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Charles J. Randel III[a]* and Nova J. Silvy[b]

[a]*Randel Wildlife Consulting, Inc., South Pasadena, CA, USA;* [b]*Wildlife and Fisheries Sciences Department, Texas A&M University, College Station, TX, USA*

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Kit fox (*Vulpes macrotis*) life history and ecology has been extensively studied in the Great Basin and California's Central Valley, with fewer studies in hot desert regions resulting in regional knowledge gaps. To augment our understanding of kit fox life history and ecology, we conducted a 2-year radio-telemetry study of the desert kit fox (*V. m. arsipus*) in southeastern California. Fifty-six desert kit foxes were fitted with morality-sensitive radio collars between October 2012 and August 2014 with individuals located five to seven nights per week to determine home range size and population density. Mean home range was 15.77 ± 1.03 km^2 (95% fixed kernel) and 18.48 ± 1.77 km^2 (minimum convex polygon), and larger than all, but one previous study. We found no difference in home range size based on sex or year. Home range overlaps were significantly larger for mated (79.3% ± 1.35%) than unmated pairs (20.9% ± 1.01%) and consistent with previous studies. Population size was estimated at 88 individuals using open population models, resulting in an estimated density of 0.34/km^2 (range 0.26−0.47/km^2) which is higher than previously reported. Our study represents the first home range and population density study for desert kit foxes in California and provided critical knowledge of this understudied kit fox population.

Keywords: California; desert kit fox; home range; population density

Introduction

The desert kit fox (*Vulpes macrotis arsipus*) inhabits hot, arid environments of the Colorado and Sonoran deserts (McGrew 1979). While kit foxes have been extensively studied in other portions of their range (e.g., California's Central Valley and Great Basin), fewer studies have been conducted in the southwest United States' hot deserts (O'Farrell & Gilbertson 1986; Zoellick & Smith 1992; Miller et al. 2000; Girard 2001). Cypher and List (2014) identified a lack of current distribution and population estimates as the most significant kit fox range-wide data gap. While not specifically enumerated by Cypher and List (2014), regional knowledge gaps including home range and abundance estimates also are lacking.

Life history and ecology traits of widely distributed species, like the kit fox (*Vulpes macrotis*), are known to vary based on local conditions. Vegetation community (Šálek et al. 2015), food resources (Šálek et al. 2014), and anthropogenic activity (Gehrt et al. 2009; Kenaga et al. 2013), among others, have been linked to variation in life history and ecology traits at local and regional scales. In the absence of reliable local or regional data resource managers must make inferences regarding a species distribution based on inadequate data.

Our objectives for this study were to estimate: (1) seasonal and annual home range size (fixed kernel and minimum convex polygon), (2) home range overlap, and (3) population densities of desert kit foxes in southeastern California.

Materials and methods

Study area

Our study area (261 km^2) was located in the upper Chuckwalla Valley, Riverside County, California (33°43′N, 115°24′W). Elevation ranged from 200 to 350 m above mean sea level. Climate was typical of the Colorado Desert having a mean annual temperature of 23.4 °C; December is the coldest month (5−19.4 °C) and July the hottest (27.6−42.7 °C). Mean annual precipitation was 7.82 cm, exhibiting a bimodal pattern, with major precipitation occurring as winter rain (January and February) and summer monsoons (August and September; Tubbs 1972; Adams & Comrie 1997; Higgins et al. 2004; Vera et al. 2006; Holmgren et al. 2010). Sonoran creosote bush (*Larrea tridentata*) scrub and dry desert wash woodland (Holland 1986; Sawyer et al. 2009) were the dominant vegetation communities.

Capture and marking

We used wire mesh live traps (Model 208, Tomahawk Live Traps, Hazelhurst, WI, USA) baited with meat scraps (e.g., bacon, chicken, and beef) to capture kit foxes from October 2012 to August 2014. Traps were placed along linear transects consisting of 10 traps spaced at 250−350 m intervals, with traps opened 30 min before sunset. Traps were checked 30 min before sunrise and all captured individuals processed no later than 1.5 hours after sunrise.

