SAN JOAQUIN KIT FOX HOME RANGE, HABITAT USE, AND MOVEMENTS IN URBAN BAKERSFIELD

by

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ABSTRACT

San Joaquin kit fox home range, habitat use, and movements in urban Bakersfield

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Habitat destruction and fragmentation has led to the decline of the federally endangered and state threatened San Joaquin kit fox (*Vulpes macrotis mutica*). Kit foxes in the San Joaquin Valley occur in and adjacent to several urban areas. The urban kit fox population in Bakersfield has the potential to contribute to recovery efforts, however, little is known about habitat use in the urban environment. Habitat use in the urban landscape was examined in 28 radiocollared adult kit foxes between 1 May 1997 and 15 January 1998.

The area of the urban environment needed to meet kit foxes' ecological requirements varied among the sexes and fluctuated throughout the year. Mean home range size was 1.72 km^2 (100% minimum convex polygon estimate) and mean concentrated use area (core area; 50% fixed kernel estimate) size was 0.16 km^2. Females had a greater median number of core areas than did males, but core area size did not differ between the sexes. Mean home range size was significantly larger during the dispersal season than during the pair formation and breeding seasons. Home range size was greater for males than females during the breeding season.

To assess the extent to which kit foxes were concentrated around limited resources, the percentage of overlap between adjacent kit foxes' home ranges and core areas was determined. Mean home range overlap was greater than 71% for family group members and less than 16% for unrelated individuals, which was less than that reported for the nearby rural population. Overlap of adjacent kit foxes' core areas indicated that kit foxes were concentrated around key urban habitat patches. Core area overlap was greater for members of the same family group than core area overlap of neighboring males and females or neighboring males.

To determine which attributes of the urban environment were used by kit foxes and may support the population over time, habitats used disproportionately were compared to what was available in home ranges and the urban landscape. Kit foxes used open and sump (water catchment basins) habitats more than their availability in both the home range area and study area. There was more open and sump habitat in home ranges than in the study area. Kit fox core areas contained a disproportionately high amount of sumps that had food and den sites and restricted public access.

Sump and open habitats were more suitable for denning and consequently, were used more than their availability in the study area. Kit foxes primarily used subterranean dens but also used pipes and other man-made structures. Dens were located farther from roads than expected and in habitat patches that were larger than the median habitat patch in the study area.

To identify which urban habitats kit foxes used for resting, foraging, and traveling, kit fox movements and travel paths through adjacent habitat patches were examined. Kit foxes moved an average speed of 1.33 km/h. Minimum speed for females was greatest from approximately 0330 - 0730 h and for males was greatest from approximately 1830 - 2230 h. Kit foxes used sump and open habitats for resting. Kit foxes also foraged in these habitats, as well as in transition and commercial habitats. Habitats used for traveling included manicured open and open habitats, in which total distance traveled per movement session was longest. Overall median speed was greatest in residential habitat. Kit foxes were observed crossing roads and using culverts and bridges to move under roads.

Demographic characteristics and weights of the kit foxes that were captured were used to assess habitat quality. Two of the 28 radiocollared kit foxes died during 6,036 days of active radiotransmitters. Radiocollared kit foxes had 15 litters, comprised of 2.8 ± 0.45 (range = 1 – 7) pups. Urban kit fox weight was similar to that for rural kit foxes.

The availability of sump and open habitats appeared to shape the distribution and abundance of the urban population. Therefore, retaining sump and open habitats throughout Bakersfield may promote the continued existence of the urban kit fox population.

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INTRODUCTION

The kit fox (*Vulpes macrotis*) is the smallest North American member of the family Canidae, with an average weight of 2.1 kg for adult females and 2.3 kg for adult males in California (Morrell 1972). Kit foxes range throughout the western United States in shortgrass prairies and other arid areas (Whitaker 1998). The San Joaquin kit fox (*Vulpes macrotis mutica*; hereafter kit fox) was described by C. H. Merriam in 1902 (McGrew 1979) and is the largest California subspecies in skeletal measurements, body size, and weight (Grinnell et al. 1937). Kit foxes inhabit arid habitats with flat to sloping terrain (Morrell 1971).

The kit fox historically ranged in the San Joaquin Valley of California, north of Tracy, west to San Joaquin County, east to La Grange, Stanislaus County, and south to Kern County (Grinnell et al. 1937, Morrell 1975). In the early 1900's, the kit fox population started to decline (United States Fish and Wildlife Service 1983), and by 1930, its range had been reduced by more than half, with the largest portion remaining in the southern and western parts of the San Joaquin Valley (Grinnell et al. 1937). In 1969, the kit fox was known to range from Los Banos, Merced County, east to White River, Tulare County, south to Kern County, and west to San Luis Obispo County (Morrell 1975). Currently, the largest remaining populations of kit foxes occur in western Kern County and in the Carrizo Plain Natural Area, San Luis Obispo County (United States Fish and Wildlife Service 1998).

In 1967, the San Joaquin kit fox was listed as a federally endangered subspecies (United States Department of the Interior 1967), and in 1971, it was designated a State threatened species (United States Fish and Wildlife Service 1998). The destruction and fragmentation of its native habitat has been a limiting factor that has led to the decline of the kit fox population (Knapp 1978, Spiegel 1996, United States Fish and Wildlife Service 1998). This habitat fragmentation has been due mainly to agriculture, urban development, and oil production (Morrell 1975, Spiegel 1996, United States Fish and Wildlife Service 1998). In 1993, the San Joaquin Valley Biological Technical Committee estimated that only about 1 - 5% of the original habitat of the kit fox remained.

Kit foxes in the San Joaquin Valley occur in and adjacent to several urban areas including the cities of Taft (Zoellick et al. 2002), Tulare, Visalia, and Porterville (United States Fish and Wildlife Service 1998), and Bakersfield, where kit foxes have been observed throughout the city (Morrell 1975, Murphy 1992, Cypher and Warrick 1993, Bjurlin and Cypher 2003). Kit foxes are known to use the Kern River Parkway in Bakersfield (Murphy 1992, Beedy et al. 1992) for denning, foraging, and traveling, despite the fact that it is bounded on the north and south by urban and industrial development and receives intensive public recreation use (Beedy et al. 1992). Additionally, urban kit foxes have been found to den close to human activities and structures (Murphy 1992), including water sumps (catchment basins) in and adjacent to urban development in Bakersfield (Stafford and Murphy 1992).

Urban habitats may be marginal for kit foxes, because the urban environment has a high level of disturbance and consists of a patchy mosaic of habitats (Morrell 1975). While urban developments negatively impact kit fox habitat, kit foxes may still survive in or near them if there are adequate den sites and prey base (United States Fish and Wildlife Service 1998). Positive attributes of urban habitats may include a constant source of water from sumps, canals, and lawn sprinklers (Murphy 1992) that could lead to a more stable prey population. While fewer natural predators, such as coyotes (*Canis latrans*) and bobcats (*Lynx rufus*), are found in the urban environment, domestic dogs (*Canis familiaris*) occur in greater abundance. Food may be available on a more consistent basis due to the presence of refuse, which constitutes part of the kit fox diet in Bakersfield (Murphy 1992, Cypher and Warrick 1993). Such use of human-derived foods suggests that kit foxes may be able to adapt to the urban setting.

Smaller canid species, such as coyotes and foxes, often do well in human-altered environments because they scavenge and forage individually on a variety of small food items and are able to utilize new food sources (Kleiman and Brady 1978). If kit foxes are adaptable enough to persist in urban environments, as are coyotes (Quinn 1995, Romsos 1998, Grinder and Krausman 2001) and red foxes (*Vulpes vulpes*; Harris 1977, Kolb 1984, 1986, Harris and Rayner 1986, Doncaster et al. 1990, Lewis et al. 1993, Sallee 1998, Kamler and Ballard 2002), the urban kit fox population could contribute to recovery efforts (Cypher and Warrick 1993). Urban kit fox populations could protect against extirpations in rural areas, and serve as a source of animals for reintroduction efforts (Cypher and Frost 1999). Favorable habitat features in urban areas also could serve as linkages or corridors between natural lands, which may minimize local extinction and genetic isolation of fox populations in fragmented habitats (United States Fish and Wildlife Service 1998, Wandeler et al. 2003).

It is important to understand how kit foxes use landscapes in all areas where they exist, including urban settings. Unfortunately, little is known about the urban kit fox population. Morrell (1975) noted that a study should be conducted to gain a better understanding of kit fox ecology in areas other than natural habitat. As part of the recovery strategy in the San Joaquin Valley Multispecies Recovery Plan (United States Fish and Wildlife Service 1998), it was recommended that better demographic information be collected for kit foxes living in residential and industrial areas. The San Joaquin Valley Biological Technical Committee (1993) expressed concern that urbanization threatens the remaining kit fox habitat and listed several kit fox research needs including further studies of mortality rates and causes, diet, distribution, home range requirements, and movements. Due to the continual loss of natural habitat, more information on urban kit fox space use, movements, survival, and reproduction may contribute to their recovery (Cypher and Warrick 1993).

Canid home range size is influenced primarily by food abundance, and also food distribution and availability of adequate denning sites (Kleiman and Brady 1978). In order to understand the ecological factors that facilitate habitat use, it is important to identify the areas of concentrated use (hereafter core areas) within the home range (Samuel et al. 1985). Optimal habitat conditions for a species may be identified by evaluating if and how core areas are used disproportionately (Ables 1969). Core areas likely have dependable food sources and rest sites (Samuel et al. 1985) such as dens, the availability of which limits the presence of kit foxes (Golightly 1981, Spiegel et al. 1996). If kit foxes are concentrated around limited resources, the home ranges and core areas of adjacent kit foxes may have substantial overlap (Golightly 1981).

If sufficient food and den sites are available, mortality is minimal, and reproduction occurs at reasonable rates, then urban habitat should support viable kit fox populations. The goal of my project was to determine which attributes of the urban environment were successfully used by kit foxes and may support the population over time. To identify the attributes of the urban environment that kit foxes used most, areas and habitats used disproportionately were compared to what was available in the urban landscape. The quantity and type of urban habitat needed to meet the ecological requirements of urban kit foxes (i.e., that used for denning, foraging, and traveling) was identified. To understand habitat use, kit fox home range size, core area size, spatial distribution of kit foxes in the urban landscape, habitat and den use, and movements were evaluated in relation to habitat type, time of night, and human activity. Assessment of habitat quality should be based on the survival, reproduction, and density of the species occupying the habitat (Van Horne 1983). Therefore, I also reported the demographic characteristics of captured urban kit foxes.

STUDY AREA

The study was conducted within the city limits of Bakersfield (Figure 1), at the southern end of the San Joaquin Valley, California. The average elevation of Bakersfield was 124 m (United States Geological Survey 1981) and in 1997, had a human population of 221,700 (State of California, Department of Finance 2002).

Bakersfield has an arid climate with an average annual precipitation of 14.5 cm (National Oceanic and Atmospheric Administration 1997) that occurs mainly between October and April. Total precipitation during the study was 10.9 cm, 3.0 cm higher than normal (Meadows Field Weather Station; National Oceanic and Atmospheric Administration 1997, National Oceanic and Atmospheric Administration 1998). Summers are hot and dry, while winters are cool and moist. During the study, average temperatures ranged from 7.9° C in December to 27.2° C in July and annual mean temperature was 19.6° C, which was -14.3° C lower than normal (Meadows Field Weather Station; National Oceanic and Atmospheric Administration 1997, National Oceanic and Atmospheric Administration 1998).

Vegetation in the study area varied by land use and was composed mostly of introduced and exotic species. Manicured open, commercial, and residential habitats were planted mainly with non-native grasses and shrubs (Table 1). Conversely, open, industrial, and some linear habitats, such as the Kern River Parkway, had a mix of introduced and endemic grasses, forbs, and shrubs. Sumps were primarily barren on the sides, often contained standing water, and had scattered native and non-native vegetation near the upper edges. In addition, sumps were distributed throughout the city, fenced, and closed to the public. Sumps had sloping sides and ranged from 0.01 to 0.03 km^2 in area.

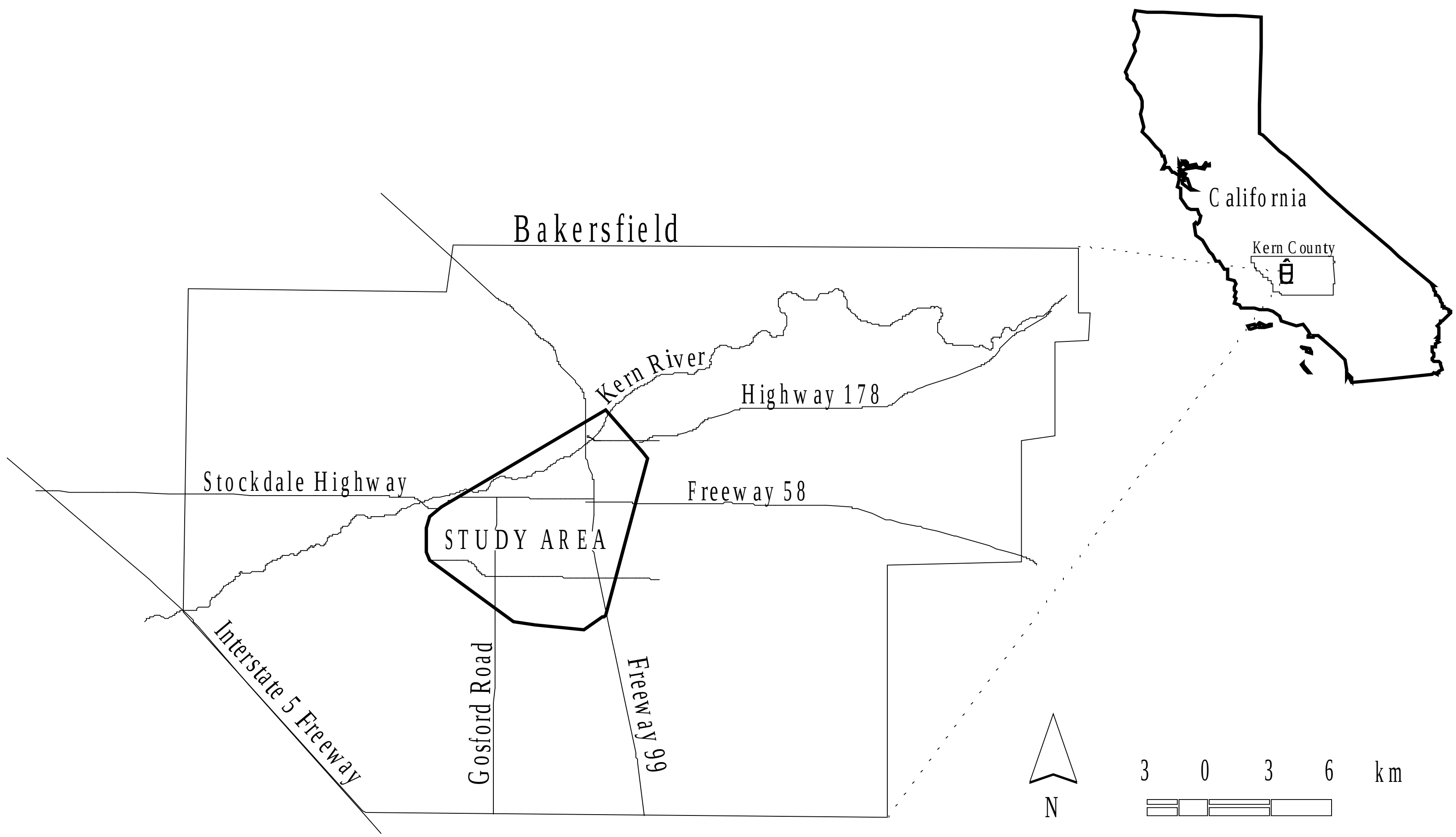

Figure 1. The study area in Bakersfield, Kern County, California for investigations of kit fox habitat use from May 1997 to January 1998.

