Research Report

Quantity and distribution of suitable habitat for endangered San Joaquin kit foxes: conservation implications

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Abstract

The San Joaquin kit fox *Vulpes macrotis mutica* is endemic to central California, and is listed as Federally Endangered and California Threatened, primarily due to profound habitat loss. This loss continues and habitat protection is urgently needed to conserve and recover this species. To identify lands to target for habitat protection, we used a GIS-based map-algebra model to determine the distribution of remaining suitable habitat for San Joaquin kit foxes. The primary variables used in the model included land use/land cover, vegetation density and terrain ruggedness. Suitability was categorized as high, medium or low based on habitat attributes relative to the presence and persistence of kit fox populations. Model results indicated that only 4,267km^2 of high suitability habitat and 5,569km^2 of medium suitability habitat remain for San Joaquin kit foxes, and much of this habitat is highly fragmented. High suitability habitat primarily is concentrated in the southern portion of the kit fox range with some also scattered along the western edge. Persistent kit fox populations appear to occur only in areas with relatively large patches of high suitability habitat or a mix of high and medium suitability habitat. Kit fox populations appear to be unable to persist in areas with high habitat fragmentation or areas with primarily medium suitability habitat. Our results underscore the urgent need to focus protection efforts on high suitability habitat and to do so in a manner that increases patch size of protected lands and reduces fragmentation.

Introduction

The San Joaquin kit fox *Vulpes macrotis mutica* was listed as Federally Endangered in 1967 and is also listed as California Threatened (U.S. Fish and Wildlife Service [USFWS] 1998). Although hunting, trapping and predator control programmes may have contributed to declining numbers in the past, the primary threat to kit foxes has been and continues to be profound habitat fragmentation, degradation and loss, largely resulting from agricultural, industrial and urban development. The remaining number of individuals is unknown, but because of continuing habitat loss, kit fox numbers are assumed to still be declining (USFWS 1998). Habitat protection is necessary for conserving the San Joaquin kit fox and preventing its extinction, and indeed is critical for maintaining any hope of recovering and eventually delisting this species.

The San Joaquin kit fox is endemic to the San Joaquin Valley and some adjacent arid valleys of central California. Approximately one-half of the natural communities in the San Joaquin Valley were converted by 1945 to other uses, primarily agricultural production (Kelly et al. 2005). The rate of habitat loss accelerated following the completion of the Central Valley Project and State Water Project, which increased the availability of water for agricultural and urban use (USFWS 1998). By 2004, approximately 70% of the over 3.9 million hectares of historical habitat in the San Joaquin Valley had been replaced by irrigated agriculture and urban development (Kelly et al. 2005). Remaining natural lands persist primarily at the edge of the valley, along the base of the Diablo and Sierra Nevada ranges, or on the valley floor as isolated patches, many of which are decreasing in size or even being converted entirely to alternate land uses (e.g. irrigated agriculture, cattle feed lots, dairies, prisons, residential development). In many valley floor locations, remaining habitat is degraded due to off-road vehicle use, trash dumping, rodent poisoning, domestic dogs and other adverse impacts (USFWS 1998).

Habitat protection efforts in the San Joaquin Valley face four significant challenges. First, more than 80% of the remaining lands with suitable habitat for kit foxes is privately owned (Orman and Phillips 2011) and not necessarily available for long-term conservation. Second, loss of high quality habitat is continuing at a rapid pace, and therefore each year less habitat is available for protection. Third, competition from different land use interests for these remaining lands is increasing. The San Joaquin Valley is one of the most highly productive agricultural areas in the world, and kit fox habitat is still being converted to croplands, particularly nut tree orchards (e.g. almonds, pistachios). Also, urban centres in the region are growing rapidly as the human population expands, and this growth consumes habitat as well as agricultural lands. Extensive oil and natural gas production also occurs in the San Joaquin Valley and discoveries of

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new reserves result in additional disturbance and destruction of habitat. More recently, thousands of hectares of kit fox habitat have been proposed for the installation of solar power generating facilities. A fourth challenge is that as lands become more scarce and competition for those lands increases, the cost of protecting those lands, whether it be by fee title or easement or some other mechanism, also increases. This effect has already impacted habitat acquisition efforts in the San Joaquin Valley (E. Cypher, California Department of Fish and Wildlife, pers. comm.), as it has elsewhere (Adams et al. 2006). An additional challenge not unique to the San Joaquin Valley is the chronically limited availability of resources habitat protection.

Consequently, habitat protection efforts should target lands that will provide the maximum benefit to San Joaquin kit fox conservation and recovery (Haight et al. 2002). This requires identifying suitable habitat remaining within the range of the kit fox and prioritising lands for protection efforts. Our objectives were to (1) identify and quantify remaining suitable habitat within the historic range of the San Joaquin kit fox using a GIS-based model, and (2) then offer recommendations for targeting lands for protection based on suitability, patch size and proximity to occupied habitat.

