that could facilitate SJAS dispersal or be enhanced to improve suitability.

SJAS are still locally abundant in the Carrizo Plain region and western Kern County. Smaller populations persist in the Panoche Valley region, and possibly other locations such as the Kettleman Hills and Cuyama Valley. Small populations also persist in at least two locations on the San Joaquin Valley floor. Much of the natural land left on the valley floor is alkali sink habitat which appears to be suboptimal for SJAS. The majority of lands where SJAS still occur are protected to some degree from habitat destruction.

Recommendations resulting from this project are to (1) conduct additional SJAS surveys on additional sites as opportunities present themselves, (2) conserve habitat on unprotected lands where SJAS have been detected as well as lands with highly suitable habitat, (3) manage vegetation on lands if necessary to reduce ground cover and enhance suitability for SJAS, (4) conduct further research into translocation strategies, (5) conduct translocations of SJAS to unoccupied sites with suitable habitat, and (6) develop and test strategies for restoring disturbed lands to make them suitable for occupation by SJAS.

INTRODUCTION

The San Joaquin antelope squirrel (*Ammospermophilus nelsoni*: SJAS) is a small ground squirrel endemic to the San Joaquin desert in central California (U.S. Fish and Wildlife Service [USFWS] 1998, Germano et al. 2011). This species once was widely distributed in arid shrubland and grassland habitats in the western and southern portions of the San Joaquin Valley from western Merced County down to Kern County and also on the Carrizo Plain (Figure 1). Much of the habitat in this region has been converted to agricultural, urban, and industrial uses (USFWS 1998). Due to this profound habitat loss, SJAS were listed as California Threatened in 1980.

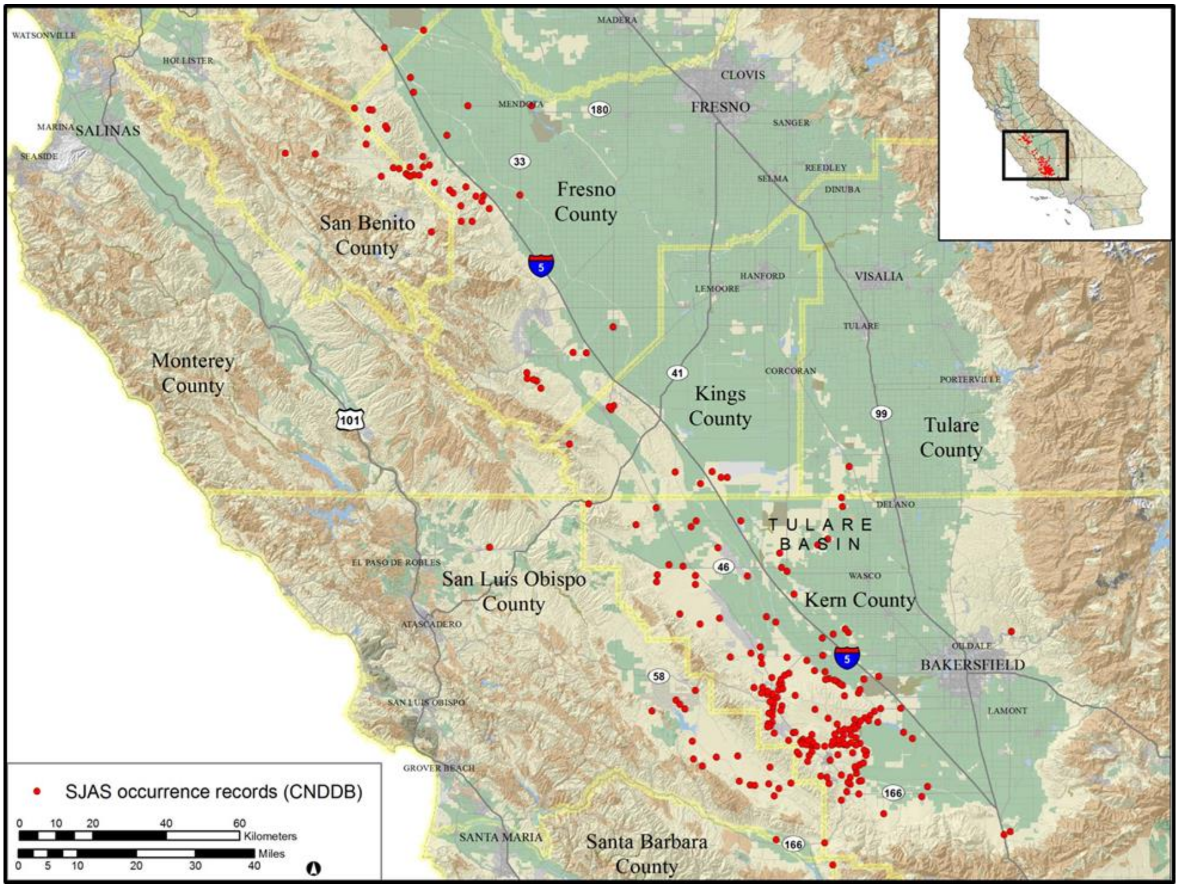

Figure 1. Range map and California Natural Diversity Data Base occurrence records for the San Joaquin antelope squirrel in central California.

Habitat loss, fragmentation, and degradation are still occurring and this continuing loss threatens to isolate and extirpate remaining populations. The current distribution of SJAS has not been assessed since the 1980s. Also, optimal habitat conditions for this species are not well known. Additionally, the effects of competitors such as California ground squirrels (*Otospermophilus beecheyi*) are poorly understood (Harris and Stearns 1991, USFWS 1998).

We conducted surveys for SJAS throughout their potential range. At each survey location, we quantified a variety of ecological attributes and correlated these with the presence of SJAS. This information was used to define preferred habitat conditions for SJAS and to prepare a habitat suitability model for the species. Finally, based on our results, recommendations were developed for conserving SJAS throughout their range.

METHODS

STUDY AREA

This project was conducted throughout the historic range of SJAS (Figure 1). The habitats in which work was conducted included annual grasslands, saltbush scrub, alkali sink scrub, and ephedra scrub (USFWS 1998), all of which are within the region known as the San Joaquin Desert (Germano et al. 2011). The regional climate is Mediterranean in nature, and is characterized by hot, dry summers, and cool, wet winters with frequent fog. Mean maximum and minimum temperatures are 35°C and 18°C in summer, and 17°C and 5°C in winter. Annual precipitation averages ca. 15 cm and occurs primarily as rain falling between October and April (National Oceanic and Atmospheric Administration 2002). Topography is varied within the range of SJAS and ranges from flat valley bottoms to steep-sloped mountain ranges with elevations ranging from ca. 100 m to 1200 m. Loss of natural habitat within the historic range of SJAS has been profound due to agricultural and urban development. Extensive areas of remaining habitat are subject to disturbance including hydrocarbon (oil, natural gas) extraction, off-road vehicle use, and cattle grazing at varying intensities (USFWS 1998).

SURVEYS

We used automated camera stations to determine whether SJAS were present at a given site. We used Cuddeback (E3 Black Flash Trail Cameras; Non Typical, Green Bay, WI), Bushnell (models 119455, HD 119437, and HD 119477; Bushnell Outdoor Products, Overland Park, KS), and Reconyx (PC800 HyperFire Professional IR and Reconynx PC900 HyperFire Professional IR; Reconyx, Holmen, WI) field cameras. The cameras use an infrared sensor to detect movement and collect images at 5-20 megapixel resolution. At each station, a 1-m t-post was hammered into the ground, and the camera was mounted on the post using a bracket and zipties. To attract squirrels to the camera stations, we placed an approximately 1-kg piece of Premium Wild Bird Block or Flock Block (Purina, Gray Summit, MO) about 2 m in front of each camera. The block consisted of a mixture of grains, seeds, molasses, and other ingredients pressed into a solid block.

Surveys primarily were conducted on public lands administered by the U.S. Bureau of Land Management (BLM) and the California Department of Fish and Wildlife (CDFW), and on conservation lands administered by the Center for Natural Lands Management and The Wildlands Conservancy. For a few locations, we received permission to establish stations on private lands. Up to 20 camera stations were established at a time, depending on the amount of habitat available. Stations were placed at least 350 m (ca. 0.25 mi) apart. This is the approximate diameter of a SJAS home range based on an estimated average home range size of 10 ha reported by Harris and Stearns (1991). This spacing substantially reduced the potential to detect a given individual at more than one station. Our goal was to operate stations for at least 7 days at each location.

Images collected by each camera were carefully examined to determine whether stations had been visited by SJAS. Detections of other species were recorded as well, particularly visits by California ground squirrels. Also, the day of first detection for SJAS was noted for each station.

HABITAT ATTRIBUTES

At each camera station, a suite of habitat attributes was characterized and recorded (Appendix A). This information was primarily qualitative so that a relatively large area (ca. 1 hectare) could be characterized quickly (ca.15 minutes). Information recorded included:

- Presence of shrubs
- Density of shrubs:
  - Sparse: estimated <10 per ha
  - Medium: estimated 10-50 per ha
  - Dense: estimated >50 per ha
- Common shrub species present
- Ground cover density:
  - Sparse: >30% bare ground
  - Medium: 10-30% bare ground
  - Dense: <10% bare ground
- Common herbaceous species
- Presence of alkali scalds (playas)
- Topography – flat, rolling, gentle slopes (≤10%), steep slopes (>10%), washes
- Presence of anthropogenic disturbances such as oil field activities, off-road vehicles, grazing
- Presence of kangaroo rats based on sign (e.g., burrows, scats)
- Presence of California ground squirrels (e.g., observations of squirrels, burrows)
- Abundance of burrows:
  - Low: From any given point, on average 0-2 burrows visible
  - Medium: From any given point, on average 3-5 burrows visible
  - High: From any given point, on average 6 or more burrows visible

At each station, observations of kangaroo rat sign and of California ground squirrels and their sign were supplemented with detections of these species on the camera from that station. The proportional occurrence of each of the habitat attributes above was compared between stations with and without SJAS detections using contingency table analysis and a Pearson chi-square test. For 2x2 analyses, a continuity correction was applied (Zar 1984). Some variables had more than 2 levels (e.g., shrub density, topography). For these variables, if the chi-square test indicated a significant difference in proportions, levels were compared pair-wise to assess which levels were different. A Cramer's V value and associated significance level were calculated along with each chi-square test to assess the strength of the association between the presence of SJAS and the presence of each habitat attribute. Cramer's V values range from 0 to 1 with "0" indicating no association and "1" indicating a very strong association.

Statistical tests were conducted using IBM SPSS Statistics, Version 24 (IBM, Armonk, NY). P-values ≤ 0.05 were considered significant and p-values >0.05-1.0 were considered marginally significant.

HABITAT SUITABILITY MODELING

We produced a habitat suitability model using information derived from SJAS site surveys. For the model boundary, we used the southern portion of the San Joaquin Valley Recovery Planning area from the *Recovery Plan for Upland Species of the San Joaquin Valley* (USFWS 1998; Figure 2). Within that boundary we developed a simple model based on vegetation classes and percent bare ground using habitat attribute information from the field surveys.

For vegetation, we used a detailed vegetation layer from the CDFW Vegetation Classification and Mapping Program (VegCAMP) where available (CDFW 2010, 2015; California Native Plant Society 2013; California State University, Chico, Geographical Information Center 2016). Where VegCAMP data were not available, we used less-detailed vegetation data derived from California Gap Analysis Project supplemented with newer land use data (U.C. Santa Barbara Biogeography Lab 1998; California Department of Conservation, Farmland Mapping and Monitoring Program 2014; California Council on Science and Technology 2015). Figure 2 shows the extent of upland vegetation by source.

Using the most detailed vegetation classification available, we ranked upland vegetation communities from 1-4 (1 = best quality) based on vegetation associations from field surveys (Table 1, Figure 3). We found that one vegetation classification (*Southwestern North American salt basin and high marsh*) was overly-broad and included vegetation alliances that should be ranked differently. To solve this problem, we added a supplemental layer of historical vegetation based on reconnaissance-level soil surveys (Phillips and Cypher 2015: Figure 4) to identify which parts were generally in areas of *Valley saltbush scrub* (Rank = 1), *Grasslands* (Rank = 2), or other upland communities such as *Alkali Sink* (Rank = 3). In Table 1 these divisions are identified as Classification level = *Group/soil*.

For percent bare ground, we used a GIS layer derived from satellite imagery (U.S. Geological Survey 2013). Based on field observations we grouped percent bare ground into three categories: 1 = more than 30% bare ground, 2 = 10-30% bare ground, 3 = less than 10% bare ground (Figure 5).

We used GIS software (ArcGIS Pro *ModelBuilder*) to create a sequence of steps (Figure 6) to combine the vegetation rankings with the three categories of bare ground (e.g., Vegetation Rank 1 = > 30% bare ground, Vegetation Rank 2 = 10-30% bare ground, etc). We then organized these into four categories of habitat quality from best to worst (Table 2).