Table 1. Habitat types and their descriptions used to typify the urban setting and kit fox habitat use in Bakersfield, California from May 1997 to January 1998.

Habitat type	Description
Commercial	Office buildings, hotels, medical facilities, and their associated parking areas.
Transition	Areas in which residential, commercial, or industrial construction is in progress or has recently been completed.
Industrial	Areas of industrial use not generally open to the public, such as manufacturing plants and shipping yards.
Linear	Kern River Parkway, canals, roads, railroads, and highway and power line right-of-ways.
Manicured Open	Parks, schools, and golf courses.
Open	Vacant lots and fallow agricultural fields.
Residential	Apartments and single-family housing developments.
Sumps	Water catchment basins used to contain urban run-off and rainwater.

Kit fox predators, including bobcat, coyote, and domestic dog (Cypher et al. 2000), were observed at the study site. Bobcats and coyotes were only observed in the Kern River Parkway (personal observation). California ground squirrel (*Spermophilus beecheyi*), Botta's pocket gopher (*Thomomys bottae*), and desert cottontail (*Sylvilagus audubonii*) (all urban kit fox prey; Cypher and Warrick 1993), were observed at the study site. Domestic cats (*Felis catus*) and opossums (*Didelphis virginiana*), which utilize some of the same food resources as urban kit foxes and red foxes, were observed in the study area (Catling 1988, Golightly et al. 1994, Read and Bowen 2001) (Appendix A).

METHODS

Trapping

Between 3 May and 18 July 1997, wire-mesh live-traps (38 x 38 x 107 cm; Model 208, Tomahawk Live Trap Company, Tomahawk, WI) were set in sumps, parks, the Kern River Parkway, and privately-owned land in Bakersfield. Traps were covered with canvas tarps to protect captured animals from sun and inclement weather, and baited with canned mackerel. Trapping frequency and trap placement was opportunistic. The trapping was limited to areas in southwest Bakersfield where kit foxes or their sign (i.e., tracks, scat, and dens) were observed.

Captured kit foxes were transferred from traps to heavy cloth bags for handling. Each animal was sexed, eartagged, weighed ($\pm$ 3%), measured ($\pm$ 1 mm; right ear and hind foot length), and released at the capture location. Uniquely-numbered metal eartags (Model 1005-4, National Band and Tag Company, Newport, KY) were affixed to the right ear for females and left ear for males. Kit foxes were aged based tooth eruption and wear (Harris 1978). Individuals with partially erupted teeth were classified as juvenile, and those with permanent teeth were classified as adults. Young of the year were classified as puppies until 14 July, and subadults from 15 July to 30 November, after which they were considered to be adults.

Locations

I attached 50-g collar-mounted radiotransmitters (Model 80, Telonics, Mesa, AZ) to captured adults. Radiocollars were equipped with mortality sensors that pulsed approximately twice the normal rate if there was no movement for four hours. Between 14 December 1997 and 15 January 1998, all but four study animals were captured and had their radiocollars removed.

Radiocollared kit foxes were located using portable receivers (Model TR-4, Telonics, Mesa, AZ), an omni-directional antenna affixed to a car, and a hand-held 2-element yagi antenna. Kit foxes were located between 1630 and 0900 h because they were primarily active at night (Egoscue 1956, Golightly 1981, White et al. 2000). At the onset of the study in May 1997, nine study animals were randomly monitored to verify that they were not active during daylight hours. With the exception of delineating the study area, only locations obtained between one hour before sunset and one hour after sunrise were used in analyses. Each kit fox was systematically located approximately once per night (hereafter referred to as daily locations) but rotated in the schedule each night. Although sampling effort for each study animal was equal at study end, every kit fox could not be found during each sampling period. When a kit fox could not be found, the area where it was previously located was searched for at least 30 min and then, if not located, it was searched for elsewhere in the study area concurrent with searches for other kit foxes.

The transmitted signal was followed until the kit fox was observed (sometimes with the aid of a flashlight) or tracked to a den, or the habitat patch from which the signal was emitted was encircled (White and Garrott 1990). This technique ensured that the location of and habitat used by each kit fox was classified without error (Samuel and Kenow 1992). I tried to stay at least 100 m from the study animals, so as to not alter their behavior (i.e., cause them to move from one habitat patch to another). To assess if this technique created a sampling bias by altering their behavior, each animal was classified as resting/walking, trotting, or running at the time of observation. When this technique was not feasible (e.g., the habitat patch was not accessible), kit fox locations were determined with triangulation, based on three bearings taken as close as possible ($\leq$ 300 m) from the loudest signal source (Springer 1979). Immediately after a kit fox was located, the observer plotted the location on a 1996 City of Bakersfield street map (scale 1:29,000, Compass Maps, Inc., Modesto, CA) and recorded the number of people that were visible (i.e., not in buildings or large habitat patches) in the same habitat patch as the kit fox.

Mapped kit fox locations were digitized into a geographic information system (GIS; ArcView 3.2 with Spatial Analyst 2.0, ESRI, Redlands, CA), and displayed over the City of Bakersfield's 1997 GIS file titled "Land Status Land Condition Land-use," as a background for guidance during digitizing. This GIS file was developed through the input of bearing and distance measurements (taken by land surveyors) to define parcel boundaries (i.e., the coordinate geometry method; Amos, R. 2005. Personal communication. City of Bakersfield, GIS Department, 1501 Truxtun Avenue, Bakersfield, CA 93301). Using methods in Romsos (1998), I characterized the urban landscape and described urban kit fox habitat use by collapsing similar urban landscapes into eight categories (Table 1).

To verify the accuracy of the habitat types and boundaries depicted in the GIS, maps generated from the GIS were compared to the actual location of habitat patches throughout the study area. When habitat was not correctly represented in the GIS, a global positioning system (GPS Pathfinder Pro XR, Trimble, Sunnyvale, CA) was used to obtain the geographic coordinates of the edges of each habitat patch. These coordinate data were differentially corrected using the GPS Pathfinder Office program to improve accuracy to within ± 1 m, imported into the GIS, and used to digitize polygons representing the correct habitat patches.

The accuracy of the habitat types and boundaries depicted in the GIS was further verified by comparison to aerial photographs (Farm Services Agency, USDA, Bakersfield, CA) of the study area that were photographed in June 1997, at the beginning of the study, and in June 1998, after the study concluded. This comparison was done primarily to identify habitats that were classified as open in 1997 but were in transition or residential in 1998. In these instances, the date each house was built was determined by consulting Kern County public records data. Any habitat patch that was open in the June 1997 aerial photograph, on which a house was built prior to the end of the study, was classified as transition habitat.

Home Range

Home range estimates were obtained using the GIS to generate the 100% minimum convex polygon, which defined the bounds of the area used (Mohr 1947, Hooge and Eichenlaub 1997). Use of kernel-based estimators may be important to identify disjunct areas of activity in urban landscapes where habitat may be fragmented (Grinder and Krausman 2001). For comparison to other urban canid studies (Romsos 1998, Grinder and Krausman 2001), home range was also estimated using the 95% fixed kernel, a probabilistic model that identified the most probable area of utilization (Worton 1989, Seaman and Powell 1996). To represent the core area for each study animal, I used the 50% fixed kernel, which identified the areas that encompassed 50% of the animal's locations (Calhoun and Casby 1958, Jennrich and Turner 1969, Anderson 1982). Large bodies of water (e.g., Lake Truxtun) were removed from the estimates of home range area and available habitat (White and Garrott 1990).

Probabilistic home range techniques (e.g., fixed kernel) are sensitive to serial autocorrelation (Anderson 1982, Hooge et al. 1999). The minimum convex polygon home range estimator assumes that location data are not time correlated (Anderson 1982, White and Garrott 1990), but are robust to violation of this assumption. Only statistically independent data (i.e., the data point provided no indication of the category for the next data point) were used to estimate home range and core area size. Time to statistical independence between successive locations was based on the time it took each kit fox to cross its home range (White and Garrott 1990, Lucherini et al. 1995, Harrison 1997). To derive this estimate, I divided the mean speed for each of 10 kit foxes that were located approximately every 15 - 30 min during two to six 3 - 5 h movement sessions (hereafter referred to as sequential locations), by the longest axis of their 100% minimum convex polygon home range (Jenness 2003).

Area-observation curves were used to determine the minimum number of kit fox locations necessary for home range estimation (Odum and Kuenzler 1955). To do so, I iteratively estimated the 100% minimum convex polygon home range for each kit fox, beginning with the first 10 locations and adding one consecutive location at a time. The area of each 100% minimum convex polygon was plotted against the number of locations from which it was estimated. The point on the curve at which each 10 additional locations did not increase the home range estimate by 10% was the minimum number of locations needed to estimate home range.

Because home range size may vary with sex (Burt 1943), a 2-sample t-test was used to determine if home range size differed between males and females (Hintze 1999). For comparison to rural kit fox studies in Arizona (Golightly 1981) and California (Zoellick et al. 1987, White and Ralls 1993, Koopman 1995), the 100% minimum convex polygon home range estimate was used for this analysis. All data were checked for normality and equal variance, and data that could not be normalized by transformation were analyzed with non-parametric tests. Significance level (α) was 0.05.

Home range size may also vary by season (Burt 1943). To assess if the area of the urban environment needed to meet kit foxes' ecological requirements fluctuated throughout the year, I determined if home range size varied with biological season for urban kit foxes, as it did for rural kit foxes (Zoellick et al. 1987). Because kernel-based estimates from small sample sizes (e.g., from subsetting the data by season) tend to overestimate home range sizes (Seaman and Powell 1996), seasonal home ranges were estimated using 100% minimum convex polygons, which is more robust than other techniques when sample size is small (Harris et al. 1990). Data were normalized with a square-root transformation and analyzed with a 2-way analysis of variance (Winer et al. 1991, Hintze 1999) to compare mean home range size for male and female kit foxes during three biological seasons: dispersal (1 June to 30 September); pair formation (1 October to 30 November); and breeding (1 December to 15 February; Zoellick et al. 1987, Reese et al. 1992, Koopman et al. 1998). A Fisher's least significant difference multiple comparison test (Hintze 1999) was used to determine what factors (i.e., season and sex) in the analysis of variance were significantly different. Study animals were located too seldom to estimate home range during the pup rearing season (16 February to 31 May).

The presence of food-rich habitat patches within territories may allow additional group members. Macdonald (1983) predicted that the home range of a mated pair of red foxes may overlap and support other foxes if there were sufficient resources. However, if food is evenly-dispersed among habitat patches, a larger home range would be required and the tolerance of additional adults in the territory of a pair would be predicted to be less. I predicted that if kit foxes were concentrated around limited resources, home ranges and core areas of adjacent kit foxes would have a high percentage of overlap. The GIS was used to identify the percentage of overlap between a) adjacent 100% minimum convex polygon home ranges and b) adjacent core area polygons between kit fox pairs comprised of a) mated pairs or family groups, b) adjacent females, c) adjacent males, and d) adjacent but unpaired males and females.

It was assumed that habitats that were used disproportionately more than available contained key resources. To assess if habitats with key resources (i.e., denning and foraging sites) were equally-dispersed or conversely, concentrated, the mean percentage of area of each 100% minimum convex polygon that the core area represented was determined. If areas of habitat use were concentrated, then the 50% fixed kernel should encompass less than 50% of the area used by each kit fox. If areas of use were uniform rather than concentrated, the 50% fixed kernel would comprise half of the area within the 100% minimum convex polygon. To assess if use of key resources differed among the sexes, the median number of core areas for females and males was compared with a Mann-Whitney U-test, and the mean core area size for males and females was compared with a 2-sample t-test.

Habitat Use

For those kit fox locations determined from triangulation, the likelihood for habitat misclassification increased with animal proximity to habitat edge and decreased as habitat-patch size increased (Samuel and Kenow 1992). To assess the probability of habitat misclassification, the GIS was used to determine the distance between each triangulated location and the nearest habitat-patch edge (Jenness 2004a). I reasoned that triangulated kit fox locations less than 100 m from the nearest habitat-patch edge may have had misclassification of habitat type. The 100 m value was selected because urban coyote studies that used similar methods to study habitat use, had average telemetry errors of 46 m (Grinder and Krausman 2001) and 102 m (Romsos 1998).

Use of habitat is considered selective if it is exploited disproportional to its availability (Johnson 1980). Habitat selection can occur at a variety of scales (Wiens 1973, Orians and Wittenberger 1991, Litvaitis et al. 1996, Apps et al. 2001). I analyzed habitat use within the individual kit fox home range and core area and for the kit fox population in the study area. To determine if kit foxes used urban habitat types (Table 1) with a frequency proportional to their availability, the independent locations that fell within a) the study area and b) each home range were selected. To delineate the study area, a 100% minimum convex polygon was generated using all daily, sequential, and trapping locations for all study animals (Litvaitis et al. 1996, Romsos 1998, Kamler et al. 2003). For comparison to other urban canid habitat use studies (Romsos 1998, Grinder and Krausman 2001), the 95% fixed kernel was used to represent the home range of each kit fox. The area of each habitat type in the study area and each home range was summed, and use of habitat types in each was compared with a Friedman's test (Alldredge and Ratti 1986, Hintze 1999; individual kit fox was the blocking factor, habitat type was the treatment factor, and the ranked numerical difference between the proportion of habitat used and the proportion of habitat available was the response variable). To determine which habitat types were used significantly more than their availability, a Fisher's least significant difference procedure (Alldredge and Ratti 1986, Hintze 1999) was used.

How kit foxes used urban habitats was determined at two scales: within each home range in proportion to what was available in the study area; and within each core area in proportion to what was available in the corresponding home range. For each habitat type, I compared the proportion a) within each home range and the study area and b) within each core area and corresponding home range. Prior to analysis, the proportion data were arcsine transformed (Winer et al. 1991) and analyzed with a matched-pair t-test, or a Wilcoxon signed-rank test if data could not be normalized (Hintze 1999).

Fox habitat use may also be influenced by human presence (Lucherini et al. 1995); therefore, I treated human activity as an attribute of habitat. After each kit fox was located, an index of human activity was gained by counting the number of vehicles and pedestrians that passed by an imaginary line that was perpendicular to the nearest road in a 15 second period. The number of people that were visible (i.e., not in buildings or large habitat patches) in the same habitat patch as the kit fox was also recorded. To determine if human activity (i.e., the number of passing vehicles, passing pedestrians, and people in the same habitat patch as the kit fox) varied among the habitat types, a Kruskal-Wallis 1-way analysis of variance was used, followed by a Kruskal-Wallis multiple comparison test to determine what factors in the analysis of variance were significantly different.

Relative to some rural landscapes that have uniformly-distributed resources (Koopman 1995, Kamler et al. 2004), urban landscapes are highly fragmented, have isolated, clumped resources (Grinder and Krausman 2001), and consist of a patchy mosaic of habitats (Morrell 1975). Some urban habitats may be more suitable for denning and consequently, are used more than their availability in the study area. If certain habitats were selected for denning, the spatial arrangement of home ranges would be influenced by the availability of the selected habitat types (Golightly 1981, Hardenbrook 1987).

