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Predicting Wildfire Damage vs. Habitat Compatibility in Endangered San Joaquin Kit Foxes: A Case Study of The Carrizo Plains

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ABSTRACT

Current research on this topic covers a large portion of external forces acting on the habitat of the endangered San Joaquin Kit Fox (SJKF). In spite of this, no sources currently exist which directly correlate fire damage with a SJKF ecosystem model. Because of the consistent and growing threat of wildfires in California, the topic of which species could be impacted by such an event is important to discuss. A comparison of GIS[1] and satellite mapping data was used to find correlations between burn-damaged areas and those inhabited by foxes; additionally, field research in the Carrizo Plains case study region was conducted to compare the locations of dens with ecosystem fire threat level based on brush quality and density, as well as their relationship with ecosystem vectors' preferred habitat. To draw conclusions and correlations on burn damage, open-source maps from several online sources were utilized. These maps were layered on one another to provide accurate representations of fire damage zones versus SJKF territory. The goal of the field research was to define the location of active fox dens within the Carrizo Plains case study region. These were compared to habitat type and ground cover as well as predator and prey visitation. From the compiled data and observations, we can extrapolate that the SJKF would see an increase in activity following a fire due to the compatibility of habitat topography and the decreased visitation of coyotes; in other words, a post-burn habitat type would more closely match their preferred habitat.

Introduction

The San Joaquin kit fox (*Vulpes macrotis mutica*), endemic to California, is listed by the U.S. Fish and Wildlife Service as a Federally Endangered as well as California Threatened[2] species. Their population is threatened by a number of factors, chief among them the agricultural and urban development of their habitat, which causes fragmentation and degradation[3]. Other human impacts include vehicles and/or roads, the dispersal of rodenticide poisons, or even purposeful shooting or trapping (Cypher, et al.; 2009). The species has several natural predators as well, including coyotes (*Canis latrans*), larger non-native red foxes, grey foxes, bobcats and birds of prey (Ralls, White; 1995). The Department of Fish and Wildlife states that fewer than seven thousand individuals remain, existing mostly in two to three large core populations and several smaller "satellite" populations.

The San Joaquin kit fox has a habitat comprised mostly of California desert scrub, chaparral, and grasslands, but also exists in urban or agricultural suburbs. They prefer open grass and scrub over higher brush or areas with larger groundcover, and create their dens underground in sturdy sandy soil. Because of the nature of their hot, dry habitat,

[1] Geographic Information System
[2] Each classification requires a specific and unique selection process, and provides different protection.
[3] Fragmentation occurs when development such as roads subdivide parcels of habitat land, and can greatly alter the environment. Degradation refers to the process of a decline in quality of habitat, largely due to human impact.

their already endangered population is very susceptible to wildfire damage; In fact, as recently as last September and for several consecutive years previously wildfires have been observed in the nearby surrounding area. If a fire were to destroy their habitat land it could have a number of negative effects on the populace.

This study aims to determine the effects which a wildfire could have on the environment and ecosystem inhabited by the San Joaquin fox, taking into account the effect on both predators and prey as well as the danger posed directly to members of the fox population. Specific objectives include: (1) To analyze the habitat inhabited by *Vulpes macrotis mutica* and compare it to trends of wildfire damage using map data and field samples; (2) To compare the habitats of predators such as coyotes as well as that of prey such as kangaroo rats, and analyze chain effects on the ecosystem; and (3) To determine and compile processes by which wildfire damage can be mitigated in the future to preserve the species and its habitat.

Research Gap and Question

Current research on this topic covers a large portion of external forces acting on the habitat of the endangered species. For use in this paper, studies were analyzed which looked at the effects of urbanization and infrastructure on San Joaquin Kit Fox (SJKF) habitat, as well as some which considered other species such as rodents and prey animals and their correlation to post-burn activity. Because of the consistent and growing threat of wildfires in California, the topic of which species could be impacted by such an event is important to discuss. Due to the limited range of the endangered SJKF, which is endemic to certain regions of California's central and San Joaquin valleys alone, the effects of a wildfire destroying any sizeable portion of that land would be disastrous to the conservation of the species- which numbers less than 7,000 individuals, according to the Department of Fish and Wildlife. In spite of this, no sources currently exist which directly correlate fire damage with a SJKF ecosystem model. In the conception phase of the research question, this was the research gap which the study intended to fill. My final research question was: How much of a threat is wildfire damage to the population of the endangered San Joaquin Kit Fox, and what effects would a wildfire have on the overall ecosystem surrounding the species?