Data in the model were represented as a grid of cells (or a *raster*) of 90 m by 90 m. To reduce small patches or thin, linear features in the output, we replaced cells that were in groupings of less than 50 cells (40 ha/100 ac) with the value of cells in neighboring, larger patches. This generalization procedure provided a less “noisy” version of the data. For comparison, we also provided a figure and table of the model results without generalization in Appendix B.

Table 1. Vegetation classification rankings used to model habitat suitability for San Joaquin antelope squirrels.

Rank	Vegetation classification	Classification level
1	Atriplex polycarpa	Alliance
	Atriplex spinifera	Alliance
	Chenopod scrubs	Supplemental data
	Ephedra californica	Alliance
	Gutierrezia californica	Provisional Alliance
	Lycium andersonii	Alliance
	Monolopia (lanceolata)-Coreopsis (calliopsidea)	Provisional Alliance
	North American Warm Semi-Desert Cliff, Scree, and Other Rock Vegetation	Macrogroup
	Southwestern North American salt basin and high marsh/Desert Scrub	Group/soil
	Xeromorphic Scrub and Herb Vegetation (Semi-Desert)	Class
2	Ambrosia salsola	Alliance
	Amsinckia (menziesii, tessellata)	Alliance
	Atriplex canescens	Alliance
	Atriplex lentiformis	Alliance
	Atriplex vallicola - Lasthenia ferrisiae - Lepidium jaredii	Provisional Association
	Barren	Supplemental data
	California Annual and Perennial Grassland	Macrogroup
	California annual forb/grass vegetation	Group
	Centaurea (virgata)	Provisional Semi-Natural Alliance
	Coastal scrubs	Supplemental data
	Encelia (actoni, virginensis)	Alliance
	Ephedra viridis	Alliance
	Ericameria linearifolia - Isomeris arborea	Provisional Alliance
	Ericameria linearifolia - Peritoma arborea	Provisional Alliance
	Ericameria nauseosa	Alliance
	Isocoma acradenia	Provisional Alliance
	Krascheninnikovia lanata	Alliance
	Lasthenia californica - Plantago erecta - Vulpia microstachys	Alliance
	Lepidospartum squamatum	Alliance
	Lupinus albifrons	Alliance
	Poa secunda	Alliance
	Southwestern North American salt basin and high marsh/Grassland	Group/soil
	subshrub scrubs	Supplemental data
	Valley and foothill grasslands	Supplemental data
3	Allenrolfea occidentalis	Alliance
	Corethrogyne filaginifolia	Provisional Alliance
	Eriogonum (elongatum, nudum)	Provisional Alliance
	Eriogonum fasciculatum	Alliance
	Great Basin scrubs	Supplemental data
	Interior dunes	Supplemental data
	Mediterranean California naturalized annual and perennial grassland	Group
	Nassella cernua	Provisional Alliance
	Riverine, Barren	-
	Salvia carduacea	Provisional Alliance
	Salvia leucophylla	Alliance
	Salvia mellifera	Alliance
	Southwestern North American salt basin and high marsh/Alkali sink	Group/soil
	Suaeda moquinii	Alliance
4	Arctostaphylos glauca	Alliance
	Artemisia californica	Alliance
	Artemisia californica - Eriogonum fasciculatum	Alliance
	Artemisia tridentata	Alliance
	Baccharis pilularis	Alliance
	Californian mixed annual/perennial freshwater vernal pool/swale/plain bottomland	Group
	Central and south coastal California seral scrub	Group
	Central and South Coastal Californian coastal sage scrub	Group
	Cercocarpus montanus	Alliance
	Chaparral	Supplemental data
	Elymus glaucus	Alliance
	Frangula californica	Alliance
	Prunus fasciculata	Alliance
	Quercus john-tuckeri	Alliance
	Ribes quercetorum	Provisional Alliance

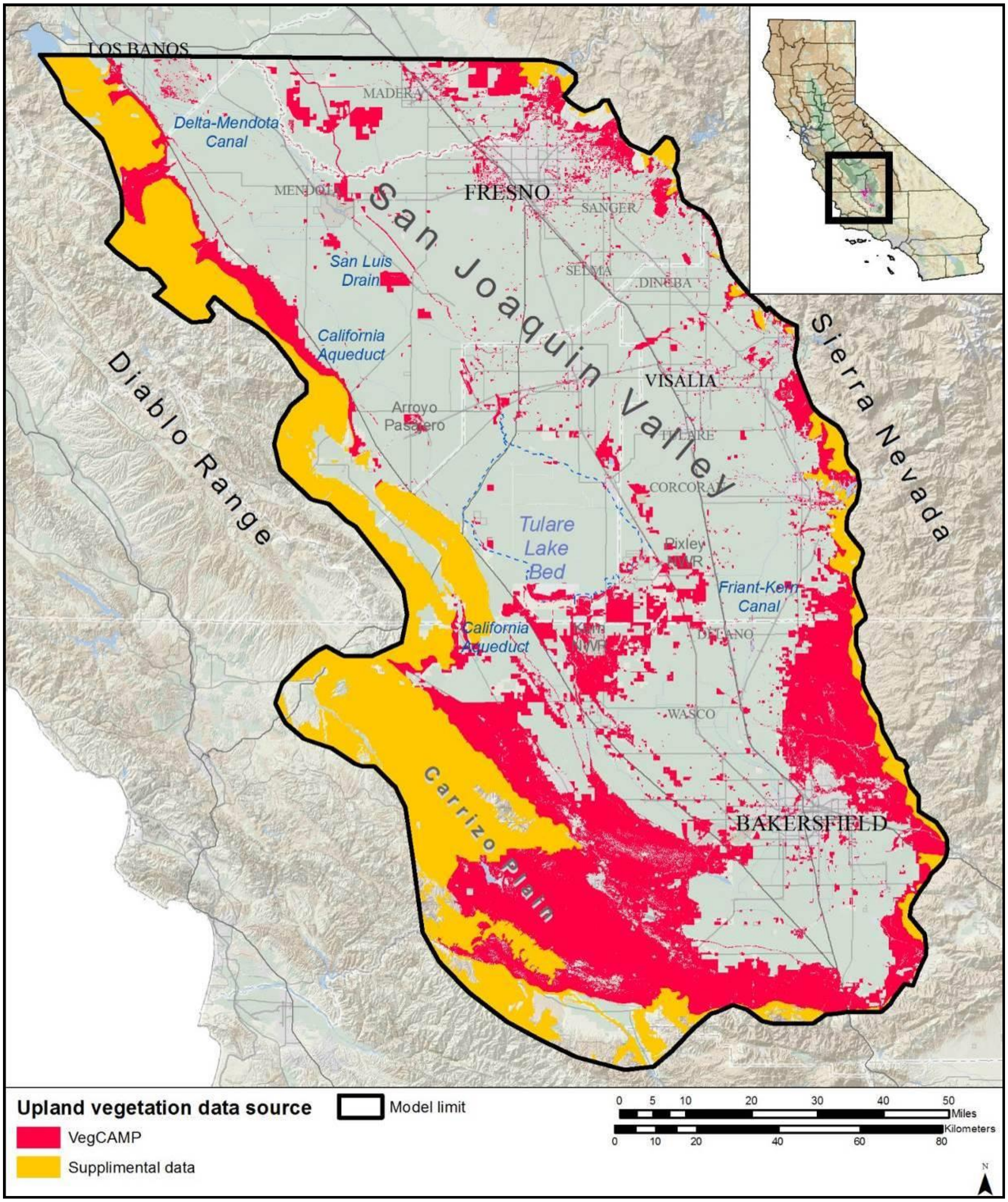

Figure 2. Extent of upland vegetation data by source within the range of the San Joaquin antelope squirrel in California.

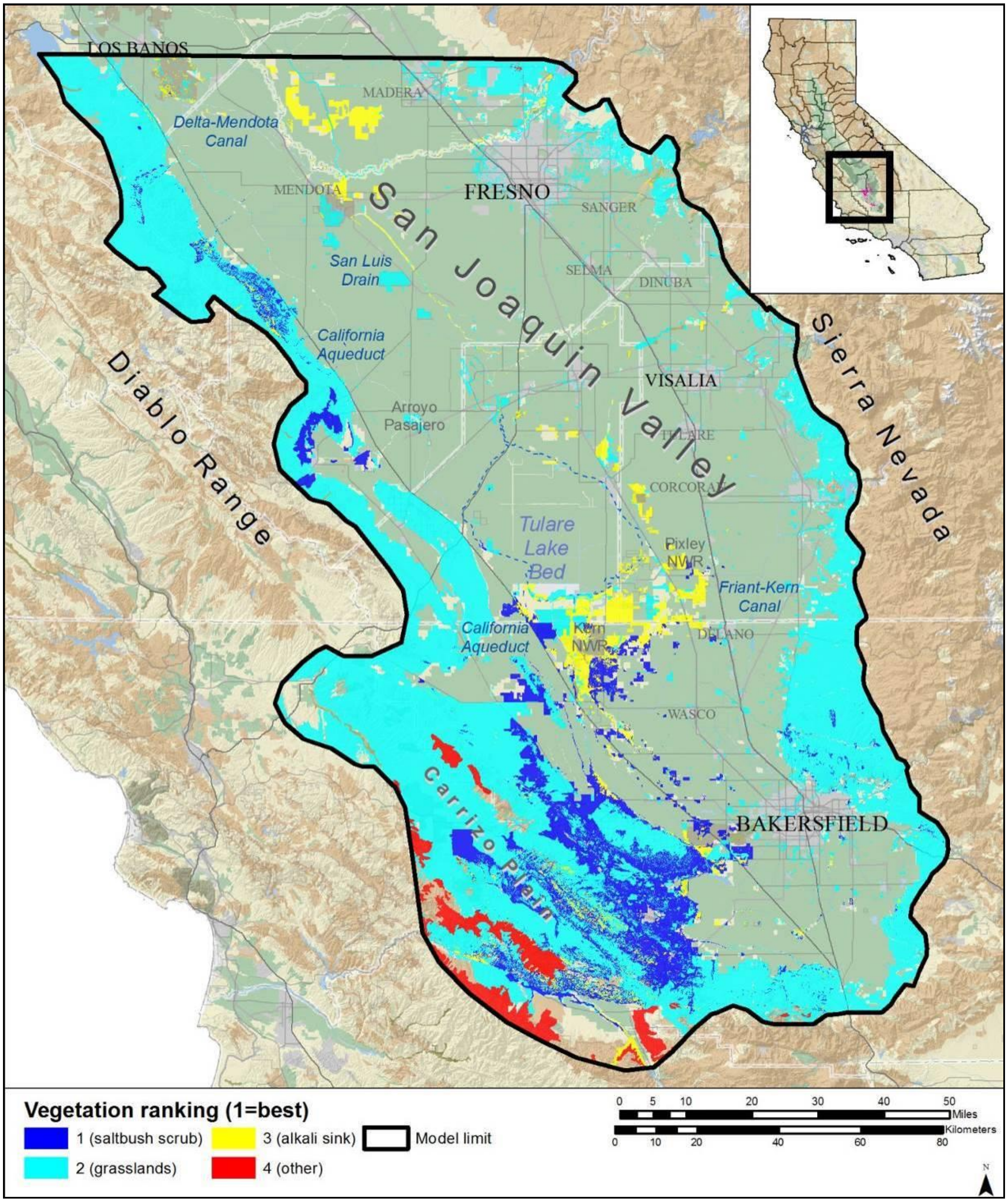

Figure 3. Vegetation class ranking based on site surveys for the San Joaquin antelope squirrel in California.