The geographic coordinates of each den (i.e., refugia receiving repeated use by the study animals) were determined using a GPS and imported into the GIS. Dens were categorized as subterranean, culvert (or pipe), or man-made structure. To understand if den sites influenced habitat use, a 1-proportion z-test (Winer et al. 1991, Hintze 1999) was used to determine if habitats were used for denning in proportion to their availability in the study area.

Using the GIS, I generated random points (with a uniform distribution) equivalent to the number of dens in the study area (Hooge and Eichenlaub 1997). To assess if road proximity influenced den locations, the GIS was used to determine the distance of each den and random point to the centerline of the nearest road (Jenness 2004a). A Mann-Whitney U-test was used to determine if den sites and random points differed with regard to distance to the nearest road. A Wilcoxon signed-rank test was used to determine if the median size of habitat patches within which dens were located differed from the median habitat-patch size in the study area.

Movements

Canid movement behavior may indicate use of habitat for resting, foraging, and traveling (Ozoga and Harger 1966, Laundré and Keller 1981, Romsos 1998). Between 8 September 1997 and 7 January 1998, a randomly-selected subsample (five females and five males) of radiocollared kit foxes was examined for movements and travel paths through adjacent habitat patches in order to identify which behaviors were associated with each habitat type. Based on behavior-specific movement types for canids in Ozoga and Harger (1966) and Laundré and Keller (1981), I categorized kit fox movement as resting/walking (i.e., inactivity at low speeds between 0 - 0.8 km/h), trotting (i.e., potentially searching for food at intermediate speeds between 0.8 - 1.8 km/h), and running (i.e., traveling from one point to another at high speeds greater than 1.8

km/h). Movements were assessed during three nocturnal sampling periods, approximately 1830 - 2230 h, 2230 - 0330 h, and 0330 - 0730 h. Each kit fox was followed two to six times during each of the three sampling periods.

While following kit foxes, sequential locations were determined approximately every 15 - 30 min during the sampling period. Movement sessions with more than one hour between any two successive locations were deemed incomplete and repeated on another day. The locations identified during each movement session were plotted on a 1996 City of Bakersfield street map (scale 1:29,000, Compass Maps, Inc., Modesto, CA). Time, habitat type, kit fox activity (e.g., resting/walking, trotting, running), and number of passing vehicles, passing pedestrians, and people in the same habitat patch as the kit fox were recorded.

GIS was used to digitize kit fox locations and generate a line from the set of sequential location points for each movement session. Each line was then intersected with the habitat types through which it passed (Jenness 2004b). Kit fox speed (the distance between two sequential locations divided by the time elapsed) was regressed against the number of passing vehicles, passing pedestrians, and people in the same habitat patch to examine the influence of humans on kit fox habitat use. A multivariate analysis of variance was used to determine if sex and movement session time influenced minimum travel speed, maximum speed, mean speed (using all speed estimates except when the kit fox was at a den or resting), and total distance moved per movement session (Woodruff and Keller 1982). Because movement session length varied, total distance moved was standardized by multiplying the distance measure by the ratio of 1) the length of time elapsed during the shortest movement session to 2) the length of time elapsed during the movement session with which the distance measure was associated.

To determine if total distance moved per movement session varied by habitat type, I used a Kruskal-Wallis 1-way analysis of variance (Zoellick et al. 1989). A Kruskal-Wallis 1-way analysis of variance was used to determine if overall median speed was influenced by habitat type. Kruskal-Wallis multiple comparison tests were used to determine what factors in these analysis of variance tests were significantly different.

A loglinear model was used to examine correlations between type of movement, frequency of relocations per habitat type, and time of movement session. To identify the habitat type and movement session (i.e., evening, middle of the night, and early morning) within which kit foxes rested/walked, trotted, and ran, standardized residuals were used to identify the greatest deviations from expected for kit fox movements.

Demographics

Reproduction and mortality in radiocollared kit foxes were measured to determine if demographic parameters of urban kit fox populations were similar to those for rural kit fox populations, and assess habitat quality in the urban landscape (Van Horne 1983). Kit foxes with a radiocollar in a mortality mode were immediately located and necropsied to assess cause of death. This information was used to determine sources and rates of kit fox mortality, which were compared to data for rural kit fox populations. I determined the number of radio-days since each kit fox was radiocollared and the survival rate for that time interval, described by Heisey and Fuller (1985) as the interval survival rate. Paired tooth puncture wounds associated with subcutaneous hematomas on the carcass were indicative of a predator kill, and if the carcass exhibited massive trauma and was located near a road, the cause of death was determined to be vehicular impact (Spiegel and Disney 1996).

The number of pups incidentally trapped or observed with radiocollared adult kit foxes and their mates were identified. Additionally, as part of a concurrent study (Storlie 1998) of juvenile kit fox dispersal and mortality, trapping effort was conducted in areas where pups were captured or observed. Capture data from both studies were used to estimate litter size for kit foxes in the study area. The annual reproductive success rate was based on the percentage of radiocollared females that produced pups.

RESULTS

Trapping

Between 1 May 1997 and 15 January 1998, 107 (30 adult males, 31 adult females, and 46 juveniles) kit foxes were captured in all habitat types in which traps were placed (Appendix A). Mean adult kit fox weight was 2.47 $\pm$ 0.05 ($\bar{x} \pm 1$ SE) kg for males and 2.16 $\pm$ 0.03 kg for females.

Locations

Radiocollars were attached to 28 adults (13 males, 15 females). Each radiocollared kit fox was located 5.1 $\pm$ 0.3 days each week. Of the 35 kit foxes located between 0900 and 1600 h, 34 were stationary (e.g., resting) or in a den. In 252 study days, a total of 1,882 sequential locations (during 111 movement sessions) and 4,824 daily locations were determined for the 28 study animals. Of these locations, 4,249 were independent, of which 2,898 (68%) were considered to be exact and the habitat types in which they occurred were correctly classified, based on being tracked to a den (n = 811) or directly observed (n = 2,087). Directly observed kit foxes were classified as stationary for 52% of the observations (Figure 2). Of the 1,351 triangulated locations, 66 were $\geq$ 100 m from the nearest habitat-patch edge. The remaining locations were on average 31.3 $\pm$ 0.6 m from the nearest habitat-patch edge.

Home Range

Based on the area-observation curves (Odum and Kuenzler 1955; Appendix D), the average number of locations needed to estimate a 100% minimum convex polygon home range was 27 $\pm$ 1.7. All sequentially-located kit foxes could cross the longest axis of their 100%

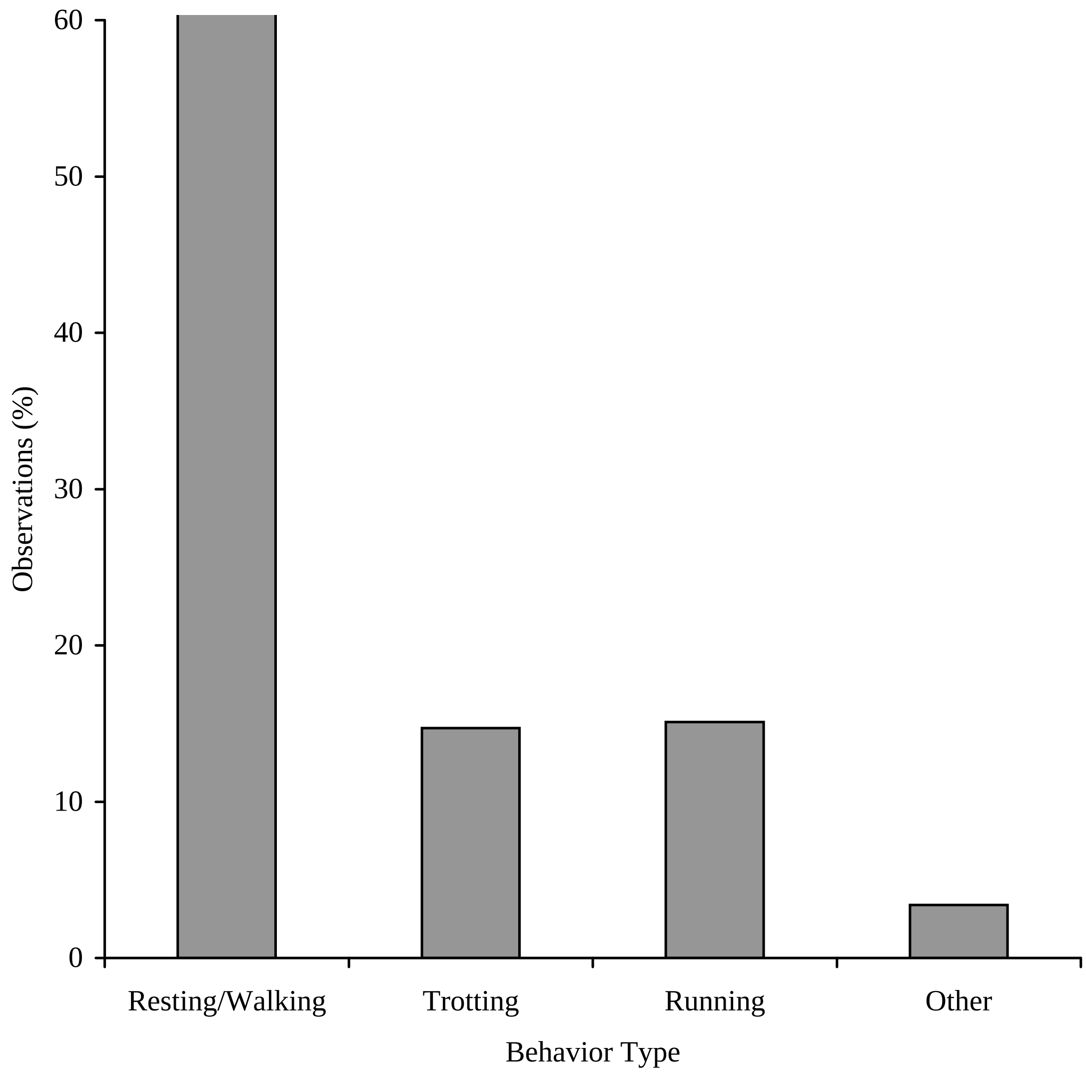

Figure 2. Behavior exhibited by directly observed kit foxes at independent daily locations (n = 2,087) in Bakersfield, California from May 1997 to January 1998.

minimum convex polygon home range in less than four hours (range = 1.23 - 3.89 h; Appendix B). Therefore, four hours was used as the time to independence between kit fox locations.

The 100% minimum convex polygon home range size for all study animals combined was 1.72 ± 0.19 km^2 and was larger for males than females (Table 2). Average 95% fixed kernel home range size for all study animals combined (excluding one outlier) was 1.2 ± 0.19 km^2 (range = 0.04 – 2.78). Excluding one outlier, core areas comprised 9.1 ± 1.2% (range = 1.9 – 19.6) of the 100% minimum convex polygon home range. Kit foxes had an average of 2.15 ± 0.23 distinct core areas, and females had more than males. Mean 100% minimum convex polygon home range size was significantly larger during the dispersal season than during the pair formation and breeding seasons ($F = 7.79$, $df = 2$, $p < 0.001$) and for males than females during the breeding season ($F = 4.47$, $df = 1$, $p = 0.04$), and there was no interaction between season and sex ($F = 2.38$, $df = 2$, $p = 0.1$) (Table 3). The percentage of home range and core area overlap between kit foxes was highest for family group members (Figure 3).

Habitat Use

The study area was 76 km^2, and had 3,908 habitat patches that averaged 0.01 ± 0.001 km^2 (range was < 0.01 - 2.03, except for a 17.88 km^2 patch that comprised all interconnecting linear features that was excluded from this calculation). Kit foxes used urban habitats disproportionate to their availability in the study area ($Q = 103.5$, $df = 7$, $p < 0.001$) and within home ranges ($Q = 91.36$, $df = 7$, $p < 0.001$; Figure 4). Open and sump habitats were used more than their availability in both the study area and in home ranges (Table 4). There was less area of residential habitat but more area of open and sump habitats in home ranges than in the study area. Area of transition, commercial, manicured open, linear, and residential habitats were less, but area of sump habitat was greater, in core areas than in home ranges (Table 5).

Table 2. Home range (100% minimum convex polygon) and core area (50% fixed kernel) size for radiocollared kit foxes in Bakersfield, California from May 1997 to January 1998.

	All			Males			Females			Males vs. Females		
Measurement	$\bar{x}$	SE	Range	$\bar{x}$	SE	Range	$\bar{x}$	SE	Range	Statistic	df	p
Home range size (km^2)	1.72	0.19	0.31 - 4.49	2.12	0.31	0.31 - 4.49	1.36	0.21	0.36 - 2.71	t = -2.08	25	0.02
Core area size (km^2)	0.16[a]	0.03	0.01 - 0.5	0.18	0.05	0.01 - 0.5	0.15	0.04	0.02 - 0.43	t = -0.57	24	0.57
Core areas per kit fox	2.15	0.23	1 – 6	1.85	0.37	1 - 6	2.43	0.27	1 - 4	z = -1.98	25	0.02

[a] Excluding one outlier (the male with two distinct home ranges).

Table 3. Seasonal home range (100% minimum convex polygon) size for radiocollared kit foxes in Bakersfield, California from May 1997 to January 1998.

	Home range (km^2)					
	All		Males		Females	
Season	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Dispersal	1.24	0.11	1.32	0.16	1.17	0.15
Pair formation	0.77	0.11	0.79	0.16	0.74	0.16
Breeding	0.66	0.12	0.95	0.16	0.38	0.16

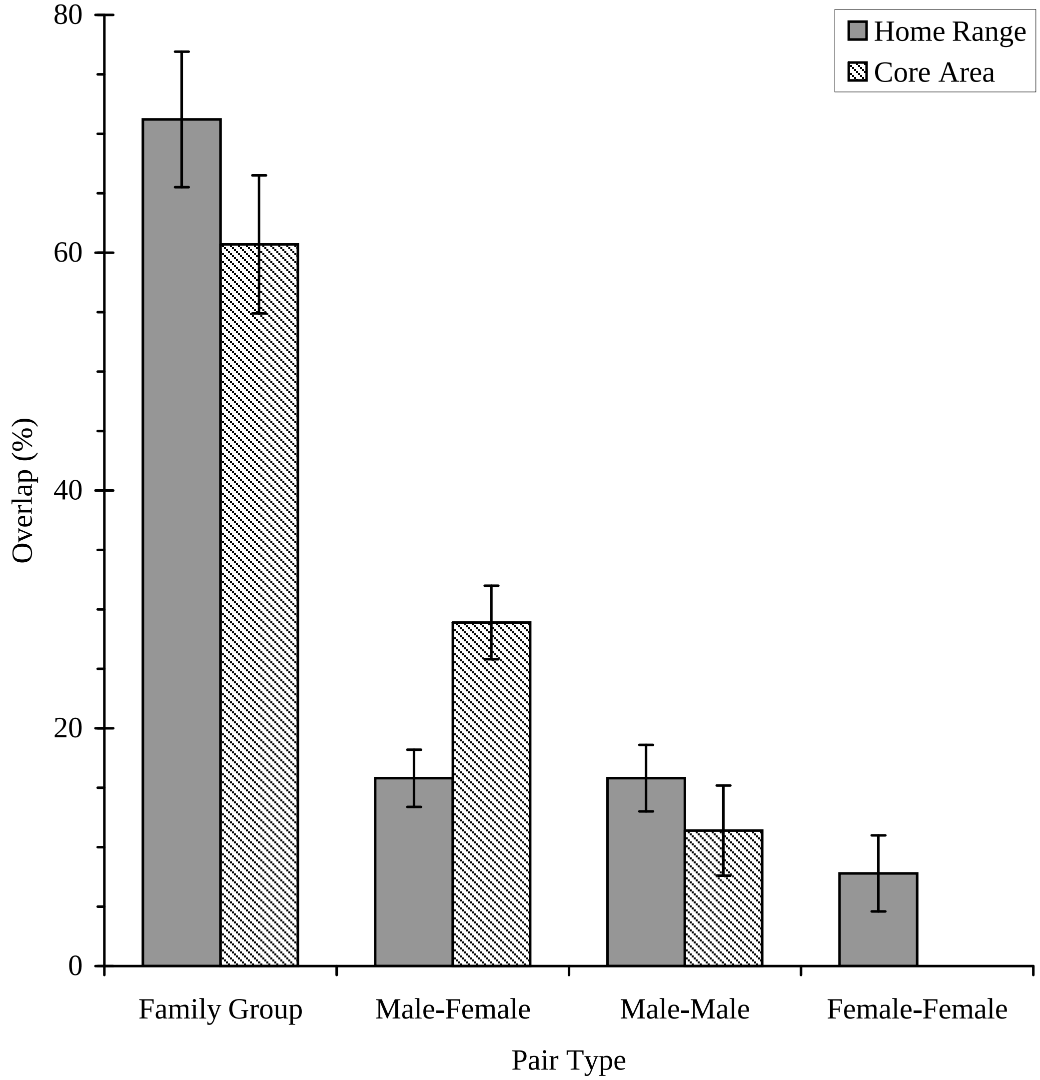

Figure 3. Percentage of home range overlap and core area overlap for pairs of radiocollared kit foxes in Bakersfield, California from May 1997 to January 1998. Vertical bars represent ± 1 SE.

