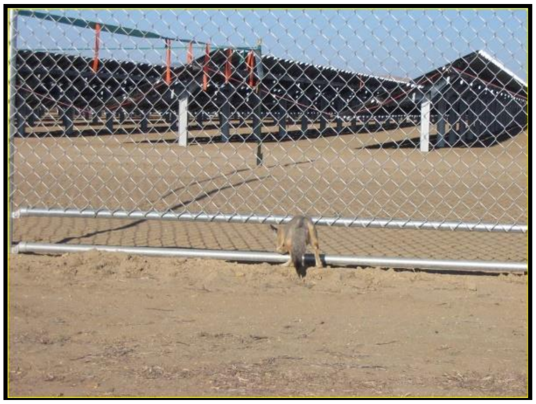
RESPONSE OF SAN JOAQUIN KIT FOXES TO TOPAZ SOLAR FARMS: IMPLICATIONS FOR CONSERVATION OF KIT FOXES

FINAL REPORT



PREPARED FOR:

BHE RENEWABLES
TOPAZ SOLAR FARMS

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EXECUTIVE SUMMARY

The use of solar technology for power generation on a utility scale 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 late 2014, construction of the 1,421-ha Topaz Solar Farms (TSF) was completed on the north end of the Carrizo Plain in eastern San Luis Obispo County, California. The Carrizo ecoregion encompasses vital habitat for a number of rare species, including the federally endangered and state threatened San Joaquin kit fox (*Vulpes macrotis mutica*).

We conducted a 3-year investigation (December 2014-November 2017) of the effects of the TSF on kit foxes. We compared various demographic and ecological attributes for kit foxes using the TSF and lands within 1.5 km ("solar site") to foxes using lands with typical regional habitats >1.5 km from the TSF ("reference site"). Attributes examined included survival, sources of mortality, reproduction, home range size, habitat use, movements, den use, food use and availability, and competitor abundance. Based on calculated annual rates and Cox proportional hazards analyses, survival was not different between the solar and reference sites, although survival rates consistently trended higher on the solar site. Survival and mortality rates on the solar site tended to be more similar to rates observed in core population areas for kit foxes while those on the reference site tended to be more similar to rates observed in satellite population areas. Coyotes (*Canis latrans*), bobcats (*Lynx rufus*), and golden eagles (*Aquila chrysaetos*) were the primary sources of mortality on both sites. However, the security fencing around arrays of solar panels (which was permeable to kit foxes) afforded some protection from larger terrestrial predators, and the solar panels afforded foxes protection from eagles. Thus, the fenced arrays may constitute areas of reduced predation risk and function as refugia for kit foxes. Reproductive success and mean litter size 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 longer exploratory movements. Six habitat types were delineated in the TSF region including solar arrays, stewardship lands, untilled conserved lands, previously tilled conserved lands, untilled private lands, and tilled private lands. The reference site comprised a higher proportion of untilled conserved lands, and these lands supported significantly higher abundance of rodents, particularly kangaroo rats, which are preferred prey of kit foxes. The solar site comprised a higher proportion of previously disturbed (e.g., from tilling and solar plant construction) habitat types that were in various stages of ecological recovery, and rodent abundance was lower in these types. Thus, differences in food availability likely were responsible for the observed differences in space use between the sites. Home range size and fox movements decreased significantly on both sites from Year 1 to Year 3 as regional rodent abundance increased markedly in response to higher annual precipitation.

Kit foxes on the reference site exhibited significant selection for untilled conserved lands while foxes on the solar site used most habitats in proportion to their availability. The lack of selection by foxes on the solar site appeared due to consistent use of arrays and stewardship lands despite relatively low prey availability. Lower predation risk may

have encouraged continued use of these habitats by foxes. Foxes on both sites exhibited avoidance of tilled private lands, where availability of food and escape cover likely were low due to frequent ground disturbance. Use of untilled private lands also was lower than expected for uncertain reasons, although practices adverse to kit foxes and their prey are a potential but unconfirmed cause.

Den use patterns were not different between kit foxes on the solar and reference sites with number of dens used per year and rate of den switching both being similar between sites. The distribution of dens among habitat types mirrored habitat selection by foxes. Dens occurred more frequently in habitats used most often by foxes. Food item use by foxes also was similar between the sites. Rodents and invertebrates were the primary items consumed. Use of rodents was generally higher on the reference site where rodent availability was greater, and use increased on both sites across years as regional rodent abundance increased in response to higher annual precipitation. Coyotes and bobcats were present on both the solar and reference sites, but coyotes appeared mostly excluded from the fenced arrays whereas bobcats occasionally gained entry. Coyote and kit fox diets exhibited considerable overlap indicating the potential for food competition between the species. Thus, due to the exclusion of coyotes, the fenced arrays constituted areas of reduced interference and exploitative competition for kit foxes.

We assessed multiple demographic and ecological attributes of San Joaquin kit foxes over a 3-year period on the TSF and adjacent reference site, and we did not identify any differences in these attributes that indicated adverse impacts to kit foxes from the solar facility. Of particular note, survival was not significantly different between the solar and reference sites but trended higher on the solar site. Differences in some ecological attributes were found, but appeared to be largely a result of differences in habitat composition between the two sites. In particular, there was a higher proportion of habitat types on the solar site with a history of disturbance. Ecological recovery was still in progress in these disturbed habitats and food availability was lower compared to the less disturbed habitats that were more abundant on the reference site. Kit foxes exhibit high levels of ecological plasticity and adaptability, and therefore their occupation and use of the solar site was not unexpected. An important caveat is that this use of the solar site is significantly facilitated by the many conservation measures implemented at the site. Security fencing permeable to kit foxes and the presence of managed vegetation in the arrays may be among the more significant ones. The TSF serves 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, particularly if constructed in areas of low habitat quality.

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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 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). Another bill recently passed by the legislature (Senate Bill 100) requires 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 2015, Moore-O'Leary et al. 2017).

San Joaquin kit foxes once were widely distributed in arid shrubland and grassland habitats in central California. 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 kit foxes occurs on the Carrizo Plain in eastern San Luis Obispo County. The Carrizo Plain National Monument encompasses the southern two-thirds of the core area. The northern third was mostly privately owned, and dry-land farming and grazing were common land uses. However, in 2011, construction began on two large solar energy generating facilities in this northern area, the Topaz Solar Farms (TSF) and the California Valley Solar Ranch (CVSR). These projects both employed photovoltaic technology and directly affected 1,421 ha and 721 ha of land, respectively (California Department of Fish and Wildlife [CDFW], unpublished data). Pre-construction surveys beginning in 2007 indicated that kit foxes were commonly using these lands. Construction of both facilities was completed in 2014.

Of concern is the ecological functionality of the areas within and around the facilities, particularly the capacity of the facilities to support kit foxes and the effects of the facilities on regional kit fox movements. To assess these effects, we compared kit fox demographic and ecological patterns on the TSF project site to those on nearby lands that had comparable pre-construction habitat conditions. The assessment of such effects was a regulatory requirement included in permits issued by the CDFW for construction of the TSF (Condition 6.9.1, CDFW 2011). Specific objectives were to:

- compare demographic attributes of kit foxes on and off site, specifically survival rates, sources of mortality, reproductive rates, and litter sizes,
- compare ecological attributes of kit foxes on and off site, specifically home range size, habitat use, movement patterns, den use patterns, foraging patterns, and competitor interactions,
- assess use of on-site developed areas and Stewardship lands relative to adjacent off-site habitat,
- and, develop recommendations to facilitate conservation of kit foxes on the TSF, in the Carrizo Plain ecoregion, and range-wide.

The results of this assessment will provide critical information for developing and refining local and regional kit fox conservation strategies, and also for improving mitigation strategies for future solar projects.

STUDY AREA

The TSF is located at the north end of the Carrizo Plain in eastern San Luis Obispo County, California (Fig. 1 and 2). The location is approximately 64 km east of Santa Margarita and is bisected by California State Route 58. The topography ranges from flat to gently rolling with elevation ranging from 580-680 m. The Mediterranean-type climate is characterized by hot summers and cool winters with most precipitation occurring as rain in winter. Annual precipitation averaged ca. 25 cm, and high temperatures were ca. 35-38°C in summer and 17-20°C in winter (National Oceanic and Atmospheric Administration 2018). Prior to the construction of the TSF, 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 absent over much of the area and where present were very sparse and consisted primarily of goldenbush (*Isocoma acradenia*).

The TSF consists of approximately 1,917 ha (Fig. 3). Facilities include arrays of solar panels, access roads, an electrical substation, and a maintenance complex (ca. 1.5 ha) consisting of an office building, storage containers, storage yard, and vehicle parking areas. The arrays occur in 11 groups ranging in size from 6 ha to 286 ha in size. Each group is surrounded by a 2.4-m tall, chain-link (3 cm x 3cm mesh) security fence with strands of barbed wire on top. The arrays consist of parallel rows of photovoltaic solar panels mounted at a 45-degree angle on posts (Fig. 4). The rows are spaced approximately 2 m apart, and the lower edge of the inclined panels are approximately 0.5 m off the ground. Vegetation has been allowed to grow within the arrays.

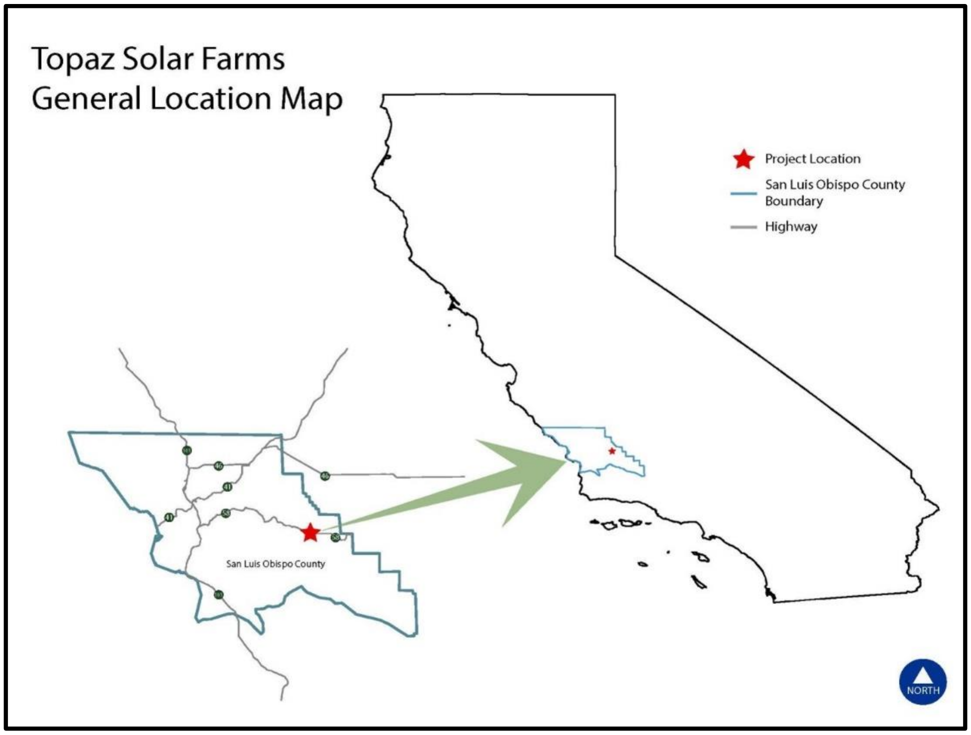

Figure 1. Location of the Topaz Solar Farms, San Luis Obispo County, California.

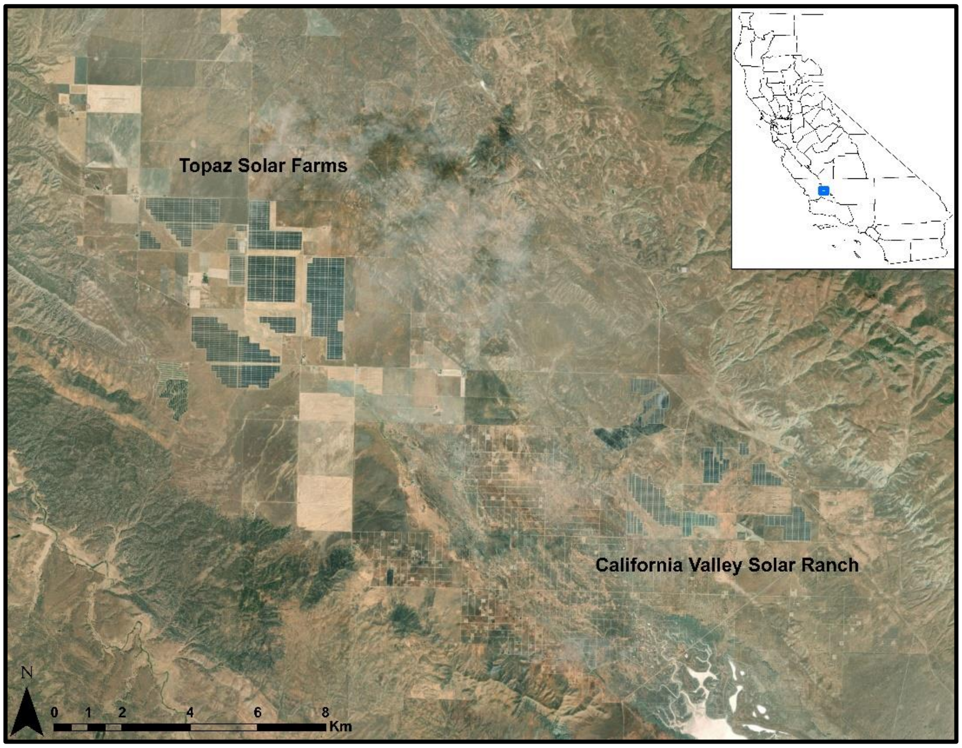

Figure 2. Satellite images of the Topaz Solar Farms and the California Valley Solar Ranch, San Luis Obispo County, California.

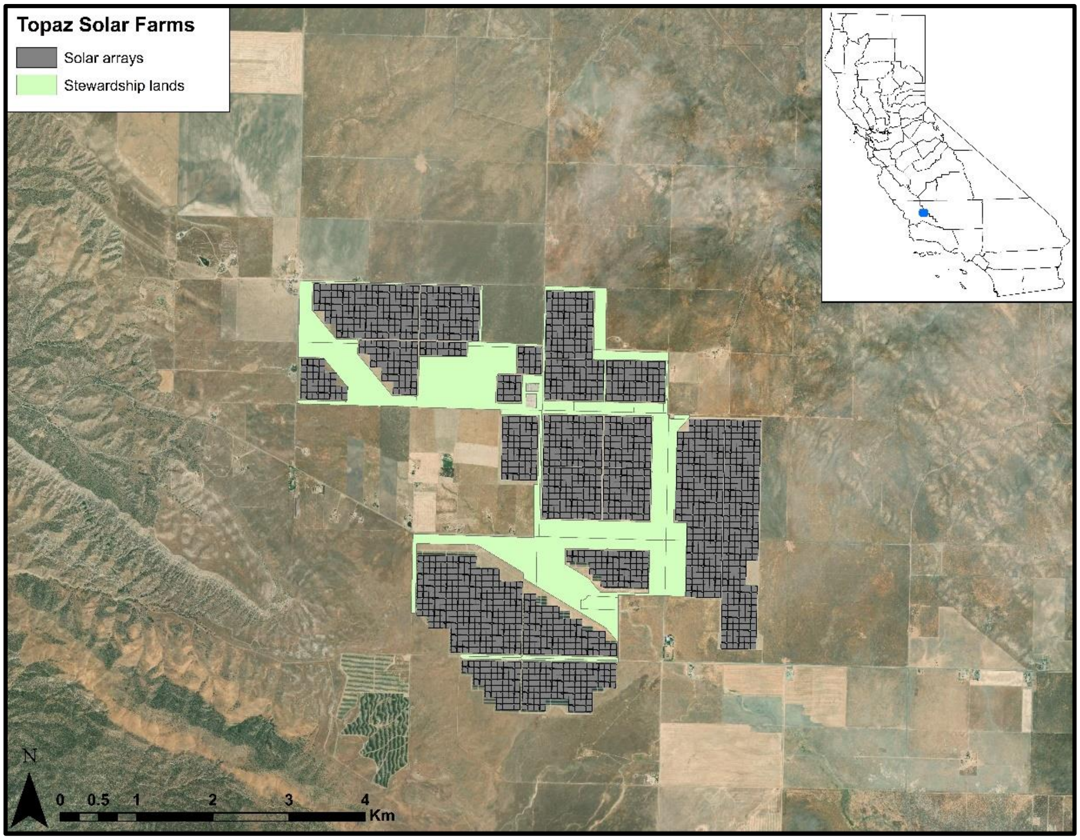

Figure 3. Solar arrays and stewardship lands at the Topaz Solar Farms, San Luis Obispo County, California.

Figure 4. Solar arrays in 2014 (left) and 2017 (right) at the Topaz Solar Farms, San Luis Obispo County, California.

A variety of measures were implemented at the TSF to mitigate impacts to San Joaquin kit foxes and to facilitate use of and movement through the facility by foxes. Instead of constructing the arrays in one or a few large contiguous groups, the arrays were distributed among a larger number of smaller groups such that habitat corridors were maintained through the project site. These corridors and open spaces are referred to as "stewardship lands" and comprise 534 ha of the 1,917-ha project site. (Fig. 3). To improve vegetation structure for kit foxes and their rodent prey (as well as to reduce fire hazard), grazing by sheep is conducted annually on the stewardship lands and within the arrays (Althouse and Meade, Inc. 2010*b*). Stewardship lands were further enhanced with the installation of 16 artificial dens to provide cover for kit foxes to escape from predators (Fig. 5). The security fence surrounding the groups of arrays was modified to permit passage by kit foxes. The bottom of the fence was raised approximately 12 cm off the ground, which allows kit foxes to pass but inhibits passage by larger predators (e.g., coyotes [*Canis latrans*] and bobcats [*Lynx rufus*]). Furthermore, a rail was installed at the bottom of the gap to inhibit larger predators from digging under the fence (Fig. 6). Other measures implemented on the facility included exclusion of domestic dogs, prohibition of firearms, and trash abatement (CDFW 2011).

Figure 5. Artificial den for kit foxes at the Topaz Solar Farms, San Luis Obispo County, California.

Figure 6. Security fence around solar arrays showing modifications to allow passage of kit foxes at the Topaz Solar Farms, San Luis Obispo County, California.

To further mitigate impacts to kit foxes, 4,196 ha of habitat were purchased in the vicinity of the facility (Fig. 7). These lands (referred to as “Topaz mitigation lands”) were transferred to the CDFW along with endowment funds for permanent conservation and management intended to benefit the regional kit fox population. As a result of legal action initiated by environmental groups, and additional 2,175 ha of habitat (referred to as “Topaz settlement lands”) was purchased and was transferred to the Sequoia Riverlands Trust for permanent conservation and management (Fig. 7). The Topaz mitigation and settlement lands are to be conserved and managed for the benefit of kit foxes as well as other native species. Similarly, lands also were acquired and conserved at the nearby California Valley Solar Ranch (Fig. 7).

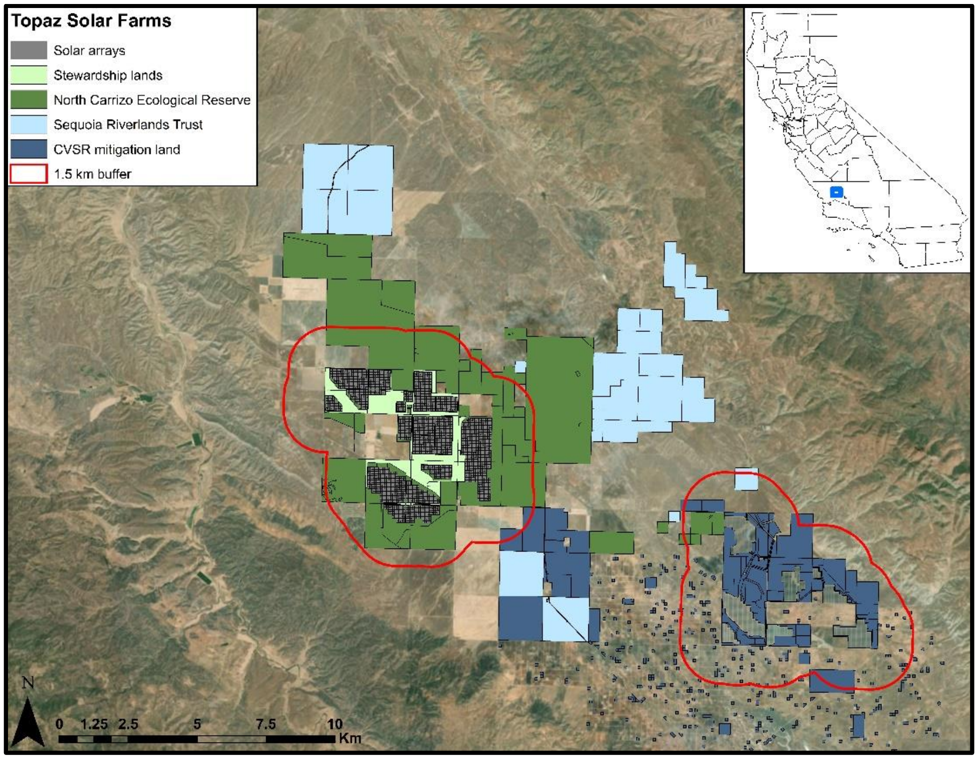

Figure 7. Conservation lands associated with the Topaz Solar Farms and the California Valley Solar Ranch, San Luis Obispo County, California.

To assess the effects of the TSF 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 TSF and any lands within 1.5 km of any TSF facilities (Fig. 7). The 1.5-km distance is approximately the radius of an average kit fox home range in this region (based on an estimated mean home range size of 6.3 km^2; Cypher et al. 2014*a*). 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. Research activities were confined to lands associated with the TSF (e.g., arrays, facilities, and stewardship lands) and conservation lands (e.g., mitigation and settlement lands associated with the TSF as well as the CVSR). However, study animals commonly traveled off of these lands and used adjacent private lands. The vegetation in the arrays and stewardship lands was grazed annually using sheep to improve habitat conditions for kit foxes and prey species, as well as reduce fire hazard. The conservation lands were not grazed during the study, although such management is planned for the future. The untilled private lands typically were grazed each year by cattle. Private tilled lands were plowed every 1-3 years for dryland farm crops, usually barley. Some of the conservation lands had been tilled previously, including some just prior to the construction of the TSF. On both the solar and reference sites, there were a few widely dispersed residences on the private lands. Habitat conditions on the conservation and private lands on the reference site were considered comparable to conditions on the conservation and private lands within the solar site and also to conditions present on the TSF prior to construction of the facility.

