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FULL RESEARCH ARTICLE

Artificial dens for the conservation of San Joaquin kit foxes

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San Joaquin kit foxes (*Vulpes macrotis mutica*) are federally endangered and California threatened, primarily due to profound habitat loss. Kit foxes are obligate den users and in some locations den availability may be limited due to natural or anthropogenic factors. We conducted a study during 2001–2004 to determine whether kit foxes would use artificial dens, and if so, whether they exhibited a preference for den designs or construction materials. We tested six different den designs, four different construction materials, and two different chamber types. We constructed 34 dens in 12 locations in Bakersfield, CA. We conducted 9,271 den checks and detected kit foxes or their sign on 1,198 of those checks. Kit foxes may not have found one of the locations, but kit foxes used (i.e., entered) 29 of the 31 dens at the other 11 locations. Kit foxes did not exhibit preferential use of any designs, materials, or chamber types. Internal conditions (i.e., temperature and relative humidity) within artificial dens can provide thermoregulatory and moisture conservation benefits to foxes, although these benefits were not as strong as those provided by natural dens. At least nine other species were documented using the artificial dens, including some that might compete with kit foxes. San Joaquin kit foxes readily used artificial dens and clearly such dens can be used to mitigate den losses or to enhance habitat for kit foxes. Due to lower cost and ease of installation, we recommend installing two-entrance dens constructed of high-density polyethylene plastic with an irrigation valve box for a subterranean chamber.

Key words: artificial dens, conservation, internal climate, mitigation relative humidity, San Joaquin kit fox, San Joaquin Valley, temperature, threatened, urban environment

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The San Joaquin kit fox (*Vulpes macrotis mutica*; SJKF) is endemic to the San Joaquin Desert in central California (U.S. Fish and Wildlife Service [USFWS] 1998; Germano et al. 2011). The SJKF once was widely distributed in arid shrubland and grassland habitats in the San Joaquin Valley, Carrizo Plain, and Cuyama Valley with intermittent populations occurring in the Salinas Valley. Considerable habitat in this region has been converted to agricultural, urban, and industrial uses (Kelly et al. 2005; Cypher et al. 2013). Due to this profound habitat loss, the SJKF was listed as federally endangered in 1967 and California threatened in 1980 (USFWS 1998).

A significant attribute of SJKF ecology is their obligate use of subterranean dens (Grinnell et al. 1937). Use of dens by most other North American canids is limited to the period of parturition and early young rearing. However, kit foxes, along with closely related swift foxes, (*V. velox*) are unique in using dens daily throughout the year (Cypher 2003). Dens are used not only for rearing young but also for diurnal resting, predator avoidance, thermoregulation, and water conservation (Koopman et al. 1998). Consequently, kit foxes annually use multiple dens, which are dispersed throughout each individual's home range. At Elk Hills in western Kern County, kit foxes used an average of 11.8 dens per year with a maximum of 16 dens (Koopman et al. 1998). At Camp Roberts in northern San Luis Obispo County, the average number of dens used annually by each individual SJKF over 3 years ranged from 11.4 to 15.5 dens with a maximum of 49 dens used by one fox in one year (Reese et al. 1992). Thus, dens are a critical resource for kit foxes and den availability can affect kit fox occupancy and persistence in a given area.

Past and continuing habitat fragmentation and degradation within the range of the SJKF can result in lower densities of foxes or even intermittent occupation of impacted areas (USFWS 1998). Without routine maintenance by foxes, dens deteriorate and eventually disappear with lack of use, and therefore infrequent use of an area by kit foxes can result in low den availability. An absence or scarcity of dens can inhibit use of an area by kit foxes, thus further limiting the abundance and distribution of the SJKF. Similarly, lands that may be "retired" from other uses (e.g., agriculture) and restored as habitat would also be lacking in dens, which could inhibit colonization by kit foxes. Although kit foxes are able to dig new dens, the creation of a network of dens required to successfully occupy an area may take months or even years.

Artificial dens are a potential solution to a dearth of natural kit fox dens. Artificial burrows have been constructed and successfully used by a number of species including burrowing owls (*Athene cunicularia*; Smith and Belthoff 2001), Chatham petrels (*Pterodroma axillaries*; Sullivan et al. 2000), desert tortoises (*Gopherus agassizii*; Bulova 1993), and eastern woodrats (*Neotoma floridana*; Horne et al. 1998). Artificial dens also have occasionally been constructed within the range of the SJKF to mitigate the destruction of natural dens or to enhance habitat (Harrison et al. 2011b). However, use of artificial dens by kit foxes and preference by foxes for particular designs or den materials have not been assessed.

During 2001–2004, we investigated use of artificial dens by SJKF in the city of Bakersfield. Our goal was to determine whether artificial dens might constitute a useful conservation tool for SJKF. The specific objectives of our investigation were to (1) determine whether kit foxes would use artificial dens, (2) determine whether kit foxes exhibited any preference among den designs and construction materials, (3) determine for what purposes kit foxes used artificial dens (e.g., resting, pup-rearing), and (4) compare internal climate conditions (temperature and relative humidity) between natural dens and artificial den designs.

METHODS

Study Area

We assessed use of artificial dens by SJKF at sites in the city of Bakersfield, California. Bakersfield is located in Kern County in the southern San Joaquin Valley, and is bounded by occupied SJKF habitat to the northeast and southwest (Cypher et al. 2013). The current human population of Bakersfield is ca. 390,000. Average elevation is 124 m, with little topographic variation. Climate is characterized by hot, dry summers and cool winters with infrequent precipitation in the form of rain. Average temperatures range from 13.7 C and 3.9 C in December and 36.2 C and 21.4 C in July. Mean annual precipitation is 164 mm (NOAA 2020).

