An evaluation of survey methods for monitoring swift fox abundance

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Abstract Swift foxes (*Vulpes velox*) were historically distributed across the shortgrass and mixed-grass prairie regions of North America. Today, the swift fox is found in small, isolated populations in the southern and western margins of its historic range. Although methods for censusing wild canids exist, an evaluation of survey techniques for monitoring trends in the abundance of swift foxes has not been conducted. We conducted a 2-year study evaluating 6 survey methods and their ability to accurately monitor changes in swift fox density (independently determined from radiocollared foxes). The study was conducted on the United States Army Piñon Canyon Maneuver Site, southeastern Colorado, from January 1997 to December 1998. We evaluated catch-per-unit-effort (trapping surveys), mark–recapture estimates, scent-post surveys, spotlight counts, scat deposition rate surveys, and an activity index. All surveys were conducted along 5 10-km transects during 3 seasons annually. All methods, except spotlight counts, were reliable and consistent for detecting swift fox presence across the 5 survey transects. Regression analyses indicated that the correlation between swift fox density and survey method varied among methods and seasons, with mark–recapture estimates being the highest predictor (r=0.711), followed by scat deposition surveys (r=0.697), scent-post surveys (r=0.608), spotlight surveys (r=0.420), trapping surveys (r=0.326), and the activity index (r=0.067). Stepwise regression analysis of all survey methods indicated that the combination of mark–recapture estimates and scent-station indices was the highest predictor of swift fox density (r=0.853). The combination of these 2 surveys would be economical and reliable for monitoring swift fox population trends. The combination of scent-station indices and scat deposition surveys was almost as reliable (r=0.829) but was far less costly than surveys involving mark–recapture estimates. A combination of more surveys did little to increase the level of prediction. Survey costs varied due to differing requirements of labor and equipment.

Key words activity index, mark–recapture, scat deposition, scent-post, spotlight, survey, swift fox, trapping, *Vulpes velox*

Swift foxes (*Vulpes velox*) were historically distributed across the shortgrass and mixed-grass prairie of North America (Banfield 1974, Scott-Brown et al. 1987), ranging from the southern portions of central Canada south to Texas, and from central Colorado east to western Iowa and Minnesota (Swanson et al. 1945, Bowles 1975, Egoscue 1979, Scott-Brown et al. 1987, FaunaWest 1991). Prior to European settlement, swift foxes were abundant (Rand 1948, Johnson 1969, FaunaWest 1991). However, by the late 1800s, their distribution and abundance had declined. The arrival of settlers and the ensuing conversion of prairie habitat, initiation of rodent- and predator-control programs, unregulated hunting and trapping, and capture by domestic dogs (Bailey 1926, Hoffman et al. 1969, Scott-Brown et al. 1987) decreased swift fox numbers until only small, isolated populations remained (Hillman and Sharps 1978, Kahn et al. 1997). Interspecific competition between the swift fox and

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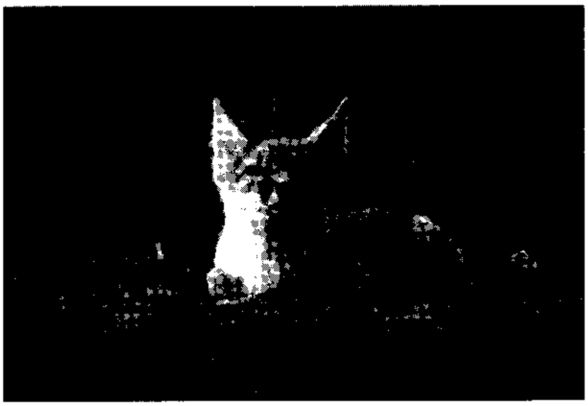
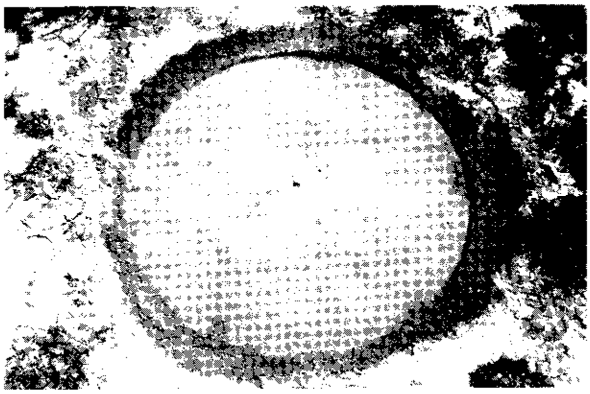
other wild canids (coyote [*Canis latrans*] and red fox [*V. vulpes*]) and a changing prey base may have maintained this restricted distribution until the mid-1900s (FaunaWest 1991). During the mid-twentieth century, swift fox populations began to recover in response to changing predator-control methods and decreasing numbers of ranching and farming operations (Floyd and Stromberg 1981).

Although swift foxes are considered to be relatively widespread, their present range is still constricted (Giddings 1997, Kahn et al. 1997, Roy 1998, Schmitt 2000). In 1992 the United States Fish and Wildlife Service (USFWS) was petitioned to list the swift fox as endangered and found that listing was "warranted, but precluded by other higher priority actions" (60 FR 31663; June 16, 1995). Following a widespread conservation initiative by state and federal wildlife agencies, the USFWS removed the swift fox from the candidate species list (66 FR 1298; January 8, 2001). However, with continuing concern about the population density of swift foxes in a given area, a test and evaluation of different census techniques was paramount. Methods for censusing wild canids include aerial surveys (Nellis and Keith 1976), catch-per-unit-effort (Clark 1972, Knowlton 1972, Davison 1980), scent-station surveys (Linhart and Knowlton 1975, Roughton and Sweeny 1982), howling response (Alcorn 1946, Wenger and Cringan 1978, Okoniewski and Chambers 1984), spotlight surveys (Ralls and Eberhardt 1997), track counts along a transect (Knowlton 1984), scat deposition rates (Clark 1972, Andelt and Andelt 1984, Knowlton 1984), an activity index (Allen and Engeman 1995, Allen et al. 1996), and mark-recapture estimates (e.g., Roemer et al. 1994). Nocturnal and fossorial habits preclude the use of aerial surveys for the swift fox. Howling surveys are impractical due to scant knowledge on fox vocalizations and the undetermined probability of a fox responding. Consequently, we initiated a 2-year study on the Piñon Canyon Maneuver Site, Colorado, to evaluate 6 methods (catch-per-unit-effort or trapping surveys, mark-recapture estimates, scent-station surveys, spotlight counts, scat deposition rate surveys, and activity index) and examine how these survey methods correlated to swift fox density as determined from radiocollared animals. We also evaluated the costs of each technique in relation to its ability to accurately predict swift fox population density.



