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DEPARTMENT OF GAME & FISH
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December 19, 2001

Ms. Joyce Johnson
U. S. Fish and Wildlife Service
Division of Federal Aid
P. O. Box 1306
Albuquerque, New Mexico 87103

Attn: Penny Bartnicki

Dear Ms. Johnson:

Enclosed is the completion report for federal aid grant E-43, Population Status, Population Viability, and Habitat Use of the Swift Fox in New Mexico. This report covers segments 1 through 3 for the period of October 1, 1998 through September 30, 2001.

If you have any questions regarding this report, please contact me (505/476-8012). Thank you.

Sincerely,

Lisa B. Evans

Lisa B. Evans
Federal Aid Coordinator

LBE/MLM

cc: Joy Nicholopolous (Ecological Services, USFWS)
Tod Stevenson (Conservation Services Division Chief, NMGF)
Chuck Hayes (Conservation Services Division Assistant Chief, NMGF)
C. Greg Schmitt (Endangered Species Biologist, NMGF)
Mary Medina (Conservation Services Division Financial Specialist, NMGF)

FINAL REPORT

State: New Mexico Project Number: E-43-3

Grant Title: Endangered Species

Study Title: Population Status, Population Viability, and Habitat Use of the Swift Fox In New Mexico.

Contract Period: October 1, 2000 To: September 30, 2001

I Project Statement

To determine the population status, population viability, and habitat use of the swift fox in New Mexico.

II. Project Objectives

1. Determine the method of population census most appropriate for swift foxes in New Mexico.
2. Determine demographic parameters necessary for assessment of population viability: natality, mortality, and sex ratios.
3. Determine whether or not and under what circumstances swift foxes will use cropland habitats.
4. Determine population density, home range size, diet, and den site selection within study area.
5. Assess threats to swift foxes.
6. Prepare a performance and completion report within 90 days after completion of this project.

Procedures

1. **Determine the method of population census most appropriate for swift foxes in New Mexico.** Information on determination of a method of population census most appropriate for swift foxes in New Mexico is found in attached Appendix 1, Population Survey Methods for Swift Fox in New Mexico.

2 **Determine demographic parameters necessary for assessment of population viability: natality, mortality, and sex ratios.** Information on swift fox demography is found in attached Appendix 2, Swift Fox Demography, Movements, Denning, and Diet in New Mexico.

3. **Determine whether or not and under what circumstances swift foxes will use cropland habitats.** This project objective was completed and reported in the performance report of segment 2 (E-43-2) of this project.

4. **Determine population density, home range size, diet, and den site selection within study area**. Information on population density, home range size, diet, and den site selection is found in attached Appendix 2, Swift Fox Demography, Movements, Denning, and Diet in New Mexico.

5. **Assess threats to swift foxes**. Information on threats to swift foxes is found in attached Appendix 2, Swift Fox Demography, Movements, Denning, and Diet in New Mexico.

6. **Prepare a performance and completion report within 90 days after completion of this project.** The final report for this project is found in Appendix 1, Population Survey Methods for Swift Fox in New Mexico and Appendix 2, Swift Fox Demography, Movements, Denning, and Diet in New Mexico.

Prepared by: Greg Schmitt
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APPENDIX 1

Population Survey Methods for Swift Fox in New Mexico

Population Survey Methods for Swift Fox in New Mexico

By

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Section 6 Project E-43
Population Status, Population Viability, and Habitat Use
of the Swift Fox in New Mexico

New Mexico Department of Game and Fish
Endangered Species Program
P. O. Box 25112
Santa Fe, New Mexico 87504

Professional Services Contract 99-516.52

17 December 2001

Population Survey Methods for Swift Fox in New Mexico

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ABSTRACT.—We examined presence/absence and absolute abundance survey methods for monitoring populations of swift fox (*Vulpes velox*) in New Mexico. For presence/absence surveys, the most efficient method is collection of scat followed by verification of species depositing scat with DNA analysis. Using scat, the detection rates of swift foxes at individual locations was 61.9% and 67.7% during surveys in 2000 and 2001, which were greater than the detection rates using scent stations (31.4% , 47.1%) or trapping (11.5%, 8.4%). We detected swift foxes using scat in 100% of the fox home ranges within the study area. Transects of three scent stations per home range operated for three nights detected swift foxes on as many as 95% of transects, depending upon fox density. Searching for tracks, spotlighting, and calling are much less efficient methods. For absolute abundance surveys, we compared trapping and resighting with cameras against counting unique microsatellite DNA genotypes from collected scats. Using trapping/resighting, we estimated the 95% confidence intervals for the swift fox population within the study area to be 17.8 - 30.0, 11.9 - 25.3, and 15.2-17.3 in the periods Nov., 1999, - Jan., 2000, Feb., 2000, and Jan. - Mar., 2001, respectively. We counted 63 and 27 unique genotypes in early 2000 and 2001, respectively. The numbers of unique genotypes, which were much greater than population estimates obtained from trapping and resighting, were overestimated because of the presence of transient swift foxes and poor quality DNA from scat leading to allelic drop-out and/or false alleles.

INTRODUCTION

The swift fox (*Vulpes velox*) is a small (<3.0 kg) canid which occurs in the short grass prairie from eastern New Mexico and northwestern Texas to southern Alberta and Saskatchewan (Egoscue, 1979). The swift fox was once abundant, but the arrival of settlers led to a drastic population decline through fur trapping, habitat loss, and trapping and poisoning campaigns directed against wolves (*Canis lupus*) and coyotes (*Canis latrans*; Egoscue, 1979; Scott-Brown *et al.*, 1987). Populations have recovered to some extent since 1950 (Kahn *et al.*, 1997), but the swift fox was temporarily a candidate for endangered species listing by the U.S. Fish and Wildlife Service (Potter, 1982; Clark, 2001). As an alternative to a federally directed recovery program, state and national wildlife management agencies within the historical range of swift fox, including the New Mexico Department of Game and Fish, formed the Swift Fox Conservation Team (SFCT) and developed a conservation strategy (Kahn *et al.*, 1997). Surveying swift fox distribution and monitoring populations is central to the conservation strategy. Presence/absence and relative abundance methods that have been used include scent-stations (Luce *et al.* 2000; Harrison and Schmitt, 1997), trapping (Finley 1999; Moehrenschlager and Moehrenschlager, 1999), track surveys (Roy *et al.* 1999; Hoagland, 2000), and spotlighting (Sovada and Roy, 1996; Harrison and Schmitt, 1997). Absolute abundance methods used include mark-resighting (Roell, 1999) and mark-recapture (Cotterill, 1997). No single survey method has been found to be suitable for all areas of swift fox range. The purpose of this research was to determine the method most appropriate for New Mexico. With the exception of mark-

recapture, we examined all of the methods mentioned above. We also examined scat collection for relative and absolute abundance (Kohn *et al.*, 1999) and calling for relative abundance (Sumner and Hill, 1980). Field work was conducted by RLH and laboratory work was conducted by DJB and JWD.

STUDY AREA

The study area was located in the Kiowa National Grasslands, northeast of Roy, NM, in Harding and Colfax counties, and included private, state, and federal lands. Habitat within the study area was entirely shortgrass prairie (described as plains-mesa grassland by Dick-Peddie, 1993). Topography was low rolling hills and elevation varied from approximately 1700 to 1900 m. Annual precipitation averages 390 mm, and varied between 257 and 565 mm from 1975 to 2000. Annual precipitation was 395, 427, and 381 mm in 1998, 1999, and 2000, respectively. The entire study area is heavily grazed and cattle are present throughout the year.

METHODS

We examined trapping, scent stations, scat collection, track searches, spotlighting, and calling as methods for determining relative abundance and presence/absence of swift fox. We studied trapping combined with resighting at bait stations with automatic cameras and microsatellite DNA analysis of scat as methods for determining absolute abundance. We conducted two absolute abundance surveys: Sep., 1999, - Feb., 2000 (2000 survey); and Dec. - Mar., 2001 (2001 survey).

We trapped swift foxes during three intensive trapping sessions, one at the beginning of the study (Jan. - Mar., 1999), and two at the beginning of each absolute abundance survey. We also trapped between intensive sessions to replace collars and to relocate missing foxes. We captured swift fox in 25cm x 30cm x 81cm single door traps (Tomahawk Traps, Tomahawk, WI) baited with beef scraps and a cod liver oil - mackerel lure (Trailing Scent, On Target A.D.C., Cortland, IL). We placed traps at 0.8 or 1.6 km intervals at conspicuous locations such as road, trail, and fence intersections and utility boxes. We covered traps with available materials, such as dry weeds or cattle droppings. We also used enclosure traps at dens (Covell 1992) to recapture foxes for replacement of radiocollars. We transferred captured foxes to a 30cm x 60cm x 76cm restraint module (Tomahawk Traps, Tomahawk, WI) and sedated them before handling. Initially, we used a combination of ketamine (25 mg/kg of body weight) and xylazine (2.5 mg/kg), based upon Kreeger (1996). However, this drug combination resulted in unnecessarily long sedation and depressed breathing and heart rates. Reduction of the dosage to 10 and 1 mg/kg, respectively, did not solve these problems. We found Telazol (10mg/kg; Kreeger, 1996) to be more acceptable. It did not depress heart or breathing rates, but in some case it caused excessive salivation and recovery with little warning. Captured foxes were dusted for fleas, inspected for sex and injury, measured, fitted with a radiocollar (telemetry system described below), and marked for individual visual identification by dying an unique portion of their fur with commercial hair dye (Miss Clairol black velvet). The University of New Mexico Main Campus Animal Care and Use Committee approved the animal handling procedures (protocol

9811-B).

Radiocollars were provided by Advanced Telemetry Systems (Isanti, MN; model 16MC) and Telonics (Mesa, AZ; model MOD-080). The receiving antenna consisted of two five-element Yagi antennas combined 180° out of phase (null) and mounted through a sunroof in the cab of the research vehicle. Tests of this configuration indicate that under ideal conditions (both transmitter and receiver on hilltops), the signal may be detected at over 2.5 miles.

We placed scent stations in transects of five evenly spaced stations within the known home ranges of radiocollared foxes. Transects were placed as much as possible within the central portions of home ranges, but availability of roads and public land resulted in placement of some transects on peripheries. Similar placement is likely when surveying areas without knowledge of existing home ranges. The separation between stations varied with the size of the home range, and was approximately 0.8 km. We operated scent stations during all seasons. Scent stations consisted of 75 cm x 75 cm areas cleared of vegetation and covered with a 1:32 mixture of mineral oil and dried plaster sand. We baited stations with approximately 4 cm^3 of canned mackerel and a plaster of paris tablet (Pocatello Supply Depot, U.S.D.A., Pocatello, ID) soaked in a cod liver oil - mackerel mixture (Trailing Scent, On Target A.D.C., Cortland, IL). We placed automatic cameras with active infrared sensors (Trailmaster 1500 with TM 35-1 camera kit and Tm1500 Photo System, Goodson & Associates, Lenexa, KS) at scent stations to identify visiting foxes. Cameras and receiving censors were placed in boat dry boxes with holes made to permit

photographs and the infrared beam. We strapped dry boxes and the infrared transmitting unit to wooden stakes driven into the ground. The system was set to take bursts of four photographs no less than 2 minutes apart when the beam was broken for 0.25 sec. In some areas, we built barbed-wire fences around the stations to exclude cattle. We observed the stations for six nights. We subsampled the visitation data to determine the percentage of transects visited as a function of number of stations per home range (i.e., spacing between stations) and number of nights observed.

We collected scat during systematic surveys of conspicuous locations (above) along roadways that passed through known swift fox home ranges. We searched all conspicuous locations along survey routes. To minimize collection of coyote scat, we selected scat of maximum diameter $\leq$ 20 mm (Danner and Dodd, 1982). We collected scat into numbered paper bags during the same periods that we operated resighting stations (below). Prior to DNA analysis, the first scat sample (2000 survey) was stored in a plastic bag at room temperature and the second sample (2001 survey) was frozen at -80 C. We assumed that the scats were adequately dried prior to collection due to the semi-arid climate of the study area. We determined the species depositing scat and the number of individual swift foxes present using mitochondrial and microsatellite DNA analysis, respectively.

We extracted total genomic DNA from each scat sample using the QIAamp DNA stool mini kit (Qiagen Inc., Valencia, CA). We followed the protocol for extraction established by the kit manufacturer, with the exception that the incubation period for digestion was extended from 10 minutes to overnight, and 50μl of the supplied

proteinase K was added instead of the specified 25µl. Increased incubation period and proteinase K concentration increased final DNA concentration, when compared with DNA that was isolated using the shorter incubation time. The Qiaamp mini stool kits were designed for use with fresh stool samples. The above modifications made to the protocol increased DNA yield in field scats which were not fresh and less preserved. Following manufacturers guidelines, isolated DNA was dissolved in 200µl elution buffer supplied in the kit. The eluted DNA was separated on 0.8% agarose gels and visualized under UV light following ethidium bromide staining to determine quality and relative quantity. Eluted DNA from all scat samples was refrigerated at 4° C until later use.

For species identification, we amplified and sequenced approximately 350 base pairs of the cytochrome *b* gene. Primers L15513 and H15915 (Irwin *et al.*, 1991) were used for amplification of the cytochrome *b* gene as these primers have been shown to amplify and distinguish canid mitochondrial DNA (Mercure *et al.*, 1993; Wayne *et al.*, 1997). The PCR conditions were: denaturation at 95 C for 30 sec, annealing at 45 C for 30 sec, and extension at 72 C for 30 sec for 40 cycles. Amplification was conducted in 25µl reactions. Reaction concentrations were 2.5 µl of 25mM $MgCl_2$, 1.2 pmol of each primer, 2.5µl 10x *Taq* buffer, 2.5µl 10x dNTPs, 0.125µl *Taq* polymerase (5 Units/µl) and 2.5µl 1mg/ml BSA. We visualized PCR products on 0.8% agarose gels. If we did not obtain a PCR product, we tried a second time. If the second reaction did not work we then re-extracted DNA from the scat sample. Then we tried at least 2 more times to amplify the cytochrome *b* gene. Following visualization, products

demonstrating amplification were cleaned using QIAQuick PCR columns (Qiagen Inc., Valencia, CA). The cleaned products were precipitated using 3M sodium acetate and 100% ethanol, frozen for 15 minutes at -20 C, and centrifuged for 15 min. Precipitates were washed using 70% ethanol, then dried and dissolved in 5.5µl 10 mM Tris elution buffer Ph 8.5 for sequencing. Cleaned and concentrated products were subjected to single stranded cycle sequencing amplification using ABI PRISM BigDye terminator cycle sequencing ready reaction (Applied Biosystems, Inc., Foster City, CA), following manufacturers guidelines. Ethanol precipitation was carried out on the sequencing reactions and products were electrophoresed on an ABI 377 DNA sequencer. We submitted completed sequences to the gene bank blast search (http://www.ncbi.nlm.nih.gov/blast/Blast.cgi) to verify species identification of each scat sample.

We tested the hypothesis that presence of a scent lure would enhance scat deposition by clearing scat from conspicuous locations, then depositing a lure (cod liver oil - mackerel mixture, Trailing Scent, On Target A.D.C., Cortland, IL) at alternate locations inside and outside of known swift fox home ranges in Jun., 1999. We collected scat at the locations during Jul., and Dec., 1999, and Jan., 2000.

We used a *t*-test to compare the maximum diameters of swift fox and unidentified scat and a Mann-Whitney test with the normal approximation (Zar 1984: 142) to compare the number of scat found at sites with and without lure. We compared the proportions of sites with and without scat using a contingency table with a normal approximation (Zar 1984: 396).