Methods

We assessed the distribution of suitable habitat for San Joaquin kit foxes in an area that encompasses the species' range as defined in the recovery plan for kit foxes (USFWS 1998). This range includes the counties of Alameda, Contra Costa, Fresno, Kern, Kings, Madera, Merced, Monterey, San Benito, San Joaquin, San Luis Obispo, Santa Barbara, Santa Clara, Stanislaus and Tulare in central California. Habitat suitability commonly is determined by examining the distribution of animal locations (e.g. telemetry fixes observations, sign) within a specified study area. Simplistically stated, habitat attributes of likely significance to a species are quantified across the landscape, and habitat conditions in areas used disproportionately more by a species are considered to be more suitable while conditions in areas used disproportionately less are considered to be less suitable (MacDonald et al. 2005). This information can then be applied to a larger landscape or even the entire range of a species to identify areas of greater suitability. In the case of a rare species, these more suitable areas will be important for the conservation of that species.

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.

To define suitable habitat for kit foxes, we assessed habitat attributes relative to the presence and persistence of kit fox populations. We assessed attributes in areas within the historic range where kit fox populations were known to be robust and persistent (high suitability), areas where kit fox populations were known to be less dense or intermittently present (medium suitability), and areas where kit fox populations appear to be absent with no or only infrequent observations of individual kit foxes (low suitability). This assessment was based on remotely sensed (rather than *in situ*) measurements of habitat attributes.

Habitat attributes considered most important to kit foxes included land use/land cover, terrain ruggedness and vegetation density (Grinnell et al. 1937, White et al. 1995, USFWS 1998, Warrick and Cypher 1998, Cypher et al. 2000, Smith et al. 2005, Warrick et al. 2007). High suitability habitats include saltbush *Atriplex polycarpa* and *A. spinifera* scrublands and grasslands dominated by red brome *Bromus madritensis* whereas medium suitability habitats include alkali sink scrublands and grasslands dominated by wild oats *Avena spp.* Other habitat types and profoundly altered anthropogenic lands (e.g. agricultural lands, urban areas) are considered low suitability. High suitability areas generally are characterized by flat or gently rolling terrain (average slopes <5%), and suitability declines as terrain ruggedness and average slope increase, largely due to an associated increase in predation risk for kit foxes (Warrick and Cypher 1998). Finally, kit foxes are optimally adapted to arid environments with sparse vegetation and a high proportion of bare ground (Grinnell et al. 1937, McGrew 1979). Thus, habitat suitability decreases as vegetation density increases.

Examples of sites with high habitat suitability included the valley floor and Elkhorn Plain areas of the Carrizo Plan National Monument in San Luis Obispo County, the Buena Vista Valley and Lokern Natural Area in Kern County, and the Panoche Valley in San Benito County. Examples of sites with medium habitat suitability included the Allensworth Ecological Reserve in Tulare County, Camp Roberts in San Luis Obispo County, and grasslands near the San Luis Reservoir in Merced County.

Habitat attributes were assessed throughout the range of the kit fox using spatial datasets on land use/land cover, terrain ruggedness and vegetation density. Land use/land cover types were mapped using multiple available sources (e.g. California Department of Water Resources Land Use Survey data [DWR], California Gap Analysis Program [GAP], National Wetlands Inventory [NWI]), aerial photography and limited field observations). We used a GIS model to create a composite land use and land cover dataset that combined agricultural and urban land use classes from the DWR data with vegetation classes from the GAP and NWI sources (California Department of Water Resources 1996, U.C. Santa Barbara Biogeography Lab 1998, USFWS 2006). We assigned habitat suitability values to land use/land cover types (Table 1) based on previous studies of kit fox habitat use (White et al. 1995, Warrick and Cypher 1998, Cypher et al. 2000, Warrick et al. 2007). Values ranged from 1-100, with 100 being most suitable.

Table 1. San Joaquin kit fox habitat suitability values for land use/land cover types.

Land use/land cover class	*Land use/land cover type*	*Habitat suitability value*
Urban/Industrial	Oil field/Extractive	65
	Urban	20
	Urban commercial	40
	Urban industrial	40
	Urban landscaped	60
	Urban residential	10
	Urban vacant	50
Agriculture	Farmstead	5
	Feed lot	10
	Field crops	10
	Grain/Pasture	30
	Idled farmland	50
	Orchard	20
	Retired farmland	75
	Rice	5
	Vineyard	10
Rangeland	Desert scrub	95
	Grassland	90
	Grassland/ruderal	75
	Heavy brush	5
	Lowland scrub	50
	Medium brush	10
Forested land	Brush and timber	5
	Forest	0
	Oak woodland	15
Water	Water	0
Wetlands	Emergent Wetlands	20
	Riparian	10
	Wetlands	5

Topographic ruggedness was classified using a 30m digital elevation interval and classifying areas as rugged according to differences in elevation between each grid cell and its neighboring cells (Valentine et al. 2004). Vegetation density was estimated using a 16-day vegetation index (Normalized Difference Vegetation Index, NDVI) product derived from remotely sensed Moderate Resolution Imaging Spectroradiometer (MODIS) imagery and produced by the Global Land Cover Facility (Carroll et al. 2007). The mean values of all 16-day MODIS NDVI products for six years (2001-2006) were used to characterise vegetation density. Mean NDVI values were rescaled from 0-100 with a linear transformation (206.25 * [-0.9375 * NDVI]) with a maximum of 100 and minimum of 0, resulting in high values (90-100) for lands that, on average, had lower amounts of green vegetation, and decreasing values (lower suitability values) for lands with increasing amounts of green vegetation. Vegetation density values for developed (agricultural and urban) lands were not used to avoid overestimating suitability based on temporary land management practices (e.g. temporary fallowing of fields or urban land being cleared for development). Instead, the weight value assigned to the land use type included an assumption of the typical vegetation density for that class.