The swift fox is an inhabitant of the shortgrass prairie ecosystem. Given the continued concern over the status of many carnivore populations, development and evaluation of survey techniques for monitoring population abundance are becoming more important.



Scent-post surveys are commonly used to monitor carnivore populations, but evaluation of their efficacy for tracking population trends is lacking.

Study area

The 1,040-km^2 Piñon Canyon Maneuver Site (PCMS) was located in Las Animas County, southeastern Colorado. The PCMS was acquired by the United States Army in 1983 for training mechanized infantry units. Prior to that acquisition, the PCMS was a collection of cattle ranches where predator-control programs were managed by individual landowners. After 1983, grazing was not allowed on site, and during our study the area was closed to recreational coyote hunting. The climate was classified as mid-latitude semiarid with mean monthly temperatures ranging from -1°C in January to 23°C in July (Andersen and Rosenlund 1991). The average annual precipitation of 32 cm fluctuated widely from year to year and among areas (United States Department of Army 1980). Elevation varied from 1,310 to 1,740 m. Topography consisted of broad, moderately sloping uplands bordered by the Purgatoire River Canyon on the east, limestone hills on the north and west, and a basalt hogback along the south (United States Department of Army 1980, Gese et al. 1988). Vegetation was dominated by shortgrass prairie and pinyon pine (*Pinus edulis*) and one-seeded juniper (*Juniperus monosperma*) woodland communities (Costello 1954, Kendeigh 1961). Grasslands comprised approximately 60% of the vegetation cover (Shaw et al. 1989), with blue grama (*Bouteloua gracilis*), sideoats grama (*B. curtipendula*), western wheatgrass (*Agropyron smithii*), galleta (*Hilaria jamesii*), and needle-and-thread (*Stipa comata*) dominating.

Methods

Capture and handling

We initially captured swift foxes with double-door box traps (80 × 25 × 25 cm; Tomahawk Live Trap Company, Tomahawk, Wisc.) baited with raw chicken (Covell 1992). To recapture certain individuals for changing radiocollars, we used a trap-enclosure system (see Covell 1992 for details). Personnel handled and restrained foxes by wearing thick leather gloves. We weighed, sexed, aged by tooth wear and body size (Rongstad et al. 1989), eartagged, radiocollared, and released each fox. We considered foxes as juveniles until the breeding season (December 15) following their birth, at which time we considered them adults. We radiocollared foxes with a 30-50 g transmitter (Advanced Telemetry Systems, Isanti, Minn.) weighing <5% of body mass (Eberhardt et al. 1982). All radiocollars included a mortality sensor that activated after 6 hours of no motion. No anesthesia was required during the handling of any fox.

Radiotelemetry

We located animals with a portable receiver (Telonics Inc., Mesa, Ariz.) and a hand-held 4-element Yagi antenna (Advanced Telemetry Systems, Isanti, Minn.). We used radiotelemetry techniques, similar to White and Ralls (1993) and White et al. (1994), to determine home-range size, spatial organization, and movement patterns of radiocollared foxes, following recommendations by White and Garrott (1990). We triangulated fox locations using LOCATE (Pacer, Truro, Nova Scotia, Canada) with at least 2 bearings taken <10 minutes apart. We maintained bearing angles between 20° and 160° (Gese et al. 1988) to minimize triangulation error. We determined telemetry error with the use of reference transmitters to be approximately ±8°. We attempted to locate foxes at least once per day. Point locations were taken at >8-hour intervals and sequential locations were taken every 0.5 hours. We attempted to equally point sample all periods of the 24-hour day. We used aerial telemetry (Mech 1973) with fixed-wing aircraft and helicopters to locate missing animals. When foxes were located in a den, we recorded the den location and general description and marked the site for future reference. We considered foxes concurrently sharing the same den to be in the same social unit. We determined adequate sample sizes of radio locations for each fox from area-observation curves (Odum and Kuenzler 1955), which indicated that foxes were required to have >30 locations within a season to be included. We defined annual seasons on the basis of changing energetic needs and behavioral characteristics: breeding and gestation (15 Dec-14 Apr), pup-rearing (15 Apr-14 Aug), and dispersal (15 Aug-14 Dec).

Estimates of fox density

The 1,040-km^2 PCMS allowed for the capture and radiocollaring of foxes in 5 different survey areas with varying swift fox densities. We named the 5 survey areas for geographic and topographic features: Tyrone, Joella, Biernacki, Rock Crossing, and Pronghorn. We spaced these 5 areas >1.5-home-range (Rongstad et al. 1989) diameters apart (1.6 km) to minimize the chance of sampling individuals from one area on 2 different survey transects, thus maintaining independent sampling during surveys. We censored animals that died or went missing from the analysis for the season within which this event occurred, unless otherwise noted. In each of the 5 survey areas, we constructed 100% adaptive kernel estimators (Worton 1989) for total use areas of individual swift foxes using CALHOME (Kie et al. 1996). We then loaded these CALHOME area-use polygons into ArcView 3.0 (Environmental Systems Research Institute, Inc., Redlands, Calif.) and overlaid on the 10-km transect over which all seasonal surveys were conducted using the Universal Transverse Mercator (UTM) projection. We then buffered these transects by the average radius of swift fox use areas for that site. We employed the outermost boundary of either a swift fox's use area or the transect buffer to define the total area of actual and potential use across a particular site. This was done to include some measure of space that was unoccupied but suitable for swift fox use. Across even the relatively small landscape of our 10-km transect, swift foxes were distributed unevenly in a patchy manner. We then calculated density as the total number of foxes at a site divided by the total area of actual and potential use.