METHODS

All data were summarized by year, which was defined as 1 December to 30 November. Thus, each year captured a complete annual biological cycle for kit foxes: mating (Dec-Jan), pup-rearing (Feb-Jun), and dispersal (Jul-Nov). Three years used for analyses were defined as: Year 1 = Dec 2014-Nov 2015, Year 2 = Dec 2015-Nov 2016, and Year 3 = Dec 2016-Nov 2017.

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, hard-boiled eggs) and covered with tarps to provide protection from inclement weather and sun. Traps were set in both study areas, typically within 100 m of dirt roads that were present on the sites. Trapping was primarily conducted during November-January, with some additional trapping being conducted during May-June and at other times as necessary. 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, overall condition, and dental condition. A uniquely numbered tag was attached to one ear and hair was collected for future genetic analysis.

Captured adult foxes were fitted with collars equipped with a GPS tracking unit (Fig. 8) and a VHF transmitter with a mortality sensor (Quantum 4000E Micro Mini Collar; Telemetry Solutions, Concord, CA). The GPS units were programmed to collect 1-3 independent locations per night. These units also included a UHF download function so that data could be retrieved remotely without having to recapture the fox. The entire telemetry package weighed approximately 65 g. Captured juvenile foxes (< 1 yr old) were fitted with 35-g VHF collars with mortality sensors (model M1930; Advanced Telemetry Systems, Isanti, MN). The GPS and VHF collar designs both were less than 3% of fox body mass as required by our permits. The mortality sensors on both units activated and produced a doubled 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 radiocollars. 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 the research permit (TE825573-2) held by California State University at Stanislaus-Endangered Species Recovery Program (CSUS-ESRP) from the U.S. Fish and Wildlife Service and a Memorandum of Understanding from the California Department of Fish and Wildlife.

Figure 8. Kit fox with a GPS collar at the Topaz Solar Farms, San Luis Obispo County, California.

KIT FOX MONITORING AND TREATMENT ASSIGNMENT

We attempted to locate the VHF signal of each fox at least weekly to determine survival status. We also attempted to download data from GPS collars at least monthly, and to track foxes to dens at least weekly. Telemetry signals initially were detected using an omni-directional antenna magnetically mounted on the roof of a vehicle. Once a signal was detected, a 3-element Yagi antenna mounted on a 2-m pole was used to determine a fox’s location more precisely and approach closer. Once sufficiently close (usually within 500 m), we attempted to download data from GPS collars using a UHF antenna mounted on the pole with the Yagi antenna. The UHF antenna was connected to a base station (Telemetry Solutions, Concord, CA) that was connected to a laptop computer. A hand-held 3 or 4-element Yagi antenna was used to track foxes to daytime resting sites, which commonly was an earthen den. Most monitoring was conducted during the day, but searches occasionally were conducted at night after the foxes had emerged from their dens and their signal was more easily detected.

Kit foxes were assigned to solar or reference treatment groups based on their telemetry locations. Foxes that commonly were located in the solar panel arrays and stewardship lands on the TSF and for which the majority of their locations were within the 1.5-km boundary were assigned to the solar group. Foxes that rarely or never were located within the solar panel arrays or stewardship lands on the TSF were assigned to the reference group. For two foxes, just over 50% of their locations were within the 1.5-km boundary but the foxes never were located within the panels or stewardship lands, and the decision was made to include these foxes with the reference group. Two foxes shifted space use sufficiently during the study such that they were included in one group one year and the other group the next year. Data for two other foxes were censored after the foxes dispersed out of the TSF area.

KIT FOX DEMOGRAPHIC COMPARISONS

Kit fox survival was assessed by monitoring collared animals. Survival analyses were only conducted for foxes greater than 9 months of age. Younger animals (i.e., pups) likely had much 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 mortalities per monitoring effort.

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 and is calculated by Micromort.

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 8 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 Moussali 2011).

Finally, we calculated a simple index of survival that is easily compared among studies with disparate monitoring methodologies (e.g., Cypher et al. 2014*a*). 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 Investigations 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 several different types of automated digital field cameras including Cuddeback Digital Attack IR (Model 1156, Non Typical Inc. Green Bay, WI) and Stealth Cam 3.0 MP Digital Scouting Cameras (Model STC-AD2/AD2RT, Stealth Cam LLC, Bedford, TX). The cameras were secured to 1.2-m (3-ft) U-posts with zip ties and duct tape. The stations were set approximately 3 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. The proportion of radio-collared females successfully reproducing was determined for each site by year. 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. 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 previous 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 also 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 a multivariate analysis of variance with a fixed effects model including all possible variable interactions.

To assess habitat use and preference by kit foxes, we first defined the types and quantities of habitats within a 100% MCP polygon formed using all kit fox locations. Using ArcMap and the California Important Farmland: 2014 layer produced by the California Department of Conservation (available through ArcMAP Online Services), we defined and delineated six types (Fig. 9): solar facilities, stewardship lands, conserved untilled lands, private untilled lands, conserved previously-tilled lands, and currently tilled private lands. These types were identified based on current and past activities that have affected the natural communities present. Solar facilities included solar panel arrays within fenced enclosures and associated features such as a maintenance building and electrical transmission facilities. Vegetation within the fenced solar arrays is grazed annually using sheep. Stewardship lands are those between and immediately surrounding the solar facilities. They are part of the solar farm and are managed by the owner. These lands also are grazed by sheep or cattle annually. Conserved untilled lands are mitigation lands that do not have obvious signs of recent tilling (i.e., within past 20 years). These lands were not grazed during the study. Private untilled lands also did not exhibit signs of recent tilling, but these lands typically were grazed with cows during the study. Conserved previously-tilled lands are mitigation lands that had been tilled to grow dryland farm crops just prior to being conserved. These lands were not grazed during the study and are in various stages of natural recovery. Tilled private lands are under current cultivation to grow dryland crops.

Habitat type availability was determined for solar site foxes and reference site foxes separately. By definition, reference site foxes never or rarely used the solar site. Therefore, solar facility and stewardship land habitat types were relatively unavailable to reference site foxes, and inclusion of these types in preference analyses would have produced biased results. For foxes on each study site (e.g., solar site and reference site), we delineated the available habitat by combining the annual 95% MCPs for all foxes into a single polygon, and then used the boundary of that polygon to calculate the proportional availability of habitat types (Fig. 10). This approach provides a conservative estimate of habitat availability that would be less appropriate for "Second Order" habitat selection (i.e., home range placement), but that facilitates a robust assessment of "Third Order" selection (i.e., use of types within home ranges) (Johnson 1980).

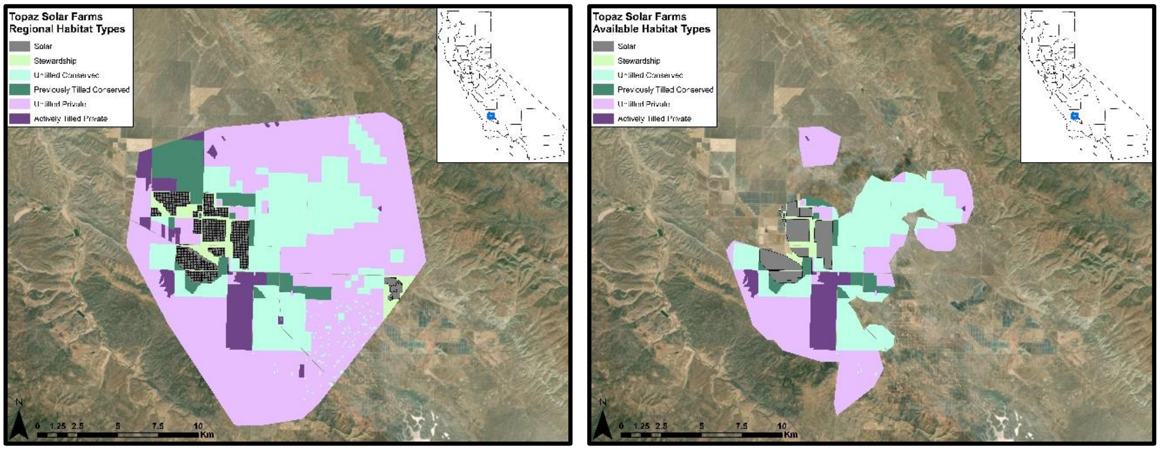

Figure 9. Habitat types in the region encompassing the Topaz Solar Farms, San Luis Obispo County, California (left) and availability of types (right) based on a composite 95% minimum convex polygon comprising nocturnal telemetry for all foxes in a study of solar farm effects.

Proportion habitat use was determined for each fox by year. For each fox, the nocturnal locations used to define their annual 95% MCP were superimposed on the appropriate habitat availability map (i.e., solar site or reference site) and the proportion of locations in each habitat type was determined. ArcMap was used for this analysis. The reason for using the 95% MCP locations was the same as that in the home range analysis. We wanted to try to exclude locations that were associated with long-distance or exploratory movements, and that therefore were less likely to reflect space use and habitat use associated with fulfilling daily life history needs.

Resource Selection Function analysis (Manly et al. 2002) was used to identify habitat preferences for solar site and reference site foxes. We used Design II (Thomas and Taylor 1990), which entails comparing habitat use by individual foxes to a set of habitat availabilities for all foxes in a given category (i.e., solar site or reference site). Furthermore, we used sampling protocol "SP-A" (Manly et al. 2002) whereby available and used habitats were randomly sampled. The analyses entail comparisons of proportional use of habitat types by individual foxes to the proportional availability of the types on the study site. We conducted all analyses on habitat use patterns within home ranges (95% MCPs) as well as within core areas (50% MCPs). We conducted three log-likelihood chi-square tests on the data (Manly et al. 2002). The first test (X_{L1}^2) was of the null hypothesis that foxes were using all habitats in the same proportions, irrespective of whether any selection is occurring. The second test (X_{L2}^2) was of the null hypothesis that all habitats were being used by foxes in a random manner, i.e., use was proportional to availability. The third test ($X_{L1}^2 - X_{L2}^2$) was of the null hypothesis that foxes on average were using habitats in proportion to their availability, irrespective of whether any selection was occurring.

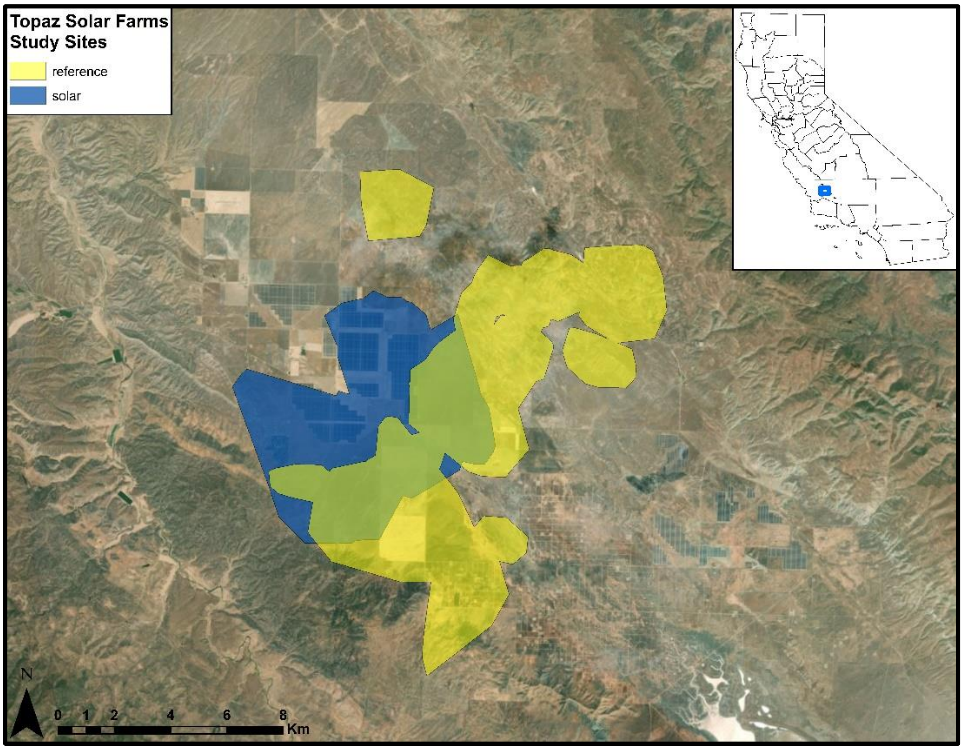

Figure 10. Polygons used to determine habitat type availability for solar site and reference site foxes at the Topaz Solar Farms, San Luis Obispo County, California. The polygons for each group were based on a composite 95% minimum convex polygon comprising nocturnal telemetry for all foxes in that group.

If the test above indicated that habitat selection was occurring, then a selection ratio was generated for each habitat type ($\hat{w}_i$ = selection ratio for habitat type *i*) along with a Bonferroni confidence interval based on *z* scores. We chose an alpha level of 0.05 for the intervals. Intervals that included the value “1.0” indicated habitats that were not used disproportionately relative to availability. Intervals where the lower confidence limit was greater than 1.0 indicated habitats used disproportionately more; i.e., use was significantly greater relative to availability. Intervals where the upper confidence limit was less than 1.0 indicated habitats used disproportionately less; i.e., use was significantly lower relative to availability.

We assessed the relationship between habitat use by foxes and both home range size and core area size by conducting simple linear regression analyses with home range or core area size for each fox as the dependent variable and proportion of nocturnal locations in a given habitat type as the independent variable. The proportions of locations were transformed using an arcsine transformation (Zar 1984). This analysis was not conducted for tilled private lands due to too few locations in this habitat type. Similarly, the analysis was not conducted between stewardship lands and reference site foxes because the foxes never were located in this habitat type.

To assess movement rates, we calculated the mean distance between nocturnal locations for each fox by year. Only locations used to calculate 95% MCPs (home ranges) were used to exclude distances that might have been associated with longer exploratory movements. Also, 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 multivariate analysis of variance with a fixed effects model including all possible variable interactions. Input values for each fox were weighted by the number of distance measurements used to calculate the mean value for a given fox.

We also 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. (These were 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 multivariate analysis of variance with a fixed effects model including all possible variable interactions. Input values for each fox were weighted by the number of distance measurements used to calculate the mean value for a given fox.

To assess den use patterns by kit foxes, we attempted to track radio-collared animals to their den at least once per week, and more frequently if possible. The coordinates of the den 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 determined the number of occasions in which a fox was found in a different den from the one that it was previously tracked to. This provided an index of den switching. The frequency with which foxes were tracked to dens varied considerably among foxes. Some foxes were more difficult to locate than others, and some foxes frequently denned on private lands to which we did not have access. Thus, to standardize data, the number of unique dens that a fox used annually and the number of den switches for each fox were divided by the number of times each fox was tracked to a den. An arcsine transformation was applied to the resulting frequencies to help normalize values (Zar 1984) prior to statistical analysis. Mean frequency of unique dens and mean frequency of den switches were compared among study sites, years, and sexes using a multivariate analysis of variance with a fixed effects model including all possible variable interactions.

We also recorded the habitat type in which the den occurred. For foxes on the solar and the reference study sites separately, we determined the proportion of dens in each habitat type. We also calculated an index of den use by habitat type by multiplying the number of dens in each habitat type by the number of times foxes had been tracked to those dens. Finally, we identified "natal" dens and determined the proportion of natal dens in each habitat type. Natal dens were defined as those in which litters of pups had been observed in the spring. The proportion of dens, den use, and natal dens in each habitat type were compared to the proportional availability of habitat types using contingency table analysis and a chi-square test for heterogeneity. When these tests were significant, then proportional den presence and use versus habitat availability were examined for each habitat type separately using a 2x2 chi-square test for heterogeneity and the Yate's correction for continuity (Zar 1984).

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 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).

Rodents typically constitute the primary prey for kit foxes (Grinnell et al. 1937, Cypher 2003), and kit fox abundance generally fluctuates with rodent abundance (Spiegel 1996, Cypher et al. 2000), particularly kangaroo rats (*Dipodomys* spp.). We assessed the relative abundance of rodents using two methods: live-trapping and sign transects. Live-trapping was conducted in the second year of the study. We trapped along 15 transects with 5 in the solar arrays, 5 in the stewardship/conservation lands on the solar site, and 5 in the reference site. Locations deemed to represent typical conditions for these habitats were selected for the transects. The transects began within about 100 m of a dirt access road and were broadly U-shaped so that researchers would complete the transect back near the road and thus expedite checking multiple transects in a morning. We used Sherman aluminum box traps (7.6 cm x 9.5 cm x 30.5 cm; H. B. Sherman Traps Inc., Tallahassee, FL) modified to prevent injury to the long tails of kangaroo rats. Forty traps were spaced 10-15 m apart along transects, opened around sunset, baited with millet bird seed, and provisioned with a paper towel for insulation and distraction. Traps were checked the next morning around sunrise. All captured animals were identified to species, age and sex were recorded, and then animals were marked on their ventral side with a non-toxic felt-tipped marker to identify recaptures. Trapping was conducted for 3 nights along each transect. The mean number of unique rodents captured per 100 trapnights and the number of kangaroo rats captured per 100 trapnights were compared between the solar and reference sites with *t*-tests. To further explore patterns of rodent abundance, we divided the solar site transects into those in the arrays and those on the stewardship lands. The mean number of unique rodents captured per 100 trapnights and the number of kangaroo rats captured per 100 trapnights were compared among the arrays, stewardship lands, and reference site using single-factor analysis of variance and Tukey’s post-hoc pair-wise comparison test.

Due to relatively low live-capture rates, we conducted sign transects in Year 3 of the study to obtain an index of rodent abundance. Forty 0.5-km transects were established in habitat representative of the arrays ($n = 10$), solar site conserved lands ($n = 8$), and the reference site ($n = 22$). Relative abundance of rabbits and rodents was assessed by counting fresh rabbit pellets and active rodent burrows in a 2-m wide belt along each transect. Fresh pellets were characterized by a golden to dark brown color and a smooth surface whereas old pellets were characterized by a gray color and surface roughened by weathering. Rodent burrows were characterized as “large” (burrow opening ≥ 3 cm) or “small” (burrow opening < 3 cm). Large burrows were typical of those used by kangaroo rats or ground squirrels while small burrows were typical of those used by mice. Burrows with openings obstructed by vegetation or spider webs were not considered active and were not counted. Assessments were conducted by two observers slowly walking along each transect. The first observer acts as orienteer and counted all active burrows within 1 m of either side of the transect. The second observer counted all fresh rabbit pellets within 1 m of either side of the transect and recorded data. Also, percent herbaceous ground cover was estimated within the belt. Mean numbers of burrows and pellets and mean percent ground cover were compared between the solar site and reference site using non-parametric Mann-Whitney tests. To further explore patterns of prey availability, we divided the solar site transects into those in the arrays and those on the stewardship lands. We then compared mean numbers of burrows and pellets and mean percent ground cover among arrays, stewardship lands, and the reference site using non-parametric Kruskal-Wallis tests. For Kruskal-Wallis tests that indicated significant differences, pair-wise comparisons of the three areas were conducted using Mann-Whitney tests.

Significant differences in food availability between the solar and reference sites might be reflected in body condition of kit foxes. We used mass measurements to compare physical condition of foxes between the study sites. Foxes were weighed to the nearest 0.05 kg when captured (see “Kit fox capture and radio collaring” above). To help reduce variability attributable to other factors, such as reproduction and age, we only used weights from adults collected during the November-January period. A large sample size of measurements was available due to extensive trapping to collar foxes during that period. 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 sexes and study sites using a two-way analysis of variance.

The competitor species present and their relative abundance was determined annually by establishing automated camera stations throughout each study area. The stations were identical to those used to assess reproductive success of foxes. However, to assess competitors, the cameras were not set at dens but were set in areas with typical habitat conditions. The cameras were operated for 30 days each fall. To attract competitors, a perforated can of cat food was staked to the ground approximately 2 m in front of each camera using 30-cm nails. A scent lure (Carman's Canine Call Lure, Russ Carman, New Milford, PA) was dripped on the can and vegetation near the camera as an extra attractant for carnivores. Images captured on camera were examined to determine the identity, frequency of visits, and distribution of each species. The number of camera stations with detections was determined by year and study site for each species.

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 several brands and models of computer tablets. A GPS booster (Bad Elf GPS Pro, Tariffville, CT) was used to increase tablet-satellite communication and improve location resolution. Data were uploaded, stored, and shared through the AmigoCollect system (AmigoCloud, San Francisco, CA), a cloud-based collaborative mapping platform. Spatial analyses and map figure production were conducted using ArcMAP (ver. 10.5; ESRI, Redlands, CA). Data were primarily analyzed using the SPSS statistical software package (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, 75 kit foxes were captured (Appendix A). Of these, 52 received radio-collars. Radio-collars were not placed on young pups captured in late spring or on new foxes captured during trapping 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 0.85 for foxes on the solar site in Year 1 to 0.32 for foxes on the reference site in Year 2. Survival probabilities were consistently higher on the solar site, but probabilities did not differ statistically between sites for any years ($p > 0.1$). Similarly, the probability across all years was higher for foxes on the solar site, but did not differ statistically from that for foxes on the reference site ($p > 0.1$). Across both sites and all years, the survival probability for males was higher than that for females at the $\alpha = 0.1$ level ($p = 0.059$).

Table 1. Probability of kit foxes surviving ($\hat{S}$) for 365 days (1 year) during December 2014-November 2017 at the Topaz Solar Farms, San Luis Obispo County, CA.

