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## **EFFECTS OF ROADS ON SAN JOAQUIN KIT FOXES: A REVIEW AND SYNTHESIS OF EXISTING DATA**

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**Abstract:** Roads have a variety of adverse impacts on wildlife populations and can seriously impact rare species. Numerous roads are present throughout the range of the endangered San Joaquin kit fox (*Vulpes macrotis mutica*), and many more are planned. We review existing literature and data to assess potential impacts from roads on kit fox conservation and recovery. In addition, we discuss mitigation strategies with their potential benefits.

### **Introduction**

In the United States, over 200 million vehicles are in use on approximately 6.2 million kilometers of public roads (Natural Research Council 1997). Roads result in a number of environmental impacts, including endangerment of wildlife populations. The direct impacts of vehicle-related mortality and habitat loss have long been recognized. Lalo (1987) estimated that about one million vertebrates are killed by vehicles each day in the United States, and Forman (2000) calculated that approximately 1 percent of the land area, roughly the size of South Carolina, is paved. Additional direct effects include habitat fragmentation, disturbance and stress, contaminants, and destruction of shelter (Hourdequin 2000). Roads also may indirectly impact wildlife by altering ecosystem processes, such as changes in prey availability, competition, non-native species colonization, fire regime, and human access and associated development. Direct and indirect impacts may be detectable over one kilometer (0.6 mi) from roads resulting in a "road-effect zone" (Forman and Deblinger 1998), and leading one author to estimate that approximately 19 percent of the total area of the conterminous United States is affected (Forman 2000). Not surprisingly, road effects 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 agassizii*; e.g., Boarman 1996), and Sonoran pronghorn (*Antilocapra Americana sonoriensis*; e.g., Castillo-Sánchez 1999). While impacts on common species are undesirable, road-related depletion of threatened and endangered species is particularly troubling and warrants careful evaluation and management.

A diversity of threatened and endangered animal species occur in the San Joaquin Valley of California (U.S. Fish and Wildlife Service 1998). Most are rare due to habitat loss from agricultural, industrial, and urban development. Among them is the endangered San Joaquin kit fox (*Vulpes macrotis mutica*), a small, nocturnal canid that has undergone an estimated 95 percent reduction in habitat (Grinnell et al. 1937, Hall 1981, Mercure et al. 1993, U.S. Fish and Wildlife Service 1998). While the effects of roads on San Joaquin kit foxes have not been directly evaluated, the relatively large space requirements and high mobility of this species makes road crossings likely throughout much of their current range. Furthermore, the human population in the San Joaquin Valley is expected to nearly triple in the next 40 years (Great Valley Center 2000), with associated construction of new roads, expansion of existing roads, and increased traffic volumes.

Some of the potential impacts on San Joaquin kit foxes are obvious and direct, such as vehicle strikes, habitat loss associated with road construction, habitat loss associated with concomitant industrial and urban development, landscape fragmentation, disturbance, and environmental contamination. Others are more subtle and indirect, such as invasions by non-native species, changes in prey availability, predator abundance, or fire regime. The aforementioned could have a variety of detrimental effects on kit foxes, including mortality, morbidity, disrupted social ecology, reduced productivity, displacement, altered space use, inhibited dispersal, reduced genetic exchange, and decreased carrying capacity.

Our objectives are to (1) summarize available data on the direct and indirect effects of roads on populations of San Joaquin kit foxes, (2) identify factors that exert the greatest influence on kit fox conservation and recovery efforts, and (3) identify critical information needs for future research and mitigation.

### **Direct Effects**

#### **Vehicle Strikes**

The majority of vehicle strikes occurs at night when many species are more active and driver visibility is at its lowest. For an animal the size of a kit fox, such strikes are typically fatal. If vehicle strikes were sufficiently frequent in a given locality, they could result in reduced fox abundance. Furthermore, the death of adult foxes during the breeding and pup-rearing seasons (Dec-May) negatively affects reproductive success and could result in the litter failure.

