FACTORS INFLUENCING SPACE AND PREY USE BY SAN JOAQUIN KIT FOXES

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ABSTRACT: We investigated patterns of space and prey use by endangered San Joaquin kit foxes (*Vulpes macrotis mutica*) on 5 sites at the Naval Petroleum Reserves in California in 1994. Our objective was to identify factors influencing these patterns. Mean values for 11 environmental variables were similar between core and peripheral areas of home ranges used by radiocollared kit foxes. Kit fox core areas may be centered around dens. Kit foxes were located near roads and dry washes more frequently than expected, and most locations were in areas with slopes <6°. The occurrence of leporids in kit fox scats varied with leporid abundance indicating that use was opportunistic. The occurrence of kangaroo rats (*Dipodomys* spp.) in scats was always greater than that for leporids, and varied independently of leporid and kangaroo rat abundance. Kangaroo rats may be used preferentially by kit foxes. Relatively flat terrain with an abundance of kangaroo rats constitutes favorable habitat conditions for San Joaquin kit foxes.

Key words: San Joaquin kit fox, *Vulpes macrotis mutica*, home range, core area, food habits, California, endangered species

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Patterns of space and prey use by endangered San Joaquin kit foxes (*Vulpes macrotis mutica*) have been addressed in several previous investigations (e.g., White and Ralls 1993, Spiegel et al. 1996, Zoellick et al. in press). However, environmental factors that influence these patterns are not well understood. Identifying environmental factors that influence the use of space and prey is important for developing effective strategies for conserving and recovering San Joaquin kit foxes (U.S. Fish and Wildlife Service 1998).

We investigated home range and prey use patterns of San Joaquin kit foxes at the Naval Petroleum Reserves in California (NPRC). We also collected data on prey item availability and dispersion, competitor abundance, and landscape characteristics to determine whether these factors influence home range attributes or prey use.

STUDY AREA

The 313-km^2 NPRC is located in the southwestern portion of the San Joaquin Valley of California, about 42 km southwest of Bakersfield (Figure. 1). The NPRC encompasses the Elk Hills, Buena Vista Hills, and surrounding alluvial plains and valleys. Elevations range from 88 to 473 m. Primary land use on the NPRC was oil and gas production, but large portions of the study area remained largely undisturbed (Warrick and Cypher 1998). Sheep were grazed intermittently on portions of the study area.

Regional weather patterns consisted of hot, dry summers and cool, damp winters (National Oceanic and Atmospheric Administration 1995). Mean daily maximum and minimum temperatures were 37°C and 20°C, respectively, in July, and 14°C and 3°C, respectively, in January. Precipitation averaged about 15 cm annually and occurred primarily between October and April. The vegetation community within NPRC was classified formerly as Lower Sonoran Grassland (Twisselmann 1967) or Valley Grassland (Heady 1977), and more recently as Allscale Series (Sawyer and Keeler-Wolf 1995). Desert saltbush (*Atriplex polycarpa*) was the dominant shrub, and other shrubs present included spiny saltbush (*A. spinifera*), cheesebush (*Hymenoclea salsola*), bladderpod (*Isomeris arborea*), and matchweed (*Gutierrezia californica*). Herbaceous vegetation was dominated by the non-natives red brome (*Bromus madritensis*) and red-stemmed filaree (*Erodium cicutarium*).

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METHODS

Space Use

We only examined use of space and prey items by kit foxes at 5 sites within NPRC (Figure 1). These locations were chosen based on the presence of radiocollared kit foxes that were being monitored as part of an on-going demographic study of kit foxes at NPRC (see Cypher et al. 2000).

We monitored nocturnal kit fox movements using portable null-peak telemetry stations. Each station consisted of two 3-element Yagi antennas set 2 m apart on a crossbar mounted on a 6-m mast. One station was mounted on a truck and the other was freestanding. Bearings were determined using a compass rosette. Prior to monitoring sessions, the stations were located at known coordinates determined using a global positioning system (GPS) unit which was calibrated using USGS location monuments. The compass rosettes were oriented using transmitter beacons placed in locations at known bearings from each station. Bearings were taken hourly on 2 beacons to measure location error. Mean (± SE) location error was 0.96 ± 0.07°. We monitored foxes during 4-5 hr sessions beginning at sunset. Kit foxes exhibit increased activity during this period (Morrell 1972, Zoellick 1990). During a given monitoring session, bearings were collected at 15-minute intervals on each fox at a given site. To reduce error due to movement of foxes between bearings, for a given location attempt, compass bearings taken >3 min apart between the 2 stations were excluded from analyses. The average time interval (± SE) between bearings from the 2 stations was 21 ± 2.4 seconds. We calculated coordinates for fox locations from paired bearings using the program Locate II (Pacer, Truro, Nova Scotia, Canada). This program automatically removed paired bearings that intersected at angles <20° or >160°. Fox locations with 95% error ellipses ≥10 ha also were removed from the data set.