A robust SJKF population occurs in the urban environment of Bakersfield (Cypher 2010; Cypher and Van Horn Job 2012). Kit fox numbers have been estimated at over 100 animals and possibly up to 400. Demographically, the population exhibits high survival and reproduction. Ecologically, the foxes forage for both natural and anthropogenic foods and use a variety of urban habitat types (Cypher and Warrick 1993; Cypher 2010; Deatherage et al. in press). They establish earthen dens in undeveloped lots, school campuses, golf courses, canal banks, drainage basins, and railroad and power line rights-of way. Kit foxes also have been found denning in culverts, pipes, rubble piles, and under buildings (Frost 2005; Cypher 2010).

We chose this study area because SJKF were abundant (Cypher 2003), thereby increasing the potential to observe use of artificial dens by kit foxes. Also, natural dens were abundant in the study area (Frost 2005; Bjurlin et al. 2005; CSU-Stanislaus Endangered Species Recovery Program unpublished data). Thus, we assumed that kit foxes would only use artificial dens by choice and any preferences by foxes for particular designs or materials would be easier to detect.

Den Designs, Materials, and Installation

We used six different designs of artificial dens: two surface den designs, two designs of subterranean dens without chambers, and two designs of subterranean dens with chambers. The two surface den designs consisted of one straight pipe either 3 m long or 6.1 m long. The pipes were laid on the ground surface and covered with ca. 0.5 m of dirt to provide some thermal insulation (Fig. 1 and 2). Both ends of each pipe were left open to provide two entrances into the den. The longer design would allow foxes to be farther away from the entrances and might give the foxes a greater sense of security. Therefore, they might be more inclined to use this longer design compared to the shorter design.

The second two designs were subterranean dens without chambers. One design consisted of a 3-m length of pipe buried underground at approximately a 30-degree angle (Fig. 3). The upper end of the pipe was exposed thus providing an entrance. The lower end, although buried, was not capped thereby providing an opportunity for foxes to excavate farther and expand the den if they desired. The other non-chambered subterranean design consisted of a "U" shaped configuration (Fig. 4). A 1-m length of pipe was buried approximately 0.5 m underground. Each end of that pipe connected at a 45-degree angle to 1.5-m pipes that extended to the surface thereby providing two entrances to the den.

The last two designs were subterranean dens with chambers. One design consisted of a 1.5-m length of pipe with one end exposed and the other end buried. The buried end was

Figure 1. A 3-m long concrete surface den for San Joaquin kit foxes before and after being covered with soil in Bakersfield, CA.

Figure 2. A 6.1-m long metal surface den being used by San Joaquin kit foxes in Bakersfield, CA.

Figure 3. A PVC one-entrance subterranean den being installed for San Joaquin kit foxes in Bakersfield, CA.

Figure 4. A HDPE two-entrance subterranean den being installed for San Joaquin kit foxes in Bakersfield, CA.

connected to a subterranean chamber using either a 45-degree or a 90-degree elbow joint (Fig. 5). The other design was similar, but it had a second entrance pipe and elbow joint leading into the opposite side of the chamber (Fig. 6). The bottoms of the chambers were buried approximately 1–1.5 m deep, and the bottoms were left open thereby allowing foxes to excavate further and expand the dens if desired.

Pipes used to construct artificial dens consisted of four materials (see Figs. 1–7): Schedule 40 polyvinylchloride (PVC), corrugated galvanized aluminum (metal), double-walled high-density polyethylene plastic (HDPE), and cement. The cement pipes were 25 cm (10 in) in diameter while all other types of pipes were 20 cm (8 in) in diameter. Strips 10 cm in width were cut out of the bottom of HDPE and PVC pipes to enhance traction for foxes and water drainage. Elbow joints consisted of PVC or HDPE with a 45-degree bend, or galvanized aluminum with a 90-degree bend. All pipe-pipe and pipe-elbow connections were covered with an approximately 60 x 20-cm strip of plastic (ca. 3-mm thick carpet runner) to exclude dirt from entering through the connection.

Two types of structures were used for artificial den chambers. One chamber type consisted of a hard plastic box used commercially to cover underground valves that are part of landscape irrigation systems (Fig. 5). The box measured 61 x 51 x 51 cm. The second chamber type consisted of a small-sized igloo style doghouse or "dogloo" (Fig. 6). The dogloos were made of hard plastic, measured approximately 61 cm tall, and had a diameter of approximately 76 cm at their base. The entrance pipes were connected to the chambers through holes cut in the sides of the chambers. All den materials were purchased or ordered through local businesses in Bakersfield.

Figure 5. A HDPE one-entrance chambered den with an irrigation box chamber being installed for San Joaquin kit foxes in Bakersfield, CA.

Figure 6. A HDPE two-entrance chambered den with a dogloo chamber being installed for San Joaquin kit foxes in Bakersfield, CA.

We chose locations in which to establish artificial dens based on several criteria. We knew of areas frequented by kit foxes based on telemetry data, sign (e.g., dens, tracks, scats), and opportunistic observations of foxes (Frost 2005; Bjurlin et al. 2005; CSU-Stanislaus Endangered Species Recovery Program, unpublished data). Such areas were targeted because establishing artificial dens in these areas would increase the potential for discovery by foxes. We also chose locations that we would be able to freely access to conduct monitoring. Finally, dens were only installed on sites where we secured permission from landowners. The final sites chosen included the tops of banks surrounding municipal sumps (storm water drainage basins), canal rights-of-way, golf courses, and a field within a natural area on a university campus. All of these sites were within fences, which reduced human access, but that were permeable to kit foxes.

At each location, a "complex" of three dens was installed (Fig. 7). Each complex included a surface den, a subterranean den, and a chambered subterranean den. Our intent was to provide foxes with a choice of designs. However, no surface dens were installed at two golf course locations, per the landowner's request. Within a given complex, the dens were constructed of different materials to provide foxes with a choice of materials. Most of the artificial dens were installed using hand tools. However, for complexes located in five sumps owned by the city of Bakersfield, a backhoe and crew were provided to excavate holes for the dens although the dens still were buried by hand. After installation, 2-3 shovels of dirt were tossed down each den entrance to provide a more natural feeling floor.

