EFFECTS OF TWO-LANE ROADS ON ENDANGERED SAN JOAQUIN KIT FOXES

PREPARED FOR THE CALIFORNIA DEPARTMENT OF TRANSPORTATION

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December 29, 2005

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ABSTRACT

San Joaquin kit foxes (*Vulpes macrotis mutica*) occur in central California and are endangered due to habitat loss and degradation. As the human population of California grows, more roads are being constructed in remaining kit fox habitat. We examined the effects of 2-lane highways on demographic and ecological patterns of kit foxes on the Lokern Natural Area (LNA) from August 2001 to June 2004. Of 63 radio-collared kit foxes, only 1 was struck by a vehicle. Foxes were assigned to 1 of 3 risk categories (high, medium, or low) based on the proportion of time spent in road effect zones, which were defined by the probability of a fox encountering a road during nocturnal movements. Fox survival probabilities, reproductive success, litter size, nocturnal movements, and den placement all were similar among risk categories. Nocturnal locations of foxes were closer to roads than den locations, and den fidelity was lowest for medium-risk foxes and highest for low-risk foxes but intermediate for high-risk foxes. Food availability and use were not affected by proximity to roads. We were unable to detect any significant detrimental effects from 2-lane roads on kit fox demography and ecology. Although encouraging, other potential effects were not assessed including facilitated human access and growth-inducing effects, which have resulted in habitat loss, habitat modification, and disturbance on the LNA.

Key words: California; Endangered species; Kit fox; Road effects; Vulpes macrotis mutica.

ACKNOWLEDGEMENTS

This study was funded by the California Department of Transportation as partial fulfillment of terms and conditions of a biological opinion (1-1-98-F-139) issued by the United States Fish and Wildlife Service for the proposed State Route 58 Corridor between State Route 99 and Interstate 5 in Kern County. Additional funding was provided by the Central Valley Project Conservation Program, U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, and the Center for Natural Lands Management. We thank the following individuals for their assistance: S. Bremner-Harrison, S. Harrison, J. Valenzuela, J. Brown, J. Murdoch, A. Brown, C. Van Horn Job, C. Wingert, E. Cypher, E. Tenant, G. Warrick, S. Phillips, P. Kelly, D. Smith, J. Storley, and L. Vredenburgh.

INTRODUCTION

The San Joaquin kit fox (*Vulpes macrotis mutica*) is listed as Federally Endangered and California Threatened (U.S. Fish and Wildlife Service, 1998). The primary threat to kit foxes is from profound habitat fragmentation, degradation, and loss, largely resulting from agricultural, industrial, and urban development. Other historic and current threats include shooting, trapping, predator control programs, rodenticide poisoning, and vehicles (Cypher et al.; 2003). Currently, San Joaquin kit foxes persist as a metapopulation consisting of 2-3 larger "core" populations and ca. 10-20 smaller "satellite" populations. The remaining number of individuals is unknown, but because habitat loss continues, kit fox numbers are assumed to still be declining (U.S. Fish and Wildlife Service; 1998).

Roads can have a variety of adverse impacts on wildlife. These impacts can include direct mortality from vehicles, habitat fragmentation and loss, altered community structure and function, disturbance, exposure to contaminants, introductions of exotic species, and increased access by humans (Foreman and Deblinger, 1998; Evinck, 2002). The significance of such impacts increases when populations of rare species are involved. Detrimental effects associated with roads have been detected for a number of rare species including gray wolves (*Canis lupus*; e.g., Thiel, 1985), Florida panthers (*Felis concolor coryi*; e.g., Maehr et al., 1991), desert tortoises (*Gopherus afassizii*; e.g., Boarman, 1996), and Sonoran pronghorn (*Antilocapra americana sonoriensis*; e.g., Castillo-Sánchez, 1999).

The known and potential impacts to San Joaquin kit foxes associated with roads were evaluated and summarized in reviews by Cypher (2000) and Bjurlin and Cypher (2003). Habitat fragmentation, degradation, and loss along with growth-inducing effects associated with roads (e.g., urban and industrial development) were determined to be particularly significant threats to kit fox conservation and recovery efforts. Also, road-associated threats are likely to increase in the San Joaquin Valley as the human population increases by an expected 100-200% over the next 40 years (American Farmland Trust, 1995; Great Valley Center, 2000). Thus, roads could have even greater impact on kit foxes in the future. However, the specific effects on kit foxes associated with roads through native habitats have not been investigated and quantified. Such information is needed to assess the magnitude of threat to San Joaquin kit foxes associated with roads.

The goal of this study was to assess negative impacts to kit foxes from roads in non-urban environments. Specific objectives were to: (1) identify the types and patterns of impacts to kit foxes associated with highways including effects on survival, productivity, space use, den locations, foraging patterns, and prey availability; (2) assess the significance of these impacts to local kit fox populations and to range-wide conservation and recovery efforts; and (3) identify and, if possible, evaluate potential mitigation strategies.

METHODS

STUDY AREA

This investigation was conducted in the Lokern Natural Area (LNA) in western Kern County, California (N35.3600 W119.58000). The LNA is located ca. 45 m west of the city of Bakersfield (Figure 1). The study area encompassed ca. 140 km^2, and comprised a mosaic of private and public lands. Public lands were owned by the U.S. Bureau of Reclamation, the California Department of Fish and Game, and the California Department of Water Resources. Much of the private land was owned by energy companies with some of these lands being committed to conservation. Other land uses included hazardous waste disposal, cattle and sheep grazing, limited energy extraction, and winter storage of bee hives. The LNA is within a region considered to be important habitat for the conservation of San Joaquin kit foxes as well as several other rare species (U.S. Fish and Wildlife Service, 1998).