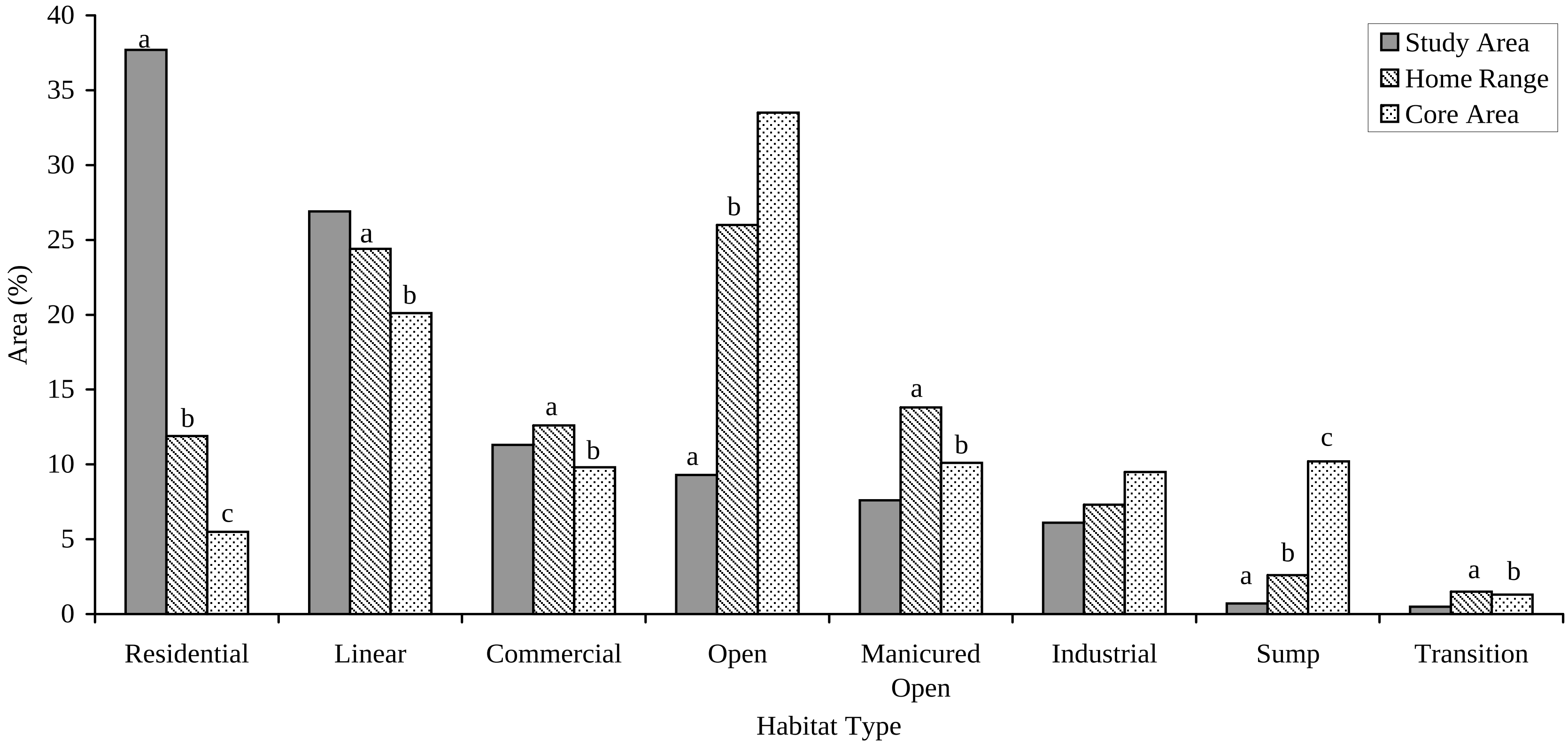

Figure 4. Mean percentage of each habitat type in the study area, which bounded the available habitat, and radiocollared kit fox home ranges (n = 27) and core areas (n = 58) in Bakersfield, California from May 1997 to January 1998. Different letters above the bars indicate a significant difference in habitat use versus availability.

Table 4. Ranked radiocollared kit fox habitat use based on habitat availability at the study area and home range area scale, in Bakersfield, California between May 1997 to January 1998. Habitat types used similarly ($p > 0.05$) are grouped by column.

Study Area					Home Range					
Habitat Types Statistically Similar in Use				Mean Rank	Habitat Types Statistically Similar in Use				Mean Rank	Rank of Use
Open				2.1	Sump				2.3	Most
Sump				2.6	Open				2.5	↑
	Transition			4.0		Transition			3.5	
	Industrial			4.0		Industrial			3.9	
	Manicured Open			4.4			Manicured Open		5.3	
		Commercial		5.4			Commercial	Commercial	5.8	
		Linear		5.6			Linear	Linear	6.2	
			Residential	7.8				Residential	6.6	Least

Table 5. Mean difference between the mean proportion of habitat available in the study area and kit fox home ranges (e.g., there was 16.7% less open habitat in the study area than within home ranges), and kit fox home ranges and core areas in Bakersfield, California between May 1997 to January 1998.

	Study Area and Home Range			Home Range and Core Area		
Habitat Type	Percent Difference	Statistic	p[a]	Percent Difference	Statistic	p[b]
Commercial	-1.3	t = 0.89	0.38	2.8	t = -2.79	<0.01
Industrial	-1.2	z = 1.43	0.15	-2.2	z = 0.05	0.47
Linear	2.5	t = 1.47	0.15	4.3	z = -2.25	0.01
Manicured Open	-6.2	t = -0.59	0.56	3.7	z = -1.77	0.02
Open	-16.7	t = -3.83	<0.01	-7.5	t = 1.46	0.16
Residential	25.8	z = 4.52	<0.01	6.4	t = -5.5	<0.01
Sump	-1.9	z = -2.88	<0.01	-7.6	z = 2.19	0.01
Transition	-1.0	t = -0.66	0.51	0.2	t = -2.30	0.01

[a,b] Because the analysis used multiple t-tests, the probability of at least one false rejection of the null hypothesis was $1 - 0.95^8 = 0.34$ (Winer et al. 1991).

Number of people in the same habitat patch as the kit fox varied between habitat types and was greatest in manicured open habitat (H = 285.7, df = 7, p < 0.001; Figure 5). Industrial and linear habitats had a higher incidence of passing vehicles than all other habitats (H = 355.1, df = 7, p < 0.001; Figure 5). A greater number of pedestrians were observed along roads near sumps than all other habitats (H = 136.8, df = 7, p < 0.001; Figure 5).

The study animals used 190 dens, comprised of 159 subterranean dens, 17 culvert or pipe dens, and 14 man-made structure dens (e.g., metal storage containers, modular office buildings, junkyard debris, a shed, and a garbage dumpster), most of which were located in open, sump, and linear habitats (Figure 6). Sump (z = 45.74, df = 1, p < 0.001) and open (z = 11.47, df = 1, p < 0.001) habitats were used for denning more than their availability in the study area (Figure 7). Residential (z = -10.5, df = 1, p < 0.001) and commercial (z = -3.67, df = 1, p < 0.001) habitats were used for denning less than their availability in the study area. Linear (z = -1.24, df = 1, p = 0.19), manicured open (z = -0.53, df = 1, p = 0.59), industrial (z = -0.3, df = 1, p = 0.76), and transition (z = -0.45, df = 1, p = 1.0) habitats were used for denning in proportion to their availability in the study area.

Dens were located farther from roads (0.10 + 0.01 km, range = 0.01 - 0.5) than randomly-generated points (0.06 + 0.01 km, range = 0.0001 - 0.55; z = 8.17, df = 378, p < 0.001). The median size of habitat patches within which dens were located (0.03 km2) was significantly larger than the median habitat-patch size in the study area (0.004 km2; z = 10.56, df = 1, p < 0.001).

Movements

Movement sessions (n = 100) lasted from 184 to 315 min long. Kit foxes moved at an average rate of 1.33 ± 0.02 km/h. Minimum speed during each movement session was influenced

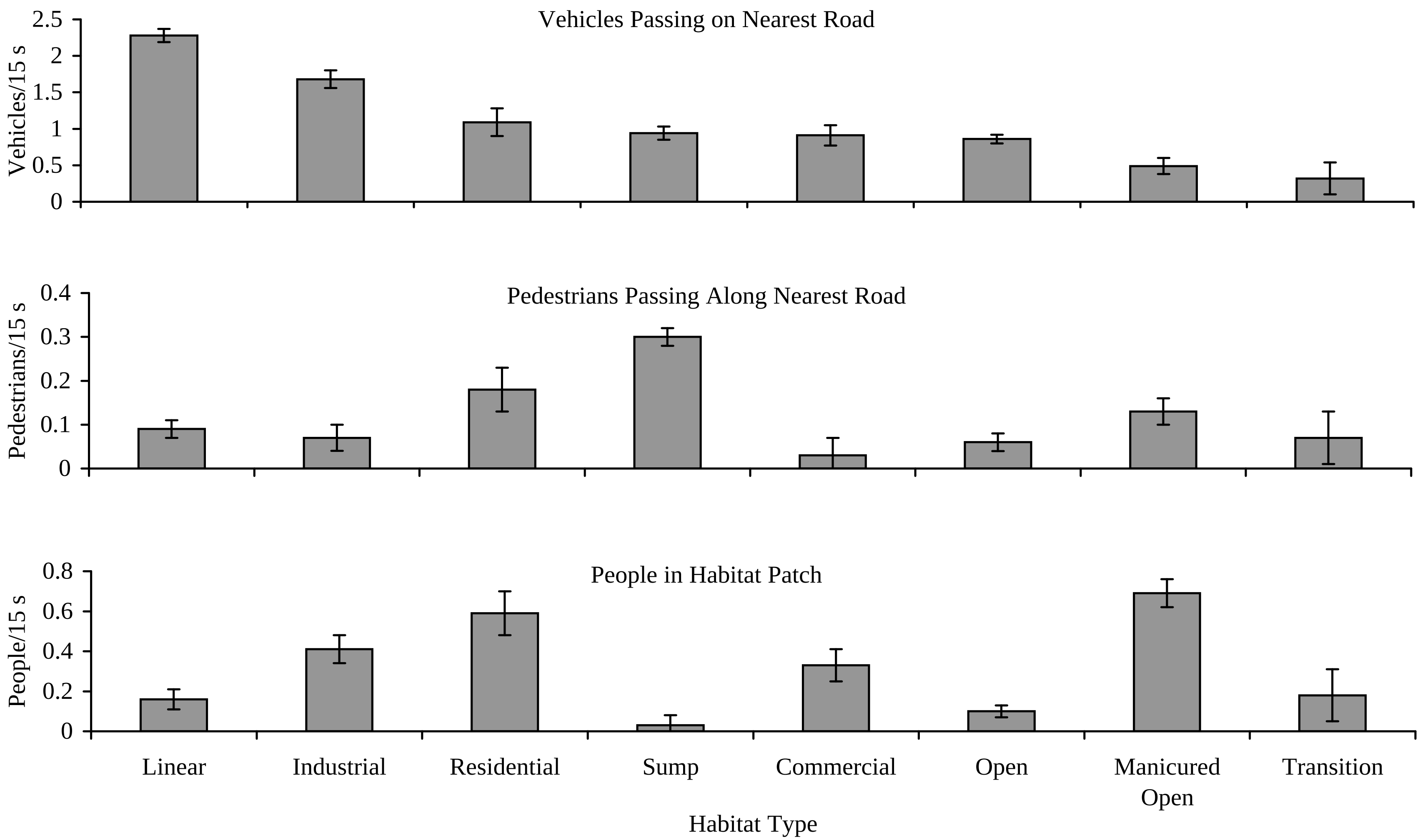

Figure 5. Mean number of passing vehicles, passing pedestrians, and people in the same habitat patch as radiocollared kit foxes at all daily locations (n = 4,824) in Bakersfield, California from May 1997 to January 1998. Vertical bars represent ± 1 SE.