Figure 7. An artificial den complex being installed for San Joaquin kit foxes in Bakersfield, CA. A concrete two-entrance non-chambered subsurface den is being installed on the upper slope and a metal two-entrance chambered den with a dogloo chamber is being installed on the lower slope. A surface den also was installed on the flat ground above the other dens.

Monitoring Den Use

To determine whether kit foxes were using the dens, we used sifted soft dirt or diatomaceous earth to create a track station approximately 0.5 m^2 in area in front of each den entrance. We also extended this track station into the den entrance to help determine whether foxes were actually entering the dens. Our goal was to visit each den complex every 2-3 days to assess use by kit foxes. Use by other species also was recorded. Track station data were supplemented with other information such as observations of kit foxes (or other species) entering or exiting dens during monitoring. Also, kit foxes with radio-collars were being monitored in the study area concurrently for another study, and collared foxes occasionally were tracked to the artificial dens. Finally, in spring 2004, trail cameras (Cuddeback Trail Cameras; Non Typical, Green Bay, WI) were used to determine whether pups were present at dens exhibiting possible pup sign (e.g., small tracks and scats, digging, prey remains), and this information also was used to supplement the track station data.

Kit fox detection rates were calculated for each den by dividing the number of kit fox detections by the number of times a den was monitored. Prior to statistical analysis, these rates were transformed using an arcsin transformation to normalize data (Zar 1984). Mean transformed rates were then compared among den categories (surface, subterranean, and chambered) and among materials (cement, metal, PVC, and HDPE) using a one-way analysis of variance and F-test. Mean rates also were compared between the two surface den types, the two subterranean den types, the two chambered den types, and the two chamber types using t-tests.

Den Climate Measurements

We measured the temperature (°C) and relative humidity (%) of natural and artificial dens in Bakersfield with a HOBO Micro Station 4-channel data logger (Onset Computer Corporation, Pocasset, MA) outfitted with 3-m and 20-m thermistor temperature/relative humidity probes. The two probes provided near-identical temperature (within 0.1 °C) and humidity (within 1%) readings. Measurements were conducted during two periods in 2003: 5–20 August (summer) and 8–28 December (winter). To standardize for variation due to time of day, we collected measurements from dens only during 1200–1500h.

We had identified natural dens from a concurrent investigation in which radio-collared kit foxes were being tracked to dens several times per week. From these known natural dens, we selected dens that were in the vicinity of artificial den complexes and that had been used by a radio-collared fox within the previous four months. The selection of dens included both single-entrance and multiple-entrance dens.

We inspected all dens, both natural and artificial, using a burrow probe to ensure that each den was not occupied by foxes or other species prior to taking measurements. Animals in the dens likely would elevate temperature and humidity thereby confounding our measurements. Also, we wanted to avoid harassing animals when we inserted the probes. We deployed the 20-m probe into dens using a small, remote controlled tractor outfitted with a miniature infrared camera. This was a "home-made" system constructed by a colleague. For chambered dens, we situated the probe in the middle of the chamber. For subterranean dens, we situated the probe at the furthest below ground point in the tunnel for the one-entrance dens, and in the middle of the underground 1-m section for the two-entrance dens. For surface dens, we positioned the probe at the midpoint of the pipe. For natural dens, we measured conditions at a point between 2 to 4 m into the den, which was similar to the distance at which measurements were collected in the artificial dens. For all dens assessed, we recorded ambient temperature and relative humidity measurements using the 3-m probe positioned just within the den entrance (usually about 0.5 m in) so that it was not in direct sunlight.

After positioning both probes, we waited 10 min before recording measurements to allow each probe to fully equilibrate to the surrounding conditions (as per manufacturer recommendations). After the 10-min equilibration period, the probes recorded temperature and relative humidity every 10 sec for 5 min into the data logger. The logger simultaneously logged den conditions and ambient conditions. The final values recorded by the logger represented a mean of the measurements recorded during the 5-min monitoring period.

For both the summer and winter periods, we used *t*-tests to compare mean temperature and mean relative humidity between: natural and artificial dens; both den types and ambient conditions; one-entrance and two-entrance natural dens; surface and subterranean artificial dens; one-entrance and two-entrance subterranean artificial dens; and chamber types. For both the summer and winter periods, we used a one-way analysis of variance to compare mean temperature and mean relative humidity among the subterranean artificial dens constructed from the four different materials.

All statistical tests were conducted in SPSS Statistics (ver. 27; IBM Corporation, Armonk, NY). We used $\alpha = 0.05$ for all tests.

RESULTS

Artificial den complexes were installed at 11 locations during July-September 2001 (Table 1). An additional complex (Sump 56) was installed in July 2002. A total of 34 dens were installed among the 12 complexes (Table 1). From July 2001 to June 2004, 9,271 den monitoring checks were conducted and kit foxes were detected on 1,198 of those checks. Eleven of the 12 complexes were used by kit foxes. No visits by kit foxes to the Calloway complex were ever detected. Kit foxes likely were not present in this area during the study based on field observations, surveys, and trapping efforts related to the radio-collar study. We excluded the dens in this complex from the analyses of kit fox use of designs and materials. Kit foxes used 29 of the remaining 31 dens (Table 1). Kit foxes were detected at 9 dens within 1–3 days following installation and at 14 dens within 7 days of installation (Table 1). First detections at the remaining dens ranged from 11–922 days.