The proportion of deaths attributable to vehicle strikes rarely exceeds 10 percent for adult foxes (table 1). Clearly, the number and type of roads passing through fox habitat play an important role in determining impact. In the city of Bakersfield where roads were abundant, 23 percent of 35 adult kit fox mortalities and 17 percent of 25 juvenile mortalities were confirmed vehicle strikes. Furthermore, an additional 9 percent of adult and 8 percent of juvenile mortalities were suspected strikes. At this urban site where coyotes and bobcats were rare, vehicles were the most commonly attributable source of mortality. In natural lands, predators remain the primary cause of mortality for both adult and juvenile foxes (Briden et al. 1992, Standley et al. 1992, Ralls and White 1995, Spiegel and Disney 1996, Cypher et al. 2000).

### Habitat Loss and Fragmentation

Paved roads are essentially permanent structures, and any habitat in the occupied area is therefore lost. The placement of a road also can fragment habitat into smaller blocks. This fragmentation effect is more likely with certain road configurations, such as multi-lane divided highways, or those with median barriers and adjacent fencing. Habitat loss and fragmentation can cause decreases in fox abundance through changes in social ecology, productivity, space use, dispersal, and survival.

Table 1

Proportion of mortalities attributable to vehicle strikes for kit and swift foxes.

Species	Location	Landuse	Period	Age	# Mortalities	% Vehicle Strike	Citations
Kit Fox	Kern County, CA	Oilfield	1980-95	Adult	225	9%	Cypher et al. 2000
Kit Fox	Kern County, CA	Oilfield	1980-95	Juvenile	142	8%	Cypher et al. 2000
Kit Fox	Kern County, CA	Natural Land	1989-93	Combined	31	3%	Spiegel and Disney 1996
Kit Fox	Kern County, CA	Oilfield	1989-93	Combined	29	0%	Spiegel and Disney 1996
Kit Fox	Kern County, CA	Natural Land	2001-03	Adult	14	7%	Cypher unpub. data
Kit Fox	Kern County, CA	Natural Land	1989-91	Combined	22	5%	Ralls and White 1995
Kit Fox	Monterey and San Luis Obispo Counties, CA	Military Reservation	1988-92	Adult	35	6%	Standley et al. 1992
Kit Fox	Monterey and San Luis Obispo Counties, CA	Military Reservation	1988-92	Juvenile	14	0%	Standley et al. 1992
Kit Fox	Merced County, CA	Natural Land	1985-87	Combined	17	12%	Briden et al. 1992
Kit Fox	Bakersfield, CA	Urban	1997-2003	Adult	35	23%	Cypher unpub. data
Kit Fox	Bakersfield, CA	Urban	1997-2003	Juvenile	25	17%	Cypher unpub. data
Swift Fox	Alberta, Canada	Natural Land	1987-91	Combined	89	6%	Carbyn 1998
Swift Fox	Western Kansas	unknown	1996-97	Adult	18	0%	Sovada et al. 1998
Swift Fox	Western Kansas	unknown	1996-97	Juvenile	14	28%	Sovada et al. 1998

While the historic and current habitat loss directly attributable to roads is unknown, estimates of the converted area under the jurisdiction of Caltrans include 239ha for Kings County, 431ha for Merced County, 817ha for Fresno County, and 1,485ha for Kern County (K. Hau, California Department of Transportation, personal communication). These estimates are based on a standard lane width of 3.6 m, and not all of this area is in kit fox habitat. However, the estimates are limited to state roads and do not include road shoulders, medians, or associated developments (e.g., interchanges, signs), which significantly increase the affected area. Of equal or greater significance is the habitat loss from urban and industrial development that has been induced by road construction.

Habitat fragmentation likely has two profound effects: (1) reduction in suitability of habitat and (2) disruption of movements, dispersal, and gene flow. Roads reduce habitat suitability by creating patches that are too small for effective use by foxes and that increase the probability of local extirpation due to stochastic events. Estimates of the average home range size of a kit fox vary from 4.3km<sup>2</sup> (Koopman et al. 2001) to 11.6 km<sup>2</sup> (White and Ralls 1993), making it difficult to estimate patch size necessary to support a small population.