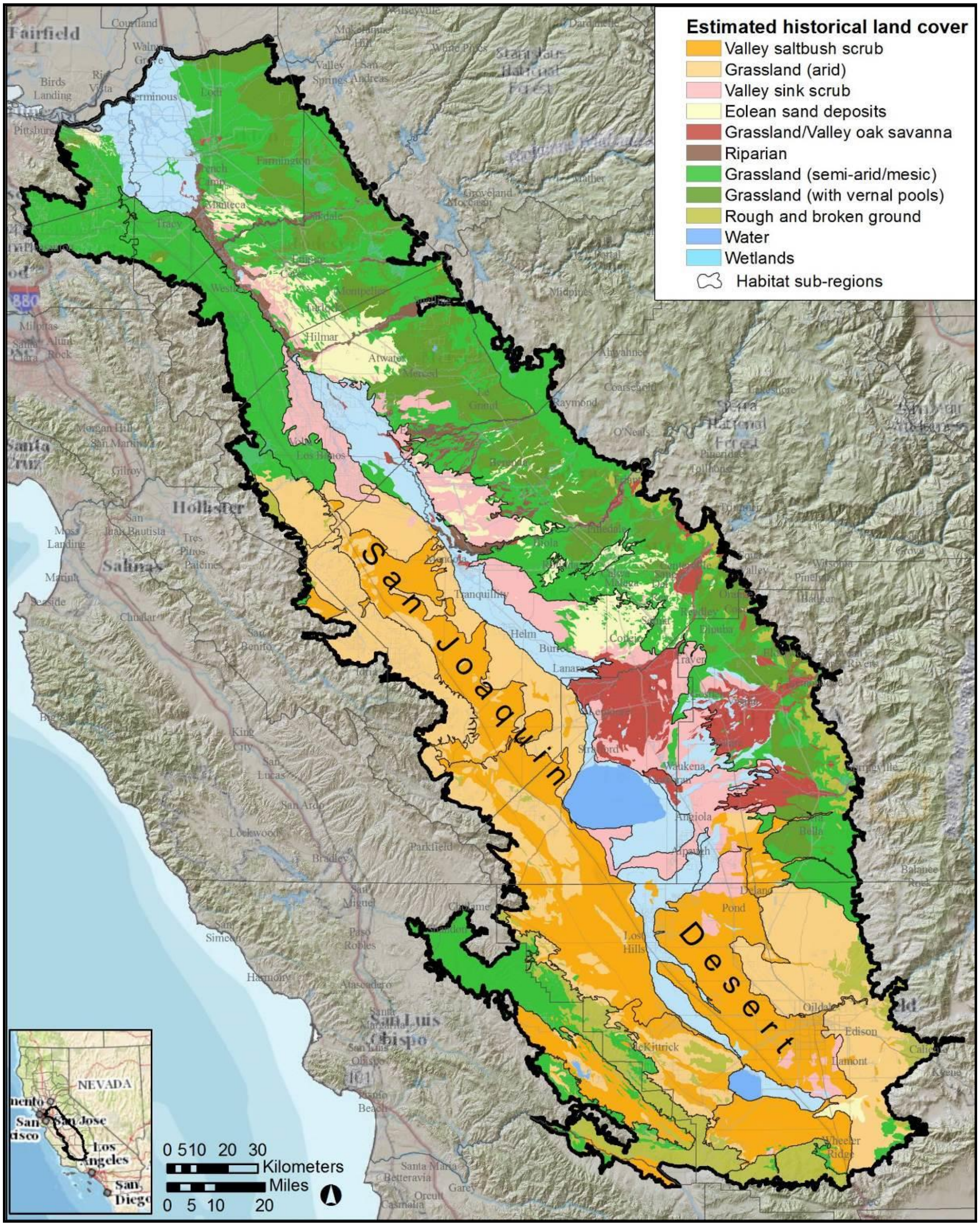

Figure 4. Estimated historical vegetation based on soil surveys within the range of the San Joaquin antelope squirrel in California (Phillips and Cypher 2015).

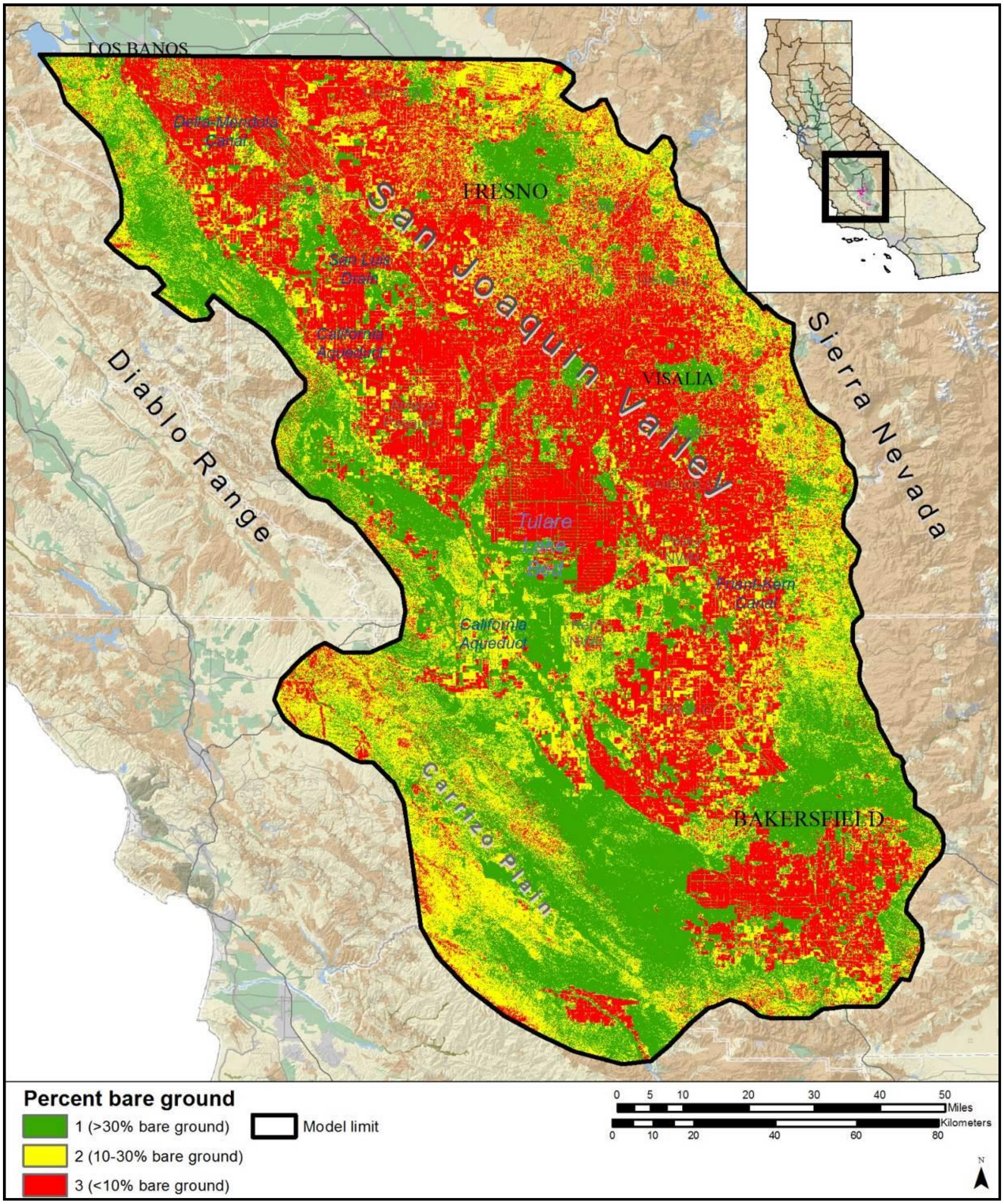

Figure 5. Percent bare ground in three categories (>30%, 10-30%, <10%) within the range of the San Joaquin antelope squirrel in California.

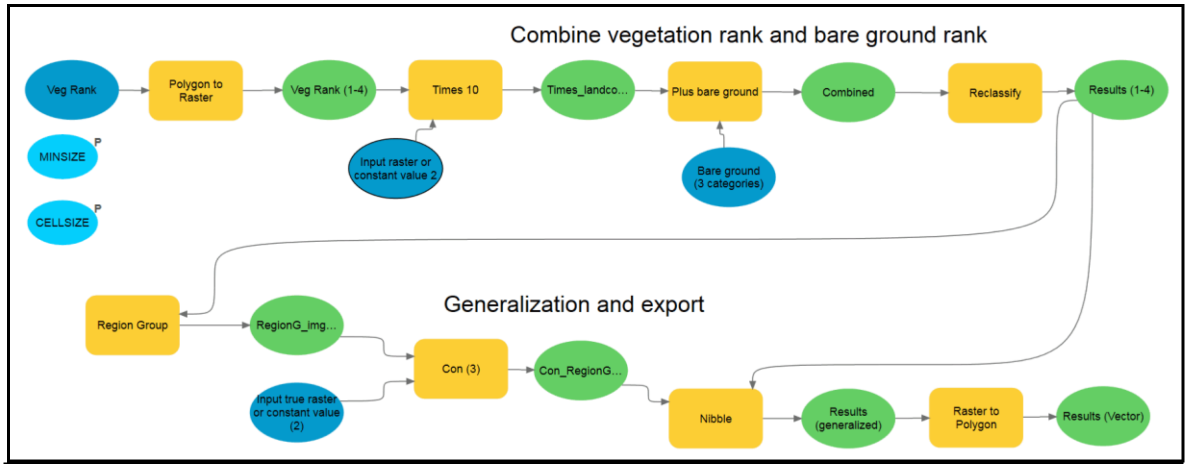

Figure 6. GIS model for combining vegetation and percent bare ground rankings to assess habitat suitability for the San Joaquin antelope squirrel in California.

Table 2. Habitat quality categories for San Joaquin antelope squirrels that combine vegetation rankings with categories of percent bare ground.

Habitat quality	What it includes
1 (highest quality)	11 - Vegetation rank 1, > 30% bare ground
2 (moderately-high quality)	12 - Vegetation rank 1, 10-30% bare ground
	21 - Vegetation rank 2, > 30% bare ground
3 (moderately-low quality)	13 - Vegetation rank 1, < 10% bare ground
	22 - Vegetation rank 1, 10-30% bare ground
4 (low quality)	All other upland vegetation

RESULTS

SURVEYS

We established camera stations at 326 locations to determine if SJAS were present. The surveys were conducted from 13 December 2017 to 28 May 2019. The majority of the locations were in western Kern County and eastern San Luis Obispo County (Figure 7). Additionally, there were a few stations (less than 20) in each of southeastern Tulare County, western Kings County, western Fresno County, and eastern San Benito County. The mean number of days that stations were operational was 9.0 days (SE = 0.16, range = 3-30) with a mode of 8 days. SJAS were detected at 160 locations (Figure 7; Appendix c). Mean latency to first SJAS detection was 2.6 days (SE = 0.17, range = 1-14) with a mode of 1 day.

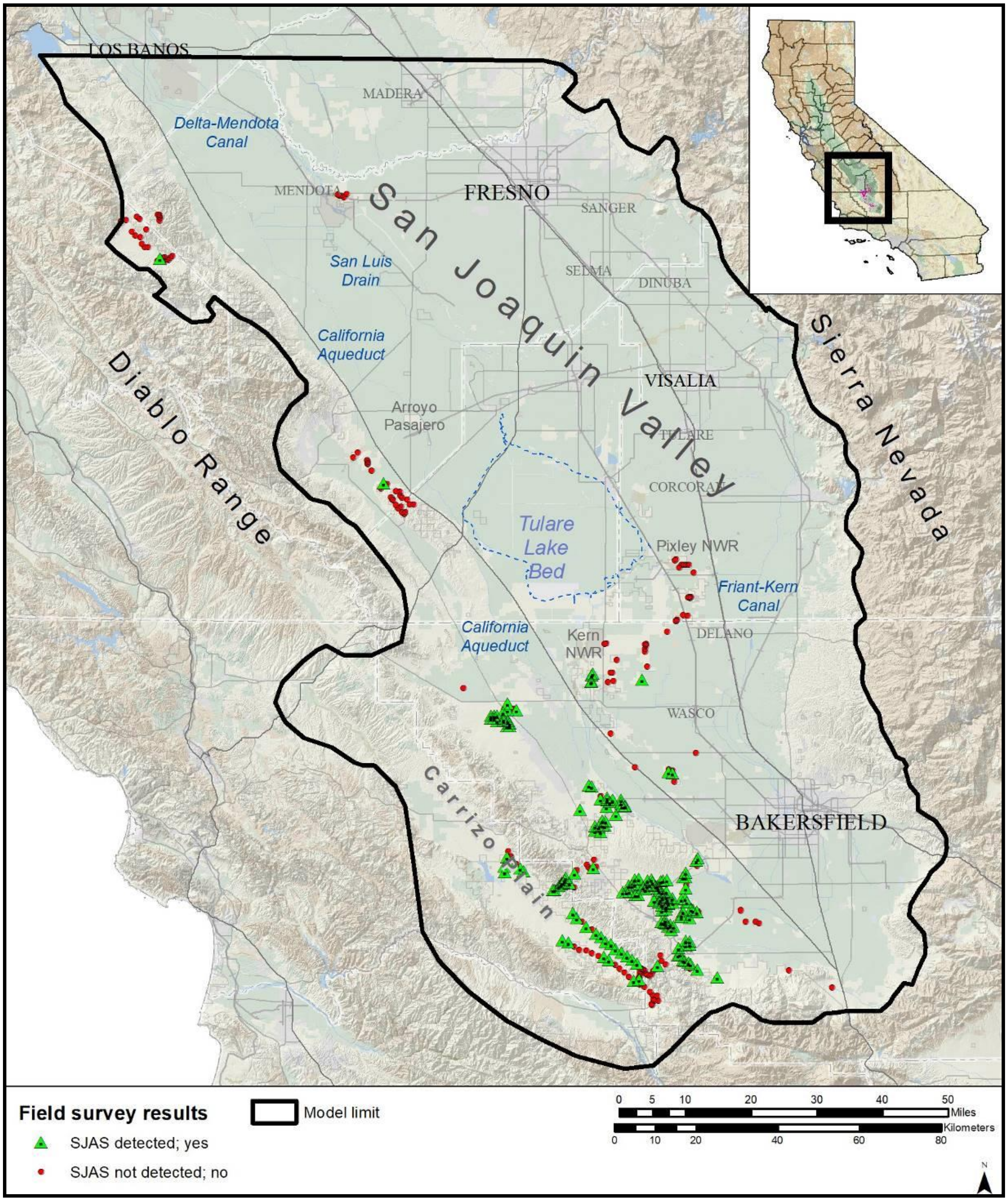

Figure 7. Results from camera stations (n = 319) established to survey for San Joaquin antelope squirrels in the San Joaquin Valley, California.

