HOME RANGE CHARACTERISTICS OF THE SAN JOAQUIN KIT FOX IN WESTERN KERN COUNTY, CALIFORNIA

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Abstract: Twenty-six radio-collared San Joaquin kit foxes (*Vulpes macrotis mutica*) were monitored over 11-12 month periods in 1989-90 and 1990-91 in undeveloped and oil-developed areas so that annual home range, core area, nocturnal range, and denning range sizes and spatial organization could be determined and compared between the area types. Mean annual range sizes for combined years were 6.13, 1.18, 5.82, and 1.61 km^2, respectively. Exclusive core areas for mated pairs and family groups from foxes in adjacent areas enabled identification of territoriality in kit foxes. Ranges did not differ between adults and juveniles. Males had consistently larger ranges than females, and significantly larger core areas when years were combined. Foxes from the undeveloped area had larger range sizes than those from developed areas during the second year and for both years combined. Differences in ranges by area may be explained by different adaptive responses to temporal changes in food distribution and spatial limitations affected by local drought and mortality conditions. Mean annual home range, core area, nocturnal range, and denning range sizes for mated pairs of 7.91, 1.34, 7.62, and 1.96 km^2, respectively, should be considered with other criteria used to design kit fox preserve areas.

Little published information exists on the size and spatial organization of home ranges of the federally endangered and California state threatened San Joaquin kit fox (*Vulpes macrotis mutica*). Morrell (1972) estimated home range size for kit foxes to be 2.6-5.2 km^2 from incidental observation. Unpublished reports have determined kit fox home and nocturnal range sizes were 4.39 km^2 (Zoellick et al. 1987) and 9.09 km^2 (Ralls et al. 1990), and denning range sizes were 3.43 km^2 (Ralls et al. 1990) and 4.73 km^2 (Brown and Wernette 1988). Ralls et al. (1990) reported range sizes of kit fox pairs to be 11.36 km^2 for home range and 3.37 km^2 for denning range. However, these estimates were derived using short (Zoellick et al. 1987, Brown and Wernette 1988) or intermittent (Zoellick et al. 1987, Brown and Wernette 1988, Ralls et al. 1990) sampling periods. Analysis of home range from short-term or interrupted data collection periods did not accurately identify the entire area utilized by coyotes (Woodruff and Keller 1982) and may not be sufficient to delineate home range sizes of kit foxes. Ralls et al. (1990) were the first to identify that kit fox social groups occupied distinct core areas within larger home range areas that overlapped considerably with home ranges of adjacent, non-social groups.

Remaining kit fox populations are most abundant in the Southern San Joaquin Valley and commonly occur in the continually expanding oil-fields of western Kern County, California (U.S. Fish and Wildlife Service 1989). Information on how kit foxes home range requirements may differ in oil-developed areas is of ecological and management interest because of the impact this land use may have on the listed species. Zoellick et al. (1987) reported that home range sizes were similar for foxes inhabiting undeveloped and oil-developed lands on the Naval Petroleum Reserves in western Kern County, but used a study area in which these land uses were not clearly distinguishable and also included areas containing urban and agricultural developments.

We monitored kit foxes for more than 11 months in 1989-90 and 1990-91. The objectives of this study were to use long-term and continuous sampling periods to determine: 1) annual home range, nocturnal range, and denning range sizes of individual and paired kit foxes; 2) spatial organization of the home ranges of individual and paired kit foxes; 3) differences in range sizes based on year, sex and age class; and 4) differences in range sizes of kit foxes inhabiting oil-developed versus undeveloped areas.

STUDY AREA

A 101 km^2 area in the Southern San Joaquin Valley, approximately 40 km west of Bakersfield, Kern County, California, was divided into 3 study areas of developed or undeveloped land (Fig. 1). The entire site is characterized as a semi-desert with an average yearly rainfall of 14.6 cm; however, localized drought conditions were in effect during both years of study. Annual rainfall was 8.4 cm for the first year of study while the second year total was 15.1 cm, 11.0 cm of which came in March of that year.