Site or Sex	Year	No. foxes monitored	Total days survived	No. mortalities	$\hat{S}$	Var $\hat{S}$	95% CI
			Study site by year				
Solar	1	8	2,314	1	0.85	0.02	0.63-1
Ref	1	16	2,968	2	0.78	0.02	0.56-1
Solar	2	5	1,172	2	0.54	0.06	0.23-1
Ref	2	17	2,577	8	0.32	0.02	0.15-0.71
Solar	3	11	2,404	4	0.54	0.03	0.30-0.99
Ref	3	15	2,639	6	0.44	0.21	0.22-0.85
			Study site for all years				
Solar	All	24	5,890	7	0.65	0.01	0.47-0.89
Ref	All	48	8,184	16	0.49	0.01	0.34-0.69
			Sex for all years				
Female	All	37	6,955	15	0.45	0.01	0.31-0.68
Male	All	35	7,119	8	0.66	0.01	0.50-0.88

Cox proportional hazards regression analysis was conducted on eight models encompassing all combinations of the three variables Site, Year, and Sex, and also a model that included these three variables plus a Year-x-Site interaction term (Table 2). The model that best fit the data was the one that included both Year and Sex. Other top models ($\Delta AIC_C < 2$) included just Year and Year-Sex-Site interaction. None of the models was particularly strong as the AIC_C values for all models were relatively high ($\geq$ 179.58) and the w_i values were relatively low (≤ 0.42). This may have been a result of small sample sizes and high variability in the number of days that foxes survived. The sum of the w_i values was 0.93 for models containing Year as a variable, 0.67 for models containing Sex as a variable, and 0.31 for models containing Site as a variable. Based on these sums, Year was the most important of the variables and Site was the least important.

Table 2. Akaike's Information Criterion results for Cox proportional hazard regression analysis of San Joaquin kit fox survival during December 2014-November 2017 at the Topaz Solar Farms, San Luis Obispo County, CA.

Model	K[a]	-2LL[b]	AIC	AIC_c	ΔAIC_C	Rel LL[c]	w_i[d]
Year + Sex	4	170.99	178.99	179.58	0.00	0.999	0.416
Year	3	174.67	180.67	181.03	1.44	0.486	0.202
Year + Sex + Site	5	170.46	180.46	181.37	1.79	0.409	0.170
Year + Site	4	173.95	181.95	182.55	2.96	0.227	0.095
Year + Sex + Site + Year*Site	6	170.36	182.36	183.65	4.07	0.131	0.054
Sex	3	178.29	184.29	184.65	5.06	0.080	0.033
Sex + Site	4	177.56	185.56	186.15	6.57	0.037	0.016
Site	3	179.90	185.90	186.26	6.68	0.036	0.015

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

Survival curves generated by the Cox analysis graphically depicted the slightly higher survival for foxes on solar site, higher survival among males, and higher survival in Year 1 versus Years 2 and 3 (Fig. 11).

The mortality index (number of mortalities per 1,000 monitoring days) across all years was 1.96 for reference site foxes and 1.19 for solar site foxes. The annual indices ranged from 0.67-3.10 for reference site foxes and from 0.43-1.71 for solar site foxes (Table 3).

Table 3. Mortalities per 1,000 monitoring days for radio-collared San Joaquin kit foxes on solar and reference sites during December 2014-November 2017 at the Topaz Solar Farms, San Luis Obispo County, CA.

Year	Site	Foxes monitored	Days monitored	Fox mortalities	Mortalities per 1,000 days
1	Solar	8	2,314	1	0.43
	Reference	16	2,968	2	0.67
2	Solar	5	1,172	2	1.71
	Reference	17	2,577	8	3.10
3	Solar	9	2,404	4	1.66
	Reference	15	2,639	6	2.27
All	Solar	22	5,890	7	1.19
	Reference	48	8,188	16	1.96

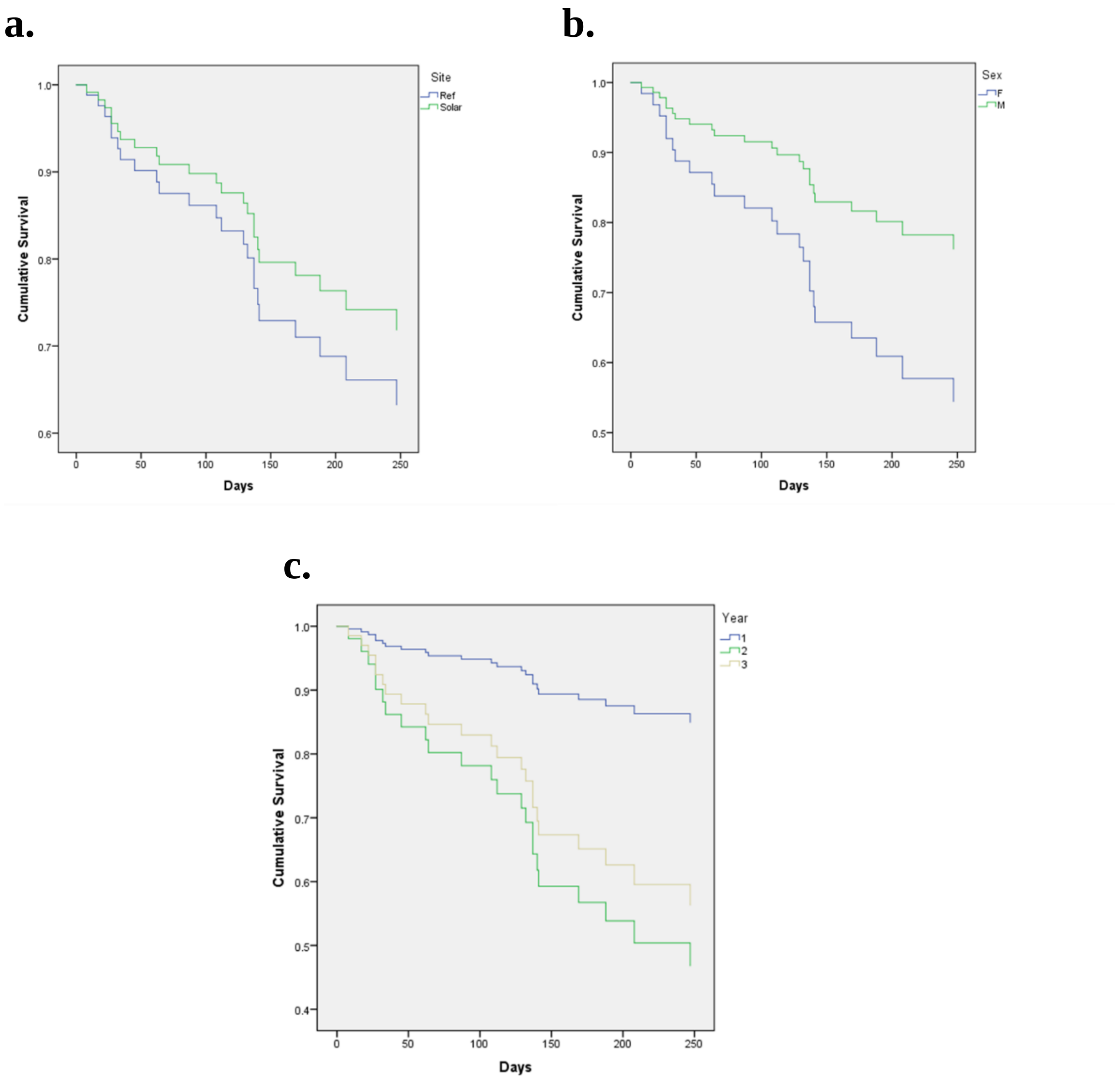

Figure 11. Cumulative survival curves for San Joaquin kit foxes by (a.) study site, (b.) sex, and (c.) year at the Topaz Solar Farms, San Luis Obispo County, CA.

During the study, 23 radio-collared adult kit foxes were found dead (Table 4). Seven of these foxes were classified as solar site foxes and 16 were classified as reference site foxes. However, 3 of the solar site foxes were found dead outside of the 1.5-km buffer that defined the solar site (Fig. 12). Of the 23 foxes (Table 5), 21 were killed by predators (these included 8 foxes for which only the radio-collar was recovered or the condition of the remains was insufficient to identify the species of predator). Cause of death could not be determined for 2 foxes. Of the 7 solar site foxes, 6 were killed by predators and the cause of death for 1 could not be determined. Of the 3 solar site foxes recovered off of the solar site, 1 was killed by a coyote, 1 was killed by an undetermined predator, and 1 died on private land and could not be recovered. Of the 4 foxes that were found dead on the solar site, 1 was found 1.3 km from the nearest arrays and had been killed by a golden eagle. The remaining 3 all died within the arrays and the cause of death was bobcat predation. Of the 16 reference site foxes, 15 were killed by predators and the cause of death was not determined for 1 fox that was found dead in a den (Table 5). One reference site fox whose home range partially overlapped the solar site was found dead from golden eagle predation just inside the 1.5-km buffer (Fig. 12).

Table 4. Adult radio-collared San Joaquin kit foxes found dead by study site and year during December 2014-November 2017 at the Topaz Solar Farms, San Luis Obispo County, CA.

	Solar site			Reference site		
Year	**Females**	**Males**	**Total**	**Females**	**Males**	**Total**
1	1	0	1	3	0	3
2	1	1	2	5	2	7
3	1	3	4	4	2	6
Total	3	4	7	12	4	16

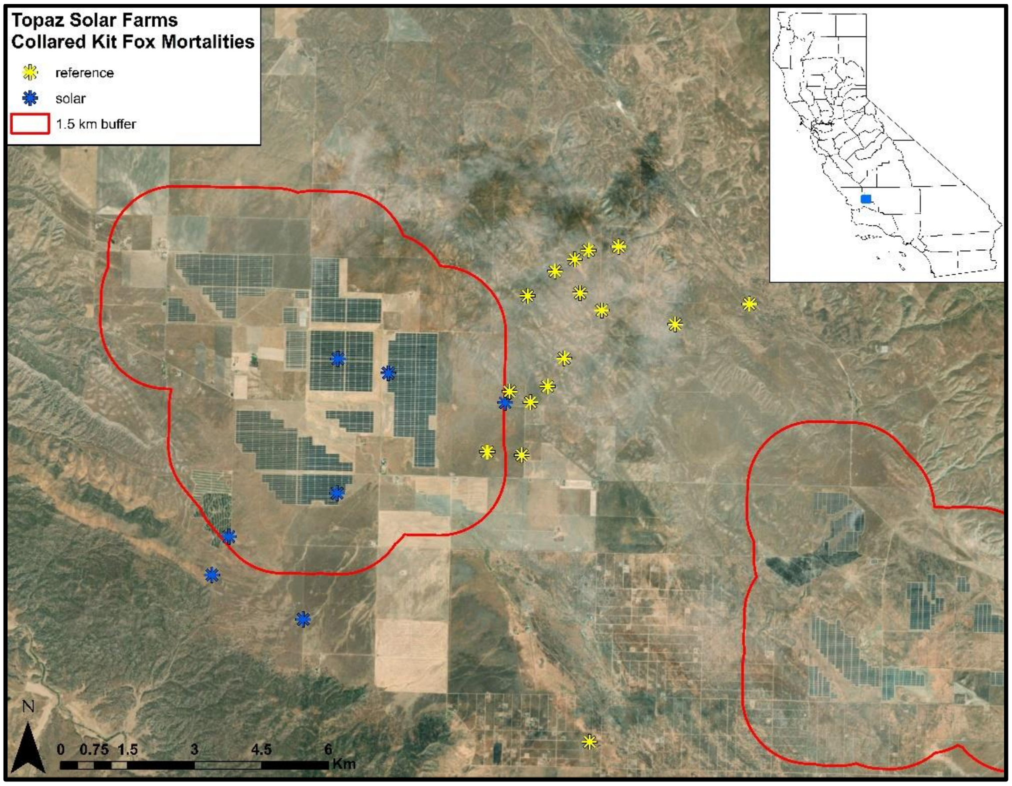

Figure 12. Locations where adult radio-collared San Joaquin kit foxes were found dead during December 2014-November 2017 at the Topaz Solar Farms, San Luis Obispo County, CA.

Table 5. Suspected cause of death for adult radio-collared San Joaquin kit foxes during December 2014-November 2017 at the Topaz Solar Farms, San Luis Obispo County, CA.

Suspected cause	Solar site	Reference site
Bobcat	3	3
Coyote	1	1
Golden eagle	1	4
Unidentified predator	1	7
Unknown	1	1

During the study, 7 other foxes also were found dead; 3 on the solar site and 4 on the reference site. Of the solar site foxes (none radio-collared), all 3 were young-of-the-year. Two were killed by vehicles on Highway 58 and 1 was killed by a golden eagle just within the 1.5-km buffer. Of the 4 reference site foxes, 3 (adult female, unknown sex adult, unknown sex pup) were killed by vehicles; none were radio-collared and all were found opportunistically. One radio-collared male pup was killed by an unknown predator (only the collar was found).

For all fox mortalities combined (collared and uncollared foxes), no notable differences between the solar and reference sites were apparent with regard to month (Fig. 13). Periods with a higher number of mortalities occurred during March-May, August, and December-January.

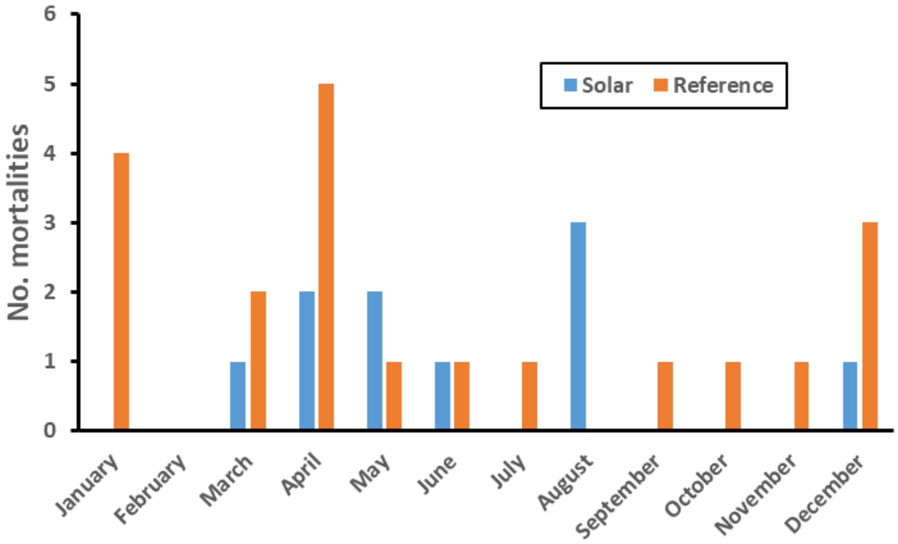

Figure 13. Number of San Joaquin kit fox mortalities by month during December 2014-November 2017 at the Topaz Solar Farms, San Luis Obispo County, CA.

Reproductive success was determined for 19 radio-collared female foxes (Table 6). All foxes evaluated reproduced successfully except for one reference site female in Year 3. For litter size comparison between sites, litters were included for which the mother was uncertain or unknown. Mean litter size (SE, range) was 4.3 (0.50, 2-8) and 3.9 (0.53, 1-7) for the solar site and reference site, respectively, and did not differ between sites ($t_{20} = 0.59$, $p = 0.55$).

Table 6. Proportion of radio-collared female San Joaquin kit foxes successfully reproducing by site and year at the Topaz Solar Farms, San Luis Obispo County, CA.

	Solar site		**Reference site**	
Year	**n**	**%**	**n**	**%**
1	3	100	4	100
2	3	100	2	100
3	4	100	3	66.7
Total	10	100	9	88.9

KIT FOX ECOLOGICAL COMPARISONS

We had sufficient data to estimate annual size for 26 home ranges and core areas (Tables 7 and 8). Home ranges for foxes on the solar site ranged from 4.5-24.1 km^2 with a mean (± SE) of 9.4 ± 1.1 km^2. Home ranges for foxes on the reference site ranged from 0.5-19.3 km^2 with a mean of 5.1 ± 0.9 km^2. Based on multivariate analysis of variance, home ranges on the solar site were larger than those on the reference site ($F_{1,37} = 8.54$, $p = 0.006$). Home range size also varied among years ($F_{2,37} = 5.96$, $p = 0.006$); home range size decreased from Year 1 to Year 3 on both sites. Home ranges of males were marginally larger than those of females ($F_{1,37} = 3.13$, $p = 0.085$).

Proportional habitat use by kit foxes within home ranges and core areas was determined by year for each study site and for all years combined on each site (Tables 9 and 10). On the solar site, foxes used primarily untilled conserved lands and untilled private lands. Tilled private lands and previously tilled conserved lands were used least frequently. On the reference site, foxes used primarily untilled conserved lands while tilled private lands and previously tilled conserved lands were used least frequently. Very infrequently, reference foxes were located in solar arrays, but this habitat type was generally unavailable to most reference site foxes.

Untilled private lands and untilled conserved lands were the most abundant habitats available to reference site foxes, based on combined 95% MCPs (Table 11). On the solar site, these two habitat types along with solar arrays were the most abundant habitats available to foxes. For each year on each study site and for all years combined on each site, all three log-likelihood chi-square tests (X_{L1}^2, X_{L2}^2, and $X_{L1}^2 - X_{L2}^2$) were significant with p values < 0.001 for habitat use within home ranges as well as core areas. The significant X_{L1}^2 values indicated that foxes were not using all habitats in similar proportions. The significant X_{L2}^2 values indicated that some habitats were being used disproportionately to availability. The significant X_{L1}^2 - X_{L2}^2 values indicated that on "average", habitat use by foxes was disproportionate to habitat availability (Manly et al. 2002).

Table 7. Mean home range size for San Joaquin kit foxes by site and year at the Topaz Solar Farms, San Luis Obispo 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	3	12.4 (2.9)	4	11.3 (4.3)	7	11.8 (2.6)
	2	2	10.7 (3.2)	2	7.0 (2.3)	4	8.8 (1.9)
	3	6	9.0 (2.4)	2	4.5 (0.1)	8	7.9 (1.9)
	All	11	10.3 (1.5)	8	8.5 (1.7)	19	9.4 (1.1)
Reference	1	5	9.6 (2.5)	5	6.7 (1.9)	10	8.1 (1.6)
	2	4	7.8 (2.4)	6	3.4 (0.7)	10	5.2 (1.2)
	3	6	2.2 (0.5)	6	2.5 (0.9)	12	2.3 (0.5)
	All	15	6.1 (1.2)	17	4.1 (1.2)	32	5.1 (0.9)

Table 8. Mean core area size for San Joaquin kit foxes by site and year at the Topaz Solar Farms, San Luis Obispo 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	3	2.7 (0.4)	4	2.5 (0.7)	7	2.6 (0.4)
	2	2	2.5 (1.3)	2	1.7 (0.9)	4	2.1 (0.7)
	3	6	1.5 (0.4)	2	1.1 (0.1)	8	1.4 (0.3)
	All	11	2.0 (0.4)	8	1.9 (0.4)	19	2.0 (0.3)
Reference	1	5	2.8 (1.1)	5	1.2 (0.1)	10	2.0 (0.6)
	2	4	1.3 (0.2)	6	0.9 (0.1)	10	1.1 (0.1)
	3	6	0.5 (0.1)	6	0.5 (0.2)	12	0.5 (0.1)
	All	15	1.5 (0.3)	17	0.8 (0.3)	32	1.2 (0.2)

Table 9. Proportional habitat use in home ranges by San Joaquin kit foxes during December 2014-November 2017 at the Topaz Solar Farms, San Luis Obispo County, CA.

				Proportion of locations (%)					
Site	**Year**	**No. foxes**	**No. locations**	**Arrays**	**Steward-ship**	**Untilled conserved**	**Tilled conserved**	**Untilled private**	**Tilled private**
Solar	1	8	4,018	16.2	9.2	34.7	7.3	30.5	2.0
	2	4	1,316	18.6	8.0	28.3	2.4	37.5	5.2
	3	8	1,379	19.7	13.0	40.8	4.1	16.3	6.0
	All	20	6,713	17.4	9.8	34.7	5.7	29.0	3.5
Reference	1	9	2,984	0.1	0	74.0	0.5	23.3	2.2
	2	10	1,984	0.2	0	85.1	3.5	11.0	0.3
	3	12	1,566	0	0	76.1	0.4	10.3	13.2
	All	31	6,534	0.1	0	77.9	1.4	16.4	4.2

Table 10. Proportional habitat use in core areas by San Joaquin kit foxes during December 2014-November 2017 at the Topaz Solar Farms, San Luis Obispo County, CA.

Site	Year	No. foxes	No. locations	Proportion of locations (%)					
				Arrays	Steward-ship	Untilled conserved	Tilled conserved	Untilled private	Tilled private
Solar	1	8	2,103	7.7	3.8	37.9	8.5	40.9	1.3
	2	4	690	18.0	9.0	27.4	1.0	36.8	7.8
	3	8	685	20.4	8.2	48.6	3.6	14.3	4.8
	All	20	3,478	12.2	5.7	38.0	6.1	34.8	3.2
Reference	1	9	1,566	0	0	75.9	0	21.9	2.2
	2	10	1,035	0	0	89.6	4.1	6.4	0
	3	12	835	0	0	76.4	0	11.6	12.0
	All	31	3,436	0	0	80.2	1.2	14.7	3.9

Table 11. Total area and proportional availability of habit types on the solar site and the reference site at the Topaz Solar Farms, San Luis Obispo County, CA.

	Solar site		Reference site	
Habitat type	**Hectares**	**%**	**Hectares**	**%**
Solar arrays	1,020	20.12	62	0.75
Stewardship	265	5.23	0	0
Untilled conserved	1,383	27.28	3,412	41.05
Previously tilled conserved	466	9.19	249	3.00
Untilled private	1,323	26.09	3,777	45.43
Tilled private	613	12.09	812	9.77
Total	5,070		8,312	

Selection ratios were generated using resource selection function analysis for habitats used by kit foxes within home ranges. Based on these ratios, foxes on the solar site (Fig. 14) generally used habitat types in proportion to their availability with the exception of tilled private lands, which appear to have been avoided. Foxes on the reference site exhibited more pronounced preferences (Fig. 14). Untilled conserved lands were used disproportionately more relative to their availability. Untilled private lands were used disproportionately less relative to their availability. The selection ratios for tilled conserved and tilled private lands approached significance as these habitats appeared to be used less than expected. Solar arrays also were used disproportionately less relative to availability, but this habitat type was generally unavailable to most reference site foxes.

Annual trends on each of the study sites were similar to the overall trends (Fig. 15). On the solar site, tilled private lands were used disproportionately less relative to their availability in Years 1 and 2 while previously tilled conserved lands were used disproportionately less relative to their availability in Years 2 and 3. The confidence intervals for use of stewardship lands were quite wide indicating that some foxes exhibited considerable use of these lands while other foxes used them little or not at all. On the reference site, foxes used untilled conserved lands disproportionately more in Years 1 and 2, and use approached significance in Year 3. Untilled private lands and solar arrays were used disproportionately less relative to availability in all years. Previously tilled conserved lands were used disproportionately less relative to availability in Years 1 and 3 while a very wide confidence interval around the ratio for this type in Year 2 indicated considerable variation in use of this type among foxes. Similarly, tilled private lands were used disproportionately less relative to availability in Years 1 and 2 while a very wide confidence interval around the ratio for this type in Year 3 indicated considerable variation in use of this type among foxes.