Surveys

Within each of the 5 survey areas, we conducted the following survey methods: catch-per-unit-effort (Clark 1972, Davison 1980), mark-recapture estimates (Schnabel 1938), scent-station surveys (Linhart and Knowlton 1975), spotlight surveys (Ralls and Eberhardt 1997), scat deposition rates (Clark 1972, Knowlton 1984, Andelt and Andelt 1984), and an activity index survey (Allen and Engeman 1995, Allen et al. 1996). Transect routes for each of the 5 survey areas were 10 km in length, and all surveys within a specific survey area were conducted over the same transect route. We then regressed an estimate of population size (mark-recapture only), or an index of visitation, capture, or sightings versus the independently derived fox-density estimate. We used the program SYSTAT (Wilkinson et al. 1992) to perform the regression analyses.

Trapping (catch-per-unit-effort) surveys. We conducted a catch-per-unit-effort or trapping survey (Clark 1972, Knowlton 1972, Davison 1980) with traps deployed at 0.5-km intervals along each 10-km survey route. We baited the traps with chicken, and these traps remained open for 4 consecutive nights, weather permitting. Processing of trapped foxes during surveys followed the protocols previously described. We calculated a trapping index as: (total number of captures/total number of operable trap nights) × 100.

Mark-recapture estimates. We calculated a mark-recapture estimate of population size using the data from the catch-per-unit-effort trapping surveys. With the number of marked foxes increasing over the 4 nights of trapping, we used an extension of the Petersen method to a series of samples. The Schnabel (1938) mark-recapture method is a weighted average of multiple Petersen estimates and uses the formula: $N=\sum(C_t M_t)/\sum R_t$; where C_t is the total number of individuals caught in sample t, M_t is the number of marked individuals in the population prior to the tth sampling, and R_t is the number of individuals already marked in sample t.

Scent-station surveys. We conducted scent-station surveys following methods modified from Linhart and Knowlton (1975). We placed scent stations at 0.5-km intervals along each 10-km survey route. Each station consisted of a 1-m circle of sifted dirt with an unscented predator survey disc (Pocatello Supply Depot, Pocatello, Id.) soaked in mackerel oil, placed in the center as an attractant. We examined scent stations and re-sifted them daily. We recorded visitation of swift foxes, coyotes, black-tailed jackrabbits (*Lepus californicus*), desert cottontails (*Sylvilagus audubonі*), and kangaroo rats (*Dipodomys* spp.), as well as all other species. We calculated a scent-station index as: (total number of visits for a species/the total number of operable scent stations) × 100. We conducted this survey over 4 consecutive nights when weather permitted.

Spotlight surveys. We conducted spotlight surveys following methods modified from Ralls and Eberhardt (1997). We drove a truck along the transect route at approximately 10–15 km/hr. Standing in the truck bed, 2 observers used spotlights of 500,000 candlepower to scan both sides of the route. If an animal was not readily discernible or identifiable, the driver stopped the vehicle and the observers used binoculars to positively identify the species. We recorded the total numbers of swift foxes, coyotes, black-tailed jackrabbits, desert cottontails, and kangaroo rats. Surveys started >1 hour after sunset and ended no later than 5 hours after sunset. We surveyed each transect 4 times per season. We conducted surveys on consecutive nights when weather permitted. The average number of foxes observed per kilometer along the transect within a season served as a spotlight index.

Scat deposition rates. We calculated these rates by determining the rate of scat deposition per km per day. This method (Clark 1972, Andelt and Andelt 1984, Knowlton 1984) entailed walking the transect to initially clear any scat from the road surface, then walking the transect again after approximately 14 days and counting the number of scat deposited. We used 2 observers to minimize the chance of missing or misidentifying scat along the route (Knowlton 1984). Each transect was cleared and re-walked twice per season. We used the average seasonal daily rates of scat deposition per kilometer as a scat deposition index.

Activity index. As described by Allen and Engeman (1995) and Allen et al. (1996), we modified survey recommendations and sifted a 1-m swath across the transect road at 1-km intervals. We examined these surfaces and re-sifted them daily. We recorded visitation of swift foxes, coyotes, black-tailed jackrabbits, desert cottontails, and kangaroo rats, as well as all other species. We calculated an activity index as: (total number of visits for a species/total number of operable tracking surfaces) × 100. We conducted this survey for 4 consecutive nights when weather permitted.

Results

Capture and radiotelemetry

From 8 January 1997 to 14 December 1998, we captured 94 swift foxes in 5 survey areas 227 times. We fitted 90 animals across these areas with radiocollars prior to release. The sex ratio of collared swift foxes was 42M:48F and was not different than parity ($\chi^2_1=0.527$, $P=0.47$). Seasonally, 53% of all captures occurred during the breeding-gestation season, with 13% and 33% occurring during the pup-rearing and dispersal seasons, respectively. The age structure of the 90 radiocollared swift foxes at the time of capture was comprised of 27.8% juveniles ($n=25$, 15M:10F) and 72.2% adults ($n=65$, 27M:38F). As previously mentioned, we considered all individuals encountered during the breeding-gestation seasons as adult (i.e., we classed juveniles as adults after 9 months of age). We conducted trapping early in the pup-rearing seasons, before kits began to wander widely from their natal dens; therefore, none were encountered in these seasons. Consequently, we captured juveniles only during the dispersal seasons. During the dispersal seasons of 1997 and 1998, juveniles accounted for 93.3% (14 of 15) and 64.7% (11 of 17) of all captures, respectively.