Study Area 1, the Lokern Natural Area, is undeveloped habitat consisting mainly of Interior Coast

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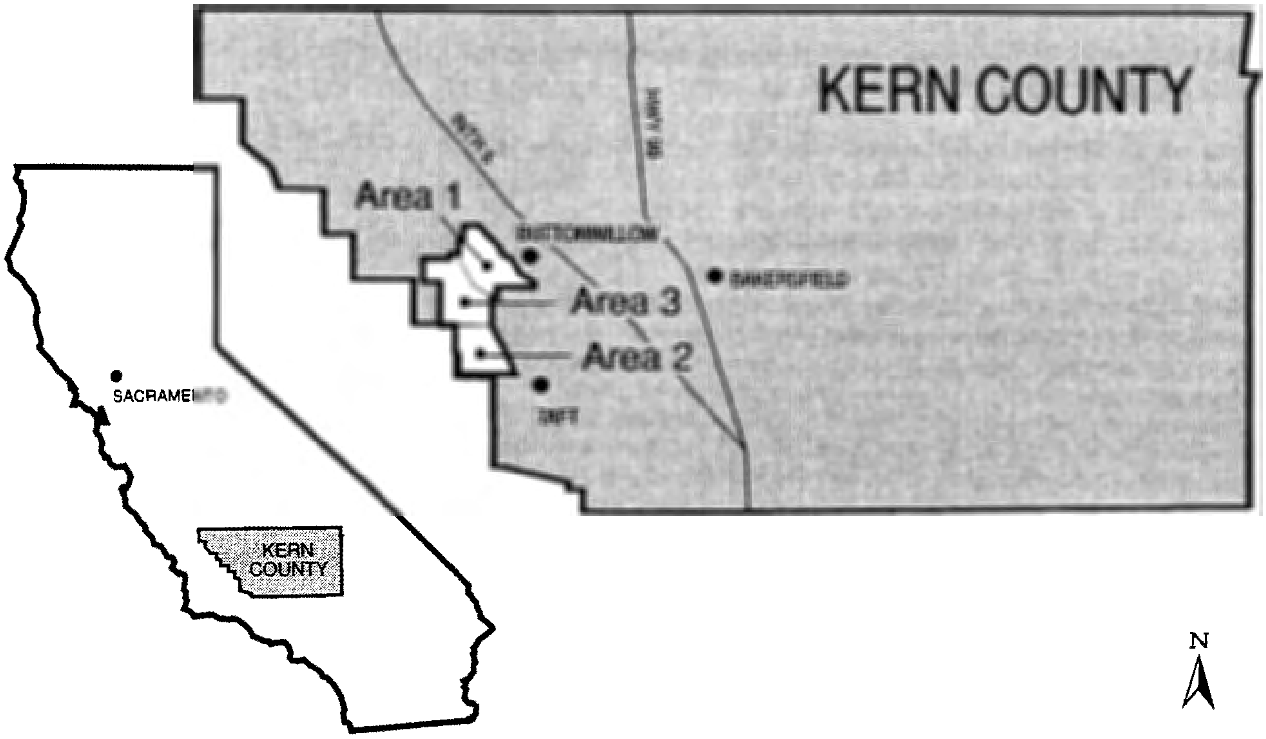


Fig 1. Location of study areas (not to scale).

Range saltbush scrub dominated by *Atriplex polycarpa*, with some open areas of non-native annual grasslands (Holland 1986, Anderson et al. 1991). Elevation ranges from 91 to 259 m. Study Area 2 in the Midway-Sunset Oil Field is predominately oil development with isolated pockets and drainages of Interior Coast Range saltbush scrub within the development and foothill non-native grasslands bordering on the west. Elevation ranges from 351 to 671 m. Study Area 3, located in the McKittrick and Cymric Oil Fields, is oil development within Interior Coast Range saltbush scrub habitat with elevation ranging from 198 to 488 m. In the first year of study, Areas 2 and 3 were combined to represent developed areas. In the second year, Area 3 was not used.

METHODS

Trapping was conducted from August to October 1989 and June to November 1990. Kit foxes were captured using 104 cm x 32 cm x 32 cm Tomahawk live traps (Tomahawk, WI) specially constructed with 1.3 cm x 2.6 cm wire mesh to avoid jaw injuries reported by other researchers (Berry et al. 1987). Kit foxes were eartagged, fitted with specially designed 50-55 gm radio collars (AVM, Livermore, Calif.), measured, weighed, and aged as either juveniles ($\leq$ 10 months) or adults based on weight and tooth wear.

