FINAL REPORT

DEMOGRAPHIC AND ECOLOGICAL RESPONSES OF ENDANGERED SAN JOAQUIN KIT FOXES TO THE PANOCHE VALLEY SOLAR FARM

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RESPONSE OF SAN JOAQUIN KIT FOXES TO THE PANOCHE VALLEY SOLAR FARM

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EXECUTIVE SUMMARY

The use of solar technology for power generation on a utility scale level has expanded rapidly in recent years, and is especially prevalent in California. Concomitant with this expansion has been concern regarding environmental impacts, particularly to rare species, due to the large land areas required for the construction of such facilities. In 2018, construction of the 504-ha Panoche Valley Solar Farm (PVSF) was completed in Panoche Valley in eastern San Benito County, California. The Panoche Valley ecoregion encompasses vital habitat for a number of rare species, and is considered a core area for the federally endangered and state threatened San Joaquin kit fox (*Vulpes macrotis mutica*).

We conducted a 3-year investigation (June 2019-May 2022) of the effects of the PVSF on kit foxes. We compared various demographic and ecological attributes for 23 kit foxes using the PVSF and lands within 1.5 km ("solar site") to 26 foxes using the nearby Silver Creek Ranch ("reference site"), which is now encompassed within the Panoche Valley Preserve. Foxes were fitted with GPS collars that also had a very high frequency (VHF) transmitter for tracking via telemetry. Attributes examined included survival, sources of mortality, reproduction, home range size, use of the solar facility, nightly and exploratory movements, den use, and diet.

Based on calculated annual rates and Cox proportional hazards analyses, survival was not different between the solar and reference sites. Sources of kit fox mortality were difficult to identify although larger predators were suspected in most cases. Reproductive success and mean litter size also did not differ between the two sites. Kit fox home range and core area size were significantly larger on the solar site as were routine movements (distance between locations on successive nights) and exploratory movements. Approximately 50% of daytime locations and 20% of the nighttime locations for solar site foxes were on the solar facility itself (i.e., within the security fence). Kit foxes apparently were foraging off of the solar facility at night but returning to the facility for daytime resting. Prey, particularly kangaroo rats, likely were more abundant outside of the facility. Possibly, kit foxes may have felt more secure resting within the fenced facility where the abundance of larger predators may have been lower. However, home range size, exploratory movement distance, and proportions of both daytime and nighttime locations on the solar facility all declined from the first to the third year of the study. Additionally, the proportion of dens used by foxes that were on the solar facility decreased from 73% in the first year to 50% by the third year. Based on these results, foxes may have gradually been spending less time on the facility. The reason for this is unclear although in the last year of the study, cattle damaged the security fencing in multiple locations, which allowed coyotes greater access to the solar array areas.

Rodents and invertebrates were the primary items consumed by kit foxes on both the solar and reference sites. Kangaroo rats were the primary rodent consumed on both sites although solar foxes also regularly preyed on ground squirrels. Commonly consumed invertebrates consisted of crickets, beetles, beetle larvae, and grasshoppers. Coyote and kit fox diets exhibited considerable overlap indicating the potential for food competition between the species. However, based on the similar high survival rates, high

reproductive success, and similar weights between the solar and reference site foxes, food availability apparently was not a limiting factor during the study.

We assessed multiple demographic and ecological attributes of San Joaquin kit foxes over a 3-year period on the PVSF and nearby reference site, and we did not identify any differences in these attributes that indicated adverse impacts to kit foxes from the solar facility. Differences in some ecological attributes were found and appeared to be associated with lower food availability within the fenced solar facility. Lower prey availability in the facility may have been associated with ground disturbance during construction as well as the fact that over 600 giant kangaroo rats were translocated off the site during construction. Despite this, kit fox survival and reproduction were similar between the solar and reference sites. Kit foxes exhibit high levels of ecological plasticity and adaptability, and therefore their occupation and use of the solar site was not unexpected. The results from this study were consistent with those obtained in similar 3-year studies conducted at the Topaz Solar Farms and the California Valley Solar Ranch in eastern San Luis Obispo County. An important caveat is that at all three of these facilities, kit fox use of the solar sites likely was markedly facilitated by the many conservation measures implemented at the sites. Security fencing permeable to kit foxes, artificial escape dens, and the presence of managed vegetation in the arrays are among the more significant ones. These three solar farms serve as solid models for designing solar facilities in a manner that minimizes impacts to kit foxes and accommodates their continued use and occupation of the sites.

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INTRODUCTION

Solar power is a rapidly growing renewable energy source worldwide, and concomitant with this has been an accelerated rate of construction of utility-scale solar energy generation facilities. The marked increase in such facilities has been particularly acute in California (Solar Energy Industries Association 2016) where lands with optimal conditions (e.g., flat terrain, high insolation rates) are abundant, and where the state legislature passed a bill in 2015 requiring all power-supplying utilities to obtain at least 50% of their electricity from renewable energy sources by 2030 (California State Senate 2015). More recently, Senate Bill 100 required that the 50% target be reached by 2026, that 60% be achieved by 2030, and that renewable and zero-carbon sources supply 100% of retail sales of electricity by 2045. This could further accelerate the construction of solar facilities in the state.

Although the rapid proliferation of solar facilities is positive in many regards (e.g., reducing emissions of greenhouse gases), a significant concern is impacts to sensitive biological resources resulting from these facilities, particularly when the facilities are constructed on lands that provide habitat for species at risk (Leitner 2009, Lovich and Ennen 2011, Stoms et al. 2013, Moore-O'Leary et al. 2017). Some of the rare species affected by recent solar projects in California include the desert tortoise (*Gopherus agassizii*; Federal Threatened, California Threatened), Mohave ground squirrel (*Xerospermophilus mojavensis*; California Threatened), giant kangaroo rat (*Dipodomys ingens*; Federal Endangered, California Endangered), and San Joaquin kit fox (*Vulpes macrotis mutica*; Federal Endangered, California Threatened) (Leitner 2009, Phillips and Cypher 2019, Moore-O'Leary et al. 2017).

San Joaquin kit foxes once were widely distributed in arid shrubland and grassland habitats in central California (U.S. Fish and Wildlife Service 1998). However, their range has been significantly reduced due to profound habitat loss and consequently they are listed as Federally Endangered and California Threatened. The San Joaquin kit fox now persists in a metapopulation consisting of three main "core" populations and probably less than a dozen "satellite" populations. To reduce extinction probability and enhance long-term population viability, it is imperative to conserve ecologically functional landscapes for kit foxes and maintain connectivity between populations (U.S. Fish and Wildlife Service 1998, Cypher et al. 2013).

One of the three core areas for San Joaquin kit fox conservation occurs in the Panoche region in eastern San Benito County and western Fresno County (Fig. 1). In 2018, construction was completed on the Panoche Valley Solar Farm (PVSF) within the Panoche region (Fig. 2). A concern was the potential impact to the local kit fox population from the PVSF. To assess these effects, we compared kit fox demographic and ecological patterns on the PVSF project site to those on nearby lands that had comparable pre-construction habitat conditions. The assessment of such effects was a mitigation requirement included in the Incidental Take Permit issued by the California Department of Fish and Wildlife (CDFW) for construction of the PVSF (Condition 10.6, CDFW 2015). Specific objectives were to:

- compare demographic attributes between kit foxes on the solar site and reference sites, specifically survival rates, sources of mortality, reproductive rates, and litter sizes,
- compare ecological attributes between kit foxes on the solar and reference sites, specifically home range size, movement patterns, den use patterns, foraging patterns, and competitor interactions,
- assess use of on-site developed areas and conservation lands relative to adjacent off-site habitat,
- and, develop recommendations to facilitate conservation of kit foxes on the PVSF as well as within the Panoche core area.

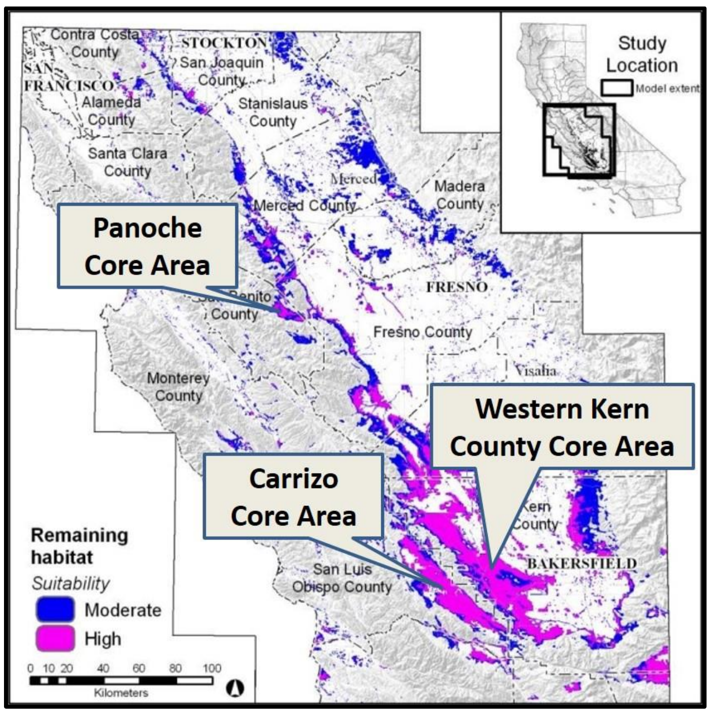


Figure 1. Location of the Panoche Core Area relative to other core areas for San Joaquin kit foxes.

Figure 2. Panoche Valley Solar Farm, San Benito County, CA (facing west).

STUDY AREA

Panoche Valley is located along the eastern edge of San Benito County, California close to the border with Fresno County (Fig. 3). It is approximately 50 km southeast of Hollister, 50 km south of Los Banos, and 100 km west of Fresno. The topography on the valley floor is generally flat or very gently rolling terrain, but quickly becomes steep and rugged in the hills that surround the valley on all sides. Elevations on the valley floor range from about 335-425 m and the hills bordering the valley extend up to about 800 m. The Mediterranean-type climate is characterized by hot summers and cool winters with most precipitation occurring as rain in winter. Annual precipitation in nearby Los Banos averaged ca. 23.4 cm, and mean high temperatures were ca. 35.8°C in July and 12.8°C in January (Western Regional Climate Center 2022). Prior to the construction of the PVSF, primary land uses were cattle grazing and dryland farming of wheat and barley. Vegetation in the area consisted primarily of non-native grasses such as red brome (*Bromus madritensis*) and wild oats (*Avena* spp.). Shrubs were sparse and consisted primarily of desert saltbush (*Atriplex polycarpa*).

The PVSF is a 130-megawatt electricity generating facility. Construction began in April 2016 and the facility was commissioned in January 2018. The area impacted by the PVSF was approximately 504 ha (1,245 ac) of combined permanent 414 ha (1,022 ac) and temporary 90 ha (222 ac) disturbances. Facilities included arrays of solar panels, access roads, an electrical substation, transmission towers and lines, and a maintenance complex. The arrays consisted of parallel rows of photovoltaic solar panels. The solar panels were mounted on a single-axis, horizontal tracking system that optimized energy capture by following the daily path of the sun (Fig. 4). The rows of panels were spaced approximately 2 m apart, and the lower edge of the panels at maximum incline was approximately 0.5 m off the ground. Vegetation was allowed to grow within the arrays. Sheep were brought into the fenced arrays each year to reduce vegetation density, both to improve habitat suitability for kit foxes and their prey and also to reduce combustible fuels. The arrays occurred in three groups with open space between the groups that functioned as wildlife movement corridors (Fig. 5). A creek and a county road also passed through one of the corridors and an electrical transmission line passed through another. The developed portions of the PVSF were enclosed within a 2.4-m tall, chain-link (3 cm x 3 cm mesh) security fence with strands of barbed wire on top.

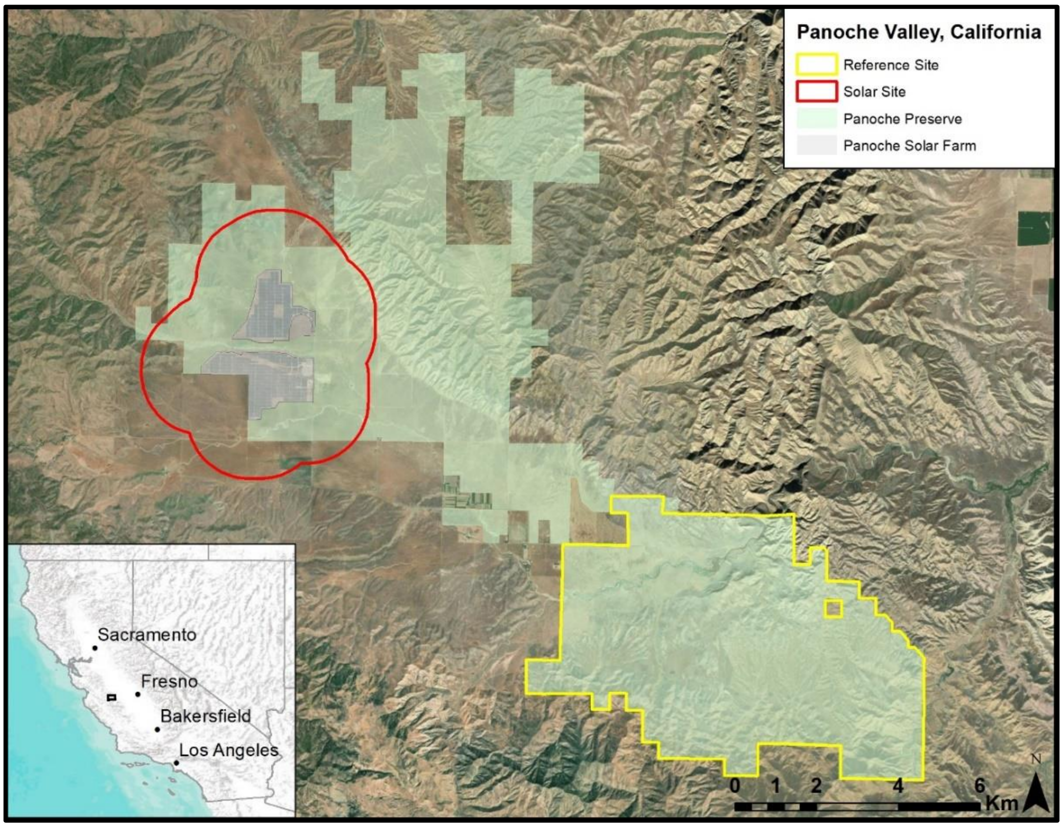


Figure 3. Panoche Valley Solar Farm study site with designated 1.5-km buffer and reference area study site, San Benito County, CA.

Figure 4. Solar panels at the Panoche Valley Solar Farm, San Benito County, CA.

Figure 5. Aerial image showing the wildlife movement corridors through the Panoche Valley Solar Farm, San Benito County, CA.

A variety of measures were implemented at the PVSF to mitigate impacts to San Joaquin kit foxes and to facilitate use of and movement through the facility by foxes. As mentioned previously, the arrays were constructed in three large blocks with wildlife movement corridors in between. The security fence surrounding the facility was modified to permit passage by kit foxes. A gap of approximately 10-15 cm between the bottom of the fence and the ground (Fig. 6) allowed kit foxes to pass but inhibited passage by larger predators (e.g., coyotes [*Canis latrans*] and bobcats [*Lynx rufus*]). To improve vegetation structure for kit foxes and their rodent prey (as well as to reduce fire hazard), grazing by sheep was conducted annually within the fenced areas. Artificial escape dens were installed along the fence lines to provide cover for kit foxes to escape from predators (Fig. 6) and chambered subterranean dens were installed throughout the site. Other measures implemented on the facility included exclusion of domestic dogs, prohibition of firearms, reduced speed limits, and trash abatement (CDFW 2015).

Figure 6. Artificial escape den for kit foxes at the Panoche Valley Solar Farm, San Benito County, CA. The gap under the security fence that allowed passage by kit foxes is visible.

To further mitigate impacts to kit foxes, approximately 10,684 ha (26,400 ac) of habitat were purchased in the vicinity of the facility. These lands along with endowment funds for long-term conservation and management were transferred to the Center for Natural Lands Management (CNLM) and the lands became the Panoche Valley Preserve (PVP; Fig. 3). The PVP will be managed in perpetuity for the benefit of kit foxes and other native species.

METHODS

To assess the effects of the PVSF on kit foxes, demographic and ecological attributes of kit foxes were compared between two areas referred to as the “solar site” and the "reference site." The solar site was defined as the PVSF and any lands within 1.5 km of the facility (Fig. 3). The 1.5-km distance is approximately the radius of an average kit fox home range and this distance was also used to delineate the area of effect around solar facilities in two previous studies (Cypher et al. 2019*b*, H.T. Harvey and Associates 2019). We assumed that a kit fox within this distance could be affected by the solar facility. Lands outside of the 1.5-km boundary were considered potential reference site lands although most reference site research activities were conducted on the Silver Creek Ranch area located in the southeastern portion of the PVP (Fig. 3). The vegetation within the PVSF was grazed annually using sheep to improve habitat conditions for kit foxes and prey species and also to reduce fire hazard. Most of the lands in the PVP outside of the PVSF were grazed each year by cattle. Private lands within (i.e., inholdings) and adjacent to the PVP were primarily used for cattle grazing. There were a few widely dispersed residences on these lands.