Due to malfunctions, 12 of the 326 camera stations ran for less than 8 days: 4 ran for 3 days, 1 ran for 4 days, 2 ran for 5 days, and 5 ran for 6 days. However, we included all 12 in our analyses because (1) all of these cameras had SJAS detections except for the 5 that ran for 6 days, (2) as stated previously, the mean and mode latency to first detection were less than 6 days, and (3) the 5 cameras that ran for just 6 days were in an area where other cameras that ran 8 or more days also did not detect SJAS.

SJAS were frequently detected at the stations in San Luis Obispo County and Kern County. Indeed, all of but 2 of the stations detecting SJAS were in these 2 counties with 1 detection being recorded each in southwestern Fresno County and eastern San Benito County.

HABITAT ATTRIBUTES

Habitat attribute data were collected at all locations surveyed for SJAS (Table 3). However, 7 stations were "extra" stations operated opportunistically after analyses were initiated, and data from these 7 were not included in the analyses. SJAS were not associated with shrubs in general or with shrub density, but they were associated with specific species. SJAS presence was strongly associated with small-leaved saltbush which primarily was desert saltbush (*Atriplex polycarpa*), but occasionally included spiny saltbush (*A. spinifera*). When saltbush was present, it usually was the dominant shrub. These species are the dominant shrubs in arid saltbush scrub habitat. SJAS were negatively associated with iodine bush (*Allenrolfea occidentalis*), sinkweek (*Sueada* spp.), and alkali goldenbush (*Isocoma acradenia*). These species are the dominant shrubs in alkali sink habitat.

Areas with SJAS were more likely to have sparse to medium ground cover (>10% bare ground) while areas without SJAS were more likely to have dense ground cover (0-10% bare ground). Arabian grass (*Schismus arabicus*) was present more frequently at locations where SJAS were present compared to locations where SJAS were not detected, and when present at sites where SJAS were detected, it tended to be a dominant species. Arabian grass typically occurs in locations that are more arid with sparse ground cover. Conversely, wild barley (*Hordeum* spp.) was present more frequently at locations where SJAS were not detected compared to locations where SJAS were present. Wild barley grows on sites with a bit more soil moisture and usually forms a dense ground cover. The presence of red brome (*Bromus madritensis* ssp. *rubens*), amsinckia (*Amsinckia* spp.), and red-stemmed filaree (*Erodium cicutarium*) did not vary between sites with and without SJAS. These plants are quite ubiquitous throughout the San Joaquin Valley region.

Topography did not appear to influence the presence of SJAS. Sites with and without SJAS had similar proportions of flat, rolling, gentle slope (≤ 10%), and steep slope (> 10%) terrain. Presence of washes also was similar between sites with and without SJAS. However, alkali scalds were less likely to be present on sites where SJAS were detected. Presence of habitat disturbances (e.g., oil field activities, off-road vehicle use) was similar between sites with and without SJAS. Presence of grazing also was similar, but when grazing was present on sites where SJAS were detected, it was much more likely to be by sheep than by cows.

Finally, kangaroo rats were more likely to be present on sites where SJAS were detected. Also, burrows sufficiently large to permit entry by kangaroo rats and SJAS were more abundant on sites where SJAS were detected. Lastly, California ground squirrels were not present on most of the sites surveyed, but when they were present, SJAS were detected less frequently.

Table 3. Habitat attributes on sites with and without San Joaquin antelope squirrel detections during surveys conducted in the San Joaquin Valley, CA.

Attribute	Sites w/ SJAS (n = 158)	Sites w/o SJAS (n = 161)	Chi-square test and Cramer's coefficient
Shrubs	Present: 114 (72.2%) Absent: 44 (27.8%)	Present: 112 (69.6%) Absent: 49 (30.4%)	$\chi^2 = 0.15$, 1 df, $p = 0.70$ $C = 0.028$, $p = 0.61$
Shrub density	Dense: 27 (17.1%) Medium: 67 (42.4%) Sparse: 64 (40.5%)	Dense: 17 (10.6%) Medium: 62 (38.5%) Sparse: 82 (50.9%)	$\chi^2 = 4.66$, 2 df, $p = 0.10$ $C = 0.121$, $p = 0.10$
Iodine bush	Dominant: 1 (0.6%) Not dominant: 2 (1.3%) Absent: 155 (98.1%)	Dominant: 9 (5.6%) Not dominant: 7 (4.3%) Absent: 145 (90.1%)	$\chi^2 = 9.48$, 2 df, $p < 0.01$ $C = 0.172$, $p < 0.01$
	Present: 3 (1.9%) Absent: 155 (98.1%)	Present: 16 (9.9%) Absent: 145 (90.1%)	$\chi^2 = 7.82$, 1 df, $p < 0.01$ $C = 0.170$, $p < 0.01$
Sinkweed	Dominant: 4 (2.5%) Not dominant: 6 (3.8%) Absent: 148 (93.7%)	Dominant: 10 (6.2%) Not dominant: 14 (8.7%) Absent: 137 (85.1%)	$\chi^2 = 6.17$, 2 df, $p = 0.05$ $C = 0.139$, $p = 0.05$
	Present: 10 (6.3%) Absent: 148 (93.7%)	Present: 24 (14.9%) Absent: 137 (85.1%)	$\chi^2 = 5.29$, 1 df, $p = 0.02$ $C = 0.139$, $p = 0.01$
Saltbush	Dominant: 87 (55.1%) Not dominant: 16 (10.1%) Absent: 55 (34.8%)	Dominant: 44 (27.3%) Not dominant: 11 (6.8%) Absent: 106 (65.8%)	$\chi^2 = 31.17$, 2 df, $p < 0.01$ $C = 0.313$, $p < 0.01$
	Present: 103 (65.2%) Absent: 55 (34.8%)	Present: 55 (34.2%) Absent: 106 (65.8%)	$\chi^2 = 29.48$, 1 df, $p < 0.01$ $C = 0.310$, $p < 0.01$
Goldenbush	Present: 5 (3.2%) Absent: 153 (96.8%)	Present: 21 (13.0%) Absent: 140 (87.0%)	$\chi^2 = 9.12$, 1 df, $p < 0.01$ $C = 0.181$, $p < 0.01$
Ground cover density	Dense: 15 (19.5%) Medium: 77 (48.7%) Sparse: 66 (41.8%)	Dense: 38 (23.6%) Medium: 66 (41.0%) Sparse: 57 (35.4%)	$\chi^2 = 11.46$, 2 df, $p < 0.01$ $C = 0.190$, $p < 0.01$
	Dense: 15 (9.5%) Med-Sparse: 143 (90.5%)	Dense: 38 (23.6%) Med-Sparse: 123 (76.4%)	$\chi^2 = 10.46$, 1 df, $p < 0.01$ $C = 0.190$, $p < 0.01$
Brome	Dominant: 80 (50.6%) Not dominant: 32 (20.3%) Absent: 46 (29.1%)	Dominant: 69 (42.9%) Not dominant: 35 (21.7%) Absent: 57 (35.4%)	$\chi^2 = 2.09$, 2 df, $p = 0.35$ $C = 0.081$, $p = 0.35$
Arabian grass	Dominant: 54 (34.2%) Not dominant: 45 (28.5%) Absent: 59 (37.3%)	Dominant: 10 (6.2%) Not dominant: 28 (17.4%) Absent: 123 (76.4%)	$\chi^2 = 56.69$, 2 df, $p < 0.01$ $C = 0.422$, $p < 0.01$
	Present: 99 (62.7%) Absent: 59 (37.3%)	Present: 38 (23.6%) Absent: 123 (76.4%)	$\chi^2 = 48.06$, 1 df, $p < 0.01$ $C = 0.394$, $p < 0.01$
Wild barley	Present: 9 (5.7%) Absent: 149 (94.38%)	Present: 33 (20.5%) Absent: 128 (79.5%)	$\chi^2 = 15.28$, 1 df, $p < 0.01$ $C = 0.219$, $p < 0.01$
Fiddleneck	Present: 14 (8.9%) Absent: 144 (91.1%)	Present: 23 (14.3%) Absent: 138 (85.7%)	$\chi^2 = 1.79$, 1 df, $p = 0.18$ $C = 0.085$, $p = 0.13$
Red-stemmed filaree	Dominant: 14 (8.9%) Not dominant: 97 (61.4%) Absent: 47 (29.7%)	Dominant: 11 (6.8%) Not dominant: 95 (59.0%) Absent: 55 (34.2%)	$\chi^2 = 0.98$, 2 df, $p = 0.61$ $C = 0.055$, $p = 0.61$
Topography	Flat: 79 (50.0%) Rolling: 34 (21.5%) Gentle slope: 21 (13.3%) Steep slope: 24 (15.2%)	Flat: 78 (48.4%) Rolling: 37 (23.0%) Gentle slope: 21 (13.0%) Steep slope: 25 (15.5%)	$\chi^2 = 0.13$, 3 df, $p = 0.99$ $C = 0.020$, $p = 0.99$
Washes	Present: 29 (18.4%)	Present: 19 (18.8%)	$\chi^2 = 2.19$, 1 df, $p = 0.14$

	Absent: 129 (81.6%)	Absent: 142 (88.2%)	$C = 0.092$, $p = 0.10$
Scalds	Present: 7 (4.4%) Absent: 151 (95.6%)	Present: 38 (23.6%) Absent: 123 (76.4%)	$\chi^2 = 22.63$, 1 df, $p < 0.01$ $C = 0.275$, $p < 0.01$
Disturbance	Present: 97 (61.4%) Absent: 61 (38.6%)	Present: 101 (62.7%) Absent: 60 (37.3%)	$\chi^2 = 0.02$, 1 df, $p = 0.90$ $C = 0.014$, $p = 0.81$
Grazing	Cow: 28 (17.7%) Sheep: 53 (33.5%) No grazing: 77 (48.7%)	Cow: 51 (31.7%) Sheep: 18 (11.2%) No grazing: 92 (57.1%)	$\chi^2 = 25.26$, 2 df, $p < 0.01$ $C = 0.281$, $p < 0.01$
	Grazing: 81 (51.3%) No grazing: 77 (48.7%)	Grazing: 69 (42.9%) No grazing: 92 (57.1%)	$\chi^2 = 1.94$, 1 df, $p = 0.16$ $C = 0.084$, $p = 0.13$
Kangaroo rats	Present: 152 (96.2%) Absent: 6 (3.8%)	Present: 119 (73.9%) Absent: 42 (26.1%)	$\chi^2 = 29.27$, 1 df, $p < 0.01$ $C = 0.312$, $p < 0.01$
Burrow density	High: 62 (39.2%) Medium: 34 (21.6%) Low: 62 (39.2%)	High: 32 (19.9%) Medium: 27 (16.8%) Low: 102 (63.4%)	$\chi^2 = 20.11$, 2 df, $p < 0.01$ $C = 0.251$, $p < 0.01$
	High-Med: 96 (60.8%) Low: 62 (39.2%)	High-Med: 59 (36.6%) Low: 102 (63.4%)	$\chi^2 = 17.61$, 1 df, $p < 0.01$ $C = 0.241$, $p < 0.01$
California ground squirrels	Present: 4 (2.5%) Absent: 154 (97.5%)	Present: 16 (9.9%) Absent: 145 (90.1%)	$\chi^2 = 6.24$, 1 df, $p = 0.01$ $C = 0.153$, $p = 0.01$

HABITAT SUITABILITY MODELING

We identified approximately 5,931 km^2 (2,291 mi^2) of high-, or moderately-high quality habitat for SJAS within the model boundary. We identified an additional 4,753 km^2 (1,835 mi^2) of moderately-low or low-quality habitat (Table 4, Figure 8). When we compared the results from field surveys (Figure 7) with output from the model we found that 58% of sites where SJAS were detected were in the highest quality habitat and 33% were in moderately-high quality habitat (Table 5). The remaining 10% were in moderately-low or low quality habitat (Table 5), and in most cases these locations were in ecotone zones near higher-quality habitat.