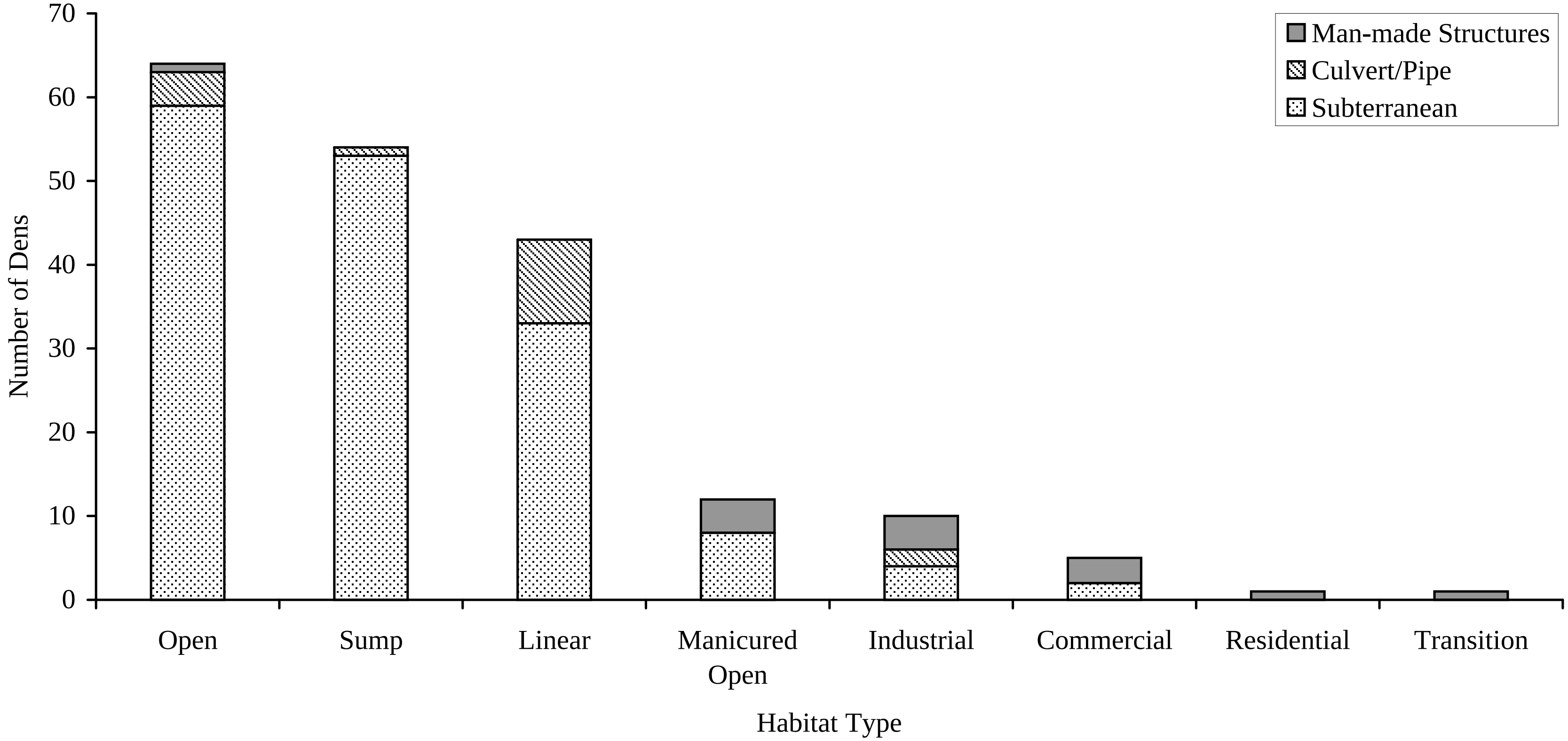

Figure 6. Number of dens used by radiocollared kit foxes in each habitat type in Bakersfield, California from May 1997 to January 1998.

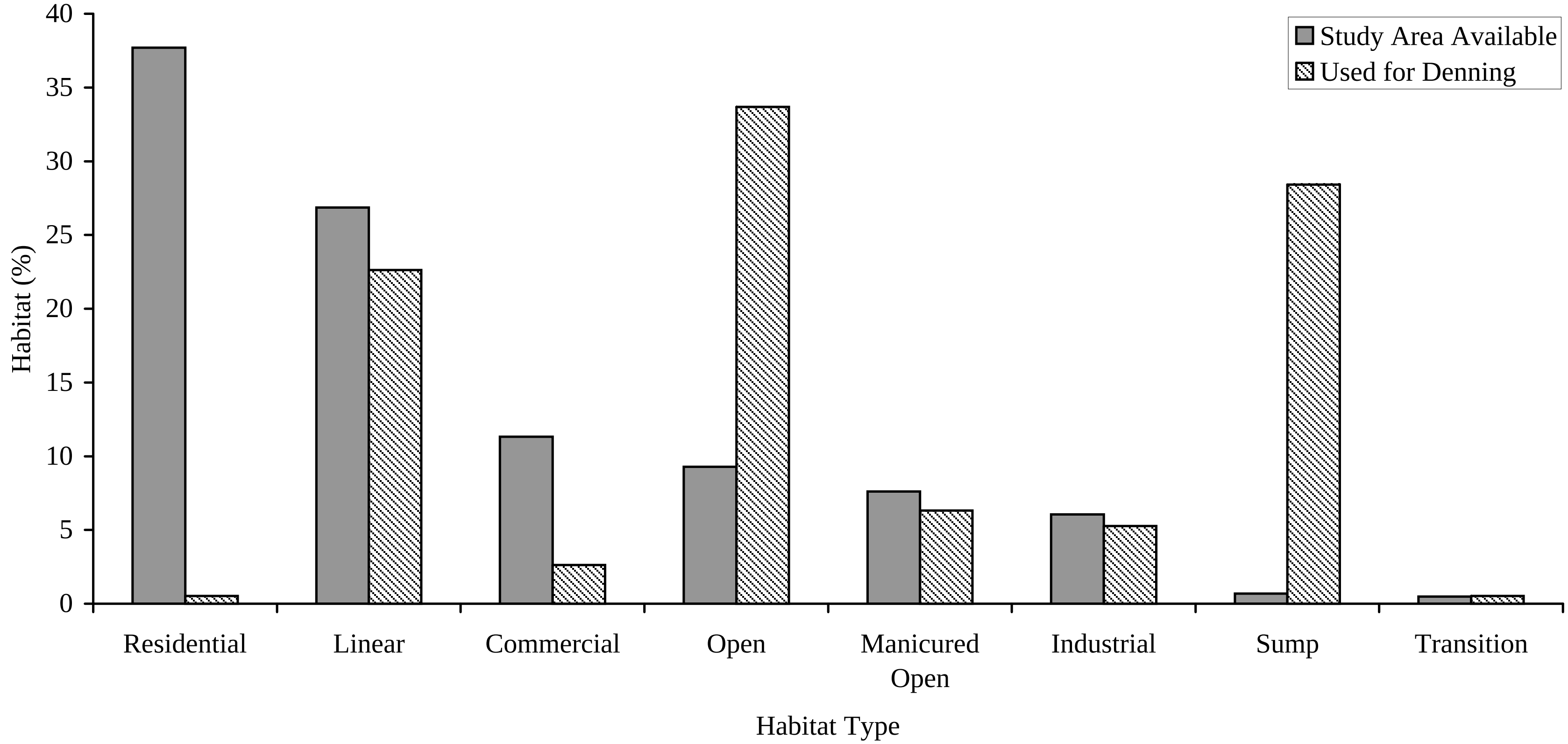

Figure 7. Percentage of available habitat in the study area compared to percentage of habitat used by radiocollared kit foxes for denning in Bakersfield, California from May 1997 to January 1998.

by the interaction of sex and time of night (Figure 8, Table 6). The regressions of kit fox speed and the number of passing vehicles ($r^2 = 0.0077$), passing pedestrians ($r^2 = 0.0016$), and people in the same habitat patch as the kit fox ($r^2 = 0.0002$), respectively, indicated that these variables (all of which could not be normalized through transformation) were not related to kit fox speed. The distance traveled during each movement session was longer in manicured open and open habitats than all other habitats ($H = 125$, $df = 7$, $p < 0.001$; Figure 9). Overall speed was faster in residential habitat than all other habitats ($H = 111.6$, $df = 7$, $p < 0.001$; Figure 10).

There was a significant interaction between kit fox movements, movement session time, and habitat type ($\chi^2 = 61.48$, $df = 28$, $p < 0.001$). Kit fox resting/walking movements deviated most from expected from 1830 – 2230 h, during which linear habitat was used more than expected and from 2230 – 0330 h, during which residential habitat was used less than expected (Table 7). Kit fox trotting movements deviated most from expected from 2230 – 0330 h during which open habitat was used more than expected, and from 2230 – 0730 h during which sump habitat was used less than expected. The greatest deviations from expected kit fox running movements were from 2230 – 0330 h during which open habitat was used more than expected, and from 0330 – 0730 h during which industrial habitat was used less than expected.

Between 27 September and 4 October 1997, a male kit fox moved $\geq$ 5.9 km from his previously-established home range to another part of the study area, where he remained until the end of the study. Kit foxes were observed crossing roads (up to four lanes), but also used culverts to move under roads. One study animal was observed to use a 0.46-m in diameter culvert to cross under a State Route 99 offramp and a 4.26 m wide by 3.66 m high vehicle access road to cross under State Route 99. Other kit foxes were observed to cross under the State Route 99 bridge over the Kern River and use a foot bridge to cross a canal.

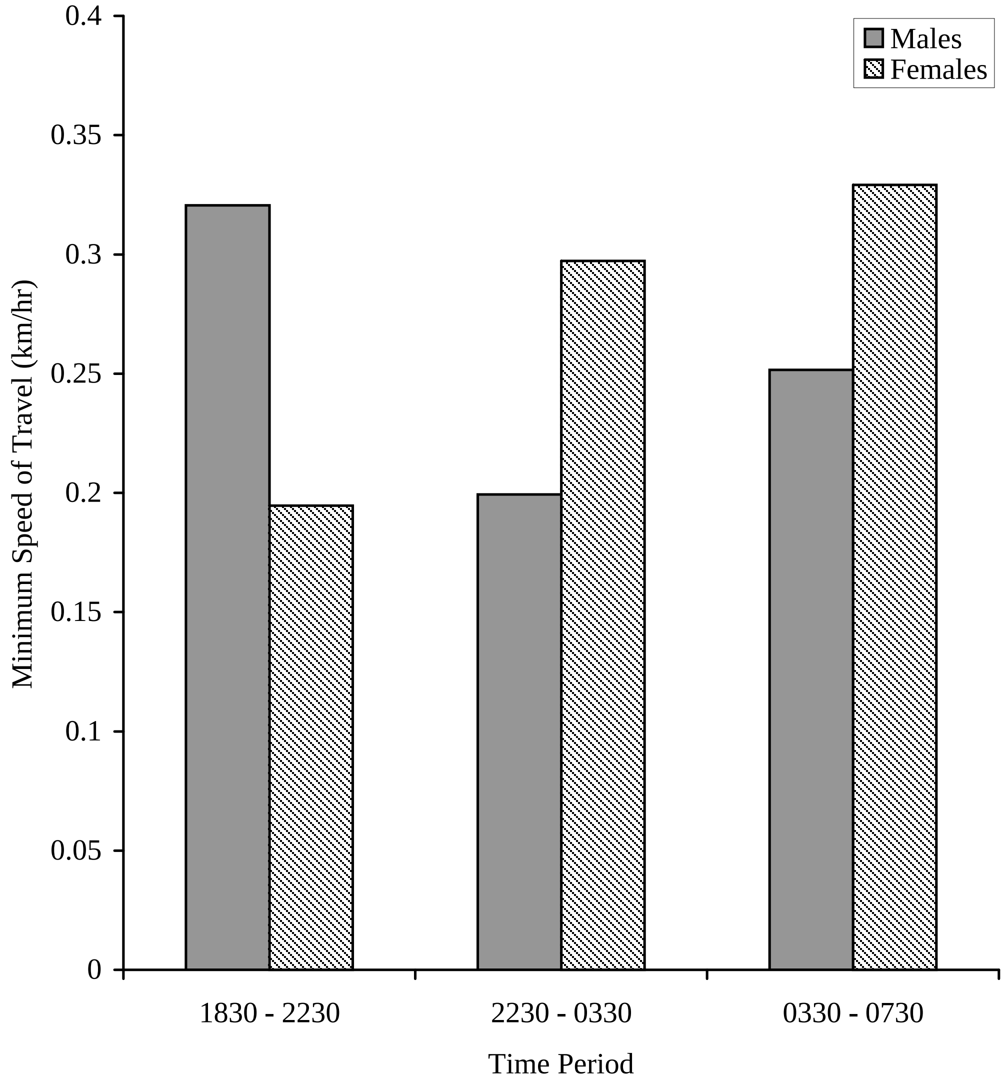

Figure 8. Minimum speed per movement session for male and female radiocollared kit foxes in Bakersfield, California from September 1997 to January 1998.

Table 6. Influence of sex, movement session time, and their interaction on minimum, maximum, and mean speed and total adjusted distance moved for 10 radiocollared kit foxes in Bakersfield, California from May 1997 to January 1998.

	Males			Females			Males vs. Females			Movement Session Time			Interaction		
Measurement	$\bar{x}$	SE	Range	$\bar{x}$	SE	Range	F-Ratio	df	p	F-Ratio	df	p	F-Ratio	df	p
Minimum Speed (km/hr^2)	0.26	0.03	0.02 - 0.75	0.27	0.03	<0.01 - 1.16	0.05	1	0.82	0.58	2	0.56	3.17	2	0.047
Maximum Speed (km/hr^2)	2.19	0.13	0.26 - 4.65	2.17	0.22	0.32 - 9.06	0.1	1	0.75	2.5	2	0.09	0.21	2	0.81
Mean Speed (km/hr^2)	1.39	0.03	0.02 - 4.65	1.25	0.03	<0.01 - 9.06	1.32	1	0.25	1.08	2	0.34	0.15	2	0.86
Total Adjusted Distance Moved (km)	1.76	0.11	0.12 - 3.34	1.62	0.15	0.13 - 4.77	0.88	2	0.35	1.81	2	0.17	1.16	2	0.32

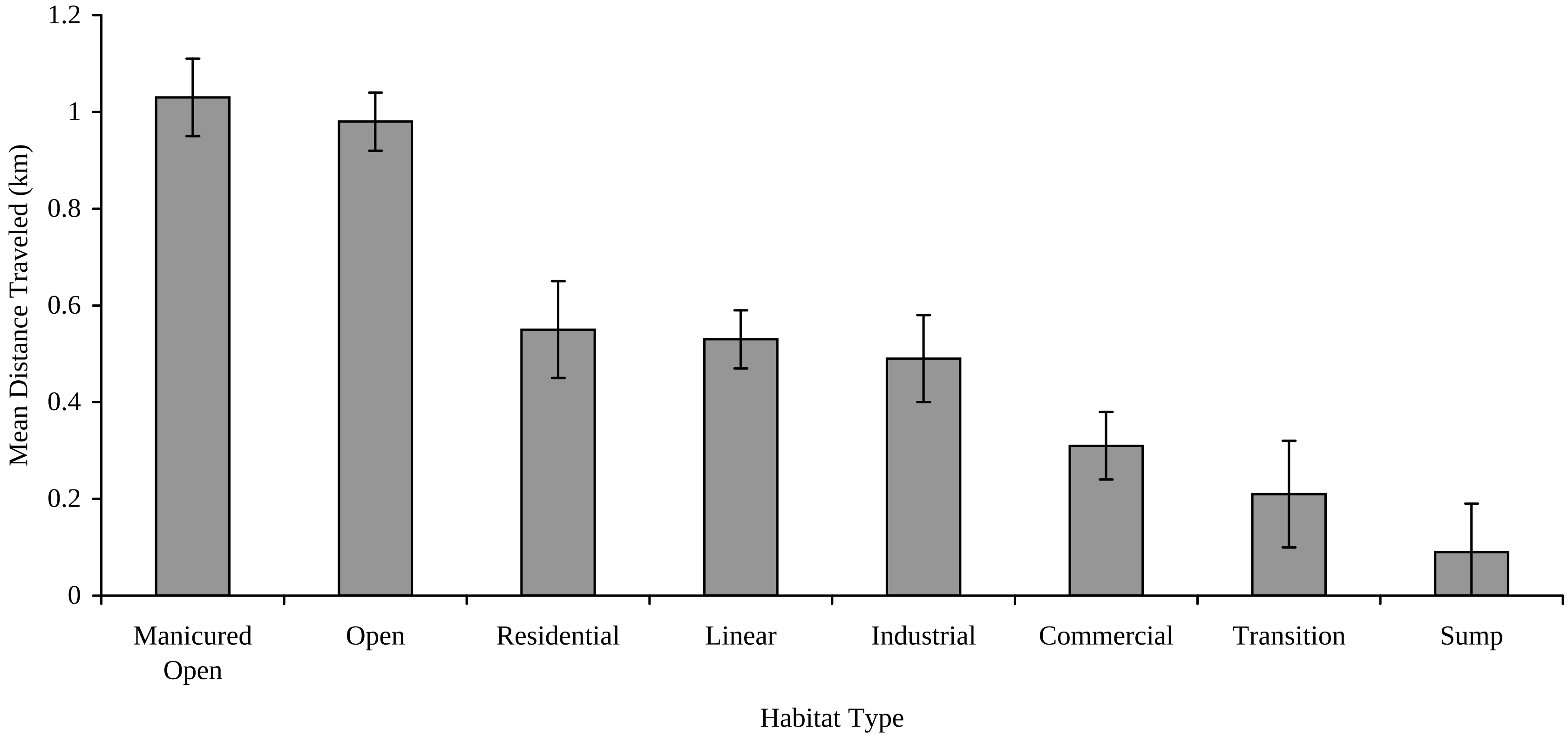

Figure 9. Mean distance radiocollared kit foxes traveled in each habitat type in Bakersfield, California from September 1997 to January 1998. Vertical bars represent ± 1 SE.