We included kit foxes with more than 75 locations in home range analyses. We estimated 100% minimum convex polygons and 75% harmonic mean isopleths (Dixon and Chapman 1980) using the program CALHOME (Kie et al. 1996). The 75% harmonic mean isopleths were considered estimates of core areas within home ranges (Dixon and Chapman 1980). Locations gathered at 15-min intervals frequently are autocorrelated (Swihart and Slade 1985*a*), and autocorrelation was detected in our data. However, Gese et al. (1990) found that coyote (*Canis latrans*) home ranges estimated from sequential locations were not significantly different from those estimated from point locations, even when the sequential locations were autocorrelated. Also, non-statistical home range estimators, such as the minimum convex polygon method, may

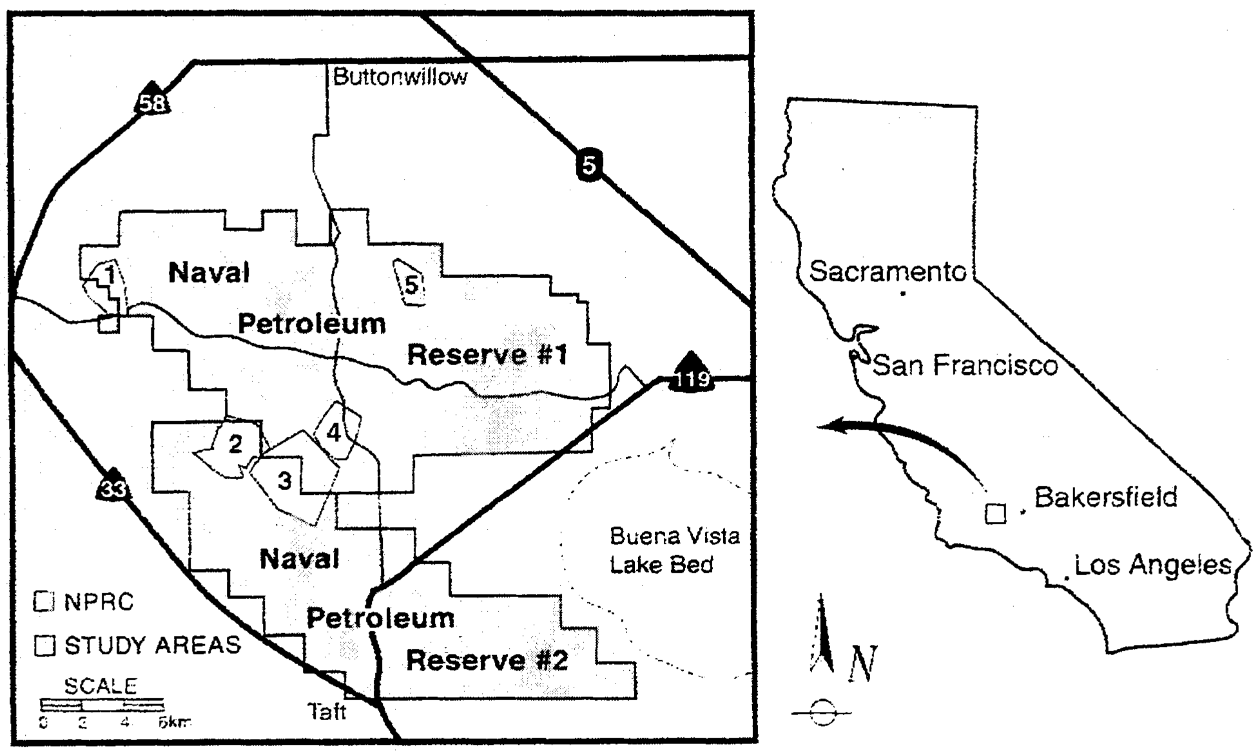

Figure 1. Location of kit fox study sites within the Naval Petroleum Reserves in California.

be less sensitive to the effects of autocorrelation (Swihart and Slade 1985*b*). Therefore, we used the sequential locations to estimate home range size, which also facilitated comparison to previous home range estimates for kit foxes at NPRC (Zoellick et al. in press).