Literature Review

A number of scholarly works exist on the *Vulpes macrotis mutica* species, which have been evaluated in preparation for this research and to define the gap in the scholarly discussion. Separate works concerning the effects of burn areas on California habitat have been evaluated and considered as well. Cypher and Warrick's 1998[4] piece on spatial distribution of the species highlights issues similar to those examined in this study, such as distribution of predators, prey, and most likely inhabited ecosystems. Both Brian Cypher and Gregory Warrick conducted research professionally at California State University- Stanislaus, and in this piece they attempted to compare visitation[5] rates by the endangered fox, their predators, and their prey, in different environments. They included zones like "burned areas" and "fenced areas" as well as studying the effects of "topographic ruggedness" and "oil field development". In order to quantita-

[4] Note that due to the nature of environmental research on the behavior of a species, it becomes less important to maintain purely very recent research. Literature about the spatial distribution of a species wouldn't be inaccurate after just 20 years.

[5] Visitation refers to the use of a certain region of land by an individual; in other words, the visitation in reference to an individual of the species increases with the amount of time spent in a region and number of times the region is traversed.

tively analyze these visitation rates, Cypher and Warrick assumed that capture rates would be proportional to visitation[6], and created distribution and variation models of their findings. This research is expanded upon in my study in relation to other species of the system, and was also used to inform some of my qualitative conclusions.

In Borchert and Borcherts' 2013 piece *Small Mammal Use of the Burn Perimeter Following a Chaparral Wildfire in Southern California*, the authors spent 10 years (2002-2011) capturing small mammals in burned and unburned habitat areas. The study counted rodent captures in different areas to draw conclusions about the preferred habitat, and discovered that some mice species had no affinity for burned versus unburned habitats, but interestingly found that giant kangaroo rats seemed to prefer open, burned spaces. This work was applied to the conclusions I drew and used to provide concrete evidence for my observations.

The 2005 piece by Cypher, Bjurlin, et al. titled *Effects of Two-Lane Roads on Endangered San Joaquin Kit Foxes* is a similar study to mine as it uses correlational research to draw conclusions. These conclusions are based on comparisons of the foxes ecosystem with an outside force; in this case, road infrastructure. Due to this similarity, this piece was used as a style index and anchor for the syntax and methodology of this study.

Katherine Ralls and Patrick Whites' 1995 study *Predation on San Joaquin Kit Foxes by Larger Canids* compares the effect of predation by larger canines on the San Joaquin Kit Fox and studied 41 specimens in the Carrizo plain during the drought from 1988 to 1991. 23 of the studied specimens were killed during the study, 78% of which were killed by larger canids. Notably, the largest percentage of kit fox deaths caused by predation was by coyotes, followed by small numbers of deaths caused by red foxes and one death caused by a domestic dog. The study concluded that high predation by larger canids coupled with less effective reproduction due to reduced prey availability during the drought caused a significant decrease in density of fox populations during the study period. The researchers also state that while coyotes pose the largest threat to fox populations, non-native red foxes may pose a greater danger in some areas. The knowledge that coyotes likely pose the largest natural threat to fox populations was applied to my conclusion, where I note that a decrease in coyote visitation would have a large impact on fox populations, perhaps more so than a change in other habitat vectors'[7] populations.

Hypothesis

The initially formulated hypothesis predicted that wildfire damage near kit fox habitat would cause individuals to create dens in the damaged area post-burn, due to the disposition of the SJKF's preferred habitat- specifically due to decreased brush height. In turn, the existing literature indicated that this would decrease predation by larger canids such as coyotes, causing population rise in turn. It was expected that wildfire damage directly on kit fox habitat would cause population decrease due to individuals coming in contact with the intense heat as well as a post-burn decrease in population size of mammalian prey. The overall assumption of these predictions was that SJKF visitation would increase in a post-burn region due to more suitable habitat vegetation, regardless of an anticipated decrease in prey availability. This hypothesis was based on information from studies including Cypher and Warricks' *Spatial Distribution* piece and Cypher, Bjurlin, and Nelsons' *Effects of Two Lane Roads*. The former states that SJKF population and visitation numbers increase in burned areas, while significant prey populations decreased after fire damage, while the latter finds that human-caused wildfires decrease rodent and leporid[8] populations.

[6] That the amount of individuals captured would be representative of the number of individuals who visited the region.

[7] A species or individual who affects the food web or extended ecosystem by carrying energy through predation. Examples of SJKF habitat vectors include all species which prey upon or are preyed upon by the SJKF.

[8] Rabbits, pikas, and hares- In the SJKF ecosystem, these include desert cottontail, brush rabbits, and black-tailed jackrabbits.

Methods

To test the hypothesis, it was found necessary to include both qualitative and quantitative reviews for fox habitat and fire damage. A comparison of GIS[9] and satellite mapping data was used to find correlations between burn-damaged regions and those inhabited by foxes, and field research in the Carrizo Plains was conducted to compare the locations of fox dens with ecosystem fire threat level based on brush quality and density, as well as their relationship with ecosystem vectors' preferred habitat.