We conducted only preliminary studies of track searches, spotlighting, and calling. We searched for tracks along unpaved roads on foot, and while slowly driving a vehicle. We also searched for tracks in the vicinity of wet areas surrounding stock tanks and while collecting scat (see above). We surveyed areas both inside and outside of known swift fox home ranges. We attempted to spotlight radiocollared foxes with one 1,000,000 candlepower spotlight, while driving slowly through their home ranges. We also attempted to call foxes within visual or audible range using prerecorded tapes of rabbit distress calls and swift fox vocalizations. We played tapes at various volumes and durations to foxes determined by telemetry to be within 0.8 km of the tape player.

Following the intensive trapping sessions, we resighted radiocollared foxes and located uncollared foxes by placing automatic cameras using active infrared sensors (above) at stations baited with canned mackerel and a lure (cod liver oil - mackerel mixture, Trailing Scent, On Target A.D.C., Cortland, IL). We placed bait/camera stations at 1.6 km intervals and operated them for four nights during Nov., 1999, - Jan., 2000, and Feb. - Mar., 2001. During Feb., 2000, we operated cameras at each station for two nights. We estimated absolute population size for each sampling period with a Lincoln-Peterson estimate for closed populations (Pollock *et al.*, 1990). The area sampled was assumed to be one average circular home range size wide on each side of surveyed roads, based upon average home range sizes observed from June through December, 1999, and September, 2000, through March, 2001.

For microsatellite analysis of DNA in scat, we used scat collected at

conspicuous locations as described above along the same route used for trapping and resighting foxes. We selected only scats determined by mitochondrial analysis to be from swift foxes. Seven microsatellite canid specific dimeric primer pairs were used for genotyping: CPH3, CPH7, CPH9, CPH10, CPH12 (Fredholm and Wintero, 1995), DB3 (Holmes *et al.*, 1993) and C213 (Ostrander *et al.,* 1993). Microsatellite primers were selected on the basis on variability within New Mexico swift fox populations (Dragoo *et al.*, in prep.) and their ability to amplify microsatellite DNA sequences from control scat. Amplifications were carried out in 12.5μl reactions. Specific conditions of each reaction varied for each primer according to optimal conditions determined by experiments testing volume of PCR production against temperatures and amount of $MgCl_2$. Reaction conditions for primers were denaturation at 95 C for 20 sec, annealing at 60 C for 25 sec, and extension at 72 C for 30 sec, with the exception that we adjusted annealing temperatures for primers CPH7 and CPH12 to 55 C and 57 C, respectively. We used 25 mM $MgCl_2$ solution in each reaction. The optimal amounts of $MgCl_2$ were: CPH3 and CPH12, 1.25μl $MgCl_2$; CPH7, 0.75μl $MgCl_2$; CPH9, 1.5μl; CPH10, DB3, and C213, 1μl $MgCl_2$. We added 0.75 pmol of each primer, 1.25μl 10x *Taq* buffer, 1.25μl 10x dNTPs, 0.125μl *Taq* polymerase (5 Units/μl) and 1.25μl 1mg/ml BSA to the reactions. Negative controls were run with all reactions to check for contamination of PCR chemicals.

We separated reactions on 2.0% agarose gels and visualized them under UV light to check for amplification. Alleles were analyzed and scored by labeling one of the primers in each pair with a fluorescent dye. Labeled PCR products were loaded on

a 377 ABI DNA sequencer and visualized using Genescan Analysis Software (Applied Biosystems, Inc., Foster City, CA).

We scored genotypes as unique if they did not have all elements in common with other genotypes. If only a portion of the loci amplified in two different scat samples, and the samples had elements in common for some of the alleles, but incomplete data for the other loci, we did not score them as different. If a locus in two samples was homozygous for different alleles, or had two different heterozygous alleles, they were considered unique even if all the other loci matched. If only a portion of the loci amplified in one sample, and a different portion amplified for a second sample, we scored the two samples as different genotypes. If two genotypes were identical at most loci, but one or two loci had the homozygous condition for one sample and the heterozygous (with one allele in common) condition for the other sample, these were scored as different genotypes, even though the homozygous condition could have been a result of incomplete amplification of target alleles (allelic drop-out). Allelic drop-out and the rules we used have potential to cause overestimation of unique genotypes.

To verify our techniques, we obtained matching blood and scat samples known to originate from the same individual, from captive swift foxes held at the Northern Prairie Wildlife Research Center, Jamestown, ND. Genomic DNA was extracted from blood samples using the QIAamp blood and tissue kit (Qiagen Inc., Valencia, CA). DNA extraction of blood followed the DNA extraction from blood protocol that was provided with the kit. Following manufacturers guidelines isolated DNA was dissolved in 200µl elution buffer supplied by the kit. To check for DNA isolation of blood and scat

controls as well as unknown scat samples, the eluted DNA was separated on 0.8% agarose gels and visualized under UV light following ethidium bromide staining. Eluted DNA from all blood samples was refrigerated at 4° C until later use. We sequenced both control blood and scat, and compared control microsatellite scat and blood genotypes to verify genotype matches. Sequence was obtained from all blood and scat controls and blast search returned results on all control samples positive for swift fox. These results verified the technique worked and was reliable for identifying species from fecal materials.

We amplified DNA from the control blood samples multiple times with the microsatellite primers, as they were often used as positive controls for all of the scat reactions. When we achieved a genotype match with a control scat, we stopped attempting to obtain microsatellite data from that particular scat. Often times the control scat had to be re-amplified, because no PCR product was obtained or only a single allele at a locus amplified when we were expecting two alleles. DNA from the control scats was extracted at least 3 times.

We also had in our lab 13 frozen tissue (livers) samples from swift foxes collected in northeastern New Mexico (NENM) during a previous study. These tissues were used to provide a reference control for the population genetic structure of swift foxes on our study site. We considered each scat survey and the frozen tissue samples as three different populations. We tested each "population" to determine if they were in Hardy-Weinberg equilibrium at each locus. Ideally, populations of foxes analyzed from scat sample DNA should behave the same as populations analyzed from

higher quality DNA. Finally, we tested population subdivisions between scat surveys, as well as between the control blood and scats, using the method of Weir and Cockerham (1984).

We used program GDA (Lewis and Zaykin, 2001) to generate descriptive statistics for microsatellite data and to examine population genetic structure with pairwise population comparisons of Theta.

To compare the efficiency of trapping, scent stations, and scat collection for detecting the presence of swift foxes, we used data from those locations where all three methods were used during the absolute abundance surveys. We used visitation to bait/camera stations as a surrogate for visitation to scent stations. Due to logistic restraints, we were unable to operate scent stations during times of absolute abundance surveys (*see* DISCUSSION). We compared the proportion of foxes captured per trap-night, the proportion of camera/bait stations visited by foxes, and the proportion of stations where scat was collected and identified as originating from swift fox, using a contingency table (Zar 1984:400). We used the Tukey test to compare pairs of proportions (Zar, 1984: 240). For these tests, we combined observations of radiocollared and uncollared foxes.

RESULTS

We captured 34 swift foxes plus 20 recaptures in 804 trap nights (4.2% without recaptures, 6.7% with recaptures; Table 1). We captured three additional foxes in

enclosure traps at dens. There were significant differences of capture success between periods without recaptures (X^2 = 11.163, ν = 6, P = 0.087), with fall and early winter producing the greatest success. There were no significant differences of capture success between periods with recaptures (X^2 = 8.729, ν = 6, P = 0.203). We radiocollared 36 foxes (18 males, 18 females).

Scent-station tests were conducted in the home ranges of 14 radiocollared foxes (ten males, four females) for 420 station-nights. Radiocollared and uncollared foxes made 51 and 61 visits to scent stations, respectively. Seventy-five percent of stations were visited within four nights. Percent of transects visited leveled off after three nights for radiocollared and uncollared foxes combined (Fig. 1), but did not level off for radiocollared foxes only (Fig. 2). Percent of transects visited by males and females were similar (Figs. 3, 4). Sample size was inadequate for seasonal comparisons.

During the 2000 population survey period, we surveyed 40.5 km of roadways, examined 48 potential scat sites, and found scat at 36 of those sites (75.0%). Of 194 scat collected, 141 (72.7%) were identified as swift fox. The median number of scat collected within a single swift fox home range was 21.5 (range 8 - 63). During the 2001 survey period, we surveyed 37.6 km of roadways, examined 39 potential scat sites, and found scat at 25 of those sites (64.1%). Of 137 scat collected, 89 (65.0%) were identified as swift fox and 4 (2.9%) were identified as coyote. The median number of scat collected within a single home range was 8.5 (range 3 - 66). The survey route passed through eight swift fox home ranges during both surveys. We found scat that was identified as swift fox within all known swift fox home ranges and within all gaps

between known home ranges where foxes had not been trapped. Home ranges were not equally surveyed, as the survey routes passed through the central portions of some ranges and peripheries of others.

Scats not identified as swift fox or coyote could not be identified to species due to unclear sequences or lack of PCR product. There were no obvious visual differences of color or size between identified and unidentified scats. The average maximum diameter of scats identified as swift fox ($\bar{x}$ = 13.9 mm, SD = 2.8 mm, n = 206; Fig. 5) was not different from the average diameter of unidentified scats ($\bar{x}$ = 13.6 mm, SD = 2.8 mm, n = 81; t = 0.924, df = 285, P = 0.356).

Collection of scat for the test of enhancement of scat deposition was inadequate for analysis 1 month after deposition of lure. Scat were collected again 7 months after the initial lure deposition. Scats were found at 63.6% of sites with lure ($\bar{x}$ = 2.9 scat/site, range 0 - 16, median 1 scat/site, n = 33 sites) and at 35.5% of sites without lure ($\bar{x}$ = 3.4 scat/site, range 0 - 14, median 2 scats/site, n = 31 sites). Scat was found at a higher proportion of sites with lure than at sites without lure (Z = 2.251, P = 0.026), but there was no difference between the average number of scats found at sites with and without lure (Z = 0.4223, P > 0.5).

We observed only one clear swift fox track on an unprepared surface during the study. No swift fox tracks were observed at 64 locations surveyed during the test of enhancement of scat deposition by lures, during 31 km of road surveys by vehicle, nor during 12.8 km of foot surveys along roads within the home ranges of three swift foxes in Jul. and Aug., 1999. We spotlighted for 187 km through the home ranges of $\geq$15

foxes in May - Jul., 1999. No foxes were seen. We made 11 attempts to call radiocollared foxes into visual or audible range in Apr. and May, 1999, and Jan., 2000. One fox responded to swift fox vocalizations by approaching the vehicle and vocalizing. No other foxes responded even though telemetry indicated they were within range of the sounds. The only homeowner within range of the calls was disturbed by the sounds.

During the 2000 resighting period, 15 radiocollared swift foxes were available. Six radiocollared and three uncollared swift foxes were photographed during 122 station-nights. Radiocollared and uncollared foxes made 24 and 12 visits to camera stations, respectively. In the period Nov. 22, 1999, to Jan. 30, 2000, the estimated population in the study area was 23.9 swift foxes (95% confidence interval: 17.8 - 30.0). During Feb., 2000, the estimated population in the study area was 18.6 swift foxes (95% confidence interval: 11.9 - 25.3). During the 2001 resighting period, 13 radiocollared foxes were available. Twelve radiocollared and three uncollared swift foxes were photographed during 107 station-nights. Radiocollared and uncollared foxes made 31 and 12 visits to camera stations, respectively. During the period Jan. 14 to Mar. 21, 2001, the estimated population in the study area was 16.2 swift foxes (95% confidence interval: 15.2 - 17.3). Based upon an average fall/winter 95% minimum convex polygon home range diameter of 4.2 km in during the 2000 survey and 4.5 km during the 2001 survey (n = 4 and 8 swift foxes, respectively), the area surveyed was 227.5 km^2 in 2000 and 231.3 km^2 in 2001. The average swift fox density was 0.105 foxes/km^2 in Nov.,1999, to Jan., 2000 (95% C. I. 0.078 - 0.132) and 0.070 foxes/km^2 in

Jan. - Mar., 2001 (95% C. I. 0.066 - 0.075).

We found 63 and 27 unique genotypes from the 2000 and 2001 scat surveys, respectively. Of these, 10 genotypes appeared in both surveys. Unfortunately, scat DNA is not the best source for genetic material. As a result we were not able to produce a PCR product for each locus for every sample. Of the seven loci examined, one (CPH12) was monomorphic for all the scats in which we obtained product. We were unable to generate enough data for two other loci (CPH10 and C213) to perform statistical analyses. Therefore, only results of the remaining four loci (CPH03, CHP07, CPH09, DB003) are discussed further.

All four loci were polymorphic for each population, and the number of alleles ranged from three to six. The two control samples (blood and scat) and the NENM sample all were in Hardy-Weinberg equilibrium (Table 2). The 2000 survey scat sample was deficient in heterozygotes at the CPH3 and CPH7 loci, and the 2001 survey scat sample was deficient in heterozygotes at the CPH3 and CPH9 loci (Table 2).

The control bloods and scats were essentially identical genetically and showed no population substructure (Table 3). The F_{ST} values for the 2000 and 2001 surveys indicated very little genetic subdivision from one year to the next (Table 3).

At locations where traps, bait/camera stations, and scat searches were located at the same site, trap success was 11.5% in 1999/2000 (95% C. I. 6.6 - 18.0%; n = 139 trap-nights) and 8.4% in 2000/2001 (95% C. I. 3.7 - 15.9%; n = 95 trap-nights). Visitation rate to bait/camera stations was 31.4% in 2000 (95% C. I. 23.1 - 40.7%; n =

118 station-nights) and 47.1% in 2001 (95% C. I. 36.9 - 57.2%; n = 102 station-nights). At least one scat identified as swift fox was found at 61.9% of locations in 2000 (95% C. I. 38.5 - 81.9%; n = 21), and at 66.7% of locations in 2001 (95% C. I. 43.0 - 85.4%; n = 21).

Detection rates for the three methods were not the same in 2000 ($X^2 = 32.157$, v = 2, $P < 0.001$), nor in 2001 ($X^2 = 64.32$, v = 2, $P < 0.001$). In both surveys, detection by scat collection was greater than by bait/camera station (2000: q = 7.34, $P < 0.001$; 2001: q = 4.56, P = 0.004), and detection by bait/camera stations was greater than detection by trapping (2000: q = 11.122, $P < 0.001$; 2001: q = 18.06, $P < 0.001$).

Discussion

The most efficient technique for determining presence/absence or relative abundance of swift fox in New Mexico is collection of scat on transects followed by species verification using DNA analysis. In our study area, scat were easily found, especially when an accumulation was present. We were able to find scat in areas where we had no evidence of swift foxes from other techniques, such as trapping or bait/camera stations. Extracting mitochondrial DNA from scats for species identification is relatively straight forward, depending on the quality of the scat sample. It may require multiple extractions in order to obtain DNA for PCR and sequencing. Using scat, the rate of detection of swift fox within known and probable home ranges was 100% in both the 2000 and 2001 surveys. At the level of individual stations, the swift fox detection rate by scat collection was greater than both scent stations and trapping

in both 2000 and 2001. Our results were based upon visual examination of conspicuous locations along the survey route and collection of every scat sighted. We simply collected the scat available and made no effort to ensure that the scat sample was fresh. It was not necessary in our area to use more intensive methods of locating scat (Smith *et al.*, 2001). Deposition of lure at collection sites prior to surveys may increase the proportion of sites where scat is found, but may not increase the number of scats collected. Deposition of lure prior to surveys doubles the amount of necessary field time, and in our opinion is not necessary given the ease of collecting scat.