Kit foxes used dens of all designs and materials. Mean kit fox detection rates (Table 2) did not differ statistically among the three den-type categories ($F_{2,28} = 1.025, p = 0.372$) or among the four pipe materials ($F_{3,27} = 0.730, p = 0.543$). Mean detection rates also were not different between the two surface den designs ($t_7 = -0.764, p = 0.470$), the two subterranean den designs ($t_9 = -0.578, p = 0.577$), the two chambered den designs ($t_9 = -0.167, p = 0.871$), or the two chamber types ($t_9 = -1.144, p = 0.282$). Kit fox family groups (i.e., adults and pups) were confirmed using den complexes on five occasions. Family groups used the dens in the Sump 143, Sump 125, and 7 Oaks East complexes in spring 2003, and the dens in the Sump 125 and City canal complexes in spring 2004.

Other species also were detected using the dens. These other species included feral cats (*Felis catus*; 34 dens, 12 complexes), striped skunks (*Mephitis mephitis*; 17 dens, 7 complexes), red foxes (*V. vulpes*; 5 dens, 3 complexes), raccoons (*Procyon lotor*; 3 dens, 1 complex), opossums (*Didelphis virginiana*; 16 dens, 8 complexes), California ground squirrels (*Otospermophilus beechyi*; 25 dens, 10 complexes), desert cottontails (*Sylvilagus*

Table 1. Artificial dens installed in Bakersfield, CA and use by San Joaquin kit foxes (KF), July 2001–June 2004.

Complex	Site	Installed	Design	Materials	Den checks	KF detections	KF detection rate	Days to first KF visit
FACT	Field	7/17/01	Surface - 3 m	Cement	306	30	0.098	1
FACT	Field	7/17/01	Subterranean - 1 entrance	Metal	306	24	0.078	1
FACT	Field	7/17/01	Chambered - 1 entrance	HDPE w/box	308	26	0.084	1
Brimhall	Canal	7/25/01	Surface - 3 m	Metal	295	0	0	-
Brimhall	Canal	7/25/01	Subterranean - 1 entrance	PVC	295	1	0.003	922
Brimhall	Canal	7/25/01	Chambered - 2 entrance	HDPE w/dogloo	295	1	0.003	922
Riverlakes	Canal	7/26/01	Surface - 3 m	PVC	295	1	0.003	557
Riverlakes	Canal	7/25/01	Subterranean - 2 entrance	HDPE	296	1	0.003	557
Riverlakes	Canal	7/25/01	Chambered - 1 entrance	Metal w/box	296	0	0	-
Calloway	Canal	7/31/01	Surface - 3 m	HDPE	241	0	0	-
Calloway	Canal	7/31/01	Subterranean - 1 entrance	Metal	241	0	0	-
Calloway	Canal	7/31/01	Chambered - 2 entrance	PVC w/box	241	0	0	-
Sump 143	Sump	8/3/01	Surface - 6.1 m	Cement	291	41	0.141	7
Sump 143	Sump	8/3/01	Subterranean - 2 entrance	Metal	291	96	0.330	3
Sump 143	Sump	8/3/01	Chambered - 1 entrance	PVC w/box	291	104	0.357	2
7 Oaks East	Golf course	8/7/01	Subterranean - 1 entrance	PVC	263	23	0.087	65
7 Oaks East	Golf course	8/7/01	Chambered - 2 entrance	HDPE w/box	263	40	0.152	65
7 Oaks West	Golf course	8/9/01	Subterranean - 2 entrance	HDPE	263	21	0.080	63
7 Oaks West	Golf course	8/9/01	Chambered - 1 entrance	PVC w/dogloo	263	70	0.266	63

Table 1. continued.

Complex	Site	Installed	Design	Materials	Den checks	KF detections	KF detection rate	Days to first KF visit
City canal	Canal	8/14/01	Surface - 6.1 m	Metal	286	10	0.035	654
City canal	Canal	8/14/01	Subterranean - 1 entrance	Cement	286	38	0.133	13
City canal	Canal	8/14/01	Chambered - 2 entrance	PVC w/box	286	29	0.101	7
Sump 125	Sump	8/15/01	Surface - 6.1 m	HDPE	286	90	0.315	2
Sump 125	Sump	8/15/01	Subterranean - 2 entrance	PVC	286	153	0.535	2
Sump 125	Sump	8/15/01	Chambered - 2 entrance	Cement w/dogloo	286	146	0.510	2
Sump 51	Sump	8/22/01	Surface - 6.1 m	PVC	282	15	0.053	5
Sump 51	Sump	8/22/01	Subterranean - 2 entrance	Cement	282	43	0.152	5
Sump 51	Sump	8/22/01	Chambered - 2 entrance	Metal w/dogloo	282	50	0.177	5
Sump 1	Sump	9/10/01	Surface - 6.1 m	HDPE	271	1	0.004	36
Sump 1	Sump	9/10/01	Subterranean - 2 entrance	PVC	271	7	0.026	11
Sump 1	Sump	9/10/01	Chambered - 1 entrance	Cement w/box	271	13	0.048	2
Sump 56	Sump	7/24/02	Surface - 3 m	Cement	184	26	0.141	31
Sump 56	Sump	7/24/02	Subterranean - 1 entrance	HDPE	186	45	0.242	47
Sump 56	Sump	7/24/02	Chambered - 1 entrance	PVC w/dogloo	186	53	0.285	47

Table 2. Mean detection rates for San Joaquin kit foxes at artificial dens by den design and materials, Bakersfield, CA, July 2001–June 2004.