As stated by Cypher et al. in 2013, qualitative data for a study of this type and magnitude is extremely difficult to obtain:

> For San Joaquin kit foxes, available location data are not sufficient to conduct an analysis as described above. Habitat types favoured by kit foxes have only been quantitatively examined at two locations (White et al. 1995, Warrick et al. 2007), and habitat attributes (e.g., terrain ruggedness, prey availability, habitat disturbance) favoured by kit foxes have only been assessed at one location (Warrick and Cypher 1998, Cypher et al. 2000). Most other information on kit fox habitat use and preferred conditions is based on qualitative data and casual observations (Methods 26).

Not only are foxes difficult to find in general, they are primarily nocturnal and crepuscular, appearing at night and at dawn and dusk. Because of this, the methodology of this study is based almost entirely on qualitative data.

To draw conclusions and correlations on burn damage, open-source maps from several online sources were utilized- Capradio Projects (Sacramento KXJZ Radio) *A History of California Wildfires*, CSU Stanislaus endangered species recovery *San Joaquin Kit Fox Location Map*, University of California Agriculture and Natural Resources *Climate, Fire and Habitat in Southern California*, and SIBR Mammal Class kit fox range map. These maps were layered on one another to provide accurate representations of fire damage zones versus kit fox territory. The resulting detailed comparison can be found in results (Figures 2, 3, 4, 5).

The field research portion of the study was considerably more involved and extensive than the correlational map overlay method. It was determined that the best research data would be recorded if as large a range of times of day and seasonal shift (as allowed by the survey period) as possible were studied. Because of this, the field research canvassing spanned several months[10] and data points were recorded at both dusk and dawn as well as just before and after. One "eyeshine", or "spotlight", type survey was conducted, as described by Constable, et al.:

> If eye-shine was detected... lights would be trained on the animal. Shape, color, size, movement and eye shine color (kit fox eye shine is blue-green in color) were used to determine the species present... Some animals occasionally were observed directly in front of the vehicle, and were illuminated and identified using the vehicle headlights. Spotlight surveys began at sunset, and usually lasted approximately 3 hours (Methods 8).

Without properly powerful lighting, the survey was unsuccessful; A 2400 lumen wide-angle light was used to cover as wide an area as possible, but the diffusion of the beam was such that the light did not carry far enough from the observer.

[9] Geographic Information System

[10] Due to study time frame limitations, the study occurred between the months of November and April, with seven out of ten surveys occurring from January through February. Notably the season for highest fox activity, including raising pups, spans April through October.

The goal of the field research was to define the location of active fox dens within the Carrizo Plains case study region. These were compared to habitat type and ground cover as well as predator and prey visitation, to prove or disprove the hypothesis. For the purposes of this specific survey, an "active den" was defined as a den where one or more of the following occurred:

1) Fox individuals were viewed
2) Fox individuals were viewed very nearby
3) Definite signs of fox visitation were apparent, such as fresh tracks or scat

Some dens were also provisionally identified by the presence of prey remains and by soil disturbance, and "inactive dens" (dens with no signs of recent visitation) were also surveyed as previously inhabited regions. Dens were determined to be SJKF dens rather than the den of another animal species by the presence of the recognizable "keyhole" shape and "apron" of loose soil[11] (Figure 1). Average brush height was determined as accurately as possible by measuring the estimated “average” brush specimens; however, numerical data on this would have required too much attention to seasonal and regional shift in brush quality. Brush density was also measured qualitatively, as to quantitatively measure distances between specimens and average them by hand would have been far too time consuming. Predator and prey visitation was measured qualitatively by observation.