Radio collared kit foxes were located at their diurnal denning sites at least twice per week using portable receivers and hand held "H" antennas (Telonics, Inc., Mesa, AZ). Denning ranges were calculated from this data using the 100% minimum convex polygon (MCP)(Mohr 1947) method from the program TELEM88 (Coleman and Jones 1990). Nocturnal locations were determined by triangulation from two or three fixed tower stations using paired 5-element antennas (Telonics, Inc.), mounted 6.1 meters above ground at sites overlooking each study area. Nocturnal locations were obtained from each study area on consecutive nights to increase the likelihood of equivalent foraging conditions (i.e. weather and moon phase) and at bimonthly intervals throughout the year. One set of bearings was recorded for each fox at 30-60 minute intervals for approximately 7 hours per night. Each bearing set was triangulated to determine a location only if both bearings were taken within 3 minutes of each other and the angle of their intersection was > 30° and < 150°. Nocturnal foraging ranges were calculated by the 95% MCP method to reduce effects of outliers (Anderson 1982, Bowen 1982, Bekoff and Mech 1984).

Home ranges were calculated using 97% MCP and 50% harmonic mean (HM)(Dixon and Chapman 1980) methods from all nocturnal, denning, trapping, and incidental observation locations. HM was used to define core areas or centers of activity. HM estimations were based on grid cell dimensions as follows: grid sides measured 1.5 times the maximum distance between any two points in a data set; cells within the grid measured 240m x 240m, and; the minimum distance between any data point used and the grid cell intersection was 240m, or one-half the cell size, to avoid contours based on over-weighted data points and reduce the effects of non-independent observations (Van Winkle 1975, Dixon and Chapman 1980).

Optimal tower locations were determined following recommendations of White (1985). Groups of stations were chosen to optimize the angle of bearing intersections (90°) to all foxes within each study area (White and Garrott 1990). Accuracy was tested by placing 2 beacons at different surveyed locations. The test beacons were checked throughout the telemetry period to insure accuracy to $\leq 1°$. Testing conducted during periods of rain, heavy fog, and moderate to high winds often resulted in $> 1°$ bearing error. Under these conditions, telemetry was discontinued.

Area observation curves (Odum and Kuenzler 1955) indicated that sizes of ranges increased < 5% after 112-176 and 90-134 radio locations were obtained for the MCP and HM methods, respectively. Foxes either meeting these criteria or monitored ≥ 11 months were included in the analysis. Mann-Whitney U-tests (Sokal and Rohlf 1981) were used to compare range sizes between sex, age class, and developed versus undeveloped areas for the first study year, the second study year, and both years combined. Statistical significance was inferred if $P \leq 0.05$.

RESULTS

Range sizes were calculated for 26 individual foxes (13 per year)(Table 1), including 5 mated pairs (Table 2). In the first study year, 8 and 5 foxes were monitored in undeveloped and developed areas, respectively (5 males, 8 females, 9 adults, and 4 juveniles). In the second study year, 6 and 7 foxes were monitored in undeveloped and developed areas, respectively (6 males, 7 females, 7 adults, and 6 juveniles)(Table 1). Two pairs were monitored in the undeveloped area in the first study year. Three pairs, 1 from the undeveloped and 2 from the developed area, were monitored in the second study year (Table 2). The average number of locations used to calculate MCP and HM ranges were 211.2 for home range, 126.3 for nocturnal range, and 68.9 for denning range.

Denning Range

Denning range sizes were highly variable among foxes during both years ranging from 0.16 to 3.99 km^2. Mean denning range sizes were 1.85 ± 0.28 km^2 (n=13) in the first year, 1.36 ± 0.28 km^2 (n=13) in the second year, and 1.61 ± 0.20 km^2 (n=26) for both years combined. Juvenile denning ranges were similar to adult denning ranges. Male denning ranges, though consistently larger were not significantly different than females. Foxes in undeveloped areas had significantly larger denning ranges than those in developed areas in the second year ($P = 0.05$) and for both years combined ($P < 0.05$). Combined denning ranges of mated pairs averaged 1.96 ± 1.26 km^2 (n=5)(range = 0.83-3.26 km^2).

There was little overlap ($\leq 5\%$) in denning ranges among foxes other than mated pairs within a study area (Fig. 2-6). Denning ranges of mated pairs were nearly identical, as pairs frequently shared dens throughout the year.