During the study, we followed 14 foxes for >20 months, and 13 remained alive at the end of the dispersal season in 1998. We followed 20 foxes for 12–20 months, 28 foxes between 4–12 months, and an additional 28 foxes were followed <4 months. During our study, we obtained 13,077 locations (845 in breeding-gestation 1997, 2,064 in pup-rearing 1997, 2,776 in dispersal 1997, 2,005 in breeding-gestation 1998, 2,131 in pup-rearing 1998, and 3,256 in dispersal 1998) for radiocollared swift foxes. The mean number of locations ($\bar{x}\pm SE$) for foxes that met the minimum requirement for estimating seasonal use areas were as follows: 32.4±3.1 and 50.8±8.8 for the breeding-gestation seasons, 64.3±13.5 and 54.2±9.56 for the pup-rearing seasons, and 69.9±13.4 and 68.1±14.6 for the dispersal seasons for 1997 and 1998, respectively.

Table 1. Density estimates of swift foxes on the 5 survey transects (BTS: Biernacki, JLA: Joella, PRN: Pronghorn, RCK: Rock Crossing, TYR: Tyrone) during 3 biological seasons over 2 years, Piñon Canyon Maneuver Site, Colorado, 1997–1998.

		Density estimates (foxes/km^2)						
Season[a]	Year	BTS	JLA	PRN	RCK	TYR	$\bar{x}$	SE
Breeding–gestation	1997	0.247	0.102	0.194	0.179	0.241	0.193	0.058
Pup rearing	1997	0.215	0.091	0.138	0.122	0.328	0.179	0.095
Dispersal	1997	0.314	0.154	0.118	0.142	0.239	0.193	0.081
Breeding–gestation	1998	0.418	0.204	0.141	0.136	0.309	0.242	0.121
Pup rearing	1998	0.263	0.172	0.106	0.153	0.314	0.201	0.085
Dispersal	1998	0.514	0.096	0.248	0.184	0.461	0.301	0.180

[a] Season: breeding–gestation (15 Dec–14 Apr), pup-rearing (15 Apr–14 Aug), dispersal (15 Aug–14 Dec).

Estimates of fox density

Swift fox density varied between survey areas and seasons (Table 1), averaging 0.218 foxes/km^2 for all seasons and years combined. Swift fox density varied seasonally from a mean low of 0.179±0.095 foxes/km^2 during the pup-rearing season of 1997, to a mean high of 0.301±0.180 foxes/km^2 during the dispersal season of 1998. Overall, seasonal densities increased during 1998 from their respective counterparts in 1997. This may have been due to an actual increase in density or an improved understanding of where foxes were as the study progressed (the high correlations with several of the survey methodologies suggest an increase in fox density).

Surveys

There were occasions when all surveys could not be completed, most notably during the dispersal season of 1997. An early winter snowfall and cold temperatures conspired to make transect roads impassable, limiting our ability to conduct surveys. In addition, we accomplished only the trapping surveys during the breeding season of 1997, owing to the tremendous initial effort required to radiocollar swift foxes in the 5 survey areas. Overall, 4 survey methods were consistent detectors of swift fox presence across the survey areas. The spotlight survey and the trapping survey failed to detect foxes