Den group	n	Mean (SE) detection rate
Design:		
Surface – 3 m	4	0.061 (0.035)
Surface – 6.1 m	5	0.109 (0.056)
Subterranean – 1 entrance	5	0.109 (0.039)
Subterranean – 2 entrance	6	0.188 (0.084)
Chambered – 1 entrance	6	0.173 (0.060)
Chambered – 2 entrance	5	0.189 (0.086)
Design category:		
Surface	9	0.088 (0.034)
Subterranean	11	0.152 (0.049)
Chambered	11	0.181 (0.048)
Material:		
Cement	7	0.175 (0.058)
Metal	6	0.103 (0.053)
PVC	10	0.172 (0.057)
HDPE	8	0.110 (0.042)
Chamber:		
Box	6	0.124 (0.051)
Dogloo	5	0.248 (0.082)

audubonii; 15 dens, 7 complexes), burrowing owls (*Athene cunicularia*; 8 dens, 3 complexes), and side-blotched lizards (*Uta stansburiana*; 10 dens, 6 complexes).

Statistical results for comparisons of internal den conditions (temperature, relative humidity) are presented in Table 3. In summer, mean temperature in natural dens and artificial dens was cooler than mean ambient temperature, and mean relative humidity was higher in both types of dens compared to ambient humidity. In winter, mean temperature and mean relative humidity were similar to mean ambient values. Mean temperature in natural dens was lower in summer and higher in winter compared to artificial dens. Mean relative humidity was higher in natural dens in summer compared to artificial dens, but did not differ between natural and artificial dens in winter. Mean temperature and mean relative humidity were not different between one-entrance and two-entrance natural dens in either summer or winter. Mean temperature did not differ between one-entrance and two-entrance artificial dens in either summer or winter, but mean relative humidity was higher in one-entrance dens in both seasons. Among artificial dens in summer, mean temperature was higher and mean relative humidity was lower in surface dens compared to subterranean dens, but neither temperature or humidity were different between surface and subterranean dens in winter. Finally, for subterranean artificial dens, mean temperature and mean relative humidity did not differ among materials (i.e., metal, PVC, concrete, and HDPE) or between chamber types.

Table 3. Comparisons of mean (±SE) temperature and relative humidity among ambient conditions, natural San Joaquin kit fox dens, artificial dens, den attributes, and den materials, Bakersfield, CA, July 2001–June 2004. *P*-values in bold are significant at **α** = 0.05.

	Temperature (°C)		Relative humidity (%)	
Comparison	Summer	Winter	Summer	Winter
Natural dens	31.2±0.8	16.2±0.7	49.2±5.4	70.2±5.6
Ambient	39.3±1.6	15.7±1.4	17.8±1.4	59.7±4.1
	t_{16} = -4.48	t_{16} = 0.09	t_{16} = 5.62	t_{16} = 2.29
	p < 0.001	p = 0.763	p < 0.001	p = 0.149
Artificial dens	35.8±0.5	14.0±0.4	31.7±2.8	63.6±2.5
Ambient	40.3±0.5	14.1±0.7	22.1±1.9	60.9±1.9
	t_{64} = -6.48	t_{58} = 0.01	t_{64} = 2.85	t_{58} = 0.73
	p < 0.001	p = 0.964	p = 0.006	p = 0.398
Natural dens	31.2±0.8	16.7±0.7	49.2±5.4	70.2±5.6
Artificial dens	35.8±0.5	14.0±0.4	31.7±2.8	63.6±2.5
	t_{40} = 20.39	t_{37} = 6.96	t_{40} = 8.51	t_{37} = 1.43
	p < 0.001	p = 0.012	p = 0.006	p = 0.239
1-entrance natural	30.9±1.8	15.0±1.1	57.6±7.4	64.4±6.6
2-entrance natural	31.4±0.7	17.1±0.9	42.5±6.9	74.8±8.6
	t_{7} = 0.10	t_{7} = 2.20	t_{7} = 2.21	t_{7} = 0.86
	p = 0.765	p = 0.182	p = 0.181	p = 0.385
1-entrance artificial[a]	35.0±0.8	14.0±0.6	44.0±6.0	74.5±5.5
2-entrance artificial[a]	35.2±0.7	14.0±0.7	28.1±3.1	58.7±2.5
	t_{21} = 0.03	t_{19} = 0.01	t_{21} = 5.94	t_{19} = 7.23
	p = 0.875	p = 0.935	p = 0.024	p = 0.015
Surface artificial	37.3±0.9	14.1±0.7	22.3±1.8	57.6±1.8
Subterranean artificial	35.1±0.5	14.0±0.5	35.7±3.6	66.2±3.4
	t_{31} = 5.30	t_{28} = 0.15	t_{31} = 5.62	t_{28} = 2.61
	p = 0.028	p = 0.904	p = 0.024	p = 0.117
Metal pipe	35.8±1.0	15.3±0.9	27.6±2.5	55.5±4.4
PVC pipe	34.9±1.2	13.8±0.8	45.1±8.8	71.0±6.5
Concrete pipe	34.6±0.4	15.0±0.9	37.9±3.2	65.6±8.5
HDPE pipe	35.2±1.0	13.0±0.9	28.5±4.1	66.2±5.9
	$F_{3,19}$ = 0.15	$F_{3,17}$ = 1.23	$F_{3,19}$ = 1.63	$F_{3,17}$ = 0.68
	p = 0.927	p = 0.331	p = 0.216	p = 0.577
Box chamber	34.8±1.1	13.5±0.8	41.6±4.6	71.4±6.0
Dogloo Chamber	35.2±1.1	14.4±1.0	35.6±8.8	63.1±7.4
	t_{9} = 0.06	t_{8} = 0.48	t_{9} = 0.33	t_{8} = 0.78
	p = 0.819	p = 0.508	p = 0.582	p = 0.404

[a] Subsurface artificial dens

DISCUSSION

In our study, SJKF used artificial dens of six different designs that were constructed of four different materials. However, some caveats are warranted regarding the rates of detection of kit foxes at the dens. First, once foxes encountered a den complex, they appeared to use all of the dens in that complex. We suspect that this was a function of the close proximity of the dens in a complex, and this increased use likely obscured any preferences the kit foxes might have exhibited for designs or materials. This effect was exacerbated when a family group was present. Trail cameras set at dens to confirm the presence of family groups captured images of pups chasing each other in and out of multiple dens in a complex during their play bouts. Another issue is that we did not have enough dens to assess any interaction effects between den designs and materials. This also likely obscured preferences for particular designs or materials. Finally, detection rates should be considered minimums because sometimes the track stations were disturbed rendering detections difficult. Rain or wind or irrigation systems (e.g., sprinklers on the golf course) sometimes affected the stations, as did heavy traffic by animals (kit foxes and other species) in and out of the dens.