Habitat suitability throughout the kit fox range was assessed using a GIS-based map-algebra model (Tomlin 1994; Figure 1). The model was developed using ArcGIS Spatial Analyst in combination with ArcGIS ModelBuilder (Environmental Systems Research Institute 2007). The model was initialized with suitability values of the land use/land cover layer with values from 0-100 (Table 1, Figure 1 – Land Use). Using a conditional operator, we replaced each cell with a suitability score of 75 or greater with a different suitability score based on mean NDVI (Figure 1 – NDVI) resulting in a composite suitability layer (Figure 1 – LU/NDVI). This step required that land classified as suitable to be both of a suitable land use class (e.g. saltbush scrub, grassland) and to, on average, have low vegetation density.

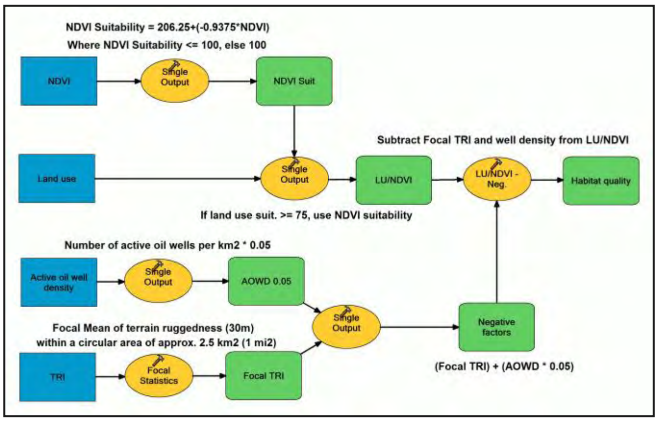

Figure 1. Habitat suitability model for San Joaquin kit foxes created in ArcGIS ModelBuilder.

From the composite suitability layer (Fig. 1 - LU/NDVI), we subtracted values (i.e., lowered the suitability score) from cells based on regional terrain ruggedness and the number of active oil wells. Increasing the terrain ruggedness and increasing oil well density both reduce habitat suitability for kit foxes. Regional terrain ruggedness was calculated as the focal mean of terrain ruggedness (TRI) within an approximately 300-m circular area around each cell. Because areas used for oil extraction are intermixed with suitable natural lands and have low vegetation density (resulting in a higher suitability score in previous model steps), we subtracted additional values for cells based on the density of oil wells. Oil well density was calculated as the number of active oil wells per km^2 (Fig. 1 - Active oil well density) multiplied by 0.05 (Fig. 1 - AOWD 0.05). We subtracted the negative factors (regional terrain ruggedness and oil well density) from our initial composite suitability values (land use/land cover or mean NDVI values) to derive an estimate of habitat quality as a continuous grid (30-m cell size) of values ranging from 0-100 with 100 being most suitable. We categorized our output into three suitability classes: high (value > 90), medium (90 >= value > 75), or low (value <= 75).

Results

Based on model results, 4,267km^2 were classified as high suitability habitat for San Joaquin kit foxes, while 5,569km^2 were classified as medium suitability habitat. All other lands were classified as low suitability or unsuitable. The majority of high and medium suitability habitat is found in Kern and San Luis Obispo counties (Table 2). Combined, these two counties combined encompass 67% and 35% of the remaining high and medium suitability habitat respectively.

The majority of the high suitability habitat is concentrated in the southern end of the range in western Kern County and eastern San Luis Obispo County (Figure 2). Other high suitability habitat occurs in central Kern County north and east of Bakersfield, and in small patches along the west side of the San Joaquin Valley from the Kern County line north to southwestern Merced County. Medium suitability habitat rims much of the San Joaquin Valley on the east, west and south sides (Figure 2). Some patches of medium suitability habitat also occur in the central portion of the valley, particularly in Kings, Tulare, Madera, and Merced counties. Except for the Carrizo Plain region in eastern San Luis Obispo County, most of the habitat outside of the San Joaquin Valley in San Luis Obispo, Santa Barbara, Monterey, and Santa Clara counties is medium suitability.