All data were summarized by year, which was defined as 1 June to 31 May. Thus, the three years used for analyses were: Year 1 = June 2019-May 2020, Year 2 = June 2020-May 2021, and Year 3 = June 2021-May 2022.

KIT FOX CAPTURE AND RADIO-COLLARING

Kit foxes were captured using wire-mesh live-traps (38 x 38 x 107 cm) baited with protein-based products (e.g., canned cat food, sardines, hot dogs, hard-boiled eggs) and covered with tarps to provide protection from inclement weather, sun and predators. Traps typically were set within 100 m of dirt roads that were present on both the solar site and the reference site. In an effort to maintain at least 10 collared foxes at all times on both sites, trapping was conducted on 18 occasions from May 2019 to October 2021. Traps were set for 1-4 consecutive nights. Traps were set in late afternoon or early evening and then checked the following morning beginning around sunrise. Captured kit foxes were coaxed from the trap into a denim bag and handled without chemical restraint. Data collected for each fox included date, location, sex, age (adult or juvenile), mass, reproductive and dental condition, and overall health. A uniquely numbered tag was attached to one ear, and hair and tissue were collected for future genetic analysis. Foxes captured on the solar site were assigned to solar group and foxes captured on the reference site were assigned to the reference group.

Captured adult foxes were fitted with radio-collars equipped with a GPS tracking unit (Fig. 7) and a very-high frequency (VHF) transmitter with a mortality sensor (Quantum 4000E Micro Mini Collar; Telemetry Solutions, Concord, CA). The GPS units were programmed to collect three independent locations during each 24-hour period; two of the locations were collected at night when the foxes were out of their dens and presumable active, and one location was collected around noon when foxes presumably were resting in or near the entrance to a den. The GPS units on the collars also included an ultra-high frequency (UHF) download function so that data could be retrieved remotely without having to recapture the fox. The entire telemetry package weighed approximately 65-70 g. The radio-collars weighed less than 3% of fox body weight as required by our permits. The mortality sensors on the units activated and produced a doubled VHF pulse rate if an animal remained motionless for 8 hr.

All foxes were released at the capture site, and additional trapping was conducted at the end of the study to remove radio-collars. All fox trapping, handling, and collaring was consistent with guidelines for the use of wild animals in research established by the American Society of Mammalogists (Sikes et al. 2016) and conducted in accordance with conditions and protocols established in an endangered species research permit (TE825573) from the U.S. Fish and Wildlife Service and a Memorandum of Understanding from the California Department of Fish and Wildlife.

Figure 7. Kit fox with a GPS collar at the Panoche Valley Solar Farm, San Benito County, CA.

KIT FOX MONITORING

The study area was visited for 1-5 days at 2-4 week intervals. During visits, we attempted to locate the VHF signal of each fox using a telemetry receiver (Model R1000, Communications Specialists, Inc., Orange, CA) to determine survival status. Telemetry signals initially were detected using an omni-directional antenna (Model RA-5A; Telonics, Mesa, AZ) magnetically mounted on the roof of a vehicle. Once a signal was detected, a 3-element handheld Yagi antenna (Model RA-150, Communications Specialists, Inc., Orange, CA) was used to navigate to the location of a given fox. Most monitoring was conducted during the day when foxes are more likely to be in a den, but searches occasionally were conducted at night after the foxes had emerged from their dens and their signal was more easily detected. We also attempted to download the stored data from the GPS collars during each visit by placing the base station on the dashboard of the vehicle, at the entrance to the occupied den, or overnight at the highest point in the area.

KIT FOX DEMOGRAPHIC COMPARISONS

Kit fox survival was assessed by monitoring collared animals. Survival analyses were only conducted for foxes greater than nine months of age. Younger animals (i.e., pups) likely had different survival rates compared to older animals (e.g., Cypher et al. 2000). We did not have sufficient data from pups to conduct survival analyses on this age group. Survival was compared between solar site and reference site foxes. Survival also was compared among the three years of the study and between sexes. Survival was assessed using three methods: Micromort survival estimates, Cox proportional hazards regression analysis, and a mortalities-per-monitoring-effort index.

To conduct the Micromort and Cox proportional hazards regression analysis, we calculated the number of days that a fox was known to be alive each year based on radio telemetry monitoring. The fate of each fox monitored was recorded for each year as: survived, died, or fate unknown. Fate was considered unknown in situations where telemetry transmitters expired and contact was lost with an animal, the fox dispersed out of the study area, or a radio-collar was removed. Data from unknown fate foxes was treated as truncated or “right-censored” for survival analyses.

Program Micromort (Heisey and Fuller 1985) produces a maximum likelihood estimate of the probability of surviving ($\hat{S}_i$) for a specified interval of time based on the number of days collared foxes survived. Use of number of days as the metric for survival allowed staggered entry of individuals (Pollock et al. 1989). The interval of time used was 365 days, and survival probabilities were calculated for foxes for each site by year, and also for each site across all years. Survival probabilities were compared between sites for each year and between sites across all years using a *z* test (Heisey and Fuller 1985):

$$z = \frac{\hat{S}_1 - \hat{S}_2}{\sqrt{var\ \hat{S}_1 + var\ \hat{S}_2}}$$

where $var\ \hat{S}_i$ is the variance for survival probability i as calculated by Micromort. Mean annual survival probability was compared between sites using a *t*-test.

Survival curves were calculated using Cox proportional hazard regression analysis (Cox and Oakes 1984). This is a multivariate analysis whereby the influence of combinations of variables on survival can be assessed through models and the importance of individual variables can be evaluated. The variables included in the analysis were all categorical and were site, year, and sex. To evaluate models, we used Akaike’s information criterion with small sample size correction (AIC_C; Hurvich and Tsai 1989) to compare the relative fit for models containing all combinations of the predictor. We evaluated eight models, including all possible combinations of predictor variables. We calculated each model’s log-likelihood, AIC_C, relative likelihood, and Akaike weight (w_i ; Burnham and Anderson 2002). We determined the AIC_C for the best fit model (i.e., $AIC_{C}min$) and then determined the ΔAIC_C for all of the other models (i.e., the difference between AIC_C for model i and that for the best fit model; $\Delta i = AIC_{C}i - AIC_{C}min$; Burnham and Anderson 2002). The w_i can be interpreted as the probability that model i is the best model, given the data and set of candidate models (Burnham and Anderson 2002). Furthermore, we evaluated the relative importance of individual parameters by summing the Akaike weights for each model that contained the parameter of interest. The closer the summed weights were to 1, the greater the assumed explanatory value of the parameter (Burnham and Anderson 2002, Symonds and Moussalli 2011).

Finally, we calculated a simple index of survival that is easily compared among studies with disparate monitoring methodologies (e.g., Cypher et al. 2019*b*). We divided the number of mortalities of collared adult foxes by the total number of days that collared foxes were monitored and multiplied that number by 1,000. Thus, the index produced is the rate of mortalities per 1,000 days of monitoring. This was calculated for both solar site and reference site foxes, and for each year and sex by site.

If a mortality signal was detected when tracking collared foxes, the signal was tracked on foot as soon as possible to locate and recover the carcass. Once located, the carcass and surrounding area were examined for clues to the cause of death. Cause of death was determined based upon physical evidence at the recovery site (e.g., tracks of larger predators, carcass caching, found on or near a road) and on the carcass (e.g., evidence of mass trauma, tooth puncture wounds, consumption of portions of the carcass). All remains of dead foxes were collected and preserved by freezing. In cases where the cause of death was not readily apparent, carcasses were submitted to the CDFW Wildlife Health Laboratory (Rancho Cordova, CA) for examination.

To assess reproductive success of kit foxes, we monitored radio-collared adult females (>1 yr old). Females < 1 yr old usually do not reproduce (Morrell 1972, McGrew 1979, Cypher et al. 2000). Parturition typically occurs in February or March (Morrell 1972, McGrew 1979). The pups are born in dens and begin emerging from these dens at 3-4 weeks of age. We examined the dens of adult females in March and April for signs of pups (e.g., small scats and tracks, prey remains). We also used camera stations to determine if pups were present and to estimate litter size. We used Cuddeback Digital C or E IR (Model 1231, Non Typical Inc. Green Bay, WI) field cameras. The cameras were secured to 1.2-m (3-ft) U-posts with zip ties. The stations were set approximately 3-6 m from the entrances of dens being used by female foxes or dens where signs of pups were present. A female was considered to have successfully reproduced if pups were observed at her den or signs of nursing were apparent by enlarged mammae or rufus-colored fur around mammae. The proportion of radio-collared females that successfully reproduced was determined for each site by year. The proportion of females successfully reproducing was compared between sites using a chi-square goodness-of-fit test. Litters of radio-collared females as well as litters for which the identity of the mother was uncertain or unknown were used to calculate mean litter size for each site. Mean litter size was compared between study areas using a *t*-test.

KIT FOX ECOLOGICAL COMPARISONS

Telemetry tracking data were used to assess spatial attributes of kit foxes, including home range, habitat selection, movements, and den use patterns. To calculate home ranges and core areas, we used the extension Home Range Tools (ver. 2.0, Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario, Canada) for ArcMAP (ver. 10.6, ESRI, Redlands, CA). Home range and core area size for each radio-collared fox was estimated by calculating a 95% and 50% Minimum Convex Polygon (MCP), respectively. MCPs provide a conservative estimate of space use and also are analytically and conceptually simple, thus facilitating direct comparison with other studies (Harris et al. 1990, White and Garrott 1990). Nocturnal locations collected by the GPS collars were used to calculate home range and core areas. We used 95% MCPs for home ranges to avoid inclusion of long-distance exploratory movements that would artificially inflate home range size and therefore would not be representative of the area used by foxes to satisfy life-history requirements. The 50% MCPs represent core areas that are areas of focal use by animals and are considered particularly important to their ecology (White and Garrott 1990). Whereas home ranges commonly overlap between adjacent social groups, core areas typically are exclusively used by a single group. Mean home range size was compared among sites, years, and sexes using an analysis-of-variance (ANOVA) with a fixed-effects model that included all possible variable interactions.

For solar site foxes, use of fenced solar array areas was compared to use of adjacent natural lands. Only locations used to calculate 95% MCPs (home ranges) were used in order to exclude locations that might have been associated with longer exploratory movements. For each year, the proportions of both nocturnal and diurnal locations within and outside of the fenced arrays were determined using ARCMap. To test whether kit foxes were selectively using the solar facility versus surrounding natural lands, the proportions of locations on versus off the facility were compared to a null hypothesis of equal proportions using a 2x2 contingency table analysis employing a chi-square test for homogeneity and Yate's correction for continuity (Zar 1984). A fixed-effects ANOVA model was used to compare mean proportions between diurnal and nocturnal periods, between sexes, and among years. An arcsine transformation was applied to the proportions prior to statistical analysis to improve normality (Zar 1984).

To assess movement rates, we calculated the mean distance between nocturnal locations for each fox by year and site. Only distances between locations on consecutive nights were used to better standardize elapsed time between locations. These distances clearly are not absolute straight-line distances as the paths traveled by foxes were unknown, but likely included considerable meandering, doubling back, and other patterns that could confound distance measurements. However, if on average foxes were moving more on one study area, then this might be detected with a large data set such as ours despite the confounding factors above. Mean movement distances were compared among study areas, years, and sexes using a fixed-effects ANOVA model including all possible variable interactions.

We assessed longer movements that might represent exploratory movements. We used the 5% of locations that were furthest from the geometric center of each fox's home range (the locations excluded from the 95% home range MCPs). We measured the distance from these locations to the home range center for each fox, and then determined the mean distance for each fox by year. Mean long-range movement distances were compared among study areas, years, and sexes using a fixed-effects ANOVA model including all possible variable interactions.

Whenever monitoring radio-collared kit foxes, we attempted to track them to a den. Generally, each fox was tracked once every 2-3 weeks. When a den was located, the coordinates were recorded and each den was assigned a unique number. We determined the number of unique dens used each year by each fox. We also identified natal dens based on observations of pups at the dens or based on sign such as the presence of pupsized scats, prey remains, and multiple entrances. For solar site foxes, we also recorded whether each den was located inside or outside the fenced array areas.

When tracking foxes during the day, they sometimes were found to be outside of dens. Foxes commonly are observed outside of dens when pups are present, but activity outside of dens on other occasions could be indicative of disturbance. For each fox, we determined the proportion of daytime tracking locations that the fox was observed outside of a den. A fixed-effects ANOVA model was used to compare mean proportions between the solar and reference site, between sexes, and among years. An arcsine transformation was applied to the proportions prior to statistical analysis to improve normality (Zar 1984). For solar site foxes, a one-way ANOVA was used to compare the transformed proportions among years.

Food item use by kit foxes was determined by analyzing scats (fecal samples). Scats were collected opportunistically from along roads and at den sites and also from inside and around traps in which foxes were captured. Individual scats were placed in paper bags labeled with the date and coordinates for the location. Scats were oven-dried at 60°C for ≥24 hr to kill any zoonotic parasite eggs and cysts. The scats then were placed in individual nylon bags, washed to remove soluble materials, and dried in a tumble dryer. The remaining undigested material was examined to identify food items. Mammalian remains (e.g., hair, teeth, bones) were identified using macroscopic (e.g., length, texture, color, banding patterns) and microscopic (e.g., cuticular scale patterns) characteristics of hairs (Moore et al. 1974) and by comparing teeth and bones to reference guides (Glass 1981, Roest 1986) and specimens. Other vertebrates were identified to class and invertebrates to order, based on feathers, scales, and exoskeleton characteristics and comparison to reference specimens. Any fleshy fruits consumed were identified at least to genus based on seed characteristics (Young and Young 1992). Frequency of occurrence of each item (number of scats with the item divided by the total number of scats) was determined for each site by year and for all years combined. For statistical analyses, items were grouped into six categories: rabbit, rodent, bird, reptile, invertebrate, and anthropogenic foods. To compare the rankings of categories between study areas and among years, we calculated a Kendall's coefficient of concordance (*W*). Shannon diversity indices (H') were calculated for seasonal and annual diets using the equation:

$$H' = (N \log N - \sum n_i \log n_i)/N$$

where N is the total number of occurrences of all items and n_i is the number of occurrences of item i (Brower and Zar 1984).

Significant differences in food availability between the solar and reference sites might be reflected in body condition of kit foxes. We used adult mass measurements to compare physical condition of foxes between the study sites. Foxes were weighed to the nearest 0.05 kg when captured. We used weights collected from September to January to assess winter condition and weights collected from May to July to assess summer condition. If a fox was captured multiple times during a given trapping session, we used the weight from the first capture for that season. Mean weight of kit foxes was compared between solar and reference sites for both sexes in both winter and summer using two-tailed *t*-tests.

Coyotes generally are the most abundant competitors sympatric with kit foxes. Coyote scats were collected opportunistically and examined using the same methods as those described above for kit fox scats. Frequency of occurrence of items and item diversity in coyote scats was determined. Use of foods by coyotes was compared to that of kit foxes on both the solar site and the reference site.

Spatial data were collected in the field using AmigoCollect software (AmigoCloud, San Francisco, CA). Spatial analyses and map figure production were conducted using ArcMAP and QGIS (ver. 3.28.2, QGIS Development Team). Data were primarily analyzed using the SPSS statistical software package (ver. 28.1; International Business Machines Corporation, Armonk, NY). We considered *p*-values to be significant at $\alpha \leq$ 0.1 for all statistical analyses. We chose a more relaxed alpha value to reduce the risk of committing a Type II error, which is considered more detrimental than a Type I error when making wildlife conservation decisions (Di Stefano 2003, Taylor and Gerrodette 1993). By relaxing the alpha value we hoped to identify potential differences and relationships that could be important for the management and conservation of kit foxes on solar sites.

RESULTS

KIT FOX DEMOGRAPHIC COMPARISONS

During the study, 74 kit foxes were captured (Appendix A). Of these, 49 received radio-collars: 23 on the solar site and 26 on the reference site. Radio-collars were not placed on young pups captured in spring and summer or on new foxes captured during trapping conducted at the end of the study to remove radio-collars.

Survival analyses were based on data from 49 foxes, many of which were monitored in multiple years. Using Program Micromort (Table 1), the estimated probability of surviving for 365 days (1 year) ranged from 1.0 for foxes on the reference site in Year 1 to 0.42 for foxes on the reference site in Year 3. Based on 2-tailed *z* scores, survival probabilities were significantly higher on the reference site in Year 1 ($z = 1.69$, $p = 0.09$) and Year 2 ($z = 1.80$, $p = 0.07$) and on the solar site in Year 3 ($z = 2.25$, $p = 0.02$), but probabilities did not differ statistically between sites for all years combined ($z = 0.01$, $p =$ 0.99). Mean annual survival probability (± SE) also did not differ ($t_{1,4} = -0.45$, $p = 0.67$) between the reference site (0.75 ± 0.17) and solar site (0.66 ± 0.09). For both sites combined, survival probability was highest in Year 1 (0.85) and lower in Year 2 (0.68) and lowest in Year 3 (0.59).