SJKF apparently readily used the artificial dens (Fig. 8). A number were used within a day or two after installation and some were used extensively (e.g., kit foxes were detected in over 50% of the den checks for two of the dens in the Sump 125 complex; Table 1). Kit foxes used the dens as they would natural dens. Foxes were observed to run into the dens at the approach of potential threats (e.g., people, dogs). Radio-collared foxes were tracked to the dens during the day indicating that foxes also were using the dens for daytime resting and also probably to avoid hot daytime temperatures. Although we were not able to determine whether any kit foxes gave birth to young in the dens, we did confirm that foxes used the dens for pup-rearing based on the presence of family groups at some of the complexes in the spring. The complexes may have provided a reasonable approximation of the large, multi-entrance natal dens that kit foxes commonly use when rearing young (Egoscue 1962; Berry et al. 1987; Spiegel et al. 1996).

Per the caveat above, our assessment of preferences by kit foxes for particular den designs was likely confounded, and consequently detection rates of the different designs were not statistically different. However, based on anecdotal evidence, chambered dens may have been used more extensively than the other designs. Although foxes were detected at all designs, fox activity based on the number of tracks entering and exiting dens seemed greater at chambered dens. Prey remains were more common outside of these dens as well, suggesting more frequent use. Also, other signs such as the appearance of new entrances excavated by the foxes typically were observed at chambered dens. Greater use of chambered dens, particularly by family groups, would not be unexpected as these dens were larger and could accommodate more foxes.

Similar to the den design analysis, our assessment of preferences by kit foxes for particular materials was likely confounded, and consequently detection rates of the different designs were not statistically different. That said, kit foxes have been documented denning in cement culverts and in both metal and PVC pipes (Berry et al. 1987; Bjurlin et al. 2005; Cypher 2010), so their use of a variety of materials was not unexpected. Interestingly, of the 31 dens in the 11 complexes in the study, the only two dens where kit fox use was never detected were both metal dens.

Assuming that kit foxes do not exhibit a preference for materials, then other factors might be considered in the installation of artificial dens. The metal and cement pipes were

Figure 8. San Joaquin kit foxes using artificial dens in Bakersfield, CA. Top: Adult fox entering a concrete surface den. Bottom: Two pups outside of a HDPE two-entrance chambered den.

more difficult to work with as both materials are heavy and could not be modified in the field (e.g., cut in any way). We noticed that on sunny days, the exposed portions of the metal dens could get quite hot and this heat may have been conducted farther down into the dens. The PVC and HDPE pipes were relatively easy to modify by cutting with almost any type of saw (e.g., hack saw, PVC saw, wood saws). The PVC and HDPE pipes were smooth on the inside and therefore potentially slippery. However, we were able to cut 10-cm wide strips out of the bottoms of these pipes so that foxes would have contact with dirt and therefore better traction. Removing the strips also provided drainage as well as opportunities for foxes to create new tunnels or chambers within the den. Single-walled HDPE pipes would be an even better choice as they are flexible and the inside surface is corrugated thus providing better traction. The foxes also exhibited no preference for chambers. The irrigation boxes were more readily available and easier to cut to create entrance holes for the pipes.

Regarding costs, in 2001, the cost per foot was $12.55 for 10-in (25-cm) concrete pipe, $9.89 for 8-in (20-cm) galvanized aluminum pipe, $5.56 for 8-in HDPE pipe, and $4.50 for 8" Schedule 40 PVC pipe. The cost for the chambers was $26.49 for the irrigation box and $52.99 for the dogloo-style doghouse. Thus, the HDPE and PVC pipes and irrigation box also would be better materials to use based on cost. Installation costs obviously will vary depending upon the labor pool used (e.g., construction company versus volunteers). However, installation of surface dens requires less excavation compared to the installation of subterranean dens, and therefore labor costs associated with installing surface dens will be lower.

The range occupied by the San Joaquin kit fox is very warm and arid. Two of the primary reasons that kit foxes use dens are to avoid temperature extremes, particularly during the heat of summer, and to conserve body moisture (Koopman et al. 1998). The ability of natural dens to provide these benefits was confirmed in that compared to ambient conditions outside of dens, internal temperatures were cooler in summer and more humid during both summer and winter. These results are consistent with those of Loredo et al. (2020) who compared ambient and internal conditions for 92 kit fox dens (44 in summer and 48 in winter) to assess potential survival times for mange mites (*Sarcoptes scabiei*).

Although not to the same degree as natural dens, the artificial dens in our study also were cooler and more humid in summer, and therefore provided thermoregulatory and moisture conserving benefits to foxes during this warm, dry season. These benefits are likely less critical during winters, which are relatively mild and moist within the range of the SJKF. Cowan et al. (2020) found that artificial dens created for northern quolls (*Dasyurus hallucatus*) in a semi-arid region of western Australia also had internal climatic conditions similar to those of natural dens. The soil of natural dens has greater moisture-holding capacity compared to the more impermeable materials we used to construct artificial dens, and this likely accounted for the more favorable conditions inside natural dens. Unsurprisingly, subterranean dens provided more favorable temperature and humidity conditions compared to surface dens with one-entrance dens having higher humidity than two-entrance dens. Surface dens only had a relatively thin cover of insulating soil and all had two entrances. Two-entrance dens have greater potential for flow-through air movement that can bring in external air and this can cause internal temperature and humidity to be more similar to ambient conditions. The materials used to construct the dens all produced similar internal conditions.