Sovada and Roy (1996) reported detection rates of 30 - 70% when collecting scat along walking transects on roads within the home ranges of radiocollared foxes. They cleared all scat from transects two weeks prior to surveys, and thus their detection rates may have been much higher if they had used all scat available. Olson *et al.* (1997) reported a detection rate of 66% when collecting scat on walking 1 km transects within the cores of known swift fox home ranges in Wyoming. Neither Sovada and Roy (1996) nor Olson *et al.* (1997) verified the species depositing their scat. It is important to verify the species depositing scat, as the diameters of scat of several species overlap. Approximately 60% of the coyote scat samples collected by Danner and Dodd (1982) and 32% of the coyote samples collected by Green and Flinders (1981) had diameters between 10 and 20 mm, overlapping 96% and 41%, respectively, of the scat we identified as from swift fox. Also, the range of diameters of red fox (*Vulpes vulpes*) scat collected by Green and Flinders (1981) is exactly the same (8 - 20 mm) as we found for swift fox (Fig. 5), with the exception of one 7-mm swift fox scat.

The number of scat that must be collected to verify presence/absence in a given area depends primarily upon the success of DNA extraction. In our study, collection of at least 10 scat from each site would have been adequate for confirming the presence of swift fox at 98% of sites examined.

Scent station transects are the second most efficient presence/absence-relative abundance technique. Depending upon fox density and level of effort, detection rates varied from 20 - 100% (Figs. 1, 2). Detection rates decreased when the sample based upon all observed foxes (Fig. 1) was reduced to radiocollared foxes only (Fig. 2), indicating that visitation rates will respond to fox density. Schauster (2001) also found that scent-station detection rates correlated consistently with swift fox density. Using transects of four stations placed 0.3 km apart and observed for 7 nights within the core areas of swift fox home ranges, Olson *et al.* (1999) observed detection rates of 66 - 88%. Using transects of 16 stations placed 0.5 km apart and observed for 3 nights, Sovada and Roy (1996) observed detection rates of 10 - 70%, or 100% if survey periods were combined.

In our study, swift fox detection rate on transects of scent stations was nearly maximized at three nights for all foxes and four nights for radiocollared foxes only. Given the observed swift fox home range size of approximately 2200 ha and assuming circular home ranges, placing five 5, 4, 3, 2, or 1 station in each home range requires a spacing between stations of 1.0, 1.3, 1.7, 2.6, or $\geq$ 5.2 km, respectively. In practice, the number of stations that may be set will likely be limited by the time available and size of the area to be surveyed. For range-wide surveys in New Mexico, scent station

transects consisting of stations spaced at 1.6 km (1.0 mi) intervals and operated for three nights appear to be the most practical. For more intensive examination of specific areas, operation for an additional night would produce approximately the same increase in percent detection as decreasing the spacing to 1.3 km.

Bait/camera stations differed from scent stations that would be used in a statewide survey by the presence of bait and camera units and the absence of a prepared tracking surface. The detection rates observed at bait/camera stations might have been greater than what would have been observed at scent stations in a statewide survey, because of the presence of bait and because it was not necessary for a fox to step within the area of the prepared tracking surface. However, we used bait in addition to a lure in order to avoid habituating study foxes to the smell of the lure. In statewide surveys, foxes would likely be attracted to a novel lure, but foxes within the study area were tested repeatedly and might have responded less to the same lure over time. Also, some foxes may have been frightened by the appearance or sounds of the camera units, and may have been unwilling to approach close enough or for long enough to be photographed. At scent stations these detractions would not be present. Occasionally, foxes were photographed running away from the camera in the first photograph of a series, and were not photographed in the remaining three photographs of the series. Also, on 12 station-nights during resighting surveys, the infrared beam was broken, but no animal was photographed. Thus there are compensating factors when using bait/camera stations as surrogates for scent stations. The results from observations at bait/camera stations were most likely reasonable approximations of the

results that would have been obtained from scent stations during the resighting surveys.

Trapping is the third most efficient presence/absence-relative abundance technique. Trapping does provide definitive species identification and the opportunity for collection of blood or other specimens, but does risk injury to the animal. Because we trapped prior to resighting and scat collection surveys, the swift fox population may have been somewhat higher during trapping due to over-winter mortality. Hence, the trapping rates we observed may be slightly higher relative to resighting and scat collection than would have been the case if all three activities occurred simultaneously.

Track, spotlight, and calling surveys are not efficient techniques in New Mexico. Precipitation is too irregular and soils in general are too hard and dry to take and hold identifiable swift fox tracks. The area visible when spotlighting comprises a very small portion of a swift fox's home range and this technique is limited by topography and the number of roads available. Harrison and Schmitt (1997) spotlighted one fox per 550 km when surveying the entire range of swift fox in New Mexico. However, in certain circumstances, such as immediately after crops are harvested, swift fox may be attracted to specific areas where they may be efficiently spotlighted (S. Bremner, pers. comm.). Sovada and Roy (1996) reported spotlighting detection rates of 16 - 32% for radiocollared swift foxes in Kansas. In New Mexico, spotlighting is useful primarily as a supplement to other methods, particularly during nighttime periods when other methods can not be pursued. Calling is limited by wind noise, and the potential to disturb homeowners must be considered. In our study, foxes appeared to be wary of vehicles

and may have been reluctant to approach. Calling also requires the most extreme response by foxes: approaching an occupied vehicle. Trapping and scent-stations require a fox to approach and enter a disturbed but unoccupied site. Scat surveys and spotlighing require no interaction with anthropogenic objects.

Once scat has been collected and identified to species, presence/absence data may be converted to a relative abundance index based upon the percentage of transects with swift fox present or upon survey effort. Schauster (2001) found that indices of trapping effort, scent-station visitation, and spotlighting correlated with swift fox density, although the significance of correlations varied between observation periods. The sample size (number of transects) necessary to detect a change in population size may be estimated assuming a binomial distribution of transect visits (Zar 1984:399). The results depend upon the level of Type I and Type II errors required. A Type I error (α error) results when it is believed the population changed when it really did not. A Type II error (β error) occurs when a real population change is not detected. In conservation situations, Type I errors are less important than Type II errors, thus α may be relaxed from the standard 0.05, while β should be relatively low, such as 0.1 or .05. For example, to decide whether or not a decrease of 20% in the proportion of transects visited between two years represented a real population decrease, and assuming $\alpha = 0.2$, $\beta = 0.1$, and first-year detection rate = 60%, 65 independent transects each year would be required. Assuming $\alpha = 0.1$ and $\beta = 0.1$, 90 transects would be required. Such numbers of transects are not impractical.

The required number of independent transects determines the minimum area

that can be sampled. For transects to be independent, they should be separated by at least one average home range diameter in all directions. Surveys of 65-90 transects require a minimum area approximately the size of New Mexico counties. Lack of road access will enlarge the minimum area sampled. For comparison, Harrison and Schmitt (1997) used 80 transects to survey the entire range of swift fox in New Mexico, which covers approximately the eastern one-quarter of the state.

Scat surveys are the most costly of the presence/absence methods examined here. We estimate the cost to survey the complete swift fox range in New Mexico, including obtaining and analyzing a sample of 200 - 400 scats from 90 transects, to be $20,000. - $30,000. Scent-station and trapping surveys require similar levels of effort, and we estimate the cost of a scent-station or trapping survey conducted over four nights to be $15,000. The field time required for a scat survey would be at most two months, whereas the time required for scent-station or trapping surveys conducted over four nights could be as great as 6 to 10 months.

The absolute population size estimates obtained from microsatellite genotypes were considerably higher than those obtained from bait/camera stations. Kohn *et al.* (1999) also reported a genotype population estimate higher than a population estimate obtained from a conventional survey method (trapping). Two factors may lead to overestimating the number of unique genotypes, and hence individual swift foxes, present. First, scat samples provide nuclear DNA of low quality and quantity, resulting in allelic drop-out, amplification of contamination from other sources, and incomplete amplification, leading to overestimation. Errors in assigning genotypes are difficult to

avoid (Taberlet *et al.*, 1999) and can affect population estimates dramatically (Waits and Leburg, 2000). We have confirmed the prediction of Waits and Leburg (2000) that population estimates based upon genotypes may be much greater than estimates based upon conventional methods. Second, scats may remain recognizable for several months (Kohn *et al.*, 1999). The number of transient foxes included in the microsatellite population estimate potentially includes all those passing through the study area within several months, and not just those foxes present in the survey area when the survey was conducted. Furthermore, obtaining nuclear DNA for individual identification is problematic. Whereas 10 to 2500 copies of mitochondrial DNA can occur in one cell, only a single copy of nuclear DNA is present (Kohn and Wayne, 1997). Solutions to these problems would be to collect only fresh scat samples (more frequent field collections) and to perform multiple DNA extractions and PCR experiments for each scat sample (Taberlet *et al.*, 1999; Waits and Leburg, 2000). Such solutions could increase costs significantly.

We found that the technique of analysis of microsatellite genotypes from scat is useful for addressing population genetic structure of swift foxes. The two populations described by control blood and scat samples were essentially identical genetically, as we expected because the sources of DNA were from the same swift fox population. However, there were slight differences in the genotypic data as a result of allelic drop-out. The three populations described by the two scat surveys and the NENM frozen tissue samples were not dissimilar (Table 3), even though DNA obtained from survey scats was of a lower quality than that obtained from control scats and blood. However,

Theta values for these comparisons were slightly were different from zero (Table 3). The NENM population provided the genetic structuring we expected from the scat surveys. This population was in Hardy-Weinberg equilibrium for all loci, whereas the scat samples were not (Table 2). The NENM population sample was collected at a different period of time than the survey scat samples, which could account for some of the observed variation among samples. Because the data from the scat samples were not notably different from the other sources of swift fox populations, we believe we have properly assessed the genetic structure of the swift fox population in the survey area. Hence, our estimates of the numbers of unique genotypes in the study area were as valid as the method and DNA available from scats permitted. The survey scat samples had lower observed heterozygosities compared to the other populations, indicating that there was allelic drop-out during the PCR amplification procedure of the survey scats. Thus, it is likely that the microsatellite genotype method overestimated the number of individuals present on our study site.

In general, trapping combined with camera resighting worked well. By using trapping combined with camera resighting, we did not violate the assumption that individual animals captured (trapped) during the first survey are less likely to be captured (photographed) during the second survey (Pollock *et al.* 1990). However, infrared-triggered camera units are expensive (ca. $675/station, including Trailmaster 1500 active infrared game monitor with photographic software and camera, protective boxes, mounting stakes, film, and film processing). The high cost of the camera resighting technique limits its use to small areas. Trapping and retrapping is less

expensive than trapping and resighting, although trapping and retrapping does violate some statistical assumptions.

To estimate the absolute abundance of swift fox in New Mexico, transects of bait/camera stations or scat surveys could be used to generate local density estimates, which could be extrapolated to fill available habitat. Assuming that 90 transects and 50 camera units were used or 200 - 400 scat collected, we estimate the cost of one trapping and resighting survey to be approximately $90,000, and one scat survey including microsatellite identification of individuals to be approximately $30,000 - $50,000.

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LITERATURE CITED

CLARK, J. R. 2001. Endangered and threatened wildlife and plants; Annual notice of

findings on recycled petitions. Federal Register, **66**:1295-1300.

COTTERILL, S. E. 1997. Population census of swift fox (Vulpes velox) in Canada: winter 1996-1997. Swift Fox National Recovery Team. Alberta Environmental Protection, Natural Resources Service, Wildlife Management Division. 50 p.

COVELL, D. F. 1992. Ecology of the swift fox (Vulpes velox) in southeastern Colorado. M.S. Thesis. University of Wisconsin, Madison. 111 p.

CYPHER, B. L., G. D. WARRICK, M. R. M. OTTEN, T. P. O'FARRELL, W. H. BERRY, C. E. HARRIS, T. T. KATO, P. M. MC CUE, J. H. SCRIVNER AND B. W. ZOELLICK. 2000. Population dynamics of San Joaquin kit foxes at the Naval Petroleum Reserves in California. *Wildl. Monographs,* **145**:1-43.

DANNER, D. A., AND N. DODD. 1982. Comparison of coyote and gray fox scat diameters. *J. Wildl. Manage.,* **46**:240-241.

DICK-PEDDIE, W. A. 1993. New Mexico vegetation, past, present, and future. University of New Mexico Press, Albuquerque. 244 p.

EGOSCUE, H. J. 1979. *Vulpes velox*. Mammalian Species, **122**:1-5.

FINLEY, D. J. 1999. Distribution of the swift fox (*Vulpes velox*) on the eastern plains of Colorado. M. A. Thesis. University of Northern Colorado, Greeley. 96 p.

FREDHOLM, M., AND A. K. WINTERO. 1995. Variation of short tandem repeats within and between species belonging to the Canidae family. *Mammal. Genome.,* **6**:11-18.

GREEN, J. S., AND J. T. FLINDERS. 1981. Diameter and pH comparisons of coyote and red fox scats. *J. Wildl. Manage.*, **45**:765-767.

HARRISON, R. L., AND C. G. SCHMITT. 1997. Swift fox investigations in New Mexico,

1997, p. 97-106. *In:* B. Giddings (ed.). Swift Fox Conservation Team annual report. Montana Department of Fish, Wildlife & Parks, Helena.

HOAGLAND, J. W. 2000. Swift fox investigations in Oklahoma, 1999, p 48-58. *In:* G. Schmitt (ed.). Swift Fox Conservation Team 1999 annual report. New Mexico Department of Game and Fish, Santa Fe.

HOLMES, N. G., C. S. MELLERSH, S. J. HUMPHREYS, M. M. BINNS, A. HOLLIMAN, R. CURTIS, AND J. SAMPSON. 1993. Isolation and characterization of microsatellites from the canine genome. *Animal Genetics,* **24**:289-292.

IRWIN, D. M., T. D. KOCHER, AND A. C. Wilson. 1991. Evolution of the cytochrome *b* gene of mammals. *J. Molec. Evol.,* **32**:128-144.

KAHN, R., L. FOX, P. HORNER, B. GIDDINGS AND C. ROY. 1997. Conservation assessment and conservation strategy for swift fox in the United States. South Dakota Department of Game, Fish, and Parks, Pierre. 54 p.

KOHN, M. H., AND R. K. WAYNE. 1997. Facts from feces revisited. *Trends Ecol. Evolu.*, **12**:223-227.

KOHN, M. H., E. C. YORK, D. A. KAMRADT, G. HAUGHT, R. M. SAUVAJOT AND R. K. WAYNE. 1999. Estimating population size by genotying faeces. *Proc. Royal Soc. London B*, **266**:657-663.

KREEGER, T. J. 1996. Handbook of wildlife chemical immobilization. International Wildlife Veterinary Services, Laramie, Wyoming. 340 p.

LEWIS, P. O, AND ZAYKIN, D. 2001. Genetic Data Analysis: Computer program for the analysis of allelic data. Version 1.0 (d16c). Free program distributed by the

authors over the internet from http://lewis.eeb.uconn.edu/lewishome/software.html

LUCE, B., L. HUNT AND J. PRIDAY. 2000. Swift fox completion report, p. 33-37. *In:* G. Schmitt (ed.). Swift Fox Conservation Team 1999 annual report. New Mexico Department of Game and Fish, Santa Fe.

MERCURE, A. K. RALLS, K. P. KOEPFLI, AND R. K. WAYNE. 1993. Genetic subdivisions among small canids: mitochondrial DNA differentiation of swift, kit, and arctic foxes. *Evol.,* **47**:1313-1328.