A survival curve generated by the Cox analysis graphically depicted the similar survival for foxes on solar site and reference site (Fig. 8). Another curve depicts the higher survival in Year 1 and the lower but similar survival in Year 2 and Year 3.

Mortality index (number of mortalities per 1,000 monitoring days) across all years was 1.09 for reference site foxes and 1.08 for solar site foxes (Table 3). The annual indices ranged from 0-2.40 for reference site foxes and from 0.66-1.92 for solar site foxes.

Cox proportional hazards regression analysis was conducted on five models encompassing combinations of the variables Site and Year and a Site*Year interaction term (Table 2). The model that best fit the data was the one that included just the Site*Year variable. However, none of the models were particularly strong as the AIC_C values for all models were relatively high (≥ 168.586). The sum of the w_i values was 0.10 for models containing the variable Year, 0.01 for models containing the variable Site, and 0.99 for models containing the variable Site*Year. Based on these sums, the variable Site*Year was the important variable for explaining the results.

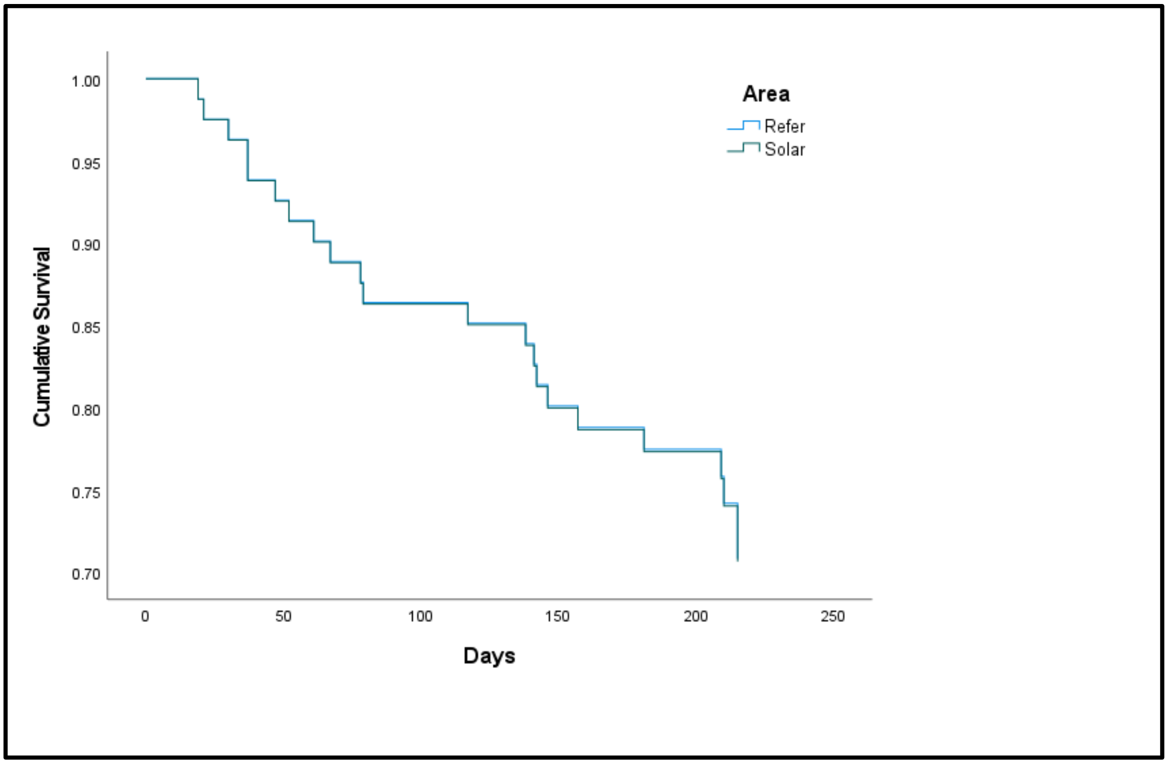
Table 1. Probability of kit foxes surviving ($\hat{S}$) for 365 days (1 year) on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

Site	Year	No. foxes monitored	Total days survived	No. mortalities	$\hat{S}$	Var $\hat{S}$	95% CI
			Study site by year				
Solar	1	8	2,109	2	0.71	0.03	0.44-1.00
Ref	1	10	2,304	0	1.00	0.00	1.00-1.00
Solar	2	12	2,599	5	0.50	0.02	0.27-0.92
Ref	2	16	4,054	2	0.84	0.01	0.65-1.00
Solar	3	16	4,517	3	0.78	0.01	0.60-1.00
Ref	3	18	3,755	9	0.42	0.01	0.24-0.74
			Study site for all years				
Solar	All	23	9,225	10	0.67	0.01	0.53-0.86
Ref	All	26	10,113	11	0.65	0.01	0.51-0.83

Table 2. Akaike's Information Criterion results for Cox proportional hazard regression analysis of San Joaquin kit fox survival on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

Model	K[a]	-2LL[b]	AIC	AIC_c	ΔAIC_C	Rel LL[c]	w_i[d]
Site*Year	3	162.23	168.23	168.59	0.00	1.000	0.900
Site + Year + Site*Year	6	162.24	172.24	173.14	4.56	0.102	0.092
Year	3	172.53	178.53	178.88	10.29	0.006	0.005
Site + Year	4	172.51	180.51	181.10	12.52	0.002	0.002
Site	3	175.27	181.27	181.62	13.04	0.001	0.001

[a] Number of parameters in the model.
[b] LL = log-likelihood
[c] Relative log-likelihood
[d] Akaike's weight



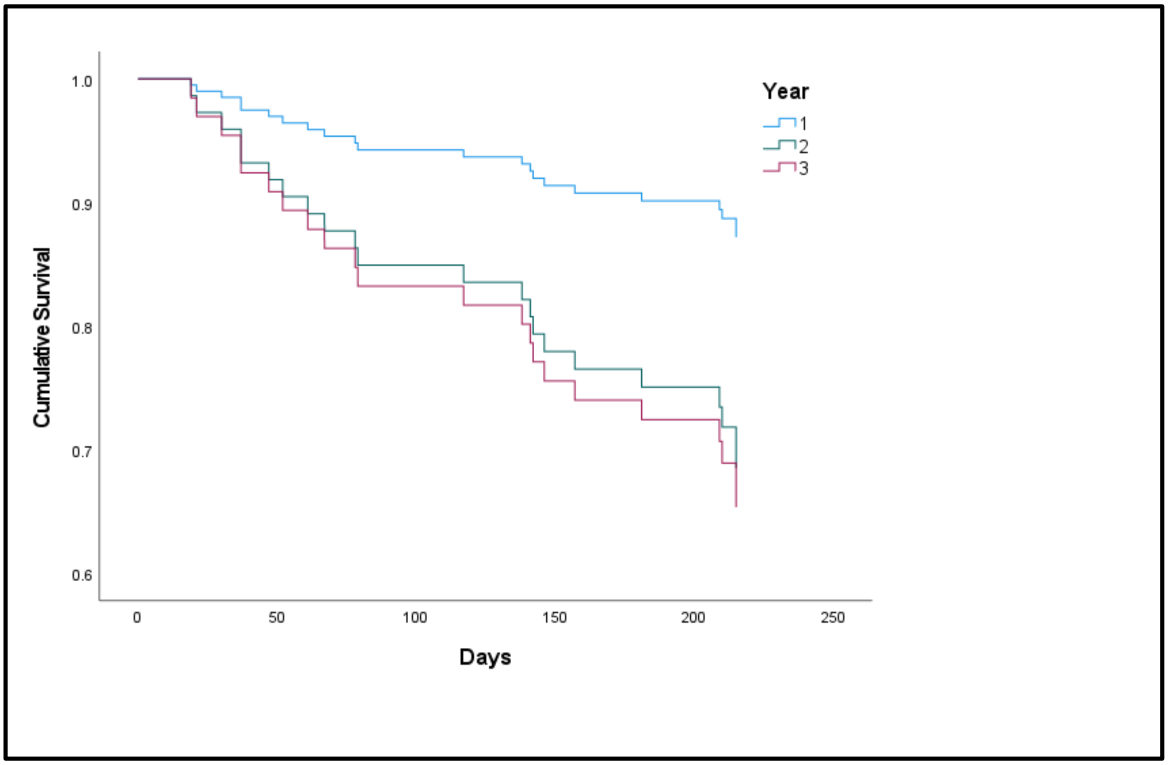


Figure 8. Cumulative survival curves for San Joaquin kit foxes by study site (top) and year (bottom) on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

Table 3. Mortalities per 1,000 monitoring days for radio-collared San Joaquin kit foxes on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

Year	Site	Foxes monitored	Days monitored	Fox mortalities	Mortalities per 1,000 days
1	Solar	8	2,109	2	0.95
	Reference	10	2,304	0	0.00
2	Solar	12	2,599	5	1.92
	Reference	16	4,054	2	0.49
3	Solar	16	4,517	3	0.66
	Reference	18	3,755	9	2.40
All	Solar	23	9,225	10	1.08
	Reference	26	10,113	12	1.09

During the study, 21 radio-collared adult kit foxes were found dead (Table 4; Figs. 9-11). Ten of these foxes were solar site foxes and 11 were reference site foxes. The cause of death was not conclusively determined for any of the dead foxes. In almost all of the cases, only a collar was found (n = 6) or too few remains were recovered (n = 11) or the fox died in a den (n = 4) and the carcass could not be recovered. None of the dead foxes were found within the fenced solar facility, and two of the solar site foxes were found outside of the 1.5-km buffer that defined the solar site. Many of the foxes likely were killed by predators, based on the locations of the carcasses and fact that many appeared to have been completely consumed (such as in the cases where only a collar was found). Two uncollared foxes also were found dead during the study period. An adult male was struck by a vehicle on Little Panoche Road within the solar site buffer and a male pup was struck by a vehicle on this same road just north of the buffer boundary.

Table 4. Adult radio-collared San Joaquin kit foxes found dead by site and year on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

	Solar site			Reference site		
Year	Females	Males	Total	Females	Males	Total
1	0	1	1	0	0	0
2	1	5	6	2	1	3
3	0	3	3	5	3	8
Total	1	9	10	7	4	11

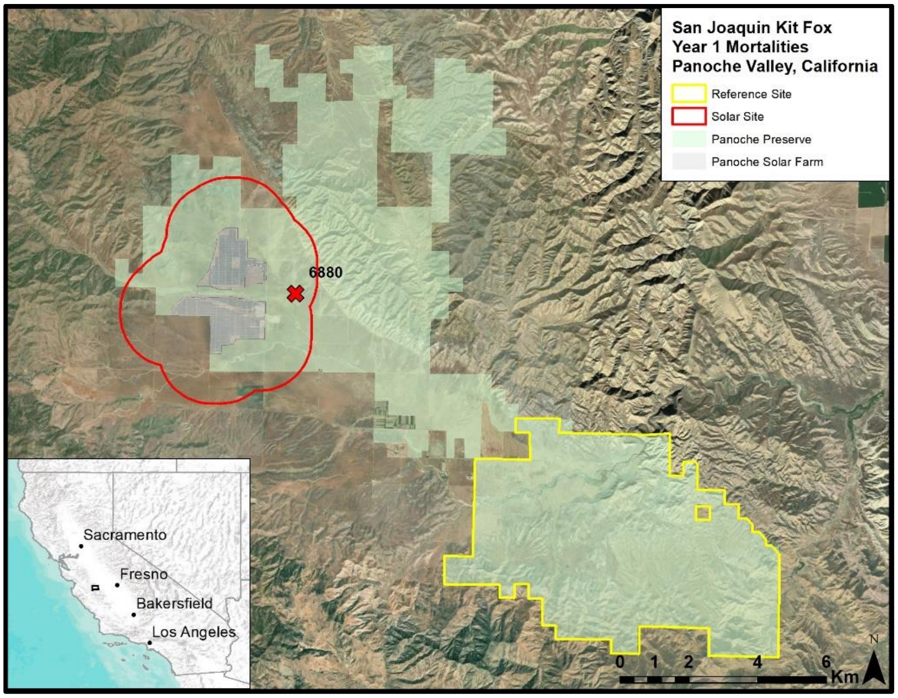


Figure 9. Locations where adult radio-collared San Joaquin kit foxes were found dead during Year 1 (June 2019-May 2020) in the Panoche Valley, San Benito County, CA.

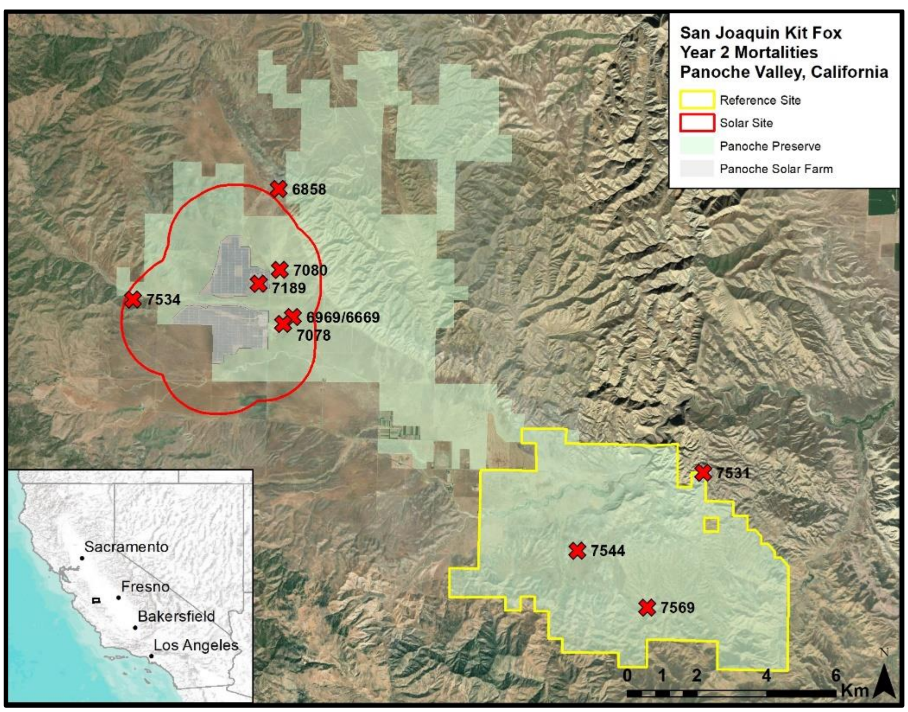


Figure 10. Locations where adult radio-collared San Joaquin kit foxes were found dead during Year 2 (June 2020-May 2021) in the Panoche Valley, San Benito County, CA.

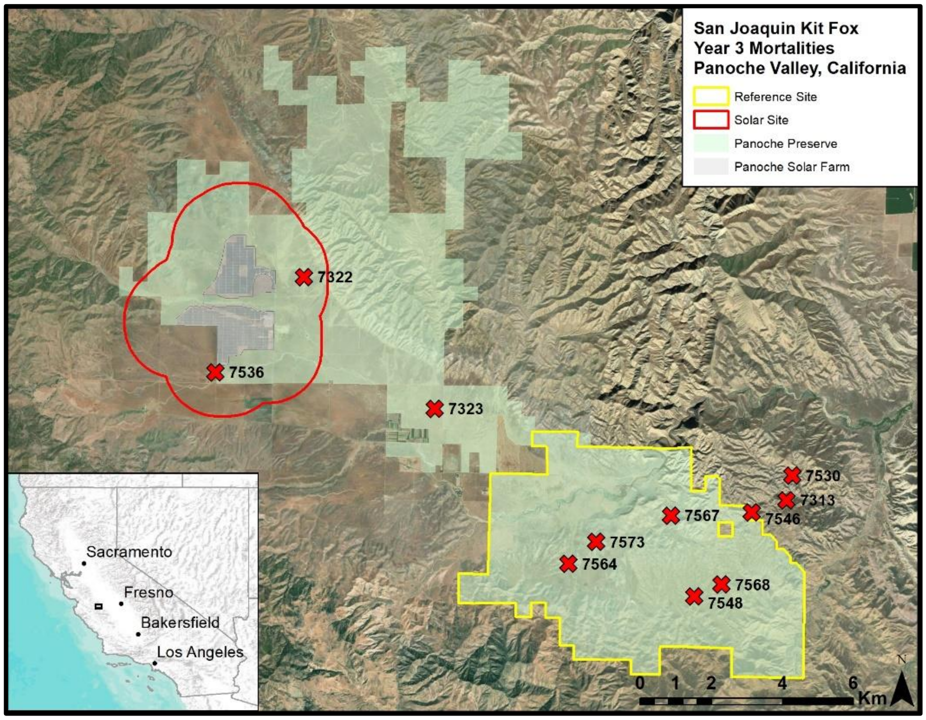


Figure 11. Locations where adult radio-collared San Joaquin kit foxes were found dead during Year 3 (June 2021-May 2022) in the Panoche Valley, San Benito County, CA.

Reproductive success was determined for radio-collared female foxes on 30 occasions over the 3-year study period (Table 5). Some females were assessed in more than one year. The proportions of females successfully reproducing did not differ between the solar and reference sites ($\chi_1^2 = 0.06$, $p = 0.806$). For litter size comparison between sites, litters were included for radio-collared females and also for litters for which the mother was uncertain or unknown. Mean litter size (SE, range) was 3.4 (0.36, 1-5) for the solar site and 4.0 (0.32, 1-7) for the reference site, and mean size did not differ between sites ($t_{27} = 1.31$, $p = 0.20$).