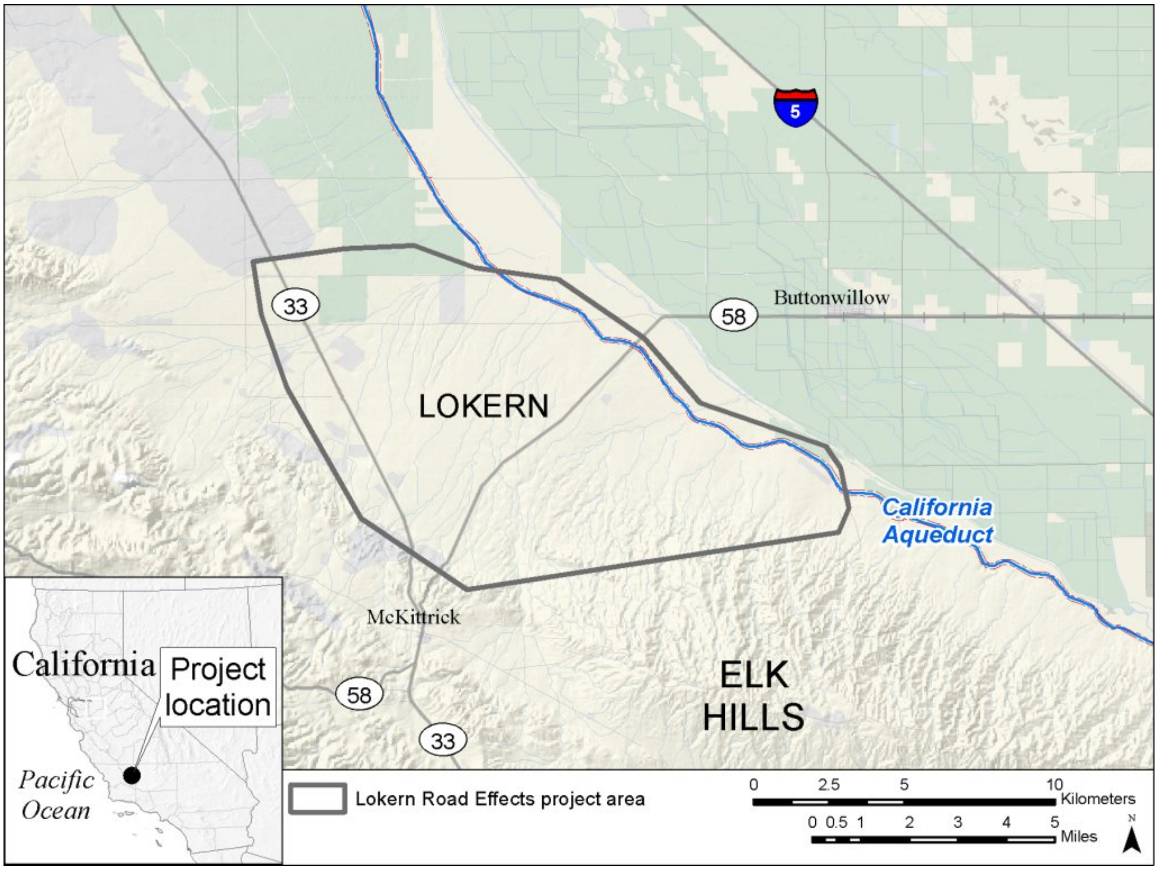

Figure 1. Lokern Natural Area, Kern County, California.

The terrain on the study area was flat to gently rolling and elevation was ca. 100 m. The regional climate was Mediterranean in nature, and was characterized by hot, dry summers, and cool, wet winters with frequent fog. Mean maximum and minimum temperatures were 35°C and 18°C in summer, and 17°C and 5°C in winter. Annual precipitation averaged ca. 15 cm and occurred primarily as rain falling between October and April (National Oceanic and Atmospheric Administration, 1996).

The vegetation community was characterized as Lower Sonoran Grassland (Twisselman, 1967) or Allscale Series (Sawyer and Keeler-Wolf, 1995). The community consisted of arid shrublands with a sometimes dense herbaceous cover dominated by non-native grasses and forbs. Desert and spiny saltbush (*Atriplex polycarpa* and *A. spinifera*) were the dominant shrubs while cheesebush (*Hymenoclea salsola*) and bladderpod (*Isomeris arborea*) also were common. Ground cover consisted primarily of annual grasses and forbs, and was dominated by red brome (*Bromus madritensis*) and red-stemmed filaree (*Erodium cirutarium*). Potential prey for kit foxes included black-tailed jackrabbit (*Lepus californicus*), desert cottontail (*Sylvilagus audubonii*), San Joaquin kangaroo rat (*Dipodomys nitratoides*), Heermann's kangaroo rat (*D. heermanni*), giant kangaroo rat (*D. ingens*), San Joaquin pocket mouse (*Perognathus inornatus*), deer mouse (*Peromyscus maniculatus*), and various birds and insects. Potential competitors included coyotes (*Canis latrans*), bobcats (*Lynx rufus*), and badgers (*Taxidea taxus*).

Two state highways (Routes 58 and 33) and a county road traversed the study site (Figure 1). These were all 2-lane roads with traffic volumes that varied from ca. 800-1500 vehicles per day (California Department of Transportation, 2003). Most traffic occurred during daylight hours.

FOX CAPTURE

We collected demographic and ecological data on kit foxes by live-trapping individuals and affixing radiocollars. We trapped for foxes primarily during September-January from 2001-2003. In 2001, traps were set throughout the study area, usually 20-250 m from a dirt road. In later years, traps were set in areas lacking radio-collared kit foxes or in areas with collared foxes that required a new collar. We used wire-mesh live-traps (38 x 38 x 107 cm) that were baited with a meat product and covered with tarps to provide protection from inclement weather and sun. Traps were set in late afternoon or early evening, and then checked beginning around sunrise. Animal processing usually was completed within 2-3 hours after 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, mass, and dental condition, and a uniquely numbered tag was placed in one ear. A radio-collar (Advanced Telemetry Systems, Isanti, MN, USA) weighing 35-40 g and comprising < 3% of body weight was placed on each fox. Each transmitter included a sensor that activated a "mortality signal" (i.e., double-speed pulse rate) if an animal remained motionless for 8 hours. All foxes were released at the capture site. Foxes were captured and handled in accordance with protocols established in a research permit (TE825573-2) from the U.S. Fish and Wildlife Service and a Memorandum of Understanding from the California Department of Fish and Game.

SURVIVAL AND CAUSES OF MORTALITY

Radiocollared kit foxes were monitored up to 5 times each week to assess survival and identify sources of mortality. Dead foxes were recovered as rapidly as possible and preserved by freezing until a necropsy could be conducted. Cause of death was determined based upon physical evidence on the carcass (e.g., tooth puncture wounds, location of bone breaks) and carcass location (e.g., in habitat, on a road). To further assess mortality from vehicles, each of the highways (Route 58, Route 33, Lokern Road) in the study area were driven ca. weekly during May 2003-June 2004 to search for kit foxes and other species struck by vehicles. Dead animals on roads also were recorded opportunistically during other field activities.

Annual survival probabilities for foxes were calculated using the program MICROMORT (Heisey and Fuller 1985). This program produces a maximum likelihood estimate of the probability of surviving 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). Data from animals whose fate was unknown (e.g., radio transmitter failed, radio collar removed) were included in the analysis, but were not counted as mortalities. These animals were censored after the last day they were known to be alive.