To examine the influence of terrain features on space use, we plotted kit fox locations on 1:6,000 or 1:24,000 scale topographic maps (the 1:6,000 maps were not available for all parts of the study area). Fox locations were examined relative to the locations of dry washes and roads. The relative availability of washes and roads was determined by overlaying a dot grid on topographic maps with the fox locations. Availability was based on the proportion of grid dots within 75 m of a wash or road. Fox locations within 75 m of a wash or road were considered to be associated with that feature. Sequential locations were plotted to determine kit fox movements relative to terrain features, and also to determine the slope of terrain used by kit foxes.

Environmental variables

We measured habitat characteristics, prey availability, and competitor abundance at 8 sampling sites within kit fox home ranges: 4 within core areas, and 4 within peripheral areas (areas within home ranges but outside of core areas). Coordinates for sampling sites were randomly chosen, and then located in the field using a GPS unit. At each sampling point, we collected data on coyote abundance, prey abundance, vegetation characteristics, and landscape features.

Coyotes were the primary cause of mortality for kit foxes at NPRC and also compete with kit foxes for food (Cypher and Spencer 1998). We assessed coyote abundance by establishing and checking scent stations for 3 consecutive nights. Scent stations were created at each sampling point by sifting fine soil over a 1-m^2 area and placing a scent tab (Pocatello Supply Depot, Pocatello, ID) in the center (Roughton and Sweeny 1982). The following morning, stations were inspected for coyote sign (e.g., tracks, feces). We estimated kangaroo rat (*Dipodomys* spp.) abundance by walking a 40-m transect centered on each sampling point and counting active rodent burrows within a 0.75-m wide belt along the transect. We estimated leporid abundance by clearing a 1-m^2 quadrat at each sampling point and counting the number of leporid fecal pellets accumulated after 1 month. Leporids on NPRC included black-tailed jackrabbits (*Lepus californicus*) and desert cottontails (*Sylvilagus audubonii*). The number of grasshoppers (*Acrididae*) observed within 10 m of the sampling point also was recorded. Other food items occurred only infrequently in kit fox scats (Koopman 1995), and so their availability was not assessed. We assessed vegetation characteristics by visually estimating the percentage of shrub, grass, forb, and total vegetation cover within a 30-m radius of the sampling point. Finally, we measured the distance from each sampling point to the nearest dry wash, road, and human disturbance (e.g., oil well or other facility).

Food use

To assess use of food items by kit foxes, we collected scats within the home ranges of kit foxes. Because scats can persist for years in arid environments, only fresh scats were collected. Scats dark in color were considered to be fresh (estimated to be <5 mo old) while scats that had turned white from weathering were considered to be of unknown age. Scats were placed in paper bags and placed in a drying over at ≥60° C for ≥24 hr to destroy potential zoonotic parasites and facilitate handling. Each scat was broken apart and constituent items (e.g., hair, bone, feathers, insect parts) were separated and identified. Items were identified to the lowest taxonomic class possible through comparison with known samples or use of guides. Mammalian prey were identified based on dental and skeletal characteristics, and both macroscopic (e.g., color, length, texture) and microscopic (e.g., cuticular scale patterns - Moore et al. 1974) hair characteristics. The percent frequency of occurrence was determined for each item by study site.

Statistical analyses

All percentage data were arcsine-transformed prior to analysis (Zar 1984). We used Student's *t*-tests to compare means for number of coyote visits, number of small mammal burrows, number of leporid pellets, number of grasshoppers, vegetation cover, and distance to roads, washes, and disturbances between core areas and peripheral areas within home ranges. We used Pearson correlations to determine whether home range or core area size was related to any of the environmental variables, and also to determine whether use of food items within study sites was related to food item availability. We used a single-factor analysis of variance and Tukey's multiple comparison test to determine whether food item availability varied among the 5 study sites. Use of food items was compared among the 5 study sites using Chi-square tests for homogeneity. A Chi-square goodness-of-fit test was used to determine whether kit foxes were located near washes or roads more frequently than expected.

RESULTS

From June to September 1994, home range and core area sizes were determined for 11 kit foxes: 8 adults and 3 juveniles (<1 year). Mean home range size (± SE) for adult and juvenile foxes was 433.7 ± 142.5 ha and 131.7 ± 25.0 ha, respectively. Mean core area size (± SE) for adult and juvenile foxes was 134.0 ± 37.6 ha and 47.0 ± 10.0 ha, respectively. Mean home range and core area sizes were similar between sexes, but were larger for adults than for juveniles (see Cypher et al. 2001).

Based on 500 locations, kit foxes were located near washes or roads more frequently than expected $X^2 = 50.08$, 2 df, $P < 0.01$) relative to the availability of these features (observed = 145, expected = 87). Of 421 movements by kit foxes, 41 (9.7%) appeared to follow washes or roads. The mean slope for movements was 3.3° and ranged from 0° to 71°; only 0.9% of movements occurred on slopes >6°.