Table 5. Proportion of radio-collared female San Joaquin kit foxes successfully reproducing by site and year on the solar and reference sites in the Panoche Valley, San Benito County, CA.

	Solar site		Reference site	
Year	**n**	**%**	**n**	**%**
1 (2020)	3	100	3	100
2 (2021)	5	100	7	71.4
3 (2022)	6	83.3	6	83.3
Total	14	92.9	16	81.3

KIT FOX ECOLOGICAL COMPARISONS

We had sufficient data to estimate annual size for 78 home ranges and core areas (Figs. 12-17). The range for one fox was not included in the analyses. During Year 1, an adult female from the reference site made numerous trips to the New Idria area (ca. 20 km south) resulting in an anomalously large home range of 36.1 km^2 that may have been motivated by some factor other than meeting routine natural history needs.

For all years combined, home ranges for foxes (Table 6) on the solar site ranged from 0.9-14.7 km^2 with a mean (± SE) of 6.1 ± 0.6 km^2. Home ranges for foxes on the reference site ranged from 0.4-12.3 km^2 with a mean of 2.4 ± 0.4 km^2. Based on an ANOVA (Table 7), home ranges on the solar site were significantly larger than those on the reference site ($F_{1,63} = 21.57$, $p < 0.001$). Home range size did not differ among years or between males and females, and interactions between factors were not significant.

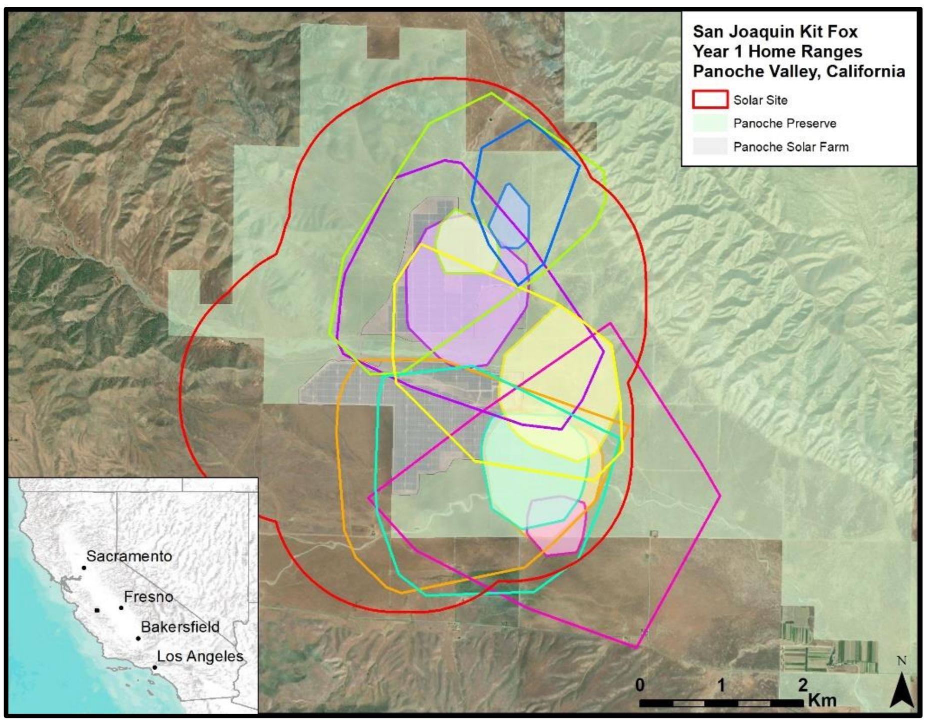


Figure 12. Home ranges (outlined 95% MCP) and core areas (shaded 50% MCP) for San Joaquin kit foxes on the solar site during Year 1 (June 2019-May 2020) at the Panoche Valley Solar Farm, San Benito County, CA.

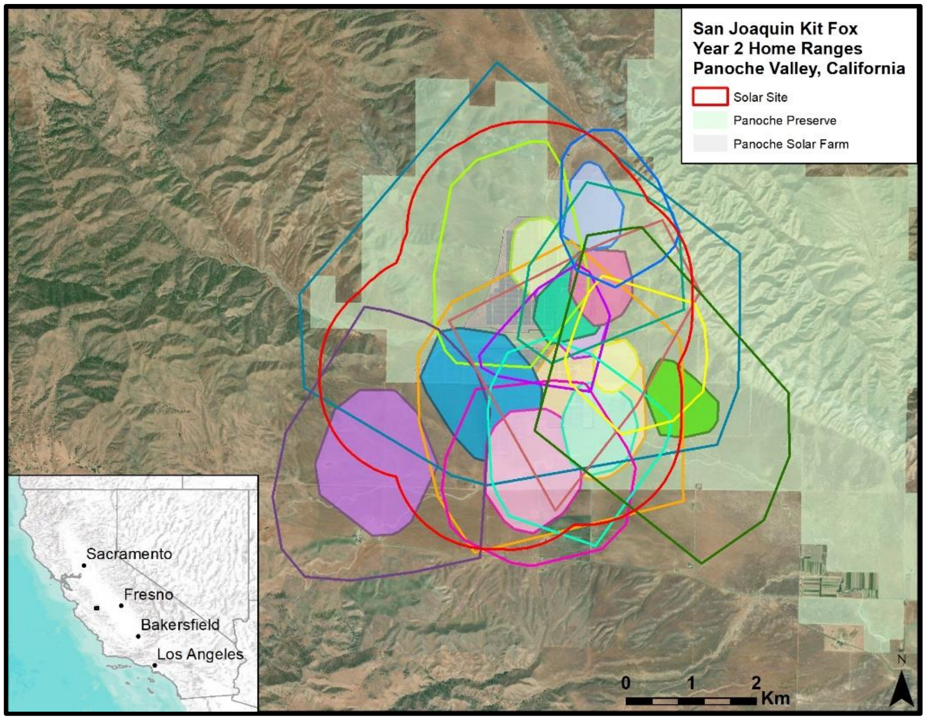


Figure 13. Home ranges (outlined 95% MCP) and core areas (shaded 50% MCP) for San Joaquin kit foxes on the solar site during Year 2 (June 2020-May 2021) at the Panoche Valley Solar Farm, San Benito County, CA.

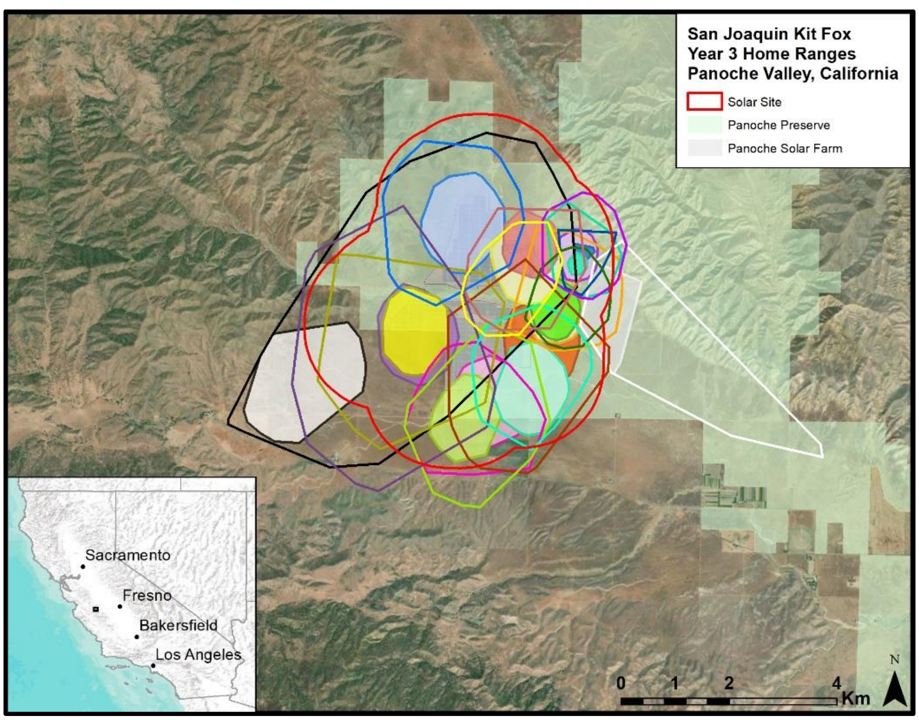


Figure 14. Home ranges (outlined 95% MCP) and core areas (shaded 50% MCP) for San Joaquin kit foxes on the solar site during Year 3 (June 2021-May 2022) at the Panoche Valley Solar Farm, San Benito County, CA.

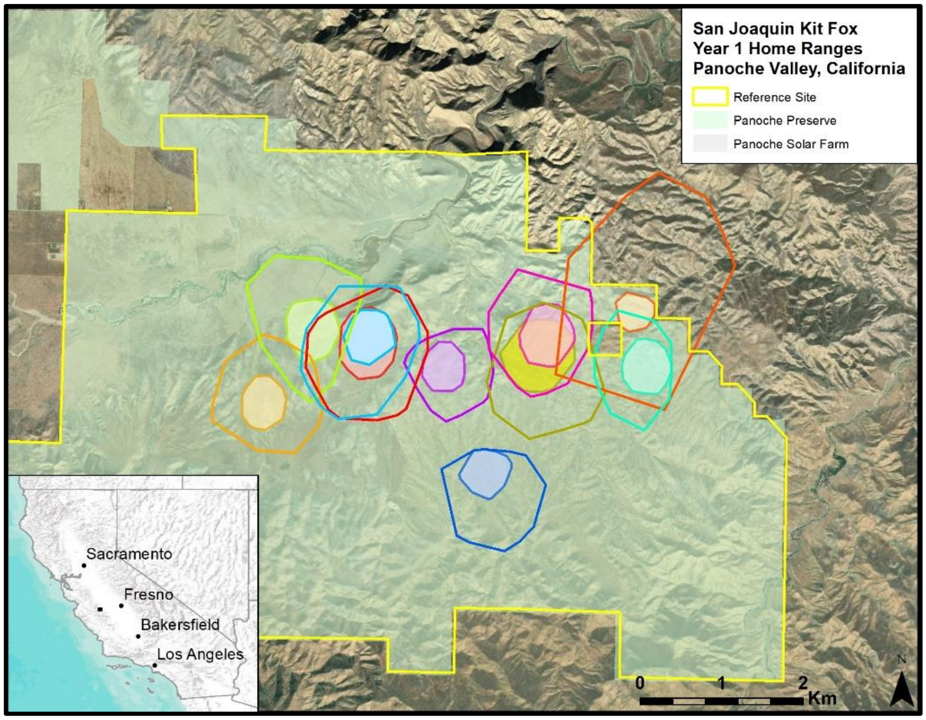


Figure 15. Home ranges (outlined 95% MCP) and core areas (shaded 50% MCP) for San Joaquin kit foxes on the reference site during Year 1 (June 2019-May 2020) in the Panoche Valley, San Benito County, CA.

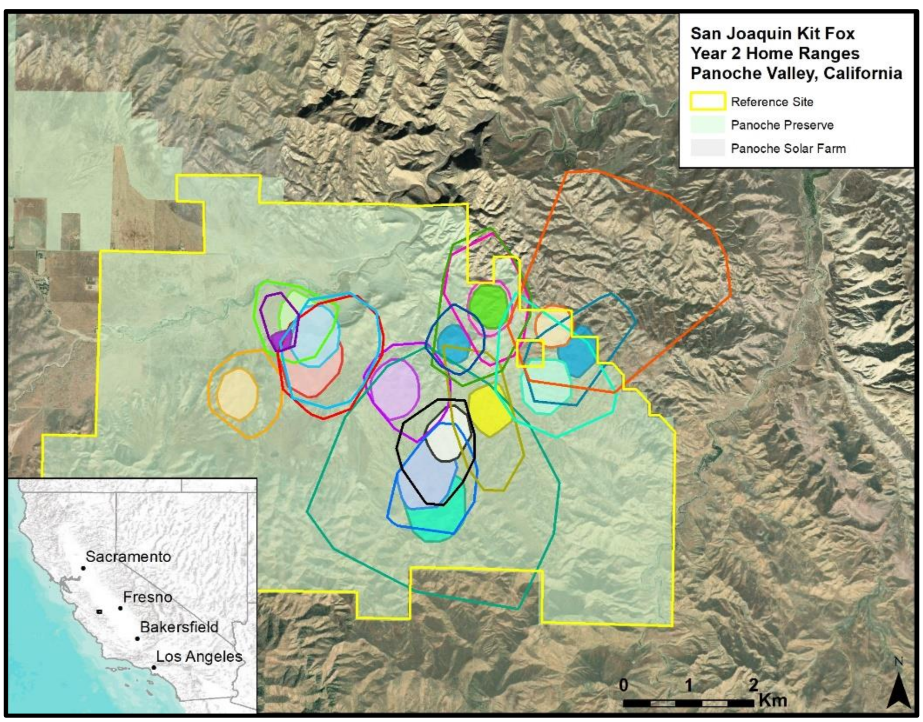


Figure 16. Home ranges (outlined 95% MCP) and core areas (shaded 50% MCP) for San Joaquin kit foxes on the reference during Year 2 (June 2020-May 2021) in the Panoche Valley, San Benito County, CA.

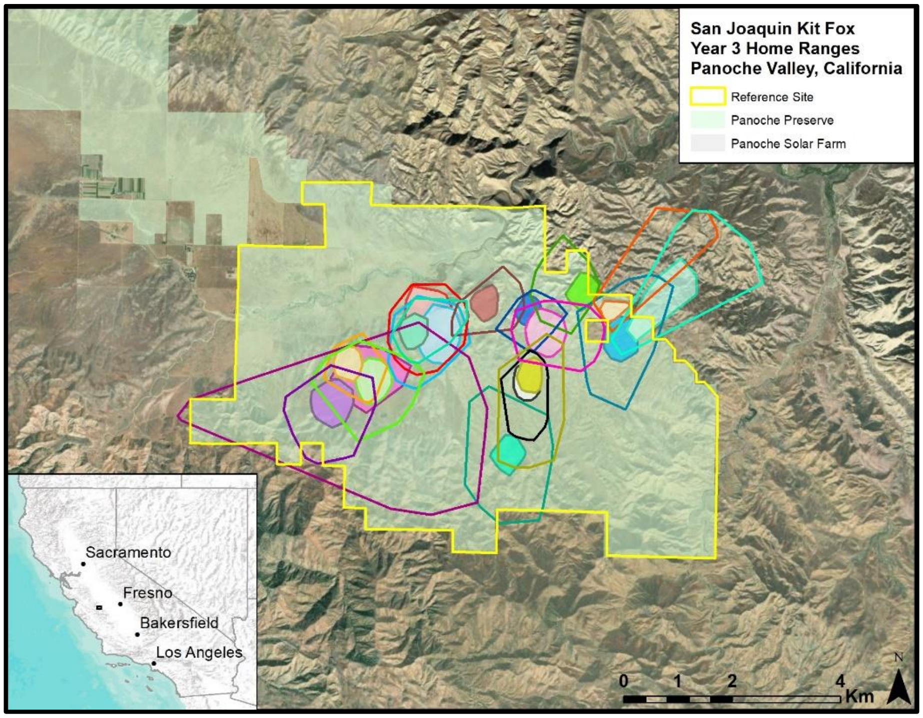


Figure 17. Home ranges (outlined 95% MCP) and core areas (shaded 50% MCP) for San Joaquin kit foxes on the reference during Year 3 (June 2021-May 2022) in the Panoche Valley, San Benito County, CA.

Table 6. Mean home range size for San Joaquin kit foxes by site, year, and sex on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

		Mean home range size (km^2)					
		Males		Females		All	
Site	**Year**	**n**	$\bar{x}$ **(SE)**	**n**	$\bar{x}$ **(SE)**	**n**	$\bar{x}$ **(SE)**
Solar	1	4	7.7 (0.6)	3	4.7 (1.5)	7	6.4 (0.9)
	2	9	7.9 (1.4)	2	4.7 (1.6)	11	7.3 (1.2)
	3	7	5.3 (1.7)	7	4.7 (1.0)	14	5.0 (0.9)
	All	20	7.0 (0.9)	12	4.7 (0.7)	32	6.1 (0.6)
Reference	1	6	2.0 (0.5)	4	1.4 (0.2)	10	1.8 (0.3)
	2	6	2.8 (1.1)	10	2.4 (0.9)	16	2.6 (0.7)
	3	6	2.3 (0.4)	11	2.7 (1.0)	17	2.6 (0.6)
	All	18	2.4 (0.4)	25	2.4 (0.6)	43	2.4 (0.4)

Table 7. Results of an analysis-of-variance of the effects of site, year, and sex on home range size for San Joaquin kit foxes on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

Source	Sum of Squares	df	Mean Square	*F*	*p*
Model	329.47	11	29.95	3.43	<0.001
Intercept	977.75	1	977.75	111.86	<0.001
Site	188.54	1	188.54	21.57	<0.001
Year	6.00	2	3.00	0.34	0.711
Sex	22.33	1	22.33	2.56	0.115
Site * Year	10.48	2	5.241	0.60	0.552
Site * Sex	15.68	1	15.68	1.79	0.185
Year * Sex	12.28	2	6.14	0.70	0.499
Site * Year * Sex	2.45	2	1.23	0.14	0.869
Error	550.66	63	8.74		
Total	2066.09	75			
Corrected Total	880.13	74			

Results were similar for core areas. For all years combined, core areas for foxes (Table 8) on the solar site ranged from 0.1-4.4 km^2 with a mean (± SE) of 1.5 ± 0.2 km^2. Core areas for foxes on the reference site ranged from 0.04-1.2 km^2 with a mean of 0.4 ± 0.04 km^2. Based on an ANOVA (Table 9), core areas on the solar site were significantly larger than those on the reference site ($F_{1,63} = 38.87$, $p < 0.001$). Core area size did not differ among years or between males and females, and interactions between factors were not significant.