REPRODUCTION

We annually assessed reproductive success among radiocollared female kit foxes from mid April through late May. This is the time period during which pups are active above ground at natal dens but prior to dispersal. Dens occupied by adult females were monitored using direct observation and video recording to determine the presence and number of pups. During direct observations, a concealed observer watched each den from a distance of ≥40 m for ca. 1 hr beginning just prior to sunset. At dens where concealing cover was lacking or where pup sign (e.g., small scats and tracks, prey remains) was present but pups were not observed during direct observations, a video monitoring system (Sandpiper Technologies, Manteca, CA) was placed near the den. The resulting recording was then checked to determine if pups were present. A female was considered to have successfully bred if pups were observed at her den. We also determined litter size among reproducing kit foxes based on direct observations at natal dens or video recordings. In addition to litter sizes from collared female foxes, we also used estimates from litters associated with collared males and litters from non-collared foxes that were located opportunistically.

SPACE USE

Space use and movements of radiocollared kit foxes were monitored beginning approximately 1 hour after sunset. Kit foxes are nocturnal and are particularly active just after sunset when they emerge from their day-time dens and begin foraging (Morrell, 1972; Zoellick, 1990). Monitoring was conducted for 4 nights each week, and an attempt was made to locate every fox once per night. For the first 4 months, foxes were located using peak-signal telemetry methods. Two observers simultaneously collected bearings on a fox using a hand-held 4-element antenna and hand-held compass. Coordinates for observer locations were collected using a global positioning system (GPS) unit. For the next 22 months, foxes were located using vehicle-mounted null-signal telemetry systems. These systems consisted of 2 2-element directional antennas mounted 2 m apart on a 4-m mast that extended through the roof of a vehicle down into the cab. To obtain a location on a fox, bearings were taken simultaneously from both vehicles. Bearings then were taken on a transmitting beacon in the other vehicle. All bearings were non-magnetic, but instead were based on a pointer affixed to the telemetry mast and a stationary compass rosette in each vehicle. With these data, observers were able to ensure that inter-bearing angles were between 20° and 160°. Geographic coordinates then were collected for each vehicle using a GPS unit, and these coordinates along with the bearings were used to calculate the location of a fox.

Fox locations were calculated using an ArcView extension program (Jenness Enterprises, Flagstaff, AZ). This post-processing program used the vehicle location coordinates, vehicle-vehicle bearings, and vehicle-fox bearings to calculate each fox location. Locations were then output into a spatially-explicit database for use in spatial analyses. Telemetry error was estimated by taking fixes on transmitters placed in known locations. Mean bearing error was 3.0±0.04 degrees.

The distance between consecutive nightly locations (i.e., inter-location distance) was determined and used as an index of space use for each fox. Preliminary analyses of space use data indicated that traditional home range delineations (e.g., minimum convex polygon, kernel analyses) produced biased results of space use patterns because ranges of kit foxes on the study site appeared to “drift” temporally or shift significantly in response to life history events such as mate loss. Inter-location distances provided a measure of space use that was less affected by these events because large shifts in range only affected one or a few consecutive locations, and not the entire estimate of space use as with traditional home range area calculations. Mean inter-location distance was calculated for foxes for which ≥ 15 locations were available.

DEN SITE SELECTION

To determine diurnal den site selection by kit foxes, radiocollared foxes were tracked to their dens weekly using a telemetry receiver and hand-held antenna. All dens were uniquely number with a wooden stake. Occasionally, a fox would be observed above ground instead of in a den, and in these instances, the general location was recorded, but not used in den analyses. Dens known to be used by females to rear young (see “Reproduction” above) were considered natal dens whereas all other dens were considered non-natal dens. The degree of den fidelity exhibited by individual foxes was determined by examining den use patterns. Consecutive den locations for a given fox were examined to determine whether the fox was using the same den or a different den. The proportion of den changes observed was used as an index of den fidelity.

PREY AVAILABILITY

In western Kern County, the primary prey consumed by kit foxes are nocturnal rodents and leporids (Spiegel et al., 1996; Cypher et al., 2000). We assessed small mammal abundance on the study site through live-trapping on transects consisting of 25 Sherman traps (8 x 8 x 30 cm) spaced 10 m apart. Traps were opened and baited with commercial birdseed in late afternoon. A paper towel also was placed in each trap to provide bedding material. Traps were checked beginning approximately 2 hours after sunset for 4 consecutive nights during each trapping session. For each captured rodent, we recorded species, sex, and mass, and each individual was marked ventrally with a non-toxic marking pen.

We assessed leporid abundance using track stations spaced ≥ 0.5 m apart along dirt roads throughout the study area. Stations were constructed by raking a 1-m^2 area clear of vegetation and rocks, and then sifting ca. 25 mm of fine soil over the area. To attract leporids, we soaked 1-cm^2 squares of plaster-of-paris in carrot oil, and placed one square along with a handful of alfalfa pellets in the middle of each track station. Stations were constructed one day, and then checked the next morning for leporid tracks. Because we could not identify number of individual leporids from tracks, each station with tracks was considered "visited" regardless of the number of tracks.

FORAGING PATTERNS

Foraging patterns of kit foxes were determine through analysis of fecal samples (scats). Scats were collected year-round on the study site, both opportunistically from along dirt roads and also from captured foxes. Scats were air-dried in paper bags and then oven-dried at 60 C for at least 24 hr to kill any parasite eggs and cysts. Samples then were placed in individual nylon bags and washed to remove soluble materials. The remaining undigested material was dried and separated and the contents identified. We 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 were identified to order based on exoskeleton characteristics and comparison to reference specimens.

ROAD EFFECTS

To assess the effects of roads on kit fox demographic and ecological attributes, we created road-effect zones based on the likelihood of a fox encountering a road during nocturnal movements. We used nocturnal telemetry locations for each fox and calculated the distance between consecutive locations (i.e., inter-location distance). Only foxes with ≥ 30 nocturnal locations were included in this analysis and only data from a 1-year period were used for each fox. Inter-location distances for each fox ($n = 32$) were normalized using Tukey's ladder of power transformation, and the mean distance for each individual was determined. Mean values were back-transformed and *z* scores were used to determine the distance from a road that would encompass 10%, 50%, and 90% of the mean inter-location distances. These distances when averaged across all foxes were 301 m, 910 m, and 1,760 m, respectively. When extended to both sides of a road, these distances defined 4 road-effect zones (Figure 2) scaled to the movement patterns of resident foxes. Thus, a fox starting in Zone 4 would have had a 90% probability of encountering a road during its nightly movements, provided that it moved in the direction of the road. Likewise, foxes beginning in Zones 3 or 2 had 50% and 10% probabilities, respectively, of encountering a road based on mean inter-location distances. A fox starting in Zone 1 was highly unlikely to encounter a road during normal movements.