MOEHRENSCHLAGER, C. A. J., AND A. MOEHRENSCHLAGER. 1999. Canadian swift fox (Vulpes velox) population assessment: winter 1999. Alberta Environment, Fisheries and Wildlife Management Division, Edmonton. 25 p.

OLSON, T. L., J. S. DIENI AND F. G. LINDZEY. 1997. Swift fox survey evaluation, productivity, and survivorship in southeast Wyoming, p. 57-76. *In:* B. Giddings (ed.). Swift Fox Conservation Team 1997 annual report. Montana Department of Fish, Wildlife and Parks, Helena.

------, F. G. LINDZEY AND J. S. DIENI. 1999. Swift fox detection probability in southeast Wyoming, p. 51 - 65. *In:* C. C. Roy (ed.). 1998 Swift Fox Conservation Team annual report. Kansas Department of Wildlife and Parks, Emporia.

OSTRANDER, E. A., G. F. SPRAHUE, JR., AND J. RINE. 1993. Identification and characterization of dinucloetide repeat $(CA)_n$ markers for genetic mapping in dog. *Genomics,* **16**:207-213.

POLLOCK, K. H., J. D. NICHOLS, C. BROWNIE AND J. E. HINES. 1990. Statistical inference

for capture-recapture experiments. *Wildl. Monographs*, **107**:1-97.

POTTER, J. C. 1982. Endangered and threatened wildlife and plants; review of vertebrate wildlife for listing as endangered or threatened species. Federal Register, **47**:58454-58460.

ROELL, B. J. 1999. Demography and spatial use of swift fox (*Vulpes velox*) in northeastern Colorado. M. A. Thesis. University of Northern Colorado, Greeley. 147 p.

ROY, C. C., M. A. SOVADA AND G. A. SARGENT. 1999. An improved method for determining the distribution of swift foxes in Kansas, p. 4-17. *In:* C. C. Roy (ed.). 1998 Swift Fox Conservation Team annual report. Kansas Department of Wildlife and Parks, Emporia.

SCHAUSTER, E. R. 2001. Swift fox (Vulpes velox) on the Pinon Canyon Maneuver site, Colorado: Population ecology and evaluation of survey methods. M. S. Thesis. Utah State University, Logan. 75p.

SCOTT-BROWN, J. M., S. HERRERO AND J. REYNOLDS. 1987. Swift fox, p. 433-441. *In:* M. Novak, J.A. Baker, M.E. Obbard, and B. Malloch (eds.). Wild furbearer management and conservation in North America. Ministry of Natural Resources, Ontario.

SMITH, D. A., K. RALLS, B. DAVENPORT, B. ADAMS AND J. E. MALDONADO. 2001. Canine assistants for conservationists. *Science*, **291**: 435.

SOVADA, M. A., AND C. C. ROY. 1996. Summary of swift fox research activities conducted in western Kansas - Annual report p. 64-68. *In:* B. Luce and F.

Lindzey (eds.). Annual report of the Swift Fox Conservation Team. Wyoming Game and Fish Department, Lander.

SUMNER, P. W., AND E. P. HILL. 1980. Scent-stations as indices of abundance in some furbearers of Alabama. *Proc. Ann. Conf. Southeast Assoc. Fish and Wildl. Agencies*, **34**:572-583.

TABERLET, P., L. P. WAITS, AND G. LUIKART. 1999. Noninvasive genetic sampling: look before you leap. *Trends Ecol. Evolu.*, **14**:323-327.

WAITS, J. L., AND P. L. LEBURG. 2000. Biases associated with population estimation using molecular tagging. *Animal Conservation,* **3**:191-199.

WAYNE, R. K., E. GEFFEN, D. J. GIRMAN, K. P. KOEPFLI, L. M. LAU, AND C. R. MARSHALL. 1997. Molecular systematics of the Canidae. *Systematic Biol.,* **46**:622-653.

WEIR, B. S., AND C. C. COCKERHAM. 1984. Estimating F – statistics for the analysis of population structure. *Evolu.*, **38**:1358-1370.

ZAR, J. H. 1984. Biostatistical analysis. Second edition. Prentice-Hall, Englewood Cliffs, New Jersey. 718 p.

Table 1.---Capture rates for swift fox in New Mexico

Period	Trap-nights	% without recaptures	% with recaptures
Jan. - Mar. 1999	181	3.9	4.4
Jan. - Mar. 2000	63	1.6	4.8
Jan. - Mar. 2001	107	3.7	9.3
Apr. - June 2001	88	0.0	2.3
May - July 2000	71	2.8	5.6
Sept. - Nov. 1999	221	5.9	8.6
Dec. 2000	62	9.7	11.3

Table 2.--- Measures of genetic diversity at loci in swift fox. n = individuals per population, A = number of alleles per locus, He = Hardy-Wienberg expectation of heterozygosity, Ho = observed heterozygosity, f = inbreeding coefficient, P = probability of Hardy-Weinberg equilibrium.

Locus	Population	n	A	He	Ho	f	P
CPH03	Control blood	13	5	0.766	0.692	0.100	0.056
	Control blood	13	5	0.766	0.692	0.100	0.056
	Control scat	13	5	0.772	0.692	0.107	0.680
	2000 Survey	42	6	0.767	0.595	0.226	0.001
	2001 Survey	18	6	0.712	0.389	0.462	0.005
	NENM	13	5	0.745	0.769	-0.034	0.116
CPH07	Control blood	13	3	0.394	0.462	-0.180	1.000
	Control scat	13	3	0.342	0.385	-0.132	1.000
	2000 Survey	61	6	0.787	0.623	0.210	0.003
	2001 Survey	26	5	0.724	0.577	0.206	0.067
	NENM	14	4	0.669	0.786	-0.182	0.428
CPH09	Control blood	13	3	0.668	0.692	-0.038	0.894
	Control scat	13	3	0.680	0.615	0.099	0.667
	2000 Survey	29	3	0.670	0.448	0.335	0.070
	2001 Survey	17	4	0.713	0.471	0.347	0.010
	NENM	11	3	0.602	0.727	-0.221	0.770
DB003	Control blood	13	6	0.735	1.000	-0.381	0.327

Control scat	13	6	0.751	0.923	-0.241	0.814
2000 Survey	61	5	0.740	0.754	-0.019	0.203
2001 Survey	25	5	0.770	0.800	-0.040	0.207
NENM	14	5	0.728	0.714	0.019	0.933

Table 3.—Theta values among swift fox populations. 95% confidence intervals for values of Theta are in parentheses

	Control blood	Control scat	2000 Survey	2001 Survey
Control scat	-0.030			
	(-0.020/-0.04)			
2000 Survey	0.061	0.059		
	(-0.005/0.140)	(-0.019/0.159)		
2001 Survey	0.028	0.026	0.014	
	(-0.010/0.069)	(-0.019/0.082)	(-0.108/0.045)	
NENM	0.061	0.059	0.028	0.045
	(0.007/0.111)	(-0.009/0.122)	(0.004/0.049)	(0.000/0.106)

Figure 1.—Percent of transects of scent stations visited by radiocollared and uncollared swift foxes combined as a function of number of stations per home range and number of nights of observation

Figure 2.—Percent of transects of scent stations visited by radiocollared swift foxes only as a function of number of stations per home range and number of nights of observation

Figure 3.—Percent of transects of scent stations visited by male radiocollared swift foxes as a function of number of stations per home range and number of nights of observation

Figure 4.—Percent of transects of scent stations visited by female radiocollared swift foxes as a function of number of stations per home range and number of nights of observation

Figure 5.—Histogram of maximum diameters of swift fox scat collected in New Mexico and identified as originating from swift fox by mitochondrial DNA analysis. n = 206

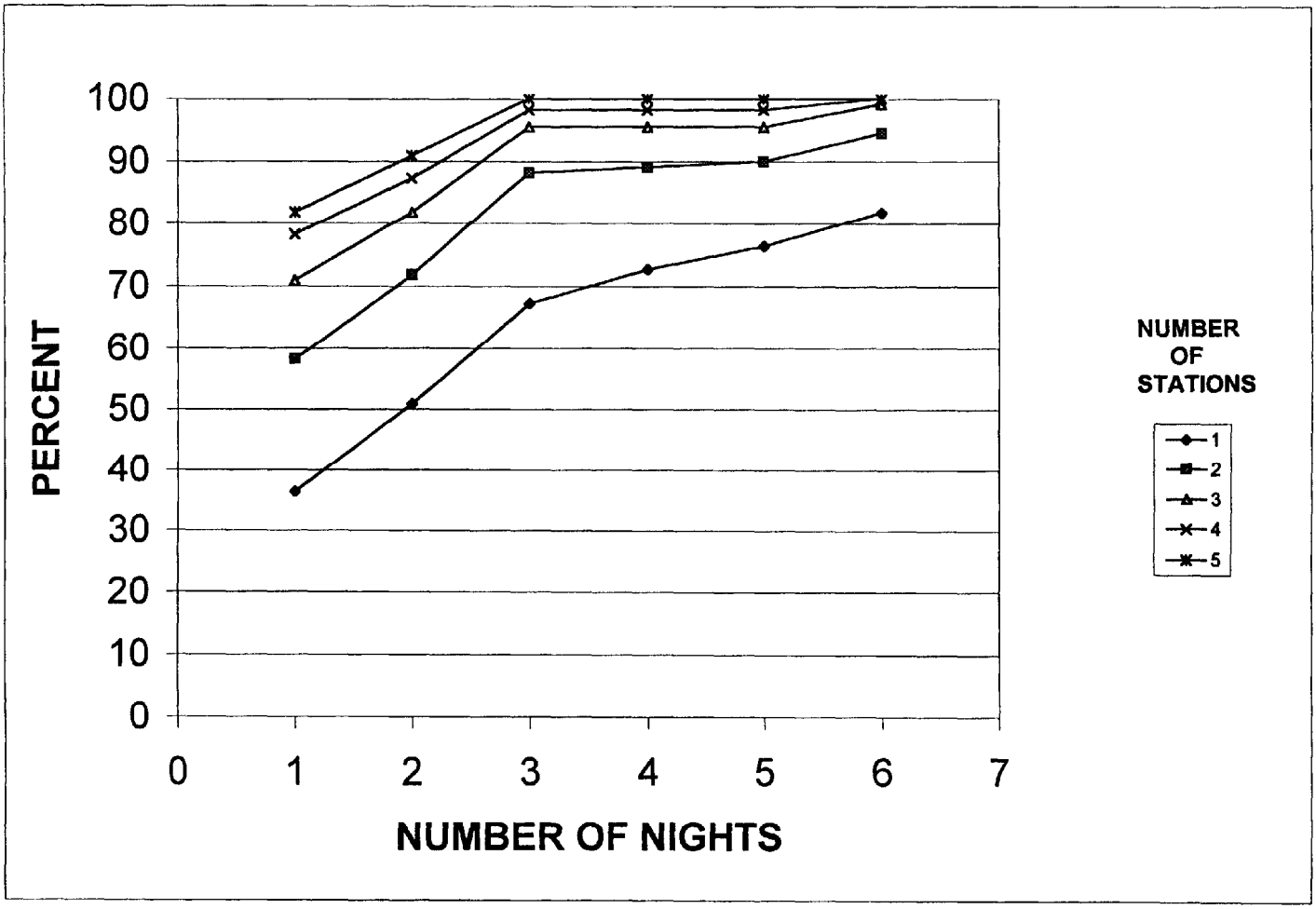
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Figure 1.

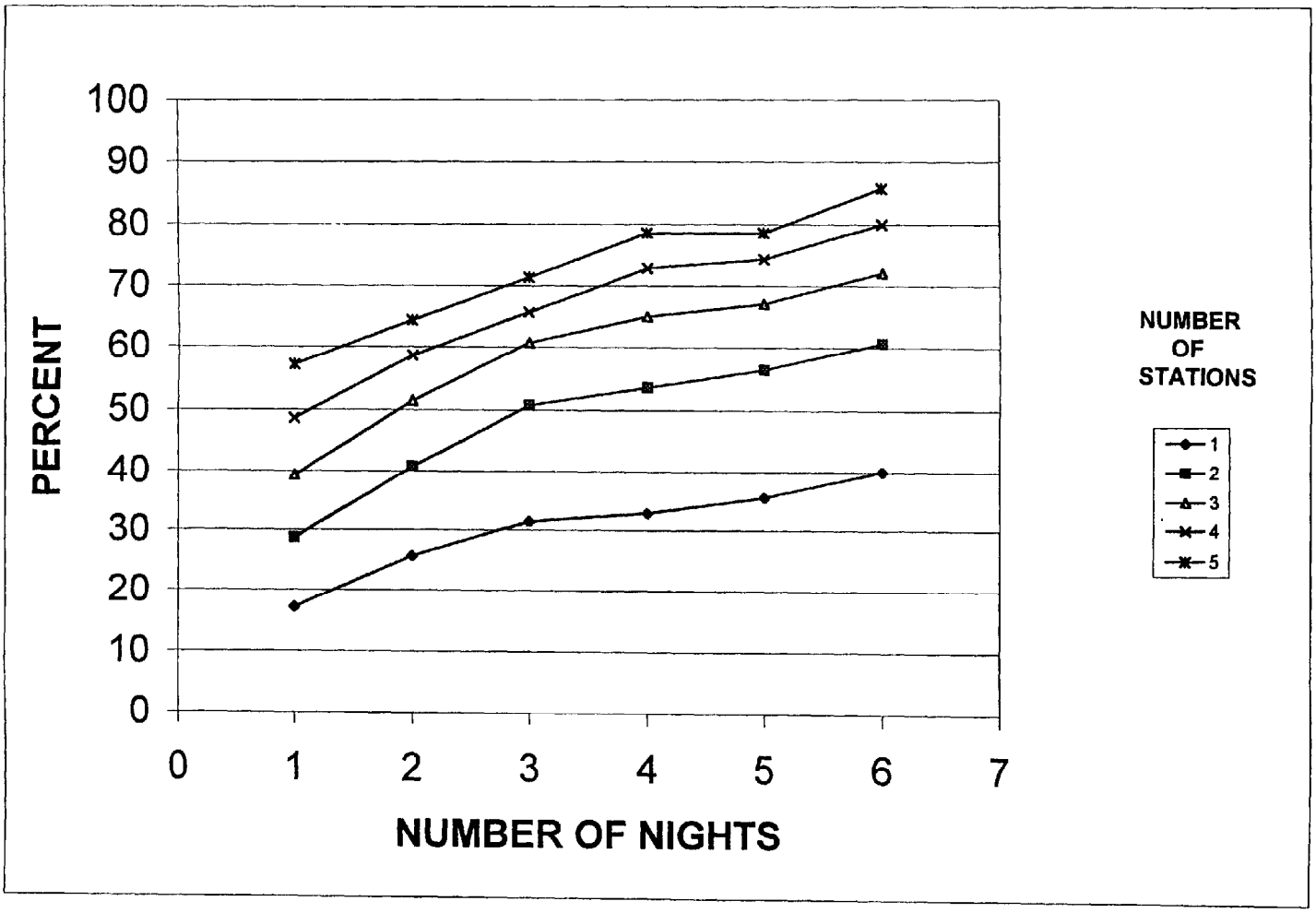
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Figure 2.