The probability of patch recolonization will depend upon the fragmenting artifacts (e.g., roads, canals, development). Large roads with high traffic volume can be impermeable to kit foxes. Knapp (1978) monitored movements of radio-collared foxes in Kern County in the vicinity of Interstate 5, a high volume four-lane highway. Numerous individuals used areas within 3km of the interstate, and most exhibited parallel movement and home range patterns. However, only on two occasions were foxes located on the opposite side of the highway from their primary areas of use.

Movement and dispersal corridors are critical to kit fox population dynamics, particularly because this species currently exists as a metapopulation consisting of multiple disjunct population centers. Movement and dispersal linkages are important for alleviating over-crowding and intraspecific competition during years when fox abundance is high and are essential for recolonization. Movement between population centers also maintains gene flow, reducing the probability of inbreeding, genetic drift, and founder effects.

### **Disturbance**

Construction, maintenance, and operational activities associated with roads may result in a disturbance effect on nearby kit foxes. Disturbance can result from noise, vibration, odors, or human activity and can range from subtle to profound. Potential impacts include: (1) disrupted sensory perception leading to decreased ability to locate prey or detect predators, (2) induced stress leading to physiological or behavior changes, and (3) resultant changes in natural history including, energetic requirements, reproductive output, immunological function, productivity, space use patterns, displacement, and even death.

Kit foxes may not be significantly impacted by disturbance, even when the source is continuous. Kit foxes appear to acclimate quickly to disturbances and exhibit a high degree of tolerance. At the Naval Petroleum Reserves in California, foxes frequently used areas near petroleum production facilities (e.g., well pads, gas plants, offices) where noise, vibrations, odors, and human activity were common (Cypher et al. 2000). Similarly, Spiegel and Small (1996) found that kit foxes continued using a highly developed oil field where sulfurous gases were ubiquitous. Kit foxes at Camp Roberts frequently foraged and denned in areas that were subject to high human and vehicular traffic (Berry et al. 1992). Most notably, populations are known to inhabit the cities of Bakersfield and Taft, and in Bakersfield individuals likely number in the hundreds (Cypher submitted). Kit foxes in urban environments are continuously subjected to high levels of vehicular traffic, human activity, noise, and vibrations. Yet, these foxes successfully forage, locate mates, breed, rear young, and disperse.

### **Den Loss**

Unlike most other canids, kit foxes use dens year-round on a daily basis (Koopman et al. 1998). Earth moving or vehicular traffic during road work jeopardizes kit fox dens. Because dens are of critical importance to avoid temperature extremes, rear young, and escape from predators (Seton 1925, Grinnell et al. 1937), den loss can result in displacement and altered space use patterns, leading to changes in social ecology and survival. Individual kit foxes use numerous dens in the course of a year (Koopman et al. 1998). Therefore, the loss of one or even several dens within an individual's home range may not constitute a significant impact. However, foxes appear to have moderate fidelity to natal dens, the loss of which could be more detrimental. Finally, earth moving and off-road traffic typically occurs during the day, a time when foxes are resting within dens. This could result in fox entombment and death.

Although the construction of roads may result in the loss of some dens, earth moving can create new denning opportunities. In Bakersfield, numerous kit fox dens have been located in the embankment of Highway 99, and several of these have served as natal dens. This is not surprising because kit foxes favor sloped locations for denning (Berry et al. 1987a, Reese et al. 1992). However, den sites along roads increase the risk of vehicle strikes, particularly when used to rear young. Egoscue (1962) reported that many of the kit foxes killed by vehicles on a study area in Utah were using dens near roads, and most of these were juveniles. This increased risk likely offsets any beneficial effect of increased den-site availability.