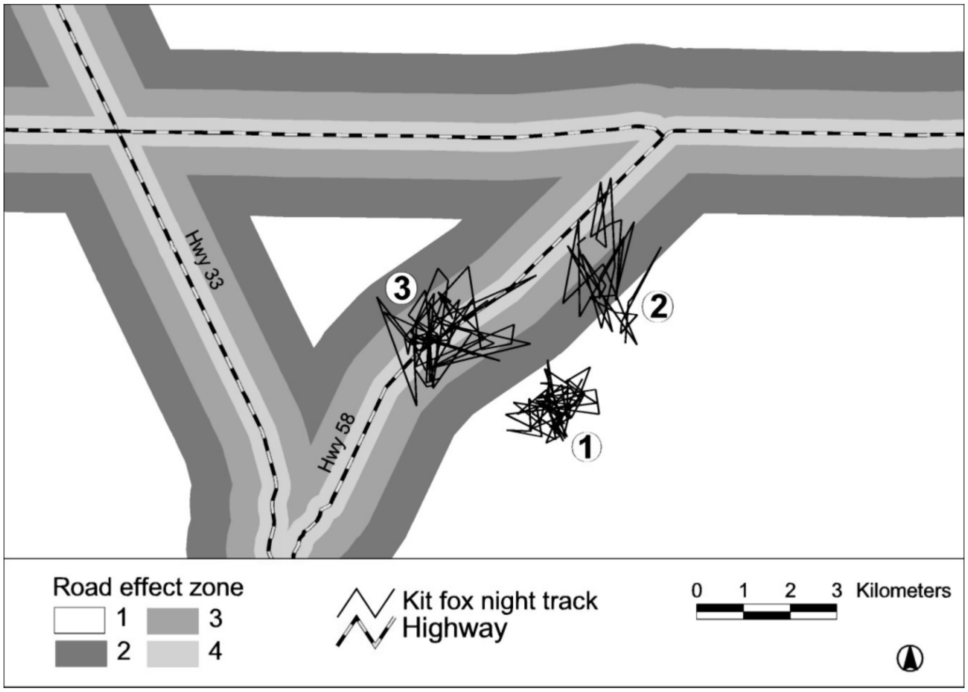

Figure 2. Four Road Effect Zones defined within the Lokern Natural Area. Circled numbers are examples of inter-location movements of kit foxes in Risk Categories 1 (low risk), 2 (medium risk), and 3 (high risk).

The road effect zones also were used in conjunction with space use patterns of individual foxes to assign each monitored kit fox to a risk category. A base map was created in ARCVIEW displaying the road effect zones established around the 3 highways traversing the study site: Route 58, Route 33, and Lokern Road (Figure 2). The inter-location movements for each fox then were plotted on the base map. The proportion of the total length of inter-location movements occurring in each road effect zone then was calculated. The percent length in each zone was multiplied by a risk factor: 4 for Zone 4, 3 for Zone 3, 2 for Zone 2, and 1 for Zone 1. The resulting products were summed for each fox, and the value then was used to assign the fox to a risk category. Values could range from 1 (all inter-location movements in Zone 1) to 4 (all inter-location movements in Zone 4). Foxes with values from 1-1.99 were assigned to Risk Category 1 (low risk), foxes with values from 2.0-2.99 were assigned to Risk Category 2 (medium risk), and foxes with values from 3.0-4.0 were assigned to Risk Category 3 (high risk) (Figure 2). Various demographic and ecological attributes then were compared among foxes in these risk categories.

Survival probabilities were calculated for foxes in each risk category and compared among categories using a modified *z*-test (Heisey and Fuller, 1985). To assess road effects on reproduction, the proportions of females successfully reproducing were compared among risk categories using contingency table analysis. Also, litter size was compared among risk categories using single-factor analysis-of-variance.

To assess space use relative to roads, mean inter-location distance was compared among risk categories using single-factor analysis of variance.

We examined den site selection relative to roads using several approaches. For female foxes known to have reproduced, the mean distance from the nearest highway was compared between natal dens and dens used during the non-breeding season (15 July-15 February) using a paired-sample 2-tailed *t*-test. This analysis was limited to foxes in Risk Categories 2 and 3 (medium to high risk individuals). To assess whether den sites were influenced by roads, the mean distance from the nearest highway was compared between den locations (i.e., resting sites) and nocturnal locations (i.e., foraging sites) for each fox using a paired-sample 2-tailed *t*-test. This analysis was limited to foxes in Risk Categories 2 and 3 with ≥ 30 nocturnal locations. Den fidelity was determined for foxes in different risk categories by calculating the proportion of instances that foxes switched dens between weekly diurnal monitoring sessions. These proportions were arcsine-transformed and mean proportions were compared among foxes in all 3 risk categories using single-factor analysis of variance.

We assessed prey availability relative to roads by comparing abundance of nocturnal rodents and leporids within Road Effect Zones 3 and 4 to abundance in Zones 1 and 2. Abundance of nocturnal rodents was assessed during 5 live-trapping sessions. In March 2003, June 2003, and March 2004, 4 transects were placed within Zones 3 and 4 (but ca.150 m from roads) and 4 were placed in Zones 1 and 2 (usually ≥ 1500 m from roads). In November 2002 and November 2003, this sampling design was repeated, but 4 additional transects were placed along road shoulders. The number of individual rodents captured per 100 trapnights was calculated for each transect, and the mean number of captures was compared between transect categories using either a *t*-test or single-factor analysis of variance. Abundance of leporids relative to roads was assessed in April, August and November of 2003, and March 2004. Data from stations were combined across all sessions, and the proportion of visited stations was compared between stations in Road Effect Zones 3 and 4 and those in Zones 1 and 2 using contingency table analysis with a continuity correction of 0.5.

Use of food items by kit foxes relative to roads was assessed by comparing items in scats collected within Road Effect Zones 3 and 4 to scats collected in Zones 1 and 2. Frequency of occurrence of items was compared using contingency table analysis with a continuity correction of 0.5.

RESULTS

SURVIVAL

During the study, we captured 69 kit foxes and outfitted 63 with radiocollars. Twenty-five collared foxes were recovered dead. Of these, 1 fox (4%) was killed by a vehicle and 12 foxes (48%) were killed by larger predators. Cause of death could not be determined for 12 foxes, usually because carcasses had been scavenged or were in an advanced state of decomposition. However, in all of these instances, the carcasses were recovered sufficiently far from roads such that vehicles were not considered a likely cause of death. In 2004, 2 non-collared kit foxes were found dead on Route 58. Other species found dead on roads included 7 rabbits, 3 coyotes, and 2 gopher snakes (*Pituophis melanoleucus*).