Table 4. Results of habitat suitability modeling analysis for San Joaquin antelope squirrel including the amount of area in each category.

Habitat quality	Km^2	Mi^2
1 (highest quality)	1,348	521
2 (moderately-high quality)	4,583	1,770
3 (moderately-low quality)	3,388	1,308
4 (low quality)	1,365	527

Table 5. Results of field surveys for San Joaquin antelope squirrels by habitat quality category.

Habitat quality	*N* Survey sites	Sites with SJAS detected	Sites with no SJAS detected
1 (highest quality)	124	92	32
2 (moderately-high quality)	126	52	74
3 (moderately-low quality)	28	11	17
4 (low quality)	35	4	31
Total	313[1]	159	154

[1] 326 total sites were surveyed, but 1 site was outside of the model boundary and 12 sites were in lands that the model classified as "non-habitat".

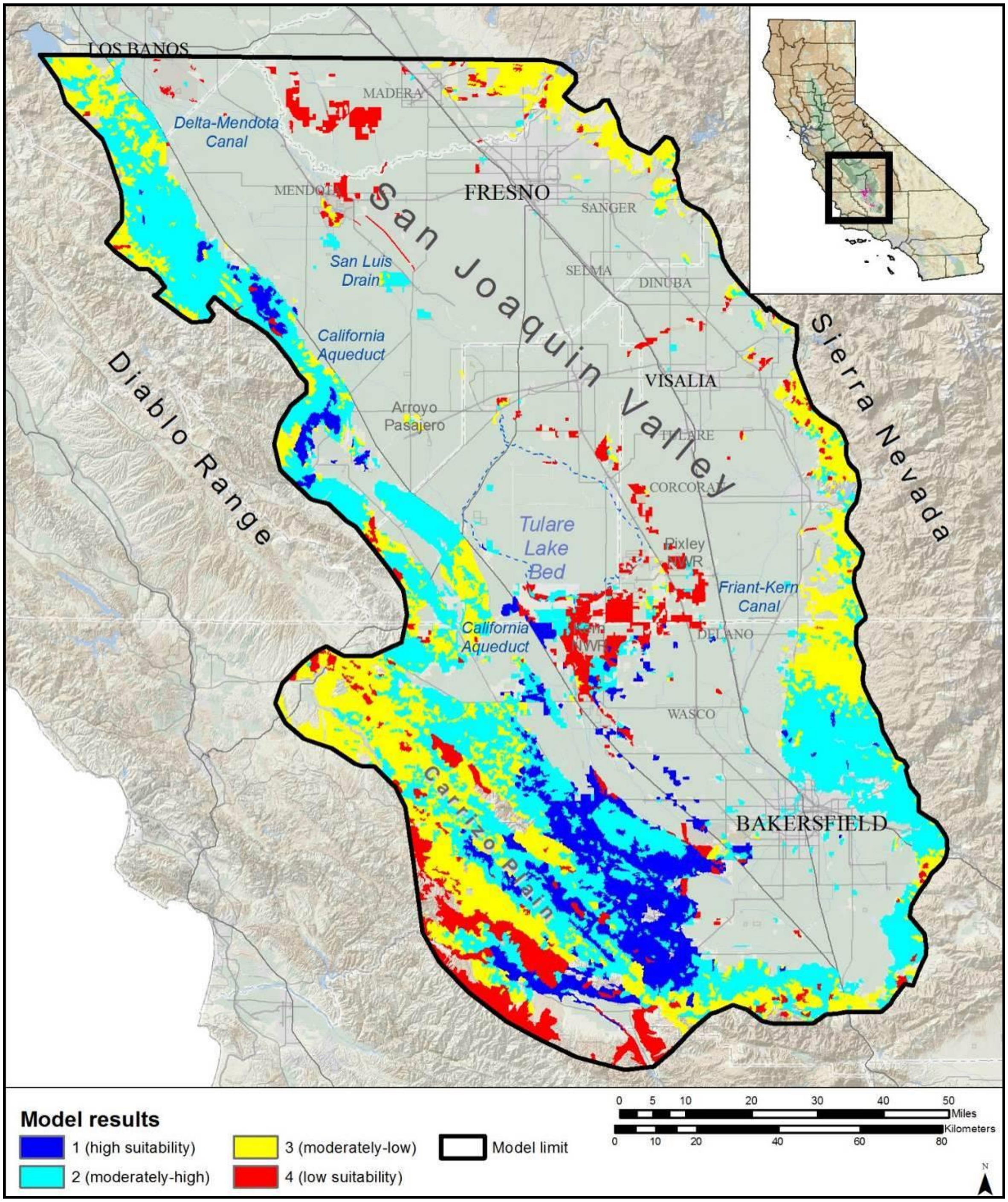

Figure 8. Results of habitat suitability modeling analysis for the San Joaquin antelope squirrel in California.

DISCUSSION

SURVEY TECHNIQUE

Automated camera stations appeared to be an effective technique for detecting SJAS presence in a given area. The stations were easy to install with installation generally requiring approximately 30 min including walking out from a road to a location and setting up the station. We found that about 20 stations could be established in the course of a day, depending upon station spacing. A location was surveyed continuously during the period that the station was operational, which on average was about 9 days. The strategy of deploying multiple cameras in a given general area is prudent as even within suitable habitat, the distribution of SJAS can be "patchy" (Grinnell and Dixon 1918, Hawbecker 1953).

The labor required to survey an area of this size using cameras likely was considerably less than that which would have been required if human observers conducted visual encounter surveys for a similar number of days. Also, human observers can only survey their immediate location whereas the cameras surveyed simultaneously and continuously in all locations in which stations were deployed. Visual encounter surveys conducted from vehicles can cover greater distances, but as with foot surveys, only the immediate area around the vehicle is surveyed at any given time. Also, the continuous camera operation mitigated survey bias or error that might have resulted from daily SJAS activity patterns or variation in climatic conditions among days. For example, SJAS may reduce activity for several hours during mid-day on days when temperatures exceed about 32 C (90^0 F) and for entire days when temperatures fall below about 10 C (50^0 F) (Best et al. 1990).

Live-trapping is another common survey technique for SJAS. However, trapping also is labor intensive as traps have to be set, then are typically checked multiple times per day. Only so many traps can be effectively monitored in one day and biologists typically remain in the field the entire time that traps are open. Also, as with any live-trapping, there always is some degree of risk of injury or death to animals during trapping.

The camera station survey approach does entail an initial investment in cameras, but the cost is generally not prohibitive. Cameras that can operate continuously and reliably for at least a week are readily available and can be purchased for under $150 each. Other costs include posts and attachment materials, batteries, SD cards, and bait block. The posts, SD cards, and possibly some of the attachment materials can be used multiple times. Also, we commonly recovered and reused all or some of the bait block, particularly from stations where SJAS were not detected.

Regarding efficacy, we did determine that the camera stations were imperfect in their detection of SJAS. For example, we expected more detections at stations in the Panoche Valley region (see "Distribution" below) where SJAS are commonly observed. The reason for the low detection rate (only 1 station) in this region is unclear. Also, during the survey we noted any observations of SJAS within approximately 0.5 km of each station. This included observations of SJAS while driving or walking to and from a given station. Of the stations without SJAS detections, SJAS were observed in the vicinity of 16 (approximately 10%). These 16 occurrences potentially represent detection errors. However, at 84 locations, SJAS were detected on a given camera but were not observed while driving or walking to and from a given station. At 74 locations, SJAS were detected both on cameras and while driving or walking in the vicinity of associated stations. Therefore, on the whole, we considered the camera stations to be an effective and cost-effective strategy for detecting SJAS in a given area.

HABITAT ATTRIBUTES

With regard to the habitat attribute data, some caveats are appropriate. As mentioned in the methods, the protocol for assessing habitat attributes at each camera station location was designed such that the information could be collected rapidly, usually within about 15-20 min. Most attributes were characterized as present or absent, or were assigned to one of 3-4 ordinal bins. Thus, the data essentially are “coarse scale” in nature. Also, given that the average home range size for SJAS may be about 10 ha (Harris and Sterns 1991), very detailed measurements immediately around the station might not have adequately characterized the overall conditions in the general area. Another caveat is that the camera station detection data likely included a number of false-negative determinations. As detailed in the results, some cameras (n = 16) failed to detect SJAS even though SJAS were observed in the vicinity of the station. Also, SJAS were detected at some stations but not at other nearby stations with apparently similar habitat conditions. The reasons for these non-detections are unknown but could include a temporarily vacant home range, camera stations unknowingly placed too far from escape cover, or some other habitat attribute that we do not yet recognize as important to SJAS. Also, the distribution of SJAS even within suitable habitat can be “patchy” (Grinnell and Dixon 1918). Consequently, the habitat attributes at any stations with false-negative findings would have been included with all stations without SJAS detections, thereby increasing the difficulty of detecting significant differences between stations with and without SJAS detections.

Despite the caveats above and the associated potentially confounding effects, a number of significant differences were detected between stations with and without SJAS detections. Shrubs were absent on over a quarter of the sites where SJAS were detected, indicating that shrubs are not a required habitat feature for SJAS. SJAS use shrubs for escape cover and thermal regulation in hot weather, but will use burrows for the same purposes when shrubs are not present. Harris and Stearns (1991) found that SJAS densities on the Elkhorn Plain actually were considerably higher in areas without shrubs and that giant kangaroo rat (*D. ingens*) burrows were abundant in these areas.

When shrubs were present, overwhelmingly they were desert saltbush or spiny saltbush. This species is the dominant shrub in the arid scrub communities that occur on the more well-drained sandier soils in the San Joaquin Desert region (USFWS 1998). Conversely, SJAS were infrequently detected in areas with iodine bush, sinkweed, and alkali goldenbush. These are the dominant shrubs in alkali sink communities.

SJAS also were detected more frequently in areas with lower ground cover. Over 90% of detections were in areas with >10% bare ground and over 40% of detections were in areas with >30% bare ground. SJAS are relatively small animals and have difficulty moving through dense vegetation. In particular, they rely on speed to reach cover and elude predators, and predation risk likely increases with herbaceous ground cover density. At both the Lokern Natural Area and the Elk Hills Naval Petroleum Reserve, SJAS abundance increased with decreasing ground cover (Cypher 2001, Germano et al. 2012). Not surprisingly, Arabian grass was a common dominant in locations with SJAS detections. This grass forms a low, sparse cover and prefers more arid sites where it is not outcompeted by species that prefer more mesic conditions, such as wild barley. Wild barley tends to form a dense cover and SJAS were rarely detected at locations where this species was present.

The lower SJAS detection rates in locations with iodine bush, sinkweed, alkali goldenbush, and wild barley along with the lower detection rates in areas with alkali scalds all indicate that alkali sink habitats, where these species and features are commonly found, are not optimal habitats for SJAS. We found that this habitat was typically only used where it was in close proximity to arid upland scrub habitat, or more commonly, locations that were in transition zones between arid upland scrub and alkali sink habitats. Our results are consistent with and further confirm those of previous researchers that also noted the suboptimal nature of alkali sink habitat for SJAS (Grinnell and Dixon 1918, Hawbecker 1953, Harris and Stearns 1991). Areas with alkali sink communities tend to occur in more low lying areas of the San Joaquin Valley with heavy clay soils where burrowing may be more difficult, the water table commonly is just a few centimeters below the surface, soils are saturated during the winter rainy season, and periodic flooding occurs. Consequently, SJAS were only detected on the valley floor in 2 locations (Semitropic Ridge area and Buttonwillow Ecological Reserve), both of which have habitat transitional between alkali sink and arid upland scrub habitat growing on slightly higher areas.

Topographic ruggedness and slope did not appear to influence SJAS presence. However, the locations where we established camera stations did not have slopes exceeding 30%, and it is possible that locations with steeper slopes may be less suitable for SJAS (USFWS 1998). Harris and Stearns (1991) found SJAS on slopes of up to 20 degrees. Also, topography may influence SJAS in other ways. In particular, vegetation characteristics can vary with elevation and aspect with ground cover being denser at higher elevations and on more northerly facing slopes (Cypher 2001).

Presence of SJAS did not appear to be affected by nearby habitat disturbances. These disturbances consisted primarily of features related to oil and gas production, such as pipelines and well pads. However, in the areas where we established camera stations, these features typically affected less than 10% of the habitat and an abundance of intact habitat remained available. In a study of oil field effects on vertebrate communities in the southwestern San Joaquin Valley (Fiehler et al. 2017), SJAS continued to be present on plots with about a third of the habitat disturbed by oil field features (e.g., roads, well pads, pipelines, storage tanks, and other facilities).