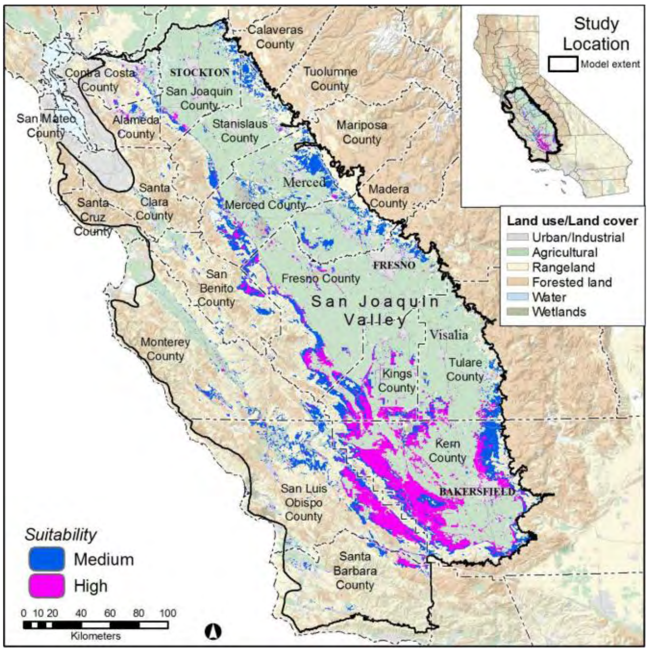

Figure 2. Remaining suitable habitat for San Joaquin kit foxes in central California based on model results.

Much of the remaining habitat for San Joaquin kit foxes is highly fragmented. Relatively large patches of high suitability habitat occur in eastern San Luis Obispo County, and in western and central Kern County. Additionally, relatively large patches of medium suitability habitat occur in central Kern County, western Kings and Fresno counties, and along the east side of the valley north of Fresno County.

Table 2. Remaining high and medium suitability habitat for San Joaquin kit foxes in California by county (listed from north to south) and the amount in blocks larger or smaller than 544 hectares.

	Remaining habitat (ha)				
				Patch size	
County	*High*	*Medium*	*Total*	*> 544ha*	*< 544ha*
Calaveras	4	2,723	2,727	2,368	359
Tuolumne	0	361	361	0	361
San Joaquin	5,277	21,064	26,340	13,485	12,855
Contra Costa	2,772	6,608	9,380	4,732	4,648
Alameda	2,043	7,358	9,401	7,156	2,245
Mariposa	23	1,646	1,669	1,274	395
Stanislaus	2,411	30,181	32,592	23,328	9,263
San Mateo	20	30	50	0	50
Santa Clara	461	2,584	3,045	0	3,045
Madera	3,015	31,310	34,325	21,690	12,634
Merced	10,761	80,523	91,284	67,543	23,739
Santa Cruz	11	32	43	0	43
Fresno	32,672	57,710	90,382	70,696	19,688
San Benito	6,019	18,478	24,497	17,648	6,850
Tulare	17,228	29,022	46,250	33,359	12,893
Monterey	3,741	24,468	28,209	13,158	15,050
Kings	45,129	36,635	81,763	75,881	5,881
San Luis Obispo	70,571	77,509	148,081	131,099	16,975
Kern	215,503	116,813	332,315	304,560	27,760
Santa Barbara	9,005	11,808	20,813	14,849	5,965
Total	**426,665**	**556,862**	**983,527**	**802,827**	**180,700**

Discussion

Inherent variability and uncertainty in any ecological system are difficult to accurately quantify, and therefore any attempts to model a system are imperfect at best. Nevertheless, models frequently provide the best picture of a given situation when extensive *in situ* sampling is not possible. This certainly is the case with regards to estimating the quantity and quality of remaining habitat for endangered San Joaquin kit foxes. Essentially, we measured landscape attributes in locations of known kit fox status (e.g. robust and persistent populations, intermittent presence, or no known occurrences), and then extrapolated across the historic range to identify other areas with similar attributes. Actual occupancy of suitable habitat by foxes should be confirmed through field surveys, and in some cases foxes may be absent from suitable habitat due to other factors, such as insufficient patch size or mortality sources (e.g. rodenticide use). However, model predictions were consistent with available data on current distribution and occupancy patterns for San Joaquin kit foxes (e.g. Smith et al. 2006, Constable et al. 2009, Cypher et al. 2010, USFWS 2010).

Habitat distribution and suitability

The distribution of remaining kit fox habitat and the relative suitability of that habitat are a function of climatological and anthropogenic influences. Precipitation in the San Joaquin Valley exhibits strong variation along a north-south gradient with annual totals in the north being roughly double those in the south. For example, annual precipitation averages 42cm in Stockton at the north end of the valley and 17cm in Bakersfield at the south end (Prism Group 2006). Consequently, the south end of the valley is considerably more arid resulting in habitat conditions more suitable to kit foxes, which are desert-adapted (McGrew 1979, Golightly and Ohmart 1983, 1984). These conditions include sparser vegetation with areas of bare ground and higher densities of kangaroo rats *Dipodomys spp*., which also are desert-adapted and are the preferred prey of kit foxes (Grinnell et al. 1937, McGrew 1979, Cypher 2003). Much of the remaining habitat also occurs in a band that rims the San Joaquin Valley. This is largely because most of the valley floor has been converted to agricultural uses, and kit foxes are unable to use croplands to any significant extent (Warrick et al. 2007). This band is relatively narrow and generally is too rugged for most agriculture but still sufficiently gentle for use by kit foxes.