The probability of surviving for 1 year for foxes in Risk Categories 1, 2, and 3 was 0.67, 0.64, and 0.64, respectively. Survival probabilities did not differ significantly among any of the Risk Categories (1 vs. 2: $z = 0.17$, $P = 0.43$; 1 vs. 3: $z = 0.01$, $P = 0.50$; 2 vs. 3: $z = 0.13$, $P = 0.45$).

REPRODUCTION

Reproductive success was determined for 24 female kit foxes: 8 in Risk Category 1, 11 in Risk Category 2, and 5 in Risk Category 3. The proportion successfully breeding for Categories 1, 2, and 3 was 50%, 55%, and 80%, respectively. Although these proportions were not statistically significant ($\chi^2 = 1.26$, d.f. = 2, $P = 0.54$), the rate was noticeably higher for foxes in Risk Category 3 (highest risk). Number of pups was estimated for 23 litters. Mean (±SE) litter size was 3.1±0.4 for 9 litters in Risk Category 1, 4.1±0.5 for 9 litters on Risk Category 2, and 4.6±1.2 for 5 litters in Risk Category 3. Mean litter size did not differ among categories ($F_{2,22} = 1.52$, $P = 0.24$). Similar to reproductive success, mean litter size was noticeably higher for litters in Risk Category 3, although the mean was strongly influenced by an uncommonly large litter of 9 pups.

SPACE USE

Mean distance between nightly locations was estimated for 49 kit foxes. Mean (±SE) distance was 926±52 m for 21 foxes in Risk Category 1, 1080±51 m for 20 foxes in Risk Category 2, and 876±103 m for 8 foxes in Risk Category 3. Mean inter-location distance did not differ among categories ($F_{2,46} = 2.92$, $P = 0.06$).

DEN SITE SELECTION

Sufficient data were available from 6 female foxes in Risk Categories 2 or 3 to compare distances from roads for natal and non-natal dens. These females used 1 or 2 natal dens during the breeding season and 7-13 dens during the non-breeding season. Mean (±SE) distance to a road was 721±146 m for natal dens and 1,034±186 m for non-natal dens, and distance did not differ between den types ($t = -1.92$, d.f. = 5, $P = 0.11$). Interestingly, for 5 individual foxes, natal dens were generally closer to roads on average than were non-natal dens (Figure 3).

For 18 foxes in Risk Categories 2 and 3, the mean (±SE) distance from roads was 922±84 m for nocturnal locations and 1,089±128 m for den locations. These distances were significantly different ($t = -2.40$, d.f. = 17, $P = 0.03$).

Den fidelity was examined for foxes in different risk categories by determining the proportion of instances that foxes switched dens between weekly diurnal monitoring sessions. The mean (±SE) proportion of switches was 41.4±3.1% for 14 foxes in Risk Category 1, 55.9±3.6% for 13 foxes in Risk Category 2, and 49.4±7.8% for 5 foxes in Risk Category 3. The mean proportion differed among categories ($F_{2,29} = 3.98$, $P = 0.30$) due to a significant difference between the means for Risk Categories 1 and 2.

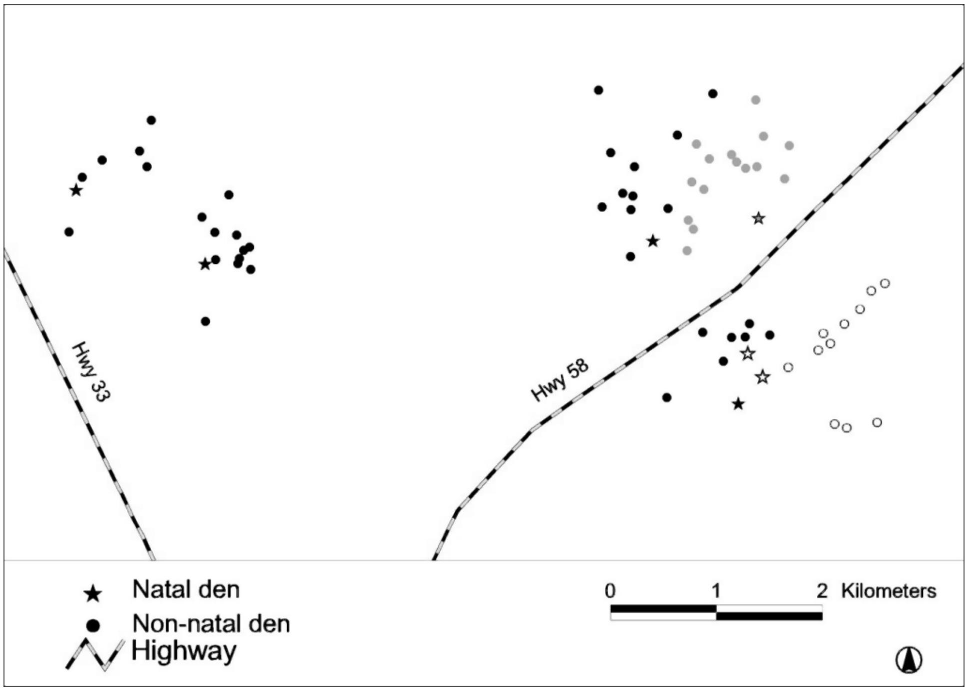

Figure 3. Natal (stars) and non-natal (circles) den locations for 5 adult female kit foxes on the Lokern Natural Area. Each cluster of dens of similar shading and fill represent 1 fox.

PREY AVAILABILITY

During the 5 nocturnal rodent trapping sessions, 954 individual rodents were captured in 4,696 trapnights. Species captured included giant kangaroo rat, Heermann's kangaroo rat, San Joaquin kangaroo rat, San Joaquin pocket mouse, California pocket mouse (*Chaetodipus californicus*), deer mouse, grasshopper mouse (*Onychomys torridus*), and San Joaquin antelope squirrel (*Ammospermophilus nelsoni*). To compensate for potential seasonal variation in rodent abundance, mean capture rates were compared by trapping session (Table 1). Rates were not significantly different between traplines in Road Effect Zones 1 and 2 versus those in Zones 3 and 4, nor for the lines placed on road shoulders (Table 1). However, diversity indices did differ significantly between the road shoulder lines and the other lines (Table 2).