*Corresponding author. Email: randel.wildlife@gmail.com

Kit foxes were removed from traps by coaxing captured individuals into a canvas bag (Cypher et al. 2009), where they were physically restrained and weights collected (taring bag weight). While physically restrained in the canvas bag we exposed the individuals' head and fitted a muzzle with eye cover to reduce stress during handling and removed prior to release. All individuals were sexed, ear and PIT tagged, and fitted with mortality sensitive VHF radio collars (V5C 162C, Sirtrack, Havelock North, NZ). All capture and marking procedures were conducted in accordance with American Society of Mammologists guidelines for the use of wild animals in research (Sikes et al. 2011) and approved by the California Department of Fish and Wildlife (Scientific Collecting Permit #7706).

Telemetry

Standard radio telemetry techniques (e.g., triangulation and homing; Millspaugh et al. 2012) were used to locate kit foxes —five to seven nights per week using a vehicle-mounted 9-element antenna. Radio-telemetry locations were taken from ≥ 3 pre-established telemetry stations <15 min apart using triangulation techniques. We used the maximum likelihood estimator in Location of A Signal (LOAS; Hegymagas, Hungary) software to determine nightly kit fox locations, censoring locations with an estimated error ellipse >2.5 ha. All locations were plotted in ArcGIS 10.1 (ESRI, Redlands, CA) and exported for analyses in Geospatial Modeling Environment (GME; Beyer 2012).

Home range estimation

We created individual annual fixed kernel (50% and 95%) and 100% minimum convex polygon (MCP) home ranges using the "kde" and "genmcp" functions in GME (Beyer 2012), respectively, using telemetry, homing, and visual location data. We defined three seasonal periods: pup-rearing (March−July), dispersal (August−October), and pair formation (November−February) based on kit fox reproductive biology and calculated fixed kernel and MCP estimates as described above. We used Mann−Whitney *U* test (Minitab Inc., State College, PA) to compare male and female home range size estimates for each period by home range estimator method. We used a one-way analysis of variance (Minitab Inc., State College, PA) to test for differences in mean seasonal and annual home range estimates based on period. Using multiple home range estimators allowed comparisons to a larger body of previous studies in Arizona, California, Utah, and Mexico.

Home range overlap

We used the "isectpolypoly" function in GME (Beyer 2012) to determine the percent overlap of 95% fixed kernel home ranges for four dyad groupings: male−male, female−female, male−female unpaired, and male−female paired. We averaged the overlap for each individual within a dyad to obtain a mean home range overlap and used a one-way analysis of variance to test for differences between groups.

Population size and density

We combined radio telemetry and capture detections to generate individual encounter histories for 101 desert kit foxes to estimate population size and density. We used the Cormack-Jolly-Seber (Krebs 1999) open population model to estimate population size and divided the population estimate by the study area size (261 km^2) to obtain a density estimate.

Results

Annual and seasonal home range

We found no difference between male and female annual kernel core and home range size, nor did we find a difference between male and female seasonal kernel core and home range size. We pooled male and female core and home ranges based on period for further analysis. We found no difference in mean core or home range size based on season in 2012−2013 ($F_{2,89} = 0.05$, $P = 0.948$ and $F_{2,89} = 0.02$, $P = 0.979$, respectively; Table 1); nor did we find a difference in mean core or home range size based on season in 2013−2014 ($F_{1,59} = 1.46$, $P = 0.232$ and $F_{1,59} = 0.03$, $P = 0.874$, respectively; Table 2).

We additionally found no difference between male and female seasonal and annual MCP home range estimates. We pooled male and female MCPs based on period for further analysis. We found no difference in MCP home range size based on season in 2012−2013 ($F_{2,89} = 1.42$, $P = 0.246$) or 2013−2014 ($F_{1,59} = 1.32$, $P = 0.254$; Table 3).

Table 1. Male (M), female (F), and combined (All) kit fox seasonal (e.g., pair formation, pup-rearing, and dispersal) and annual kernel core (50%) and home range (95%) estimates ($\bar{x} \pm$ SE; km^2), 2012−2013, southeastern California.