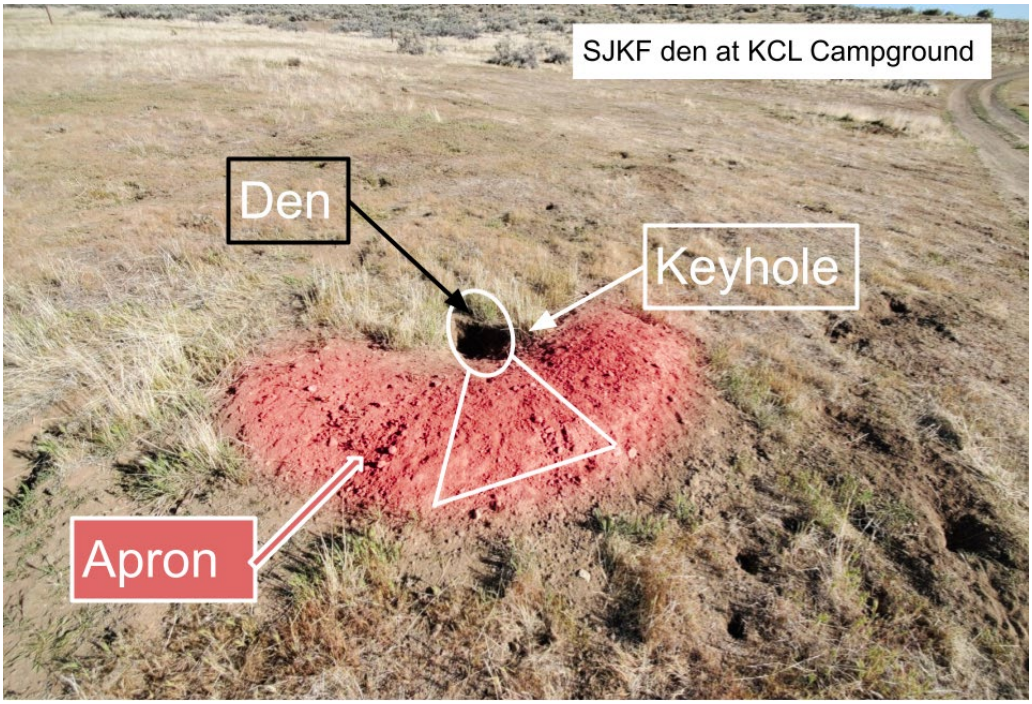

Figure 1. SJKF den shape (Site 5). Recognizable features are superimposed on the image.

[11] The term "keyhole" is an industry-standard reference to the shape of the fox dens. The "apron" of soil is caused by digging and spreads in an oblong amorphous region in line with the angle of the den hole. When viewed from above the shape of the apron and den opening appears like a keyhole, as shown in Figure 1.

Study Area

These canvassing survey sessions were conducted from November through April of 2020-2021. Each analysis was conducted in the Carrizo Plain region off of the California highway 58- a hot spot for kit fox sightings- along different sections and cross-sections of a predetermined loop[12], over 10 study sessions and over 24 total hours. According to the Los Padres Forest Watch, "...the largest remaining populations [of San Joaquin Kit Fox] are in western Kern County, Kern County, and in the Carrizo Plain. The Carrizo Plain is the largest of the three remaining core populations, making this area vital to the recovery of the species (Los Padres 2018)." The location was chosen for this reason. It is worth noting that for this study the survey region did not have a prevalent burn area present at the time of the study.

Results

Fox Habitat Type: Survey Findings

Over the course of my physical canvassing sessions a fairly well-considered impression of the preferred den site habitat for foxes in the survey area was developed. The most densely populated areas of den sites, as identified by the previously defined features, are marked in relation to the survey route in figure 2 and figure 5. Each of these points represents a colony of holes, but does not necessarily refer to currently active den sites as the survey only identified two dens with individuals present. By looking at the surroundings near each of these locations, we can generalize the primary fox habitat type. Each location was documented by photograph (figure 3).

Site 1 was characterized by sage/ saltbush scrub and floodplains north of Soda Lake. The average plant height was approximately (h[13]$\cong 32$ *inches*), with brush bunches spaced apart, leaving dirt exposed. The brush was not dry or dead, so while there was a larger concentration of high fuel/brush it might burn no faster or only slightly faster than the other sites. As the area adjacent the road was more clear, the highest concentration of dens lined the raised dirt edges. Giant Kangaroo Rats were most prevalent at this site compared to the other survey regions.

Site 2 was near the Carrizo Plains visitor center, and was sparsely covered with dirt and dry one-sided blue-grass ($h \cong 12$ *inches*). It was referred to locally as a site of high SJKF activity, though no individuals were viewed there. The most prevalent bird species included songbirds and other small bird species (House Finch, California Quail, Western Meadowlark, American Crow, Common Raven, Loggerhead Shrike, Say's Phoebe), and the endangered San Joaquin Antelope Squirrel (SJAS) was very prominent here in later survey months. As such, these smaller prey animals were followed by birds of prey and ecosystem vectors including coyotes.

Site 3 was the most bare, with very little vegetation whatsoever. It had the highest concentration of dens- including SJKF and SJAS dens- although the possibility of survey error should be considered as the lack of plant material could have simply allowed the dens to be visible. The area near this site was very active, however, with members of the SJKF's immediate ecosystem- Including predators such as coyotes and birds of prey (noted- Northern Harrier, Red-Tailed Hawk, Short-Eared Owl) as well as prey like the Giant Kangaroo Rat, Black-tailed Jackrabbit, and SJAS.