None of the environmental variables measured differed between core areas and peripheral areas within kit fox home ranges (Table 1). Also, neither home range size nor core area size was correlated with any of the variables (r values ranged from <0.10 to 0.62, P values all (0.28). For this latter analysis, only values for adult foxes were used due to differences in home range and core area size between adults and juveniles.

Indices of abundance (Table 2) varied among the 5 study sites for kangaroo rats ($F = 15.1$; 4, 68 df; $P < 0.01$) and leporids ($F = 7.9$; 4, 68 df; $P < 0.01$), but not for grasshoppers ($F = 1.0$; 4, 68 df; $P = 0.41$). Frequency of occurrence in scats (Table 2) varied among the sites for leporids ($X^2 = 11.2$, 4 df, $P = 0.03$) and insects ($X^2 = 9.6$, 4 df, $P = 0.05$), but not for kangaroo rats ($X^2 = 7.9$, 4 df, $P = 0.10$). Other items found in kit fox scats included Botta pocket gopher (*Thomomys bottae*), unidentified bird, and unidentified reptile. Insects in scats consisted primarily of grasshoppers, but beetles (mostly *Eleodes* spp.) and Jerusalem crickets (Gryllacridae) were occasionally observed. The occurrence of kangaroo rats and grasshoppers in scats on the 5 study sites was not related to abundance indices for these items ($r = 0.32$, $P = 0.54$ and $r < 0.10$, $P = 0.93$, respectively). The occurrence of leporids was marginally related to leporid abundance indices ($r = 0.84$, $P = 0.07$).

DISCUSSION

Home ranges of many mammalian species typically encompass one or more core areas that are considered to be "biological centers of activity" (Ables 1969), and in which animals spend disproportionate periods of time (Laundré and Keller 1981). Presumably, habitat conditions within core areas are more favorable, and quantifying these conditions would assist in identifying optimal habitat. However, none of the environmental variables we measured were significantly different between core and peripheral areas of kit fox home ranges. Therefore, kit foxes were not selecting core area locations based on any of these variables.

Dens are an important component of kit fox ecology; dens are used for daytime resting, predator avoidance, thermoregulation, and pup rearing (Koopman et al. 1998). Because kit foxes use dens on a daily basis, fox activity is consequently concentrated around den sites. Dens may be the resource around which core areas are centered, as was reported by Spiegel et al. (1996). Indeed, commonly used dens were present in the core areas of all monitored kit foxes.

Home range size for San Joaquin kit foxes varies among locations, possibly due to local differences in prey availability (Zoellick and Smith 1992, White and Ralls 1993). The mean estimate of 4.3 km² we observed at NPRC was smaller than the estimate of 11.6 km² from the Carrizo Plain

Table 1. Mean (± SE) values and statistical comparisons for environmental variables measured in core and peripheral areas of home ranges of 11 San Joaquin kit foxes at the Naval Petroleum Reserves in California, 1994.

Variable	Core area	Peripheral area	t (135 df)	P
No. rodent burrows	7.8±0.7	9.5±0.6	-1.7	0.1
No. leporid pellets	16.0±2.9	17.4±3.0	-0.3	0.8
No. grasshoppers	0.5±0.2	0.6±0.2	-0.7	0.5
No. coyote visits	0.9±0.2	1.0±0.1	-0.6	0.5
Distance to disturbance (m)	169.1±21.8	170.5±17.4	-0.05	0.9
Distance to dry wash (m)	59.7±13.3	50.5±7.5	0.6	0.5
Distance to road (m)	243.3±23.0	228.1±18.8	0.5	0.6
Total cover (%)	67.1±2.9	65.0±2.3	0.5	0.6
Shrub cover (%)	31.9±2.4	34.0±1.9	0.5	0.7
Forb cover (%)	4.9±0.8	4.8±0.6	0.2	0.8
Grass cover (%)	61.2±3.3	60.1±2.4	0.2	0.8

located approximately 40 km west of NPRC (White and Ralls 1993) and also smaller than the estimates of 6.7 km^2 and 4.8 km^2 from 2 areas located approximately 10 km north of NPRC (Spiegel et al. 1996). The mean core area size of 1.3 km^2 we observed was similar to the 1.3 km^2 reported by Spiegel et al. (1996) and the 1.2 km^2 reported by Zoellick et al. (in press). Despite annual variations in prey availability, neither White and Ralls (1993) nor Spiegel et al. (1996) observed annual variation in home range size, consistent with the Resource Dispersion Hypothesis proposed by MacDonald (1981). Our estimate of home range size was similar to the estimate of 4.6 km^2 reported for kit foxes at NPRC during 1984-85 when the primary item in fox diets was leporids (Zoellick et al. in press).