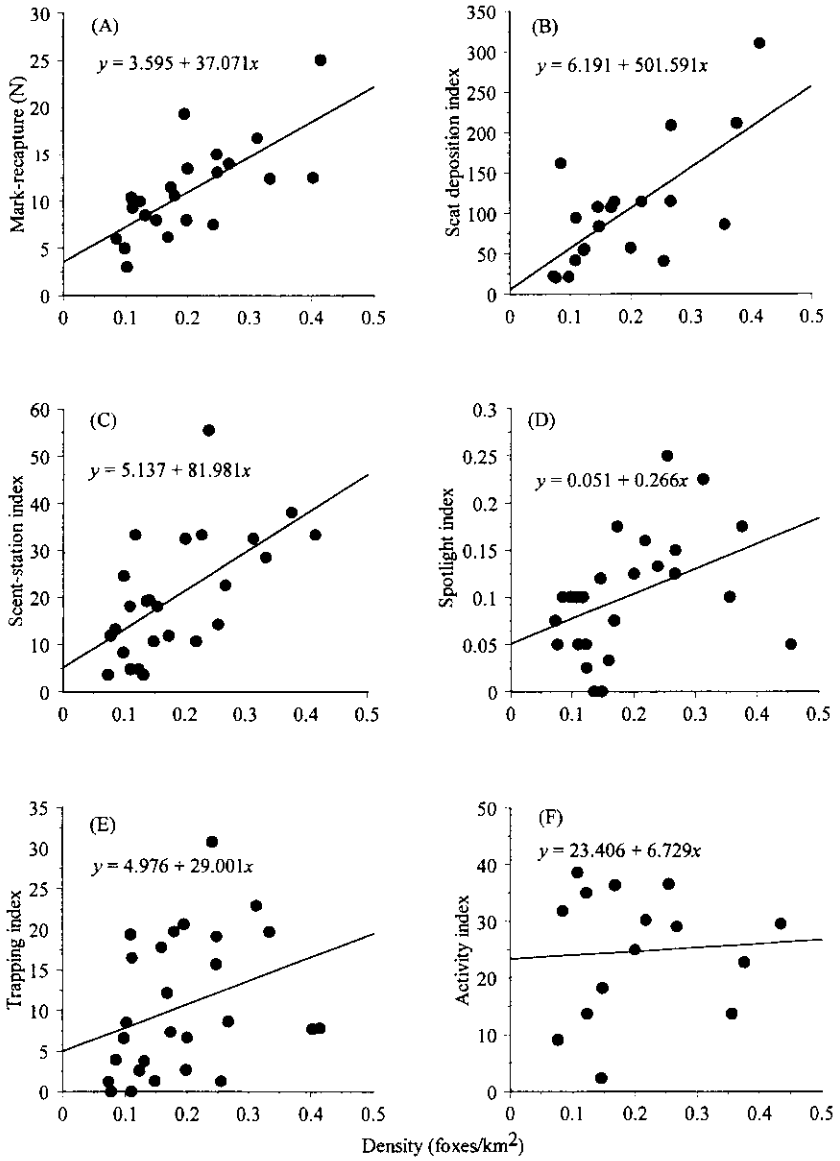


Figure 1. Relationship between (A) mark-recapture estimates, (B) scat deposition index, (C) scent-station index, (D) spotlight index, (E) trapping index, and (F) activity index, and swift fox density, Piñon Canyon Maneuver Site, Colorado, 1997–1998.

during 2 surveys, even though foxes were present in those areas during the surveys.

Mark-recapture estimates. We conducted 27 trapping surveys yielding 22 mark-recapture data sets; 5 trapping surveys did not yield a recapture of a marked fox, thus a mark-recapture estimate could not be derived. Regression of swift fox density versus the population size estimates found that the mark-recapture method was the highest predictor (based upon the r value) of swift fox density (r= 0.711, $F_{1,20}$=20.397, P<0.001). The correlation between the mark-recapture estimate and the independently derived swift fox density was linear (Figure 1A) and positively correlated during all seasons (Table 2).

Scat deposition rates. Scat deposition surveys began in the pup-rearing season of 1997 and were conducted each season afterward, except the dispersal season of 1997, for a total of 20 surveys. Scat deposition rates varied widely across seasons and transects, averaging 0.101 fox scats/km (range = 0.020–0.208). Overall, scat deposition rates were the second highest predictor of swift fox density (r=0.697, $F_{1,18}$=16.971, P = 0.001), although they were not statistically different than mark-recapture estimates (based upon P values). Overall scat deposition rates were positively correlated with density (Figure 1B), except during one season (pup-rearing 1998) when the relationship between fox density and scat deposition rate was negatively correlated (Table 2).

Scent-station surveys. We began scent-station surveys in the pup-rearing season of 1997 and conducted them for every season thereafter for a total of 25 surveys. Overall, the rate of scent-station visitation during the survey period for all seasons and transects averaged 0.191 fox visits per station (range = 0.036–0.405). Regression of fox density and the scent-station index found this index to be the third highest predictor of swift fox density (r= 0.608, $F_{1,23}$=13.519, P=0.001). The overall indices of scent-station visitation were positively and linearly related with fox density (Figure 1C). Seasonal surveys were also positively related to fox density (Table 2).

Table 2. Results of regression analyses examining the relationship between swift fox density and 6 survey methods during 3 biological seasons over 2 years, Piñon Canyon Maneuver Site, Colorado, 1997–1998.

		Mark-recapture		Scat		Scent station		Spotlight		Trapping		Activity	
		r	*P*	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Breeding	1997	0.537	0.351							0.704	0.185		
Pup rearing	1997	0.950	0.201	0.779	0.120	0.972	0.006	0.582	0.303	0.729	0.162		
Dispersal	1997					0.490	0.403	0.852	0.067				
Breeding	1998	0.591	0.294	0.493	0.399	0.639	0.246	0.533	0.355	0.374	0.536	–0.448	0.449
Pup rearing	1998	0.319	0.681	–0.566	0.320	0.426	0.474	0.876	0.051	–0.874	0.052	0.298	0.749
Dispersal	1998	0.481	0.681	0.955	0.011	0.840	0.075	0.384	0.523	0.887	0.045	0.832	0.080

Spotlight surveys. We conducted spotlight surveys for every season beginning with the pup-rearing season of 1997 for a total of 25 surveys. For the entire study, foxes observed averaged 0.105 foxes/km (range=0–0.225); spotlight counts failed to detect any foxes during 2 surveys. Regression analysis found spotlight surveys to be the fourth highest predictor of swift fox density ($r=0.420$, $F_{1,23}=4.936$, $P=0.036$). Overall, spotlight indices were correlated with fox density (Figure 1D), and this relationship was positive during all seasons (Table 2).

Trapping surveys (catch-per-unit-effort). We conducted trapping surveys during every season of the study, except the dispersal season of 1997, for a total of 27 surveys. Capture rates varied widely across seasons and transects and averaged 0.093 foxes per trap night (range=0–0.31); 2 surveys failed to trap any foxes even though they were present in the area. Regression analysis showed trapping surveys to be one of the lowest predictors of fox density ($r=0.326$, $F_{1,25}=2.981$, $P=0.097$, Figure 1E). The trapping index was negatively related to fox density during the pup-rearing season of 1998 (Table 2).

Activity index. We added activity index surveys during the second year of study for a total of 15 surveys. During 1998, overall visitation rates averaged 0.247 fox visits per station (range= 0.023–0.386). Activity indices were not correlated with fox density ($r=0.067$, $F_{1,13}=0.059$, $P=0.812$, Figure 1F). The activity index was negatively related to fox density during the 1998 breeding season (Table 2).