Selection ratios also were generated for habitats used by kit foxes within core areas. Based on these ratios, foxes on the solar site generally used habitat types in proportion to their availability with the exception of tilled private lands, which appear to have been avoided (Fig. 16). Foxes on the reference site exhibited more pronounced preferences

(Fig. 16). Untilled conserved lands were used disproportionately more relative to their availability. Untilled private lands, previously tilled conserved lands, and tilled private lands all were used disproportionately less relative to their availability. Solar arrays also were used disproportionately less relative to availability.

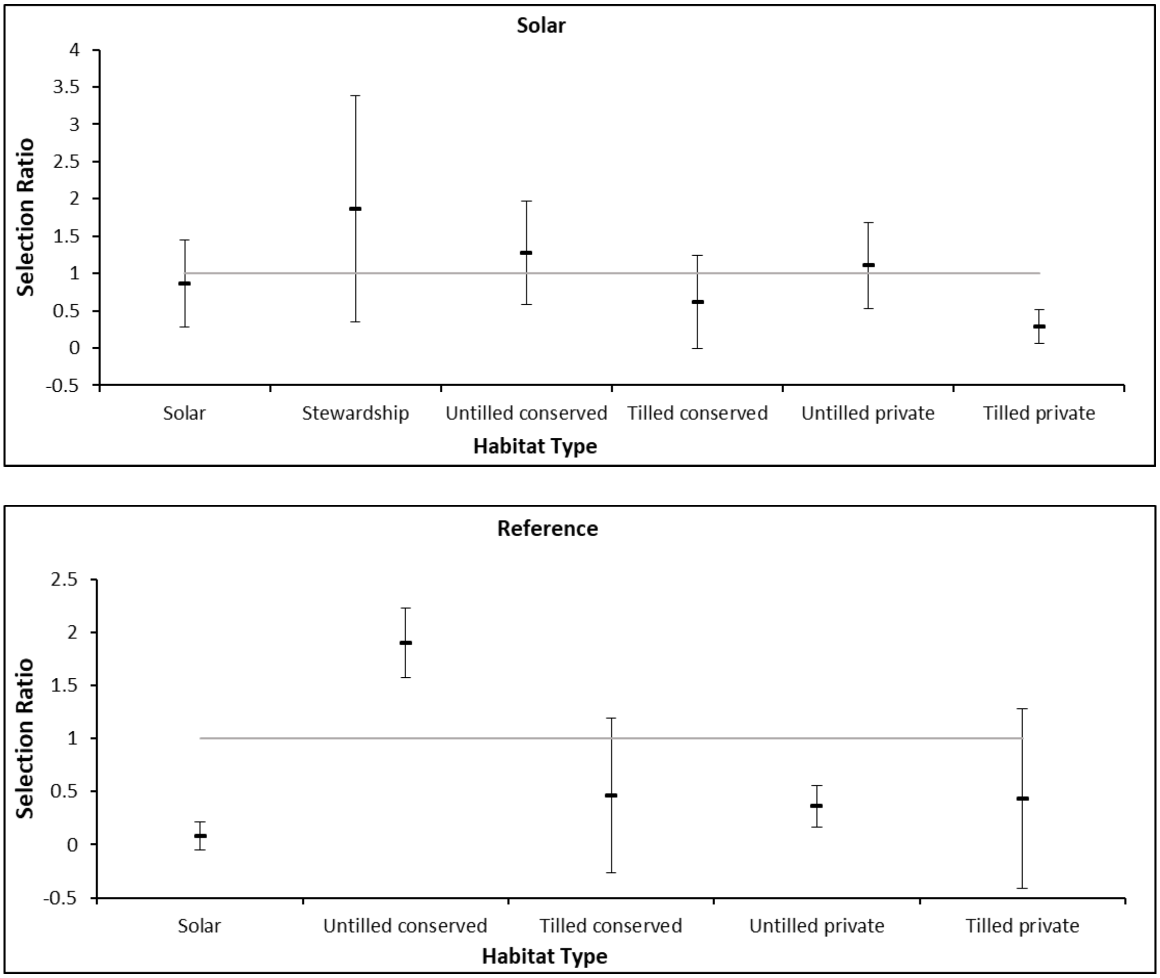

Figure 14. Habitat selection ratios for use of habitat types by San Joaquin kit foxes within home ranges on the solar site and reference site at the Topaz Solar Farms, San Luis Obispo County, CA.

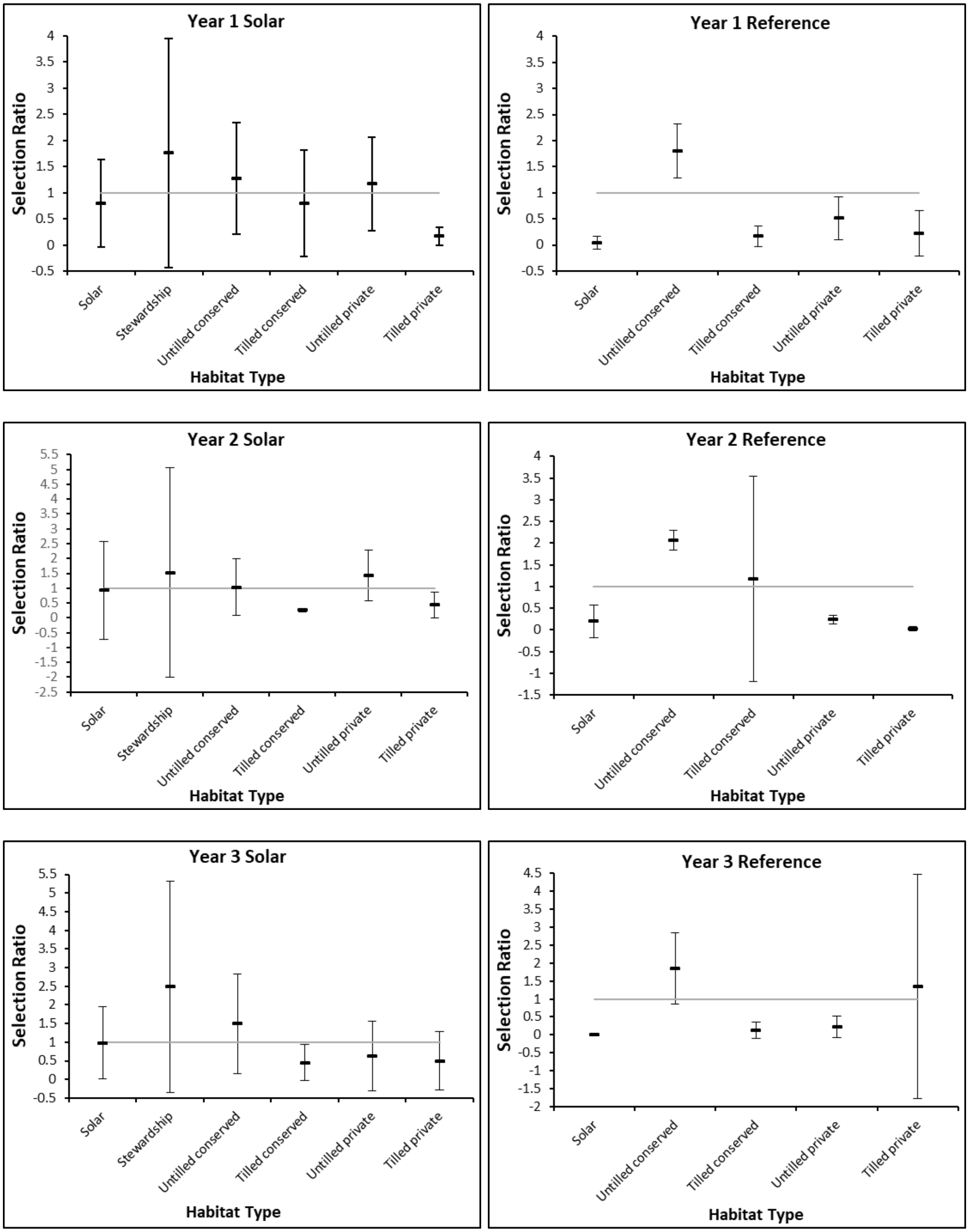

Figure 15. Selection ratios for use of habitat types by San Joaquin kit foxes within home ranges by year on the solar site and reference site at the Topaz Solar Farms, San Luis Obispo County, CA.

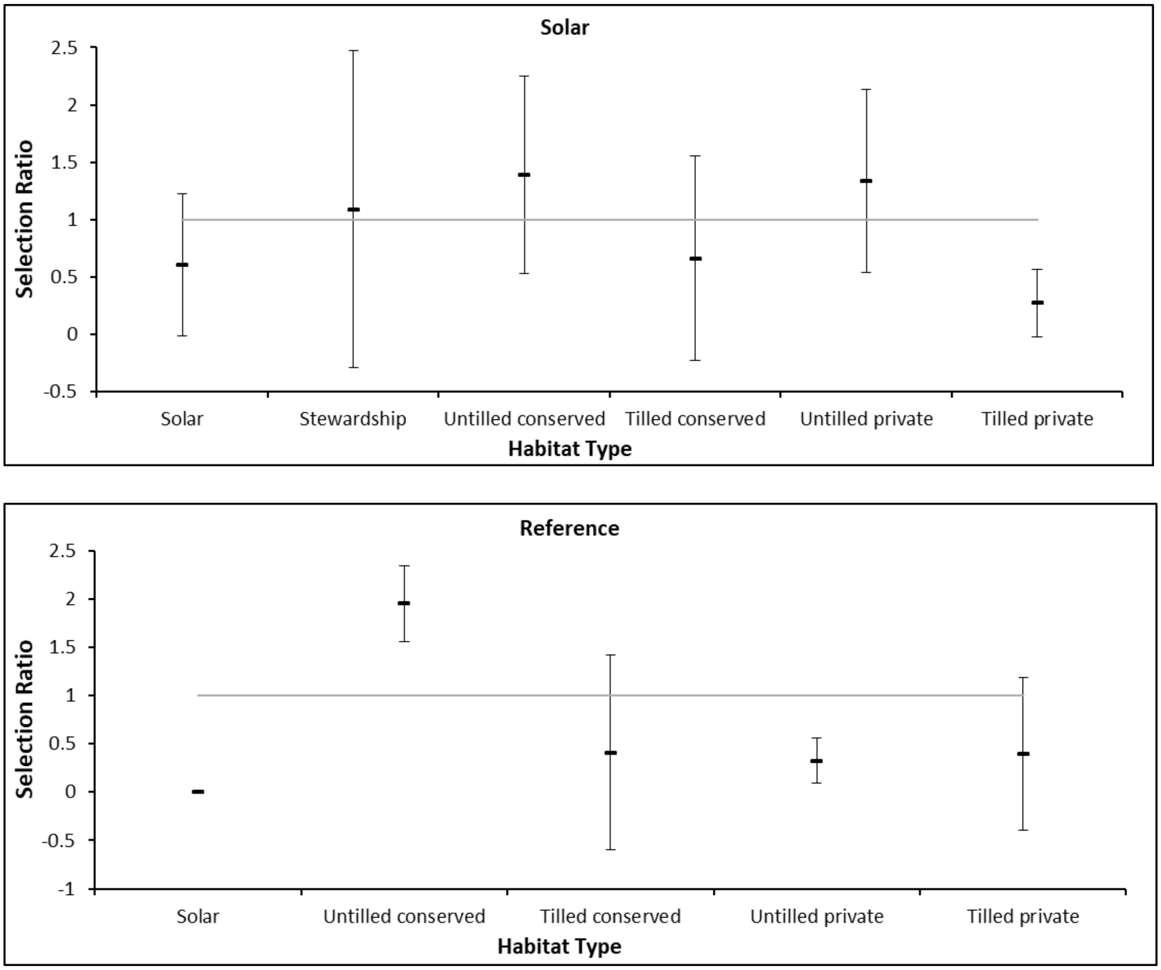

Figure 16. Habitat selection ratios for use of habitat types by San Joaquin kit foxes within core areas on the solar site and reference site at the Topaz Solar Farms, San Luis Obispo County, CA.

Annual trends for habitat use in core areas on each of the study sites were similar to the overall trends (Fig. 17). On the solar site, foxes generally used habitat types in proportion to their availability with the exceptions of tilled private lands, which were used disproportionately less relative to their availability in Year 1, and previously tilled conserved lands, which were used disproportionately less relative to their availability in Year 2. Within core areas on the reference site, foxes used untilled conserved lands disproportionately more in Years 1 and 2, and use approached significance in Year 3. Untilled private lands and solar arrays were used disproportionately less relative to availability in all years. Previously tilled conserved lands were used disproportionately less relative to availability in Years 1 and 3 while a very wide confidence interval around the ratio for this type in Year 2 indicated considerable variation in use of this type among foxes. Similarly, tilled private lands were used disproportionately less relative to availability in Years 1 and 2 while a very wide confidence interval around the ratio for this type in Year 3 indicated considerable variation in use of this type among foxes.

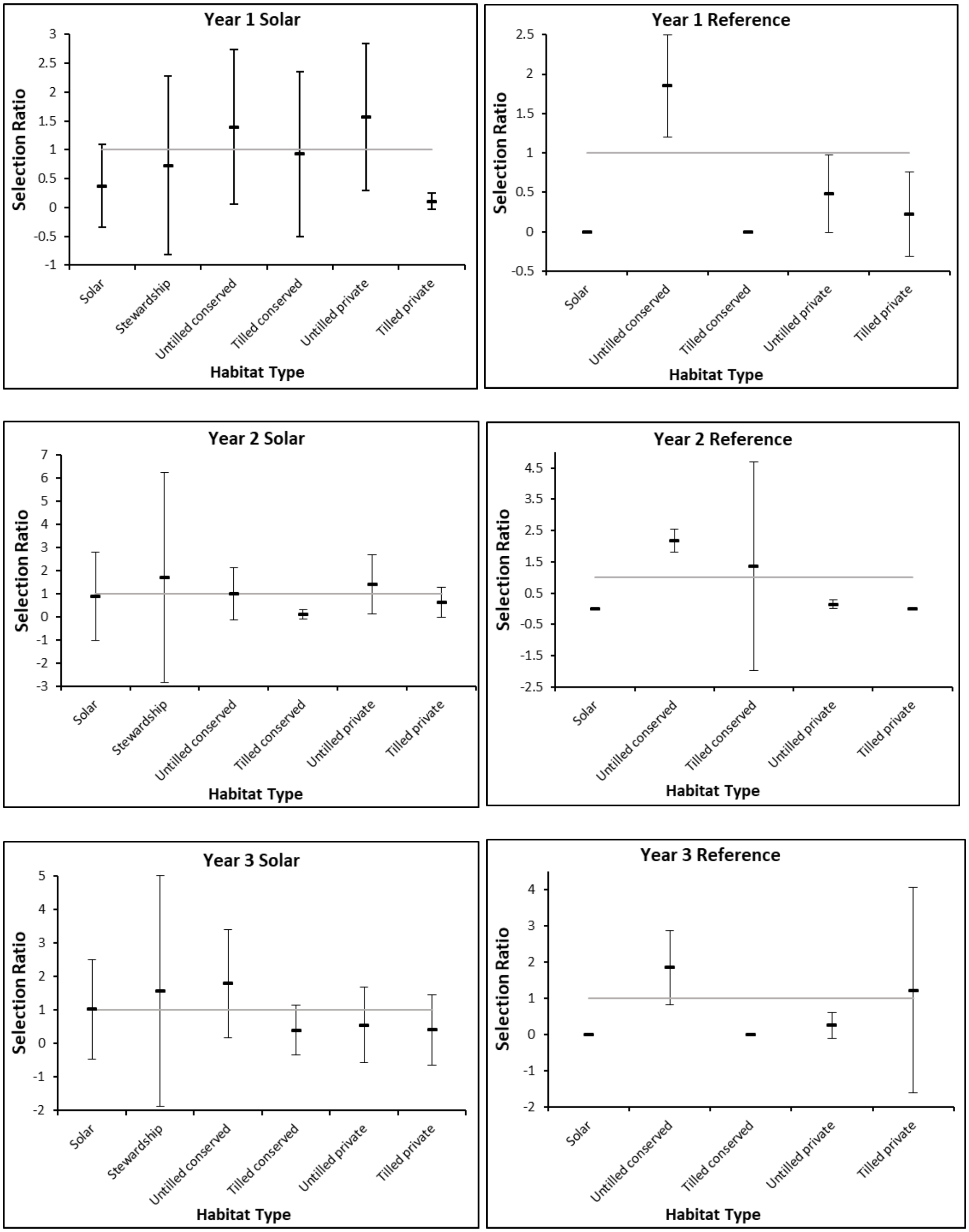

Figure 17. Selection ratios for use of habitat types by San Joaquin kit foxes within core areas by year on the solar site and reference site at the Topaz Solar Farms, San Luis Obispo County, CA.

Results of linear regression analyses revealed some relationships between proportional habitat use by foxes and home range size and core area size on each of the study sites

(Table 12). None of the relationships were significant on the solar site. However, on the reference site, proportional use of untilled conservation lands by foxes was negatively related to both home range size and core area size. Thus, as use of this habitat type increased, both home range and core area size decreased. Conversely, proportional use of previously tilled conservation lands and untilled private lands by foxes was positively related to both home range size and core area size. Also, proportional use of arrays was positively related to home range size of reference site foxes. In these situations, as use of these habitat types increased, home range size and core area size increased.

Table 12. Results for linear regression tests of relationships between proportional habitat use and both home range size and core area size for San Joaquin kit foxes on the solar site and reference site at the Topaz Solar Farms, San Luis Obispo County, CA. Results in bold are significant at $\alpha = 0.1$.

Value	Arrays	Stewardship	Untilled conservation	Previously tilled conservation	Untilled private
Solar site home ranges (*n* = 19)					
F[a]	1.47	1.03	0.50	0.30	0.46
p	0.25	0.33	0.49	0.60	0.51
R^2	0.09	0.06	0.03	0.02	0.03
B[c]	-8.18	-6.53	3.12	-9.94	3.48
Reference site home ranges (*n* = 32)					
F[b]	**8.80**	-[d]	**9.08**	**20.41**	**4.84**
p	**<0.01**		**<0.01**	**<0.01**	**0.04**
R^2	**0.23**		**0.23**	**0.41**	**0.14**
B	**80.82**		**-4.56**	**27.03**	**3.88**
Solar site core areas (*n* = 19)					
F[a]	0.82	0.64	0.01	0.19	1.16
p	0.38	0.44	0.98	0.67	0.30
R^2	0.05	0.04	0.00	0.01	0.07
B	-0.89	-0.98	0.02	1.51	1.02
Reference site core area (*n* = 32)					
F[b]	0.17	-[d]	**6.98**	**3.11**	**5.54**
p	0.68		**0.01**	**0.09**	**0.03**
R^2	0.01		**0.19**	**0.09**	**0.16**
B	3.67		**-1.18**	**3.72**	**1.18**

[a] Df = 1,15.

[b] Df = 1,30.

[c] Regression coefficient for the independent variable (proportion of habitat type used).

[d] Reference site foxes did not use Stewardship lands.

We obtained 7,324 estimates of distances moved between nocturnal locations for 38 foxes across the three years of the study (Table 13). Mean movements for foxes on the solar site ranged from 0.68-1.75 km with an overall mean (± SE) of 1.09 ± 0.06 km. Mean movements for foxes on the reference site ranged from 0.23-1.85 km with an overall mean of 0.96 ± 0.06 km. Based on multivariate analysis of variance, mean movements by foxes on the solar site were larger than those for foxes on the reference site ($F_{1,47} = 11.18$, $p = 0.002$). Mean movements also varied among years ($F_{2,47} = 15.36$, $p < 0.001$); mean movement decreased from Year 1 to Year 3 on both sites. Also, there was a significant area by year interaction ($F_{2,47} = 3.58$, $p = 0.036$); mean movement distances declined markedly in successive years on the reference site while the decline was less marked on the solar site with little difference between Years 1 and 2 (Table 13). Mean movements of males were marginally larger than those of females ($F_{1,47} = 3.67$, $p = 0.062$).

Table 13. Mean distance moved between nocturnal locations on consecutive nights for San Joaquin kit foxes by sex, site, and year at the Topaz Solar Farms, San Luis Obispo County, CA.

		Mean distance (km)					
		Males		**Females**		**All**	
Site	**Year**	**n**	**$\bar{x}$ (SE)**	**n**	**$\bar{x}$ (SE)**	**n**	**$\bar{x}$ (SE)**
Solar	1	3	1.29 (0.09)	4	1.22 (0.09)	7	1.27 (0.06)
	2	6	1.34 (0.11)	2	1.17 (0.18)	8	1.26 (0.11)
	3	6	1.00 (0.10)	2	0.91 (0.19)	8	0.95 (0.11)
	All	15	1.21 (0.06)	8	1.10 (0.09)	23	1.16 (0.05)
Reference	1	5	1.48 (0.10)	5	1.03 (0.10)	10	1.25 (0.07)
	2	5	0.91 (0.11)	8	0.81 (0.12)	13	0.86 (0.08)
	3	6	0.62 (0.14)	7	0.66 (0.10)	13	0.64 (0.09)
	All	16	1.00 (0.07)	20	0.84 (0.06)	36	0.92 (0.05)

We obtained 708 estimates of long distance movements for 36 foxes across the three years of the study (Table 14). Mean movement distance for foxes on the solar site ranged from 0.64-6.23 km with an overall mean (± SE) of 2.92 ± 0.31 km. Mean movement distance for foxes on the reference site ranged from 0.76-4.62 km with an overall mean of 2.20 ± 0.18 km. Based on multivariate analysis of variance, mean distance for foxes on the solar site and the reference site were not different ($F_{1,39} = 2.46$, $p = 0.125$). Mean distance did vary among years ($F_{2,39} = 4.23$, $p = 0.022$); mean movement decreased from Year 1 to Year 3 on both sites. Mean movements of males were marginally larger than those of females ($F_{1,39} = 3.67$, $p = 0.062$). There were no significant interactions among factors. The five longest movements exhibited by solar site foxes and reference site foxes indicated that foxes sometimes made long exploratory movements but then returned to their home range (Fig. 18).