Site 4 lay on the extra route tail on the way to the Kern Cattle and Land Ranch (KCL) Campground site; It was a prime example of the hypothesized ideal fox habitat biome, being flat and low but with a medium quantity of grasses ($h \cong 10$ *inches*) separated by bare dirt. The dens and habitat seemed promising during early surveys, and proved to be the only site where fox individuals were seen during the study period. Two separate dens were identified with at least one individual present at each.

[12] Soda Lake Road, Elkhorn Road, Seven Mile Road, Panorama Road, Painted Rock Road, and the KCL Campground site were all surveyed extensively

[13] Height

Site 5- the KCL Campground- represented an interesting case study, as it lay directly on the margin between the plains and a higher shrubland biome (shown in green on figure 2) in the Southern Coast Ranges near Caliente Mountain. Here the fox dens looked recently inhabited, and coexistent species such as cottontail rabbits and red-tailed hawks were noted nearby. Hearsay by way of local photographers suggested that these dens have shown much activity in past years, but no signs of activity were seen during the study period. The average adult shrub on the margin of growth was measured at ($18\ inches \leq h \leq 30\ inches$), while the bare ground showed only slight groundcover by grasses resembling site 4.

Figure 2. Survey route with key den site locations imposed over a Google Maps image of the region.

Figure 3. Site topography and vegetation by photograph. For example, site 1 has sparse shrubs while site 3 has low grasses/ no large cover vegetation.

Fire Threat

By layering fire damage/history maps with fox territory maps (figure 4) as described in the methods section, I found that there is very little occurrence of major wildfires within SJKF territory as compared to other regions nearby. The central valley, San Joaquin Valley, and Carrizo Plains areas which house the largest population concentrations are conspicuously less prone to large burns. Figure 5 shows the survey area loop with major den complexes layered over previously burned areas. Due to the foxes' preferred habitat of very low to nonexistent brush alongside grasses and bare ground, wildfires are unlikely to spread quickly or very far. Besides the occurrence of an uncontrolled fire in this habitat being unlikely, San Luis Obispo's county fire station 42 is near survey site 1 and fire response mobilization time is very short; according to the station's workload report for the year of 2019 (SLO Calfire 2020), out of 23 fire-related calls between 1/09/2019 and 12/28/2019, they responded to 16 vegetation fires. In the event of a fire, human intervention would significantly decrease the chance of a fire spreading. Because of this, the SJKF may not come in contact with burned land as a habitat option as much as predicted; however, it doesn't necessarily speak to the habitat's compatibility with dens, predators, or prey.