The relatively large areas of high suitability habitat in eastern San Luis Obispo County and western Kern County support the two largest remaining populations of kit foxes and are considered to be "core" populations (USFWS 1998). This underscores the importance to kit foxes of large, contiguous blocks of high suitability habitat. A sizeable kit fox population inhabits the Panoche Valley region where there is a mix of high and medium suitability habitat in eastern San Benito and western Fresno counties. This population also is considered a "core" population (USFWS 1998), but is not of the same magnitude as the other two core populations, which are about 180km to the south. Small populations of foxes also are known to occur in the region immediately north and east of Bakersfield in Kern County, in the Cuyama Valley in northeastern Santa Barbara County, the band of habitat along the western edge of the San Joaquin Valley from Kern County north to the Panoche Valley region, the grasslands from the Panoche Valley region north to the San Luis Reservoir in western Merced County, in the area along the southeastern edge of the San Joaquin Valley south of Bakersfield in Kern County, and in a matrix of habitat fragments in the centre of the valley on the Kern-Tulare county line (USFWS 1998; Smith et al. 2006, Constable et al. 2009, Cypher et al. 2010). All of these small populations occur in areas characterised by a mix of high and medium suitability habitat, which again highlights the necessity of high suitability habitat for kit foxes.

Three areas with large quantities of primarily medium suitability habitat warrant discussion. Kit fox populations previously occurred in the Salinas Valley region of Monterey County in at least two locations: Camp Roberts and Fort Hunter-Liggett (O'Farrell et al. 1987, USFWS 1998). However, kit fox numbers progressively declined at both sites, and neither appears to currently support a kit fox population. Disease, specifically rabies spilling over from striped skunks *Mephitis mephitis*, was implicated in the decline of kit foxes at Camp Roberts (White et al. 2000). However, rabies did not appear to be a factor in the Fort Hunter-Liggett decline, and populations have not re-established at either location. Both sites are characterised by highly fragmented medium suitability habitat consisting primarily of wild oats-dominated grasslands and oak *Quercus spp*. savannah (O'Farrell et al. 1987). These habitat conditions may not be sufficient to sustain persistent kit fox populations.

A second region is the "northern range" consisting of the narrow band of habitat along the western edge of the San Joaquin Valley from the San Luis Reservoir in western Merced County north to central Alameda and Contra Costa Counties. The San Joaquin kit fox was first described from this area (Tracy, San Joaquin County; Merriam, 1902), and kit foxes occurred in this region in recent decades (e.g. Orloff et al. 1986, USFWS 1998), but currently kit fox observations are rare and no populations are known to be present (Smith et al. 2006, Constable et al. 2009). Similar to the Salinas Valley region, this northern range area is characterised by highly fragmented medium suitability habitat consisting primarily of dense grasslands dominated by wild oats, and these habitat conditions may not be sufficient to sustain persistent kit fox populations. Furthermore, this region, which is close to the highly urbanised San Francisco Bay Area, is rapidly developing.

Finally, an extensive region of medium suitability habitat was identified along the eastern edge of the San Joaquin Valley from Fresno County north to San Joaquin County. This habitat is reasonably intact and unfragmented. Kit foxes are observed in this region, but only occasionally (e.g. Smith et al. 2006). The value of the habitat for kit foxes in this region was potentially inflated by our analysis. The terrain is relatively flat or gently rolling, and the area is characterised by a significant grassland component. However, these grasslands are dominated by a diversity of more mesic-loving species that can get quite dense (Heady 1977). Cattle are grazed on most lands throughout this region and the reduction in vegetation density from the grazing might have resulted in a higher suitability rating by our model. Furthermore, this region is recognised as one of the premier remaining vernal pool areas in California (USFWS 2005). Consequently, a substantial proportion of the region is inundated or saturated on a seasonal basis and unavailable to kit foxes for denning or foraging, which significantly reduces the functional habitat suitability for kit foxes.

Habitat quantity and potential kit fox numbers

Based on our analysis, the total quantity of suitable habitat remaining for San Joaquin kit foxes is cause for concern. Except for a small number of urban areas (see below), no kit fox populations currently are known to be present in areas characterised as low suitability habitat. Individual foxes are occasionally observed in low suitability areas, and likely are transient or dispersing through. The remaining high and medium suitability habitat combined total 9,835km^2 or 983,527ha. Based on three studies conducted in areas with high suitability habitat (Spiegel et al. 1996, Zoellick et al. 2002, Nelson et al. 2007), average home range size for San Joaquin kit foxes is approximately 544ha. Thus, the remaining high and medium suitability habitat potentially could support 1,808 home ranges. If each home range was occupied by a breeding pair (Ralls et al. 2007), this would translate into 3,616 breeding adults, but we believe this to be an overestimate, and perhaps a very significant one.

Our model results indicated that much of the remaining habitat is extensively fragmented. Many of these fragments (approximately 18%; Table 2) are too small to support even one kit fox home range, let alone a population of foxes. Also, the average home range size used in the calculation above is based on estimates from high suitability habitat. No home range studies have been conducted in medium suitability habitat, but such home ranges are likely to be larger as home range size generally varies inversely with habitat quality. For example, kit fox home ranges in an area with high habitat suitability averaged 1,160ha during a period of severe drought and low prey availability (White and Ralls 1993). Furthermore, all potential home ranges are not likely to be occupied by a pair of breeding foxes. Mortality, primarily from larger predators such as coyotes *Canis latrans* and bobcats *Lynx rufus*, is quite high among kit foxes (Cypher 2003). Mean annual survival rates range from 0.44 (Cypher et al. 2000) to 0.60 (Ralls and White 1995), and rates in some years can be as low as 0.20 (Cypher et al. 2000). Thus, annual population turnover is high and at any given point in time, some home ranges will be vacant or only occupied by one breeding adult.