Pooled survey results

Stepwise regression analysis of all 6 surveys combined versus swift fox density identified the best-fitting model as that including mark-recapture estimates and the scent-station indices ($r=0.853$, $F_{2,14}=18.755$, $P<0.001$). The combination of scent-station indices and scat deposition surveys was almost as effective in predicting swift fox density ($r=0.829$, $F_{2,17}=18.637$, $P<0.001$). Combining the three best predictors (i.e., mark-recapture estimates, scent-station indices, and scat deposition surveys) increased the predictability of swift fox density only slightly ($r=0.867$, $F_{3,11}=11.088$, $P=0.001$). Using the 4 surveys that were independently identified as being significantly correlated with fox density (i.e., mark-recapture estimates, scent-station indices, scat deposition surveys, and spotlight surveys) did not add much more ability to predict swift fox density ($r=0.885$, $F_{4,11}=9.072$, $P=0.002$).

Time and materials

The survey methods used during our study differed in both effort and equipment required (Table 3). Thus, total costs required for conducting these surveys varied as well. However, if the initial equipment costs were amortized over several survey periods, what appeared as a rather "expensive" survey technique ultimately became a more cost-effective solution in the long term. For example, the annual cost for conducting trapping surveys 3 times a year on 5 transects (15 surveys, 10 km in length) included 97.5 person-hours and a capital investment of $1,302, for a total of $2,427, whereas a seemingly simple survey that required no equipment, such as the scat deposition rate surveys, ended up costing almost as much at $2,400 a year because of the high amount of labor involved (240 person-hours). The activity index survey was the least costly survey method, due to its modest equipment and time requirements; it cost only $634 annually (Table 3). However, the ability of each technique to accurately reflect changes in swift fox density must also be considered. For example, while the activity index was the lowest in expense, it was the lowest predictor of fox density (Figure 2). In contrast, the mark-recapture method was the

Table 3. Equipment and time estimates required to complete each survey method along one 10-km transect, Piñon Canyon Maneuver Site, Colorado, 1997–1998.

Survey method	Equipment	Equipment cost	Set-up time[a]	Survey time[b]	Total costs[c]
Mark-recapture	21 box traps	$1,302 ($62 each)	2.5	8.0	$1,427
	bait (chicken)	$10			
	ear tags	$10			
Trapping	21 box traps	$1,302 ($62 each)	2.5	4.0	$1,377
	bait (chicken)	$10			
Spotlight	2 spotlights	$84 ($42 each)	0	12.0	$354
	2 binoculars	$150 ($75 each)			
Scent station	survey discs	$100 (100 discs)	2.5	2.0	$215
	scent	$36 (1 gallon)			
	sifting screen	$15			
	small shovel	$14			
	dusting brush	$5			
Scat	none required	N/A	0	16.0	$160
Activity	sifting screen	$15	2.5	2.0	$79
	dusting brush	$5			
	small shovel	$14			

[a] Set-up time: total person-hours required for survey set-up and take down (if applicable). One person used to set-up mark-recapture, trapping, scent-station, and activity surveys.

[b] Survey time: total person-hours required to actually conduct the survey. One person required for trapping, scent station, and activity surveys; 2 persons required for mark-recapture and scat deposition surveys; 3 persons required for spotlight surveys.

[c] Total costs: equipment costs and person-hours (rated at $10/hr) combined.

most expensive technique, yet was the best predictor of fox density. The combination of mark-recapture and scent-stations increased the ability to predict fox density (from 0.71 to 0.85) without greatly increasing the costs (Figure 2). The combination of scent stations and scat deposition surveys was equally reliable ($r=0.83$), yet cost relatively little ($375 combined) and was far less expensive than surveys involving mark-recapture estimates (Table 3).

Discussion

In 1994 state and federal wildlife management agencies formed the Swift Fox Conservation Team (SFCT). The SFCT recognized that "a divergence of opinion exists regarding techniques and the relationship of survey results to actual population densities" (Luce and Lindzey 1996:3). Kahn et al. (1997:vi) recognized that the "development of a survey protocol to monitor trends in the distribution and population status of swift fox throughout the species range" was critical for successful conservation of swift foxes. Sargeant et al. (1998:1235) stated "estimates of animal abundance are among the most important information needs of wildlife managers and researchers." Yet the seemingly simple relationship between animal density and survey results continues to remain problematic and complex. This confusion results partly from the life history traits and behavioral characteristics of many carnivores. Many exist at low densities under normal or even ideal conditions and in environments commonly described as rugged and remote (Knowlton 1984, Sargeant et al. 1998). In addition, some carnivores are intolerant of human presence and are secretive, nocturnal, fossorial, and far-ranging, making direct observation and detection complicated (Lewis 1970, Knowlton 1984, Sargeant et al. 1998, Gese 2001). All of these in combination make quantitative assessments of relative or absolute abundance difficult, if not impossible (Knowlton 1984, Sargeant et al. 1998). However, as concern for carnivores throughout the world grows (Schaller 1996) and continuing research enhances our understanding

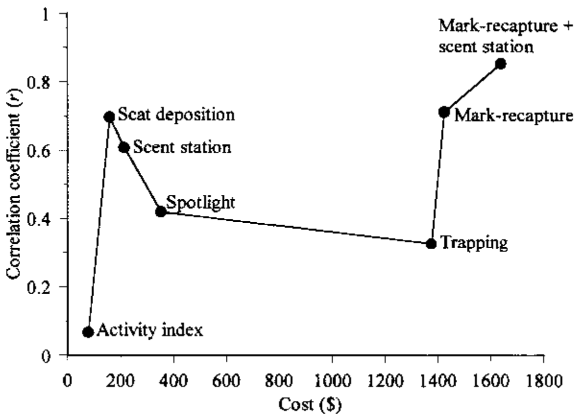


Figure 2. Relationship between correlation coefficient (r) and cost of survey method, Piñon Canyon Maneuver Site, Colorado, 1997–1998.

and appreciation for the important role these species play in their ecosystems (Estes 1996, Mech 1996), wildlife managers and researchers are still left asking the simple questions of "where?" and "how many?"