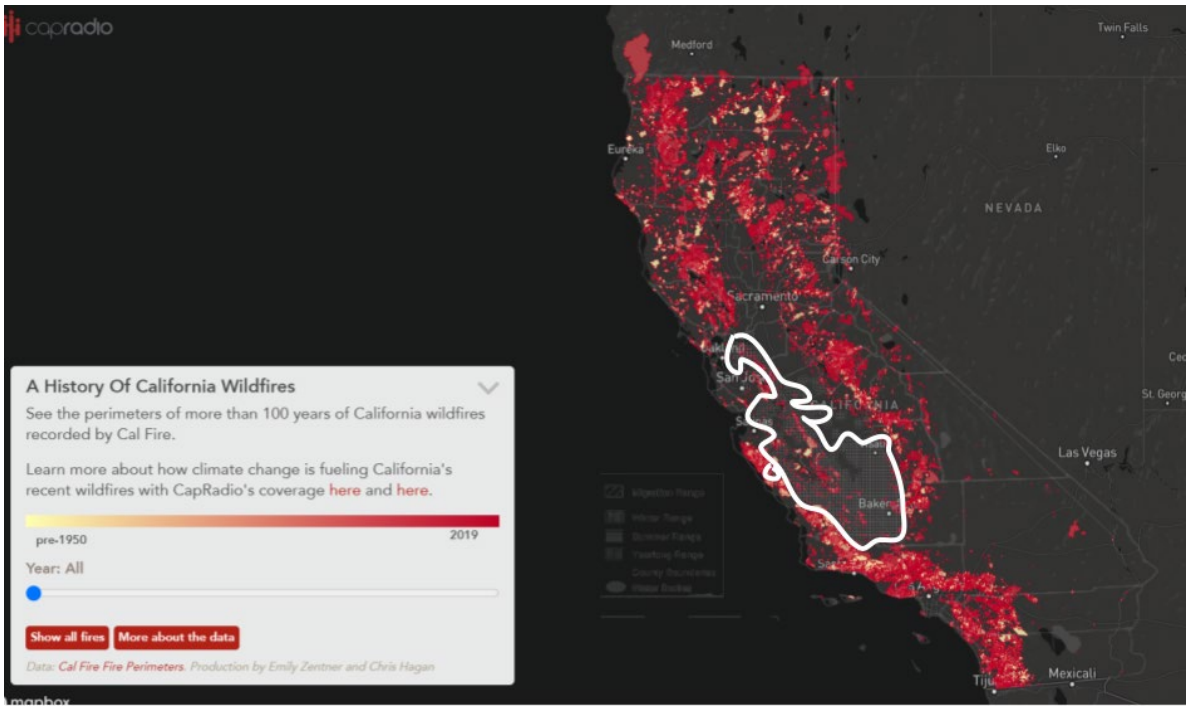

Figure 4. A Capital Public Radio, Sacramento (*A history, 2019*) document shows wildfire occurrence by year- where darker red is most recent- and by area, imposed over a state map. Superimposed over the top is an estimated range of the San Joaquin Fox habitat zone.

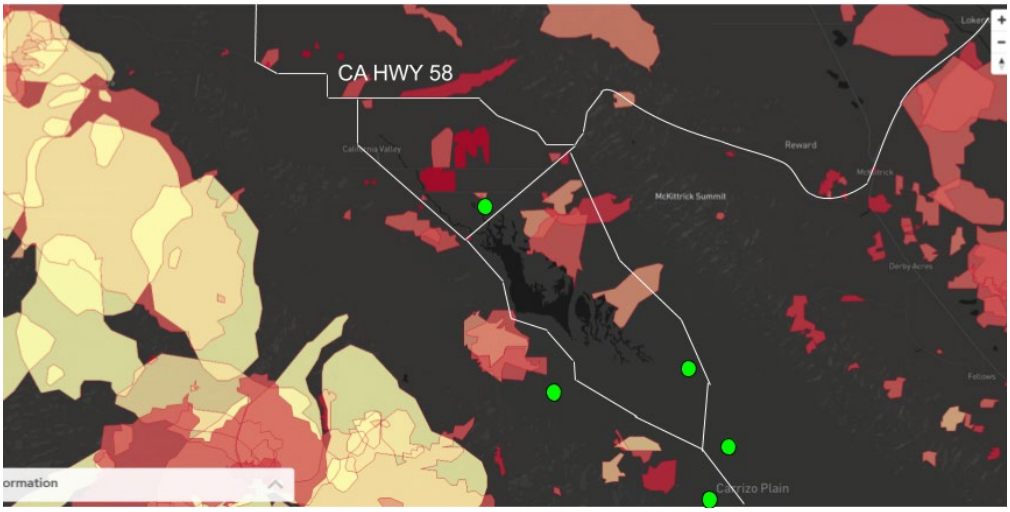

Figure 5. By zooming in on the previous fire map we can locate the primary survey area. Highlighted in white is the survey route and extended survey areas, while green points represent major focus regions high in inhabited/uninhabited dens.

Extended Ecosystem

In considering the impact of wildfire burn areas on San Joaquin Kit Fox habitat, the relation between ecosystem vectors and burn areas was just as important as that of den use. If prey visitation of burned areas was reduced post-fire it would mean that foxes would be less likely to visit the area, and vice versa. The opposite would certainly be true of predator visitation; an increase in predators would lead SJKF individuals to find a safer region. This could provide justification for burned habitat compatibility besides whether or not dens were observed in the locale.

Important members of the kit fox food web to consider include major predator and prey species; refer to figure 7, "*Species Sighted During Canvassing*", for the complete sighted species list from the survey period. Predators include coyotes, larger foxes, hawks, eagles, and owls, while common prey animals include sciurids[14], heteromyids[15], and leporids[16]- San Joaquin Antelope Squirrels, Giant Kangaroo Rats, Cottontail, Brush, and Jackrabbits. The SJKF also consumes insects and small reptiles, but with respect to the scale of the survey and the difficulty of sighting them from a distance these species were omitted; due to the difficulty and rarity of fox sightings, grey foxes were also given less consideration. Kit foxes also consume some vegetation, mostly grass (US EPA 2010)- This ought to be considered when determining the effect of a drastic decrease in consumable vegetation post-fire.

Coyotes were the most abundant predator sighted during surveying, with up to four individuals being sighted per survey period. They were most commonly observed at dawn or dusk along Elkhorn Road (Fig 2: North from site 3) and in tall grasses elsewhere. Species individuals seemed to travel primarily in pairs and stay within high grass if not the higher shrubland strip to the West of Elkhorn Road, although evidence of coyote visitation to kit fox dens in open areas was visible. Overall it can be concluded with a fair degree of certainty that the coyotes prefer more dense vegetation and concealment. Birds of prey[17] were primarily noted around sites 3, 4, and 5, south of Soda Lake in the open spaces where perch-like structures were available. They weren't nearly as prevalent in the first two locations. This is likely because the clear ground space allows for more ease in finding prey animals from the sky. Squirrels, specifically endangered San Joaquin Antelope Squirrels and ground squirrels were often noted along Elkhorn Road and in the clear space south of Soda Lake as well as a large population near Painted Rock Road. Their population and activity increased greatly in the later months of the study towards the spring.