Track station data were combined across the 4 sessions to assess potential road effects on leporid abundance. Within Road Effect Zones 3 and 4, 158 stations were established while 118 were established in Zones 1 and 2. The proportions of stations visited by leporids were 44.3% and 46.6%, respectively, and were not significantly different ($\chi^2 = 0.07$, d.f. = 1, $P = 0.80$).

Table 1. Abundance of rodents by distance from roads on the Lokern Natural Area, 2002-2004.

Distance from road[a]	Mean ± SE rodents/100 trap-nights				
	Nov. 2002	Mar. 2003	June 2003	Nov. 2003	Mar. 2004
Shoulder	16.5 ± 1.0	- [d]	- [d]	25.1 ± 1.5	- [d]
ca. 150 m[b]	13.4 ± 2.8	17.1 ± 6.5	19.6 ± 1.3	27.8 ± 2.2	17.9 ± 3.7
> 1,000 m[c]	17.6 ± 2.2	19.9 ± 8.7	21.7 ± 7.3	24.8 ± 7.4	23.1 ± 8.9
	F = 1.08	t = -0.25	t = -0.30	F = 0.13	t = -0.54
	P = 0.34	P = 0.81	P = 0.78	P = 0.88	P = 0.61

Table 2. Rodent diversity indices by distance from roads on the Lokern Natural Area, 2002-2004. Within a trapping session, indices with the same letter were not significantly different at α = 0.05.

Distance from road[a]	Shannon Diversity Index				
	Nov. 2002	Mar. 2003	June 2003	Nov. 2003	Mar. 2004
Shoulder	1.17 A	- [d]	- [d]	1.31 A	- [d]
ca. 150 m[b]	0.73 B	0.86 A	1.14 A	0.94 B	1.02 A
> 1,000 m[c]	0.70 B	0.96 A	1.18 A	0.85 B	0.88 A

FOOD HABITS

Items found in kit fox scats included black-tailed jackrabbits, desert cottontails, Heermann's kangaroo rats, San Joaquin kangaroo rats, giant kangaroo rats, San Joaquin pocket mice, California pocket mice, deer mice, grasshopper mice, Western harvest mice (*Reithrodontomys megalotus*), San Joaquin antelope squirrels, pocket gophers (*Thomomys bottae*), domestic sheep (*Ovis aries*), unidentified birds, unidentified snakes and lizards, various crickets and grasshoppers (Orthoptera), various beetles (Coleoptera), other insects (Lepidotera and Hymenoptera), scorpions (Scorpionida) and solpugids (Solpugida). Other items included occasional anthropogenic materials (e.g., food wrappers, cloth), and items ingested incidentally such as plant material and ticks (Acarina). Based upon preliminary frequency calculations, items were grouped into the following categories for analysis: mammals, rodents, kangaroo rats, other rodents, leporids, birds, reptiles, insects, orthopterans, coleopterans, and arachnids.

A total of 484 scats were collected and analyzed. Frequency of occurrence of items did not differ between scats collected within Road Effect Zones 3 and 4 versus those from Zones 1 and 2 (Table 3). Most items were found in scats from both areas. Exceptions included 1 occurrence of antelope squirrel in Zone 3 and 4, and 1 occurrence each of sheep, fish, lepidopteran, hymenopteran, and solpugid in Zones 1 and 2. A greater proportion of the study area was in Zones 1 and 2, which could explain the occurrence of the extra items.

Table 3. Food item use by kit foxes by proximity to roads on the Lokern Natural Area, Kern County, California, 2002-2004.

	Frequency of occurrence	
	Road Effect Zones 1 and 2 (*n* = 226)	Road Effect Zones 3 and 4 (*n* = 258)
Mammal	95.3	94.7
Rodent	93.4	91.6
Kangaroo rat	68.6	67.3
Other rodent	9.7	9.7
Leporid	3.5	3.5
Bird	2.7	4.0
Reptile	7.0	3.5
Invertebrate	38.4	38.1
Orthopteran	24.4	21.7
Coleopteran	5.4	5.8
Arachnid	1.9	2.7

DISCUSSION

SURVIVAL

On the LNA, roads did not appear to significantly impact kit fox survival. Only 1 of 63 radiocollared kit foxes was killed by a vehicle during the 33-month study in which foxes were monitored for a total of 19,909 radio-days. The observed mortality rate from vehicles was similar to or lower than rates reported from other studies of kit foxes in exurban habitats. In an investigation conducted on the LNA during 1989-93, none of 54 radiocollared foxes was killed by a vehicle (Spiegel and Disney, 1996). In other kit fox investigations, number of mortalities from vehicles included 2 of 28 collared foxes in western Merced County (Briden et al., 1992), 2 of 94 collared foxes in Monterey/San Luis Obispo Counties (Standley et al., 1992), 1 of 41 collared foxes in San Luis Obispo County (Ralls and White, 1995), and 20 of 341 adult foxes and 11 of 184 juvenile (<1 yr) foxes in western Kern County (Cypher et al., 2000). Mortality rates from vehicles appear to be equally low for closely related swift foxes (*V. velox*; Covell, 1992; Sovada et al., 1998; Kitchen et al., 1999).

On the LNA, as well as in all of the studies cited above, larger predators were the primary cause of mortality for kit foxes. Most predator-caused deaths are attributable to coyotes and bobcats, but kit foxes also have been killed by badgers, non-native red foxes (*Vulpes vulpes*), golden eagles (*Aquila chrysaetos*), and free-ranging dogs (Briden et al., 1992; Standley et al., 1992; Ralls and White, 1995; Spiegel and Disney, 1996; Cypher et al., 2000). On the LNA, predators killed 12 radiocollared kit foxes. Based on carcass location and condition, we suspect that predators also were responsible for the deaths of most foxes for which the cause could not be definitively identified. Thus, in most exurban locations, larger predators appear to be the primary factor affecting kit fox survival.

Roads potentially could influence kit fox survival through effects on competitor abundance or distribution. On the LNA, the effect of roads on the primary competitors, coyotes, was difficult to evaluate. Scent station surveys conducted early in the study yielded visitation rates that were too low to derive meaningful indices. These low rates also were incongruous with our frequent casual observations of coyotes and coyote sign (e.g., scats, tracks). Coyotes occasionally were observed crossing roads, and based on a companion study of coyote ecology and movements, they commonly crossed roads on the study site during nocturnal foraging activity (Nelson, 2005). On several occasions, coyotes were observed picking up vehicle-killed animals (usually rabbits), and therefore, coyotes potentially were attracted to roads as a food source. Conversely, people occasionally attempted to shoot coyotes, which potentially caused coyotes to avoid vehicles and roads. Thus, the effect of roads on coyotes on the study site was unclear. However, if roads were significantly influencing coyote distribution, this might have been reflected in differential kit fox survival rates among risk categories. No such differences in survival rates were detected.