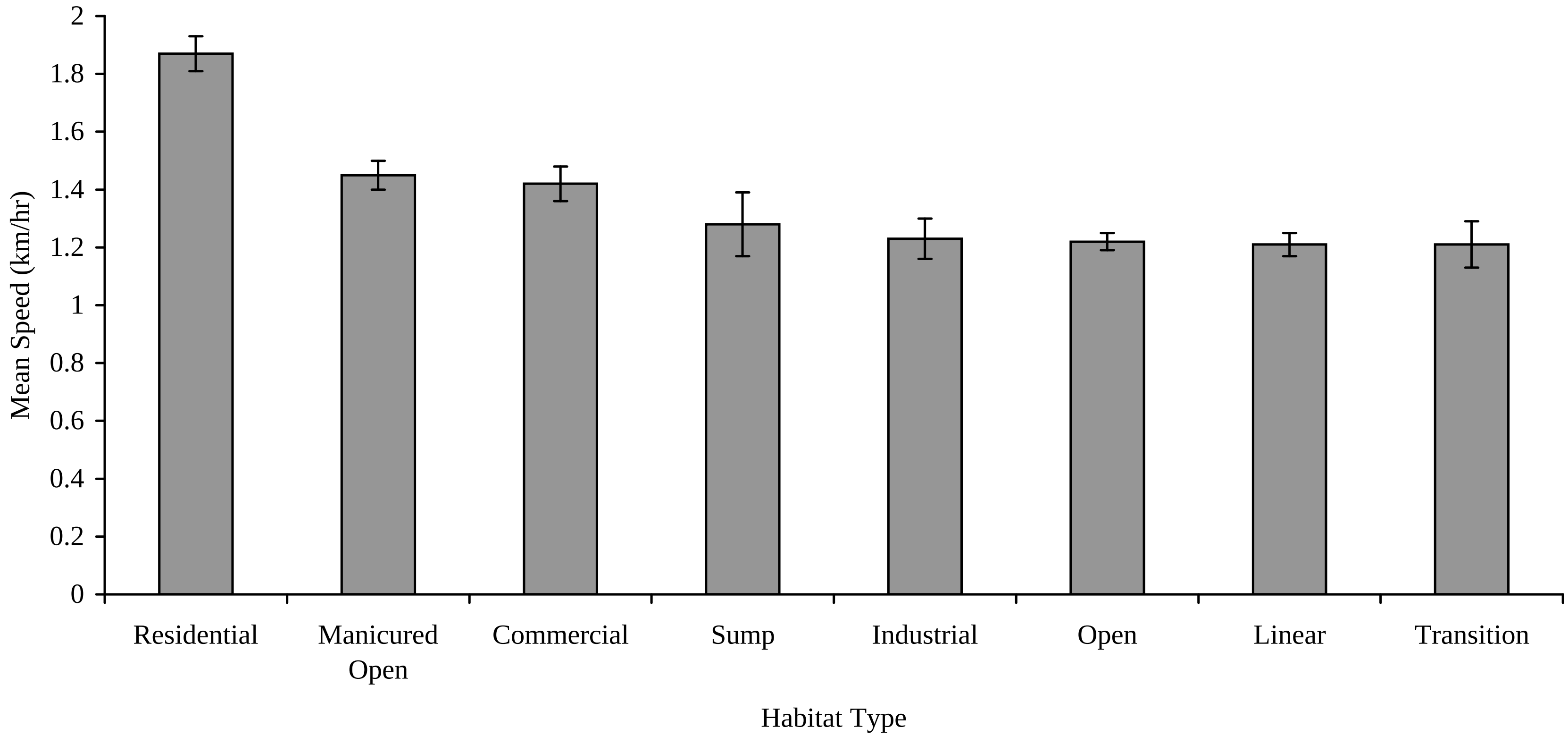

Figure 10. Mean speed radiocollared kit foxes traveled in each habitat type in Bakersfield, California from September 1997 to January 1998. Vertical bars represent ± 1 SE.

Table 7. Movement session time, type of movement, and habitat associations for radiocollared kit foxes in Bakersfield, California from September 1997 to January 1998.

Movement Type	Movement Session Time (h)	Habitat Type	Observed Frequency[a]	Standardized Residual[b]
Resting/Walking	1830 - 2230	Sump	11	-5.19
		Transition	18	-4.16
		Residential	19	-4.02
		Commercial	30	-2.40
		Industrial	58	1.71
		Manicured Open	107	8.91
		Open	185	20.37
		Linear	205	23.30
	2230 - 0330	Residential	6	-5.93
		Transition	12	-5.05
		Sump	13	-4.90
		Commercial	28	-2.69
		Manicured Open	76	4.36
		Industrial	78	4.65
		Linear	89	6.27
		Open	194	21.69
	0330 - 0730	Commercial	15	-4.60
		Residential	15	-4.60
		Transition	26	-2.99
		Sump	35	-1.67
		Industrial	38	-1.23
		Manicured Open	57	1.56
		Open	164	17.28
		Linear	174	18.75

Table 7. Movement session time, type of movement, and habitat associations for radiocollared kit foxes in Bakersfield, California from September 1997 to January 1998 (continued).

Movement Type	Movement Session Time (h)	Habitat Type	Observed Frequency[a]	Standardized Residual[b]
Trotting	1830 - 2230	Sump	12	-5.05
		Transition	12	-5.05
		Residential	25	-3.14
		Industrial	29	-2.55
		Commercial	33	-1.96
		Manicured Open	45	-0.20
		Open	96	7.29
		Linear	105	8.62
	2230 - 0330	Sump	6	-5.93
		Transition	13	-4.90
		Residential	14	-4.75
		Industrial	25	-3.14
		Manicured Open	30	-2.40
		Commercial	41	-0.79
		Linear	94	7.00
		Open	115	10.08
	0330 - 0730	Sump	6	-5.93
		Transition	20	-3.87
		Industrial	25	-3.14
		Commercial	28	-2.69
		Manicured Open	29	-2.55
		Residential	46	-0.05
		Linear	72	3.77
		Open	97	7.44

Table 7. Movement session time, type of movement, and habitat associations for radiocollared kit foxes in Bakersfield, California from September 1997 to January 1998 (continued).

Movement Type	Movement Session Time (h)	Habitat Type	Observed Frequency[a]	Standardized Residual[b]
Running	1830 - 2230	Sump	6	-5.93
		Industrial	14	-4.75
		Transition	16	-4.46
		Commercial	19	-4.02
		Linear	50	0.54
		Manicured Open	54	1.12
		Residential	61	2.15
		Open	64	2.59
	2230 - 0330	Transition	6	-5.93
		Sump	7	-5.78
		Industrial	25	-3.14
		Residential	27	-2.84
		Commercial	35	-1.67
		Manicured Open	38	-1.23
		Linear	53	0.98
		Open	66	2.89
	0330 - 0730	Industrial	2	-6.51
		Sump	4	-6.22
		Transition	6	-5.93
		Commercial	8	-5.63
		Linear	21	-3.72
		Manicured Open	24	-3.28
		Open	30	-2.40
		Residential	30	-2.40

[a] Number of times a kit fox movement path intersected each habitat type, separated by movement type and movement session time.

[b] Negative values indicate that a habitat was used less than expected and positive values indicate that a habitat was used more than expected. If the value is > $\pm$ 2.00 (2 standard deviations), it is significant.

Demographics

During 6,036 days of active radiotransmitters, two of the 28 radiocollared kit foxes died and the interval survival rate was 0.92. One female was hit by a vehicle and another female was likely killed by a coyote or domestic dog, based on 30 to 35-mm paired puncture wounds on the torso of the intact, unburied carcass (Spiegel and Disney 1996). It was unknown if another female that could not be located after 3 September 1997, died, dispersed, or had a malfunctioning radiocollar.

Pups were detected with 15 family groups, comprised of 22 radiocollared adult kit foxes. Eleven of the 15 radiocollared females reproduced during one breeding season. Four of these 11 females had radiocollared mates. An additional four radiocollared males had uncollared mates that also reproduced in the same breeding season. Kit fox litters averaged 2.8 $\pm$ 0.45 (range = 1 – 7) pups. The litter of 7 pups was observed denning with two radiocollared females, of which one exhibited reproductive condition and one did not.

DISCUSSION

Demographics

The urban kit foxes had lower mortality and similar reproduction and body weight compared to rural populations (Morrell 1972). Conversely, Cypher and Frost (1999) found that kit foxes in Bakersfield (i.e., females in winter and juveniles) were heavier than their counterparts in a nearby rural population. Urban kit foxes' normal weights may be attributed to good nutrition. The constant source of water from sumps, canals, and lawn sprinklers in Bakersfield (Murphy 1992) may provide a more stable prey population. Like urban red foxes in Orange County, California (Lewis et al. 1993) and Toronto, Canada (Rosatte et al. 1991), urban kit foxes were supplementally fed (i.e., anthropogenic sources of food, including bread and burritos) by people and observed opportunistically foraging on both anthropogenic and natural food items (personal observation).

Urban kit foxes in Bakersfield may have lower mortality rates than rural foxes (Table 8). Of 22 adult kit foxes from a nearby rural population that were radiocollared prior to or during late November and December 1995 through September 1996, 15 (68.2%) died and two were lost (Enterprise Advisory Services, Inc. 1997). Of 35 adult kit fox mortalities (including the two from this study) in the Bakersfield area from 1997 to 2003, 23% were due to vehicular impact (Bjurlin and Cypher 2003). The interval survival rate for urban kit foxes (0.92) was much greater than that for rural kit foxes (0.58; Ralls and White 1995; 0.44; Cypher et al. 2000).

Coyote predation may be more likely if a fox is far from its den (Kitchen et al. 1999) or in the peripheral areas of its home range (Sovada et al. 1998, Olson and Lindzey 2002). The majority of swift fox (*Vulpes velox*) deaths were due to coyotes and occurred outside the 85%

Table 8. Rural kit fox and swift fox cause-specific mortality rates reported within their geographic range for comparison to that for urban kit foxes in Bakersfield, California from May 1997 to January 1998.

Reference	Species	Location	Cause-Specific Mortality Rate (%)	
			Predation	Vehicular Impact
Cypher et al. 2000	Kit Fox	Kern County, CA	48.5	5.0
Ralls and White 1995	Kit Fox	Carrizo Plain, CA	78.0	4.0
Hardenbrook 1987	Kit Fox	Churchill County, NV	60.0	10.0
Spiegel and Disney 1996	Kit Fox	Kern County, CA	66.7	1.7
Standley et al. 1992	Kit Fox	Monterey and San Luis Obispo Counties, CA	75.0	6.3
Kamler et al. 2003	Swift Fox	Dallam County, TX	33.0	42.0
Matlack et al. 2000	Swift Fox	Sherman and Wallace Counties, KS	45.0	36.0

(Kitchen et al. 1999) or 95% (Sovada et al. 1998, Olson and Lindzey 2002) isopleth of the fox's home range and more than 1 km from the den that the fox most recently occupied. Likewise, the urban kit fox that died as a result of coyote or dog predation was located outside the 85% isopleth of her range.

Production of young exceeded the number of kit foxes that died, which may have indicated that the urban kit fox population was demographically healthy during the period of study and habitat was of sufficient quality to support a source population (Van Horne 1983, Pulliam 1988, Noss et al. 1997). Seventy-three percent of radiocollared females produced pups, more than that observed for rural kit foxes in southwestern Kern County (64%; Spiegel and Tom 1996; 61%; Cypher et al. 2000). The mean number of pups per litter was within the range of that for rural populations: 2 (White and Ralls 1993) to 4 (Morrell 1971, Cypher et al. 2000).

Kit fox reproduction has been positively correlated with prey availability (White and Ralls 1993). Raccoons and skunks in Toronto, Canada weighed more and had higher reproductive success than their rural counterparts, which Rosatte et al. (1991) attributed to abundant and varied natural and human-derived food sources in the urban setting. The results of a supplemental feeding study indicated that kit fox survival and reproductive success were influenced by food availability (EG&G Energy Measurements 1993). Supplemental feeding by humans and the availability of refuse may contribute to the demographic health of urban kit foxes.

Locations

During daylight hours, urban kit foxes were found to be resting or in dens on all but one occasion. Like rural kit foxes in California (Morrell 1971, Morrell 1972, White et al. 2000), Utah (Egoscue 1956, O'Neal et al. 1987, Arjo et al. 2003), and Arizona (Golightly 1981, Golightly and Ohmart 1983) and urban red foxes in Orange County, California (Sallee 1998), urban kit foxes were almost entirely nocturnal. Similarly, urban coyotes in Orange County, California (Romsos 1998), Seattle, Washington (Quinn 1995), and Tucson, Arizona (Grinder and Krausman 2001) were less active during daylight than at night. Urban kit foxes were primarily nocturnal and limited their daytime activity to the immediate vicinity of the den, similar to rural kit foxes (Morrell 1971, Morrell 1972), rural swift foxes (Kilgore 1969, Kitchen et al. 1999, Kamler et al. 2004), and urban red foxes (Voight and Macdonald 1984). Urban canids may benefit from being active only at night when interactions with humans are less likely.

Home range

Knowledge of home range size and spatial distribution can be used to manage urban habitat for the benefit of kit foxes. Home range estimates were much smaller than those for rural kit foxes (Table 9), but consistent with observations that foxes (Voight and Macdonald 1984, Murphy 1992) and raccoons and skunks in urban areas have smaller ranges than their rural counterparts (Rosatte et al. 1991).

Macdonald (1983) and Doncaster et al. (1990) attributed the tendency for red fox home ranges to be smaller in cities (e.g., Oxford) than in rural areas, to the spatial and temporal patchiness of food dispersion. Red foxes in Orange County, California had smaller home ranges where they were supplementally fed (Sallee 1998). Ables (1969) noted that the smaller home ranges for red foxes in south-central Wisconsin may have been due to habitat richness (i.e., a high interspersion of habitat types and abundant wild fruits and berries). Artificial food sources associated with urban and oilfield development may have led to decreases in the home range size of kit foxes in southwestern Kern County (Zoellick et al. 1987, Spiegel and Bradbury 1992). Conversely, kit fox home ranges increased in size during times of low prey availability (White and Ralls 1993) and were negatively correlated with prey density (Morrell 1971, White and Garrott 1997). Thus, the small size of urban kit fox home ranges indicated that abundant food

Table 9. Kit fox home range size reported within various habitats within their geographic range for comparison to home range size of urban kit foxes in Bakersfield, California from May 1997 to January 1998.