Finally, as alluded to previously, no persistent populations of kit foxes currently are known to occur in areas with only medium suitability habitat. Although all of these areas have not been surveyed recently, no kit fox populations have been detected in the ones that have (e.g. Smith et al. 2006, Constable et al. 2009). Yet, medium suitability habitat comprises 57% of the combined medium and high suitability habitat total. Therefore, for the reasons detailed above, the number of breeding adult kit foxes very likely is far less than the 3,616 calculated strictly on the basis of the total remaining medium and high suitability habitat.

Interestingly, although urban development is one of the prime causes of habitat destruction, kit foxes occur in several urban areas including the cities of Bakersfield, Taft, Maricopa, and Coalinga (Cypher 2010). In the case of the last three, these are communities of less than 15,000 people, and evidence suggests that most of the foxes observed in these towns are also using adjacent natural habitat (B. Cypher, pers. obs.). However, in the case of Bakersfield, several hundred foxes may inhabit the city. Natural habitat is virtually absent and the foxes are almost exclusively using anthropogenically altered habitat (e.g. golf courses, school campuses, parks, undeveloped lots, canals, storm-water drainage basins). This population appears to be demographically robust and persistent (Cypher and Frost 1999, Cypher 2010). Thus, although classified as low suitability by our model, some urban areas actually may support substantial populations of foxes, which could help to boost range-wide numbers and potentially contribute to particular conservation initiatives (e.g. reintroduction).

Conservation implications

We believe our results offer three important implications for the conservation and recovery of endangered San Joaquin kit foxes. First, the distribution of kit fox populations relative to habitat suitability clearly emphasises the importance of high suitability habitat as well as large, contiguous blocks of habitat. Although this may seem intuitive, the apparent absence of persistent kit fox populations in highly fragmented areas or in areas with primarily medium suitability habitat is striking. Thus, habitat protection efforts should target high suitability habitat and should strive to increase the patch size of protected lands. Similarly, Haight et al. (2002) conducted population viability simulations relative to habitat protection strategies and concluded that increasing patch size of protected lands in areas with existing populations provided a greater increase in long-term population viability for San Joaquin kit foxes.

Consequently, habitat protection efforts for kit foxes should particularly target lands in the southern portion of the range and along the western edge of the San Joaquin Valley. The vast majority of habitat in these areas currently is unprotected and is vulnerable to further loss and degradation from continuing agricultural, urban and industrial developments. Much of the high suitability habitat in eastern San Luis Obispo County is protected within the Carrizo Plain National Monument. However, only a small proportion of the high suitability habitat in western Kern County is protected, and what is protected primarily consists of scattered fragments as opposed to large patches. Likewise, the high suitability habitat in the Panoche Valley region and in the band of habitat from Kern County north to the San Luis Reservoir in western Merced County is virtually all unprotected. Conserving lands in all of these areas will be critical to preventing further declines in kit fox numbers and increasing long-term population viability.

A second conservation priority is conserving lands in corridors between kit fox populations. In many cases, these lands are low suitability. However, maintaining or creating opportunities for demographic and genetic exchange between populations will be vital for maintaining the viability of the kit fox metapopulation. Many of these corridor areas are identified in the recovery plan for kit foxes (USFWS 1998). Accordingly, the California Department of Fish and Wildlife has been striving to protect corridor areas in northern Kern County using the funds generated from the Metropolitan Bakersfield Habitat Conservation Plan (K. Tomlinson, California Department of Fish and Wildlife, pers. comm.). Similar efforts are needed throughout the range, but especially in parts of Fresno, Madera and Merced counties, where kit fox populations have the potential to be restored and cross-valley connectivity reestablished.

Finally, the retirement of unproductive agricultural lands in the San Joaquin Valley could contribute to kit fox conservation efforts. Vast areas consisting of hundreds of thousands of hectares along the west side of the San Joaquin Valley suffer from poor drainage due to heavy clay soils, hardpan formations and shallow water tables. The resulting soil saturation and salt concentrations significantly reduce the agricultural productivity of these lands (Ritter and Lair 2007). Some lands have already been retired from farming and much more may be retired in the future (San Joaquin Valley Drainage Program 1990, U.S. Bureau of Reclamation 2007). These retired lands potentially could revert to natural habitat either through natural succession or active restoration, although the latter may be very challenging (Ritter and Lair 2007). While these lands would likely constitute medium suitability (due to heavy clay soils and shallow water tables), they may represent a net gain of habitat available for colonisation by kit foxes and could potentially increase connectivity between remaining areas of highly suitable habitat.

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References

Adams, C.E., Lindsey, K.J. and Ash S,J. 2006. *Urban Wildlife Management*. CRC Press, Boca Raton.