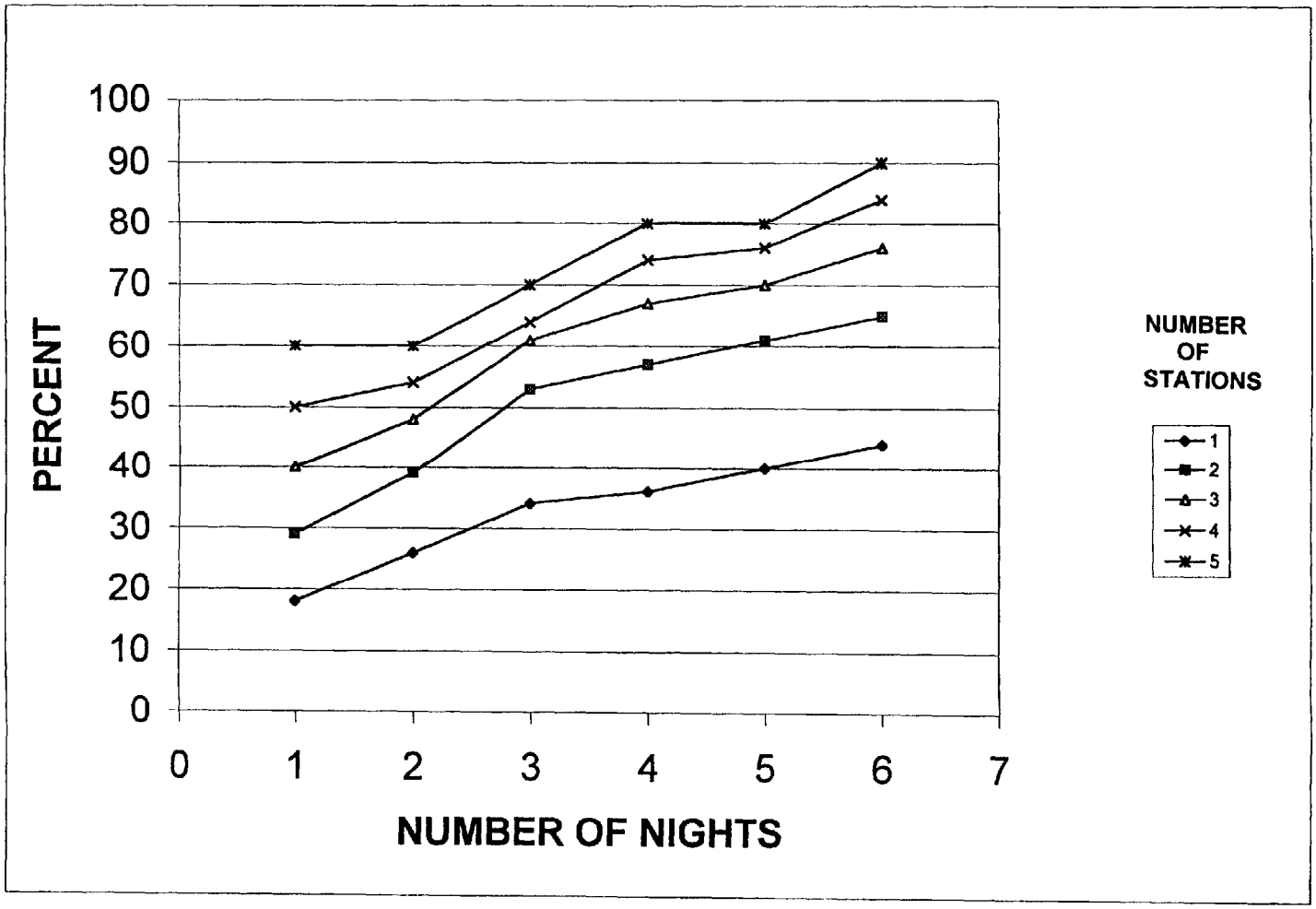
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Figure 3.

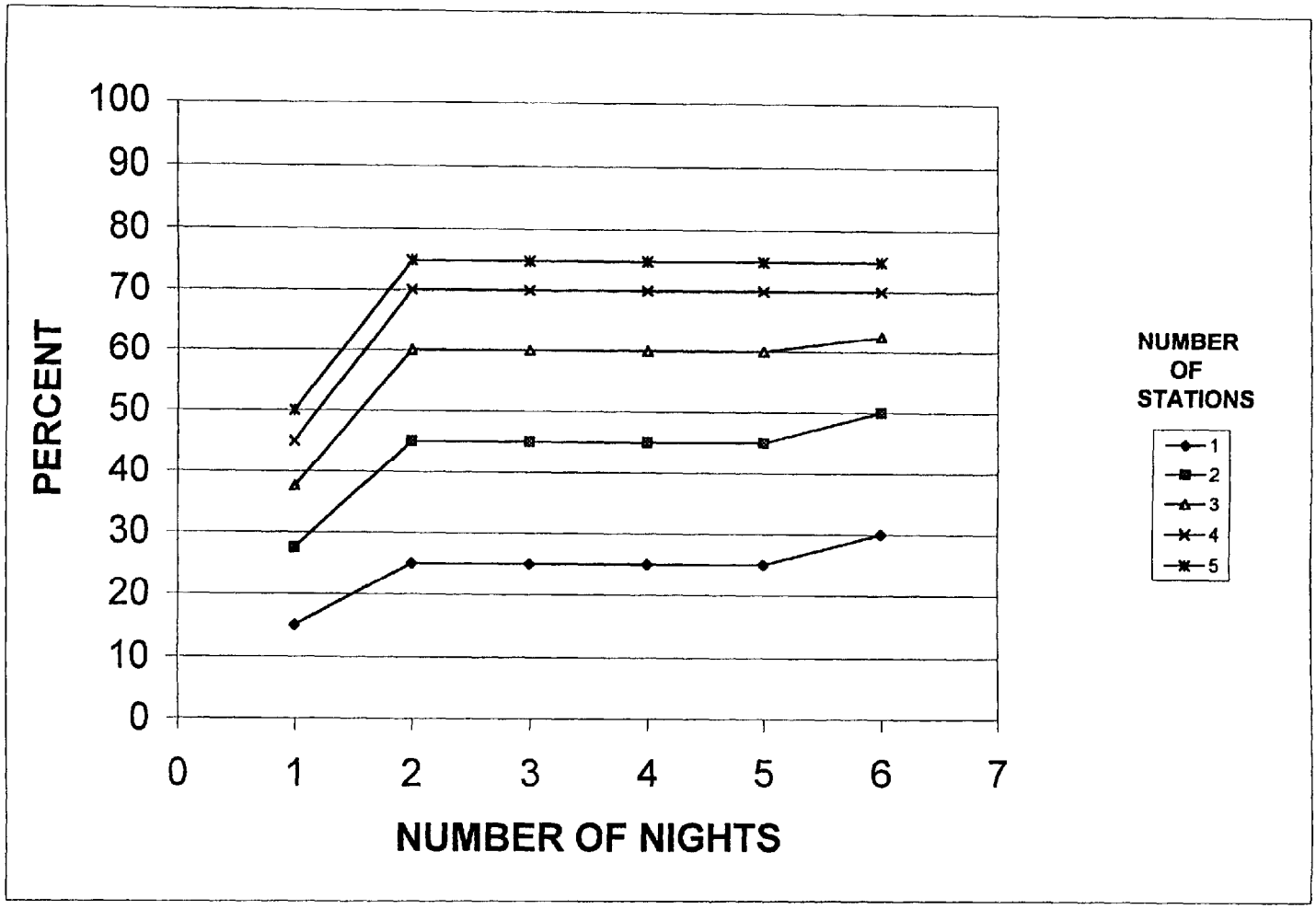
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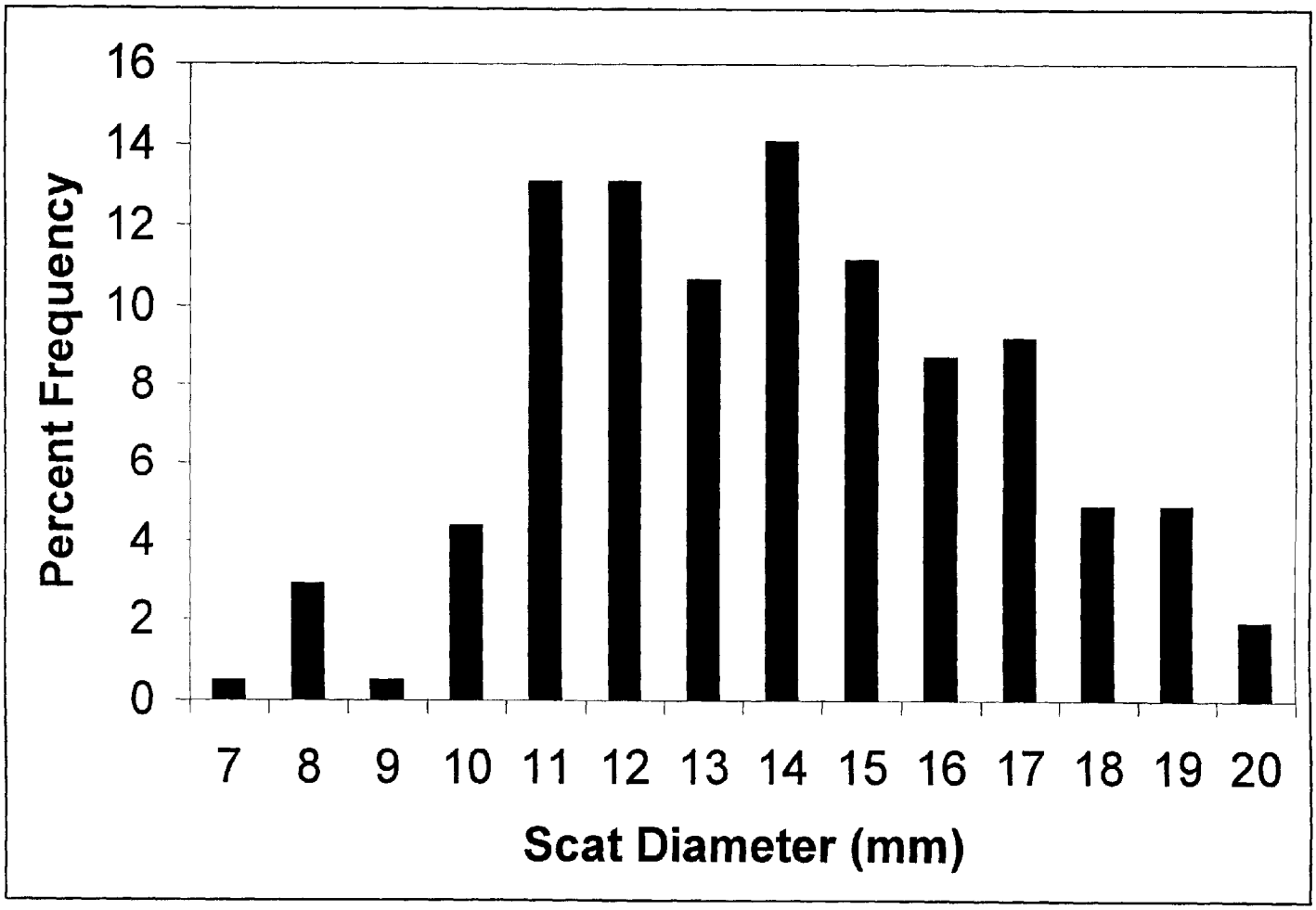
Figure 4.


Percent Frequency
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2
0
7
8
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11
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16
17
18
19
20
Scat Diameter (mm)

Figure 5.

APPENDIX 2

Swift Fox Demography, Movements, Denning, and Diet in New Mexico

SWIFT FOX DEMOGRAPHY, MOVEMENTS, DENNING, AND DIET IN NEW MEXICO

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ABSTRACT-I examined swift fox (Vulpes velox) demography, home range size, dispersal, den site selection, and diet in northeastern New Mexico. Juveniles comprised the most numerous age class. The average number of pups observed per female was 2.3 (range 1-4). Male and female radiocollared swift foxes reached adult weights by at most 9 and 5 months, respectively. For swift foxes within the adult weight range, body length, body plus tail length, hind foot length, and weight were larger in males than females. Body size measurements were generally as large or larger, and weights were smaller, than those reported from more northern areas. Traumatic injury, presumably by coyotes (Canis latrans), was the primary cause of death. Annual survival rates for adults averaged 0.53. Of 36 swift foxes captured during the study, four remained alive on the study area, 21 died, and 11 left the study area by the end of 32 months of field work. One swift fox tested positive for antibodies to Yersinia pestis. No fox lived long enough or was observed enough for home range size estimates to stabilize. The 95% MCP home range size estimate, using all points for foxes with $\geq$60 relocation points, was 1842.3 ha. The annual 95% MCP home range size estimate was 1494.5 ha. Diet was dominated by invertebrates and mammals. At den sites, swift foxes showed preferences for the vicinity of roads, areas with greater road density, low slope, hilltops, and sandy loam and clay soils, when compared with random points. Swift foxes did not show preferences regarding proximity of anthropogenic sites nor soil water holding capacity.

INTRODUCTION---The swift fox (Vulpes velox) is a small (<3.0 kg) canid which occurs in the shortgrass prairie from eastern New Mexico and northwestern Texas to southern Alberta and Saskatchewan (Egoscue, 1979). The swift fox was temporarily a candidate for endangered species listing by the U.S. Fish and Wildlife Service (Potter, 1982; Clark, 2001). Candidacy highlighted the lack of modern knowledge of swift fox ecology, especially in the southern portions of its range. Cutter (1958a, 1958b) examined denning and diet of swift fox in northern Texas. Kilgore (1969) studied denning, parasites, reproduction, diet, mortality, and movements of swift fox in the Oklahoma panhandle. No swift fox studies were conducted in New Mexico prior to candidacy. In response to candidacy and the strategy of the Swift Fox Conservation Team (Kahn et al., 1997), the New Mexico Department of Game and Fish initiated a series of studies, including a review of the status of swift fox in New Mexico (J. P. Hubbard, 1994, unpublished report to NMDGF), a survey of swift fox distribution and habitat selection (Harrison and Schmitt, in press), a study of survey procedures (Harrison et al., in review), and the current study. Using radiocollared swift foxes, I examined swift fox demography, home range size, dispersal, den site selection, and diet in northeastern New Mexico.

METHODS AND MATERIALS-The study area was located in the Kiowa National Grasslands, northeast of Roy, NM, in Harding and Colfax counties. The extended study area covered approximately 1250 km^2. Most activities were concentrated within a core area of approximately 330 km^2. The study area included private, state, and

federal lands. Habitat within the study area was entirely short-grass prairie (described as plains-mesa grassland by Dick-Peddie, 1993). Dominant plant species were blue grama (Bouteloua gracilis), hairy grama (B. hirsuta), western wheatgrass (Pascopyrum smithii), threeawn (Aristida sp.), and needle and thread (Hesperostipa comata). The most common shrubs were broom snakeweed (Gutierrezia sarothrae) and Yucca. Snakeweed was extensive in some sections, but Yucca occurred only in isolated stands. Topography was low rolling hills and elevation varied from approximately 1700 to 1900 m. Annual precipitation averages 390 mm, and varied between 257 and 565 mm from 1975 to 2000. Annual precipitation was 395, 427, and 381 mm in 1998, 1999, and 2000, respectively. Growing season precipitation has been found to correlate with abundance of kit fox (Vulpes macrotis; Cypher et al., 2000), a species closely related to swift fox. Growing season (July - August) precipitation in the study area averages 37.4% of annual precipitation, and varies from 11 to 65% of annual precipitation. Growing season precipitation was 55.5%, 31.6%, and 33.8% of annual precipitation in 1998, 1999, and 2000, respectively. Minimum monthly average low and high temperatures are -6.5°C (January) and 29.9°C (July). The entire study area is heavily grazed and cattle are present throughout the year.