Table 14. Mean long distance movements by San Joaquin kit foxes by sex, site, and year at the Topaz Solar Farms, San Luis Obispo County, CA.

		Mean distance (km)					
		Males		Females		All	
Site	Year	n	$\bar{x}$ (SE)	n	$\bar{x}$ (SE)	n	$\bar{x}$ (SE)
Solar	1	3	3.28 (0.41)	4	3.13 (0.40)	7	3.20 (0.29)
	2	2	3.17 (0.61)	2	2.34 (0.90)	4	2.76 (0.54)
	3	6	3.02 (0.58)	2	1.55 (0.97)	8	2.28 (0.56)
	All	11	3.16 (0.31)	8	2.34 (0.46)	19	2.75 (0.28)
Reference	1	5	3.73 (0.43)	5	2.20 (0.44)	10	3.00 (0.31)
	2	4	2.01 (0.55)	6	1.92 (0.59)	10	2.00 (0.40)
	3	6	1.46 (0.82)	6	1.74 (0.54)	12	1.60 (0.49)
	All	15	2.40 (0.36)	17	1.95 (0.30)	32	2.18 (0.24)

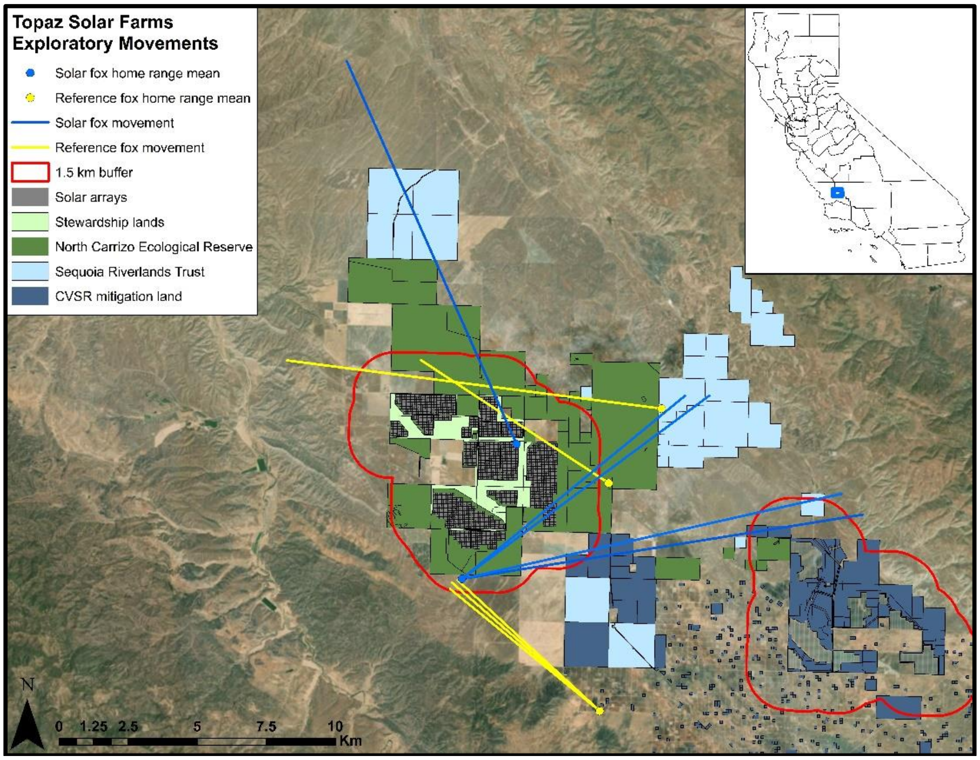

Figure 18. Five longest exploratory movements by San Joaquin kit foxes on the solar and reference sites at the Topaz Solar Farms, San Luis Obispo County, CA.

During the three years of the study, kit foxes were tracked to dens 1,807 times; 786 times for solar site foxes and 1,021 times for reference site foxes. A total of 367 unique dens were identified. Solar site foxes used 189 dens, reference site foxes used 216 dens, and of the combined total 38 dens were used by foxes from both sites. The mean number of dens used per fox appeared higher for solar site foxes, Year 1, and females (Table 15). However, when standardized by the number of times each fox was tracked to a den, the MANOVA model that include site, year, and sex as factors and all potential interaction effects was not significant ($F_{11,59} = 0.69$, $p = 0.744$). Similarly, the mean number of den switches per fox also appeared higher for solar site foxes, Year 1, and females (Table 16). However, when standardized by the number of times each fox was tracked to a den, the MANOVA model that include site, year, and sex as factors and all potential interaction effects was not significant ($F_{11,59} = 0.60$, $p = 0.820$).

Table 15. Mean number of unique dens used by San Joaquin kit foxes by sex, site, and year at the Topaz Solar Farms, San Luis Obispo County, CA.

	Dens per fox			
Factor	**n (foxes)**	**Mean**	**SE**	**Range**
Site				
Solar	26	11.2	1.9	1-33
Reference	45	8.4	1.2	1-31
Year				
1	22	13.4	2.3	1-33
2	25	7.5	1.4	1-23
3	24	7.7	1.4	1-29
Sex				
Male	37	8.6	1.5	1-33
Female	34	10.2	1.4	1-30

Occasionally during daytime tracking, kit foxes were found resting outside of dens or traveling. The number and proportion of locations where a fox was found resting outside of a den or traveling appeared higher for solar site foxes than for reference site foxes (Table 17). However, one individual (Male 6697) on the solar site was responsible for 62.5% and 88.9% of the resting locations in Year 1 and Year 2, respectively, and 71.4% and 33.3% of the traveling locations in Year 1 and Year 2, respectively. When these locations were removed from the summaries, the proportions of resting and traveling locations appeared to be very similar between the solar and reference sites (Table 17).

Kit fox den locations and natal den locations were plotted by habitat type (Fig. 19 and 20). An important caveat is that we did not have permission to access all private lands used by foxes. Thus, the number of dens on private lands may be underestimated. However, the distribution of dens among habitat types was similar to the distribution of nocturnal fox locations, and so the bias in den locations resulting from the lack of access probably did not significantly alter results. On the solar site, most dens (72.8%) were located in untilled conserved lands (Table 18, Fig. 21). Relative to the availability of habitat types, dens on the solar site were not distributed randomly among types (χ_5^2 = 226.0, $p < 0.001$). Dens were disproportionately more abundant in untilled conserved and stewardship lands and disproportionately less abundant in arrays, tilled conserved, untilled private, and tilled private habitat types (Table 18). When den locations on the solar site were weighted by the number of times foxes were tracked to each den, the results were similar. Relative to the availability of habitat types, den use on the solar site was not distributed randomly among types (χ_5^2 = 479.0, $p < 0.001$). Den use was disproportionately higher in untilled conserved and stewardship lands and disproportionately lower in arrays, tilled conserved, untilled private, and tilled private habitat types (Table 18). Relative to the availability of habitat types, natal dens on the solar site (Table 18, Fig. 21) also were not distributed randomly among types (χ_5^2 = 28.3, $p < 0.001$). Natal dens were disproportionately more abundant in untilled conserved lands and disproportionately less abundant in untilled private lands (Table 18).

Table 16. Mean number of den switches by San Joaquin kit foxes by site, year, and sex at the Topaz Solar Farms, San Luis Obispo County, CA.

	Den switches per fox			
Factor	**n (foxes)**	**Mean**	**SE**	**Range**
Site				
Solar	26	14.2	2.5	0-37
Reference	45	9.9	1.5	0-35
Year				
1	22	15.6	2.9	0-37
2	25	8.6	1.8	0-29
3	24	10.5	2.2	0-37
Sex				
Male	37	10.7	1.9	0-37
Female	34	12.2	1.9	0-37

On the reference site, most dens (95.4%) were located in untilled conserved lands (Table 18, Fig. 22). Relative to the availability of habitat types, dens on the reference site were not distributed randomly among types (χ_4^2 = 233.0, $p < 0.001$). Dens were disproportionately more abundant in untilled conserved lands and disproportionately less abundant in tilled conserved, untilled private, and tilled private habitat types (Table 18). When den locations on the reference site were weighted by the number of times foxes were tracked to each den, the results were similar. Relative to the availability of habitat types, den use on the reference site was not distributed randomly among types (χ_4^2 = 1040.0, $p < 0.001$). Den use was disproportionately higher in untilled conserved lands and disproportionately lower in stewardship, tilled conserved, untilled private, and tilled private habitat types (Table 18). Relative to the availability of habitat types, natal dens on the reference site (Table 18, Fig. 22) also were not distributed randomly among types ($\chi_4^2 = 24.3$, $p < 0.001$). All of the natal dens found on the reference site were in the untilled conserved lands. Natal dens were disproportionately more abundant in untilled conserved lands and disproportionately less abundant in untilled private lands (Table 18).

Table 17. Daytime locations in which San Joaquin kit foxes were found resting or traveling on the solar and reference sites at the Topaz Solar Farms, San Luis Obispo County, CA.

	Year 1	Year 2	Year 3	Total
		Solar site		
Foxes	8	7	6	12[1]
Total locations	392	122	192	706
Resting at dens	40	18	6	64
% resting at dens	10.2	1.5	3.1	9.1
Traveling	7	6	2	15
% traveling	1.8	4.9	1.0	2.1
		Solar site w/o M6697		
Foxes	7	6	6	11[1]
Total locations	292	67	192	551
Resting at dens	15	2	6	23
% resting at dens	5.1	3.0	3.1	4.2
Traveling	2	4	2	8
% traveling	0.7	6.0	1.0	1.5
		Reference site		
Foxes	11	11	5	17[1]
Total locations	286	391	142	819
Resting at dens	11	11	4	26
% resting at dens	3.8	2.8	2.8	3.2
Traveling	6	4	0	10
% traveling	2.1	1.0	0	1.2

[1] Locations were obtained on some individuals in multiple years; thus, the sum of annual fox totals exceeds the total across all years.

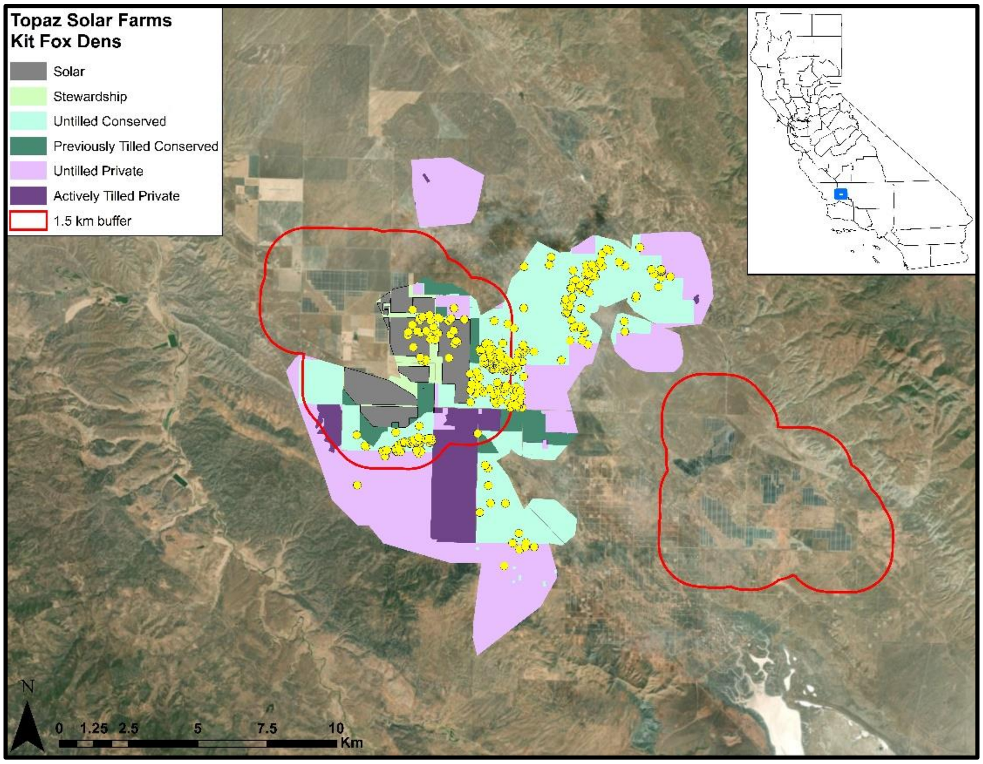

Figure 19. Locations of San Joaquin kit fox dens by habitat type at the Topaz Solar Farms, San Luis Obispo County, CA.

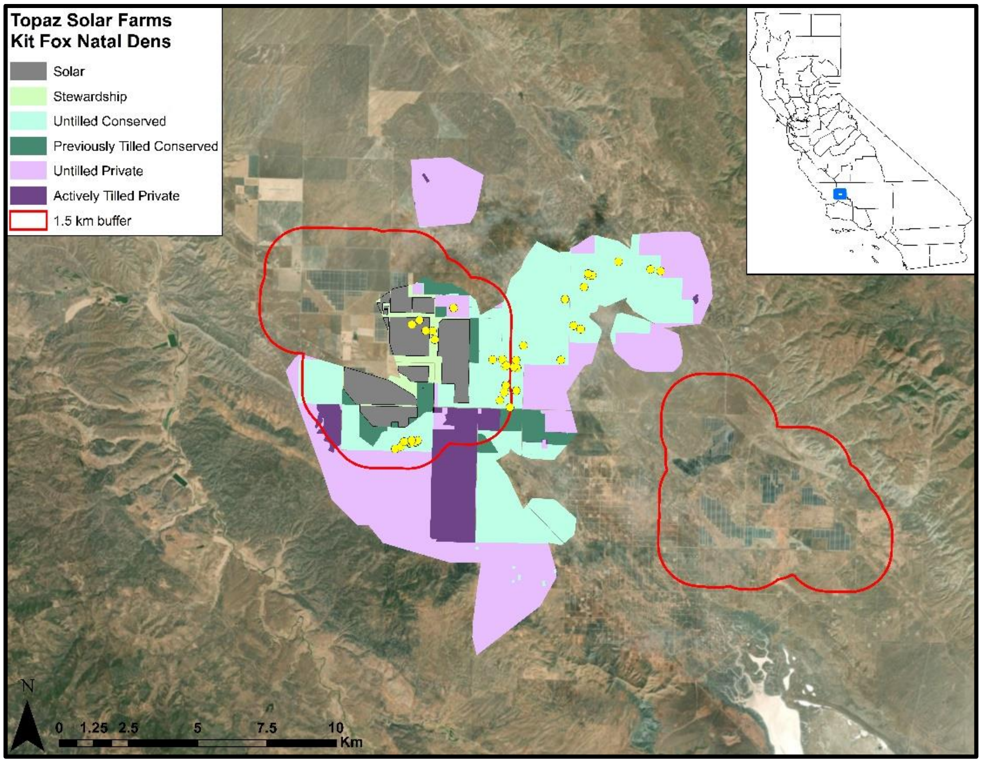

Figure 20. Locations of San Joaquin kit fox natal dens by habitat type at the Topaz Solar Farms, San Luis Obispo County, CA.

Table 18. Locations of San Joaquin kit fox dens by habitat type and tests of proportional abundance of dens in each habitat type relative to the proportional availability of each type on the solar and reference sites at the Topaz Solar Farms, San Luis Obispo County, CA.

Habitat	ha	Dens	χ_1^2 p	Den use[1]	χ_1^2 p	Natal dens	χ_1^2 p
				Solar site			
Arrays	1,020	17	11.83	191	11.28	3	0.34
	(20.1%)	(9.4%)	<0.001	(25.5%)	<0.001	(13.0%)	0.560
Stewardship	265	24	20.43	103	78.86	2	0.08
	(5.2%)	(13.3%)	<0.001	(13.8%)	<0.001	(8.7%)	0.777
Untilled conserved	1,383	131	173.15	398	205.12	17	22.70
	(27.3%)	(72.5%)	<0.001	(53.2%)	<0.001	(73.9%)	<0.001
Tilled conserved	466	0	17.04	0	73.50	0	1.35
	(9.2%)	(0%)	<0.001	(0%)	<0.001	(0%)	0.245
Untilled private	1,323	7	44.15	51	133.20	1	4.55
	(26.1%)	(3.9%)	<0.001	(6.8%)	<0.001	(4.3%)	0.033
Tilled private	613	1	21.29	5	88.38	0	2.12
	(12.1%)	(0.6%)	<0.001	(0.7%)	<0.001	(0%)	0.145
				Reference site			
Arrays	62	0	0.63	0	5.62	0	1.11
	(0.8%)	(0%)	0.427	(0%)	0.018	(00%)	0.292
Untilled conserved	3,412	188	230.95	872	1041.47	17	21.97
	(41.1%)	(95.4%)	<0.001	(97.9%)	<0.001	(100%)	<0.001
Tilled conserved	249	0	5.07	0	26.31	0	0.0
	(3.0%)	(0%)	0.024	(0%)	<0.001	(0%)	1.0
Untilled private	3,777	9	128.52	19	621.04	0	12.36
	(45.4%)	(4.6%)	<0.001	(2.1%)	<0.001	(0%)	<0.001
Tilled private	812	0	20.16	0	94.25	0	0.90
	(9.8%)	(0%)	<0.001	(0%)	<0.001	(0%)	0.343

[1] Den use = number of dens in each habitat multiplied by the number of times foxes were tracked to those dens.

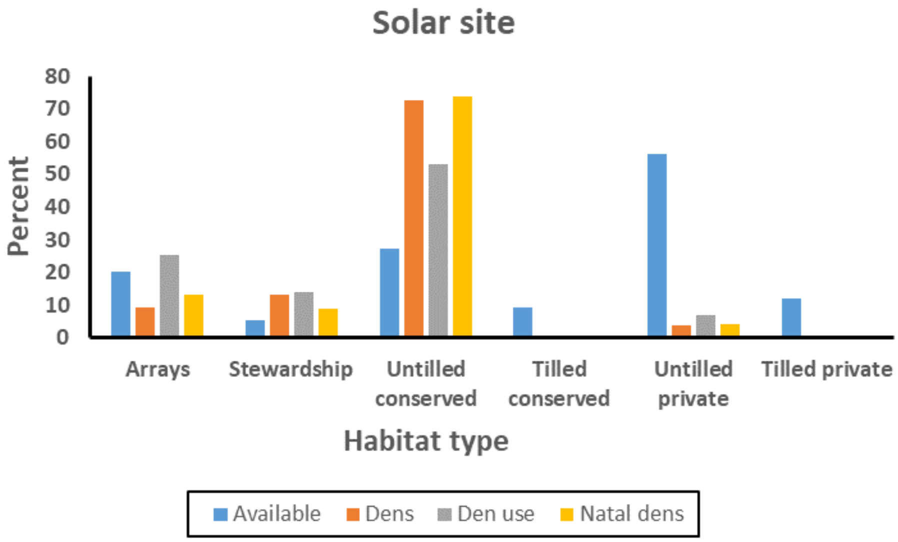

Figure 21. Proportional abundance of San Joaquin kit fox dens relative to proportional abundance of habitat types on the solar site at the Topaz Solar Farms, San Luis Obispo County, CA.

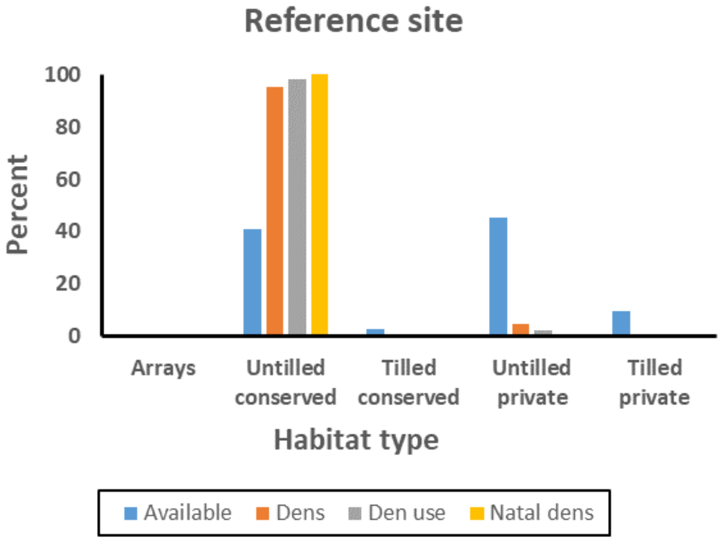

Figure 22. Proportional abundance of San Joaquin kit fox dens relative to proportional abundance of habitat types on the reference site at the Topaz Solar Farms, San Luis Obispo County, CA.

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 [*D. ingens*]), pocket mouse (San Joaquin pocket mouse [*Perognathus inornatus*] or California pocket mouse [*Chaetodipus californicus*]), 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*]), 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.), other unidentified beetles and larvae (Order Coleoptera), scorpion (Order Scorpiones), solpugid (Order Solifugae), domestic animal, olive (*Olea* spp.), and anthropogenic material (e.g., foil). Use of individual food items generally was similar between the solar site and the reference site (Table 19) with few exceptions. Use of rodents by foxes was consistently high on both sites. However, the species composition of rodents consumed varied over time. Use of pocket mice and deer mice decreased while use of kangaroo rats increased with the increase being notably higher on the reference site. Foxes from the solar site occasionally consumed olives from a nearby olive grove, which was more accessible to solar site foxes than to reference site foxes.

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 20, Fig. 23). Use of item categories was significantly similar among years on both the solar site (W = 0.91, χ_6^2 = 16.35, p = 0.012) and the reference site (W = 0.85, χ_6^2 = 15.34, p = 0.018). For all years combined, use of item categories was significantly similar between the solar and reference sites (W = 0.98, χ_6^2 = 11.73, p = 0.068). Based on Shannon indices (Table 20, Fig. 24), dietary diversity generally was similar between sites. However, there was a slight increase in dietary diversity from Year 1 to Year 3 on the solar site. Conversely, there was a slight decrease in dietary diversity from Year 1 to Year 3 on the reference site that corresponded with increased use of rodents by foxes and decreased use of other items.