California Department of Water Resources (DWR). 2006. *Land Use Survey Data. 1:24,000*. California Department of Water Resources Division of Planning and Local Assistance, Sacramento, CA. URL: <http://landwateruse.water.ca.gov/basicdata/landuse/landusesurvey.cfm> [Accessed 12 August 2012].

Carroll, M.L., DiMiceli, C.M., Sohlberg, R.A. and Townshend, J.R.G. 2007. *250m MODIS Normalized Difference Vegetation Index (all composites for 2005)*. University of Maryland, College Park, MD. URL: <http://glcf.umiacs.umd.edu/data/ndvi/> [Accessed 10 August 2012].

Constable, J.L., Cypher, B.L., Phillips, S.E. and Kelly, P.A. 2009. *Conservation of San Joaquin kit foxes in western Merced County, California*. California State University-Stanislaus, Endangered Species Recovery Program, Fresno.

Cypher, B.L. 2003. Foxes. Pp. 511-546 in G.A. Feldhamer, B.C. Thompson and J.A. Chapman (eds.), *Wild mammals of North America: biology, management, and conservation*. 2nd edition. Johns Hopkins University Press, Baltimore.

Cypher, B.L. 2010. Kit foxes. Pp. 49-60 in S.D. Gehrt, S.P.D. Riley and B.L. Cypher (eds.), *Urban carnivores: ecology, conflict, and conservation*. Johns Hopkins University Press, Baltimore.

Cypher, B.L. and Frost, N. 1999. Condition of kit foxes in urban and exurban habitats. *Journal of Wildlife Management* 63: 930-939.

Cypher, B.L., Van Horn Job, C.L., Tennant, E.N. and Phillips, S.E. 2010. *Mammalian species surveys in the Acquisition Areas on the Tejon Ranch, California*. California State University-Stanislaus, Endangered Species Recovery Program, Fresno.

Cypher, B.L., Warrick, G.D., Otten, M.R.M., O'Farrell, T.P., Berry, W.H., Harris, C.E., Kato, T.T., McCue, P.M., Scrivner, J.H. and Zoellick, B.W. 2000. Population dynamics of San Joaquin kit foxes at the Naval Petroleum Reserves in California. *Wildlife Monographs* 45:1-43.

Environmental Systems Research Institute. 2007. *An overview of ModelBuilder*. URL:<http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=An_overview_of_ModelBuilder> [Accessed 6 June 2012].

Golightly, R.T. and Ohmart, R.D. 1983. Metabolism and body temperature of two desert canids: coyotes and kit foxes. *Journal of Mammalogy* 64:624-635.

Golightly, R.T. and Ohmart, R.D. 1984. Water economy of two desert canids: coyote and kit fox. *Journal of Mammalogy* 65:51-58.

Grinnell, J., Dixon, D.S. and Linsdale, J.M. 1937. *Fur-bearing mammals of California*. Vol 2. University of California Press, Berkeley.

Haight, R.G., Cypher, B., Kelly, P.A., Phillips, S., Possingham, H.P., Ralls, K., Starfield, A.M., White, P.J. and Williams, D. 2002. Optimizing habitat protection using demographic models of population viability. *Conservation Biology* 16:1386-1397.

Heady, H.F. 1977. Valley grassland. Pp. 491-514 in M.G. Barbour and J. Major (eds.), *Terrestrial vegetation of California*. California Native Plant Society, Sacramento.

Kelly, P.A., Phillips, S.E. and Williams, D.F. 2005. Documenting ecological change in time and space: the San Joaquin Valley of California. Pp. 57-78 in E.A. Lacey and P. Myers (eds.), *Mammalian diversification: from chromosomes to phylogeography*. Publications in Zoology Series, University of California Press, Berkeley.

MacDonald, L.L., Alldredge, J.R., Boyce, M.S.and Erickson, W.P. 2005. Measuring availability and vertebrate use of terrestrial habitats and foods. Pp. 465-488 in C.E. Braun (ed.), *Techniques for wildlife investigations and management*. The Wildlife Society, Bethesda.

McGrew, J.C. 1979. *Vulpes macrotis*. *Mammalian Species* 123:1-6.

Merriam, C.H. 1902. Three new foxes of the kit and desert fox groups. *Proceedings of the Biological Society, Washington* 15:73-74.

Nelson, J.L., Cypher, B.L., Bjurlin, C.D. and Creel, S. 2007. Effects of habitat on competition between kit foxes and coyotes. *Journal of Wildlife Management* 71:1467-1475.

O'Farrell, T.P., Berry, W.H. and Warrick, G.D. 1987. *Distribution and status of the endangered San Joaquin kit fox, Vulpes macrotis mutica, on Fort Hunter Liggett and Camp Roberts, California*. U.S. Department of Energy Topical Report EGG10282-2194, Washington, D.C.

Orloff, S.G., Hall, F. and Spiegel, L. 1986. Distribution and habitat requirements of the San Joaquin kit fox in the northern extreme of their range. *Transactions of the Western Section of The Wildlife Society* 22:60-70.

Orman, L. and Phillips, S.E. 2011. *Cataloging protected lands in the San Joaquin Valley using geographic information systems*. California State University-Stanislaus, Endangered Species Recovery Program, Turlock.