Because they were not collared, the risk categories were unknown for the 2 kit foxes found dead on Route 58 during road kill surveys. However, even with these 2 additional deaths, the number of vehicle-killed kit foxes was still low. Relatively few other species were observed killed on roads in the study area. Frequently, carcasses observed one day were not present the next day. These carcasses presumably were being removed by scavenging animals, which could have included kit foxes. Thus, vehicle-killed animals potentially constituted a food source for kit foxes, but also could have increased risk of vehicle strikes by attracting kit foxes to roads. Smith (1978) reported that kit foxes killed on roads in Utah may have been hit while searching for carrion, and Hines (1980) reported a similar result for swift foxes in South Dakota.

Survival rates were similar for kit foxes in the 3 risk categories. Thus, foxes spending more time near roads did not exhibit lower survival from vehicles or any other indirect factors that might have been associated with roads, such as prey or competitor abundance.

REPRODUCTION

Roads did not appear to affect reproduction by kit foxes. Reproductive success and litter size were similar among foxes in the 3 risk categories. Potential effects could have included disturbance by traffic noise on whelping and rearing behaviors, decreases in food availability, or increases in competitor abundance. Kit foxes at other locations have been observed successfully rearing young in very close proximity to roads (<50 m; Bjurlin et al., 2005; B. Cypher personal observation), although in at least one instance this resulted in some of the young being struck by vehicles (Bjurlin et al., 2005). Young kit and swift foxes appear to be more vulnerable to vehicle strikes (Egoscue, 1962; Sovada et al., 1998), probably due to inexperience.

SPACE USE

Based on distances between nightly locations, roads did not appear to affect space use patterns by kit foxes. Because ≥ 24 hr typically separated each location, a kit fox essentially could be in any portion of its home range by the subsequent observation. Thus, if proximity to roads caused foxes to increase or decrease space use, this would have been reflected in inter-location distances, which was not the case on the LNA. Furthermore, scat deposition patterns were recorded during a companion study, and kit fox scats were equally distributed relative to the four road effect zones (D. Smith, University of Washington, unpublished data). This further indicated that kit foxes were not exhibiting avoidance of roads.

Finally, many of the radio collared foxes crossed roads. Some foxes were detected crossing only on a few occasions, but other foxes routinely crossed roads (Figure 4) and obviously were not deterred by roads. These regular movements across roads indicated that critical demographic and ecological processes, such as dispersal and genetic flow, still occur on the LNA. Roads were found to inhibit movements of bobcats (Lovallo and Anderson, 1996), lynx (Barnum, 1999), mountain lions (*Felis concolor*; Van Dyke et al., 1986), and endangered Sonoran pronghorn (Castillo-Sánchez, 1999). However, bobcats in southern Texas did not appear to avoid roads, although this resulted in a high mortality rate from vehicles (Cain et al., 2003).

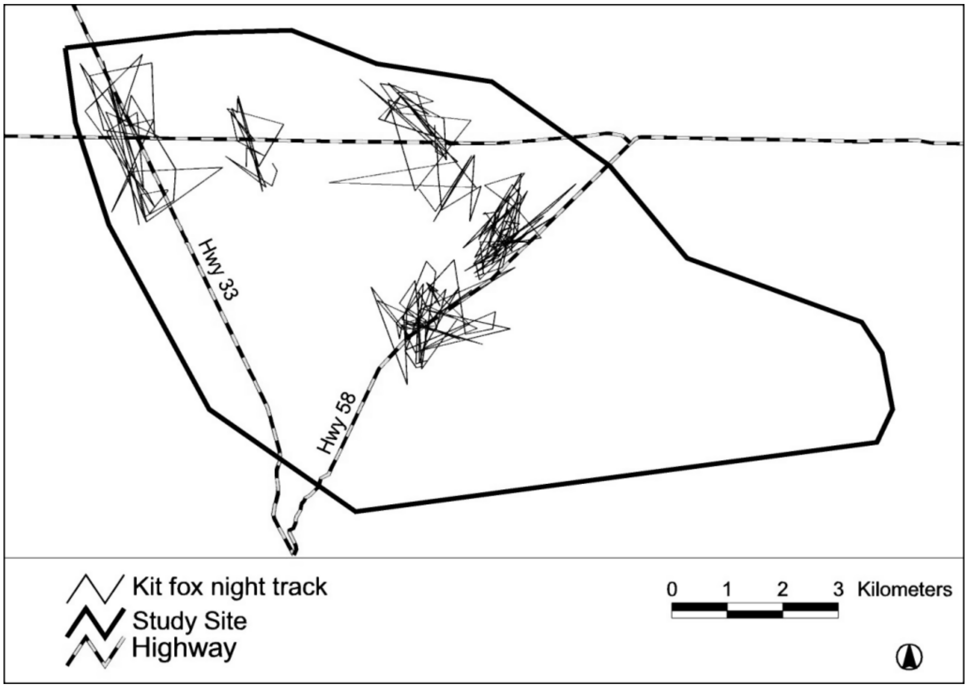

Figure 4. Inter-location movements for 5 kit foxes that routinely crossed roads on the Lokern Natural Area.

DEN SITE SELECTION

Kit foxes are obligatory den users, and they use dens year-round. Dens are used for daytime resting, avoiding predators, avoiding temperature extremes, moisture conservation, and bearing and rearing young (Koopman et al., 1998). Kit foxes establish multiple dens throughout their home ranges, and foxes will use on average 12 (range = 1-

16) different dens each year (Koopman et al., 1998). Thus, dens are an important aspect of kit fox ecology.

Although not statistically significant, it was interesting that the natal dens of foxes in medium and high risk categories on the LNA were closer to roads on average than non-natal dens. This was true for 5 of 6 female foxes for which data were available. This result might have been a function of a small sample size, but regardless, it clearly indicates that kit foxes were not selecting natal dens that were further from roads. In contrast, overall den locations for a given fox were further from roads than nocturnal locations. One possible explanation is that kit foxes were indeed avoiding roads at some scale when selecting den sites. An alternate explanation is that kit foxes were attracted to roads during nocturnal foraging activities (e.g., scavenging opportunities). Therefore, it is unclear whether these differences in den sites versus foraging sites were caused by positive or negative road effects.

The results of the den fidelity analysis also were unclear. Foxes in the higher risk categories tended to switch dens somewhat more frequently, which could indicate a disturbance affect associated with roads. However, this hypothesis is not strongly supported in that foxes in the highest risk category did not exhibit the highest rate of den switching.