Table 8. Mean core area size for San Joaquin kit foxes by site, year, and sex on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

		Mean core area size (km^2)					
		Males		Females		All	
Site	**Year**	**n**	**$\bar{x}$ (SE)**	**n**	**$\bar{x}$ (SE)**	**n**	**$\bar{x}$ (SE)**
Solar	1	4	2.2 (0.8)	3	1.3 (0.5)	7	1.8 (0.5)
	2	9	1.6 (0.3)	2	1.1 (0.2)	11	1.5 (0.3)
	3	7	1.1 (0.3)	7	1.4 (0.2)	14	1.3 (0.2)
	All	20	1.5 (0.2)	12	1.3 (0.2)	32	1.5 (0.2)
Reference	1	6	0.4 (0.1)	4	0.2 (0.1)	10	0.3 (0.1)
	2	6	0.5 (0.1)	10	0.5 (0.1)	16	0.5 (0.1)
	3	6	0.5 (0.1)	11	0.4 (0.1)	17	0.4 (0.1)
	All	18	0.5 (0.1)	25	0.4 (0.1)	43	0.4 (< 0.1)

Table 9. Results of an analysis-of-variance of the effects of site, year, and sex on core area size for San Joaquin kit foxes on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

Source	**Sum of Squares**	**df**	**Mean Square**	***F***	***p***
Corrected Model	23.18	11	2.11	5.14	<.001
Intercept	51.29	1	51.29	125.09	<0.001
Site	15.94	1	15.94	38.87	<0.001
Year	0.24	2	0.12	0.30	0.745
Sex	0.73	1	0.73	1.77	0.188
Site * Year	1.05	2	0.52	1.28	0.286
Site * Sex	0.28	1	0.28	0.69	0.411
Year * Sex	1.2	2	0.60	1.47	0.237
Site * Year * Sex	0.85	2	0.43	1.04	0.359
Error	25.83	63	0.41		
Total	105.45	75			
Corrected Total	49.01	74			

For solar site foxes, the 15,806 locations used to define 95% MCP home ranges were used to examine use of the solar facility. Of these locations, 14,342 were night locations and 1,464 were day locations. When tested against a null hypothesis of equal proportions of locations on the solar facility versus off the solar facility (i.e., outside the solar facility fence-line, but within the 1.5 km buffer), the proportion of night locations off the facility was significantly higher each year and for all years combined (Table 10). For day locations, the proportion of locations on the facility was significantly higher in Year 1 and for all years combined, significantly lower in Year 3, and similar to the proportion off the facility in Year 2 (Table 10). The proportion of locations on the solar facility was significantly higher for day locations compared to night locations (Tables 11 and 12) and this was true for both sexes (females: $p = 0.046$; males: $p = 0.005$; Fig. 18). The proportion of locations on the solar facility did not differ among years or between sexes (Table 12).

Table 10. Mean proportion of locations on versus off the solar facility by year for San Joaquin kit foxes during June 2019-May 2022 at the Panoche Valley Solar Farm, San Benito County, CA.

Year	No. foxes	Total locations	Proportion on solar (%)	Proportion off solar (%)	χ^2	*p*
			Night locations			
1	8	2,895	33.9	66.1	152.69	<0.001
2	12	4,062	19.6	80.4	824.65	<0.001
3	15	7,385	14.8	85.2	2,092.05	<0.001
All	35	14,342	20.0	80.0	2,834.69	<0.001
			Day locations			
1	8	404	79.7	20.3	76.89	<0.001
2	12	503	51.1	48.9	0.06	0.806
3	15	557	42.7	57.3	5.49	0.019
All	35	1,464	55.8	44.2	9.67	0.002

Table 11. Mean proportion of locations on the solar facility by year, sex, and period of day for San Joaquin kit foxes during June 2019-May 2022 at the Panoche Valley Solar Farm, San Benito County, CA.

		Locations on solar site (%)	
Variable	**Level**	**Mean**	**SE**
Year	**1**	44.1	7.3
	2	31.0	6.7
	3	29.5	5.2
Sex	**Female**	33.3	6.0
	Male	36.4	4.5
Period	**Day**	50.4	5.3
	Night	19.3	5.3

Table 12. Results of an analysis-of-variance of the effects of year, sex, and time of day on the proportion of locations on the solar facility for San Joaquin kit foxes during June 2019-May 2022 at the Panoche Valley Solar Farm, San Benito County, CA.

Source	Sum of Squares	df	Mean Square	*F*	*p*
Corrected Model	2.71	11	0.25	1.67	0.104
Intercept	18.86	1	18.86	127.66	<0.001
Year	0.36	2	0.18	1.22	0.304
Sex	0.03	1	0.03	0.22	0.644
Day-or-Night	1.71	1	1.71	11.54	0.001
Year * Sex	0.23	2	0.12	0.79	0.459
Year * Day-or-Night	0.03	2	0.01	0.10	0.909
Sex * Day-or-Night	<0.01	1	<0.01	0.02	0.880
Year * Sex * Day-or-Night	0.00	2	0.00	0.01	0.998
Error	8.57	58	0.15		
Total	34.00	70			
Corrected Total	11.28	69			

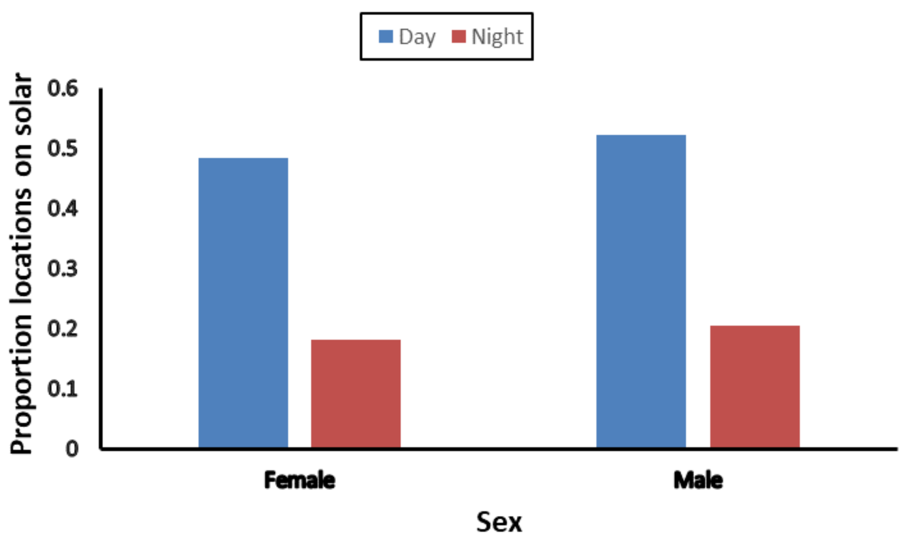


Figure 18. Proportion of day and night locations on the solar facility by sex for San Joaquin kit foxes during June 2019-May 2022 at the Panoche Valley Solar Farm, San Benito County, CA.

We obtained 17,139 estimates of distances moved between nocturnal locations for 49 foxes across the three years of the study (Table 13). Mean movements for foxes on the solar site ranged from 0.48-3.42 km with an overall mean (± SE) of 1.36 ± 0.09 km. Mean movements for foxes on the reference site ranged from 0.34-2.42 km with an overall mean of 0.83 ± 0.07 km. Mean movements by foxes on the solar site were larger than those for foxes on the reference site (Table 14) but did not vary between sexes or among years.

Table 13. Mean distance moved between nocturnal locations on consecutive nights for San Joaquin kit foxes by sex, site, and year on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

		Mean distance (km)					
		Males		Females		All	
Site	**Year**	**n**	$\bar{x}$ **(SE)**	**n**	$\bar{x}$ **(SE)**	**n**	$\bar{x}$ **(SE)**
Solar	1	5	1.73 (0.22)	3	0.93 (0.28)	8	1.33 (0.18)
	2	9	1.39 (0.16)	3	1.85 (0.28)	12	1.62 (0.16)
	3	8	1.17 (0.17)	8	1.09 (0.17)	16	1.13 (0.12)
	All	22	1.43 (0.11)	14	1.29 (0.14)	36	1.36 (0.09)
Reference	1	6	0.73 (0.20)	5	0.97 (0.22)	11	0.85 (0.15)
	2	8	0.95 (0.17)	11	0.69 (0.15)	19	0.82 (0.11)
	3	6	0.86 (0.20)	11	0.79 (0.15)	17	0.83 (0.12)
	All	20	0.85 (0.11)	27	0.82 (0.10)	47	0.83 (0.07)

Table 14. Results of an analysis-of-variance of the effects of sex, site, and year on the mean distance moved between nocturnal locations on consecutive nights for San Joaquin kit foxes on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

Source	**Sum of Squares**	**df**	**Mean Square**	***F***	***p***
Corrected Model	8.55	11	0.78	3.36	<0.001
Intercept	83.72	1	83.72	361.76	<0.001
Sex	0.13	1	0.13	0.55	0.461
Site	4.87	1	4.87	21.06	<0.001
Year	0.79	2	0.40	1.71	0.188
Sex * Site	0.06	1	0.06	0.24	0.628
Sex * Year	0.37	2	0.18	0.79	0.459
Site * Year	0.85	2	0.42	1.83	0.168
Sex * Site * Year	1.97	2	0.98	4.25	0.018
Error	16.43	71	0.23		
Total	113.89	83			
Corrected Total	24.98	82			

We obtained 1,896 estimates of long distance movements for 46 foxes across the three years of the study (Table 15). Mean movement distance for foxes ranged from 1.0-6.50 km on the solar site and from 0.50-5.30 km on the reference. Based on ANOVA (Table 16), mean distance was greater for foxes on the solar site (2.34 km) compared to the reference site (1.36 km) but mean distance did not vary among years or between males and females. The interaction between site and year was significant (Table 16) with mean distances declining on the solar site across years but increasing on the reference site (Table 15). The interaction between sex and year also was significant (Table 16) with mean movements increasing from Year 1 to Year 3 for females (1.28 km, 2.08 km, and 2.07 km, respectively) and decreasing for males (2.28 km, 1.90 km, and 1.53 km, respectively).

Table 15. Mean long distance movements by San Joaquin kit foxes by sex, site, and year on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

		Mean distance (km)					
		Males		Females		All	
Site	**Year**	**n**	**$\bar{x}$ (SE)**	**n**	**$\bar{x}$ (SE)**	**n**	**$\bar{x}$ (SE)**
Solar	1	4	3.30 (0.54)	3	1.77 (0.63)	7	2.53 (0.41)
	2	9	2.42 (0.36)	3	3.00 (0.63)	12	2.71 (0.36)
	3	7	1.73 (0.41)	8	1.94 (0.38)	15	1.83 (0.28)
	All	20	2.48 (0.26)	14	2.24 (0.32)	34	2.34 (0.21)
Reference	1	6	1.25 (0.44)	4	0.80 (0.54)	10	1.03 (0.35)
	2	6	1.38 (0.44)	10	1.16 (0.34)	16	1.27 (0.28)
	3	6	1.33 (0.44)	11	2.21 (0.54)	17	1.77 (0.28)
	All	18	1.32 (0.26)	25	1.39 (0.24)	43	1.36 (0.18)

During the three years of the study, kit foxes were tracked to dens 516 times; 289 times for solar site foxes and 227 times for reference site foxes. A total of 277 unique dens were identified through tracking (Fig. 19). Solar site foxes used 145 different dens, 79 of which were within the fenced solar facility. Reference site foxes used 132 different dens. For solar site foxes, the mean (± SE) proportion of dens used by each fox that were located within the solar facility was 72.6 ± 11.7% in Year 1, 61.0 ± 11.5% in Year 2, and 50.4 ± 6.8% in Year 3.

Table 16. Results of an analysis-of-variance of the effects of sex, site, and year on the mean exploratory distances for San Joaquin kit foxes on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

Source	Sum of Squares	df	Mean Square	*F*	*p*
Corrected Model	31.08	11	2.825	2.41	0.014
Intercept	222.16	1	222.16	189.70	<0.001
Sex	0.13	1	0.13	0.11	0.738
Site	16.20	1	16.20	13.83	<0.001
Year	0.60	2	0.30	0.25	0.776
Sex * Site	0.40	1	0.40	0.34	0.560
Sex * Year	6.27	2	3.14	2.68	0.076
Site * Year	8.42	2	4.21	3.59	0.033
Sex * Site * Year	2.57	2	1.29	1.10	0.339
Error	76.13	65	1.17		
Total	361.02	77			
Corrected Total	107.20	76			

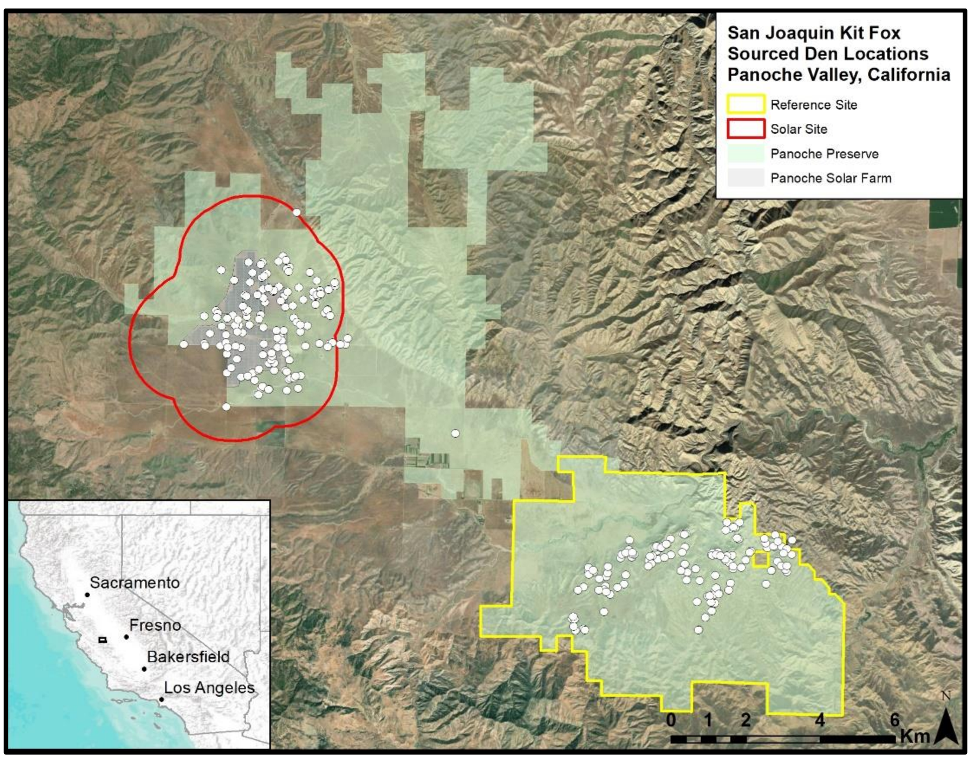


Figure 19. Den locations for San Joaquin kit foxes on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

Over the study period, 112 natal dens were identified with 85 of these on the reference site and 27 on the solar site (Fig. 20). Of the solar site dens, 8 were located within the fenced facility.