Table 19. Frequency of occurrence of food items in San Joaquin kit fox scats by site and year at the Topaz Solar Farms, San Luis Obispo 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	3	0	8	0	2	1
Kangaroo rat	3	4	12	21	28	64	9	18
Pocket mouse	19	35	35	38	10	12	23	31
Deer mouse	26	30	38	35	5	6	28	27
House mouse	1	1	1	0	0	0	1	1
Ground squirrel	4	1	4	3	5	0	4	1
Gopher	1	2	5	0	10	0	3	1
Unknown rodent	37	23	23	21	25	30	32	24
Bird	4	3	6	12	10	6	5	5
Snake	5	3	7	9	3	0	5	3
Lizard	1	1	1	3	3	0	1	1
Jerusalem cricket	49	53	37	21	43	36	45	44
Cricket	10	9	6	0	6	0	8	6
Grasshopper	8	20	14	9	13	6	10	16
Beetle	6	10	3	9	23	18	7	11
Beetle larva	22	4	0	0	3	3	13	3
Unknown insect	13	13	14	0	15	9	14	10
Solpugid	1	2	2	3	0	3	1	2
Olive	1	1	4	0	5	0	2	1
Anthropogenic	1	3	1	0	0	0	1	2
No. scats	196	113	98	34	40	33	334	180

Table 20. Frequency of occurrence of food items by item category and Shannon diversity indices for San Joaquin kit fox diets by site and year at the Topaz Solar Farms, San Luis Obispo 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	3	0	8	0	2	1
Rodent	83	81	89	97	83	100	84	88
Bird	4	3	6	12	10	6	5	5
Reptile	6	4	8	12	5	0	6	4
Invertebrate	49	53	37	21	43	36	45	44
Anthropogenic	2	4	5	0	5	0	3	2
No. scats	196	113	98	34	40	33	334	180
Diversity index	0.42	0.44	0.50	0.41	0.54	0.32	0.47	0.43

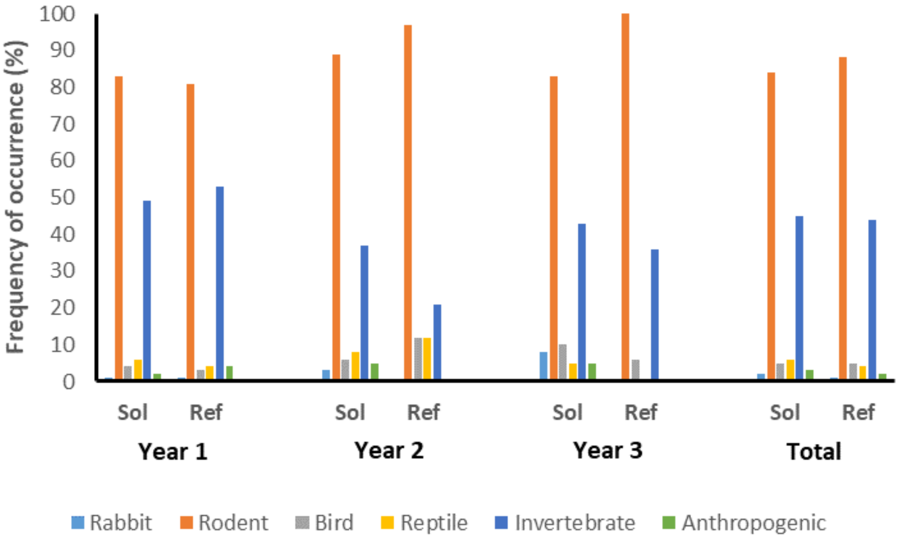

Figure 23. Frequency of occurrence of food items by item category for San Joaquin kit fox diets by site and year at the Topaz Solar Farms, San Luis Obispo County, CA.

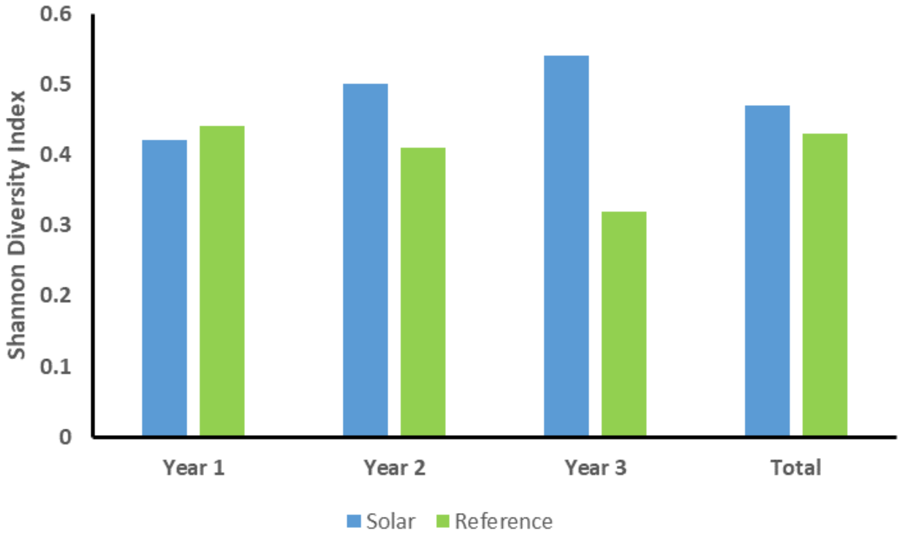

Figure 24. Shannon diversity indices for San Joaquin kit fox diets by site and year at the Topaz Solar Farms, San Luis Obispo County, CA.

Live-trapping was conducted in June 2016 to assess small mammal abundance (Fig. 25). Species captured (Table 21) included Heermann's kangaroo rat, giant kangaroo rat, California pocket mouse, San Joaquin pocket mouse, deer mouse, and grasshopper mouse (*Onychomys torridus*). The number of unique rodents captured per 100 trapnights (Fig. 26) was significantly higher on the reference site compared to the solar site ($t_{1,13} = 41.96$, $p < 0.001$). Similarly, the number of kangaroo rats captured per 100 trapnights (Fig. 26) also was significantly higher on the reference site compared to the solar site ($t_{1,13} = 19.40$, $p = 0.001$). When the solar site was divided into arrays and stewardship lands, the number of unique rodents captured per 100 trapnights (Fig. 27) varied among areas ($F_{2,12} = 32.46$, $p < 0.001$). Based on post-hoc analysis, the number was higher on the reference site compared to the arrays ($p < 0.001$), and the number on the stewardship lands was less than that on either the arrays ($p = 0.068$) or the reference site ($p < 0.001$). Similarly, the number of kangaroo rats captured per 100 trapnights (Fig. 27) also varied among areas ($F_{2,12} = 9.56$, $p = 0.003$). Based on post-hoc analysis, the number was higher on the reference site compared to both the arrays ($p = 0.014$) or the stewardship lands ($p = 0.004$), but the number was similar between the arrays and the stewardship lands ($p = 0.771$).

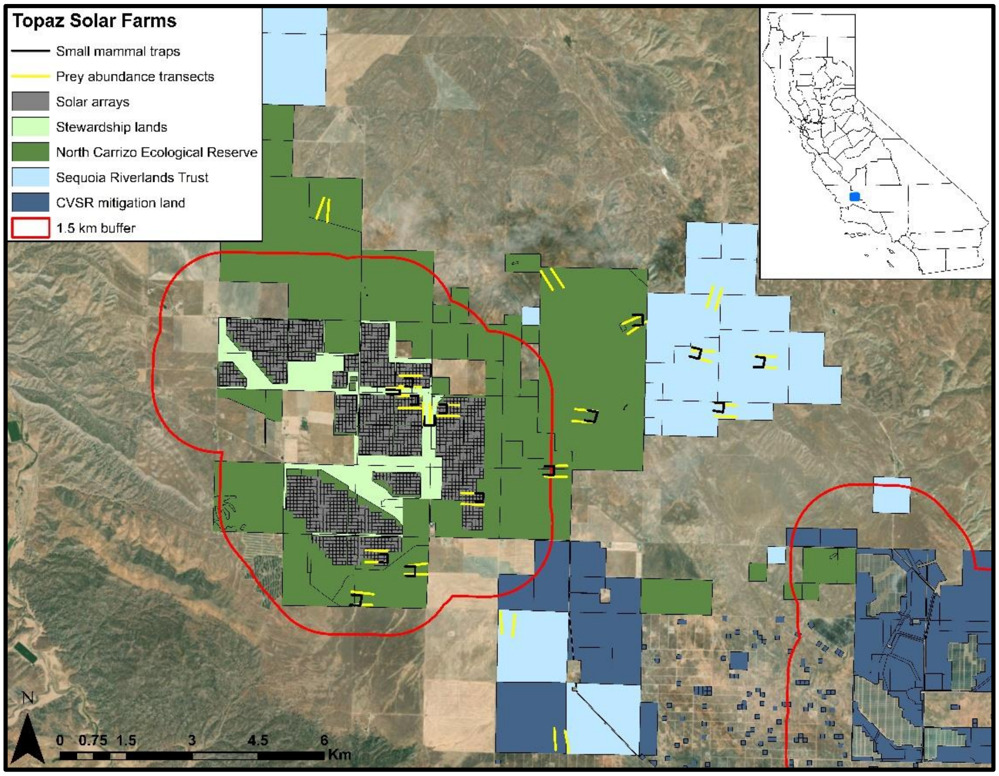

Figure 25. Locations of small mammals live-trapping transects and prey availability transects at the Topaz Solar Farms, San Luis Obispo County, CA.

Table 21. Number of individual small mammals live-trapped in arrays, stewardship lands, and the reference site in June 2016 at the Topaz Solar Farms, San Luis Obispo County, CA.

	Number of individuals		
	Arrays	**Stewardship**	**Reference**
Heermann's kangaroo rat	12	4	47
Giant kangaroo rat	0	0	4
California pocket mouse	36	9	67
San Joaquin pocket mouse	0	5	9
Deer mouse	25	7	49
Southern grasshopper mouse	0	0	1
Total rodents	73	25	177
Total kangaroo rats	12	4	51

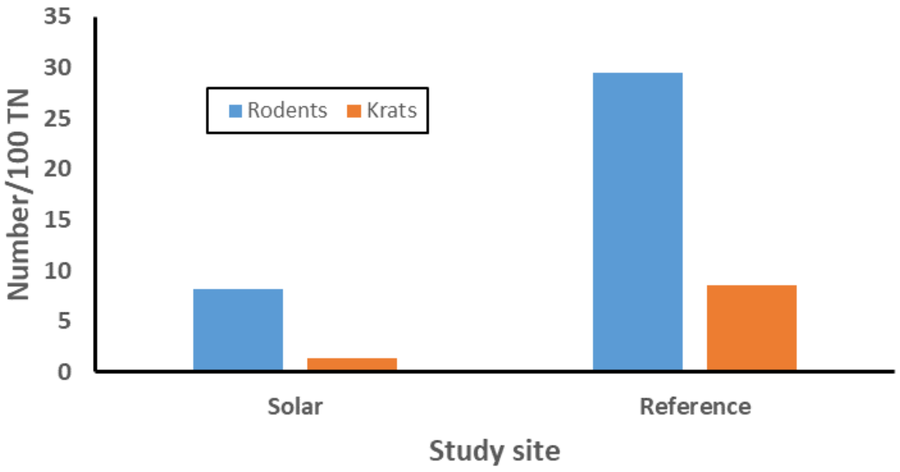

Figure 26. Number of rodents captured per 100 trapnights on the solar and reference sites at the Topaz Solar Farms, San Luis Obispo County, CA.

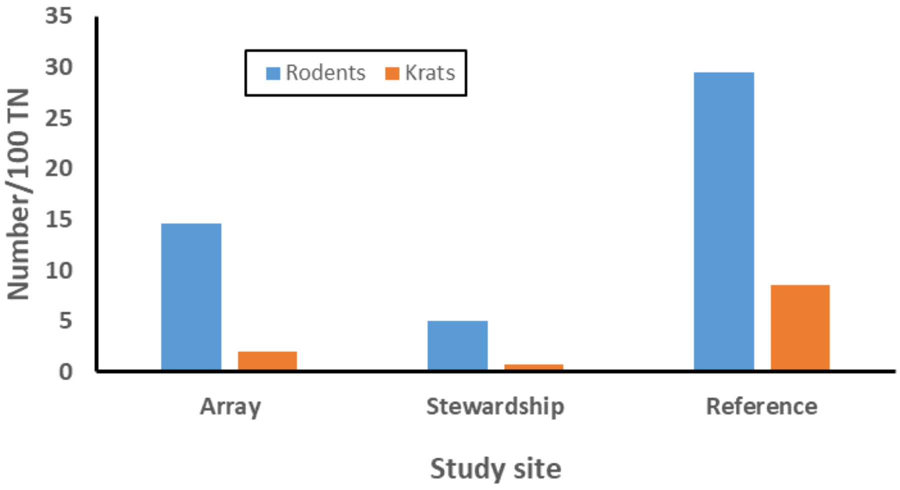

Figure 27. Number of rodents captured per 100 trapnights in the arrays, stewardship lands, and reference site at the Topaz Solar Farms, San Luis Obispo County, CA.

Based on the prey availability transects conducted in June 2017, small rodent burrows and large rodent burrows were more abundant on the reference site compared to the solar site, rabbit pellets were more abundant on the solar site, and cover was similar between the two sites (Table 22). When the solar site was divided into arrays and stewardship lands, abundance of both small burrows and large burrows was significantly higher on the reference site while abundance for both was similar between the arrays and stewardship lands (Table 23). Abundance of rabbit pellets was significantly higher in the arrays, but similar between the stewardship lands and reference site. Herbaceous cover was similar across all three areas.

Table 22. Comparison of prey availability indices based on transect surveys conducted on the solar site and the reference site at the Topaz Solar Farms, San Luis Obispo County, CA.

	Mean (SE)			
	Solar (n = 18)	**Reference (n = 22)**	***W*[1]**	***p***
Small burrows	3.7 (1.0)	10.7 (2.3)	253.0	0.005
Large burrows	3.3 (0.9)	12.7 (1.8)	225.5	<0.001
Rabbit pellets	111.2 (39.6)	10.1 (5.2)	456.5	0.015
% cover	83.1 (3.2)	82.1 (2.5)	391.5	0.549

[1] *W* = Mann-Whitney statistic.

Table 23. Comparison of prey availability indices based on transect surveys conducted in arrays, stewardship lands, and the reference site at the Topaz Solar Farms, San Luis Obispo County, CA.

	Mean (SE)				
	Arrays (n = 10)	**Stewardship (n = 8)**	**Reference (n = 22)**	***H*[1]**	***p***
Small burrows	4.6 B[2] (1.7)	2.5 B (0.9)	10.7 A (2.3)	10.56	0.005
Large burrows	3.4 B (1.3)	3.1 B (1.2)	12.7 A (1.8)	15.34	<0.001
Rabbit pellets	180.1 A (61.3)	25.1 B (24.8)	10.1 B (5.2)	16.33	<0.001
% cover	83.8 A (5.6)	82.1 A (2.5)	82.1 A (2.5)	1.21	0.546

[1] *H* = Kruskal-Wallis statistic.

[2] Across rows, means with similar letters are not significantly different based on Mann-Whitney tests.

Mean kit fox weight (Table 24) differed between males and females ($F_{1,34} = 35.16$, $p < 0.001$), as expected, but did not differ between study sites ($F_{1,34} = 1.20$, $p = 0.281$) and there was no interaction effect between sex and site ($F_{1,34} = 1.34$, $p = 0.255$).

Table 24. Mean weight of San Joaquin kit foxes by sex and study site at the Topaz Solar Farms, San Luis Obispo County, CA.

	Mean weight (kg) (SE)			
Site	*n*	Male	*n*	Female
Solar	9	2.48 (0.04)	8	2.16 (0.10)
Reference	10	2.64 (0.06)	11	2.16 (0.07)

Potential competitors of kit foxes were present both on the solar site and the reference site, based on annual camera station surveys (Table 25). Coyotes were detected more frequently on the reference site (24 detections) than on the solar site (15 detections). Red foxes were only detected on the solar site. Badgers were detected slightly more frequently on the reference site (6 detections) than on the solar site (2 detections), and a bobcat was detected once on the reference site. Two of the solar site camera stations were located within the security fence surrounding arrays of solar panels. No competitors were detected on these cameras except for one red fox detection in 2015.

Table 25. Detections of potential kit fox competitor species by year on the solar and reference sites at the Topaz Solar Farms, San Luis Obispo County, CA.

	Number of cameras with detections					
	Solar site			Reference site		
	2015 ***n* = 13**	**2016** ***n* = 14**	**2017** ***n* = 14**	**2015** ***n* = 13**	**2016** ***n* = 14**	**2017** ***n* = 14**
Coyote	8	6	1	11	8	5
Red fox	2	4	1	0	0	0
Badger	2	0	0	1	1	4
Bobcat	0	0	0	1	0	0

Food items identified in coyote scats included rabbit, kangaroo rat, pocket mouse, deer mouse, house mouse, vole (*Microtus californicus*), pocket gopher, ground squirrel, woodrat (*Neotoma fuscipes*), unidentified bird and eggshells, unidentified snake and lizard, Jerusalem cricket, field cricket, grasshoppers, earwig, darkling beetle, other unidentified beetles and larvae, domestic animal, olive, and juniper berries (*Juniperus* spp.). Use of individual food items varied between the solar and reference sites (Table

26), although some of this variability may be attributable to the relatively small sample sizes for scats. When grouped into broader categories (Table 27), items occurring more frequently in coyote scats from the solar site included rabbits and anthropogenic materials while items occurring more frequently in scats from the reference site included rodents, reptiles, and invertebrates. Anthropogenic items included domestic animals and crops, and likely came from areas near human habitations near the solar site. Also, an important caveat is that coyotes have large home ranges compared to kit foxes and can travel considerable distances. Therefore, coyotes easily could have obtained foods from one study site but deposited scats containing those food remains on another study site.

When compared with use of food items by kit foxes (Table 27), coyotes more frequently consumed rabbits and anthropogenic materials on the solar site, invertebrates on the reference site, and birds and reptiles on both sites. Kit foxes more frequently consumed rodents on the solar site. Although there were some differences in use of items, diets of coyotes and kit foxes exhibited considerable overlap.

Table 26. Frequency of occurrence of food items in coyote scats by site at the Topaz Solar Farms, San Luis Obispo County, CA.

	Frequency of occurrence (%)	
Food item	**Solar**	**Reference**
Rabbit	29	6
Kangaroo rat	26	15
Pocket mouse	29	36
Deer mouse	26	58
House mouse	3	0
Vole	3	0
Ground squirrel	10	3
Gopher	0	3
Woodrat	3	0
Unknown rodent	7	21
Bird	19	21
Snake	3	21
Lizard	7	9
Jerusalem cricket	0	21
Cricket	7	6
Grasshopper	19	27
Beetle	7	36
Beetle larva	13	12
Unknown insect	7	18
Olive	13	3
Juniper berries	0	3
No. scats	31	33

Table 27. Frequency of occurrence of food items by item category in coyote and San Joaquin kit fox scats by site at the Topaz Solar Farms, San Luis Obispo County, CA.

	Frequency of occurrence (%)			
	Solar		Reference	
Food category	**Coyote**	**Kit fox**	**Coyote**	**Kit fox**
Rabbit	29	2	6	1
Rodent	68	84	88	88
Bird	19	5	21	5
Reptile	10	6	30	4
Invertebrate	48	45	70	44
Anthropogenic	23	3	6	2
No. scats	31	334	33	180

DISCUSSION

KIT FOX DEMOGRAPHIC COMPARISONS

We assessed kit fox survival and mortality patterns at the TSF using a variety of approaches. We did not find any evidence that the facility was adversely impacting kit fox survival, and in fact, there was evidence that the facility potentially provided some benefits. Based on the Micromort and Cox proportional hazards analyses we conducted, kit fox survival did not differ between the solar and reference sites. Although not statistically significant, survival indices actually were consistently higher on solar site. Furthermore, three 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 significantly higher survival of solar site foxes compared to those on the reference site.

Survival rates of kit foxes on the two study sites on the TSF were similar to those reported for San Joaquin kit foxes in other multi-year studies (Table 28), with the rate from the solar site being among the highest. High survival rates on the solar site are not necessarily surprising. As with other canids, kit foxes seem to 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. At the TSF, the fencing around the solar arrays likely inhibited use by coyotes, although coyotes still were occasionally observed in the arrays. Although bobcats clearly can scale the fences, as evidenced by the foxes killed by bobcats within the arrays, the fences may serve to at least reduce bobcat activity in the arrays. The solar panels comprising the arrays also likely provide some cover to the foxes from aerial attack by golden eagles. Thus, predation risk may be lower in the fenced array areas and these areas may function in essence as refugia for kit foxes. Similarly, anthropogenically altered areas (e.g., homesteads and urban areas) were found to serve as refugia for red foxes from coyotes in Illinois (Gosselink et al. 2003) and Wisconsin (Mueller et al. 2018). In southern California, habitat fragments within urbanized areas served as refugia for gray foxes (*Urocyon cinereoargenteus*) from coyotes (Crooks and Soulé 1999).

Year and sex both were significant explanatory variables for kit fox survival. For unknown reasons, survival was markedly higher on both the solar and reference study sites in Year 1 versus Years 2 and 3. A similar trend was observed among kit foxes on the nearby California Valley Solar Ranch (H.T. Harvey and Associates 2018). These trends do not appear to have been a function of food availability or predators, based on limited evidence. Abundance of food resources, particularly small mammals, apparently increased from Year 1 to Year 3 based on fox food habits. The abundance of predators may have declined based on the camera station surveys, although the abundance of certain important predators, such as golden eagles, was not adequately monitored by the cameras. Annual variation in kit fox survival also was documented in two long-term studies in western Kern County (Spiegel and Disney 1996, Cypher et al. 2000). On the TSF, male survival was consistently higher than that of females on both study sites. Again, the reason for this result is unclear as survival generally is similar between sexes (Standley et al. 1992, Ralls and White 1995, Spiegel and Disney 1996, Cypher et al. 2000). However, Nelson et al. (2007) also reported a difference in survival between sexes, although in that study female survival was significantly higher than that of males.

Table 28. Annual survival probabilities ($\hat{S}$) reported for San Joaquin kit foxes in various multi-year studies.