Reference	Location	Habitat	Estimator	Range Type	Area km^2
Knapp 1978	Kern County, CA	Agriculture	100% Minimum convex polygon[a]	Home Range	2.52
Koopman 1995	Kern County, CA	Saltbush scrub	100% Minimum convex polygon	Home Range	3.52
Zoellick et al. 1987	Kern County, CA	Saltbush scrub	100% Minimum convex polygon	Home Range	4.63
White and Ralls 1993	Carrizo Plain, CA	Grassland	100% Minimum convex polygon	Home Range	11.60
O'Neal et al. 1987	Great Basin, UT	Saltbush scrub	100% Minimum convex polygon	Home Range	3.11
Spiegel and Bradbury 1992	Kern County, CA	Saltbush scrub	97% Minimum convex polygon[b]	Home Range	6.13
Spiegel and Bradbury 1992	Kern County, CA	Saltbush scrub	95% Minimum convex polygon[b]	Nocturnal Range	5.82
Hardenbrook 1987	Churchill County, NV	Greasewood	Modified Minimum Area Method	Home Range	9.74
Arjo et al. 2003	Tooele County, UT	Salt playa	95% Adaptive Kernel	Home Range	43.09
Arjo et al. 2003	Tooele County, UT	Greasewood	95% Adaptive Kernel	Home Range	13.29
Arjo et al. 2003	Tooele County, UT	Sagebrush	95% Adaptive Kernel	Home Range	11.51
Koopman 1995	Kern County, CA	Saltbush scrub	75% Harmonic Mean	Core area	0.73
Spiegel and Bradbury 1992	Kern County, CA	Saltbush scrub	50% Hamonic Mean[b]	Core area	1.18
Zoellick et al. (2002)	Kern County, CA	Saltbush scrub	50% Hamonic Mean	Core area	1.2

[a] May have been underestimated due to small sample size.

[b] Estimates using non-independent data may have been inflated, as demonstrated in Koopman (1995).

resources were concentrated in key urban habitats around which home ranges were configured. Further evidence of this was that urban kit foxes' core area size constituted only 9% of the home range size, whereas that for rural kit foxes constituted 17% of the home range (Spiegel and Bradbury 1992). This may be because suitable denning habitat for urban kit foxes was concentrated around sumps and undeveloped lots.

Female urban kit foxes had a greater median number of core areas than did males, indicating that females had a higher number of distinct denning sites. Female kit foxes in Arizona (Golightly 1981) and Nevada (Hardenbrook 1987) spent more time near their dens than males. Fenced sumps in core areas provide denning habitat that may ensure safe reproduction in the urban population.

The home ranges and core areas of adjacent kit foxes may have substantial overlap if kit foxes are concentrated around limited resources (Golightly 1981), such as food-rich habitat patches (Macdonald 1983). Mean home range overlap was greater than 71% for family group members and less than 16% for unrelated individuals, which was less than that for the nearby rural population (Zoellick et al. 2002, Spiegel and Bradbury 1992).

Core area overlap was greater for members of the same family group (61%) than core area overlap of neighboring males and females (29%) or neighboring males (11%), similar to that for rural kit foxes (Spiegel and Bradbury 1992). Unpaired male and female urban kit foxes had a higher percentage of core area overlap than home range overlap. Because core areas were centered around denning sites, male and female kit foxes' home ranges may have overlapped in a central denning area, as was the case for kit foxes in Arizona (Golightly 1981) and Nevada (Hardenbrook 1987). Kitchen et al.'s (2005) findings that male swift foxes spent more time on the boundary of the home range, while females spent more time in the group core area, may explain why female urban kit foxes had the least home range overlap and no core area overlap.

Overlap of home ranges and core areas indicated that kit foxes were concentrated around key urban habitat patches and food resources were not evenly-distributed. It was likely that urban kit foxes were able to find foraging and denning habitat in close proximity because of uniformly-distributed sumps, which may be important to the success of the urban kit fox population.

Due to refuse and human-derived foods, urban kit foxes may be able to meet their resource needs in a smaller area than rural kit foxes. The presence of these food resources distributed among disjunct habitat patches may explain why urban kit foxes had smaller and less overlapping home ranges than their rural counterparts. Given the constant and widespread availability of human-derived food in the urban landscape, suitable denning habitat may be a limiting factor for the urban kit fox population. This is consistent with Golightly's (1981) conclusion that kit fox den sites in rural Arizona were limited by soils suitable for denning.

Estimates of 100% minimum convex polygon home range size were greater for males than females, perhaps due to fewer seasonal movements by females and increased foraging requirements for males during pup-rearing (Spiegel and Bradbury 1992). While Golightly (1981) found that male kit foxes in Arizona had much larger home ranges than females, home range size for other rural kit fox (Zoellick et al. 1987, Spiegel and Bradbury 1992, White and Ralls 1993, Koopman 1995), swift fox (Kitchen et al. 1999, Kamler et al. 2003), and Blanford's fox (*Vulpes cana*; Geffen and Macdonald 1992) populations did not differ among the sexes.

Because home range size may vary with season (Burt 1943), the quantity of urban habitat needed to meet kit foxes' ecological requirements may fluctuate over time. Home range size was greater for males than females during the breeding season, but did not differ between the seasons for kit foxes in Utah (Arjo et al. 2003), swift foxes (Kitchen et al. 1999), Blanford's foxes (Geffen and Macdonald 1992), and culpeo foxes (*Pseudalopex culpaeus*; Salvatori et al. 1999). In order to search for a mate during the breeding season, male foxes may increase their number of exploratory movements, which may be especially pronounced in the urban environment where patches of habitat suitable to support kit foxes are small and disjunct. Home range size may have been underestimated during the pair formation and breeding seasons, because fewer kit foxes were located during this time. This may explain why mean home range size was significantly larger during the dispersal season than the pair formation and breeding seasons.

Habitat use

Habitats were known to be correctly classified for 68% of all independent locations, which were obtained by following the transmitted signal until the animal was observed or tracked to a den. It was unlikely that visually observed kit foxes were behaviorally pushed from one habitat to another, because kit foxes were resting or walking 67% of the time. However, distance between the animal and the radio-receiver, as well as broken topography, can increase telemetry error (Harris et al. 1990). Telemetry error was a concern because correct assignment of habitat use required accurate locations. Based on average telemetry error in urban coyote studies (Romsos 1998, Grinder and Krausman 2001), triangulated kit fox locations less than 100 m from the nearest habitat-patch edge may have been misclassified. The remaining 32% of locations were determined by triangulation or encircling the habitat patch. These locations averaged 31 m from the nearest habitat-patch edge and may have included some misclassification.

Like urban kit foxes, rural kit foxes do not use habitat within their home range in a uniform manner (Golightly 1981, Hardenbrook 1987) and have distinct core areas of concentrated activity (Koopman 1995). Kit foxes used open and sump habitats more than their availability in both the study area and in home ranges, and there was significantly more open and sump habitat in home ranges than in the study area. Likewise, urban red foxes (Sallee 1998) and coyotes (Romsos 1998) in Orange County, California used vacant field habitats more than expected. The higher vegetative cover in vacant fields may facilitate predator avoidance and support a more abundant prey base (Adams and Dove 1989) than the other less used urban habitats. Likewise, sumps had marsh vegetation, which provides food and cover for wildlife and facilitates use by terrestrial wildlife (Adams and Dove 1989). Therefore, sumps may serve as artificial urban wetlands that provide denning habitat with their sloping sides, foraging opportunities based on the abundance of active small mammal burrows (personal observation), and a constant source of water, which I observed an urban kit fox drinking. In hot environments, such as Arizona, rural kit foxes meet their water needs through prey consumption (Golightly and Ohmart 1984). With the availability of free-standing water in the urban environment, kit foxes may require less food.

The number of people in the same habitat patch as the kit fox was lowest in open and sump habitats. While the greatest number of pedestrians observed along roads were near sumps, the fencing around sumps provided a physical and visual barrier between kit foxes and passing pedestrians. The shelter and security that the fenced perimeters provided may also explain why Stafford and Murphy (1992) found kit fox dens in 10 of the 95 sumps that they surveyed in Bakersfield. Likewise, urban red foxes disproportionate use of industrial habitats may be attributed to security personnel and perimeter fencing, which limited intrusion by humans and their pets (Sallee 1998).

There was significantly less residential habitat in urban kit fox home ranges than in the study area; the opposite was true for urban coyotes in Tucson, Arizona (Grinder and Krausman 2001). Harrison (1997) found that gray foxes (*Urocyon cinereoargenteus*) in New Mexico avoided high-density residential subdivisions. Urban coyotes (Romsos 1998) and red foxes (Sallee 1998) in Orange County, California avoided high-density residential and commercial habitats, perhaps due to a greater possibility for human and domestic animal interactions. Likewise, Lucherini et al. (1995) found that red foxes used habitats with less human access and disturbance.

Industrial and linear habitats had a higher incidence of passing vehicles than all other habitats. This may be because industrial habitats tend to occur along major roads. In linear habitat, from 1800 to 1859 h and 0700 to 0759 h, both the number of kit fox locations and number of passing vehicles peaked (Appendix E). However, during these times, 84% of the kit foxes using the linear habitat were located in dens that sheltered them from the disturbance of the passing vehicles.

The kit fox is one of the few canids that utilizes an underground den throughout the year (Berry et al. 1987, Koopman et al. 1998). Because dens are used for whelping and rearing pups, for escape cover from predators (Grinnell et al. 1937), and to minimize water loss and heat stress in summer and metabolic costs in winter (Golightly 1981, Golightly and Ohmart 1983), kit fox presence is limited by the availability of (Spiegel et al. 1996) or their ability to build dens. Like rural kit foxes in California (Knapp 1978, Berry et al. 1987, Reese et al. 1992) and Utah (Egoscue 1956, Arjo et al. 2003) and swift foxes (Kilgore 1969), urban kit foxes primarily used subterranean dens. However, they also used alternative dens, including pipes. Use of pipes that are known to interfere with radio signals, may have caused an underestimation of the number of alternative dens used in this study (Berry et al. 1987, Spiegel et al. 1996, Koopman et al. 1998).

Like Golightly (1981), I found that kit foxes did not randomly select den sites. Because kit foxes selected sump habitats for denning, there was more area of sump habitat in core areas than in home ranges. Sumps may also be used for denning because they are fenced and not accessible to the public. Likewise, most urban red fox dens occurred within fenced areas that may have isolated dens from human disturbance (Sallee 1998). Stafford and Murphy (1992) found that the majority of sumps used by urban kit foxes for denning were adjacent to undisturbed habitat, which likely has a low human presence.

Furthermore, I found that urban kit foxes denned in open habitats more than their availability in the study area. Likewise, rural kit foxes in California (Morrell 1971, Morrell 1972), Utah (Egoscue 1956, Egoscue 1962), and Arizona (Zoellick et al. 1989) and urban red foxes (Lewis et al. 1993) frequently denned in flat, open areas. Kit foxes may be less vulnerable to coyote and bobcat predation on flat or rolling grasslands (Warrick and Cypher 1998).

Linear habitats (i.e., along canals, railroads, freeway embankments, and powerline right-of-ways) were used in proportion to their availability for denning. Like swift foxes, urban kit foxes utilized dens in road right-of-ways (Matlack et al. 2000). However, urban kit foxes denned near roads less than expected and in larger habitat patches than expected. Similarly, red foxes used habitats with less human access and disturbance for resting (Lucherini et al. 1995).

Movements

Kit foxes moved at an average rate of 1.33 km/h, nearly identical to that for kit foxes in southwestern Kern County (1.35 km/h; Koopman 1995) but slower than that for kit foxes in Arizona (males: 2.73 km/h; females: 1.49 km/h; Golightly 1981) and faster than that for swift foxes (males: 0.68 km/h; females: 0.59 km/h; Kitchen et al. 1999). Between dusk and dawn (i.e., approximately 10 to 14 h, depending on time of year), rural kit foxes in Arizona moved an average distance of 14.3 km for males and 11.8 km for females (Zoellick et al. 1989) and in southwestern Kern County, moved an average distance of 9.8 km for males and 10.9 km for females (Zoellick et al. 1987), yielding average movement rates similar to that for urban kit foxes. The average distance that captured urban red foxes, raccoons, and skunks in Toronto, Canada moved from the point of release was less than that for their rural counterparts, which indicated that food and habitat in the urban environment were not limited in availability (Rosatte et al. 1991).

Males, which had larger 100% minimum convex polygon home ranges than females, may travel at higher rates of speed during the early part of the evening to cover their larger territory. In Arizona, kit fox activity peaked in the early evening and a few hours before sunset, and males spent twice as much time out of the den, traveled 3.6 times farther, and maintained home ranges

2.6 times larger than females (Golightly 1981). However, in the urban setting, I did not detect a difference between sexes, movement session times, or their interaction with regard to maximum speed, mean speed, or total adjusted distance moved during each movement session. Similarly, lengths of nightly movements did not differ among sexes for rural kit foxes (Zoellick et al. 2002) and Blanford's foxes (Geffen and Macdonald 1992). Compared to Arizona, where male kit foxes spent much time by the boundaries of their territory to defend a non-uniformly distributed resource base (Golightly 1981), urban kit foxes were able to meet their resource needs within small home ranges and did not need to travel far due to the concentration of resources within distinct habitat patches in the urban landscape.

Kit fox movement speed was not correlated with the number of passing vehicles, passing pedestrians, or people in the same habitat patch. This is consistent with the findings in Lewis et al. (1993), which indicated that urban red foxes were tolerant of humans. Nevertheless, kit foxes may have attempted to avoid human interactions by traveling at a high rate through residential, manicured open, and commercial habitats, all which had a high incidence of people.

Sump and transition habitats were typically small patches that were free of people at night when kit foxes were active. Kit foxes were observed foraging in and caching food scavenged from construction sites. Furthermore, the remains of several species that live in sumps, including bullfrog (*Rana catesbeiana*), burrowing owl (*Athene cunicularia*), duck (unidentified species), pocket gopher, squirrel, and opossum, were observed on kit fox dens in sumps (personal observation). Use of sump and transition habitats for hunting or scavenging refuse may explain why kit foxes traveled short distances at low speeds in these habitats.

Kit foxes used linear habitats (i.e., the Kern River Parkway, canals, and right-of-ways for highways, railroads, and powerlines) as corridors to move throughout their home range. Because highway, railroad, and powerline right-of-ways were fenced to prohibit public access, kit foxes may not have been compelled to move quickly through this habitat type. Kit foxes moved long distances quickly through manicured open habitats, perhaps because this habitat had a high occurrence of humans and was used mostly as a corridor for traveling, similar to urban red foxes' use of golf courses in Toronto, Canada (Rosatte et al. 1991).

Kit foxes in urban areas may have shorter nightly movements due to anthropogenic food sources (Zoellick et al. 1987). Consequently, movement distance may be influenced by foraging efficiency. Movement distance was less in commercial habitats (where kit foxes were observed foraging in parking lots and trash dumpsters) and transition habitats, both which tend to have an abundance of discarded food items (personal observation). Conversely, kit foxes moved longer distances in open, grassland habitat. This may have been because small, insectivorous prey of kit foxes and swift foxes tend to be evenly distributed in grassland habitats (Kamler et al. 2004). Similarly, Koopman (1995) noted that food resources were uniformly distributed in rural kit fox home ranges.