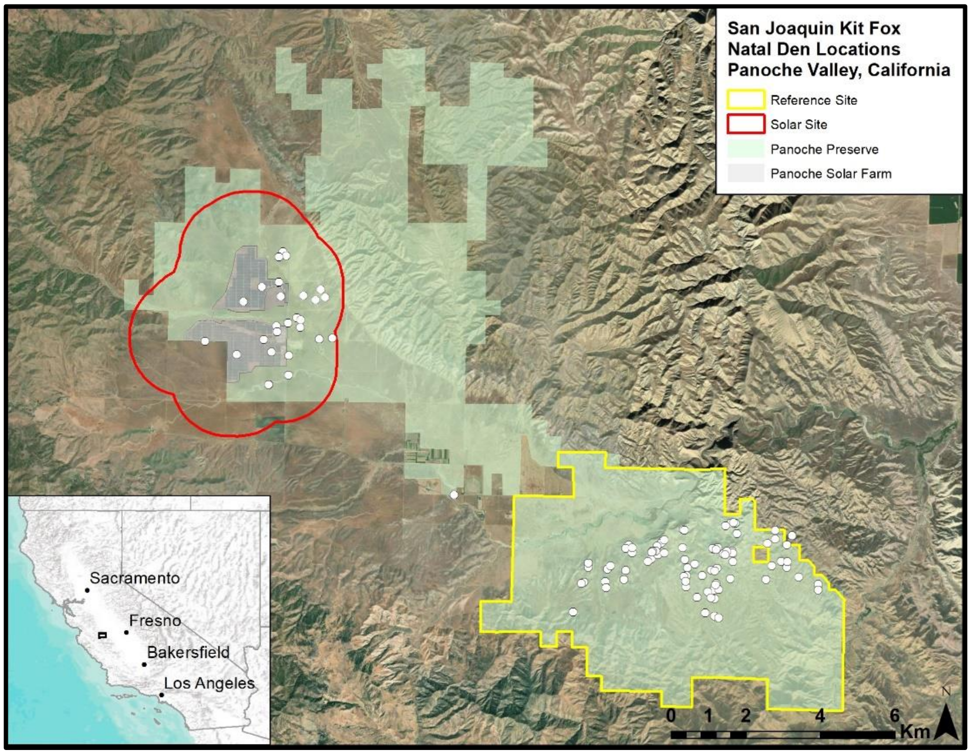


Figure 20. Natal den locations for San Joaquin kit foxes on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

When tracking foxes during the day, they occasionally were found resting above ground instead of in a den. The mean (± SE) proportion of locations above ground was 15.4 ± 3.1% for foxes on the reference site and 13.9 ± 3.4% for foxes on the solar site, and these proportions were not significantly different ($F_{1,72}$ = 0.02, p = 0.895). The proportions did differ among years ($F_{2,72}$ = 4.63, p = 0.013) with Year 2 (21.1 ± 3.7%) being significantly higher than Year 3 (7.6 ± 3.5%) but neither were different statistically from Year 1 (15.2 ± 4.6%). The interaction between year and site was not significant ($F_{2,72}$ = 1.26, p = 0.291).

Across all years combined, the number of kit fox scats collected and analyzed was 378 from the solar site and 530 from the reference site. Food items identified in kit fox scats included rabbit (jackrabbit [*Lepus californicus*] or desert cottontail [*Sylvilagus audubonii*]), kangaroo rat (Heermann's kangaroo rat [*Dipodomys heermanni*] or giant kangaroo rat), San Joaquin pocket mouse (*Perognathus inornatus*), deer mouse (*Peromyscus maniculatus*), house mouse (*Mus musculus*), pocket gopher (*Thomomys bottae*), ground squirrel (California ground squirrel [*Otospermophilus beecheyi*] or San Joaquin antelope squirrel [*Ammospermophilus nelsoni*]), woodrat (*Neotoma spp.*), unidentified bird and eggshells (Class Aves), unidentified snake (Order Squamata), unidentified lizard (Order Squamata), Jerusalem cricket (Family Stenopelmatidae), camel cricket (Family Rhaphidophoridae), field cricket (Family Gryllidae), grasshoppers (Order Orthoptera), earwig (*Forficula auricularia*), darkling beetle (*Eleodes* spp.), June beetle (*Phyllophaga spp.*), other unidentified beetles and larvae (Order Coleoptera), scorpion (Order Scorpiones), solpugid (Order Solifugae), and domestic animal or other anthropogenic material (e.g., twine, rubber pieces). Use of individual food items generally was similar between the solar site and the reference site (Table 17) with a few exceptions. Use of rodents by foxes was consistently high on both sites. However, the rodents consisted primarily of kangaroo rats on the reference site while foxes on the solar site also commonly consumed ground squirrels. Invertebrates, particularly crickets, beetles, and grasshoppers, commonly were consumed on both sites.

The similarity in use of food items by foxes on the solar and reference sites was even more pronounced when items were grouped into broader categories (Table 18, Fig. 21). Use of item categories was significantly similar among years on both the solar site (W = 0.93, $\chi_6^2 = 16.69$, $p = 0.010$) and the reference site (W = 0.89, $\chi_6^2 = 16.01$, $p = 0.014$). For all years combined, use of item categories was significantly similar between the solar and reference sites (W = 0.78, $\chi_6^2 = 28.24$, $p < 0.01$). Based on Shannon indices (Table 18, Fig. 22), dietary diversity generally was similar between sites although trended higher on the solar site. Birds and reptiles were consumed occasionally by solar site foxes but only rarely by reference site foxes and this may have contributed to the slightly higher diversity indices for the solar fox diets.

Table 17. Frequency of occurrence of food items in San Joaquin kit fox scats by site and year on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

	Frequency of occurrence (%)							
	Year 1		Year 2		Year 3		Total	
Food item	Sol	Ref	Sol	Ref	Sol	Ref	Sol	Ref
Rabbit	1	1	1	1	5	1	2	1
Kangaroo rat	44	49	36	46	41	57	40	50
Pocket mouse	8	1	3	0	10	0	7	1
Deer mouse	1	0	1	0	1	0	1	0
Woodrat	0	0	0	1	0	0	0	1
Ground squirrel	7	1	23	2	8	2	13	2
Gopher	3	0	0	0	0	1	1	1
Unknown rodent	34	40	32	43	28	35	31	40
Bird	6	0	8	0	8	0	7	0
Snake	3	0	3	1	1	1	2	1
Jerusalem cricket	3	7	6	17	5	7	5	10
Camel cricket	0	1	2	5	0	0	1	2
House cricket	4	15	1	1	3	3	2	7
Field cricket	7	2	2	3	6	11	5	5
Grasshopper	8	5	10	18	34	15	18	12
Beetle	1	1	4	7	2	2	2	4
Beetle larva	1	1	9	10	21	26	11	10
Unknown insect	2	10	10	15	3	7	5	11
Scorpion	0	3	1	10	0	6	1	6
Solpugid	5	1	1	5	2	4	3	3
Anthropogenic	0	0	0	1	1	0	1	1
No. scats	106	209	138	190	134	131	378	530

Table 18. Frequency of occurrence of food items by item category and Shannon diversity indices for San Joaquin kit fox diets by site and year on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

	Frequency of occurrence (%)							
	Year 1		Year 2		Year 3		Total	
Food category	**Sol**	**Ref**	**Sol**	**Ref**	**Sol**	**Ref**	**Sol**	**Ref**
Rabbit	1	1	1	1	5	1	2	1
Rodent	93	89	91	91	84	92	89	90
Bird	6	0	8	0	8	0	7	0
Reptile	3	0	3	1	1	1	2	1
Invertebrate	26	40	44	64	59	64	44	55
Anthropogenic	0	0	1	1	1	0	1	1
No. scats	106	209	138	190	134	131	378	530
Diversity index	0.37	0.28	0.44	0.34	0.46	0.32	0.44	0.32

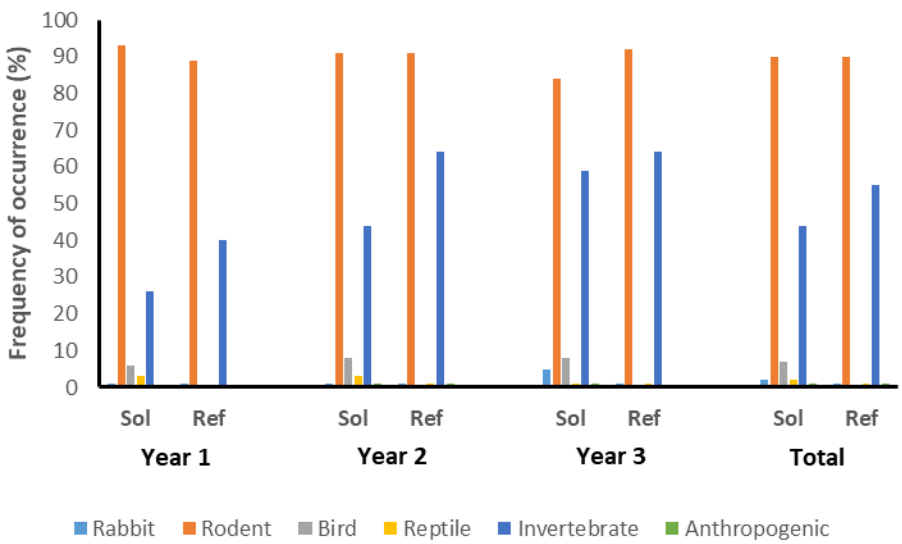


Figure 21. Frequency of occurrence of food items by item category for San Joaquin kit fox diets by site and year on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

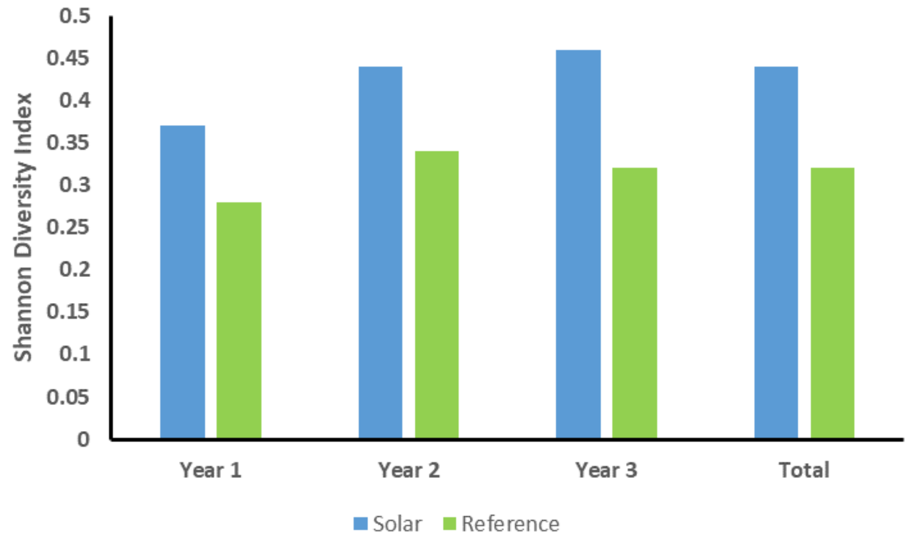


Figure 22. Shannon diversity indices for San Joaquin kit fox diets by site and year on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

Mean kit fox weight (Table 19) did not differ between solar and reference sites for adult females in summer ($t_{1,11} = -1.08$, $p = 0.304$) or winter ($t_{1,24} = 1.51$, $p = 0.145$). Similarly, mean weight did not differ between sites for adult males in summer ($t_{1,12} = -1.15$, $p = 0.274$) or winter ($t_{1,22} < -0.01$, $p = 0.999$).

Table 19. Mean weight of San Joaquin kit foxes by season, study site, and sex on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

		Mean weight (kg) (SE)			
Season	**Site**	*n*	Male	*n*	Female
Summer (May to Jul)	Solar	8	2.55 (0.04)	8	2.18 (0.03)
	Reference	6	2.67 (0.11)	5	2.30 (0.14)
Winter (Sep to Jan)	Solar	13	2.67 (0.04)	10	2.25 (0.04)
	Reference	11	2.67 (0.08)	16	2.17 (0.03)

Food items identified in coyote scats included rabbit, kangaroo rat, pocket mouse, vole (*Microtus californicus*), pocket gopher, ground squirrel, unidentified bird and eggshells, unidentified snake and lizard, Jerusalem cricket, field cricket, house cricket, camel cricket, grasshoppers, earwig, darkling beetle, June beetle, other unidentified beetles and larvae, scorpion, solpugid, domestic animal (likely cattle), and fruits including juniper berries (*Juniperus* spp.), cherry (*Prunus* spp.), and honey mesquite (*Prosopis glandulosa*). Use of individual food items varied between the solar and reference sites (Table 20) with coyotes on the solar site consuming more ground squirrels and juniper berries while coyotes on the reference site consumed more kangaroo rats and a greater diversity of fruits. When grouped into broader categories (Table 21) there was relatively little difference between coyote diets on the solar and reference sites. Anthropogenic items included domestic animals, mostly cattle, but it is unknown whether this constitutes predation or scavenging. Dead cattle were occasionally observed on both sites.

When compared with use of food items by kit foxes (Table 21), coyotes more frequently consumed rabbits, reptiles, fruits, and anthropogenic materials on the solar site, and more rabbits, birds, and fruits on the reference site. Dietary diversity indices for coyotes were 0.72 on the solar site and 0.74 on the reference site, and were higher than the corresponding indices for kit foxes.

Table 20. Frequency of occurrence of items in coyote scats by site on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

	Frequency of occurrence (%)	
Food item	**Solar**	**Reference**
Rabbit	11	12
Kangaroo rat	13	24
Pocket mouse	1	0
Vole	0	1
Ground squirrel	36	5
Gopher	1	5
Unknown rodent	5	12
Bird	11	8
Snake	10	4
Lizard	0	1
Jerusalem cricket	0	3
Other cricket	4	3
Grasshopper	19	9
Beetle	10	19
Beetle larva	13	7
Other invertebrate	4	5
Juniper berries	45	36
Other fruit	0	10
Anthropogenic	7	5
No. scats	142	113

Table 21. Frequency of occurrence of food items by item category in coyote and San Joaquin kit fox scats by site on the solar and reference sites during June 2019-May 2022 in the Panoche Valley, San Benito County, CA.

	Frequency of occurrence (%)			
	Solar		Reference	
Food category	**Coyote**	**Kit fox**	**Coyote**	**Kit fox**
Rabbit	11	2	12	1
Rodent	51	89	43	90
Bird	11	7	9	0
Reptile	10	2	4	1
Invertebrate	40	44	34	55
Fruit	45	0	46	0
Anthropogenic	7	1	5	1
No. scats	142	378	133	530

DISCUSSION

KIT FOX DEMOGRAPHIC COMPARISONS

We assessed kit fox survival and mortality patterns at the PVSF using several approaches. We did not find any evidence that the facility was adversely impacting kit fox survival. Based on the analyses we conducted, kit fox survival did not differ between the solar and reference sites. Furthermore, two solar site foxes died outside of the 1.5-km buffer that defined the solar site. Exclusion of these individuals from the analyses potentially would have resulted in even higher survival estimates for solar site foxes.

Survival rates of adult kit foxes on the solar site and reference site were among the highest of those reported for San Joaquin kit foxes in other multi-year studies (Table 28). Similar studies to this one were conducted previously on the Topaz Solar Farms (Cypher et al. 2019*b*) and the California Valley Solar Ranch (H.T. Harvey and Associates 2019), both in eastern San Luis Obispo County. In both of these studies, kit fox survival probability values were higher on the solar sites compared to the associated reference sites (Table 22), although the values were not significantly different between the solar and reference sites.

High survival rates on the solar site are not necessarily surprising. As with other canids, kit foxes possess a considerable capacity to adapt to anthropogenically altered environments. At the Naval Petroleum Reserves in California, kit fox survival was higher in areas with oil field activities compared to undeveloped areas (0.57 vs 0.38; Cypher et al. 2000), and in another study the rates were similar between oil field and undeveloped areas (Spiegel and Disney 1996). Also, survival rates trended higher in an urbanized area compared to natural habitat areas (Cypher 2010). Clearly, kit foxes are able to tolerate disturbance associated with anthropogenically altered areas and also may benefit from reduced abundance of natural predators in these areas, particularly coyotes, bobcats, and golden eagles (*Aquila chrysaetos*). The security fencing around solar facilities is designed to be permeable to kit foxes but may inhibit entry by larger predators into the solar array areas and the solar panels may provide some cover to the foxes from aerial attack by golden eagles.

A significant year by site interaction was detected. Survival on the solar site was relatively consistent across years. However, survival declined noticeably on the reference site from Year 1 to Year 3. The reason for this is unclear. However, we found more coyote scats in Years 2 and 3 indicating that coyote abundance may have increased. No real changes were detected on the reference site across the years. Survival did not differ between male and female kit foxes.

For all years combined, the mortality indices we calculated (mortalities per 1000 monitoring days) were almost identical for the solar and reference sites. However, annual indices were consistent with the variable survival across years on the solar site and the declining survival on the reference site. This index has the advantage that it can easily be compared between studies with disparate methods. The indices for the two study sites at the PVSF were among the lower of values derived for multi-year studies at other locations (Table 23).

Table 22. Mean annual adult survival probabilities ($\hat{S}$) reported for San Joaquin kit foxes in various multi-year studies.

Location	Study years	No. foxes	$\hat{S}$	Data source
California Valley Solar Ranch – solar site, eastern San Luis Obispo County	2014-17	24	0.76	H.T. Harvey and Associates 2019
Panoche Valley Solar Farm – reference site, eastern San Benito County	2019-22	26	0.75	This study
Lokern Natural Area, western Kern County	2001-04	41	0.71	Cypher et al. 2009
Panoche Valley Solar Farm – solar site, eastern San Benito County	2019-22	23	0.66	This study
California Valley Solar Ranch – reference site, eastern San Luis Obispo County	2014-17	26	0.66	H.T. Harvey and Associates 2019
Topaz Solar Farms – solar site, eastern San Luis Obispo County	2014-17	17	0.65	Cypher et al. 2019*b*
Camp Roberts, northern San Luis Obispo County	1988-91	67	0.53	Standley et al. 1992
Topaz Solar Farms – reference site, eastern San Luis Obispo County	2015-17	35	0.49	Cypher et al. 2019*b*
Naval Petroleum Reserves in California, western Kern County	1980-95	341	0.44	Cypher et al. 2000

Unfortunately, the cause of death could not be conclusively determined for any of the collared foxes found dead during the study. Either the carcasses could not be recovered (e.g., deep in dens) or too few remains were found (Fig. 23). In a number of cases, only the radio-collar was found (Fig. 23). In these cases, the foxes may have been consumed by a predator or a scavenger. However, based on the locations of the mortalities and the scant evidence that was available, there was no evidence to suggest that any of the foxes died as a direct result of solar farm operations and maintenance activities. Similarly, no foxes appeared to have died due to solar site operations at the Topaz Solar Farms and California Valley Solar Ranch (Cypher et al. 2019*b*, H.T. Harvey and Associates 2019). For the solar site foxes in the PVSF study, none of the mortality sites were located within the fenced solar facility. Furthermore, two of the mortality sites were located outside of 1.5-km buffer that defined the solar study site.