Location	Study years	No. foxes	$\hat{S}$	Source
Topaz Solar Farms – solar site	2015-2017	17	0.65	This study
Carrizo Plain, eastern San Luis Obispo County	1989-1991	24	0.60	Ralls and White 1995
Lokern Natural Area/Midway-Sunset oilfield, western Kern County	1989-1993	103	0.56	Spiegel and Disney 1996
Camp Roberts, northern San Luis Obispo County	1988-1991	67	0.53	Standley et al. 1992
Topaz Solar Farms – reference site	2015-2017	35	0.49	This study
Naval Petroleum Reserves in California, western Kern County	1980-1995	341	0.44	Cypher et al. 2000

The mortality indices we calculated (mortalities per 1000 monitoring days) were consistent with the higher survival rates in Year 1 and on the solar 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 TSF again were both within the range of values derived for studies at other locations (Table 29). Interestingly, the value for the solar site was more similar to those from sites within “core” population areas (e.g., Lokern, Carrizo, S. Carrizo), as defined in the recovery plan that includes San Joaquin kit foxes (U.S. Fish and Wildlife Service 1998). Sites within core population areas generally have more optimal habitat conditions for kit foxes (Cypher et al. 2013). Conversely, the value for the reference site was more similar to those from sites in “satellite” population areas (e.g., Camp Roberts, Los Banos Grandes, Semitropic Ecological Reserve) where habitat conditions are considered to be less optimal due to lower habitat quality, high habitat fragmentation, or increased predation risk.

Typical of most other locations, predators were the primary cause of kit fox mortality on both the solar and reference sites at the TSF. In many cases, the species of predator could not be identified due to insufficient evidence (e.g., too few remains, desiccated carcass).

Sometimes, just the radio-collar was found. However, coyotes, bobcats, and golden eagles all were identified as sources of kit fox mortality at the TSF. 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. A high rate of predation on foxes by golden eagles was documented in this study. Golden eagles have been identified as a potential predator on kit foxes, but such predation has rarely been documented (Clark 2009). We identified golden eagles as the likely predator in at least six fox mortalities on the TSF. All occurred in the spring when kit foxes exhibit more diurnal above-ground activity associated with pup rearing. Two foxes, an adult and a pup, were killed by golden eagles on the solar site, but both mortalities occurred on lands outside of the solar arrays. Significant predation by golden eagles also has been documented on island foxes (*Urocyon littoralis*; Coonan et al. 2010), swift foxes (*Vulpes velox*; Moehrenschlager et al. 2007), and corsac foxes (*Vulpes corsac*; Ellis et al. 1999), all of which are similar in size to kit foxes.

Table 29. Mortality index (deaths/1000 monitoring days) for various studies on San Joaquin kit foxes.

Study site	Source	No. foxes	Monitoring days	Deaths	Deaths/1000 days
Lokern Natural Area, western Kern County	Cypher et al. 2009	47	5,857	4	0.68
Carrizo Plain, eastern San Luis Obispo County	Ralls and White 1995	24	13,339	10	0.75
S. Carrizo, eastern San Luis Obispo County	Cypher et al., unpubl.	9	1,818	2	1.10
Topaz-solar, eastern San Luis Obispo County	This study	22	5,890	7	1.19
N. Carrizo, eastern San Luis Obispo County	Cypher et al. 2014*a*	10	1,649	2	1.21
Camp Roberts, eastern San Luis Obispo County	Standley et al. 1992	67	20,366	35	1.72
Elk Hills (normal-wet years), western Kern County	Cypher et al. 2000	366	62,352	121	1.94

Topaz-reference, eastern San Luis Obispo County	This study	48	8,184	16	1.96
Panoche Valley, eastern San Benito County	Cypher et al., unpubl.	11	2,381	5	2.10
Semitropic Ecological Reserve, northern Kern County	Cypher et al. 2014*b*	11	1,592	4	2.51
Los Banos Grandes, western Merced County	Briden et al. 1992	14	2,775	7	2.52
Elk Hills (drought years), western Kern County	Cypher et al. 2000	205	32,169	104	3.23

None of the foxes in our study were killed by vehicles. However, five non-study foxes were opportunistically found dead on roads. Vehicle mortality is not uncommon among kit foxes (Spiegel and Disney 1996, Cypher et al. 2000, Cypher 2003, Cypher et al. 2009). At least three of the five foxes struck by vehicles in this study were young-of-the-year that may have been less experienced in crossing roads. No other sources of mortality were identified in our study, and no fox deaths appeared associated with operations activities at the TSF.

Temporal patterns of mortalities generally were similar between the solar and reference sites. Noticeable spikes in the number of mortalities were observed during March-May, August, and December-January. The March-May period coincides with pup-rearing and is a time of increased above-ground activity by both pups and adults. The extended time out of dens predisposes foxes to increased predation. Of particular note is that foxes frequently are active outside dens diurnally during this time. Six foxes (four reference site and two solar site) apparently were killed during this period by golden eagles, which hunt diurnally (Clark 2009). Coyotes also visit kit fox dens more frequently during this period, presumably to try to catch pups (CSUS-ESRP, unpublished data). Increased mortality in August may be associated with dispersal by pups and the inherent associated risks. Indeed, two of the three foxes that died in August were pups that were killed on roads. The increased mortality in December and January likely was the result of increased activity, and therefore increased predation risk, associated with foxes seeking mates, defending mates, and seeking extra-pair fertilization opportunities (Zoellick et al. 1989, 2002; Murdoch et al. 2008). However, no obvious differences between the solar and reference sites were apparent in the observed patterns.

Reproductive success was primarily based on observations of pups with adult females in the spring. Neonatal and natal survival to the point where pups are observed above ground (usually at around 3 weeks of age) is largely a function of adequate food resources to support gestation and lactation coupled with the survival of the adult female.

(If the female dies during the nursing period, neither the adult male or any “helper” foxes that may be present are able to provide milk for the pups.) Food resources apparently were sufficiently abundant on both the solar and reference sites that pups survived to the point of emerging from dens. However, we did not consider in our reproduction evaluation females that died prior to being assessed or pup survival after emergence from dens. Based on several observations, the rate of actual pup production might have differed between the solar and reference sites. Two females on the reference site were killed by predators prior to reproductive assessments. One was found to be lactating and therefore, her death likely meant that a litter was lost as well. The other female did not exhibit signs of reproduction. Two other females, one on the reference site and one on the solar site, died in March after they were assessed. The female on the reference site and her mate were killed by an eagle and were associated with a litter of four pups. The fate of the pups was unknown, although a pup was observed at the natal den along with an adult, possibly a helper fox, a few days after the mortalities. The female on the solar site did not exhibit signs of having reproduced. Thus, recruitment rates may be lower on the reference site compared to the solar site due to higher predation risk.

We did not monitor kit fox abundance during this study. However, abundance on the solar site has been assessed since 2009 by conducting systematic surveys for fresh scats, and then genetically analyzing those scats to identify individuals (Althouse and Meade, Inc., Working Dogs for Conservation, and Smithsonian Conservation Biology Institute, unpublished data). Based on this analysis, the minimum number of unique individuals on the solar site appears to have been generally increasing (Fig. 28). This may be a further indication that the habitats on and in close proximity to the solar site are recovering, and the refugia effect of the arrays potentially contribute to this trend. The increasing trend in these data, as opposed to a declining trend, also may further indicate that the solar farm does not appear to be adversely impacting local kit fox abundance.

KIT FOX ECOLOGICAL COMPARISONS

Within a species, space use by individuals 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 fulfil energy requirements in a smaller area. Also, reduced 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).

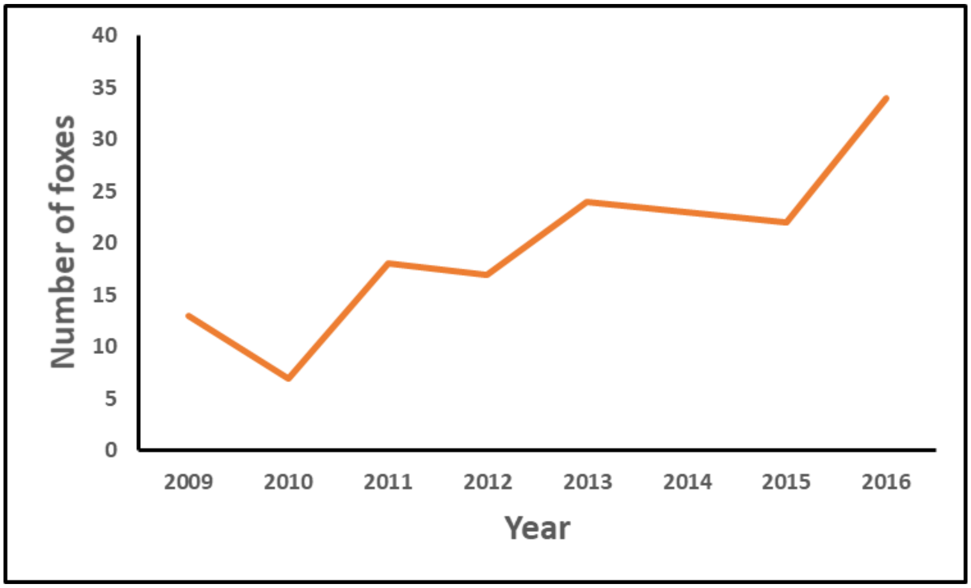

Figure 28. Number of unique San Joaquin kit foxes identified by genetic analysis of scat samples collected at the Topaz Solar Farms, San Luis Obispo County, CA. (Data supplied by Althouse and Meade, Inc.)

At the TSF, kit fox home ranges and core areas were almost twice as large on average on the solar site compared to the reference site. The marked difference in size indicated that habitat quality, particularly food availability, may have been considerably higher on the reference site. Indeed, based on live-trapping and sign transects, the abundance of rodents, the primary prey of kit foxes, was markedly higher on the reference site compared to the solar site. When compared to home range estimates from other sites, the estimate for the reference site was more similar to estimates from sites considered to have high quality habitat with an abundance of rodents, particularly kangaroo rats (Table 30). The solar site estimate was more similar to estimates from sites where food availability was lower, either due to lower habitat quality or due to extended drought effects (e.g., White and Ralls 1993).

Marked temporal variation in space use was observed during the three years of the study with home range size decreasing each successive year on both the solar site and reference site. However, size was still larger on the solar site each year, and the proportional difference between the two sites actually increased from Year 1 to Year 3. The solar site:reference site size ratio increased from 1.5 to 3.4 for home ranges and from 1.3 to 2.8 for core areas. Annual precipitation was just below average in Year 1, about average in Year 2, and above average in Year 3 (National Oceanic and Atmospheric Administration 2018). Food abundance for kit foxes, particularly rodents, likely increased with higher precipitation levels, as is typically observed in the arid areas inhabited by San Joaquin kit foxes (Otten and Holmstead 1996, Germano et al. 2012, Germano and Saslaw 2017, Grinath et al. 2018). This increase may have been greater on the reference site where the habitat has been subjected to less historic and recent disturbance.

Table 30. Mean home range size for various studies on San Joaquin kit foxes.

Study site	Source	Home range method	Mean home range size (km^2)
Semitropic Ecological Reserve, northern Kern County	Cypher et al. 2014*b*	100% MCP[1] 95% MCP	3.7 2.4
S. Carrizo, eastern San Luis Obispo County	Cypher et al., unpubl. data	95% MCP	4.2
Elk Hills, western Kern County	Koopman et al. 2001	100% MCP	4.3
Elk Hills, western Kern County	Zoellick et al. 2002	100% MCP	4.6
Topaz-reference, eastern San Luis Obispo County	This study	95% MCP	5.1
Lokern Natural Area, western Kern County	Nelson et al. 2007	95% fixed kernel	5.9
Lokern Natural Area, western Kern County	Spiegel and Bradbury 1992	95% MCP	6.1
Topaz-solar, eastern San Luis Obispo County	This study	95% MCP	9.4
N. Carrizo, eastern San Luis Obispo County	Cypher et al. 2014*a*	100% MCP 95% MCP	10.0 6.4
Carrizo Plain, eastern San Luis Obispo County	White and Ralls 1993	100% MCP	11.6

[1] MCP = minimum convex polygon.

On both the solar and reference sites, home ranges and core areas of males were larger than those of females. In other studies, reported home range sizes for San Joaquin kit foxes have either been larger for males (Spiegel and Bradbury 1992, Cypher et al. 2014*a*) or similar between sexes (White and Ralls 1993, Koopman et al. 2001, Zoellick et al. 2002, Nelson et al. 2007, Cypher et al. 2014*b*).

Kit foxes on the solar site did not exhibit strong preferences for specific habitat types with the exception that tilled private lands were consistently avoided. Although the selection ratios were not significant, foxes consistently used stewardship and untilled conserved lands. Kit foxes on the reference site exhibited consistent selection for untilled conserved lands, while use of other types were consistently low relative to availability with avoidance being significant in some years. Habitat preferences exhibited by kit foxes at the TSF likely were a function of habitat-specific resource availability and possibly also predation risk and anthropogenic risks (on the private lands). The available habitats varied markedly with regard to these factors.

Tilled private lands were used infrequently or avoided. This avoidance of tilled private lands was obvious when, as part of exploratory data analyses, we calculated fixed kernel density isopleths that used location density to portray fine-scale use of specific areas (Fig. 29). These lands are under active cultivation, and although a crop (usually barley or wheat) may only be produced every second or third year, the land is still tilled at least once and sometimes twice annually. Also, when crops are grown, herbicides are typically used (Althouse and Meade, Inc. 2010*a*). Tilling has several adverse impacts on

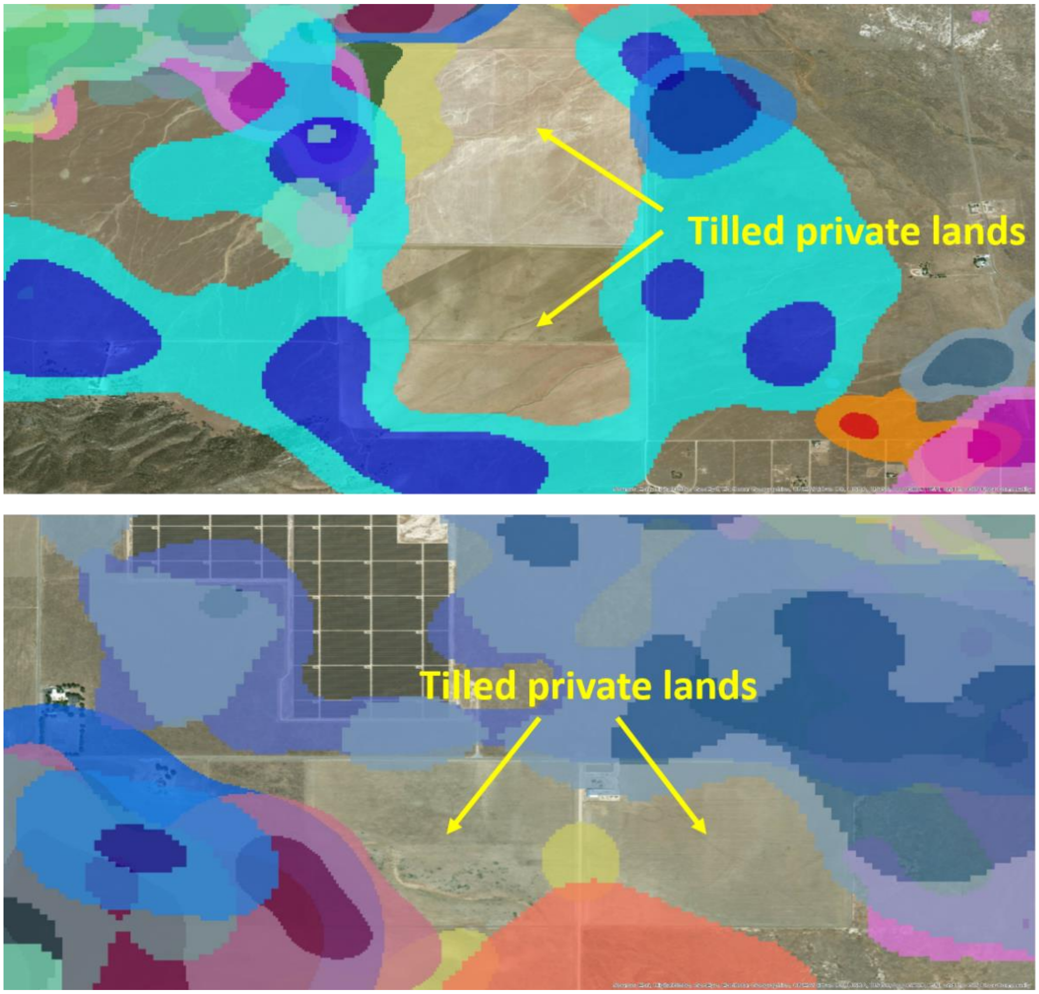

Figure 29. Fixed kernel density isopleths for various San Joaquin kit foxes (each different color isopleth represents a different fox) depicting avoidance of tilled private lands near the Topaz Solar Farms, San Luis Obispo County, CA.

kit foxes. The tilling removes vegetative cover and disturbs the soil to a depth of 20 cm or more (Knapp 1978). Thus, cover is limited or absent and burrows are collapsed, all of which has the effect of precluding most kit fox prey. The soil disturbance also can damage or destroy kit fox dens, and there is a risk of harm or even death if foxes are in a den during tilling. Kilgore (1969) reported that disking completely closed the entrances to dens of swift foxes, which are closely related to kit foxes and have similar ecologies, and that these entrances were seldom reopened by the foxes. In a unique study in Kern County, Knapp (1978) monitored 13 radio-collared kit foxes on natural lands actively being converted to agriculture. Two of the collared foxes and an uncollared fox died when entombed in their dens during tilling and several other foxes were displaced and dispersed. The remaining foxes either avoided or exhibited only infrequent use of the tilled areas. The reduction or elimination of preferred prey also was documented.

Ecological recovery from tilling clearly requires some number of years, particularly in an arid environment such as the Carrizo Plain ecosystem. As described previously, to mitigate impacts to kit foxes resulting from construction of the TSF, lands in the immediate region were acquired and conserved. Many of these lands had been in active cultivation until acquisition. Once acquired, cultivation ceased. However, during our study, use of these lands by kit foxes generally was low relative to their availability. These previously tilled conserved lands likely are still in a process of natural recovery. With time, ecological processes should improve and use by kit foxes likely will increase.

Likewise, much of the area that is now stewardship lands and solar arrays also was previously tilled prior to acquisition and construction of the solar farm facilities. In addition, these lands were subject to additional and more recent disturbance from the actual construction of the farm. Thus, similar to the previously tilled conserved lands, the solar arrays and stewardship lands also are in the process of ecological recovery. Further evidence for this was the significantly lower rodent abundance on the solar site, where all of the live-trapping transects were in these three habitat types. Thus, with regards to food availability, the current value of these three habitat types to kit foxes may be similar. However, relative to their availability, the solar arrays and stewardship lands were used more by kit foxes compared to the previously tilled conserved lands. This could be a function of lower predation risk. As described previously, the security fencing surrounding the arrays likely affords the foxes some degree of protection from larger mammalian predators, and the solar panels may afford some protection from avian predators. The stewardship lands are all in very close proximity to the arrays, and therefore, a fox pursued by a predator would not need to travel far to gain refuge. Thus, the protection associated with these habitat types might enhance their use by kit foxes. Similarly, kit foxes in other locations were found to preferentially use habitat types that had lower food availability but also lower predation risk. Kit foxes on the Carrizo Plain (White et al. 1995) and the Lokern Natural Area (Nelson et al. 2007) exhibited lower use of areas with more shrubs despite higher kangaroo rat abundance in these areas. Due to the shrub cover, coyotes preferentially used these areas and therefore predation risk to kit foxes was enhanced. Likewise, kit foxes in Arizona exhibited limited use of riparian areas where rodents were more abundant and preferentially used more open scrublands where predation risk was lower (Zoellick et al. 1989). Similarly, swift foxes in Colorado favored habitats where the risk of predation from coyotes was lower (Thompson and Gese 2007).

Untilled lands are the least disturbed and most ecologically intact of the habitat types available at the TSF. Based on our assessments, rodent abundance was higher on the reference site, which consisted primarily of untilled lands. Other foods such as invertebrates also may be more abundant in these less disturbed areas. Of note was the relatively low use of untilled private lands. These lands typically are grazed with cattle. Grazing generally is considered compatible with kit foxes and indeed may even be beneficial to kit foxes and their prey by creating a more suitable vegetation structure (Germano et al. 2012, U.S. Bureau of Land Management 2010). Thus, reduced use by kit foxes probably was not due to grazing. An alternate explanation could be reduced rodent abundance associated with rodenticide use. Broadcast distribution of rodenticide-laced baits has been observed on grazed private lands in multiple locations (H. Clark, CSUS-ESRP and R. McCormick, McCormick Biological – personal communications), including on lands in the TSF area (D. Meade, personal observation).

The relationships between home range or core area size and habitat types were consistent with the assessments above regarding habitat suitability. On the reference site, home range and core area size decreased with increased use of untilled conservation land by foxes, and increased with increased use of previously tilled conservation lands and untilled private lands. As discussed previously, space use by canids tends to be inversely related to food availability (Macdonald 1981, Macdonald et al. 2004), and prey likely were more abundant on untilled conservation lands compared to previously tilled conservation lands and possibly even untilled private lands. The lack of any significant relationships between habitat use and space use on the solar site may again reflect higher use of arrays and stewardship lands where food abundance was more limited, but predation risk was lower.

Routine movements by kit foxes were similar to home range patterns in that mean distances moved were longer on the solar site, mean distances declined in successive years on both sites with a more rapid temporal decline on the reference site, and mean distances were greater among males compared to females. 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. As prey abundance increased across years on both the solar and reference sites due to greater annual precipitation, foxes likely did not need to travel as far to secure food. Longer movements by males have been observed in other locations as well (Zoellick et al. 1989, Cypher et al. 2001*b*) and may be related to territorial maintenance.

The longer "exploratory" movements generally were similar in pattern to the routine movements. Foxes subjected to chronic disturbance might exhibit greater exploratory movements in an effort to avoid or escape such disturbance and to locate a new home range farther from the source of the disturbance. For example, woodland caribou (*Rangifer tarandus*) and elk (*Cervus elaphus*) both exhibited altered daily movements in response to petroleum exploration and logging activity, respectively (Edge and Marcum 1985, Bradshaw et al. 1997). However, these movements were similar between foxes on the solar and reference sites and did not provide any evidence of disturbance to foxes associated with the solar farm.