PREY AVAILABILITY AND FOOD HABITS

All of the potential effects of roads on kit foxes also could affect the distribution and demographics of their prey species. Vehicle mortality, vegetation changes, disturbance, contaminants, and other factors all could influence the abundance of prey near roads.

Roads did not appear to affect the abundance of nocturnal rodents on the LNA. Interestingly, rodent abundance on road shoulders was not only similar to areas further from roads, but rodent diversity was higher. Most of the LNA was grazed by cattle or sheep. However, fences excluded livestock from road shoulders resulting in taller, denser patches of vegetation. Also, stands of exotic species, such as shortpod mustard (*Hirschfeldia incana*), cheeseweed (*Malva parviflora*), and horse nettle (*Solanum elaeagnifolium*), thrived in the disturbed soils along road shoulders in the LNA, as is frequently observed in other locations (Gelbard and Belnap, 2003). Lastly, in arid climates such as the southern San Joaquin Valley, plants along roads can receive significant additional moisture due to runoff, and this can increase plant productivity (Johnson et al., 1975; Vasek et al., 1975). The higher plant species and structural diversity along roads is the most likely explanation for the increased rodent diversity. This increased diversity potentially could have attracted kit foxes to road sides and increased risk of vehicle strikes. While such effects were not reflected in food habits or survival rates, nocturnal foraging locations were closer to roads than diurnal resting locations.

We did not detect any effects on leporid abundance associated with roads. Although rabbits were the most commonly observed species during surveys for vehicle-killed animals, this mortality apparently was not sufficient to suppress abundance.

Foraging patterns of kit foxes did not appear to be affected by the presence of roads. The same items were found at similar frequencies in scats regardless of proximity to roads. This result was expected given the lack of detectable road effects on prey availability.

ROAD EFFECTS SUMMARY

In our evaluation of demographic and ecological attributes of endangered San Joaquin kit foxes on the LNA, we were unable to detect any significant effects attributable to roads. Two-lane roads with moderate traffic volumes did not appear to negatively affect survival, reproduction, space use, den site selection, prey availability, or foraging patterns. Vehicle strikes are the most frequently considered effect primarily because they result in direct mortality and also because they are so visible. But numerous other effects potentially can affect kit foxes, and we attempted to examine as many parameters as we were able.

We must caution that these results only apply to 2-lane highways. The effects of larger, busier roads on kit foxes have not been examined, but are likely to be more significant. In nearby Bakersfield, kit foxes were struck by vehicles proportionally more frequently on roads with more lanes, higher speed limits, and higher traffic volumes (Bjurlin et al., 2005). In North Carolina, the number of road crossings by black bears (*Ursus americanus*) was inversely related to traffic volume (Brody and Pelton, 1989). Conversely, smaller roads, particularly dirt roads on the LNA, actually appeared to be used by kit foxes as travel corridors. Wolves also were found to travel along roads closed to public access (Thurber et al., 1994).

Our inability to detect detrimental impacts to kit foxes should not be interpreted as assurance that impacts do not exist. We were unable to assess all potential effects. For example, roads facilitate human access to habitat. In the LNA, this access results in incidents of illegal trash dumping, target shooting, and off-road vehicle driving. The effects of these activities on kit foxes are unknown, but potentially are detrimental. Road access increased human-caused mortality of wolves (Mech, 1989) and Iberian lynx (*Felis pardina*; Ferreras et al., 1992). Roads also induce growth. In the LNA, several large hazardous waste facilities have been constructed adjacent to existing roads. This has resulted in some loss (ca. 250 ha) and fragmentation of habitat, and the bright lights and chemical fumes generated by the facilities are detectable many kilometers from the facilities. Again, any effects from these facilities on kit foxes are unknown.

Perhaps the most significant impact associated with human access on the LNA has been human-caused wild fires. Smaller fires (<10 ha) occur annually on the site, and major fires that cover extensive portions of the LNA occur 1-2 times each decade. These fires significantly modify vegetation communities on site, primarily by killing the shrubs, which are not fire-adapted. Habitat modification from fire affects prey availability and distribution (both rodents and leporids) as well as coyote and kit fox space use patterns (Nelson, 2005). Most fires have started along roads while other roads ultimately acted as firebreaks, thereby limiting the extent of the burned area.

Disturbance is another potential effect that we did not assess. Such disturbance could be in the form of noise, lights, odors, or human activity. Disturbance has been demonstrated to affect other species, such as black bears (Lovallo and Anderson, 1996), grizzly bears (*Ursus arctos*; McLellan and Shackleton 1988), elk (*Cervus elaphus*; Witmer and deCalesta, 1985), and lapwings (*Vanellus vanellus*) and black-tailed godwits (*Limosa limosa*; Van der Zande et al., 1980). However, available evidence suggests that kit foxes exhibit a relatively high tolerance to disturbance. Kit foxes are commonly found in oil fields (Spiegel and Small, 1996; Cypher et al., 2000) and several urban areas (Cypher et al., 2003; Bjurlin et al., 2005) where noise, odors, and human activity are common.

Finally, although we did not detect detrimental effects on kit foxes, the potential for such effects is likely to increase as additional roads are constructed within the range of this species. Swift fox mortality from vehicles was significantly higher on a site with 125 m of roads compared to a study site with only 66 m of roads. Also, bobcats in Wisconsin selected areas with lower road densities (Lovallo and Anderson, 1996), and habitat suitability for gray wolves declined with increasing road density (Thiel, 1985, Jensen et al., 1986; Mech et al., 1988). Thus, impacts increase with greater road density.

Given our inability to detect effects to kit foxes associated with roads, appropriate mitigation strategies are not apparent. Crossing structures such as culverts, tunnels, underpasses, and “green bridges” have all been used in other locations to facilitate road crossings by wildlife (e.g., Forman et al., 2003). These structures are most effective when animals commonly cross roads at specific locations, such as valley bottoms, ridge tops, or riparian courses. On the LNA, use of specific crossing locations by kit foxes was unlikely due to the relative homogeneity of the habitat. Fencing also has been used as a strategy to keep animals off of roads and to guide them to crossing structures. However, in locations such as the LNA where foxes appear able to easily cross roads and frequently do so, fencing might actually be detrimental to movements and gene flow. Jaeger and Fahrig (2004) concluded that fencing is most appropriate where vehicle-mortality is a limiting factor and the population of interest is declining, but discouraged use of fencing when the population is stable, animals are successfully crossing roads, and mortality from vehicles is not a limiting factor. This latter scenario appears applicable for kit foxes on the LNA. Thus, based upon our results, it does not appear that standard mitigation strategies would significantly benefit kit foxes on the LNA.

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