Nocturnal Range

Mean nocturnal ranges were 5.82 ± 0.45 km^2 (n=26) and similar in size between years, age class, and sex. Nocturnal ranges of foxes from the undeveloped area (6.68 ± 0.58 km^2, n=14) averaged 39% (range = 18-63%) larger than foxes from developed areas (4.81 ± 0.59 km^2, n = 12) and were significantly larger for both years combined ($P < 0.05$). Combined nocturnal ranges for mated pairs ranged from 3.87 to 11.53 km^2 and averaged 7.62 ± 0.48 km^2 (n=5) in size. There was a strong spatial relationship between nocturnal range and den site locations (Fig. 7).

Home Range

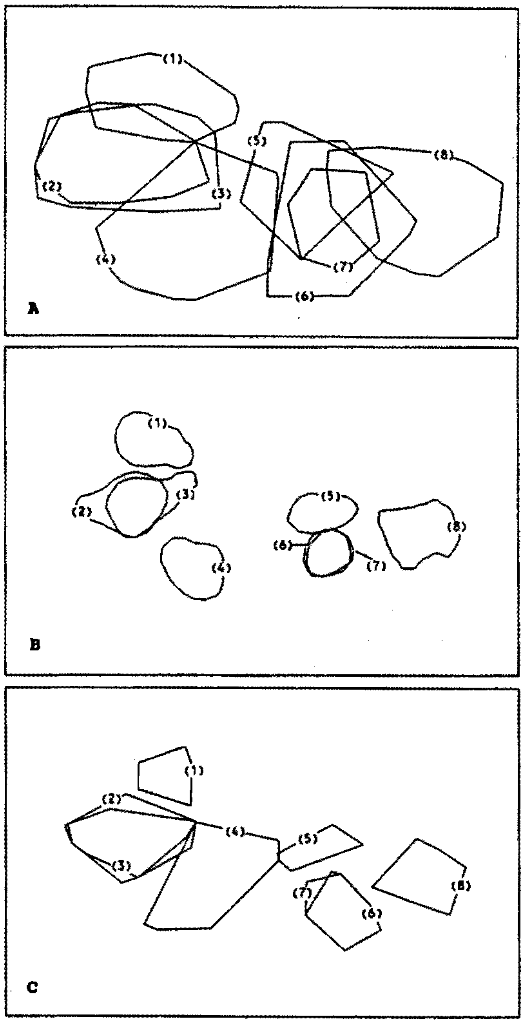
Home range sizes determined by the MCP method averaged 6.13 ± 0.45 km^2 (n=26). In the second year, the home range of one male (11.18 km^2) from the undeveloped area was extremely large and the home range of one female (1.69 km^2) from the developed area was extremely small. Mean home range sizes were similar between years, age class, sex, and area. Males home range sizes averaged 18% larger than females. Foxes from the undeveloped area had home range sizes that averaged 31% larger than foxes from the developed areas. Home ranges of mated pairs ranged from 4.23 to 12.02 km^2 and averaged 7.91 ± 1.28 km^2 (n=5) for both years combined.

Home ranges defined by the 97% MCP overlapped considerably (up to 50%) between adjacent foxes and up to 100% for mated pairs (Fig. 2-6). Male home ranges encompassed the range of their mates in all but one case.

Centers of activity (core areas) defined by the 50% HM method averaged 1.18 ± 0.11 km^2 (n=26) and were 7% to 34% ($\overline{X} = 20\%$) the size of the entire home ranges

Table 1. Mean yearly range sizes [km^2 (SE)] for kit foxes by year, age class, sex and area using minimum convex polygon (MCP) and harmonic mean (HM) methods. Means with like superscripts differ significantly ($P \leq 0.05$).