	2012−2013					
	50%			95%		
	M	F	All	M	F	All
Pair Formation	3.65 ± 0.60	2.81 ± 0.31	3.20 ± 0.33	15.60 ± 2.44	13.17 ± 1.36	14.31 ± 1.35
Pup-Rearing	3.61 ± 0.46	3.29 ± 0.42	3.26 ± 0.30	13.25 ± 1.59	15.15 ± 2.02	14.23 ± 1.29
Dispersal	3.26 ± 0.41	3.45 ± 0.29	3.35 ± 0.25	13.16 ± 1.51	16.18 ± 1.58	14.61 ± 1.11
Annual	3.66 ± 0.40	3.40 ± 0.39	3.53 ± 0.28	15.91 ± 1.52	15.63 ± 1.44	15.77 ± 1.03

Table 2. Male (M), female (F), and combined (All) kit fox seasonal (e.g., pair formation, pup-rearing, and dispersal) and 10-month kernel core (50%) and home range (95%) estimates ($\bar{x} \pm$ SE; km^2), 2013–2014, southeastern California.

	2013–2014					
	50%			95%		
	M	F	All	M	F	All
Pair formation	2.33 ± 0.23	2.68 ± 0.51	2.52 ± 0.29	11.27 ± 1.36	11.20 ± 2.01	11.24 ± 1.24
Pup-rearing	2.89 ± 0.51	4.04 ± 1.48	3.51 ± 0.82	11.02 ± 2.37	10.90 ± 0.95	10.96 ± 1.19
Dispersal	–	–	–	–	–	–
Annual	2.74 ± 0.49	2.49 ± 0.28	2.60 ± 0.27	13.51 ± 3.06	11.09 ± 1.14	12.15 ± 1.47

Table 3. Kit fox seasonal (e.g., pair formation, pup-rearing, and dispersal) and annual 100% MCP home range estimates ($\bar{x} \pm$ SE; km^2), 2012–2014, southeastern California.

	2012–2013			2013–2014		
	M	F	All	M	F	All
Pair formation	10.06 ± 1.57	10.96 ± 1.83	10.52 ± 1.20	8.84 ± 1.72	7.52 ± 0.99	8.15 ± 0.96
Pup-rearing	9.56 ± 1.20	15.69 ± 2.82	12.72 ± 1.64	9.72 ± 1.84	9.81 ± 1.05	9.77 ± 1.01
Dispersal	6.55 ± 0.96	11.28 ± 2.22	9.30 ± 1.40	–	–	–
Annual	16.84 ± 1.82	20.04 ± 2.99	18.48 ± 1.77	15.95 ± 5.01*	12.86 ± 1.45*	13.96 ± 1.97*

* indicates 10-month estimate.

Home range overlap and population density

We found a statistically significant ($F_{3,152} = 31.32$, $P = 0.000$) effect of group on annual home range overlap. A post hoc comparison using the Tukey honest significant difference (HSD) test indicated mean home range overlap for mated pairs ($\overline{X} = 79.3\%$, SD = 5.58) was significantly different than unmated pairs ($\overline{X} = 20.9\%$, SD = 19.4; Figure 1).

Population size and density

A total of 101 encounter histories were generated using radio telemetry and capture data. The Cormack-Jolley-Seber open population model estimated 88 kit foxes (range 68–123) were present in the study area. Our resulting density estimate was 0.34/km^2 (range 0.26–0.47/km^2).

Discussion

List and Macdonald (2003) cautioned comparing results between home range studies due to the influence of the estimator of choice (e.g., kernel or MCP). To facilitate comparison and more accurately represent our study results we calculated annual and seasonal home ranges