Table 23. Mortality index (adult deaths/1000 monitoring days) for multi-year studies on San Joaquin kit foxes.

Study site	Source	No. foxes	Monitoring days	Deaths	Deaths/1000 days
California Valley Solar Ranch – solar site, eastern San Luis Obispo County	H.T. Harvey and Associates 2019	24	7,818	6	0.77
Lokern Natural Area, western Kern County	Cypher et al. 2009	41	15,313	16	1.04
Panoche Valley Solar Farm – solar site, eastern San Benito County	This study	23	9,225	10	1.08
Panoche Valley Solar Farm – reference site, eastern San Benito County	This study	26	10,113	11	1.09
California Valley Solar Ranch – reference site, eastern San Luis Obispo County	H.T. Harvey and Associates 2019	26	7,819	9	1.15
Topaz-solar, eastern San Luis Obispo County	Cypher et al. 2019*b*	17	5,890	7	1.19
Camp Roberts, eastern San Luis Obispo County	Standley et al. 1992	67	20,366	35	1.72
Topaz-reference, eastern San Luis Obispo County	Cypher et al. 2019*b*	35	8,184	16	1.96
Elk Hills, western Kern County	Cypher et al. 2000	341	94,521	225	2.38

Figure 23. Remains (left) and a radio-collar (right) from dead San Joaquin kit foxes in the Panoche Valley Solar Farm study, San Benito County, CA.

Larger predators such as coyotes and bobcats are common sources of mortality for kit foxes (Cypher 2003). Coyotes were commonly observed on both the solar and reference site. Coyotes were only infrequently observed inside the fenced arrays. However, the frequency of such observations increased in the final year of the study. Cattle apparently were creating holes in the security fence in order to feed within the arrays (Fig. 24) and we noted a corresponding increase in coyote observations within the arrays. However, no increase in kit fox mortality was observed concomitant with the increased access to the solar facility by coyotes.

Bobcats were present on both the reference and solar sites, based on occasional observations and detections at camera stations operated by CNLM staff. Bobcats were not detected within the fenced arrays although they likely could access the arrays either through the same holes in the fencing that coyotes were using or by climbing over the fence. Bobcats were regularly observed inside the fence arrays at the Topaz Solar Farms and were observed on several occasions scaling the security fences to access the arrays (Cypher et al. 2019*b*). Bobcats also were suspected of having caused the mortality of a number of foxes in the Topaz study. Bobcats have been identified as a significant cause of kit fox mortality in other studies (Benedict and Forbes 1979, Spiegel and Disney 1996, Cypher et al. 2000, Cypher et al. 2014). Badgers (*Taxidea taxus*) also were commonly observed on both study sites. Badgers have been identified as a cause of mortality for kit foxes (e.g., Standley et al. 1992), but such mortality apparently is quite rare.

Figure 24. **Cow near a kit fox den in the solar panels on the Panoche Valley Solar Farm, San Benito County, CA.**

Potential kit fox predators are abundant in Panoche Valley including coyotes, bobcats, golden eagles, badgers, and free-roaming domestic dogs. Coyotes are present throughout the range of the kit fox and commonly kill kit foxes. Much of this mortality is assumed to constitute interference competition, particularly because the fox carcasses commonly are not consumed by the coyotes (Cypher and Spencer 1998, Ralls and White 1995). Mortality from bobcats appears to constitute more classic predation in that the fox carcasses typically are consumed. Many of the carcasses of dead foxes in this study appear to have been consumed although it is unknown whether a predator or scavenger consumed the carcass. Golden eagles can be significant predators of kit foxes (Cypher et al. 2019*a*) and were commonly observed around both the reference and solar sites. A collar from a dead fox actually was found in a tree suggesting avian predation, although a scavenger could have been responsible as well.

None of the foxes in our study were killed by vehicles. However, two non-study foxes were opportunistically found dead on Little Panoche Road. One of these mortalities occurred within the 1.5-km buffer defining the solar site and one occurred outside of the buffer. Little Panoche Road runs along the east boundary of the PVSF and is the road primarily used to access the facility. A lower speed limit (25 mph) is in place along the stretch of this road passing by the solar facility and surrounding conservation lands. Compliance with the limit is reasonably good among drivers associated with the solar facility, possibly due to disincentives implemented by the facility owner for non-compliance. However, Little Panoche Road is a public road used extensively by local residents and compliance with the speed limit has been observed to be lower among these drivers. Several kit foxes were also killed along this road in a previous study conducted prior to construction of the PVSF (CSUS ESRP, unpublished data).

No other sources of mortality were identified during our study. However, three foxes that were found dead in winter/spring just before the study was initiated tested positive for canine distemper virus (CDV). CDV was assumed to be the cause of death for these foxes (CSUS ESRP, unpublished data). Disease generally is not a significant cause of mortality for kit foxes outside of urban environments (Cypher et al. in press). CDV did cause some mortality among desert kit foxes near a solar facility in the Mojave Desert during construction (J. Rudd, CDFW, personal communication). Given the fact that dead foxes with CDV were found in the Panoche Valley just prior to this study, the potential exists that some of our study foxes may have died of CDV but were not recovered prior to scavenging or died down in dens and therefore could not be tested.

Almost all of the adult female foxes that we monitored on both the solar site and the reference site successfully reproduced based on observations of pups with these females (Fig. 25). Reproductive success also was similar between the solar sites and reference sites in the Topaz Solar Farms and California Valley Solar Ranch studies (Cypher et al. 2019*b*, H.T. Harvey and Associates 2019). Reproductive success is largely a function of adequate food resources being available to support gestation and lactation and eventually the provisioning of the pups with prey items (Cypher 2003). Food resources apparently were sufficiently abundant on both the solar and reference sites to support successful reproduction. In particular, abundance of giant kangaroo rats was high throughout Panoche Valley during all years of the study (Center for Natural Lands Management, unpublished data). Kit foxes are highly adept at foraging on kangaroo rats. Kit foxes were frequently observed bringing kangaroo rats back to natal dens to feed to pups (Fig. 26). This abundance of kangaroo rats likely contributed considerably to the high rates of reproductive success that we observed in this study.

Figure 25. San Joaquin kit fox pups at a natal den under solar panels in March 2020 at the Panoche Valley Solar Farm, San Benito County, CA.

Figure 26. San Joaquin kit fox on the reference site returning to a natal den with four giant kangaroo rats in March 2020, Panoche Valley, San Benito County, CA.

KIT FOX ECOLOGICAL COMPARISONS

Space use by individuals of a given species is largely determined by social ecology (e.g., mating system, territoriality) and habitat quality (e.g., the abundance and dispersion of critical resources such as food, water, and cover). Kit foxes are socially monogamous, not gregarious, and not highly territorial (Geffen et al. 1996, Macdonald et al. 2004, Ralls et al. 2007). Therefore, space use is primarily determined by spatial and temporal patterns in resource availability, especially food. In particular, home range size in canids tends to be inversely related to food availability (Macdonald 1981, Macdonald et al. 2004). Thus, if food resources are more abundant per unit area, then animals can fulfill energy requirements in a smaller area. Also, decreased foraging time reduces exposure to predators. At a study site in Utah, desert kit foxes with smaller home ranges were in better condition and had higher survival rates compared to foxes with larger home ranges (O'Neal et al. 1987). Similarly, San Joaquin kit foxes on the Carrizo Plain National Monument also had smaller home ranges and higher survival when prey were abundant (Cypher et al. 2022).

In the PVSF study, kit fox home ranges were over twice as large on average on the solar site compared to the reference site and core areas were almost four times as large. Similarly, in the Topaz Solar Farms study, kit fox home ranges on the solar site were about twice as large as those on the reference site. The marked difference in size in the PVSF study indicated that habitat quality, particularly food availability, may have been considerably higher on the reference site. This is not surprising as the disturbances associated with construction of the solar facility very likely resulted in at least a temporary reduction in prey abundance. Also, over 600 endangered giant kangaroo rats were translocated from the project site before or during facility construction (B. Vanherweg, personal communication) and this certainly significantly reduced the abundance of an important prey species. Kangaroo rats, most likely giant kangaroo rats, were the primary item in kit fox diets on both the reference and solar sites.

When compared to home range estimates from other multi-year studies in natural lands, the home range size estimate for the reference site was the smallest report (Table 24). This is a reflection of the very high quality of the habitat on the reference site. The solar site estimate, although much higher, was not dissimilar from estimates in studies in core habitat areas. Also, home ranges of solar site foxes declined noticeably by Year 3 suggesting that food availability may have been increasing over time on the solar site. Similarly, reductions in home range sizes also were observed at the Topaz Solar Farms and the California Valley Solar Ranch (Cypher et al. 2019*b*, H.T. Harvey and Associates 2019). Following completion of solar farm construction, disturbance levels on the facilities become quite low and this may facilitate recovery by prey populations.

The analysis of the proportion of locations for solar site foxes on versus off of the solar facility revealed interesting trends. Based on night locations when kit foxes typically are out of their dens and actively foraging, the foxes spent about one-fifth of their time on the solar facility on average. In contrast, on average over half of their day locations, when the foxes typically are resting in or near dens, were within the fenced facility. Thus, foxes apparently were commonly traveling outside of the facility to forage but then returning to the facility to rest. These movement patterns may have contributed to the larger home range sizes observed among solar site foxes. Foxes may have felt more secure inside the security fence where access by larger predators, particularly coyotes, was inhibited and where the solar panels may have provided some cover from attack by golden eagles. However, for both night and day locations, the proportion on the solar facility actually decreased markedly over the three years of the study with the proportions in Year 3 being about half of what they were in Year 1. The reason for this is unclear.

Table 24. Home range size estimates from multi-year studies on San Joaquin kit foxes where similar analytical techniques were used to derive the estimates.

Study site	Source	Home range method	Mean home range size (km^2)
Panoche Valley Solar Farm – reference site, eastern San Benito County	This study	95% MCP[1]	2.4
California Valley Solar Ranch – solar site, eastern San Luis Obispo County	H.T. Harvey and Associates 2019	95% MCP	3.9
California Valley Solar Ranch – reference site, eastern San Luis Obispo County	H.T. Harvey and Associates 2019	95% MCP	4.2
Topaz-reference site, eastern San Luis Obispo County	Cypher et al. 2019*b*	95% MCP	5.1
Lokern Natural Area, western Kern County	Spiegel 1996	95% MCP	5.8
Lokern Natural Area, western Kern County	Nelson et al. 2007	95% fixed kernel	5.9
Panoche Valley Solar Farm – solar site, eastern San Benito County	This study	95% MCP	6.1
Topaz-solar site, eastern San Luis Obispo County	Cypher et al. 2019*b*	95% MCP	9.4

[1] MCP = minimum convex polygon.

Routine movements by kit foxes were similar to home range patterns in that mean distances moved were longer on the solar site. Thus, patterns in movement distances mirrored space use patterns. The greater distances on the solar site likely were related to lower prey densities necessitating foraging over a larger area to meet daily food requirements. In Arizona, distances traveled by kit foxes were greater in habitats with lower prey abundance (Zoellick et al. 1989).

The longer “exploratory” movements observed among solar foxes were consistent with the location and routine nightly movements results. Foxes may initially have been exploring more in response to disturbances associated with the solar farm construction, but then reduced these movements as they settled into specific home range areas. However, exploratory movement distances by foxes on the reference site, where no disturbances were occurring, actually increased from Year 1 to Year 3. Thus, movement patterns by the solar site foxes may have been related to some factor other than disturbance.

Three foxes exhibited very long movements (Fig. 27). Two of these, a male and a female, did so as juveniles and likely were exploring new areas in which to potentially disperse. Both left the solar site and traveled north to the vicinity of the Little Panoche Reservoir, and one also traveled to lands near the reference site. Interesting, both eventually returned to the solar site and settled into home ranges. The third fox was more of an enigma. This was a large adult female who had a home range on the reference site but made repeated trips (at least 22) south to the New Idria area where, based on GPS points from her collar, she appeared to have a second home range area. We eventually lost track of this fox and her fate is unknown.

Dens are a critical aspect of kit fox ecology (Grinnell et al. 1937, Koopman et al. 2001, Cypher 2003). Kit foxes are primarily nocturnal and typically rest in dens during the day. Dens are used year-round and also aid in avoiding temperature extremes (especially heat), conserving moisture, evading predators, and rearing pups. Kit foxes use multiple dens that are distributed throughout their home ranges. Ground-disturbing activities, such as the construction of a solar farm, potentially could affect den availability or den use patterns. However, denning opportunities on the PVSF appeared to be abundant. In addition to many earthen dens, foxes were tracked a number of times to artificial dens, escape dens, culverts, under sea-trains, and under pallets inside the solar facility. Of the unique dens used by solar site foxes, more were located on the facility compared to the number used on lands outside of the facility. The decline in the proportion of dens that was on the facility from Year 1 to Year 3 was consistent with the decline in the proportion of day locations on the facility.

Natal dens occurred on the solar site, including within the fenced facility. Natal dens appear to be carefully selected by kit foxes. Also, once litters of pups have been successfully raised in a den, it commonly is used in subsequent years to raise young. Thus, natal dens may accumulate slowly over time. The presence of at least eight natal dens with the facility in the first three years following completion of construction indicates that foxes are comfortable raising young on the site.

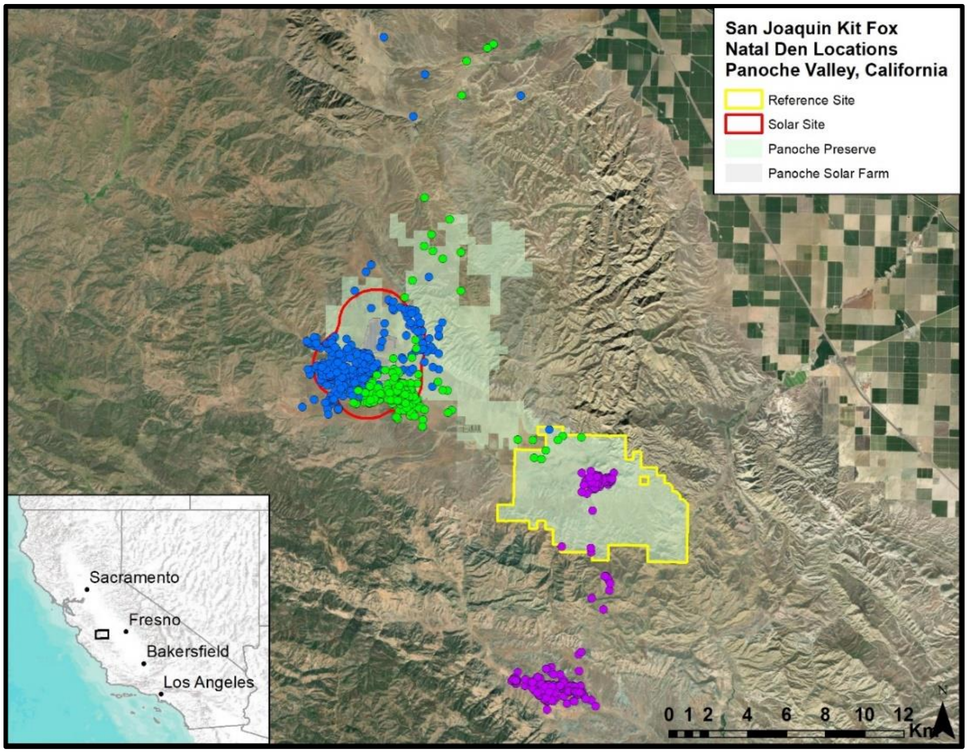


Figure 27. Unusually long-distance movements by three San Joaquin kit foxes, Panoche Valley, San Benito County, CA. The blue and green icons are locations for two juvenile foxes while the purple icons are locations for an adult female.

Occasionally, kit foxes are found above ground during the day (Morrell 1972, Egoscue 1962). Above ground activity is more common in the spring when pups are present, but kit foxes also will occasionally bask outside of dens at other times of year. On rare occasions, kit foxes are found traveling above ground during the day. In what may be a more extreme example, kit foxes at Camp Roberts in northern San Luis Obispo County were found above ground 17% of the time when tracked during the day (Reese et al. 1992). Above ground activity could be indicative of disturbance, such as ground vibrations, that might cause foxes to leave dens. However, in the PVSF study, the proportions of above ground locations was similar between the solar and reference sites. Similarly, the proportion of above ground locations also was similar between solar and reference sites at the Topaz Solar Farms (Cypher et al. 2019*b*).