### **Contaminants**

Roads contaminate natural lands in a variety of ways (see Forman et al. 2003 for a review). Substances used in road building or reconditioning can leach into adjacent habitat. Heavy metals (lead, aluminum, iron, cadmium, copper, manganese, titanium, nickel, zinc, and boron) and organic pollutants (dioxins, polychlorinated biphenyls) are all emitted in vehicle exhaust and may be higher in adjacent soils (Benfenati et al. 1992, Trombulak and Frissell 2000). Ozone levels are higher in the air near roads (Trombulak and Frissell 2000), and vehicles also leak hazardous substances (lubricants, antifreeze). Furthermore, a wide variety of pollutants could be introduced during small spills or catastrophic accidents.

Kit foxes using areas adjacent to roads could be exposed to contaminants through inhalation, dermal contact, direct ingestion, and ingestion of contaminated flora or fauna. Exposure to contaminants could cause short- or long-term morbidity, possibly resulting in reduced productivity or even mortality. Carcinogenic substances could cause genetic damage, sterility, reduced productivity, or reduced fitness among progeny in foxes or their prey. Little information is available on the effects of contaminants on fox demographics. Morbidity or mortality likely would occur after animals have left the contaminated site, and more subtle effects such as genetic damage could only be detected through intense study and monitoring. However, at the Naval Petroleum Reserves in

California, three kit foxes are known to have died by drowning in spills of crude oil (Cypher et al. 2000). Also, Spiegel and Disney (1996) reported a fox that was covered with crude oil and later died, despite treatment.

## **Indirect Effects**

### **Reduced Prey Availability**

Road construction, maintenance, and operation could result in a local reduction in prey availability, indirectly affecting kit fox populations. Potential causes include direct mortality associated with construction activities or vehicle strikes, habitat loss or degradation, disturbance, contaminants, or alteration of adjacent vegetation communities. Reduced prey availability could cause fox avoidance of adjacent lands, reduced productivity, and in extreme cases morbidity or mortality.

Little information is available on the effects of roads on kit fox prey. Foxes primarily prey upon rodents, leporids, and insects, but will opportunistically eat a variety of natural and anthropogenic foods (Knapp 1978, Spiegel et al. 1996, White et al. 1996, Cypher et al. 2000). Disturbed habitats adjacent to roads may provide conditions favorable to colonization by California ground squirrels (e.g., Balestreri 1981, Hall 1983). California ground squirrels can displace giant kangaroo rats (*Dipodomys ingens*) as well as other kangaroo rats and San Joaquin antelope squirrels (*Ammospermophilus nelsoni*) that are commonly consumed by foxes (D. Williams, Endangered Species Recovery Program, pers. comm., Taylor 1916; Harris and Stearns 1991).

### **Increased Competition**

Habitat modification associated with road construction and operation may create conditions more favorable for native species that compete for resources or kill kit foxes. Increased predation risk or decreased prey availability could reduce fox habitat quality and local carrying capacity, or exclude kit foxes altogether. At the Naval Petroleum Reserves in California, shrub density increased along roads, possibly due to increased moisture from precipitation runoff (pers. obs). Dense shrubs are known to provide cover for coyotes (*Canis latrans*) and bobcats (*Lynx rufus*) (Ralls and White 1995, White et al. 1995, Cypher and Spencer 1998, Warrick and Cypher 1998). Also, utility lines frequently are installed along roads and dramatically increase perching and nesting sites for raptors (Knight et al. 1995, 1999). Golden eagles occasionally kill kit foxes (Briden et al. 1992) and raptors and owls compete with foxes for food resources. Roads also may serve as travel corridors for other kit fox competitors, such as red foxes.

### **Invasive Species**

Construction and maintenance of roads can sometimes facilitate the invasion of non-native species that flourish in disturbed environments. Roads also enable invasive species to hitchhike on vehicles and livestock into otherwise remote landscapes. Non-native plants and animals may reduce habitat quality for kit foxes or their prey. A particularly problematic species within the range of the San Joaquin kit fox is yellow star thistle (*Centaurea melitensis*), dense stands of which form along roadsides and then spread into adjacent habitat. Yellow star thistle competes with native plants for resources, does not appear to be used by kit fox prey, and may be difficult for foxes to move through due to its large size (up to 1m tall), dense growth habit, and numerous sharp spines. Other species of invasive flora include mustards (*Brassica spp.*) and Russian thistle (*Salsola tragus*) (Tellman 1997), but the effects of these plants on kit foxes or their prey species have not been assessed.