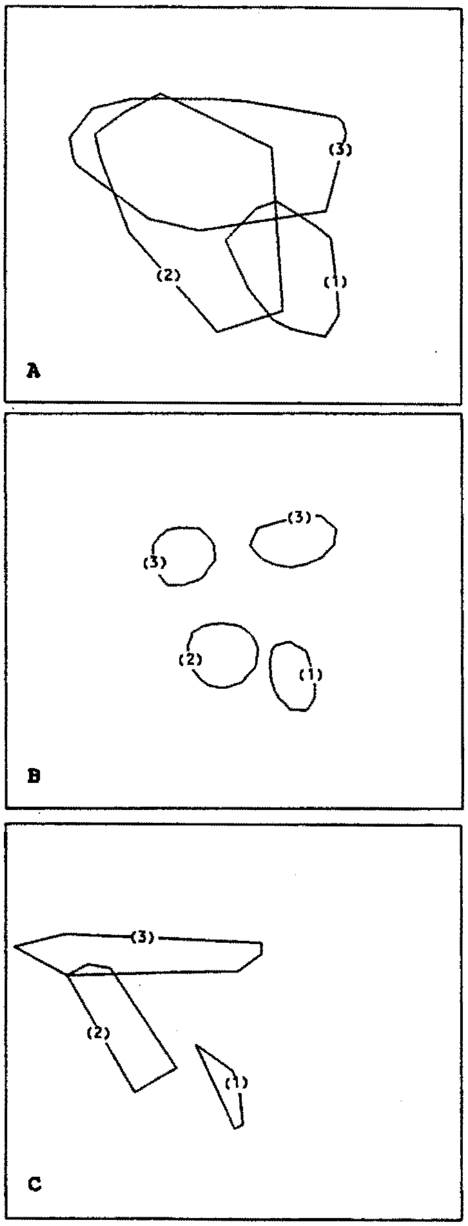
	Home Range		Foraging Range	Denning Range	
	97% MCP	50% HM	95% MCP	100% MCP	n
1989-90					
Adults	6.17 (0.61)	1.37 (0.17)	6.02 (0.67)	1.76 (0.31)	9
Juveniles	6.20 (1.28)	1.14 (0.19)	5.60 (1.17)	2.07 (0.65)	4
Males	6.85 (0.45)	1.57 (0.23)	6.70 (0.54)	2.10 (0.34)	5
Females	5.76 (0.83)	1.13 (0.39)	5.39 (0.83)	1.70 (0.41)	8
Undeveloped	6.40 (0.71)	1.30 (0.15)	6.26 (0.77)	2.07 (0.39)	8
Developed	5.83 (0.93)	1.29 (0.27)	5.30 (0.83)	1.50 (0.39)	5
All	6.18 (0.55)	1.30 (0.13)	5.89 (0.56)	1.85 (0.28)	13
1990-1991					
Adults	6.06 (1.27)	1.20 (0.31)	5.57 (1.13)	1.57 (0.51)	7
Juveniles	6.09 (0.68)	0.89 (0.16)	6.02 (0.61)	1.11 (0.15)	6
Males	6.62 (1.14)	1.39 (0.28)	6.15 (1.20)	1.54 (0.49)	6
Females	5.61 (0.97)	0.77 (0.19)	5.40 (0.92)	1.20 (0.33)	7
Undeveloped	7.55 (0.88)	1.40 (0.29)	7.25 (0.92)	1.98 (0.49)[a]	6
Developed	4.81 (0.91)	0.76 (0.43)	4.45 (0.84)	0.83 (0.13)[a]	7
All	6.01 (0.73)	1.06 (0.18)	5.75 (0.72)	1.36 (0.28)	13
Both years					
Adults	6.12 (0.63)	1.30 (0.16)	5.81 (0.62)	1.68 (0.27)	16
Juveniles	6.13 (0.61)	0.99 (0.12)	5.83 (0.58)	1.49 (0.30)	10
Males	6.73 (0.63)	1.47 (0.18)[b]	6.40 (0.67)	1.80 (0.31)	11
Females	5.69 (0.61)	0.96 (0.12)[b]	5.39 (0.59)	1.47 (0.27)	15
Undeveloped	6.89 (0.55)	1.35 (0.15)	6.68 (0.58)[c]	2.03 (0.29)[d]	14
Developed	5.24 (0.65)	0.98 (0.16)	4.81 (0.59)[c]	1.11 (0.19)[d]	12
All	6.13 (0.45)	1.18 (0.11)	5.82 (0.45)	1.61 (0.20)	26



Fox ID	Fox ID
(1) 4410	(5) 4015
(2) 4409[b]	(6) 4404[c]
(3) 4408[b]	(7) 4403[c]
(4) 4405	(8) 4401

2 km

Fig. 2. The 97% minimum convex polygon (A) and 50% harmonic mean (B) home ranges, and 100% minimum convex polygon denning ranges (C) for San Joaquin kit foxes in an undeveloped area of southwestern Kern County, CA in 1989-90 (year 1). Like superscripts denote mated pairs.