The artificial dens we installed were used by a number of other species. The benefits and detriments of this result likely vary with perspective and also with the particular species. Many biologists as well as members of the public might find use of the dens by other species desirable because it enhances biodiversity in the urban environment or they simply like seeing more wildlife. However, use by other species also might be viewed as undesirable. Species such as red foxes, striped skunks, raccoons, and California ground squirrels occasionally create nuisance issues. Species such as skunks and raccoons might even be viewed as threats due to noxious odors and the potential for rabies. Feral cats used all 34 dens (Fig. 9). Their presence and any actions that facilitate their presence can elicit strong reactions from people, both positive and negative (Lord 2008; Loyd and Miller 2010; Crowley et al. 2020). Finally, the presence of some species in the dens also may be detrimental for kit foxes. Kit foxes can be competitively excluded by red foxes, raccoons, skunks (Fig. 9), and even feral cats (Harrison et al. 2011a). Thus, the kit foxes may not be able to use the dens (or the areas around them) when they are occupied by these other species. Also, use of the dens by other species can expose kit foxes to greater risk of disease.

Burrowing owls used a number of artificial dens. Burrowing owls are a California Species of Special Concern (CDFW 2008). They are regularly observed in Bakersfield (Wingert 2012) and frequently observed using kit fox dens and California ground squirrel burrows. Similar to kit foxes, burrowing owls are burrow obligates (Gervais et al. 2008) and also will use man-made structures including artificial burrows (Smith and Belthoff 2001). Thus, although installed for kit foxes, artificial dens also could contribute to the conservation of burrowing owls in Bakersfield by providing additional shelter.

In conclusion, kit foxes appear to readily use artificial dens and installation of such dens may constitute a useful conservation strategy, particularly in areas where natural dens may be uncommon or absent. Such areas might include lands that had been disturbed for other uses (e.g., agriculture) but that are being restored back to habitat. Artificial dens also can be used to mitigate for loss of natural dens due to focal disturbances, such as road or well pad construction. We recommend installing chambered dens with two entrances as these larger dens have the greatest utility to kit foxes (e.g., escape cover, daytime resting, thermoregulation, moisture conservation, and rearing young). For materials, we recommend single-wall HDPE for the entrances and an irrigation box for the chamber (Fig. 10). These materials are easy to work with and relatively inexpensive. In areas where habitat is being restored or where predation risk might be high, a combination of chambered dens and surface dens might enhance kit fox occupancy and survival. The surface dens are easy to install and can provide additional escape cover. In northwest Texas, surface dens were installed for swift foxes at a density of 36/2.6 km^2 in three study areas, one of which was unoccupied by swift foxes (McGee et al. 2006). Swift fox survival was significantly higher on the treatment areas compared to nearby control areas, and swift foxes successfully colonized the previously unoccupied area where dens had been installed. Kit foxes likely would respond similarly.

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Figure 9. Feral cat (top) and striped skunk (bottom) using artificial dens installed for San Joaquin kit foxes in Bakersfield, CA.

Figure 10. Recommended artificial den design for San Joaquin kit foxes: single-walled HDPE two-entrance chambered den with an irrigation valve box for the chamber.

LITERATURE CITED

Berry, W. H., T. P. O'Farrell, T. T. Kato, and P. M. McCue. 1987. Characteristics of dens used by radiocollared San Joaquin kit fox, *Vulpes macrotis mutica*, Naval Petroleum Reserve #1, Kern County, California. U.S. Department of Energy Topical Report EGG 10280-2177, National Technical Information Service, Springfield, VA, USA.

Bjurlin, C. D., B. L. Cypher, C. M. Wingert, and C. L. Van Horn Job. 2005. Urban roads and the endangered San Joaquin kit fox. California State University-Stanislaus, Endangered Species Recovery Program, Turlock, CA, USA.

Bulova, S. J. 1993. Observations on burrow use by captive desert tortoises. Pages 143–150 in K. R. Beaman, editor. Proceedings of the 1992 Desert Tortoise Council Symposium. Desert Tortoise Council, Palm Desert, CA, USA.

California Department of Fish and Wildlife (CDFW). 2008. Bird Species of Special Concern. California Department of Fish and Wildlife, Sacramento, CA, USA.

Cowan, M. A., J. A. Dunlop, J. M. Turner, H. A. Moore, and D. G. Nimmo. 2020. Artificial refuges to combat habitat loss for an endangered marsupial predator: how do they measure up? Conservation Science and Practice 2020:2:e204.

Crowley, S. L., M. Cecchetti, and R. A. McDonald. 2020. Our wild companions: domestic cats in the Anthropocene. Trends in Ecology and Evolution 35:477–483.

Cypher, B. L. 2003. Foxes. Pages 511–546 in G. A. Feldhamer, B. C. Thompson, and J. A. Chapman, editors. Wild Mammals of North America: Biology, Management, and Conservation. Second edition. The Johns Hopkins University Press, Baltimore, MD, USA.

Cypher, B. L. 2010. Kit foxes. Pages 49–60 in S. D. Gehrt, S. P. D. Riley, and B. L. Cypher, editors. Urban Carnivores: Ecology, Conflict, and Conservation. Johns Hopkins University Press, Baltimore, MD, USA.

Cypher, B. L., S. E. Phillips, and P. A. Kelly. 2013. Quantity and distribution of suitable habitat for endangered San Joaquin kit foxes: conservation implications. Canid Biology and Conservation 16:25–31.

Cypher, B. L., and C. L. Van Horn Job. 2012. Management and conservation of San Joaquin kit foxes in urban environments. Proceedings of the Vertebrate Pest Conference 25:347–352.