Nitrogen deposition from vehicle exhaust is another important factor that appears to promote growth of non-native flora, particularly exotic grasses (Weiss 1999). These grasses, such as red brome (*Bromus madritensis rubens*), create dense ground cover in the San Joaquin Valley, and may reduce habitat quality for certain rodents (e.g., kangaroo rats) that are important prey for kit foxes (Goldingay et al. 1997, Cypher 2000).

Roads also may serve as travel corridors for non-native red foxes, as has been reported in Australia (Bennett 1991). Red foxes kill and exclude kit foxes (Ralls and White 1995, Clark 2001) and likely compete for food and dens (Cypher et al. 2001). However, red foxes are only infrequently observed in large blocks of undisturbed habitat within the range of the San Joaquin kit fox, possibly due to the absence of anthropogenic water sources or the presence of coyotes.

### **Increased Public Access**

Roads are established to facilitate human travel and commerce. Although posting adjacent lands or installing fences may reduce human use, they do not prevent it completely. While recreating on natural lands, people engage in a variety of activities that are detrimental to kit foxes, including illegal shooting or trapping, legal and illegal hunting of prey species, habitat destruction and degradation (e.g., off-road vehicle use), den destruction, and illegal dumping.

Most effects from increased public access have not been quantified, and can only be inferred. However, illegal fox hunting has been reported on several occasions and typically occurs near roads. While only one fox was found shot at the Naval Petroleum Reserves in California during 1980-95 (Cypher et al. 2000), Morrell (1972) reported that during a one-year period at NPRC, five of six fox deaths were caused by gunshot wounds. Four kit foxes were found shot at the Lokern Natural Area in western Kern County (Spiegel and Disney 1996), two at the California Aqueduct in Kern County (K. Brown, California Department of Water Resources, personal communication), and one in the Santa Nella area (S. Clifton, Endangered Species Recovery Program, personal communication). Most illegal kills are likely never discovered; therefore, the effect of this source of mortality on kit foxes is difficult to assess.

### **Associated Development**

While human population and economic growth precipitates road construction, roads also can have a growth-inducing effect by increasing access to lands desirable for development. Development along roads commonly begins as transportation services, and later urban and industrial centers. Associated developments range from very small (1-2ha) to extensive (1km<sup>2</sup>), ultimately producing entire cities in some cases.

Associated development produces all of the negative effects to kit foxes discussed above, the most significant of which are habitat loss, fragmentation, and degradation. Because associated development cannot always be accurately predicted, the long-term cumulative effects are likely underestimated in environmental reviews of road construction projects.

### **Changes in Fire Regime**

Roads often are a source of wildfire in arid lands, with dramatic effects on ecosystem processes. Vehicle sparks, overheating engines and brakes, arson, and accidental ignition all contribute to increased fire frequency. In some landscapes where lightning strikes traditionally were rare, anthropogenic wildfires have dramatically altered vegetation, reducing vertical structure and creating conditions that are suitable for invasive species.

Because foxes maintain well-insulated dens throughout their home ranges, it is unlikely that they frequently die in wildfire. However, much of the kit fox's geographic range is dominated by shrubs and grasses, and frequent burns will make grasslands more common. Furthermore, changes in vegetation affect abundance of fox prey and predators. For example, both coyotes and leporids (desert cottontail and black-tailed jackrabbit) are known to favor shrublands in the southern San Joaquin Valley. The effect of fire upon kit fox ecology and life history is currently unknown, but significant impacts are to be expected as these relationships are investigated.