Figure 6. San Joaquin Antelope Squirrel near Painted Rock Road.

[14] Family Sciuridae- Small rodents including squirrels and chipmunks.
[15] Family Heteromyidae- Kangaroo rats and other similar mice
[16] Family Leporidae- rabbits, hares, and pikas
[17] Red-Tailed Hawks, Northern Harriers, Short- and Long-Eared Owls, and Golden or Bald Eagles

Rabbits- both cottontails and jackrabbits- were seen at sites 1, 2, 3, and 5. They acted averse to cleared areas, preferring to gain partial concealment in vegetation.

Giant Kangaroo Rats were seen only during one survey session, after dark on a moonless night; the species is known to be considerably more active when not threatened by the moon's illumination so we picked a night for rodent surveying where we could draw correlations about visitation areas of the kangaroo rat. A 2013 study by Upman and Hafner states, "kangaroo rats (*Dipodomys*) displayed significant moonlight avoidance patterns; they were maximally active at significantly different moonlight levels and avoided bright moonlight to a greater extent than co-occurring rodents." They were viewed only at sites 1, 2, and 3, but sites 4 and 5 were not included in the nighttime canvassing session. Individuals appeared briefly from their holes in the spaces between larger shrubs, and were not seen in larger open areas.

Species Sighted During Canvassing: Complete List

Species:	**Survey Site:**		**Survey Site:**
Mammals:		**Birds Continued:**	
Tule Elk	2, 4	Horned Lark	1, 2, 3, 4, 5
San Joaquin Antelope Squirrel	2, 3, 4, 5	Loggerhead Shrike	2, 3, 5
Giant Kangaroo Rat	1, 2, 3	House Finch	1, 2, 3, 4, 5
Desert Cottontail Rabbit	1, 2, 5	California Quail	2, 4, 5
Brush Rabbit	2	Red-Tailed Hawk	1, 2, 3, 4, 5
Black-tailed Jackrabbit	2, 3, 5	Northern Harrier	3, 4
Pronghorn Antelope	2, 4	American Kestrel	1, 3
Coyote	2, 3, 4, 5	Mourning Dove	1, 2, 3, 4
San Joaquin Kit Fox	4	Short-eared Owl	2, 3
Birds:		Western Meadowlark	1, 2, 3, 4, 5
Common Raven	1, 2, 3, 4, 5	Say's Phoebe	1, 2, 5
American Crow	1, 2, 3, 4, 5		

*Not including unidentified "LBB's" (Little Brown Birds)

Figure 7. Complete list of all species sighted during canvassing, along with the survey sites at which they were viewed.

Prey Habitat Compatibility

Of the four prey animals, only the antelope squirrel seemed to show a proclivity for open (post-burn comparable) space. The kangaroo rat seemed only slightly averse to open space, while the cottontail rabbit and jackrabbit were more so. However, Borchert and Borcherts' 2013 piece- summarized in the literature review section- states that the kangaroo rat showed a preference for open post-burn land, a conclusion somewhat consistent with my observations.

Directly relatable to the effect of a fire is the availability of vegetation; it needs no explanation to understand that any fox who's diet relies heavily on vegetation will be negatively affected by a burn area.

Predator Habitat Compatibility

Between the studied predators- omitting the grey fox- there seemed to be a negative association between coyote visitation and open land, but a positive correlation between predatory bird presence and such cleared areas. The coyotes remained primarily on the fringes of higher alkali scrub or grasses, not lingering in open space, but hawks and harriers specifically were conspicuous in their perching above open spaces. Nelson, et. al., provided great evidence to support this conclusion concerning coyote visitation in their 2007 study; They state that the survival of the endangered fox is inversely related to the amount of shrubland in the nearby habitat, and suggest that an open or heterogeneous habitat may benefit kit foxes. Due to the research conducted by Ralls and White in 1995, explained in the literature review above, slightly more weight was placed on the change in coyote visitation when considering the overall effect on fox population.

Because of the amassed data, several points differ as to whether the fox would be more or less compatible with a post-burn land area, as seen in Figure 8 below.

Pros	Cons
Den site suitability- the low vegetation closely matches that of the foxes preferred habitat	No individuals or dens were actively viewed in the area
Prey- The antelope squirrel seemed to prefer open space, and the kangaroo rat showed only slight uncertainty. It can be assumed that lizard visitation increases in open areas.	The rabbits did not spend time in very open places; Due to a lack of groundcover it's more likely that a bird of prey could find an animal on the ground.
Predators- There was fair evidence to suggest that coyotes, a major predator vector, would have less visitation to an open (post-burn) space.	Birds of prey had a considerably easier time hunting on open ground.