Cypher, B. L., and G. D. Warrick. 1993. Use of human-derived food items by urban kit foxes. Transactions of the Western Section of The Wildlife Society 29:34–37.

Deatherage, N. A., B. L. Cypher, J. D. Murdoch, T. L. Westall, E. C. Kelly, and D. J. Germano. Urban landscape attributes affect San Joaquin kit fox occupancy patterns. Pacific Conservation Biology. In press.

Egoscue, H. J. 1962. Ecology and life history of the kit fox in Tooele County, Utah. Ecology 43:481–497.

Frost, N. 2005. San Joaquin kit fox home range, habitat use, and movements in urban Bakersfield. Thesis, Humboldt State University, Arcata, CA, USA.

Germano, D. J., G. B. Rathbun, L. R. Saslaw, B. L. Cypher, E. A. Cypher, and L. M. Vredenburgh. 2011. The San Joaquin desert of California: ecologically misunderstood and overlooked. Natural Areas Journal 31:138–147.

Gervais, J. A., D. K. Rosenberg, and L. A. Comrack. 2008. Burrowing owl (*Athene cunicularia*). Pages 218–226 in W. D. Shuford and T. Gardali, editors. California Bird Species of Special Concern: A Ranked Assessment of Species, Subspecies, and Distinct Populations of Birds of Immediate Conservation Concern in California. Studies of Western Birds 1. Western Field Ornithologists, Camarillo, CA, and California Department of Fish and Game, Sacramento, CA, USA.

Grinnell, J., D. S. Dixon, and J. M. Linsdale. 1937. Fur-bearing Mammals of California. Volume 2. University of California Press, Berkeley, CA, USA.

Harrison, S. W. R., B. L. Cypher, S. Bremner-Harrison, and C. L. Van Horn Job. 2011a. Resource use overlap between urban carnivores: implications for endangered San Joaquin kit foxes (*Vulpes macrotis mutica*). Urban Ecosystems 14:303–311.

Harrison, S. W. R., B. L. Cypher, and S. E. Phillips. 2011b. Enhancement of satellite and linkage habitats to promote survival, movement, and colonization by San Joaquin kit foxes. California State University-Stanislaus, Endangered Species Recovery Program, Fresno, CA, USA.

Horne, E. A., M. McDonald, and O. J. Reichman. 1998. Changes in cache contents over winter in artificial dens of the eastern woodrat (*Neotoma floridana*). Journal of Mammalogy 79:898–905.

Kelly, P. A., Phillips, S. E. and Williams, D. F. 2005. Documenting ecological change in time and space: the San Joaquin Valley of California. Pages 57-78 in E. A. Lacey and P. Myers, editors. Mammalian Diversification: From Chromosomes to

Phylogeography. Publications in Zoology Series, University of California Press, Berkeley, CA, USA.

Koopman, M. E., J. H. Scrivner, and T. T. Kato. 1998. Patterns of den use by San Joaquin kit foxes. Journal of Wildlife Management 62:373–379.

Loredo, A. I., J. L. Rudd, J. E. Foley, D. L. Clifford, and B. L. Cypher. 2020. Climatic suitability of San Joaquin kit fox (*Vulpes macrotis mutica)* dens for sarcoptic mange (*Sarcoptes scabiei*) transmission. Journal of Wildlife Disease 56:126–133.

Lord, L. K. 2008. Attitudes toward and perceptions of free-roaming cats among individuals living in Ohio. Journal of the American Veterinary Medical Association 232:1159–1167.

Loyd, K. A. T., and C. A. Miller. 2010. Influence of demographics, experience and value orientations on preferences for lethal management of feral cats. Human Dimensions and Wildlife 15:262–273.

McGee, B. K., W. B. Ballard, K. L. Nicholson, B. L. Cypher, P. R. Lemons, and J. F. Kamler. 2006. Effects of artificial escape dens on swift fox populations in northwest Texas. Wildlife Society Bulletin 34:821–827.

National Oceanic and Atmospheric Administration (NOAA). 2020. Bakersfield climate. National Weather Service, Hanford, CA, USA. Available from: https://www.weather.gov/hnx/bflmain

Reese, E. A., W. G. Standley, and W. H. Berry. 1992. Habitat, soils, and den use of San Joaquin kit fox (*Vulpes velox macrotis*) at Camp Roberts Army National Guard Training Site, California. U.S. Department of Energy Topical Report EGG 10617-2156, National Technical Information Service, Springfield, VA, USA.

Smith, B. W., and J. R. Belthoff. 2001. Effects of nest dimensions on use of artificial burrow systems by Burrowing Owls. Journal of Wildlife Management 65:318–326.

Spiegel, L. K., T. C. Dao, and J. Tom. 1996. Characteristics of San Joaquin kit fox dens at oil-developed and undeveloped sites in southwestern Kern County, California. Pages 15–38 in L. K. Spiegel, editor. Studies of the San Joaquin kit fox in undeveloped and oil-developed areas. California Energy Commission, Sacramento, CA, USA.

Sullivan, W. J., K-J. Wilson, and A. Paterson. 2000. Influence of artificial burrows and microhabitat on burrow competition between Chatham Petrels *Pterodroma axillaris* and Broad-billed Prions *Pachyptila vittata*. Emu - Austral Ornithology 100:329–333.

U. S. Fish and Wildlife Service (USFWS). 1998. Recovery plan for upland species of the San Joaquin Valley, California. United States Fish and Wildlife Service, Portland, OR, USA.

Wingert, C. M. 2012. Seasonal food habits of burrowing owls (*Athene cunicularia*) in human-altered landscapes. Thesis, California Polytechnic State University, San Luis Obispo, CA, USA.

Zar, J. H. 1984. Biostatistical Analysis. Prentice-Hall, Inc., Englewood Cliffs, NJ, USA.

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