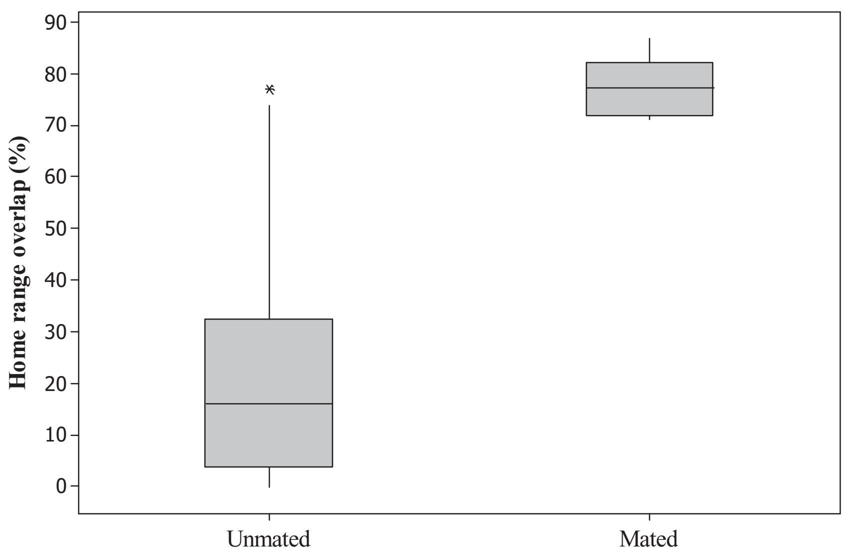

Figure 1. Percent 95% fixed kernel annual home range overlap for unmated and mated kit fox pairs, Upper Chuckwalla Valley, California (2012–2014).

using both 100% MCP and 95% fixed kernel, as well as core range using the 50% fixed kernel.

Annual male MCP home range size during our study was similar to those reported in western Arizona (16.8 ± 2.6 km^2; Zoellick & Smith 1992) and 4.9 times larger than those reported in Utah (3.4 km^2; O'Neal et al. 1987). Annual female MCP home range size during our study was 1.9 times larger than western Arizona (10.7 ± 1.2 km^2; Zoellick and Smith (1992) and nearly 6.7 times larger than Utah (3.0 km^2; O'Neal et al. 1987). The mean combined annual MCP home range during our study was 1.3 times larger than western Arizona (14.2 ± 1.92 km^2; Zoellick & Smith 1992), 1.6 times larger than Carrizo Plains National Monument (11.6 ± 0.9 km^2; White & Ralls 1993), 1.7 times larger than Mexico (11.0 ± 4.6 km^2; List & Macdonald 2003), 4.3 times larger than the Naval Petroleum Reserve in California (4.34 ± 1.43 km^2; Cypher et al. 2001), and nearly 5.0 times larger than the Barry M. Goldwater Air Force Range, Arizona (3.73 ± 0.28 km^2; Bowles et al. 1995).

Mean annual kernel home range size during our study was 15.91 ± 1.52 km^2 for males, 15.63 ± 1.44 km^2 for females, and 15.77 ± 1.03 km^2 when combined (Table 1). Kernel home range size during our study was 1.3 times larger than from Mexico (11.5 ± 4.1 km^2; List and Macdonald 2003), 63% larger than Lokern Natural Area, California (5.91 ± 0.44 km^2; Nelson et al. 2007). Conversely, kernel home range size during our study was 23.1% smaller than kernel home ranges from Utah from 2010 to 2012 (20.5 km^2; Dempsey et al. 2014).

Seasonal kernel home range sizes during our study were smaller than those estimated by Dempsey et al. (2014). The decreased seasonal home range size observed during our study is likely due to different season lengths used in each study.

Mean kit fox annual core range size during our study was 3.66 ± 0.40 km^2 for males, 3.40 ± 0.39 km^2 for females, and 3.53 ± 0.28 km^2 when combined (Table 1). Annual kit fox core range sizes have not been previously reported and therefore not comparable to previous studies.

Annual mated pair home range overlaps during our study (79.3%) were higher than previously reported for western Arizona (75%; Zoellick & Smith 1992), California (70%; White & Ralls 1993), and Utah (74.2%; Daneke et al. 1984). we found a similar pattern for unmated dyad groups with home range overlaps during our study (20.9%) being higher than western Arizona (12%; Zoellick & Smith 1992), California (13.7%; White & Ralls 1993), and Utah (Daneke et al. 1984) where no overlap was found between neighboring unmated pairs.

Population density

Desert kit fox densities were estimated as 0.34 ± 0.04/km^2. Density estimates were similar to densities at the Carrizo Plain, California (0.19), from 1989–1992 (White & Ralls 1993), Dugway Proving Ground, Utah (0.17), from 1966–1969 (Egoscue 1975), and the Desert Ecology Range, Utah (0.16), from 1983 (O'Neal et al. 1987). White and Garrott (1997) summarized 11 kit fox studies from 1955 to 1996 across the range reporting a kit fox densities range of 0.14–1.57/km^2, with a mean density of 0.25/km^2 and median reported density of 0.24/km^2.

Differences in vegetation community composition, prey availability, study methods and objectives, and/or small sample size in previous studies could potentially explain larger home range size and decreased population density estimates during our study than those previously reported.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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