Censusing techniques and survey methods often are employed at very scale-specific degrees of resolution. The general question of "Where is an animal found?" is an attempt to address the gross level of an organism's distribution and is often answered by documenting species presence. Swift fox researchers from various state and federal agencies have been using a variety of methods to document swift fox presence since the early 1990s, and all have met with varying degrees of success. Survey methods have included spotlighting, baited tracking stations and plates, systematic ground and air searches for tracks and active dens, trapping, road-kill surveys, sighting and harvest reports, review of museum specimens, questionnaire mailings, and interviews with landowners and trappers (see Allen et al. 1995, Luce and Lindzey 1996, Roy 1998, Schmitt 2000). Most of the 6 methods evaluated during this study were reliable and consistent detectors of swift fox presence. As noted previously, both the catch-per-unit-effort and spotlight surveys failed to detect swift fox presence on 2 surveys. Of noteworthy mention, however, is that during both "failed" trapping surveys, swift fox activity and presence at different trap sets could be determined by fox sign (tracks or scat).

Once a species' presence has been established, the next reasonable question is "How many?" Again, managers and researchers must decide the degree of precision required to assess an animal's abundance. Relative abundance can be assessed using any of the surveys previously discussed. Typically, indirect survey methods (where the animal itself is not necessarily encountered but where its presence and activity are indexed) are used and indices compared between areas of concern or over time intervals of interest. These indirect techniques do not attempt to estimate the actual size of the population. By comparison, direct counts (e.g., trapping) are used to estimate the actual size of a population by directly counting either all the individuals in an area of concern or those individuals within a subset of the population's total area and extrapolating across the wider area of distribution. The use of any of these survey methods to estimate relative or absolute abundance hinges on the assumption that survey indices are on some level correlated with density. This assumption has rarely been tested (Gese 2001), and in some studies has been shown to be unfounded (Messick and Hornocker 1981, Messick 1987, Smith et al. 1994).

Before discussing the practical advantages and limitations of each survey method, a few general considerations are worth mentioning. First, we conducted our study at a relatively small spatial scale with fairly short transect lengths, but within practical application (Knowlton 1984). Therefore, individual surveys conducted during specific seasons might have lacked the sensitivity to demonstrate a clear association between density and survey index in any one season (i.e., small sample size). Supporting this rationale was the fact that swift foxes on the PCMS seemed to exist at low densities, and this fact, combined with relatively low survey response rates, may have helped to limit our ability to detect a clear association between density and survey indices on a seasonal basis (Table 2). It is interesting to note that during the dispersal season of 1998, when fox densities were highest, several of our survey methods did appear to detect an association between density and survey index. In addition, when we pooled the survey data, we were able to establish correlations between survey indices and fox density for 4 survey methods: mark–recapture, scat deposition, scent-station surveys, and spotlight surveys (Figure 1).

Second, survey methods varied in the length of time animals were exposed to the specific technique being used. For example, both trapping and spotlight surveys allowed an animal to be encountered only once, while the other surveys allowed responses (visitation or scats deposited) to accumulate over time. Response rates, therefore, were not dependent on encounter rates alone, but on an animal's level of activity over a period of time. It seems reasonable to assume that in areas of lower density (especially when this condition is due to lower prey densities or more marginal habitat types), animals may be spending more time searching larger areas and traveling greater distances to sustain themselves. If this is the case, allowing more time for animals to respond to a survey may not only increase overall response rates but would also allow for more consistent level of response from one survey period to the next.

Third, whether a survey method actively encourages or just passively records animal response may also affect how indices associate with density. Active survey methods, where animal response is elicited by an attractant (e.g. baited traps or scent stations), may expose a wider area to the survey, thus increasing sampling area. However, the attractant used or the medium upon which it is used (e.g., sooted track plates) should be carefully considered as it may preferentially attract one species while repulsing another. During our study, we recorded greater coyote response on the activity index stations (a passive method) as compared with the scent stations. The natural wariness of the target species should be considered if a particular survey method is to be successful. The effect of previous experience should be taken into account before surveying an area—both experience prior to the onset of survey and experience associated with the technique itself when it is used repeatedly. We did not see evidence that radiocollared foxes avoided traps or scent stations, but it is likely that animal behavior could change over time when a specific survey technique involves a negative experience (e.g., being trapped). This could confound comparisons between different survey areas and also between surveys from different time periods in the same area.

Finally, biologists should also consider the seasonal timing of surveys. Conner et al. (1983:149) found that "gray fox scent-station visitation rates were affected both by population density and movements." In Wyoming, swift fox detection rates were greatest during a fall sampling period on both scat surveys and tracking plates (Dieni et al. 1996). For many canid species in North America, autumn corresponds with a time of year when populations are at their highest levels, due to the addition of young of the year, and species mobility is increased due to dispersal. If the primary goal of the survey effort is to document distribution, fall may be a suitable time of year. However, if the principal objective is to monitor the status of a resident population, fall may be the least desirable time of year "since yearly variations detected in population size could reflect differences in productivity of local populations" (Dieni et al. 1996:58). Surveys conducted in the spring would reflect the breeding population and be more representative of the surviving nucleus of resident animals required for population persistence.