I captured swift foxes in 25cm x 30cm x 81cm single door traps (Tomahawk Traps, Tomahawk, WI) baited with beef scraps and a cod liver oil - mackerel lure (Trailing Scent, On Target A.D.C., Cortland, IL). Foxes of weight <1.5 kg were released without further procedures. I transferred captured foxes to a 30cm x 60cm x 76cm restraint module (Tomahawk Traps, Tomahawk, WI) and sedated them with

Telazol (10mg/kg). Captured foxes were dusted for fleas, inspected for sex and injury, measured (nose to base of tail, base of tail to end of tail bones, hind foot, ear), fitted with a radiocollar (telemetry system described below), and marked for individual visual identification by dying an unique portion of their fur with commercial hair dye (Miss Clairol black velvet). The University of New Mexico Main Campus Animal Care and Use Committee approved the animal handling procedures (protocol 9811-B). Authorization for trapping and collecting protected wildlife was provided by the New Mexico Department of Game and Fish (Authorization No. 2932).

Radiocollars were provided by Advanced Telemetry Systems (Isanti, MN; model 16MC) and Telonics (Mesa, AZ; model MOD-080). The receiving antenna consisted of two five-element Yagi antennas combined 180° out of phase (null) and mounted through a sunroof in the cab of the research vehicle. Tests of this configuration indicate that under ideal conditions (both transmitter and receiver on hilltops), the signal may be detected at over 2.5 miles. Accuracy and precision tests using radiocollars at known locations (n = 24) revealed a systematic error of 1.0° and a random error (2 SD) of 1.18°. At one kilometer, with two observations taken at 90° to each other, the 90% error polygon is .0064 km^2 (White and Garrott 1990: 53), which represents <1% of the average home range size. To relocate collared foxes, I used 2 - 5 bearings taken within a few minutes of each other by driving between observation sites. Foxes were relocated 3 - 4 times per biweekly field trips. In some cases, swift foxes were located by aerial surveys.

Age of recovered dead swift foxes was determined by Matson's Laboratory

(Milltown, MT), using tooth cementum analysis. It was not possible to accurately age foxes that were alive. I assumed April 1 to be the date of birth of all swift foxes (Kilgore, 1969). Swift foxes were designated as juveniles if <1 year old and as adults if ≥1 year old. To determine fecundity, I counted the number of pups visible at dens of females in early summer and counted placental scars on uteri collected from recovered dead radiocollared females. After counting the number of visible scars, I bleached the uteri in hydrogen peroxide, dried them, and then cleared them with ethyl salicylate (Wright and Rausch, 1955). I also examined swift fox uteri from specimens collected throughout the range of swift fox in New Mexico by Harrison and Schmitt (in press). Cause of death was determined by observations in the field or by necropsy by Veterinary Diagnostic Services (New Mexico Department of Agriculture, Albuquerque, NM). If foxes died due to non-vehicle traumatic injuries, I assumed that the agent was a coyote (Canis latrans), as coyotes were present on the study area and have been known to kill foxes (Sovada et al., 1998). Other potential predators, such as badgers (Taxidea taxus) and golden eagles (Aquila chrysaetos) were uncommon on the study area. I estimated survival rates using a Kaplan-Meier estimator with a staggered entry design (Pollock et al., 1989). Foxes were tested for antibodies to Yersinia pestis (the causative agent of plague) using Nubuto strips by the Centers for Disease Control and Prevention (Fort Collins, CO) and for antibodies to Francisella tularensis (the causative agent of tularemia), canine distemper virus, and canine parvovirus by Veterinary Diagnostic Services.

I calculated home range sizes using CALHOME (Kie et al., 1996). To determine

the minimum number of relocations required for home range size estimates to stabilize, I calculated cumulative home range sizes at intervals of 10 points. To obtain average annual home range sizes, I calculated one-year home range size estimates, advancing the one-year interval by two months through the period of observation for each fox.

I located den sites during all months of the year by radiotracking swift foxes to their dens. All dens where characteristics were recorded were occupied by swift foxes. I used a stratified random design to locate non-den random points for comparison of site characteristics. Because nearly all radiocollared foxes were captured along roads, I located random points within the home ranges of radiocollared swift foxes rather than throughout the study area in order to avoid biasing the comparison of distances to roads. At den sites, I recorded average new and old grass length, direction of opening of den entrances (N, NE, E, SE, S, SW, W, NW), and number of entrances. At both den sites and random points, I used topographic maps to measure distance to nearest primary road (paved or gravel), distance to nearest secondary road (two-track) used at least weekly, distance to nearest anthropogenic site (occupied house or well visited at least weekly), length of primary and secondary roads within 1 km and 2 km radii, slope, slope aspect (NE, NW, SE, SW, or flat if slope $\leq$ 0.4%), and position on hillside (top, middle, bottom). I did not measure distances to the nearest water source, as year-round water sources were not available within all swift fox home ranges. I obtained soil texture and water holding capacity at den sites and random points from soil surveys of Harding and Colfax counties (U. S. Department of Agriculture, 1973, 1982). I did not distinguish natal and non-natal dens.

I collected scat for diet analysis during systematic surveys of conspicuous locations, such as fence and road intersections, throughout the extended study area. To minimize collecting coyote scat, I selected scat of maximum diameter $\leq$ 20 mm (Danner and Dodd, 1982). I placed individual scats in numbered nylon bags and washed them for several cycles with detergent in a washing machine (Johnson and Hansen, 1979). Dr. M. Johnson (Louisiana State University) performed identification of prey items to lowest taxonomic division possible using reference collections. I defined season as: Spring, Mar. - May; Summer, June - Aug.; Fall, Sep. - Nov.; and winter, Dec. - Jan.

RESULTS-I captured and radiocollared 36 swift foxes (18 males, 18 females) between Jan., 1998, and Aug., 2001. Juveniles comprised the most numerous age class when captured, at death, and at the time of the maximum number of study animals alive (May, 1999; Fig. 1). The ratio of numbers of juveniles to numbers of adults when caught was not different from the ratio of juveniles to adults at the time of maximum swift fox numbers (X^2_c = 0.170, df = 1, P = 0.702). Two additional swift foxes collected as road kills at the end of April, 2001, were 1 and 3 years old.

Male and female radiocollared swift foxes reached adult weights by at most 9 and 5 months, respectively (Figs. 2 and 3). For swift foxes within the adult weight range, weight, average body length, average body plus tail length, and average hind foot length were larger in radiocollared males than radiocollared females (Table 1). Average tail length and average ear size were not different between males and females

(Table 1).

The overall sex ratio of swift foxes caught was 1M:1F. Among foxes known to be juveniles or adults when first captured, the sex ratios were 3M:7F and 6M:4F, respectively. The sex ratio of juveniles was not different from 1:1 (log-likelihood ratio G = 1.646, df = 1, P = 0.215). The sex ratio of adults was also not different from 1:1 (G = 0.403, df = 1, P = 0.537).

Four, two, and one pups were observed at dens of one, two, and one radiocollared females, respectively, in June. By early July, only one pup remained with each of three of the four females. The fourth female was dead and presumably her one pup did not survive. An uncollared female was observed with two pups in late June. An additional radiocollared female was located on one occasion in a den with a juvenile in late July. Pups were not seen with this female on any other occasion, and she may have been a helper. Anecdotal reports from local residents indicate that 2 - 3 pups are commonly seen with females in June.

The number of placental scars observed on 4 uteri from radiocollared swift foxes was 0 (juvenile fox), 4 (1 year old fox), 2 (2 year old fox), and 4 (6 year old fox). Placental scars appeared as obvious black spots in the horns of the uteri. No faded scars were found after bleaching and clearing. Two pups were observed with the 2 year old swift fox.

Observed causes of mortality of radiocollared swift foxes were: non-vehicle traumatic injury (6 adult males, 4 adult females, 4 juvenile females, 1 female of unknown age), vehicle strikes (1 radiocollared adult of unknown sex reported by a

motorist, 2 uncollared adults, and 2 uncollared pups), trapping (1 juvenile male), and unknown (2 adult males, 2 adult females, 1 juvenile female).

Confidence intervals for survival estimates were too wide to draw statistical conclusions, but estimates for males appeared to be higher than for females (Table 2). Survival estimates for all female swift foxes appeared to be lower than for adult females only, due to high mortality among juvenile females. Calculations of juvenile survival were not made because of bias from the circumstance that the only swift foxes known to be juveniles when captured (4 males, 7 females) were those that died and were submitted for cementum analysis. Other foxes that left the study area before death (4 males, 7 females) may have been juveniles when captured. Of the swift foxes known to be juveniles when captured, three of ten survived to become adults.

Five swift foxes died within two months of radiocollaring. Four (2 adult males, 1 adult female, 1 juvenile female) were wearing Telonics radiocollars. The fifth fox (a juvenile female) was wearing an Advanced Telemetry Systems (ATS) radiocollar. Two other males (one adult, one of unknown age) carried Telonics radiocollars for 7.5 and > 4 months. Two other adult females carried Telonics radiocollars for 5 and 7.5 months. No other swift foxes carried Telonics radiocollars. Telonics and ATS radiocollars weighed 46 and 60 gm, respectively. Telonics radiocollars weighed 2.4 and 2.6% of body weight of males that died, and 2.5 and 2.7% of body weight of males that survived >4 months. Telonics radiocollars weighed 2.6 and 3.0% of body weight of females that died, and 3.0 and 3.8% of body weight of females that survived >4 months. ATS radiocollars on males and females weighed an average of 2.1% (range 1.8-3.1%) and

2.3% (range 1.9-2.6%), respectively, of body weight. The volume of Telonics and ATS radiocollars are 100 and 50 ml, respectively. The widths of the neck collars of Telonics and ATS radiocollars were 28 and 13 mm, respectively.

Of 36 swift foxes captured during the study, only 4 (2 adult males, 2 adult females) remained alive on the study area at the end of 32 months of field work. These four foxes were initially captured 8-22 months before the end of the study. Of the other 32 foxes, 21 (8 males, 13 females) died in the study area, and 11 (8 males, 3 females) left the area. Months of dispersal were: 2 juvenile males, Feb., Sept.; 3 adult males, Feb., Mar., July; 3 adult females, May, Aug., Oct.; 3 males of unknown age, Feb., Mar., May. The adult males which left their home ranges in Mar. and July did so following the deaths of their mates. Two juvenile females were observed to disperse within the study area distances of 10 and 3 km in Oct. and Nov., respectively. One adult male and one adult female were observed to shift their home ranges approximately 2 km into adjacent home ranges in Aug. and Sept., respectively. Both adult females observed to leave or shift their home ranges in August may have been helpers. One of the helpers was relocated by aerial survey 16 km from her original home range. One juvenile male fox was trapped 10 km from his initial capture location and one juvenile male was not located by aerial survey within 10 km of his capture location.

Sixteen swift foxes (8 males, 8 females) were tested for antibodies to Yersinia pestis. One male was positive and the rest were negative. Two males tested negative for antibodies to Francisella tularensis, and one female fox was negative for canine distemper and positive for canine parvovirus. No other disease tests were conducted.

Swift fox were located 1427 times (range of locations/fox: 1-154). No fox lived long enough or was observed enough for home range size estimates to stabilize (Fig. 4). Cumulative home range size estimates reached a peak around 60 points, but loss of study foxes to death or emigration reduced the number of animals relocated ≥60 times.

Home range size estimates using all points obtained for foxes with ≥60 relocation points (*n* = 8: 5 males, 3 females) were: 95% adaptive kernel (AK), 2722.4 ha (range: 1881-3854 ha); 50% AK, 534.4 ha (range: 427-710 ha); 95% minimum convex polygon (MCP), 1842.3 ha (range: 1304 -2298 ha); and 50% MCP, 510.0 ha (range: 311-779 ha). Home range size estimates for males only, using all points obtained for foxes with ≥60 relocation points (*n* = 5) were: 95% AK, 2690.2 ha (range: 1956-3854 ha); 50% AK, 563.2 ha (range: 427-710 ha); 95% MCP, 1899.6 ha (range: 1360-2298 ha); and 50% MCP, 506.6 ha (range: 311-779 ha). The number of months of observation of these five males ranged from 14 to 27.5 months. Home range size estimates for females only, using all points obtained for foxes with ≥60 relocation points (*n* = 3) were: 95% AK, 2776.0 ha (range: 1881-3458 ha); 50% AK, 486.3 ha (range: 438-517 ha); 95% MCP, 1746.7 ha (range: 1304-2014 ha); and 50% MCP, 515.7 ha (range: 333-629 ha). The number of months of observation of these three females ranged from 8 to 15.5 months.

Annual home range size estimates for five males and one female combined were: 95% AK, 2191.9 ha (range: 1428-3735 ha); 50% AK, 465.6 ha (range: 308-796 ha); 95% MCP, 1494.5 ha (range: 1004-2210 ha); and 50% MCP, 339.7 ha (range:

206-625 ha). The average number of locations/annual home range was 59.3 (range: 40-80). Seasonal sample size was not adequate for analysis.

The number of entrances per den site averaged 1.54 (SD = 1.1, median = 1, range = 1-9, *n* = 104). The percentages of openings in each direction were: N 13.7%, NE 12.8%, E 20.2%, SE 8.3%, S 12.8%, SW 11.9%, W 16.5%, and NW 3.7% (*n* = 109). The opening directions of den entrances were not randomly distributed between directions (X^2 = 15.11, df = 7, P = 0.037). Average length of new and old grass combined was 13.4 cm (SD = 10.4 cm, range 2-30 cm, *n* = 99). The average length of new grass only was 4.7 cm (SD = 2.3 cm, range = 2-13 cm, *n* = 32).

The average distances of den sites to the nearest anthropogenic site, nearest primary road, and nearest secondary road if a secondary road was closer than the nearest primary road, were not different from the average distances of random points (Table 3). The average distance of den sites to the nearest road, whether primary or secondary, was less than the average distance of random points (Table 3). The average lengths of secondary roads within 1 and 2 km of den sites were greater than the average lengths within 1 and 2 km of random points (Table 3). The average length of primary roads within 1 km of den sites was almost greater than the average length within 1 km of random points, but the average length of primary roads within 2 km of den sites was not different from the average length within 2 km of random points (Table 3).

The average slope at den sites was less than at random points (Table 3). The directions of slope aspect at den sites (NE 20.7%, SE 24.5%, SW 17.9%, NW 24.5%,

flat 12.3%, *n* = 106) were not distributed differently than at random points (NE 19.8%, SE 28.3%, SW 28.3%, NW 19.8%, flat 3.8%, *n* = 106; X^2 = 21.104, df = 105, P > 0.999). The distribution of positions of den sites on hillsides (top 34.9%, middle 47.2%, bottom 17.9%, *n* = 106) was not the same as the distribution of random points (top 21.7%, middle 60.4%, bottom 17.9%, *n* = 106; X^2 = 11.584, df = 2, P = 0.004). Most dens and random points were in the middle of hillsides, but den sites were located toward the tops of hillsides more than random points.