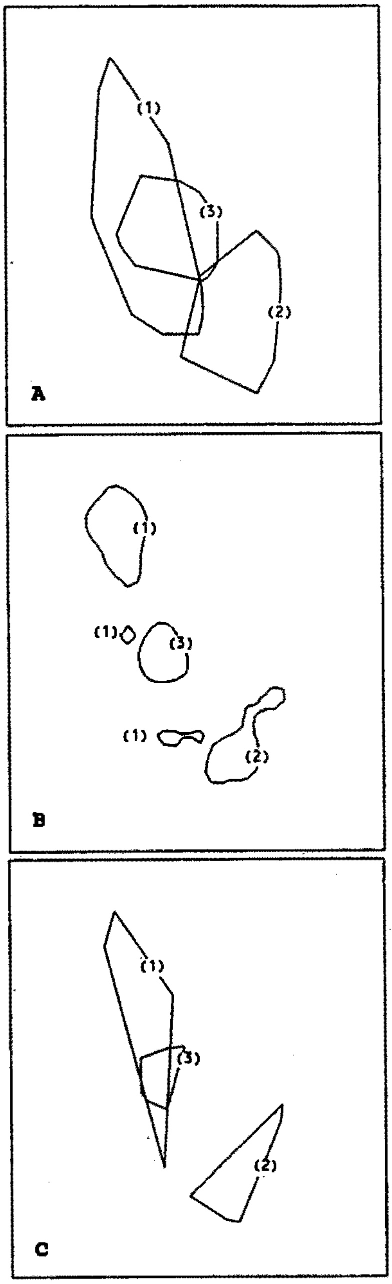


Fox ID

(1) 4411
(2) 4416
(3) 4417

2 km

Fig. 3. The 97% minimum convex polygon (A) and 50% harmonic mean (B) home ranges, and 100% minimum convex polygon denning ranges (C) for San Joaquin kit foxes in the Midway-Sunset oil field of southwestern Kern County, CA in 1989-90 (year 1).

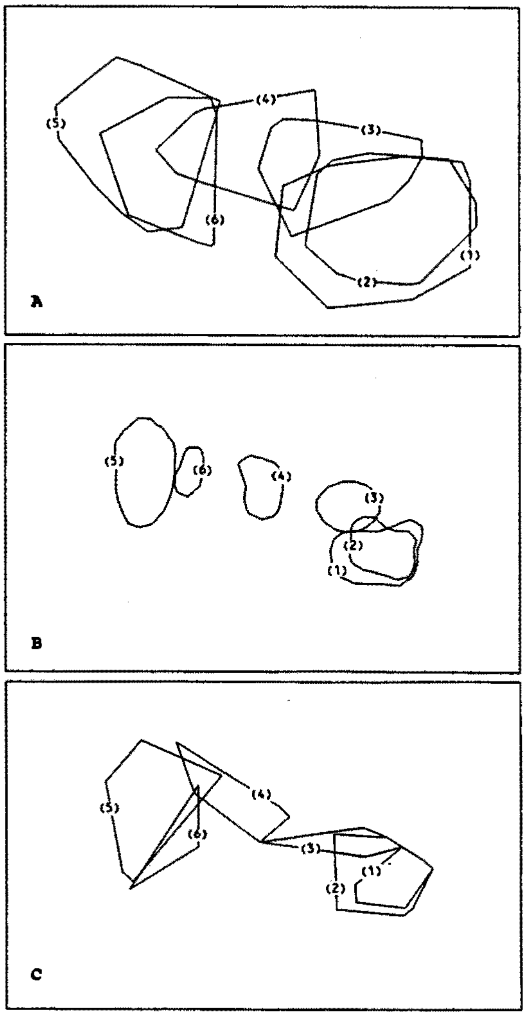


Fox ID

(1) 4424
(2) 4425
(3) 4427

2 km

Fig. 4. The 97% minimum convex polygon (A) and 50% harmonic mean (B) home ranges, and 100% minimum convex polygon denning ranges (C) for San Joaquin kit foxes in the McKittrick-Cymric oil field of southwestern Kern County, CA in 1989-90 (year 1).



Fox ID	Fox ID
(1) 4401[a]	(4) 4449
(2) 4432[a]	(5) 4441
(3) 4010	(6) 4448

2 km

Fig. 5. The 97% minimum convex polygon (A) and 50% harmonic mean (B) home ranges, and 100% minimum convex polygon denning ranges (C) for San Joaquin kit foxes in an undeveloped area of southwestern Kern County, CA in 1990-91 (year 2). Like superscripts denote mated pairs.