Presence of SJAS also did not appear to be affected by grazing. When grazing was occurring on sites where SJAS were detected, the grazers usually were sheep. However, this may have been due to a sampling bias. Cows typically are not pastured on more arid lands, which are preferred by SJAS, due to sparser forage and shorter grazing seasons. Also, to some extent, we avoided areas where cows were grazing as these animals, out of curiosity, commonly investigate and disturb camera stations, sometimes to the point of destroying them. However, SJAS were observed to be abundant and were detected on 16 out of 20 camera stations established on a site near Blackwell’s Corner in northern Kern County that was being grazed by cows. Harris and Stearns (1991) also observed SJAS in areas that were heavily grazed by cows.

The association between SJAS presence and kangaroo rat presence was not surprising. Kangaroo rats also are arid-adapted rodents that prefer areas with sparser ground cover (Goldengay et al. 1997, Cypher 2001, Germano et al. 2012). Thus, kangaroo rats and SJAS share similar habitat preferences. Furthermore, SJAS may benefit from the presence of kangaroo rats. Although SJAS can create their own burrows (Grinnell and Dixon 1918), Hawbecker (1947, 1953) reported that SJAS mostly use burrows created by kangaroo rats. Hawbecker (1953) expressed that the presence of SJAS was likely strongly influenced by the presence of kangaroo rats, particularly Heermann's kangaroo rats (*D. heermanni*) and giant kangaroo rats. These are larger kangaroo rats and SJAS can fit into their burrows with little or no modification (Hawbecker 1947). Harris and Stearns (1991) also reported an association in occurrence between SJAS and giant kangaroo rats. Consistent with these observations, we found that burrow abundance was typically higher in areas where SJAS were detected, and most of these were kangaroo rat burrows.

The negative association between SJAS and California ground squirrels also was not surprising as this relationship has been noted previously (Taylor 1916, Best et al. 1990, Harris and Stearns 1991). The nature of this negative association is not well understood. The two species may be spatially segregated by differential habitat preferences with SJAS preferring more arid areas with sparser vegetation and California ground squirrels preferring more mesic areas with denser vegetation. Indeed, California ground squirrels have a much wider distribution and are found in dense grasslands, chaparral, oak woodland savannahs, and even montane meadows (Jameson and Peeters 1988). Anthropogenic modification of natural habitats in the San Joaquin Valley may have increased the abundance and distribution of California ground squirrels as they are abundant in agricultural areas, urban areas, and even highly disturbed oil field areas (Fiehler et al. 2017). This may have brought this species into closer proximity to SJAS. In areas where the two species co-occur, California ground squirrels may locally displace SJAS. Harris and Stearns (1991) observed California ground squirrels simply moving into SJAS burrow complexes and the resident SJAS moving to other nearby burrows. No aggression was observed. Similarly, we observed both species feeding together on the bait block at one of our stations. California ground squirrels are larger than SJAS and likely can displace SJAS through interference or exploitative competition, or a combination of the two.

SUITABILITY MODELING

In developing our habitat suitability model, we attempted to use the best available information on SJAS occurrence and preferred habitat attributes based on information from our surveys. However, we caution that as with any suitability model, the results do not guarantee that SJAS are present or absent at any given location. Instead, modeling results should be viewed as an estimate of the potential for SJAS to occur on given lands; higher suitability rankings indicate a higher probability of SJAS occurrence. Surveys to determine the presence of SJAS or at least to assess habitat conditions should be conducted on any parcel prior to initiating conservation (e.g., acquisition) or habitat-disturbing activities.

Williams (1981) estimated that the historic range of the SJAS encompassed approximately 1,398,600 ha (3,456,000 ac), and that by 1979 just 274,200 ha (680,000 ac) remained, of which only 41,300 ha (102,000 ac) was fair to good quality habitat. These estimates were for the San Joaquin Valley proper. Our habitat suitability modeling effort indicated that approximately 593,100 ha (1,465,582 ac) of high or moderately-high quality habitat apparently is still present within the historic range of SJAS, which includes the San Joaquin Valley, Carrizo Plain region, and Cuyama Valley. An almost equal quantity (475,300 ha or 1,174,492) of low and moderately-low quality habitat also is available. Possibly, some of this lower quality habitat might be enhanced to improved suitability for SJAS.

The largest quantities of remaining high and moderately-high quality habitat are located in western Kern County and eastern San Luis Obispo County. Considerable high and moderately-high quality habitat also occurs in a band along the western edge of the San Joaquin Valley from the Kern County line up into western Merced County. Significant areas of high quality habitat occur in the Coalinga area and also on the eastern toe of the Coast Ranges south of the Panoche region. Also, as mentioned previously, a large area of mostly moderately-high quality habitat occurs along the southeastern margin of the San Joaquin Valley from about Poso Creek just north of Bakersfield down to about Pastoria Creek in the very southeastern corner of the valley on Tejon Ranch lands. A number of small fragments of high quality habitat occur on the valley floor, primarily toward the drier west side. Many of these fragments may be too small to support a self-sustaining population of SJAS. Indeed, over half of these fragments “disappeared” when the model was “generalized” to eliminate patches less than 40 ha (100 ac), thus providing a more accurate estimate of available habitat (see Appendix B for non-generalized model results).

DISTRIBUTION

The historic range of the SJAS is described as extending from western Merced County down the western side of the San Joaquin Valley, across the southern valley in Kern County, up the eastern side to southern Tulare County, and in the Carrizo Plain and Cuyama Valley (Williams 1981, USFWS 1998). Within this range, Grinnell and Dixon (1918) described the distribution of the species as “patchy”, even where habitat conditions appeared favorable. Harris and Stearns (1991) reported that the current range was still similar in extent to the historic range, but that less of the range was occupied due to habitat loss. Williams (1981) concluded that SJAS had mostly been extirpated on the floor of the San Joaquin Valley. The Carrizo Plain and Elkhorn Plain in eastern San Luis Obispo County and the Elk Hills-Lokern area in western Kern County were considered strongholds for remaining SJAS populations (Grinnell and Dixon 1918, Harris and Stearns 1991).

During our survey effort, SJAS were commonly detected at the stations in the Carrizo Plain region. The Carrizo Plain, particularly the southern portion including the Elkhorn Plain, is recognized as a “core area” for imperiled arid upland species, including SJAS, that are endemic to the San Joaquin Desert region (USFWS 1998). SJAS were particularly prevalent along the Elkhorn Plain and also on the north-central portion of the Carrizo. SJAS were present but detected less frequently along Soda Lake Road in the southeastern portion of the Carrizo. The Elkhorn Plain and northcentral portions of the Carrizo are a bit elevated topographically with more well-drained soils compared to the Soda Lake Road portion, much of which is closer to the valley floor of the Carrizo with heavier soils (U.S. Bureau of land Management 2010).

The Temblor Range roughly follow the boundary between San Luis Obispo County and Kern County. We ran transects of cameras over this range along Crocker Grade Road and Elkhorn Grade Road, primarily in an effort to determine the effect of rugged topography on SJAS. We obtained few detections of SJAS along the Elkhorn Grade transect, but SJAS were detected at most of the camera stations on the Crocker Grade transect. Thus, rugged steep terrain did not appear to be a limiting factor for SJAS. More limiting was the denser vegetation, particularly non-native grasses, that was present on north facing slopes.

In western Kern County, SJAS were detected at most of the stations established in the Midway Valley, Buena Vista Valley, Buena Vista Hills (all of these in the Elk Hills region), Lokern area, and Blackwells Corner area. All of these areas are within a second core area identified in the recovery plan for imperiled arid upland species (USFWS 1998).

SJAS were detected at one site in the very southern San Joaquin Valley. They were not detected in four sites on BLM parcels on the valley floor that supported alkali sink communities. Four other sites were in saltbush scrub communities on the Wind Wolves Preserve and SJAS were detected at the western most site on the Preserve. SJAS were detected in the past near this location (Cypher et al. 2011). The two sites on the eastern side of the Wind Wolves Preserve appear to have appropriate habitat conditions for SJAS but are no longer connected to areas occupied by SJAS. Some past events (e.g., rodenticide use, flooding) could have caused the extirpation of SJAS in these areas, and the lack of connectivity to occupied habitat may have prevented recolonization.

Surveys were conducted at 26 sites in the Kettleman Hills on the west side of the San Joaquin Valley at the border between Fresno County and Kings County. These sites were characterized by moderate to dense ground cover of primarily non-native grasses. SJAS were only detected at one of these sites, although interestingly the site with the detection was in the middle of the cluster of 26 sites. Apparently, a small population of SJAS persists in the vicinity of this survey location.

Camera stations were established throughout the Panoche Valley region. This area is recognized as a third core area for listed species in the San Joaquin Valley upland species recovery plan (USFWS 1998). SJAS were only detected at 1 station out of 25 in this region. The location was on the Silver Creek Ranch in what is now the Panoche Valley Preserve managed by the Center for Natural Lands Management. This was surprising as we have observed SJAS at the southern and northern ends of the valley, and to a lesser extent along the east side of the valley and up into the Panoche Hills. Similar to our results, Harris and Stearns (1991) only detected SJAS in the Silver Creek Ranch area.

Out on the San Joaquin Valley floor, five camera stations were established at the Alkali Sink Ecological Reserve just east of Mendota. Alkali sink habitat dominates in this area and no SJAS were detected. However, Hawbecker (1947) reported finding SJAS near Los Banos and Mendota in non-native grassland areas devoid of shrubs. Thus, SJAS used to be present in this region.

Survey results were interesting in the area in the vicinity of Kern National Wildlife Refuge in northern Kern County. SJAS only were detected on an approximately 4-km long “sand ridge”, called Semitropic Ridge, south of the refuge. This ridge is a relictual dune complex that is 1-3 m higher than the surrounding land and has sandier soil and supports a saltbush scrub vegetation community. One exception was the detection of a SJAS on an approximately 260-ha (640-ac) parcel with high suitability habitat located 10 km southeast of the refuge. Otherwise, no SJAS were detected at the numerous other survey sites to the east and northeast all the way up to Pixley National Wildlife Refuge. These sites are in lower lying areas that primarily support intact or degraded alkali sink vegetation communities and also are more prone to occasional flooding. However, SJAS historically were detected in areas with saltbush habitat at the Allensworth Ecological Reserve, and thus, used to be present in this region.

Similarly, SJAS were detected at 2 of 7 stations on Buttonwillow Ecological Reserve in Kern County. Similar to the area described above by Kern National Wildlife Refuge, this area is ecotonal between alkali sink and saltbush scrub communities, but saltbush was the dominant shrub at most of the survey sites, including the 2 where SJAS were detected. SJAS were not detected at any other sites on the valley floor.

Some areas where SJAS potentially are present were not surveyed during this project, primarily due to lack of access (i.e., private lands) or depleted resources for additional surveys. Two CNDDB records of SJAS are located down in the very southern end of the San Joaquin Valley in the Grapevine area on the east side of present-day Interstate 5 (Figure 1). This area is all under private ownership and was not accessible. Most of the remaining habitat in that area was categorized as moderately-low suitability in our model. Some environmental consultants have had access to this area in recent years but have not reported any observations of SJAS. Also, California ground squirrels are abundant in this area. Thus, the prospects are low that SJAS are still present in this area.

Another CNDDB record is located in the Cuyama Valley in southeastern San Luis Obispo County. Most of the saltbush scrub habitat in this valley has been converted to agricultural uses leaving small fragments. However, it is possible that SJAS persist on the north fringe of the valley at that base of the Caliente Range where our model indicated the presence of a thin strip of highly suitable habitat. We did not have an opportunity to survey this region. However, Harris and Stearns (1991) did conduct surveys in this region in 1988 and commonly detected SJAS on the north side of the Cuyama River along the base of the Caliente Range. Our model indicated that a band of high quality habitat is present in this area, which increases the potential that a population of SJAS may still be present in the Cuyama Valley.

North of Kern County, a mostly continuous band of good quality habitat extends north along the western margin of the San Joaquin Valley. Other than in the Panoche Valley region, most of this habitat is on private land where obtaining access is challenging. Based on our model, a large area with highly suitable habitat is present just southeast of Panoche Valley between the Coast Ranges and the California Aqueduct. A number of occurrence records in CNDDB are from this area (Figure 1). Our model also indicated that another large area with suitable habitat is present west and north of the city of Coalinga. Large portions of this area consist of oil fields that may have a remote sensing signature, particularly with regards to bare ground and low vegetation density, consistent with good habitat quality. No SJAS occurrences from this region are included in the CNDDB, and no recent SJAS observations have been reported from this area despite the frequent presence of biologists conducting surveys for rare species (K. Twist, Chevron, personal communication). However, there are CNDDB records of SJAS at the Pleasant Valley Ecological Reserve located east of Coalinga. We ran camera stations there but did not detect SJAS.

The band of suitable habitat along the west side of the valley continues up into western Merced County. Most of this is again private land and restricted access precluded surveys. Harris and Stearns (1991) described SJAS distribution in the northern part of their range as being “spotty”.