Movements of kit foxes differed with regard to habitat type and time of night. From 1830 – 2230 h, linear habitat was used more than expected for kit fox resting/walking movements. This was probably because 23% of kit fox dens were in linear habitat. From 2230 – 0330 h, kit fox trotting and running movements were higher than expected in open habitat, which was likely used for foraging and traveling. From 2230 – 0330 h, kit fox resting/walking movements were less than expected in residential habitat, in which only one den was located. Kit foxes' high rate of speed through residential habitat indicates that they used this habitat type as a means to get to a more used habitat. From 2230 – 0730 h, kit fox trotting movements were less than expected in sump habitat, which may be used primarily for denning rather than foraging. From 0330 – 0730 h, industrial habitat was used less than expected for kit fox running movements. Kit fox speed may have been lower in industrial habitats during these hours due to the absence of humans or the presence of refuse.

Urban habitat was of sufficiently high quality to support kit foxes with low mortality and normal weight and offspring production. This was likely due to the widespread availability of natural and human-derived food sources and protected (i.e., fenced) areas with cover. Kit fox core areas contained a disproportionately high amount of sumps, which had food and den sites and restricted public access. The availability of sump and open habitats, which kit foxes selected for denning, may shape the distribution and abundance of the urban population. Portions of the urban landscape without these prime denning habitats may not be able to support kit foxes.

MANAGEMENT RECOMMENDATIONS

The kit foxes in Bakersfield had low mortality, similar weight and mean litter size, and high reproductive success, compared to that for rural kit foxes. Urban kit foxes appeared to have adapted to urban conditions and resources, and may contribute to the San Joaquin Valley metapopulation.

Urban kit foxes were observed crossing roads (up to four lanes), but also used culverts and a bridge to move under them, which may help explain the relatively low mortality. Vehicular mortality should be monitored around sump and open habitats. If increased mortality is observed, additional culverts may need to be placed and maintained under roads, along with animal-proof fencing to direct kit foxes to the culverts (Ng et al. 2004). Mid-sized mammals' (i.e., raccoons and skunks) use of culverts is positively correlated to culvert length and negatively correlated to culvert area (Ng et al. 2004). Small diameter culverts (i.e., 0.5 m) may serve a dual purpose by providing a place for urban kit foxes to hide from larger predators and facilitating kit fox movement in a fragmented landscape.

To promote the continued existence of kit foxes in urban settings, such as Bakersfield, habitat will need to be retained and managed to meet their needs. Urban kit foxes denned farther from roads than expected in habitat patches that were larger than expected, and thus, may benefit from the retention of larger open and sump habitat patches for denning. Urban kit foxes had less spatial overlap and smaller home ranges and core areas than their rural counterparts. The greater presence of anthropogenic food sources in cities may enable urban kit foxes to meet their energetic needs in a smaller area than kit foxes in rural, grassland habitats, where food resources may be more dispersed (Kamler et al. 2004). Kit foxes utilized open lots and sumps more than all other urban habitat types.

Golightly (1981) concluded that dens were important to kit fox energetics and a consideration in the management of this species. If kit foxes are to be retained in Bakersfield, open lots, to provide foraging and denning habitat, and uniformly-distributed, sumps that are fenced and closed to the public, to provide kit fox denning habitat, will need to be maintained throughout the city. Sump maintenance (e.g., grading or paving) may be a potential hazard to kit foxes (Murphy 1992) and should be avoided. With sensitivity to kit fox presence in the urban environment, much protection can be afforded at a low cost.

The kit fox recovery strategy identified that “connections need to be established, maintained, and promoted between populations to counteract negative consequences of inbreeding, random catastrophic events (e.g., droughts) and demographic factors” (United States Fish and Wildlife Service 1998). Urban kit foxes used the Kern River Parkway to move throughout their home range. The Kern River Parkway should be maintained and managed to facilitate kit fox movement. In addition, dog management may be required because dogs may pose a threat to urban kit foxes as they have for rural kit foxes (Ralls and White 1995, Cypher et al. 2000).

Like urban red foxes in Great Britain (Kolb 1984) and Toronto, Canada (Rosatte et al. 1991) that use railroad corridors to move throughout their home range, urban coyotes (Romsos 1998), red foxes (Lewis et al. 1993, Sallee 1998), and kit foxes used canals (including foot bridges over canals) and railroad, highway, and powerline right-of-ways for moving and denning. The continued existence of these right-of-ways, which are fenced to prohibit public access, will facilitate kit fox movement throughout the city. Kit foxes can persist in urban areas if an adequate mosaic of habitat is conserved and managed appropriately.

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Appendix A. Sites of live-captured kit foxes, domestic cats, and opossums between May 1997 and January 1998 in Bakersfield, California.

		Species captured		
Habitat type	Trap-nights	Kit foxes	Domestic cats	Opossums
Residential	5	1	0	0
Commercial	11	6	2	0
Industrial	41	13	5	0
Linear	84	19	3	1
Manicured open	53	21	0	0
Open	54	23	3	0
Sump	327	128	33	2
Total	575	211[a]	46	3

[a] Includes recaptures but excludes 32 captures which occurred when the number of traps in use was not recorded.

Appendix B. Kit fox location data and estimates for home range size, core area size, and time to independence for 28 radiocollared kit foxes that were monitored between May 1997 and January 1998 in Bakersfield, California.

		Kit Fox Locations			Home Range (km^2)		50% Fixed Kernel	
Eartag	Sex	Sequential	Daily	Independent	100% MCP[a]	95% Fixed Kernel	Core Area (km^2)	Time to Independence (h)
3468	F	-	166	149	1.17	0.41	0.05	-
5468	F	190	193	166	1.36	0.94	0.08	1.69
5702	F	190	196	184	0.72	0.40	0.06	2.29
5703[b]	F	-	8	7	-	-	-	-
5705	F	-	183	163	2.71	2.70	0.20	-
5708	F	133	164	151	1.89	1.67	0.32	1.70
5713	F	-	162	131	2.19	1.59	0.28	-
5723	F	-	190	161	0.93	0.41	0.02	-
5741	F	166	181	174	1.32	0.66	0.08	3.89
5742	F	-	213	177	2.69	2.78	0.43	-
5747	F	165	187	173	0.38	0.28	0.04	1.23
5752	F	-	182	155	0.59	0.52	0.03	-

Appendix B. Kit fox location data and estimates for home range size, core area size, and time to independence for 28 radiocollared kit foxes that were monitored between May 1997 and January 1998 in Bakersfield, California (continued).

Eartag	Sex	Kit Fox Locations			Home Range (km^2)		50% Fixed Kernel Core Area (km^2)	Time to Independence (h)
		Sequential	Daily	Independent	100% MCP [a]	95% Fixed Kernel		
5753	F	-	198	162	1.07	0.67	0.06	-
5754	F	-	79	64	1.63	2.75	0.32	-
5756	F	-	189	164	0.36	0.35	0.07	-
5674	M	167	181	168	3.33	2.69	0.46	2.61
5701	M	-	206	178	0.86	0.22	0.02	-
5704	M	230	203	193	2.16	2.40	0.39	1.80
5707	M	-	179	160	2.70	2.50	0.50	-
5710	M	187	153	145	1.21	0.37	0.05	2.67
5711	M	-	180	164	2.60	0.15	0.05	-
5712	M	-	167	137	1.90	1.30	0.11	-
5721	M	-	185	158	2.02	1.70	0.27	-

Appendix B. Kit fox location data and estimates for home range size, core area size, and time to independence for 28 radiocollared kit foxes that were monitored between May 1997 and January 1998 in Bakersfield, California (continued).

Eartag	Sex	Kit Fox Locations			Home Range (km^2)		50% Fixed Kernel Core Area (km^2)	Time to Independence (h)
		Sequential	Daily	Independent	100% MCP [a]	95% Fixed Kernel		
5743	M	219	186	165	2.13	1.14	0.09	1.90
5744	M	-	190	156	2.72	2.27	0.22	-
5746	M	-	176	147	0.31	0.04	0.01	-
5755	M	163	168	154	1.11	0.30	0.03	1.74
5757	M	-	159	143	4.49 [c]	15.58 [d]	4.00 [d]	-
Total		1810	4824	4249	-	-	-	-
Mean		181	172.3	151.75	1.72	1.2	0.16	2.15
SE		9.04	7.62	6.89	0.19	0.19	0.03	0.24

[a] Minimum convex polygon.

[b] Located too few times to be included in the home range and habitat use analyses.

[c] Sum of two distinct home ranges in the southeastern (3.19 km^2) and northwestern (1.31 km^2) parts of the study area, approximately 3.1 km apart.

[d] Outlier that was excluded from calculation of $\bar{x} \pm 1$ SE.

Appendix C. Weight, hind foot, and ear measurements for captured adult, subadult, and pup kit foxes in Bakersfield, California between May 1997 and January 1998.

		Male			Female				
Body Measurement	Age	n	$\bar{x}$	SE	n	$\bar{x}$	SE	Statistic[a]	p
Weight (kg)	Adult	29	2.47	0.05	32	2.16	0.03	t = -5.53	<0.001
	Subadult	7	2.09	0.11	6	1.87	0.14	t = -1.29	0.22
	Pup	20	1.73	0.04	13	1.44	0.05	t = -4.25	<0.001
Hind foot (mm)	Adult	27	125.5	1.0	31	119.8	0.8	t = -4.4	<0.001
	Subadult	6	121	1.2	5	118.4	0.9	t = -1.67	0.13
	Pup	18	121	1.2	9	112.2	1.4	t = -4.36	<0.001
Ear from notch[b] (mm)	Adult	28	81.4	0.6	31	78.6	0.7	z = 3.28	<0.001
	Subadult	6	82.5	0.6	5	78.4	1.3	t = -3.04	0.007
	Pup	19	80.1	0.8	10	75.3	1.1	t = -3.65	<0.001
Ear from rear[c] (mm)	Adult	28	84.4	0.7	31	81.5	0.7	t = -2.81	0.002
	Subadult	6	84.8	1.1	5	81.2	2.2	t = -1.56	0.15
	Pup	19	80.8	0.8	10	77.1	1.1	t = -2.6	0.007

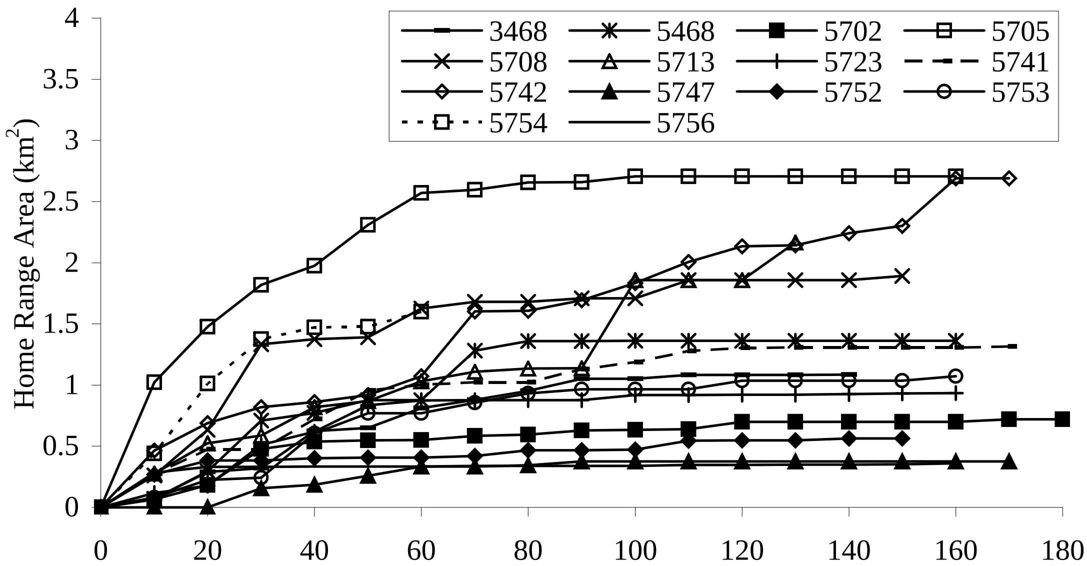
[a] I used a 2-sample t-test to determine if means differed between the sexes. For data that was not normally distributed, I used a Mann-Whitney U-test to determine if medians differed between the sexes.

[b] Tip of ear to notch at anterior base.

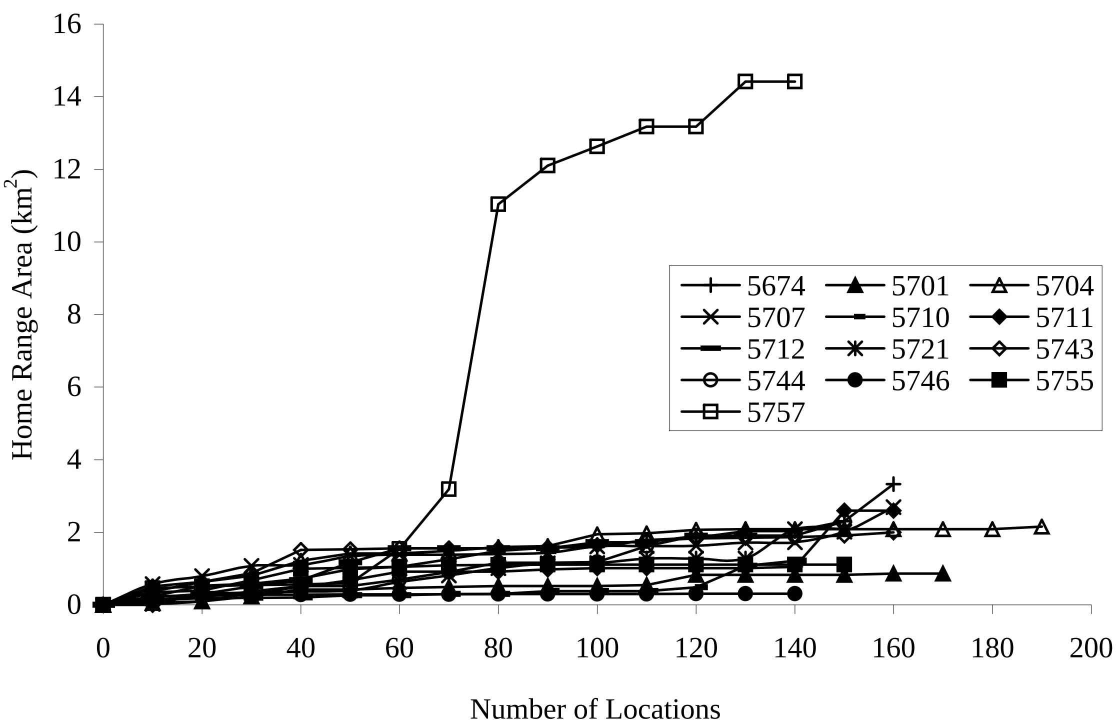
[c] Tip of ear to posterior base.

Appendix D. Area-observation curves using the 100% minimum convex polygon home range for 27 kit foxes in Bakersfield, California from May 1997 to January 1998.

Females



Males



Appendix E. The percentage of all radiocollared kit fox daily locations (n = 4,824) and passing vehicles documented in linear habitats during each hour in Bakersfield, California from September 1997 to January 1998.