Use of food items was very similar between the solar and reference sites. Typical of findings from other locations (Morrell 1972, Spiegel et al. 1996, White et al. 1996, Cypher et al. 2000, Cypher 2003, Nelson et al. 2007, Cypher et al. 2014, Cypher et al. 2022), nocturnal rodents and invertebrates were the primary items consumed by kit foxes on both sites. Nocturnal rodents, particularly Heteromyids such as kangaroo rats and pocket mice, are preferred prey for kit foxes, and indeed, kit foxes are considered to be “kangaroo rat specialists” (Grinnell et al. 1937, Laughrin 1970). Thus, habitat suitability increases with increasing kangaroo rat abundance (Cypher et al. 2013). Based on monitoring conducted by CNLM (unpublished data), giant kangaroo rats were abundant on both the reference site and the solar site. However, this monitoring was conducted on lands outside of the solar facility and the abundance of giant kangaroo rats within the facility is unknown.

Foxes on the solar site consumed ground squirrels more frequently than foxes on the reference site. Most squirrels consumed were likely California ground squirrels, which appeared to be more abundant on the solar site, based on casual observation. Foxes on both sites also extensively consumed invertebrates. Invertebrates commonly comprise a significant proportion of kit fox diets (Spiegel et al. 1996, Cypher 2003, Cypher et al. 2014, Cypher et al. 2022). There were very few occurrences of anthropogenic items in kit fox scats.

It is unknown whether overall food availability differed between the solar and reference sites. However, food resources clearly were not a limiting factor on either of the sites during the study. This was evident in the relatively high survival and reproductive success rates on both sites, and the lack of differences in these rates or fox weights between the sites. Survival, reproductive success, and body weight all can decline during periods when food availability is lower (White and Ralls 1993, Warrick and Cypher 1999, Cypher et al. 2000, Cypher et al. 2014, Cypher et al. 2022).

Coyotes and kit foxes used many of the same food items as has been reported in previous studies (White et al. 1995, Nelson et al. 2007, Cypher and Spencer 1998, Cypher et al. 2022). However, coyotes used them in different proportions and also consumed items, such as fruits, that were not consumed by kit foxes. The diversity of coyote diets on both the solar and reference sites was markedly higher than that of kit foxes. Coyotes have considerably larger home ranges and this may allow them to access more foods. For example, most of the fruits consumed by coyotes were not present on either of the study sites. Junipers only occur higher up in the surrounding hills. Grapes and cherries may have come from wild sources but also could have come from anthropogenic sources such as ornamental or garden plants located around residences.

CONCLUSIONS AND CONSERVATION IMPLICATIONS

We assessed multiple demographic and ecological attributes of San Joaquin kit foxes at the PVSF in an effort to identify any adverse impacts to foxes from a utility-scale solar powered generating facility. Over three years, we compared these attributes for foxes on a study site encompassing the facility to foxes on a nearby site with habitat conditions characteristic of the Panoche Valley ecoregion. In particular, we examined critical demographic attributes, such as survival, causes of mortality, and reproduction, along with ecological patterns that might affect these attributes, such as space use, den use, and food habits. Some differences in attributes and patterns between sites were identified, but none were indicative of significant adverse impacts associated with the solar facility.

A significant finding was that survival of foxes did not differ between the solar and reference sites, and for some indices it was virtually identical. This finding is important in that regardless of any differences in ecological responses to the solar site, fox survival was not adversely affected. Although sources of mortality were not well delineated in this study, none of the circumstances regarding the deaths of the solar site foxes suggested that operations or maintenance activities at the facility might have contributed to the deaths.

The larger home ranges of solar site foxes, the greater proportion of night locations, and the movement indices all suggested that foxes likely were moving off of the solar facility to forage. This was not surprising because prey availability likely was lower on the facility due to ground disturbance associated with construction and also the fact that over 600 giant kangaroo rats were translocated off of the facility during construction. Kit foxes still appeared to largely be returning to the solar facility for daytime denning and resting. They may have felt more secure within the facility as the security fencing likely reduced entry by coyotes and the panels provide some cover from aerial attack by golden eagles. Foxes exhibited less use of the solar facility in the final year of the study. Potentially, this may have been due to increased coyote presence within the fenced arrays as a result of cattle damaging the security fence and creating openings.

Food availability apparently was not a limiting factor on either the solar site or reference site during the study. This is based on the high survival and reproductive success observed on both sites and similar fox weights. Kit foxes were primarily consuming rodents and invertebrates. Kangaroo rats are extremely abundant in the Panoche Valley ecosystem and unsurprisingly were the primary rodents consumed on both sites. Solar site foxes more frequently consumed ground squirrels, birds, and reptiles leading to slightly higher dietary diversity indices. It is unknown whether the availability of these items was greater on the solar site although disturbance, such as that associated with the construction of the facility, sometimes create novel niches resulting in higher species diversity.

The assumption that large-scale industrial developments will have significant ecological impacts on a given species is reasonable given that such developments typically result in marked changes to local environmental conditions and ecological processes. However, equally reasonable is the expectation that impacts will vary among species depending upon their ecology, life-history requirements, and adaptive capacity relative to the altered conditions and processes. Our inability to identify adverse impacts to kit foxes associated with the PVSF may not be unusual when viewed in the context of other situations involving kit foxes and landscape-scale developments. Cypher et al. (2000) used data spanning 1980-1995 to assess the response of kit foxes to oil field development on a 216-km^2 study site in Kern County that encompassed the highly developed portions of the Elk Hills and Buena Vista oil fields. Similar to the PVSF study, various demographic and ecological attributes were compared between highly developed (mean habitat disturbance = 26%) and relatively undeveloped areas of the oil field. Also similar to the PVSF study, survival rates were higher in the developed areas and otherwise few differences were found. In another study of oil field effects, Spiegel (1996) and associates also compared various demographic and ecological attributes for kit foxes between an intensively developed site (habitat disturbance >70%) and an undeveloped site in western Kern County. They found no differences in attributes other than that the carrying capacity was lower on the developed site due to the loss of habitat and food habits differed between the sites due to habitat alterations and the presence of anthropogenic foods on the developed site. Finally, in on-going studies of kit fox demography and ecology in the highly urbanized environment within the city of Bakersfield (human population ca. 407,000 as of 2021) in central Kern County, preliminary results indicate that fox survival and reproductive rates are significantly higher, density is higher, and weights are higher compared to foxes in natural lands (Cypher and Frost 1999, Cypher 2010, Cypher and

Van Horn Job 2012). Thus, kit foxes exhibit considerable ecological plasticity and adaptive capacity, and in that regard, our findings from the PVSF study are not unexpected.

Although no significant adverse impacts to kit foxes were identified in the PVSF study, an important caveat is warranted. A number of conservation measures were implemented in the construction and operation of the solar farm, and the intent of these measures was to mitigate or avoid impacts to foxes. Adverse impacts potentially might have occurred in the absence of the measures. These measures included the acquisition and management of off-site conservation lands, management of on-site conservation lands, preservation of movement corridors through the facility, security fencing permeable to foxes, maintenance and management of vegetation in the arrays by grazing, installation of artificial dens, worker education, and beneficial policies including prohibitions on feral dogs, firearms, trash, off-road travel, high vehicle speeds, and biocide use. Among these measures, the permeable fencing may rank among the more important as it not only maintained access and movements by foxes, but also may have functioned to create refugia for foxes from predation by larger predators. Additionally, the maintenance and management of vegetation in the arrays also was important as it is facilitating the recovery of prey species. This is in contrast to the vast majority of solar projects in California where vegetation in the arrays has been completely removed and regrowth is actively prevented (Cypher et al. 2021). Thus, the absence of significant adverse effects at the PVSF, although partly attributable to the adaptability of kit foxes, also is largely attributable to the implementation of a multitude of conservation measures designed to benefit kit foxes. Similarly, numerous conservation measures were implemented at the Topaz Solar Farms and the California Valley Solar Ranch, and these likely contributed to the relative absence of impacts to kit foxes detected in these studies (Cypher et al. 2019*b*, H.T. Harvey and Associates 2019).

The conservation implications of the results of this study are clearly important. As with the Topaz Solar Farms (Cypher et al. 2019*b*), California Valley Solar Ranch (H.T. Harvey and Associates 2019), and other facilities (Cypher et al. 2021), the results of the PVSF study demonstrate that the construction of solar energy facilities can be compatible with kit foxes if they are designed appropriately with "fox friendly" conservation measures. The facilities can be made permeable to kit foxes such that movements are not impeded and opportunities for regional demographic and genetic exchange are maintained. Habitat on the facilities can be managed such that they are sufficiently suitable for kit foxes to occupy and reside on the sites and to successfully reproduce. Despite this, we still highly recommend against siting new solar facilities in high quality habitat for San Joaquin kit foxes or other rare species. Areas that are particularly sensitive within the range of San Joaquin kit foxes were identified in an analysis conducted by Phillips and Cypher (2019). The effects of constructing a facility in high quality habitat are uncertain, and in any regard, doing so would be imprudent as the loss of high quality habitat is the primary factor in the endangerment of San Joaquin kit foxes (U.S. Fish and Wildlife Service 1998). Alternatively, based on the results of this study, siting a facility in non-habitat (e.g., row crops) or low-quality habitat may actually enhance suitability for kit foxes, especially if appropriate conservation measures and site management were implemented. Such enhancement would be particularly beneficial if the facility were sited in an area of unsuitable/low-suitability habitat separating two areas of higher quality habitat, this providing connectivity between these areas (Phillips and Cypher 2019). The Panoche Valley Solar Farm joins the Topaz Solar Farms and the California Valley Solar Ranch in serving as a solid model for designing solar facilities in a manner that minimizes impacts to and even facilitates conservation of kit foxes and other species.

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APPENDIX A – SAN JOAQUIN KIT FOXES CAPTURED AT THE PANOCHE VALLEY SOLAR AND REFERENCE STUDY SITES

Eartag	Sex	Date of 1st Capture	Latitude	Longitude	Age at 1st Capture	Site of 1st Capture	1st Collared	Last Known Fate
6858	F	1/8/2020	36.657079	-120.878611	adult	solar	1/8/2020	deceased
6880	M	6/27/2019	36.635950	-120.896254	adult	solar	6/27/2019	deceased
6966	F	5/14/2019	36.634386	-120.891087	yearling	solar	5/14/2019	collar expired
7076	M	9/22/2020	36.624394	-120.866520	young of the year	solar	NA	not collared
7077	F	9/22/2020	36.650966	-120.892355	young of the year	solar	6/9/2021	collar expired
7078	M	9/22/2020	36.650773	-120.877684	young of the year	solar	12/1/2020	deceased
7079	M	9/22/2020	36.657600	-120.878733	young of the year	solar	NA	not collared
7080	M	9/23/2020	36.644517	-120.878173	adult	solar	9/23/2020	deceased
7081	F	9/23/2020	36.657600	-120.878733	young of the year	solar	NA	not collared
7082	M	9/24/2020	36.639119	-120.867600	young of the year	solar	NA	not collared
7100	M	12/1/2020	36.645868	-120.885512	adult	solar	12/1/2020	collar removed
7170	F	6/12/2019	36.626363	-120.894285	adult	solar	6/12/2019	collar expired
7171	F	6/28/2019	36.579950	-120.719302	young of the year	reference	NA	not collared
7173	F	6/28/2019	36.581640	-120.724747	young of the year	reference	NA	not collared
7189	M	6/13/2019	36.634226	-120.877194	adult	solar	6/13/2019	deceased
7302	F	12/1/2020	36.653116	-120.866354	young of the year	solar	6/11/2021	collar expired
7304	M	12/2/2020	36.631844	-120.907231	yearling	solar	12/2/2020	collar expired
7306	F	12/2/2020	36.624465	-120.874743	young of the year	solar	NA	not collared
7308	F	12/3/2020	36.621607	-120.892880	young of the year	solar	10/15/2021	collar expired
7313	M	12/2/2020	36.583918	-120.725876	adult	reference	12/2/2020	deceased
7314	M	5/27/2021	36.572601	-120.786932	adult	reference	5/27/2021	collar expired

7315	F	6/8/2021	36.635741	-120.880071	adult	solar	6/8/2021	collar expired
7318	M	6/8/2021	36.623446	-120.875993	yearling	solar	6/8/2021	collar expired
7319	F	6/9/2021	36.635741	-120.880071	yearling	solar	6/9/2021	collar removed
7320	F	6/9/2021	36.634751	-120.872194	young of the year	solar	NA	not collared
7321	M	6/9/2021	36.634845	-120.872188	young of the year	solar	NA	not collared
7322	M	6/11/2021	36.643149	-120.869732	yearling	solar	6/11/2021	deceased
7323	M	6/11/2021	36.631930	-120.863314	adult	solar	7/6/2021	deceased
7426	M	10/5/2021	36.575434	-120.746312	adult	reference	10/5/2021	collar expired
7427	F	10/6/2021	36.575695	-120.746158	adult	reference	10/6/2021	collar expired
7428	F	10/7/2021	36.583680	-120.760838	young of the year	reference	NA	not collared
7429	M	10/13/2021	36.639201	-120.896941	young of the year	solar	NA	not collared
7430	M	10/13/2021	36.646218	-120.867637	young of the year	solar	10/13/2021	collar removed
7431	F	10/15/2021	36.646321	-120.867688	young of the year	solar	NA	not collared
7443	M	5/24/2022	36.572348	-120.780462	yearling	reference	NA	not collared
7444	F	5/26/2022	36.583738	-120.741411	young of the year	reference	NA	not collared
7526	F	11/7/2019	36.563377	-120.750618	young of the year	reference	9/16/2020	collar expired
7528	F	11/8/2019	36.583601	-120.752991	young of the year	reference	NA	not collared
7530	M	11/26/2019	36.585217	-120.736873	yearling?	reference	11/26/2019	deceased
7531	M	11/26/2019	36.576288	-120.733558	adult	reference	11/26/2019	deceased
7534	M	1/9/2020	36.650970	-120.877776	yearling	solar	1/9/2020	deceased
7536	M	1/10/2020	36.636093	-120.867291	young of the year	solar	1/10/2020	deceased
7539	M	9/15/2020	36.576855	-120.780948	young of the year	reference	NA	not collared
7540	F	9/15/2020	36.576824	-120.781042	young of the year	reference	6/23/2021	collar expired
7542	F	9/15/2020	36.582335	-120.775660	adult	reference	9/15/2020	collar expired
7543	M	9/15/2020	36.584648	-120.765368	young of the year	reference	NA	not collared
7544	F	9/16/2020	36.582335	-120.775660	young of the year	reference	10/5/2021	deceased
7545	F	9/16/2020	36.583882	-120.741244	yearling	reference	9/16/2020	collar expired
7546	F	9/16/2020	36.577982	-120.732766	adult	reference	9/16/2020	deceased

7548	F	9/17/2020	36.586680	-120.738129	adult	reference	9/17/2020	deceased
7549	F	9/22/2020	36.631918	-120.907260	young of the year	solar	12/1/2020	collar expired
7551	M	5/15/2019	36.634386	-120.891087	young of the year	solar	NA	not collared
7552	M	5/15/2019	36.626271	-120.894115	yearling?	solar	5/15/2019	collar expired
7553	M	7/10/2019	36.592726	-120.758945	young of the year	reference	NA	not collared
7555	M	7/11/2019	36.580351	-120.761691	adult	reference	7/11/2019	collar expired
7556	F	7/11/2019	36.576987	-120.769065	young of the year	reference	NA	not collared
7558	F	7/12/2019	36.581116	-120.761733	adult	reference	7/12/2019	collar expired
7559	M	8/7/2019	36.586598	-120.751820	young of the year	reference	NA	not collared
7560	M	9/18/2019	36.581166	-120.748261	young of the year	reference	NA	not collared
7561	F	9/19/2019	36.581090	-120.748077	young of the year	reference	11/5/2019	collar expired
7562	M	11/5/2019	36.573077	-120.745118	young of the year	reference	NA	not collared
7563	M	11/5/2019	36.571532	-120.773296	yearling	reference	11/5/2019	collar expired
7564	M	11/5/2019	36.571483	-120.773182	adult	reference	11/5/2019	deceased
7566	F	11/5/2019	36.579427	-120.765671	adult	reference	11/5/2019	collar expired
7567	F	11/5/2019	36.583463	-120.752950	young of the year	reference	10/5/2021	deceased
7568	M	11/6/2019	36.573077	-120.745118	adult	reference	11/6/2019	deceased
7569	F	11/6/2019	36.566208	-120.744580	young of the year	reference	11/6/2019	deceased
7570	M	11/6/2019	36.566248	-120.744393	young of the year	reference	NA	not collared
7571	F	11/6/2019	36.563247	-120.750607	young of the year	reference	9/15/2020	collar expired
7572	F	11/6/2019	36.571532	-120.773296	young of the year	reference	5/25/2021	collar expired
7573	F	11/6/2019	36.579319	-120.765598	young of the year	reference	10/6/2021	deceased
7574	F	11/7/2019	36.582712	-120.749651	yearling	reference	11/7/2019	collar expired
7575	F	11/7/2019	36.573077	-120.745118	young of the year	reference	NA	not collared
6969/6669	M	12/1/2020	36.639302	-120.867461	adult	solar	12/1/2020	deceased

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