PRISM Group at Oregon State University. 2006. *United States average annual precipitation, 1971–2000*. The PRISM Group at Oregon State University, Corvallis.

Ralls, K. and White, P.J. 1995. Predation on San Joaquin kit foxes by larger canids. *Journal of Mammalogy* 76:723-729.

Ralls, K., Cypher, B.L. and Spiegel, L.K. 2007. Social monogamy in kit foxes: formation, association, duration, and dissolution of mated pairs. *Journal of Mammalogy* 88:1439-1446.

Ritter, N.P. and Lair, K.D. 2007. *Central Valley Project Improvement Act Land Retirement Demonstration Project – a synthesis of restoration research conducted near Tranquility, California*. U.S. Department of Interior, Land Retirement Team, Fresno.

San Joaquin Valley Drainage Program. 1990. *A management plan for agricultural subsurface drainage and related problems on the west side of the San Joaquin Valley*. California Department of Water Resources, Sacramento.

Smith, D.A., Ralls, K., Cypher, B.L. and Maldonado, J.E. 2005. Assessment of scat-detection dog surveys to determine kit fox distribution. *Wildlife Society Bulletin* 33:897-904.

Smith, D.A., Ralls, K., Cypher, B.L., Clark, Jr., H.O., Kelly, P.A., Williams, D.F. and Maldonado, J.E. 2006. Relative abundance of endangered San Joaquin kit foxes (*Vulpes macrotis mutica*) based on scat-detection dog surveys. *Southwestern Naturalist* 51:210-219.

Spiegel, L.K., Dao, T.C. and Bradbury, M. 1996. Spatial ecology and habitat use of San Joaquin kit foxes in undeveloped and oil-developed lands of Kern County, California. Pp. l93-114 in L.K. Spiegel (ed.), *Studies of the San Joaquin kit fox in undeveloped and oil-developed areas*. California Energy Commission, Sacramento.

Tomlin, C. 1994. Map algebra: one perspective. *Landscape and Urban Planning* 30:3-12.

U.C. Santa Barbara Biogeography Lab. 1998. *California Gap Analysis Vegetation Layer (Statewide) 1:100,000-1:250,000*. University of California, Santa Barbara, CA.
URL:<http://www.biogeog.ucsb.edu/projects/gap/gap_home.html> [Accessed 3 March 2012].

U.S. Bureau of Reclamation. 2007. *San Luis Drainage Feature Re-evaluation: Record of Decision*.
URL:<http://www.usbr.gov/mp/sccao/sld/docs/sld_feature_reeval_rod.pdf> [Accessed 6 September 2011].

U.S. Fish and Wildlife Service. 1998. *Recovery plan for upland species of the San Joaquin Valley, California*. U.S. Fish and Wildlife Service, Region 1, Portland.

U.S. Fish and Wildlife Service. 2005. *Recovery plan for vernal pool ecosystems of California and Oregon*. U.S. Fish and Wildlife Service, Region 1, Portland.

U.S. Fish and Wildlife Service. 2006. *NWIDBA.CONUS_wet_poly: Classification of Wetlands and Deepwater Habitats of the United States*. U.S. Department of the Interior, Fish and Wildlife Service, FWS/OBS-79/31, Washington, D.C.

U.S. Fish and Wildlife Service. 2010. *San Joaquin kit fox (Vulpes macrotis mutica) 5-year review: summary and evaluation*. U.S. Fish and Wildlife Service, Sacramento.

Valentine, P.C., Fuller, S.J. and Scully, L.A. 2004. *Terrain ruggedness analysis and distribution of boulder ridges and bedrock outcrops in the Stellwagen Bank National Marine Sanctuary region - seabed ruggedness*. U.S. Geological Survey poster.
URL:<http://woodshole.er.usgs.gov/projectpages/stellwagen/posters/rugged.html> [Accessed 5 May 2011].

Warrick, G.D., Clark, Jr., H.O., Kelly, P.A., Williams, D.F. and Cypher, B.L. 2007. Use of agricultural lands by San Joaquin kit foxes. *Western North American Naturalist* 67:270-277.

Warrick G.D. and Cypher, B.L. 1998. Factors affecting the spatial distribution of a kit fox population. *Journal of Wildlife Management* 62:707-717.

White, P.J., Berry, W.H., Eliason, J.J. and Hanson, M.T. 2000. Catastrophic decrease in an isolated population of kit foxes. *Southwestern Naturalist* 45:204-211.

White, P.J. and Ralls, K. 1993. Reproduction and spacing patterns of kit foxes relative to changing prey availability. *Journal of Wildlife Management* 57:861-867.

White, P.J., Ralls, K. and Vanderbilt-White, C.A. 1995. Overlap in habitat and food use between coyotes and San Joaquin kit foxes. *Southwestern Naturalist* 40:342-349.

Zoellick, B.W., Harris, C.E., Kelly, B.T., O'Farrell, T.P., Kato, T.T. and Koopman, M.E. 2002. Movements and home ranges of San Joaquin kit foxes relative to oil-field development. *Western North American Naturalist* 62:151-159.

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