Nine categories of soil texture were found at den sites and random points (Table 4). Among those six soil textures found at >5% of den sites or random points, the distribution of soil textures was not the same at den sites and random points (X^2 = 19.005, df = 5, P = 0.003). Excluding sandy loam, the distribution of soil textures was different at den sites and random points (X^2 = 10.005, df = 4, P = 0.042). Excluding sandy loam and clay, the distribution of soil textures was nearly different at den sites and random points (X^2 = 6.985, df = 3, P = 0.077). Without sandy loam, clay, and loam, the distribution of soil textures was not different between den sites and random points (X^2 = 2.934, df = 2, P = 0.237). Den were found in soils with less clay, more sandy loam, and probably more loam, than soils at random points. Average soil water capacity at den sites ($\bar{x}$ = 0.171 cm water/cm depth, SD = 0.289 cm/cm, range 0.095-0.200 cm/cm, *n* = 106) was not different from average soil water capacity at random points ($\bar{x}$ = 0.176 cm water/cm depth, SD = 0.238 cm/cm, range 0.110-0.200 cm/cm, *n* = 106; *t* = -1.310, df = 210, P = 0.192).

In scat, percentage frequency of prey was dominated by invertebrates and

mammals (Table 5).

DISCUSSION-Swift fox age distribution, fecundity, survival, and causes of mortality in northeastern New Mexico (neNM) were similar to those reported from other areas (Hines and Case, 1999; Sovada et al., 1998; Roell, 1999; Matlack et al., 2000). Reported average fecundity, as measured by observations of pups emerging from dens, has ranged from 1.6 to 4.6 (Kilgore, 1969; review in Olson, 2000; Schauster, 2001). My observations of emerging pups and placental scars were severely limited by the low survival of females, but averaged 2.7 (range 1-4). Body size and weight were somewhat different in neNM when compared to other areas. Body size measurements of neNM swift foxes were generally as large or larger and weights were smaller than those reported from more northern areas (Cameron, 1984; Zimmerman, 1998; Roell, 1999; Matlack et al., 2000). Body size measurements of neNM swift foxes were comparable to those reported by Kilgore (1969) for swift foxes from the vicinity of the Oklahoma panhandle, but weights of neNM foxes were less than Kilgore (1969) reported.

Non-vehicle traumatic mortality, presumably by coyotes, occurred throughout the year. Vehicle strikes of swift foxes were rarely observed, but are likely to be more common during spring and summer when pups are more abundant. All three adult roadkills were occurred during spring and summer. There was no active commercial or sport trapping on the study area, although trappers were active during the trapping season (Nov. - Mar.) on nearby ranches. Swift fox are not a target species for trappers,

but may be caught incidentally to coyote trapping.

Estimates of mortality in the neNM study area may have been slightly exaggerated by the use of relatively bulky Telonics radiocollars. If Telonics radiocollars did in fact increase mortality when compared with ATS radiocollars, it was not likely to be the result of the greater weight of Telonics radiocollars. All radiocollars weighed < 5% of swift fox weight, a guideline suggested by Cypher (1997). Telonics radiocollars as used in this study were considerably bulkier than ATS radiocollars. Foxes wearing the bulkier radiocollars may have required a greater length of time in which to become accustomed to the collars. Beyond 2-3 months, survival rate of ATS and Telonics seemed similar, although my data were insufficient for statistical analysis. Cypher (1997) noted a similar effect in kit foxes.

Home range sizes of swift foxes in neNM were considerably larger than reported from other areas (Southeastern Colorado: 660 - 940 ha, 95% AK, Kitchen et al., 1999; Schauster, 2001; northeastern Colorado: 430 ha, MCP, Roell, 1999; north-central Montana: 1230 ha, AK, Zimmerman, 1998), with the exception of that reported from Nebraska (3230 ha, MCP, Hines and Case, 1991). Length of observation and number of relocation points were comparable between studies. Accurately estimating home range size for swift fox is made difficult by the dynamic nature of swift fox populations. Many foxes did not live long enough or remain in the study area long enough for home range estimates to stabilize (Fig. 4). In addition, I observed that swift foxes used new areas and abandoned previously used areas throughout the period of observation. Standardization of periods of observation would make comparisons more meaningful.

Annual home range estimates may be the most useful and biologically relevant.

The density of swift fox in neNM was lower than reported in other studies. Harrison et al. (in review) found the swift fox density to be 0.105 fox/km^2 (95% C. I.: 0.078 - 0.132) in early 2000, and 0.070 fox/km^2 (95% C. I.: 0.066 - 0.075) in early 2001. Schauster (2001) reported a swift fox density of 0.18 - 0.30 in southeastern Colorado, Roell (1999) reported a swift fox density of 0.27 fox/km^2 in northern Colorado, and Dieni et al. (1996) reported a swift fox density of 0.16 fox/km^2 in Wyoming.

Swift fox den site selection in neNM was completely consistent with that reported from other areas (see review in Harrison and Hoagland, in press). Swift foxes denned in a variety of situations, but did show some preferences. They preferred sites closer to roads and areas with more secondary roads than random points. Swift fox did not show preference or avoidance of anthropogenic sites, as also found by Cutter (1958a). However, anthropogenic sites were not very common in the neNM study area. Swift foxes showed a preference for den sites of low slope, near the tops of hills, and in sandy loam, clay, or loam soil. The distribution of the directions of den openings was non-random, and swift foxes preferred den sites with western slope aspects. Other studies have reported non-random slope aspects at dens, but there has been no consistent pattern in the directions preferred. Soil water holding capacity was not different at den sites and random points. Water capacity is a function of the amount of organic matter, soil texture, and soil structure (U. S. Department of Agriculture, 1973). High water capacity in soils may lead to dryer dens.

Percentage frequency of prey remains was highest for invertebrates, followed by

mammals and birds (Table 5). Percentage frequency of mammals was generally low compared to studies in Kansas (Sovada et al., 1998) and Wyoming (Olson, 2000), but comparable to one study in Colorado (Cameron, 1984). Consumption of invertebrates was high compared to Cameron (1984), comparable to Olson (2000), and low compared to Sovada et al. (1998). Consumption of birds was comparable to Sovada et al. (1998) and Olson (2000), but higher in general than Cameron (1984). Comparisons between studies must be considered in light of the fact that prey populations can vary dramatically in response to prior-year precipitation and other factors (Cypher et al., 2000).

The swift fox population in neNM appears to be very dynamic. Swift foxes generally lived no more than a few years, and there was rapid turnover of the population. In three home ranges, all the radiocollared foxes dispersed or were killed, presumably by coyotes, within a few months. The same three home ranges were occupied by new swift foxes within a few months. Thus, home ranges may be completely vacated and reoccupied very rapidly. Coyotes are themselves subject to heavy mortality from ranchers and U. S. Dept. of Agriculture Wildlife Services agents. In addition, precipitation in neNM varies, sometimes dramatically, from year to year. The tracks of individual thunderstorms can provide heavy rains within some home ranges, and no rain in others, prompting variations in growth of vegetation and intensity of grazing. Prey density and swift fox populations probably follow precipitation patterns, as has been found in kit fox (Cypher et al., 2000).

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LITERATURE CITED

CAMERON, M. W. 1984. The swift fox (Vulpes velox) on the Pawnee National Grassland: Its food habits, population dynamics and ecology. Unpublished M.S. Thesis. University of Northern Colorado. Greeley, CO.

CLARK, J. R. 2001. Endangered and threatened wildlife and plants; Annual notice of findings on recycled petitions. Federal Register 66:1295-1300.

CUTTER, W. L. 1958a. Denning of the swift fox in northern Texas. Journal of Mammalogy 39:70-74.

CUTTER, W. L. 1958b. Food habits of the swift fox in northern Texas. Journal of Mammalogy 39:527-532.

CYPHER, B. L. 1997. Effects of radiocollars on San Joaquin kit foxes. Journal of Wildlife Management 61:1412-1423.

CYPHER, B. L., G. D. WARRICK, M. R. M. OTTEN, T. P. O'FARRELL, W. H. BERRY, C. E. HARRIS, T. T. KATO, P. M. MC CUE, J. H. SCRIVNER AND B. W. ZOELLICK. 2000. Population dynamics of San Joaquin kit foxes at the Naval Petroleum Reserves in California. Wildlife Monographs 145:1-43.

DANNER, D. A., AND N. DODD. 1982. Comparison of coyote and gray fox scat diameters. Journal of Wildlife Management 46:240-241.

DICK-PEDDIE, W. A. 1993. New Mexico vegetation, past, present, and future. University of New Mexico Press, Albuquerque.

DIENI, J. S., F. G. LINDZEY, T. WOOLLEY, S. H. ANDERSON, R. ROTHWELL, and B. LUCE. 1996. Swift fox density estimation and survey technique evaluation in

southeastern Wyoming, 1996. In: Luce, B., and F. Lindzey, editors. Annual report of the Swift Fox Conservation Team 1996. Wyoming Game and Fish Department, Lander. Pp. 53-63.

EGOSCUE, H. J. 1979. Vulpes velox. Mammalian Species 122:1-5.

HARRISON, R. L., and J. W. HOAGLAND. In press. A literature review of swift fox habitat and den site selection. L. N. Carbyn and M. A. Sovada, editors. Ecology and conservation of swift foxes in a changing world. Canadian Circumpolar Institute. University of Alberta, Edmonton, Canada.

HARRISON, R. L., AND C. G. SCHMITT. In press. Current swift fox distribution and habitat selection within areas of historical occurrence in New Mexico. L. N. Carbyn and M. A. Sovada, editors. Ecology and conservation of swift foxes in a changing world. Canadian Circumpolar Institute. University of Alberta, Edmonton, Canada.

HINES, T. D., and R. M. CASE. 1991. Diet, home range, movements, and activity periods of swift fox in Nebraska. Prairie Naturalist 23:131-138.

JOHNSON, M. K. and HANSEN, R. M. 1979. Estimating coyote food intake from undigested residues in scats. American Midland Naturalist 102:363-367

KAHN, R., L. FOX, P. HORNER, B. GIDDINGS AND C. ROY. 1997. Conservation assessment and conservation strategy for swift fox in the United States. South Dakota Department of Game, Fish, and Parks, Pierre.

KIE, J. G., J. A. BALDWIN, AND C. J. EVANS. 1996. CALHOME: a program for estimating animal home ranges. Wildlife Society Bulletin 24:342-344.

KILGORE, D. L., Jr. 1969. An ecological study of the swift fox (Vulpes velox) in the Oklahoma panhandle. American Midland Naturalist 81:512-534.

KITCHEN, A. M., E. M. GESE, and E. R. SCHAUSTER. 1999. Resource partitioning between coyotes and swift foxes: space, time, and diet. Canadian Journal of Zoology 77:1645-1656.

MATLACK, R. S., P. S. GIPSON, and D. W. KAUFMAN. 2000. The swift fox in rangeland and cropland in western Kansas: relative abundance, mortality, and body size. Southwestern Naturalist 45:221-225.

OLSON, T. L. 2000. Population characteristics, habitat selection patterns, and diet of swift foxes in southeast Wyoming. Unpublished M. S. Thesis. University of Wyoming. Laramie, WY.

POLLOCK, K. S., S. R. WINTERSTEIN, C. M. BUNCK, AND P. D. CURTIS. 1989. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management 53:7-15.

POTTER, J. C. 1982. Endangered and threatened wildlife and plants; review of vertebrate wildlife for listing as endangered or threatened species. Federal Register 47:58454-58460.

ROELL, B. J. 1999. Demography and spatial use of swift fox (*Vulpes velox*) in northeastern Colorado. Unpublished M. A. Thesis. University of Northern Colorado. Greeley, CO.

SCHAUSTER, E. R. 2001. Swift fox (Vulpes velox) on the Pinon Canyon Maneuver site, Colorado: Population ecology and evaluation of survey methods. Unpublished

M. S. Thesis. Utah State University. Logan, Utah.

SOVADA, M. A., C. C. ROY, J. B. BRIGHT, and J. R. GILLIS. 1998. Causes and rates of mortality of swift foxes in western Kansas. Journal of Wildlife Management 62:1300-1306.

U. S. DEPARTMENT OF AGRICULTURE. 1973. Soil survey of Harding County, New Mexico. National Cooperative Soil Survey. Soil Conservation Service, Forest Service, and New Mexico Agricultural Experiment Station. U. S. Government Printing Office, Washington, D. C.

U. S. DEPARTMENT OF AGRICULTURE. 1982. Soil survey of Colfax County, New Mexico. National Cooperative Soil Survey. Soil Conservation Service, Forest Service, and New Mexico Agricultural Experiment Station. U. S. Government Printing Office, Washington, D. C.

WHITE, G. C., AND R. A. GARROTT. 1990. Analysis of Wildlife Radio-Tracking Data. Academic Press, San Diego, CA.

WRIGHT, P. L., AND R. RAUSCH. 1955. Reproduction in the wolverine, Gulo gulo. Journal of Mammalogy 36:346-355.

Zimmerman, A. L. 1998. Reestablishment of swift fox in north central Montana. Unpublished M. S. Thesis. Montana State University. Bozeman, MT

Table 1 - Weight and body size measurements of adult swift foxes in northeastern New Mexico. [a] $P \leq 0.05$.

	n	$\bar{x}$	SD	Minimum	Maximum	*t*	df	P
Weight (kg):								
Males	18	2.24	0.17	2.0	2.5	4.573	30	<0.001 [a]
Females	14	1.95	0.20	1.6	2.3			
Body length (mm):								
Males	17	521.6	18.1	485	550	3.532	32	0.001 [a]
Females	17	498.9	19.5	475	540			
Tail length (mm):								
Males	17	282.7	27.0	245	340	1.076	26	0.292
Females	17	274.5	15.9	245	302			
Body + Tail length (mm):								
Males	17	804.4	34.8	730	870	2.806	32	0.008 [a]
Females	17	773.4	29.2	725	830			
Hind foot length (mm):								
Males	17	121.4	3.2	115	127	3.435	32	0.002 [a]
Females	17	116.3	5.2	109	126			
Ear length (mm):								
Males	16	63.8	2.3	59	68	0.845	31	0.405
Females	17	63.1	2.8	57	68			

Table 2 - Estimates (S) and upper and lower confidence intervals of survival of swift fox in northeastern New Mexico.

	S	Lower C. I.	Upper C. I.
August 1, 1999, - August 1, 2000			
All foxes	0.48	0.27	0.70
All males	0.76	0.49	1.00
All females	0.22	0.00	0.44
All adults	0.64	0.37	0.90
Adult males	0.74	0.43	1.00
Adult females	0.38	0.00	0.79
August 1, 2000, - August 1, 2001			
All foxes	0.37	0.11	0.62
All males	0.41	0.05	0.77
All females	0.27	0.00	0.58
All adults	0.41	0.13	0.69
Adult males	0.44	0.07	0.82
Adult females	0.38	0.00	0.79

Table 3 - Characteristics of den sites of radiocollared swift foxes and random points (points) located within the home ranges of radiocollared swift foxes in northeastern New Mexico. [a] $P \leq 0.05$. Additional den site characteristics are described in RESULTS.

	n	$\bar{x}$	SD	Minimum	Maximum	*t*	df	P
Distance (km) to nearest anthropogenic site:								
Dens	106	1.05	0.59	0.12	3.00	1.059	210	0.291
Points	106	0.96	0.56	0.05	3.20			
Distance (km) to nearest primary road:								
Dens	106	0.66	0.59	0.00	3.11	-1.300	210	0.197
Points	106	0.77	0.65	0.14	3.01			
Distance (km) to nearest road, whether primary or secondary:								
Dens	106	0.37	0.36	0.00	1.44	-2.820	210	0.005 [a]
Points	106	0.51	0.34	0.00	1.40			
Distance (km) to nearest secondary road, if a secondary road was closer than the nearest primary road:								
Dens	39	0.36	0.33	0.00	1.32	-0.707	67	0.482
Points	30	0.41	0.25	0.00	1.07			
Length (km) of primary roads within 1 km:								
Dens	106	1.45	1.13	0.00	3.47	1.790	210	0.075
Points	106	1.19	1.04	0.00	3.59			
Length (km) of primary roads within 2 km:								

Dens	106	4.71	1.88	0.00	8.86	0.686	203	0.494
Points	106	4.51	2.26	0.00	13.20			
Length (km) of secondary roads within 1 km:								
Dens	106	0.90	0.87	0.00	2.99	4.102	188	< 0.001 [a]
Points	106	0.48	0.61	0.00	2.87			
Length (km) of secondary roads within 2 km:								
Dens	106	2.63	1.51	0.00	6.95	5.145	210	< 0.001 [a]
Points	106	1.56	1.52	0.00	8.02			
Slope (%):								
Dens	106	2.63	2.23	0.00	12.70	-1.997	196	0.047 [a]
Points	106	3.35	2.93	0.00	25.50			

Table 4 - Percentages of swift fox den sites and random points found within soil texture types in New Mexico. n = 106 for both den sites and random points.