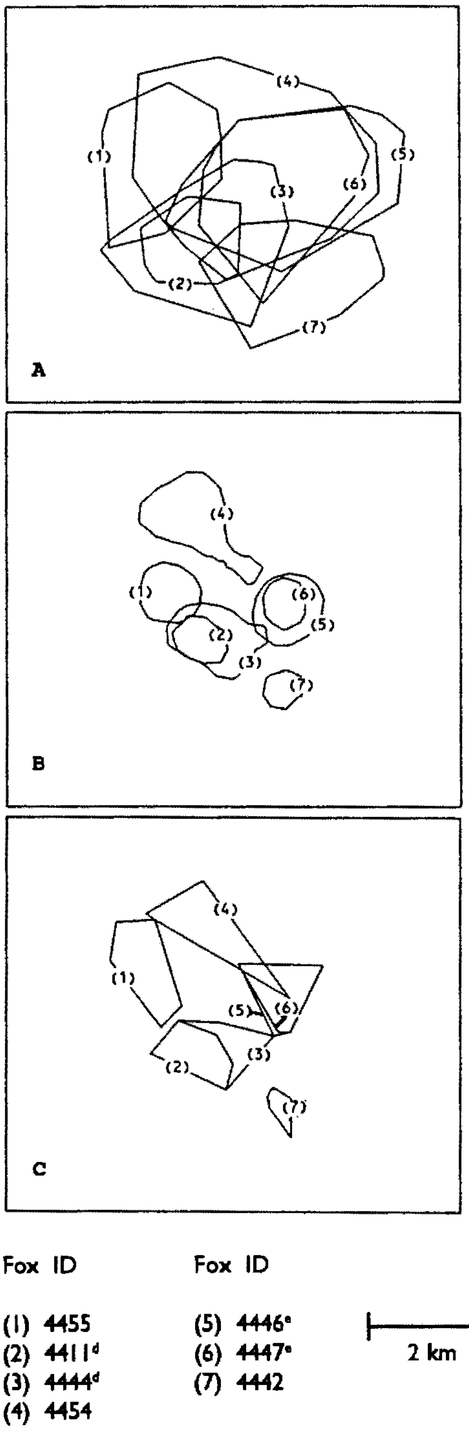


Fig. 6. The 97% minimum convex polygon (A) and 50% harmonic mean (B) home ranges, and 100% minimum convex polygon denning ranges (C) for San Joaquin kit foxes in the Midway-Sunset oil field of southwestern Kern County, CA in 1990-91 (year 2). Like superscripts denote mated pairs.

be established by intensive behavior observations to determine if an area is actually defended. However, territoriality can be inferred if definable areas are stable over time and used exclusively by social units (e.g. families)(Windberg and Knowlton 1988). Kit foxes are not social outside of the family group. This study and similar findings by Ralls et al. (1990) indicate that kit foxes are territorial.

There was little difference in range sizes between sex and age class with the exception that males always had somewhat larger range sizes than females and significantly larger core areas when data from both years were combined. The distinction in size between sexes may be due to fewer seasonal movements by females and, conversely, greater foraging requirements by males during pup-rearing. Lack of difference between age class is not surprising since young may begin to den and forage on their own by about 4 months of age.

Foxes from undeveloped and developed areas had similar range sizes in the first year, but showed more divergence in the second year with ranges in the undeveloped area exceeding those in developed areas. In fact, most range sizes in the second year appeared to be significant between areas and lack of statistical significance may be due to the insensitive nature of the non-parametric test used (Sokal and Rohlf 1981). Most of the difference was explained by decreases in range sizes for foxes in developed areas during the second year, particularly in harmonic mean and denning ranges. However, about a 15% increase was observed for home and foraging ranges described by MCP methods in the undeveloped area in year two.

A seasonal breakdown of home range sizes into 4 3-month periods showed that range sizes in the undeveloped area were highest during the December-February period in year two, and significantly higher than for that same period in year one. This pattern was not observed for foxes from developed areas. We offer two possible explanations for this occurrence: food distribution and territorial behaviors. Foxes from the developed areas rely to some extent on supplemental food sources as indicated by observations of foxes in trash receptacles and food wrappers at den sites, and verbal accounts by oil-field workers. Supplemental food sources would have been most important in early winter of year two, when the effects of a drought had visually reduced plant production and apparently resulted in reduced small mammal populations (B. Peyton, University of California, Berkeley, pers. comm.). It's possible that during this time of scarce natural food resources, foxes in developed areas relied more heavily on supplemental food which required smaller foraging ranges than hunting.