Evaluation of survey methods used and recommendations

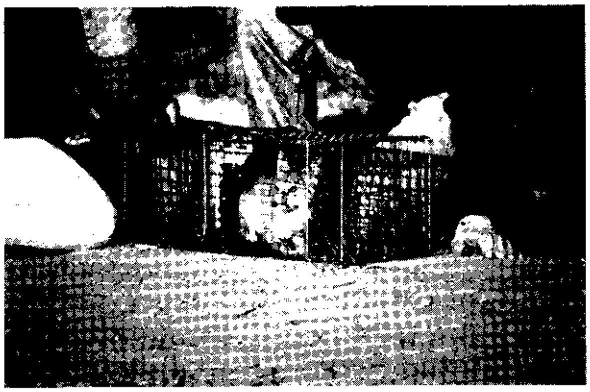
While the catch-per-unit-effort or trapping surveys ranked fifth among the 6 surveys for predicting fox density, using this method to generate data for a mark-recapture estimate produced the best predictor for monitoring changes in swift fox density. Essentially, adding the costs of ear tags to mark the foxes captured during trapping made trapping surveys highly effective for mark-recapture estimation of population size. However, trapping surveys do pose significant risk to the welfare of individual animals. We encountered injuries ranging from minor scrapes and chipped teeth to one case of a broken lower mandible. Our traps were constructed of wire mesh, which allowed foxes to bite down and chew on the trap's structure (we recommend modifying traps by reducing mesh size). Another potential problem with this survey method could be the immense start-up costs in terms of equipment, especially if an expansive area is to be surveyed at one time, requiring very large numbers of traps. However, this cost is offset by the fact that one trained person can effectively set and run a trapping line or grid, and if surveys are continued over several seasons or years, initial costs are amortized over the duration of a study. Researchers should also consider the potential for increased wariness of the target species to continual use of certain baits and traps. An inability to recapture individuals over a long time period will violate certain assumptions for determining mark-recapture estimates.

Scent-station indices were consistently associated with swift fox density. In addition, they reliably detected swift fox presence on all survey areas during all seasons. Scent-station surveys were modest in cost, could be done by one person, and posed little risk to individual animals. Accurate track identification, careful preparation of the tracking substrate surface, favorable weather (no precipitation and lack of wind), and the need for stations to be conveniently located but not disturbed are all requirements for this technique to be successful (Linhart and Knowlton 1975, Knowlton 1984). The wariness of animals to a sifted substrate with an attractant should also be considered (Knowlton 1984, Gese 2001). Roughton and Sweeny (1982), Smith et al. (1994) and Sargeant et al. (1998) should be consulted before scent-station surveys are initiated.

Spotlighting allowed for the definite identification and direct counting of individual animals. This method posed little risk to study animals and was modest in cost. Spotlighting does require more than one observer (two observers and a driver) and should be calibrated to occur during peak hours of activity. Additionally, road access, favorable weather, and good sightability are required for this technique to be effective (Progulske and Duerre 1964, Wooley et al. 1995, Ralls and Eberhardt 1997). Significant associations between fox density and spotlight counts were not observed seasonally, and it ranked fourth among all techniques. In addition, spotlighting did not detect swift foxes in 2 survey areas during different seasons. We routinely carried a receiver and omnidirectional antenna while spotlighting, and the presence of radiocollared animals was known only to the driver. During both "failed" spotlight surveys, radiocollared animals were present in the study area, but the exact location of radioed animals was unknown; thus, it is likely they were outside the range of the spotlight. Both vegetation and terrain affect the sighting distance from the transect and may confound comparisons between survey areas or between survey periods (Wooley et al. 1995, Ralls and Eberhardt 1997).

Scat deposition rate surveys (Clark 1972) for coyotes reliably correlated with species abundance (Davison 1980, Knowlton 1984). This association also was observed for the swift fox. Balcomb (unpublished report cited in Knowlton 1984) noted the following considerations: 1) removal of scats may slightly reduce deposition rate in subsequent days (animals are motivated to deposit "new" scats when "old" ones are encountered), 2) observer variability bias is low, and 3) scat persistence is negatively correlated with the amount of vehicle traffic. Knowlton (1984) also noted that up to 30% of individual scats were routinely missed each time transects were walked, regardless of the observer, and suggested that transects be walked twice. Another potential limitation of this method was that scats may be hard to differentiate if many small canid species occupy the area (Murie 1954, Green and Flinders 1981, Danner and Dodd 1982). However, the simplicity and practicality of this technique may make it one of the more useful methods tested. Target species were not required to respond or act in any unnatural manner, and this method "is not dependent upon creating special substrates or circumstances, requires a minimum of observer skill and training, and accumulates information over a period of time without an observer in attendance" (Knowlton 1984:4). This technique ranked second in accurately predicting fox density and was relatively inexpensive.

Allen and Engeman (1995) found the activity index to be a more sensitive technique than scent stations when attempting to detect changes in dingo (*Canis familiaris dingo*) activity. However, when compared with other methods used in this study, the activity index ranked last among all methods in accurately tracking changes in swift fox density. Similar to the scent-station survey, the following are requirements for this technique to be successful: accurate track identification, careful preparation of the tracking substrate surface, favorable weather (no precipitation and lack of wind), and the need for stations to be conveniently located but not disturbed (Allen and Engeman 1995, Gese 2001).



Researchers attempt to coax a trapped swift fox into a canvas bag prior to processing and radiocollaring.

Based upon the stepwise regression analysis, the combination of the mark-recapture and scent-station survey provided the best predictor ($r=0.85$) for tracking changes in swift fox density. Combining two techniques was advantageous for documenting abundance and trend analysis, rather than depending on one technique that may vary seasonally and annually, as our data illustrated (Table 2). In combination, these techniques were not too expensive, but required a modest level of person-hours in the field. Equally reliable was the combination of scent-station indices and scat deposition surveys ($r=0.83$), which cost far less than the surveys for mark-recapture estimates and were noninvasive techniques. However, to generate the most accurate estimates of swift fox density utilizing radiocollared individuals, determination of social unit size and estimation of home range size required a tremendous amount of effort and resources (>$3,000 per month for our study, dependent upon the number of foxes monitored). By comparison, either mark-recapture and scent-station surveys, or scat deposition and scent-station surveys (both noninvasive techniques), would be economically feasible, efficient, and generate a relatively good correlation to swift fox density. Our evaluation of survey methods has direct application for monitoring the abundance of small and medium-sized carnivores, particularly the close cousin of the swift fox, the San Joaquin kit fox (*V. macrotis mutica*), currently a Federally listed endangered species.

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