## **Potential Mitigation Strategies**

### **Compensation for Loss of Habitat**

Compensating for habitat loss is a mitigation strategy commonly implemented for kit foxes. This strategy involves protecting habitat of like or better quality in return for authorization to alter, disturb, or destroy habitat in another location. The amount of compensatory habitat required typically exceeds 1:1. This strategy has several shortcomings. First, new habitat is rarely created as a result of mitigation, so compensation results in a net loss of available lands. Second, there is an implicit assumption that the carrying capacity on compensatory habitat can be increased through habitat management such that the total carrying capacity across all lands remains unaffected. This assumption has never been validated and is questionable. Third, compensation is only required for the amount of habitat physically disturbed during road construction. Roads precipitate a slew of associated impacts described above for which compensation is rarely requested.

### **Avoidance of Important Habitats**

Impacts to kit foxes can be reduced during the planning process by selecting project sites that avoid areas that are required for recovery of the species. Such areas include core and satellite populations and movement corridors. Understandably, there may be limited options in selecting the route for a proposed road. However, avoiding routes that transect large blocks of habitat would reduce detrimental effects significantly. A clear drawback to this strategy is increased project costs and decreased efficiency resulting from alternate routes. Rerouting of roads was identified as a key strategy to avoid fragmenting wildlife habitats in the Rocky Mountains (Reed et al. 1996) and also to avoid increased mortality to Florida scrub-jays (Mumme et al. 1999).

### **Den Avoidance**

Den avoidance is a common mitigation strategy employed on projects in kit fox habitat. Typically, work sites are prescreened for fox dens, and care is taken during construction to avoid sensitive areas. Den avoidance may be difficult when a kit fox den lies within the path of a proposed road. From a cost-benefit perspective, rerouting a road around a den is rarely feasible. If the den is currently active and the occupants do not leave

voluntarily, relocation may be necessary. As mentioned previously, dens in the vicinity of roads may increase the risk of vehicle strikes, and this potential impact should be considered when deciding whether to protect dens or relocate occupants.

### **Relocation**

Foxes are rarely relocated because of well-documented negative impacts, including low survival probability (Scrivner et al. 1993), injury, and attempted return to the area of origin. The release can either be “hard”, whereby foxes are immediately released, or “soft”, whereby foxes are released after a period (of days to months) of acclimation in a holding pen. A number of conditions must be met prior to relocation. First, the release site must be of suitable condition and size to support the number of transplanted individuals. Second, relocation must not negatively impact resident foxes at the release site. Third, if ongoing genetic studies identify distinct subpopulations, then foxes should only be moved within subpopulations and not between them. An optimal release site would be one that is occupied by kit foxes, but where the fox population currently is below carrying capacity. To be considered successful, relocated foxes should remain in the release area and exhibit survival rates similar to that of resident foxes. Several attempted relocation efforts were insufficiently monitored (Jensen 1972, Knapp 1978, Hansen 1988, Paveglio and Clifton 1988) or deemed unsuccessful (Scrivner et al. 1993).

Relocation may be appropriate when a small, isolated block of habitat occupied by kit foxes will be unavoidably fragmented by a road project. Additionally, persistent endangerment may be cause for relocation. For example, individuals occasionally return to denning and foraging sites that have recently been destroyed. Kit foxes continued to forage in the median of Highway 99 in Bakersfield after all vegetation had been removed (Perry Coy, California Department of Transportation, Fresno), while others were entombed after excavating and occupying a den on a construction site in Bakersfield (Endangered Species Recovery Program unpublished data).

### **Artificial Dens**

Construction of artificial dens may be appropriate where den destruction is unavoidable or road construction has resulted in increased risk of predation. A variety of artificial den designs have been built or proposed. These designs range from a simple length of pipe placed above ground, to complex buried chambers and tunnels with multiple entrances. Use by kit foxes or other species rarely has been monitored and optimal den designs have not been identified. However, dens should be of appropriate size to exclude predators, provide additional burrowing options, and provide sufficient thermal protection.