Figure 8. Burned Area vs. Fox Habitat Compatibility.

Limitations and Future Research

This study has numerous limitations which could be expanded upon during future research. First and foremost, the single study location significantly decreases the certainty of the results; The easiest way to improve the accuracy of the research would be to canvass other San Joaquin Kit Fox populations around the state. Options for this future canvassing include Kern county, especially farther east along California Highway 58 from the Carrizo Plains, and Wildlife refuges farther north, including Kern, Pixley, Merced, and San Luis. Los Padres Forest Watch backs this up, saying, "Kit foxes are found in the Carrizo Plain National Monument as well as the Los Padres National Forest in the upper Cuyama Valley and on the eastern slopes of the La Panza Range in San Luis Obispo County... Highly scattered and fragmented, the largest remaining populations are in western Kern County, Kern County, and in the Carrizo Plain (Los Padres 2018)."

Another major limitation of the work is that the study didn't look specifically at a current burn region- it instead intended to predict the outcome of such an event. If future research was conducted following a burn in a kit fox habitat region and surveying the population development for an extended period afterward, these results could be proved or disproved.

Lastly, it proved to be a major issue to confine the survey period to such a small window of time, especially centering on the month of January. This time of year is not part of the foxes' active or breeding season, and the short window made it extremely difficult to draw conclusions for a year-round prediction. Future research would benefit greatly from expanding the canvassing period to include several months, spanning both the active and inactive seasons as well as the burn-prone dry season and the wet season. Existing research and observation dictate that the best/most active time period would include months from spring (fox activity increasing, brush drying out, and fire threat increasing) to fall (fox activity decreasing, wet season starting, fire threat decreasing).

Implications

This research describes the way in which the ecosystem of a San Joaquin Kit Fox would change due to wildfire damage and how it would affect the population of the fox, but it also helps to define the ecosystem patterns of predation and habitat compatibility. Due to the large amount of development activity in the foxes' range, this information could be helpful to builders and developers in conservation efforts, as well as by researchers hoping to prevent fire damage to the endangered species' habitat. The development of the area is evidenced by the creation of Topaz Solar Farm, a 9.5 square mile field of solar panels placed directly on fox territory. The project employed researchers to reduce the impact of the development, but this study could have aided in their efforts. The research conducted for the project may only have included effects on the fox population which were deemed to be foreseeable, such as mortality from roadways and range or habitat restrictions; since climate change has increased the frequency of fires around the state[18], the effect of fire damage on habitat should be more highly ranked as a threat to all habitat types. While the knowledge of fox habitat is not new, the discussion has been expanded by this research to include fire threat and damage to the already threatened endangered species. While the implications of this study are, admittedly, lessened slightly by the negative correlation found between fox habitat and fire-prone habitat, it is still extremely important to conservation efforts to realize the possibility as well as the predicted outcomes of such an event.

Conclusion

Overall, the results did not yield a definite answer in favor of fox habitat compatibility after wildfire damage has occured. Since no wildfire occurred in the survey region during the time period, we must examine the ecosystem in an advanced way to draw conclusions on whether or not the kit fox would be more or less likely to return to burned areas after a time. It was determined that in order for a San Joaquin Kit Fox to increase visitation to a burnt area, the area would have to provide either a far more suitable den-building habitat or a considerably more stable ecosystem with fewer predators and more prey. Although no burn region was existent to study directly, The very low post-burn vegetation *is* comparable to common den site topography elsewhere. The San Joaquin Antelope Squirrel and the kangaroo rat seemed to prefer open areas; significantly, the coyote clearly preferred some vegetation. The birds of prey, due to their ability to view prey from above, preferred open spaces. Between all of the members of this ecosystem, it becomes difficult to generalize which aspects would have the largest impact on the endangered species, and without canvassing ever including large burn areas we can't with certainty know what the effect would be. However, from the compiled data and observations we can extrapolate that the San Joaquin Kit Fox would see an increase in activity

[18] Although this is somewhat widely accepted knowledge, Rebecca Miller's 2020 article *Climate Change IS Central To California's Wildfires* provides numbers: "Climate change plays an undeniable role in the unprecedented wildfires of recent years. More than half of the acres burned each year in the western United States can be attributed to climate change. The number of dry, warm, and windy autumn days—perfect wildfire weather—in California has more than doubled since the 1980s."

following a fire due to the compatibility of habitat topography and the decreased visitation of coyotes; in other words, a post-burn habitat type would more closely match their preferred habitat.

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