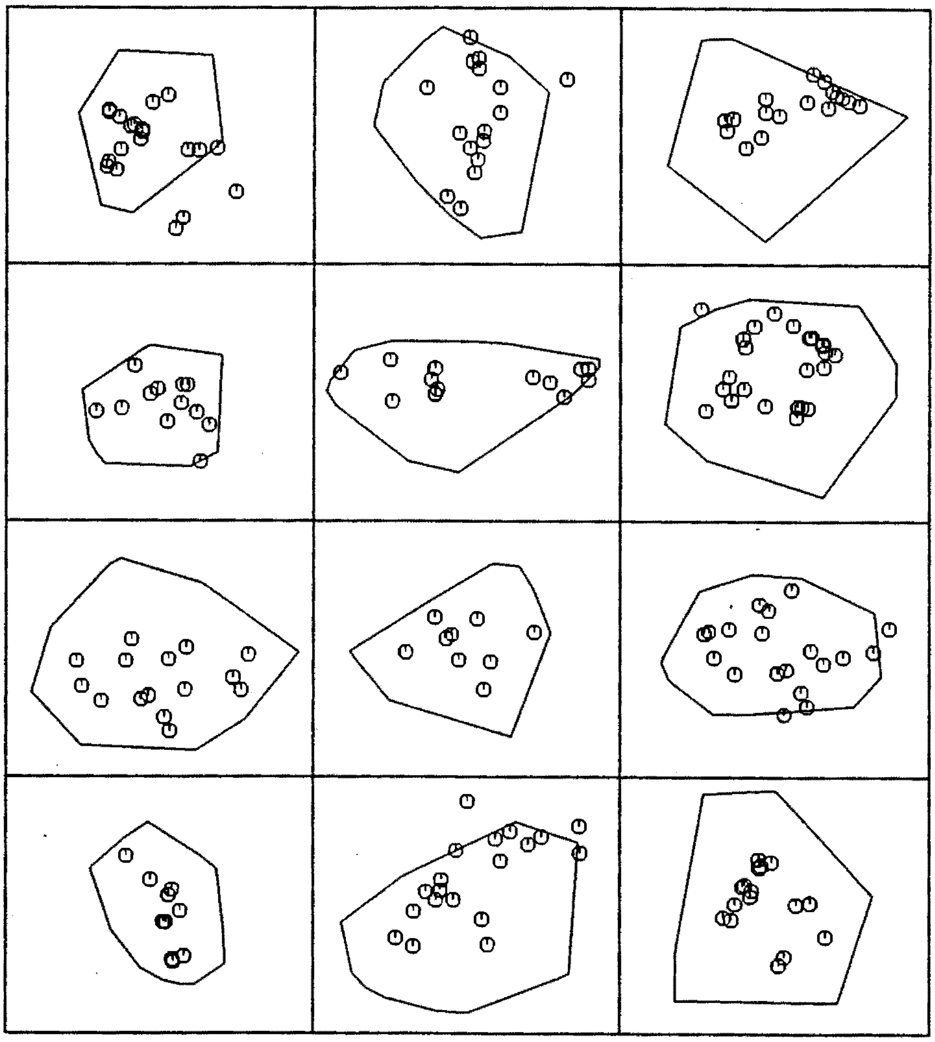


Fig. 7. Yearly foraging ranges (polygons) defined by 95% minimum convex polygon and denning locations for 12 kit foxes in southwestern Kern County, CA (August 1989 - December 1991).

Conversely, foxes from undeveloped areas would have required larger foraging ranges to fulfill food requirements (Gese et al. 1988). Smaller nocturnal ranges for foxes in the developed area likely dictated smaller denning ranges that, in turn, would have resulted in smaller high activity or core areas.

A second explanation for increases in range sizes for foxes from undeveloped areas during early winter 1990 is that spatial parameters were less limiting during that time. Foxes experienced unusually high mortality rates in fall of 1990 due, in part, to the presence of feral dogs (Spiegel et al. 1991). Vacancies present in the otherwise mutually exclusive core areas would have allowed greater range opportunities for adjacent foxes.

Mean home range sizes of mated pairs should be considered when designing kit fox preserves. The existing mitigation ratio used to compensate for the permanent loss of kit fox habitat due to proposed development projects in the Southern San Joaquin Valley is three units of area preserved for every one unit of area lost. Since the average home range size of mated pairs is 7.91 km^2, developments requiring an area of habitat less than 2.6 km^2 may result in compensatory preserves too small to support one fox pair.