Of note, two CNDDB records are located west of the Panoche Valley outside of the area we modeled. The records are along the current-day Panoche Road. Due to the proximity to the SJAS population in the Panoche Valley region, SJAS could extend into this area, if not permanently then possibly intermittently. Similarly, the same may apply to the much of the western edge of SJAS distribution. This edge corresponds to the eastern-most Coast Ranges, and SJAS could extend into these ranges along “fingers” of suitable habitat.

Another CNDDB record is located just east of Paso Robles in north-central San Luis Obispo County. However, this record was clearly plotted incorrectly. The description for the location is “35 mi SE of Simmler on Soda Lake Road”, which would put the actual location in the southern Carrizo Plain, where SJAS are common.

Another very interesting record is from a location northeast of Bakersfield near current-day Hart Park. At this location, 35 individual SJAS were reportedly collected in 1911 and deposited in the Museum of Vertebrate Zoology at the University of California at Berkeley. No extant populations of SJAS are currently known from the eastern side of the San Joaquin Valley. Most of the saltbush scrub habitat along the east side of the valley has been destroyed. Much of the remaining habitat may not be suitable for SJAS. North of Poso Creek, which is just north of Bakersfield, the ground cover probably is too dense and California ground squirrels are extremely abundant, and these conditions likely exclude SJAS. South of Poso Creek along the southeastern fringe of the San Joaquin Valley, from the Kern River oilfield area down to the Grapevine and Wind Wolves Preserve area, there are patches of saltbush scrub habitat, some quite sizeable, that appear suitable for SJAS. SJAS were present at one time in this area. Grinnell and Dixon (1918) reported seeing SJAS “in grain fields at the base of the Tehachapi Mountains.” SJAS were extirpated for one reason or another, and the isolation of the remaining habitat patches and lack of connectivity to occupied areas may have precluded recolonization by SJAS. We did not conduct surveys along this southeastern margin of the San Joaquin Valley primarily because biologists have had access to much of this area in recent years and there have been no reports of SJAS sightings.

CONCLUSIONS

Our surveys for SJAS were far from exhaustive. We had limited resources to survey a relatively large area, and also we were not able to access many private lands where SJAS may be present. However, based on our survey results as well as opportunistic observations in the past 2 years, SJAS are generally still relatively wide-spread. They are present throughout the Carrizo Plain region and along the western margin of the San Joaquin Valley from the very southwestern corner of the valley up to about the Merced County line. They are locally abundant in the Carrizo Plain region, western Kern County, and Panoche Valley region. These 3 regions were identified in the recovery plan (USFWS 1998) as core areas for rare arid upland species, including SJAS. Additional robust populations potentially occur in other locations, particularly in high suitability habitat that appears to be present (based on our modeling) in areas that we were not able to survey along the western margin of the San Joaquin Valley and northern margin of the Cuyama Valley.

SJAS are present at only a few locations on the floor of the San Joaquin Valley. This is primarily because so little natural habitat remains on the valley floor and most of this remaining habitat is alkali sink, which is of suboptimal suitability for SJAS. Two notable exceptions are the Semitropic Ridge area south of Kern National Wildlife Refuge and the Buttonwillow Ecological Reserve, both in Kern County. The SJAS populations are relatively small and restricted in distribution at these locations, and there is poor connectivity to areas with robust SJAS populations. Thus, SJAS at these two sites are at heightened risk of extirpation from catastrophic or stochastic events, and if extirpation were to occur, prospects for natural recolonization are poor.

Fortunately, large portions of all of the areas mentioned above that are known to have extant populations of SJAS are protected from habitat conversion in some manner. Much of the Carrizo Plain is within a national monument or conservation lands managed by CDFW, Sequoia Riverlands Trust, or other entities. Large portions of western Kern County also are in preserves or other conserved land managed by a number of entities, or are public lands with restrictions on development. A very large portion of the Panoche Valley region also is protected in preserves managed by the Center for Natural Lands Management and CDFW, or are public lands with development restrictions. The Buttonwillow Ecological Reserve is managed by CDFW, and much of the Semitropic Ridge SJAS population is on preserve lands managed by CDFW and the Center for Natural Lands Management. The prospects for persistence are enhanced for SJAS populations on conserved lands.

Our analysis of habitat attributes on sites with SJAS detections was informative. The analysis revealed that SJAS primarily occur in locations with arid upland shrub scrub communities, typically with saltbush or jointfir as the dominant shrubs and with sparse ground cover. This confirms similar findings from previous surveys (e.g., Grinnell and Dixon 1918, Hawbecker 1975, Harris and Stearns 1991). Also consistent with these earlier findings, alkali sink habitat appears to constitute suboptimal habitat for SJAS and is rarely used unless it is located in close proximity to and is ecotonal with arid upland shrub scrub communities. On the floor of the San Joaquin Valley, alkali sink communities were historically prevalent in areas not covered by the extensive lakes, sloughs, wetlands, and riparian forests that existed there prior to European settlement (Kelly et al. 2005). Thus, suitable habitat for SJAS may not have been abundant on the floor historically. Much of the remaining natural habitat on the valley floor consists of alkali sink communities, and consequently few SJAS populations occur there.

SJAS currently persist in a metapopulation structure consisting of populations of varying size and connectivity. Based on habitat suitability modeling, considerable connectivity appears to be present along the western margin of the San Joaquin Valley and with the Carrizo Plain and Cuyama Valley regions. A few populations of SJAS are present on the floor of the San Joaquin Valley and these are probably the most vulnerable due to relatively small size and lack of connectivity to larger populations. For all SJAS populations but particularly those on the valley floor, goals for SJAS conservation should include conserving as much of the remaining unprotected higher quality habitat as possible, expanding buffers around occupied habitat, and increasing connectivity between habitat patches to facilitate genetic and demographic flow, all of which will help maintain more optimal metapopulation dynamics and reduce extinction risk. This is particularly important due to the marked environmental fluctuations in this region attributable to annual precipitation patterns, which increases the potential for local extirpation of SJAS from patches thus necessitating recolonization via linkages between patches. Assisted dispersal and reintroduction also should be considered as proactive conservation strategies to maintain or increase the number of SJAS populations.

RECOMMENDATIONS

Based on the results of this project, the following recommendations are offered for SJAS conservation.

1. ADDITIONAL SURVEYS ON UNSURVEYED LANDS WHEN POSSIBLE

Many areas with potential SJAS habitat have not been surveyed because they consist of private land where access is limited or prohibited. If any such lands become accessible in the future, then SJAS surveys should be conducted to identify additional populations. Particular areas of interest include those with high quality habitat, based on our model, on private lands from Coalinga up to the Panoche region.

2. HABITAT PROTECTION

Lands that appear to have high suitability habitat for SJAS based on modeling should be targeted for protection if they are not already conserved. Lands with lower quality habitat also may be valuable if they provide connectivity between patches with high quality habitat.

3. HABITAT MANAGEMENT

Lands where habitat quality is lower due to dense ground cover, particularly from non-native grasses, potentially could be managed to improve suitability for SJAS. Grazing with livestock likely would be the most efficient and cost-effective management strategy.

4. FURTHER TRANSLOCATION RESEARCH

No large-scale translocations of SJAS have been attempted. Most efforts to date have entailed moving SJAS a short distance (e.g., up to 0.5 km) and releasing them. In many cases, the animals returned to the original capture site within a day or two. Vacant habitat could become available due to extirpations, acquisition and change of management (e.g., rodenticide use) on otherwise suitable lands, or acquisition and restoration of degraded habitat or agricultural lands. Thus, research should be conducted on effective strategies for translocating SJAS and establishing new populations.

5. TRANSLOCATIONS TO SUITABLE, UNOCCUPIED HABITAT

SJAS should be translocated to protected lands with suitable habitat conditions in order to establish additional populations. Source animals could come from salvage efforts on occupied sites where habitat destruction has been authorized, or from larger and more robust populations such as those in western Kern County and the Carrizo Plain. Some potential reintroduction sites that appear to have suitable habitat but no evidence of SJAS presence include valley floor lands in the Wind Wolves Preserve (particularly the Pleito Creek and Salt Creek outlet areas), Comanche Point area on Tejon Ranch, and the “Kern Front” oilfield area north of Bakersfield. Additional areas where reintroductions might be considered include Pixley National Wildlife Refuge and the Allensworth Ecological Reserve, but only if these sites are appropriately managed to reduce dense ground cover conditions and flooding concerns associated with Deer Creek and the White River are addressed.

6. HABITAT RESTORATION

Habitat loss is still occurring within the range of SJAS. Restoration of previously disturbed lands could contribute to SJAS conservation. Strategies for restoring arid shrub scrub habitat have not been perfected. Efforts should be made to develop and test restoration strategies. This could benefit SJAS as well as co-occurring species, many of which also are rare.

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Appendix A. Form used to assess habitat attributes on sites surveyed for San Joaquin antelope squirrels.

San Joaquin Antelope Squirrel Survey Project
Habitat Attributes Assessment

Site number: ____________________________

Camera ID: ________________

Date set: _______________________________

SD card ID: ________________

Date collected: ___________________________

Camera Coor: _______________
____

Site pictures: **Y** **N**

Settings info: _______________

Bait used: ___________________

Shrubs

Present: Yes No

Density: (if present)

________ Sparse (generally couldn't hit the next one with a rock)

________ Medium (generally could easily hit the next one with a rock)

________ Dense (commonly have to alter course to get around shrubs)

Species (check if more than just 1 or 2 are present on site; put a "D" by the dominants):

______ small-leaved Atriplex (desert or spiny saltbush)
______ large-leaved Atriplex (valley saltbush, quailbush)
______ bladderpod
______ Ephedra (Mormon tea, jointfir)
______ Suaeda (sinkweed, seepweed)
______ Allenrolfea (iodine bush)
______ Isocoma (alkali goldenbush)
______ Salsola (tumbleweed, Russian thistle)
______ Bassia (4-hook bassia)
______ tamarisk
______ Other ____________________________(***or collect a sample***)

Ground cover

Density:

________ Sparse (>30% bare ground)
________ Medium (10-30% bare ground)
________ Dense (<10% bare ground)

Alkali scalds present: **Yes** **No**

Species (check all that appear abundant on the site):

______ red brome
______ salt grass
______ Arabian grass
______ Amsinkia
______ filaree
______ alkali heath
______ tarweed
______ doveweed
______ mustard

______ wild oats (Avena)
______ wild barley (Hordeum)
______ other grass
______ other
______ other
______ other

Topography

______ Generally flat
______ Gently rolling
______ Gentle slopes (< 10%)
______ Steep slopes (> 10%)
_______Wash w/i 100 m

Anthropogenic disturbances

Anthropogenic (check all that apply):

______ well pads
______ pipelines
______ solar or other infrastructure
______ canals
______ previous earth moving
______ grazing (circle one: cow, sheep, horse, goat, other)
______ off-road vehicles
______ trash dumping
______ shooting
______ previous tilling
______ bee hives
______ other ____