### **Exclusionary Fencing**

While exclusionary fencing likely would reduce vehicle strikes it is not appropriate for all roads. Unless crossing structures are available, fencing will increase negative impacts associated with habitat fragmentation. Along smaller roads (e.g., 2-lane roads) or larger roads with lower traffic volumes where the risk of vehicle strikes is not high, it would be better to allow kit foxes to cross roads to maintain movement corridors and facilitate local space use patterns.

### **Wildlife Overpasses and Underpasses**

Overpasses and underpasses are being created with greater frequency for wildlife. Designs range from small culverts under roads to 200-m-wide overpasses that are planted with natural vegetation. The creation of crossing structures could benefit kit foxes. Individuals have been observed to use bridges in order to cross roads and canals (pers obs.). Foxes also regularly enter pipes and culverts, although their use for road crossing has not been documented. Underpasses likely would be the most appropriate structures, particularly because many roads within the range of the kit fox are on raised beds. The dimensions of underpasses probably would need to be at least 0.5m high and 0.5m wide to be used by kit foxes. To maintain normal daily movement patterns in occupied habitat, underpasses probably should be spaced at least every 0.5 km. Exclusionary fencing along roads with underpasses would be necessary to encourage foxes to use the structures.

### **Reduced Speed Limits**

Reduced vehicle speeds through kit fox habitat is a simple and effective strategy to avoid incidental mortality. Reduced speed limits along one - or two-lane roads were credited with reducing the number of kit foxes killed by vehicles at the Naval Petroleum Reserves in California (Cypher et al. 2000) and at the Midway-Sunset oilfield (Spiegel and Disney 1996). This strategy will be more difficult to implement and enforce on larger roads with high traffic volumes. A related strategy is the use of signs along roads to warn drivers of the possible presence of kit foxes. Such signs are commonly used for other wildlife species (e.g., deer crossing signs), but their efficacy is debated.

## **Summary and Conclusions**

The construction, operation, and maintenance of roads can have a variety of potential impacts on endangered San Joaquin kit foxes. While vehicle strikes have received the most attention, other negative effects may exert greater force on fox population dynamics. In natural lands, vehicle strikes rarely exceed ten percent of known mortality. When populations are robust, this may not significantly impact abundance, but where small populations are susceptible to local extirpation, roadkills may be of greater concern.

Habitat loss, fragmentation, and degradation associated with road activities likely has the greatest affect on fox populations. The long and narrow configuration of roads results in a considerable disturbance perimeter. Perimeter effects on wildlife are well documented and with the San Joaquin kit fox result in increased probability of road crossings, exposure to contaminants, and access to habitat by people. Furthermore, high traffic volume roads with no crossing structures can effectively stop fox dispersal, resulting in local extirpation and genetic damage. Fragmentation of remaining habitat poses one of the largest obstacles to kit fox recovery.

The growth-inducing effect of roads also presents a serious concern. Development that occurs along linear rights-of-way causes habitat loss, fragmentation, and degradation that can be orders of magnitude greater than that caused by road work. The potential impacts from associated development sometimes are recognized in assessments of project-specific "cumulative effects," but no additional compensation or mitigation is required.

Other impacts associated with roads likely affect San Joaquin kit foxes on a relatively local scale. Although these local effects do not threaten the range-wide kit fox population, the cumulative effect of localized impacts could be substantial. Over time, these cumulative effects could affect kit fox conservation and recovery efforts.

A variety of potential mitigation strategies exist. Relatively few have been implemented for San Joaquin kit foxes, and virtually no data are available on mitigation efficacy. Many of the strategies that reduce detrimental impacts to habitat also help reduce kit fox mortality from vehicles. The following should be considered where roads and critical habitat or linkages coexist: (1) careful site selection for proposed projects, routing through non-habitat where possible, (2) habitat compensation, (3) road overpass and underpass structures, (4) exclusionary fencing, and (5) den avoidance or supplementation. Fox relocation is rarely successful or advisable. Future research needs include (1) quantifying factors that contribute to vehicle strikes of kit foxes, (2) assessing the effects of roads on fire ecology, (3) assessing invasions by non-native species along roads, and (4) evaluating the efficacy of mitigation strategies.

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