Seven other movements of interest were documented during the study. Three adult foxes were originally classified as solar site foxes for their first year, but then shifted their home ranges sufficiently such that they were classified as reference site foxes the next year. Two of these foxes constituted a mated pair and shifted concurrently. A fourth adult, a male, was resident on the reference site, but then dispersed out of the TSF study area and moved south approximately 24 km to the northern Carrizo Plain National Monument. The remaining three foxes were all pups that dispersed from natal areas, which is a normal occurrence. A female pup dispersed from the southern portion of solar site and moved approximately 5 km east to the reference site. A male pup dispersed from the southern portion of the solar site and moved approximately 6 km southeast to an area included within the reference site. Another male pup also dispersed from the southern portion of the solar site and moved approximately 13 km southeast to the northwest corner of the Carrizo Plain National Monument. All seven foxes moved to areas that likely had higher food abundance. Five of the foxes moved to the reference site where rodent abundance was higher, and the two that left the TSF study area moved to areas where kangaroo rat abundance was high (R. Powers, HT Harvey and Associates, personal communication).

Dens are a critical aspect of kit fox ecology (Grinnell et al. 1937, Koopman et al. 1998, 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, we did not detect any differences in use patterns between the solar and reference sites. The mean number of dens used annually by each fox and the mean rate of den switching (more frequent den switching could be indicative of disturbance) were higher for solar site foxes, but there was no difference between sites when these parameters were standardized by tracking effort. Although not statistically significant, the mean number of dens used (11.2 on the solar site and 8.4 on the reference site) and mean number of den switches (14.2 on the solar site and 9.9 on the reference site) consistently trended higher among foxes on the solar site compared to those on the reference site. However, the greater space use and movements observed among foxes on the solar site may result in more dens being used and more frequent switching. The estimates of mean number of dens used annually per fox for sites, years, and sexes all were similar to those reported from other study sites. At Elk Hills in western Kern County, kit foxes used 11.8 dens per year with a maximum of 16 (Koopman et al. 1998). At Camp Roberts in northern San Luis Obispo County, the average estimates for 3 years ranged from 11.4 to 15.5 dens per fox annually with a maximum of 49 dens used by one fox in one year (Reese et al. 1992).

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, particularly traveling, could be indication of disturbance, such as ground vibrations, that cause foxes to leave dens. At the TSF, above ground activity by foxes was noticeably higher on the solar site. However, at least half of this activity was attributable to one individual, M6697. This fox had a history of unusually high levels of movement and above ground activity in studies preceding this one (Cypher et al. 2014*a*; Althouse and Meade, unpublished data). When this individual was excluded from analyses, the frequency of diurnal locations above ground or traveling were similar between the solar site and reference site.

The distribution of dens among habitat types at the TSF largely mirrored habitat use patterns by kit foxes. Den locations potentially influenced habitat use by foxes. However, as discussed previously, habitat use patterns by foxes at TSF likely were largely influenced by food availability and predation risk. Thus, a more parsimonious scenario for the observed distribution of dens is that foxes constructed more dens in the habitats that they were using most frequently. Furthermore, although kit foxes are completely capable of constructing dens, they commonly facilitate their efforts by acquiring an existing burrow and modifying it for their needs (McGrew 1977). These existing burrows commonly are those initially created by ground squirrels or kangaroo rats (O'Neal et al. 1987, Cypher 2003). Kit foxes also will enlarge badger (*Taxidea taxus*) "digs" (Grinnell et al. 1937, Morrell 1972), which are excavations created in an effort to capture ground-dwelling rodents, and therefore are more common in habitats where these prey species are more abundant. Thus, it is logical that kit fox dens would occur more frequently in habitats such as untilled conserved lands where prey were more abundant.

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*a,b*), 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). Other prey items such as rabbits, ground squirrels, gophers, birds, and reptiles were consumed infrequently. Also, there were very few occurrences of anthropogenic items in kit fox scats. This likely is partly a function of the "no trash" policy on the TSF. Some human habitations are located near the TSF, but kit foxes either were not visiting these or were not finding anthropogenic food items. Interesting, olives were present in a few scats, particularly scats from the solar site. A grove of commercial olive trees is located at the southwest corner of the solar site, and most of it is even included within the 1.5-km buffer that defines the site. Clearly, kit foxes occasionally visit the grove and consume olives when they are available.

Patterns of food item use at the TSF reflected kit fox prey preferences mediated by spatial and temporal availability of items. As discussed above, kit foxes exhibit preferences for Heteromyid rodents such as kangaroo rats and pocket mice. The abundance of small mammals, including Heteromyids, was higher on the reference site where untilled habitats comprised a greater proportion of the available habitat compared to the solar site. Consequently, use of kangaroo rats and pocket mice was somewhat higher on the reference site. Use of kangaroo rats increased markedly from Year 1 to Year 3 on both study sites. As discussed previously, annual precipitation increased across years and rodent abundance likely increased as well. Based on transect surveys conducted at another study site approximately 60 km southeast on the Carrizo Plain National Monument, kangaroo rat abundance increased significantly from Year 1 to Year 3 (CSUS-ESRP, unpublished data). A significant increase in kangaroo rat abundance during this period also was documented at the California Valley Solar Ranch, located just 8 km east of the TSF (H.T. Harvey and Associates 2018). The substantial increase in use of kangaroo rats was particularly evident on the reference site as declining food item diversity in scats indicated greater dietary specialization. Such dietary shifts and specialization in response to increasing kangaroo rat abundance has been observed in other kit fox studies (Cypher et al. 2000, Kelly et al. submitted)

Although not used extensively by kit foxes during our study, rabbits appeared to be more abundant on the solar site based on the prey transects. The abundance of other food items used by foxes, such as ground squirrels, gophers, birds, reptiles, and invertebrates, was not quantified. Rabbits (Egoscue 1962, Cypher et al. 2000), California ground squirrels (Hall 1983, Briden et al. 1992, Logan et al. 1992), and invertebrates (Spiegel et al. 1996, Cypher et al. 2014*a*, Kelly et al. submitted) all can be used extensively by kit foxes. Furthermore, although nocturnal rodents may have been more abundant on the reference site, food resources clearly were not a limiting factor on the solar site. This was evident in the similar reproductive success rates and mean weights of kit foxes between the solar and reference sites. Both reproductive success and body weight decline during periods when food availability is lower (White and Ralls 1993, Warrick and Cypher 1999, Cypher et al. 2000).

Larger predators such as coyotes and bobcats can adversely affect kit foxes through both interference (e.g., mortality, harassment, exclusion) and exploitative (e.g., consuming shared resources such as food items or dens) competition (Ralls and White 1995, White et al. 1995, Cypher and Spencer 1998, Arjo et al. 2007, Nelson et al. 2007, Kozlowski et al. 2008, Kelly 2017). Thus, the response of larger predators to the TSF was relevant to assessing the effects of the solar farm on kit foxes. Coyotes were commonly detected on both the solar and reference site. However, within the solar site, coyotes only occurred infrequently inside the fenced arrays. Bobcats were only detected once on the camera stations and that detection was on the solar site. However, bobcats were opportunistically observed on multiple occasions on both the solar and reference sites. Furthermore, bobcats were observed inside the fenced arrays on several occasions, and on at least two occasions they were observed scaling the security fences around the arrays. As discussed previously, bobcats were suspected of causing the deaths of all three kit foxes found dead inside the arrays. The fencing may have reduced use of the arrays by larger predators, but did not completely exclude them. On the reference site, bobcats also killed at least three kit foxes and probably more as the predator could not be conclusively identified for seven other foxes killed by predators. 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*a*).

Badgers also were detected 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. Red foxes were detected on camera at the solar site and also were commonly observed on the site. Similar to badgers, kit fox mortalities attributable to red foxes have been reported (White and Ralls 1995, Clark et al. 2005), but apparently are quite rare. Red foxes in central California, where they are not native, are competitively excluded by coyotes and typically only occur in areas where coyotes are absent or less abundant (Cypher et al. 2001*a*, Clark et al. 2005). Such areas commonly include urban areas or areas near human habitations or activity (Dekker 1983, Sargeant et al. 1987). Indeed, the red foxes at the TSF primarily were observed on the western portion of the site, where there were more private residences, but were not observed on the reference site. Red foxes may persist on the solar site due to proximity to human habitations and also the fact that they can retreat inside the security fence, similar to kit foxes. However, red foxes or badgers likely do not constitute significant threats to kit foxes.

Coyotes, bobcats, badgers, and red foxes all likely use food items that also are used by kit foxes. We were only able to locate and analyze coyote scats, and therefore were only able to examine overlap in resource use between this species and kit foxes. Coyotes consumed a diversity of food items on both the solar and reference sites. Many of these items also were used by kit foxes as has commonly been reported in other studies (White et al. 1995, Arjo et al. 2007, Nelson et al. 2007, Kozlowski et al. 2008, Cypher and Spencer 1998, Kelly 2017). On the solar site, some resource partitioning was evident with coyotes consuming more rabbits, birds, reptiles, and anthropogenic foods while kit foxes consumed more rodents. On the reference site, the frequency of rodents in the coyote diet was identical to that of kit foxes. Coyotes also consumed a diversity of other items while kit foxes primarily consumed rodents and invertebrates. Thus, during periods of low food availability, particularly rodents, competition for food between coyotes and kit foxes may be more intense on the reference site compared to the solar site. Furthermore, on the solar site, the fenced arrays would constitute areas from which coyotes where mostly excluded and therefore would not compete for resources with kit foxes.

CONCLUSIONS AND CONSERVATION IMPLICATIONS

We assessed multiple demographic and ecological attributes of San Joaquin kit foxes at the TSF 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 northern Carrizo 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, food habits, and competitor presence. Some differences in attributes and patterns between sites were identified, but none were indicative of significant adverse impacts associated with the solar facility. Instead, these differences typically were attributable to factors other than the presence of a solar facility, and in some instances, potential benefits associated with the facility were identified.

A significant finding was that survival of foxes was similar between the solar and reference sites, and if anything, trended higher on the solar site. Also, mortality sources differed somewhat with fewer fox deaths on the solar site attributable to coyotes and golden eagles. The design of the security fencing that surrounds the arrays of solar panels was likely largely responsible for these findings. The fence design is permeable to kit foxes but generally inhibits access by coyotes and bobcats. Furthermore, we documented unprecedentedly high levels of golden eagle predation on kit foxes, almost all of which occurred on the reference site. The only occurrence of golden eagle predation on the solar site occurred over a kilometer outside of the arrays. Within the arrays, the solar panels may have provided foxes with some protection from aerial attack. Thus, our results indicated that the fenced arrays may be areas of reduced predation risk and in essence function as refugia for kit foxes. Furthermore, this effect may have extended to the stewardship lands. These lands are located in very close proximity (<500 m) to the arrays thus offering a potential escape route through the fence for any foxes pursued by a larger predator. Finally, because use by larger predators was reduced, competition for food resources also was reduced within the arrays. Thus, the fenced solar facilities and, to some extent the immediately adjacent lands, appeared to constitute areas of reduced interference and exploitative competition for kit foxes.

Several significant differences in ecological patterns were identified between foxes on the solar and reference sites. Space use (e.g., home range and core area size) generally was greater on the solar site as were movements by foxes. Habitat use patterns differed with foxes on the solar site mostly using types in proportion to their availability while foxes on the reference site exhibited strong selection for untilled conserved lands. Also, foxes on the reference site had a higher frequency of rodents, particularly kangaroo rats, in their diet. These differences appeared largely attributable to differences in the availability of habitat types between sites and the relative quality of those types for kit foxes.

The TSF was largely constructed on lands that were formerly tilled and dry-farmed (Althouse and Meade, Inc. 2010*a*). These activities are detrimental to kit foxes and their prey. The disking associated with these activities removes or significantly reduces ground cover, and it also causes the collapse of rodent burrows and fox dens. Consequently, food availability is low and predation risk is high. We observed general avoidance of actively tilled lands by kit foxes. Thus, prior to acquisition, many of the lands upon which the TSF was constructed likely had low suitability for kit foxes. Foxes may have occasionally used these properties, as documented by pre-construction surveys (Althouse and Meade, Inc. 2010*a*), but the carrying capacity was likely low and the use by foxes likely was a function of proximity to untilled lands.

Following acquisition and the cessation of tilling, ecological recovery began on these previously tilled lands. However, this can be a slow process, particularly in arid environments. Germane to kit foxes, the process entails recolonization by plants, recolonization by prey species, increased opportunities for den creation (e.g., rodent burrows, badger digs), and increased use by foxes as these resources become more abundant. Obviously, lands on which the arrays and other facilities were built were subjected to additional disturbance during construction, but now also are in a state of ecological recovery. Thus, the suitability of these lands for kit foxes is probably still less than that of lands that had not been tilled, but their suitability should improve with time. The higher proportion of untilled lands on the reference site and associated greater abundance of food resources likely was responsible for the smaller home ranges, shorter movements, and higher occurrence of rodents in the diet. The effect of resource availability was obvious from temporal patterns. With increasing annual precipitation across study years, home range size and movement distances declined and use of rodents increased on both study sites.

Despite lower resource availability (at least with regards to rodent abundance), foxes on the solar site exhibited consistent use of arrays and stewardship lands. As discussed previously, predation risk apparently was lower on these lands and that likely encouraged use by kit foxes.

Somewhat disturbing was the relatively low use of untilled private lands by foxes. This finding causes some suspicion that food availability may be lower or risk may be higher on these lands compared to that on conserved untilled lands. Despite questionable legality, practices such as rodenticide use and "predator control" are known to occur on some private lands.

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 TSF 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 TSF 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 TSF 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. 370,000 as of 2018) 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 TSF study are not unexpected.

Although no significant adverse impacts to kit foxes were identified in the TSF study, an important caveat must be included. 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. Potentially, adverse impacts 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. Thus, the absence of significant adverse effects at the TSF, 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 in the oil fields assessed in the Cypher et al. (2000) and Spiegel (1996) studies, and these contributed to the relative absence of impacts identified in these studies.

The conservation implications of the results of this study are clearly important. The results 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, including successful reproduction. 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 (2015). 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 2015). The TSF serves 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 TOPAZ SOLAR FARMS 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
6571	F	11/21/2014	35.36422000	-120.07733000	adult	solar	11/21/2014	collar removed
6610	F	12/10/2014	35.37236000	-120.00258000	adult	reference	12/10/2014	deceased
6612	F	12/1/2015	35.39711600	-119.99973200	adult	reference	12/1/2015	deceased
6619	F	11/18/2014	35.33728000	-120.06030000	adult	solar	11/18/2014	deceased
6621	M	7/17/2015	35.34798000	-119.98104000	young of the year	reference	NA	not collared
6622	M	8/18/2015	35.36565500	-120.00998300	young of the year	reference	8/18/2015	dispersed off site
6623	M	8/18/2015	35.33713000	-120.05847000	young of the year	solar	NA	not collared
6624	F	8/21/2015	35.34515000	-120.04697000	adult	solar	8/21/2015	deceased
6625	M	8/25/2015	35.40756500	-119.99393800	adult	reference	8/25/2015	collar expired
6626	F	11/18/2014	35.36016000	-120.02583000	adult	solar	11/18/2014	collar expired
6628	F	6/3/2015	35.39317000	-119.98777000	yearling	reference	6/3/2015	deceased
6652	F	5/14/2015	35.36676000	-120.01085000	adult	solar	6/30/2015	deceased

Eartag	Sex	Date of 1st Capture	Latitude	Longitude	Age at 1st Capture	Site of 1st Capture	1st Collared	Last Known Fate
6653	F	7/3/2015	35.36649800	-120.00888900	young of the year	reference	NA	not collared
6655	F	12/1/2015	35.37987100	-120.02274800	young of the year	solar	6/3/2016	deceased
6663	F	5/10/2017	35.36759000	-120.01779000	adult	solar	5/10/2017	collar removed
6664	F	5/10/2017	35.33753000	-120.05717000	adult	solar	5/10/2017	collar removed
6665	F	5/11/2017	35.37982000	-120.04710000	young of the year	solar	NA	not collared
6666	M	5/11/2017	35.34044500	-120.04677100	yearling	solar	5/11/2017	collar removed
6697	M	11/18/2014	35.38081000	120.05611000	adult	solar	11/18/2014	deceased
6702	M	11/18/2014	35.35959000	-120.02587000	adult	solar	11/18/2014	deceased
6706	F	11/18/2014	35.35942000	-120.02567000	adult	solar	11/18/2014	deceased
6709	F	1/15/2015	35.38160000	-120.04320000	adult	solar	1/15/2015	collar removed
6726	F	12/8/2014	35.38839000	-119.95396000	yearling	reference	12/8/2014	deceased
6727	F	12/10/2014	35.39905000	-119.98937000	adult	reference	12/10/2014	collar expired
6728	M	12/11/2014	35.38708000	-119.97184000	adult	reference	12/11/2014	dispersed off site
6729	M	12/11/2014	35.38845000	-119.95399000	adult	reference	12/11/2014	collar expired
6731	F	12/31/2014	35.37943000	-119.96574000	adult	reference	12/31/2014	deceased

Eartag	Sex	Date of 1st Capture	Latitude	Longitude	Age at 1st Capture	Site of 1st Capture	1st Collared	Last Known Fate
6776	M	9/4/2015	35.39506000	-119.97890000	adult	reference	9/4/2015	collar expired
6778	F	5/18/2016	35.39210300	-119.98174400	young of the year	reference	11/23/2016	deceased
6779	M	5/18/2016	35.37623700	-120.04382400	young of the year	solar	NA	not collared
6780	M	5/18/2016	35.37644200	-120.04381400	young of the year	solar	NA	not collared
6782	F	5/26/2016	35.33709000	-120.04886000	young of the year	solar	11/16/2016	deceased
6783	F	5/26/2016	35.33709225	-120.06107244	young of the year	solar	NA	not collared
6784	M	5/26/2016	35.37638582	-120.04551487	young of the year	solar	NA	not collared
6785	M	6/2/2016	35.36628500	-120.01429000	adult	solar	6/2/2016	collar removed
6786	M	8/9/2016	35.37667000	-120.04589000	young of the year	solar	NA	not collared
6787	M	8/9/2016	35.38091500	-120.04415000	young of the year	solar	NA	not collared
6788	M	11/15/2016	35.37500800	-120.04275000	yearling	solar	11/15/2016	deceased
6789	M	11/16/2016	35.33708300	-120.06280000	yearling	solar	11/16/2016	collar expired
6790	F	11/30/2016	35.37473000	-120.00287000	young of the year	reference	11/30/2016	collar removed
6791	M	12/2/2016	35.30882000	-120.00305000	yearling	reference	12/2/2016	collar expired
6792-6617	M	11/18/2014	35.33709000	-120.06046000	adult	solar	11/18/2014	deceased

Eartag	Sex	Date of 1st Capture	Latitude	Longitude	Age at 1st Capture	Site of 1st Capture	1st Collared	Last Known Fate
6793	F	8/12/2016	35.33722000	-120.04721900	young of the year	solar	5/10/2017	collar removed
6794	M	8/11/2016	35.33722000	-120.04721900	young of the year	solar	NA	not collared
6795	F	8/11/2016	35.37675100	-120.04283200	young of the year	solar	NA	deceased
6796	F	8/9/2016	35.38068800	-120.04551000	young of the year	solar	NA	not collared
6797	M	8/10/2016	35.33722000	-120.04721900	young of the year	solar	NA	not collared
6798	M	9/4/2015	35.39793000	-119.98105000	adult	reference	NA	not collared
6799	M	8/26/2015	35.39912400	-119.98912500	adult	reference	8/26/2015	collar expired
6851	F	12/23/2014	35.41166000	-120.05981000	yearling	reference	12/23/2014	collar expired
6852	F	12/31/2014	35.40002000	-119.97242000	adult	reference	12/31/2014	deceased
6853	M	5/28/2015	35.33706000	-120.05708000	young of the year	solar	8/18/2015	deceased
6854	M	7/1/2015	35.37699800	-119.96585800	yearling	reference	7/1/2015	collar expired
6860-6611	M	5/28/2015	35.33707000	-120.04727000	adult	solar	5/28/2015	deceased
6861	F	12/1/2015	35.39711600	-119.99973200	young of the year	reference	12/1/2015	deceased
6862	M	12/2/2015	35.37942000	-119.99509000	adult	reference	12/2/2015	collar removed
6863	M	12/2/2015	35.39711600	-119.99973200	young of the year	reference	12/2/2015	collar expired

Eartag	Sex	Date of 1st Capture	Latitude	Longitude	Age at 1st Capture	Site of 1st Capture	1st Collared	Last Known Fate
6888	M	11/15/2016	35.33768351	-120.04785797	yearling	solar	11/15/2016	deceased
6889	M	11/16/2016	35.36644885	-120.02231813	yearling	solar	11/16/2016	collar removed
6890	F	11/23/2016	35.37432000	-120.00272000	young of the year	reference	11/23/2016	deceased
6891	M	12/2/2016	35.37432000	-120.00272000	yearling	reference	12/2/2016	deceased
6951	M	12/6/2016	35.33652200	-120.02258800	yearling	reference	12/6/2016	collar removed
6952	F	12/7/2016	35.30886000	-120.00255300	adult	reference	12/7/2016	collar expired
6953-6618	M	11/18/2014	35.33759000	-120.04796000	adult	solar	11/18/2014	collar expired
6954	M	5/25/2017	35.33680000	-120.02248000	adult	reference	7/20/2017	collar removed
6955	M	5/25/2017	35.38778000	-119.98906000	adult	reference	5/25/2017	deceased
6956	M	5/31/2017	35.37648000	-120.04419000	young of the year	solar	NA	not collared
6957	M	6/1/2017	35.37639300	-120.04435300	young of the year	solar	NA	not collared
6958-6781	F	5/24/2016	35.33709000	-120.04888600	young of the year	solar	11/16/2016	collar removed
6959	F	11/30/2017	35.33710000	-120.05456000	yearling	solar	NA	not collared
6960	M	12/5/2017	35.30870000	-120.00283000	yearling	reference	NA	not collared
6961	M	12/14/2017	35.35362000	-120.00551000	adult	reference	NA	not collared

Eartag	Sex	Date of 1st Capture	Latitude	Longitude	Age at 1st Capture	Site of 1st Capture	1st Collared	Last Known Fate
6962	M	12/15/2017	35.36596000	-120.02697000	adult	solar	NA	not collared
6973	M	12/20/2017	35.32191000	-120.02242000	adult	reference	NA	not collared
6974	M	12/13/2017	35.38071000	-120.04978000	adult	solar	NA	not collared