Other factors

______ California ground squirrels present
______ Giant kangaroo rats present
______ Other krats present.

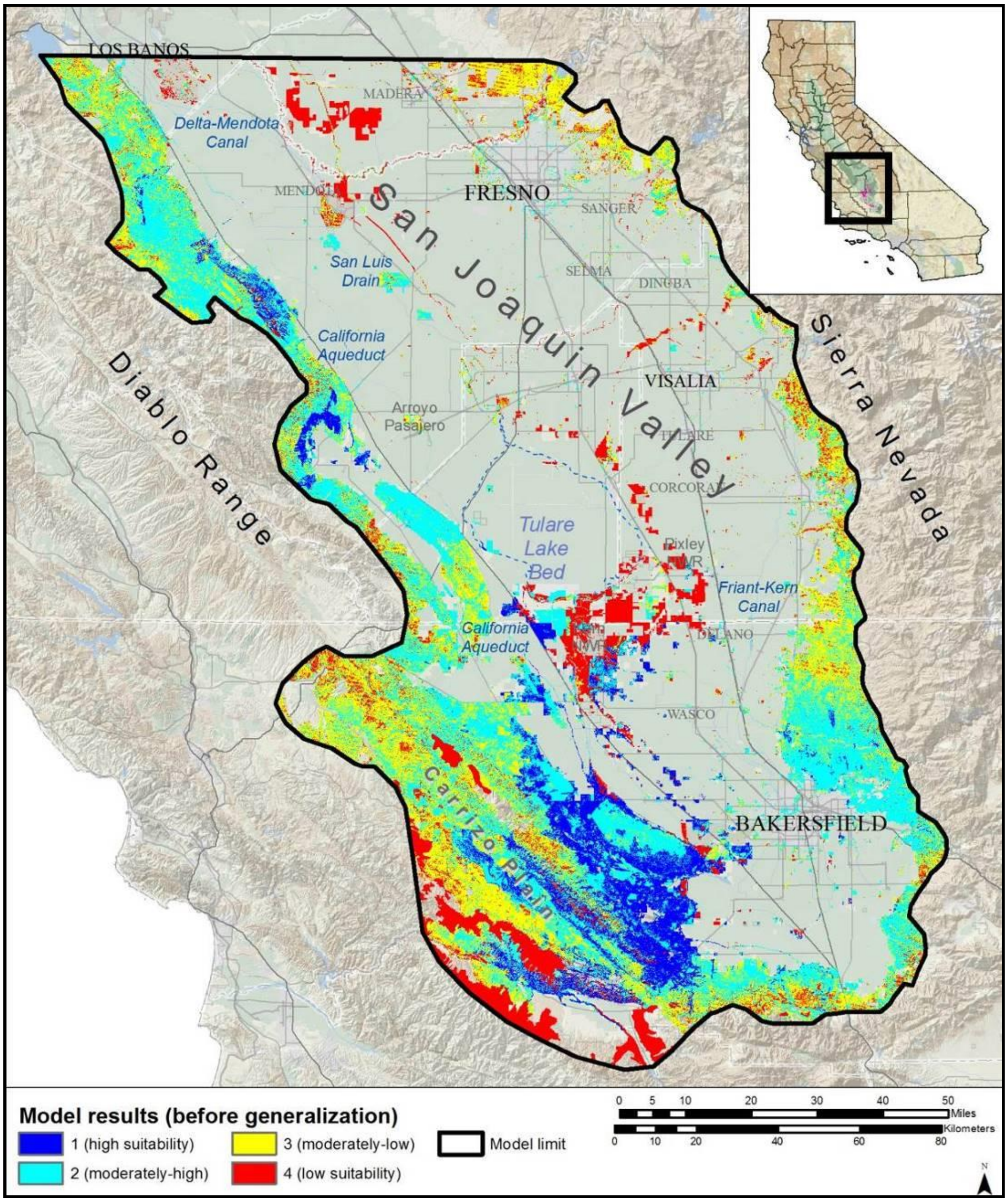
Burrow abundance (openings >= 5 cm):
______ Low (from any given point, can see on average 0-2 burrows)
______ Medium (from a given point, can see on average 3-5 burrows)
______ High (from a given point, can see on average 6+ burrows)

No. scats collected: _______

SJAS observed in vicinity: Y N

Notes:

APPENDIX B. RAW OUTPUT OF SAN JOAQUIN ANTELOPE SQUIRREL HABITAT SUITABILITY MODEL PRIOR TO GENERALIZATION.



Habitat quality	Km²	Mi²
1 (highest quality)	1,236	477
2 (moderately-high quality)	4,593	1,774
3 (moderately-low quality)	3,527	1,362
4 (low quality)	1,892	730

APPENDIX C. LOCATION COORDINATES AND DATES FOR SURVEY SITES WHERE SAN JOAQUIN ANTELOPE SQUIRRELS WERE DETECTED.

Site_number	Date_collected	Latitude	Longitude
SJAS 006	4/3/2018	35.136964	-119.350993
SJAS 007	4/3/2018	35.150259	-119.331406
SJAS 009	4/3/2018	35.156319	-119.346488
SJAS 010	4/3/2018	35.15328	-119.342134
SJAS 011	4/3/2018	35.138781	-119.374187
SJAS 012	4/3/2018	35.144246	-119.374167
SJAS 013	4/3/2018	35.151252	-119.369052
SJAS 014	4/18/2018	35.057263	-119.378435
SJAS 015	4/18/2018	35.055005	-119.383487
SJAS 016	4/18/2018	35.071335	-119.381867
SJAS 017	4/18/2018	35.07706	-119.361991
SJAS 018	4/18/2018	35.078285	-119.351252
SJAS 019	4/18/2018	35.08562	-119.351572
SJAS 020	4/18/2018	35.086597	-119.362736
SJAS 021	4/18/2018	35.043733	-119.369994
SJAS 022	4/18/2018	35.042779	-119.365598
SJAS 024	4/18/2018	35.03919	-119.354474
SJAS 025	4/18/2018	35.03571	-119.350012
SJAS 027	4/18/2018	35.023264	-119.332207
SJAS 028	4/18/2018	35.111033	-119.400268
SJAS 029	4/18/2018	35.118232	-119.394793
SJAS 030	4/18/2018	35.12238	-119.402933
SJAS 031	4/18/2018	35.118951	-119.409682
SJAS 032	5/3/2018	35.129244	-119.427299
SJAS 033	5/3/2018	35.126886	-119.4206
SJAS 034	5/3/2018	35.124441	-119.414973
SJAS 035	5/3/2018	35.131719	-119.417067
SJAS 036	5/3/2018	35.153665	-119.424987
SJAS 037	5/3/2018	35.156298	-119.41546
SJAS 038	5/3/2018	35.162979	-119.414271
SJAS 039	5/3/2018	35.164964	-119.42511
SJAS 040	5/3/2018	35.170931	-119.432384
SJAS 042	5/3/2018	35.174865	-119.445703
SJAS 043	5/3/2018	35.177648	-119.430381
SJAS 044	5/3/2018	35.181236	-119.423306
SJAS 045	5/3/2018	35.182124	-119.412842
SJAS 046	5/3/2018	35.194271	-119.413361
SJAS 047	5/3/2018	35.193029	-119.424905
SJAS 048	5/3/2018	35.196574	-119.433227

Site_number	Date_collected	Latitude	Longitude
SJAS 049	5/3/2018	35.20147	-119.436483
SJAS 050	5/3/2018	35.206201	-119.437211
SJAS 051	5/3/2018	35.207042	-119.441851
SJAS 052	5/17/2018	35.267349	-119.328076
SJAS 053	5/17/2018	35.262779	-119.331781
SJAS 054	5/17/2018	35.235456	-119.360549
SJAS 055	5/17/2018	35.225523	-119.361583
SJAS 056	5/17/2018	35.225628	-119.36864
SJAS 058	5/17/2018	35.202074	-119.361417
SJAS 060	5/17/2018	35.178724	-119.362368
SJAS 061	5/17/2018	35.170664	-119.357927
SJAS 062	5/17/2018	35.176918	-119.372953
SJAS 063	5/17/2018	35.180021	-119.397254
SJAS 064	5/17/2018	35.170244	-119.395377
SJAS 065	5/17/2018	35.168759	-119.407029
SJAS 066	5/17/2018	35.176876	-119.409907
SJAS 067	5/17/2018	35.220125	-119.412358
SJAS 068	5/17/2018	35.218424	-119.422887
SJAS 069	5/17/2018	35.217714	-119.42878
SJAS 070	6/7/2018	35.214859	-119.45034
SJAS 071	6/7/2018	35.22142	-119.453131
SJAS 072	6/7/2018	35.219446	-119.464526
SJAS 073	6/7/2018	35.208961	-119.457401
SJAS 074	6/7/2018	35.206766	-119.466114
SJAS 075	6/7/2018	35.199057	-119.470697
SJAS 076	6/7/2018	35.204909	-119.475832
SJAS 078	6/7/2018	35.221159	-119.497477
SJAS 079	6/7/2018	35.222503	-119.487539
SJAS 080	6/7/2018	35.210475	-119.497937
SJAS 081	6/7/2018	35.208171	-119.50502
SJAS 082	6/7/2018	35.208459	-119.514941
SJAS 084	6/7/2018	35.195202	-119.512542
SJAS 085	6/7/2018	35.194098	-119.520575
SJAS 086	6/7/2018	35.193712	-119.531567
SJAS 088	6/7/2018	35.187532	-119.497259
SJAS 089	6/7/2018	35.187825	-119.489115
SJAS 091	7/24/2018	35.397621	-119.534959
SJAS 092	7/24/2018	35.389705	-119.534947
SJAS 093	7/24/2018	35.382486	-119.524661
SJAS 094	7/24/2018	35.382678	-119.532002
SJAS 095	7/24/2018	35.39782728	-19.5572457
SJAS 096	7/24/2018	35.395887	-119.570969

Site_number	Date_collected	Latitude	Longitude
SJAS 097	7/24/2018	35.393265	-119.563716
SJAS 098	7/24/2018	35.40238	-119.572075
SJAS 099	7/24/2018	35.39918	-119.588876
SJAS 101	7/24/2018	35.427611	-119.613398
SJAS 102	7/24/2018	35.429221	-119.620758
SJAS 103	7/24/2018	35.351942	-119.585656
SJAS 104	7/24/2018	35.350669	-119.576969
SJAS 105	7/24/2018	35.339977	-119.578561
SJAS 106	7/24/2018	35.341274	-119.584064
SJAS 107	7/24/2018	35.338482	-119.593998
SJAS 108	7/24/2018	35.329612	-119.604981
SJAS 109	7/24/2018	35.326435	-119.590112
SJAS 110	7/24/2018	35.339348	-119.605231
SJAS 117	8/7/2018	36.095212	-120.176005
SJAS 130	8/22/2018	35.560378	-119.841085
SJAS 131	8/22/2018	35.560877	-119.834208
SJAS 132	8/22/2018	35.566398	-119.834608
SJAS 133	8/22/2018	35.571041	-119.837803
SJAS 134	8/22/2018	35.572261	-119.849873
SJAS 135	8/22/2018	35.576362	-119.84977
SJAS 137	8/22/2018	35.571164	-119.868141
SJAS 138	8/22/2018	35.577266	-119.875826
SJAS 139	8/22/2018	35.577999	-119.885587
SJAS 140	8/22/2018	35.583988	-119.885098
SJAS 141	8/22/2018	35.583893	-119.875314
SJAS 142	8/22/2018	35.583669	-119.868287
SJAS 143	8/22/2018	35.590595	-119.852549
SJAS 144	8/22/2018	35.596444	-119.816704
SJAS 147	8/22/2018	35.596189	-119.840037
SJAS 149	8/22/2018	35.609991	-119.839199
SJAS 150	9/5/2018	35.199148	-119.719359
SJAS 151	9/5/2018	35.199266	-119.713671
SJAS 153	9/5/2018	35.2074	-119.701859
SJAS 154	9/5/2018	35.211332	-119.696786
SJAS 155	9/5/2018	35.215004	-119.694696
SJAS 156	9/5/2018	35.215519	-119.690424
SJAS 157	9/5/2018	35.22113	-119.687109
SJAS 158	9/5/2018	35.226051	-119.684313
SJAS 159	9/5/2018	35.213887	-119.67419
SJAS 161	9/5/2018	35.23547	-119.660159
SJAS 166	9/5/2018	35.248293	-119.609266
SJAS 170	10/5/2018	35.037359	-119.493596

Site_number	Date_collected	Latitude	Longitude
SJAS 171	10/5/2018	35.045462	-119.50725
SJAS 172	10/5/2018	35.053906	-119.519903
SJAS 173	10/5/2018	35.06231	-119.535213
SJAS 174	10/5/2018	35.069071	-119.551079
SJAS 175	10/5/2018	35.080386	-119.562307
SJAS 176	10/5/2018	35.085377	-119.577608
SJAS 177	10/5/2018	35.096049	-119.590107
SJAS 178	10/5/2018	35.104002	-119.603236
SJAS 180	10/5/2018	35.118337	-119.629555
SJAS 183	10/5/2018	35.137786	-119.654257
SJAS 184	10/5/2018	35.149279	-119.665493
SJAS 185	10/6/2018	35.247484	-119.805816
SJAS 188	10/6/2018	34.999115	-119.502864
SJAS 193	10/6/2018	35.045231	-119.569444
SJAS 194	10/6/2018	35.052831	-119.582815
SJAS 200	10/6/2018	35.084504	-119.676811
SJAS 201	10/6/2018	35.089616	-119.693222
SJAS 202	10/6/2018	35.238702	-119.848752
SJAS 203	10/6/2018	35.250886	-119.849035
SJAS 205	10/6/2018	35.271392	-119.841399
SJAS 208	10/7/2018	35.262573	-119.826629
SJAS 209	10/7/2018	35.240648	-119.796763
SJAS 211	10/2/2018	36.588111	-120.789367
SJAS 239	11/15/2018	35.032844	-119.438198
SJAS 252	11/15/2018	35.001509	-119.488178
Semi cam 1a	1/5/2018	35.65832	-119.61257
Semi cam 1b	1/5/2018	35.65776	-119.61369
Semi cam 2a	1/5/2018	35.67217	-119.61183
Semi cam 2b	1/5/2018	35.67559	-119.60964
SJAS cam 6	5/10/2018	35.00592	-119.27757
SJAS Cam 9	9/13/2018	35.45584	-119.39564
SJAS Cam 10	9/27/2018	35.45815	-119.40606
SJAS Cam 13	10/23/2018	35.3754	-119.64499
SJAS Cam 14	10/23/2018	35.36478	-119.54745
SJAS Cam 18	10/31/2018	35.38181	-119.57343
SJAS Cam 19	10/31/2018	35.38411	-119.52232
SJAS Cam 26	4/22/2019	35.66167	-119.47511

* World geodetic system 1984