We attempted to explain observed differences in the sizes of home ranges and core areas of kit foxes on a given study area. However, home range and core area size for kit foxes at NPRC were not related to any of the environmental variables measured. In a study of kit foxes in Nevada, O'Neal et al. (1987) found a strong inverse relationship between home range size and total length of ravines within home ranges. The authors speculated that prey might be more abundant along ravines, and that foxes with more ravines within their home ranges required less space to obtain resources.

Our data did indicate that kit foxes used dry washes and roads more frequently than expected. Prey, particularly rodents, may have been more abundant in these areas (e.g., Williams 1985). Morrell (1972) reported that kit foxes were commonly observed hunting along washes. Also, kit foxes may use washes and roads as travel corridors. Other canids (e.g., gray wolves [*Canis lupus*], coyotes) commonly use roads for travel (Parker and Maxwell 1989, Paquet 1991). Most kit fox locations at NPRC also were in relatively gentle terrain with slopes <6°. Although kit foxes occasionally can use more rugged terrain, they may be more vulnerable to predation by larger predators in such areas and thus either avoid these areas or are excluded from them (Warrick and Cypher 1998). Relatively flat terrain previously has been identified as optimal for kit foxes in the San Joaquin Valley (Grinnell et al. 1937, Morrell 1972) and elsewhere (Egoscue 1962, Zoellick et al. 1989).

Kangaroo rats and leporids are both important prey items for San Joaquin kit foxes. Previous investigators reported a strong association between kit foxes and kangaroo rats (Grinnell et al. 1937, Laughrin 1970, Morrell 1972, Fisher 1981). Conversely, leporids were the primary prey of kit foxes in Utah (Egoscue 1962) and at a site 15 km east of NPRC (Knapp and Chesemore 1992). At NPRC, leporids were the primary prey used by kit foxes in the early 1980s, but use of kangaroo rats gradually increased

Table 2. Mean (±SE) abundance indices and frequency of occurrence in San Joaquin kit fox scats for kangaroo rats, leporids, and grasshoppers on 5 study sites at the Naval Petroleum Reserves in California, 1994. Values with the same letter within columns were not significantly different (P>0.05).

Area	Kangaroo rats		Leporids		Grasshoppers	
	Index	% occurence	Index	% occurrence	Index	% occurrence
1	3.71 ± 1.08 A	62.5 A	39.57 ± 5.87 A	12.5 A	0.50 ± 0.23 A	25.0 A
2	9.06 ± 0.98 B	61.5 A	3.12 ± 5.33 B	31.1 B	.059 ± 0.36 A	33.9 A
3	12.95 ± 0.88 C	67.4 A	22.33 ± 4.8 AB	1.1 B	0.15 ± 0.08 A	28.4 A
4	4.62 ± 1.12 B	83.3 A	2.15 ± 6.10 B	0.0 B	1.29 ± 0.76 A	12.5 B
5	5.75 ± 1.43 B	78.3 A	2.75 ± 7.77 B	0.0 B	0.75 ± 0.75 A	13.0 B

and they were the primary item used in the early 1990s (Cypher et al. 2000). Of interest is whether either of these 2 prey items is used preferentially, or whether use is proportional to availability and therefore opportunistic. Our data offer some insights on this issue. Use of leporids on all 5 study sites was always lower than use of kangaroo rats and varied with leporid abundance. Use of kangaroo rats did not vary with abundance indices, and importantly, kangaroo rat use remained consistently high regardless of leporid abundance. This suggests that kangaroo rats may have been used preferentially whereas leporids were a secondary item used more opportunistically. Throughout NPRC, use of kangaroo rats was consistently higher than use of leporids in the early 1990s when abundance of both items was increasing (Cypher et al. 2000).

Insects were frequently consumed by kit foxes, but usually comprised only a small proportion of the material found in each scat. Thus, frequency of occurrence in scats may overestimate the contribution of insects to kit fox diets. Insects may be consumed opportunistically while kit foxes are searching for other prey.

Habitat loss is the primary cause of endangerment of San Joaquin kit foxes, and habitat conservation is an important component of the current recovery strategy for these animals (U.S. Fish and Wildlife Service 1998). Our results indicate that areas with relatively gentle terrain and an abundance of kangaroo rats may provide favorable habitat conditions for San Joaquin kit foxes. Unprotected areas where such habitat conditions occur, particularly in large blocks, warrant targeting for conservation.

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