	Den Sites (%)	Random Points (%)
clay	3.8	8.8
silty clay	0.0	0.3
clay loam	35.7	43.9
silty clay loam	10.2	8.8
sandy clay loam	7.5	10.8
loam	27.4	18.9
silt loam	1.2	1.4
sandy loam	9.4	3.8
caliche	4.7	3.3

Table 5 -Percent frequency of prey remains in swift fox scat in northeastern New Mexico.

	Annual	Spring	Summer	Fall	Winter
n	385	148	45	50	142
Mammals	45.7	33.8	51.1	40.0	54.9
Heteromyidae					
Dipodomys	22.0	20.9	17.8	22.0	24.6
Perognathus	2.3	2.0	2.2	6.0	1.4
Muridae					
Microtus	3.6	1.4	6.7	10.0	2.1
Neotoma	0.3	0.0	0.0	0.0	0.7
unidentified	2.3	1.4	8.9	2.0	1.4
Sciuridae					
Spermophilus	0.8	1.4	0.0	0.0	0.7
Leporidae	11.4	5.4	4.4	0.0	23.9
Unidentified	0.5	1.4	0.0	0.0	0.0
Invertebrates	72.6	80.4	75.6	82.0	62.0
Coleoptera	16.0	12.2	51.1	22.0	7.7
Diptera	0.5	0.7	0.0	0.0	0.7
Orthoptera	56.1	67.6	24.4	60.0	53.5
Birds	19.6	26.7	37.8	16.0	7.0
Passeriformes					

Sturnella	0.3	0.7	0.0	0.0	0.0
unidentified	1.8	2.7	0.0	0.0	2.8
Piciformes	0.8	0.0	0.0	0.0	2.1
Unidentified	16.8	23.6	37.8	16.0	2.8
Carrion					
Antilocapra americana	0.8	0.7	2.2	0.0	0.7
Vegetation					
grass	2.8	4.0	0.0	2.0	1.4
unidentified seeds	0.3	0.0	0.0	0.0	0.7
Reptiles					
Serpentes	0.3	0.0	4.4	0.0	0.0
Feces					
rabbit pellets	1.3	0.7	2.2	0.0	2.1
rodent pellets	0.3	0.0	0.0	0.0	0.7
Other					
paper & string	0.6	0.7	0.0	0.0	0.7
sand	3.6	4.0	15.5	2.0	0.0

Fig. 1. Age distribution of radiocollared swift foxes in New Mexico when captured (n = 20), at death (n = 20), and at the time of maximum number of study animals alive (May, 1999; n = 16).

Fig. 2. Weight and age of male swift foxes in New Mexico.

Fig. 3. Weight and age of female swift foxes in New Mexico.

Fig. 4. Average adaptive kernel and minimum convex polygon home range size of swift foxes in New Mexico as a function of number of relocation points. The sample size of foxes is also indicated.

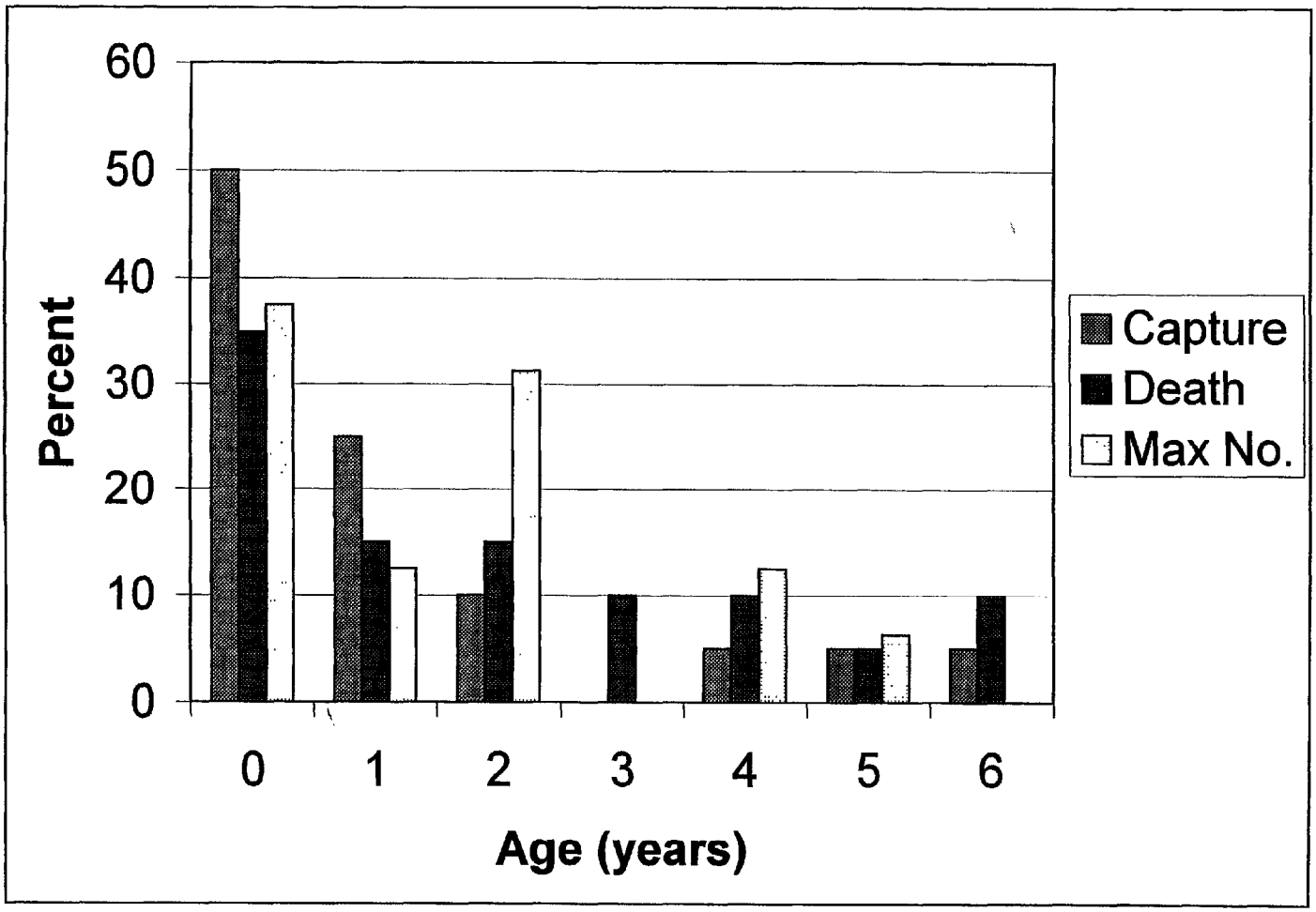
60
50
40
30
20
10
0
Percent
0
1
2
3
4
5
6
Age (years)
Capture
Death
Max No.

Figure 1.

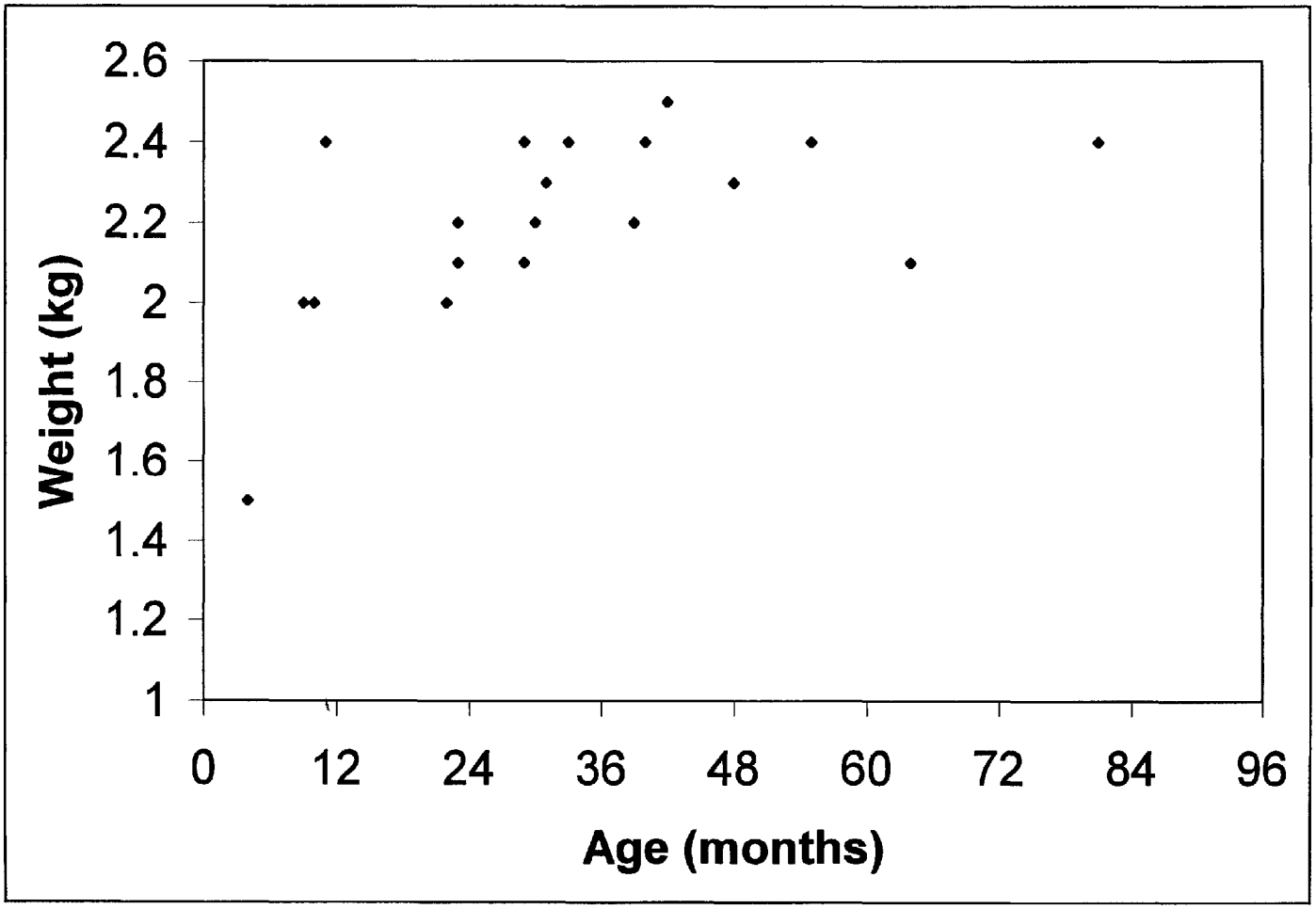
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
Weight (kg)
0
12
24
36
48
60
72
84
96
Age (months)

Figure 2.

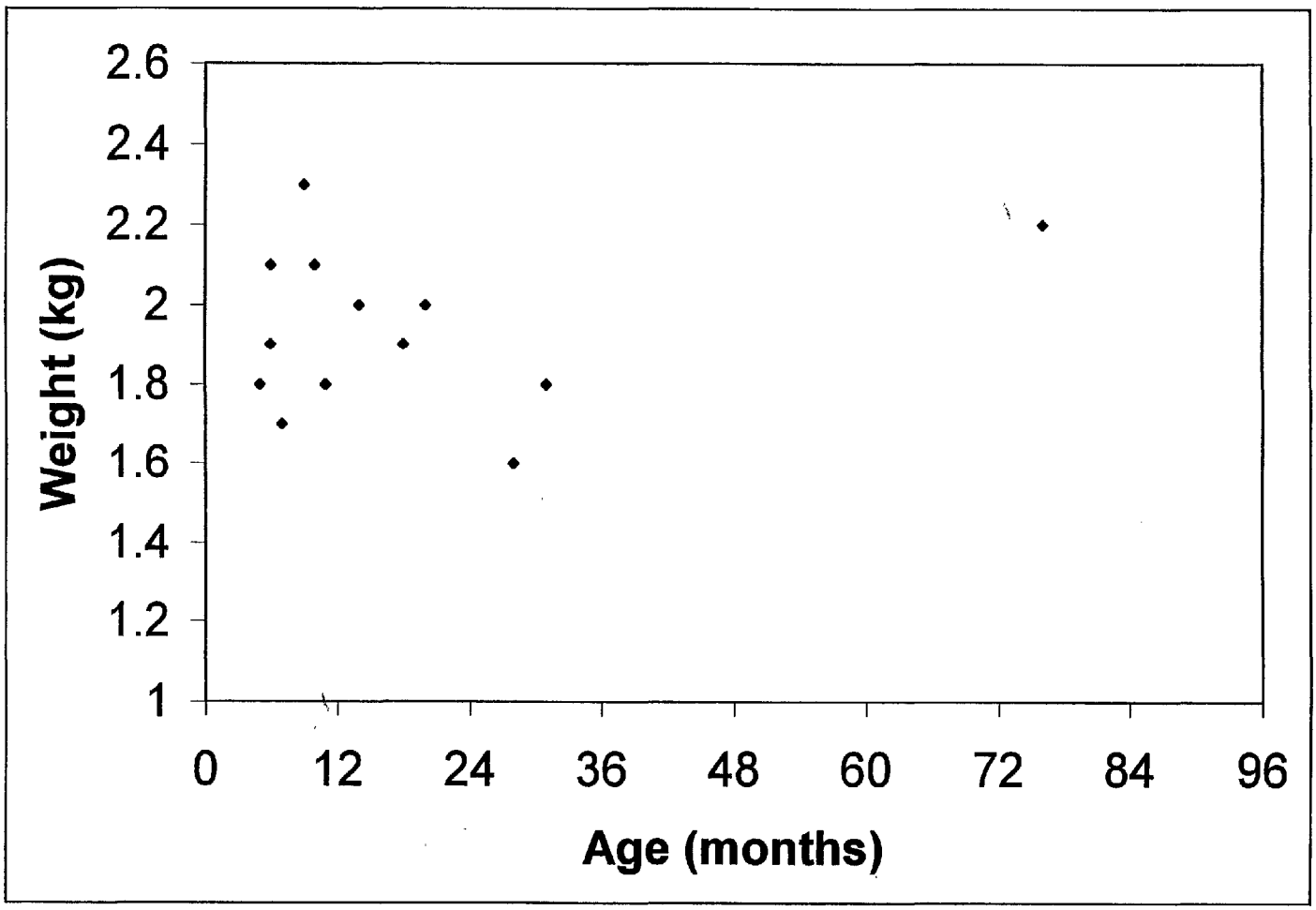
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
Weight (kg)
0
12
24
36
48
60
72
84
96
Age (months)

Figure 3.

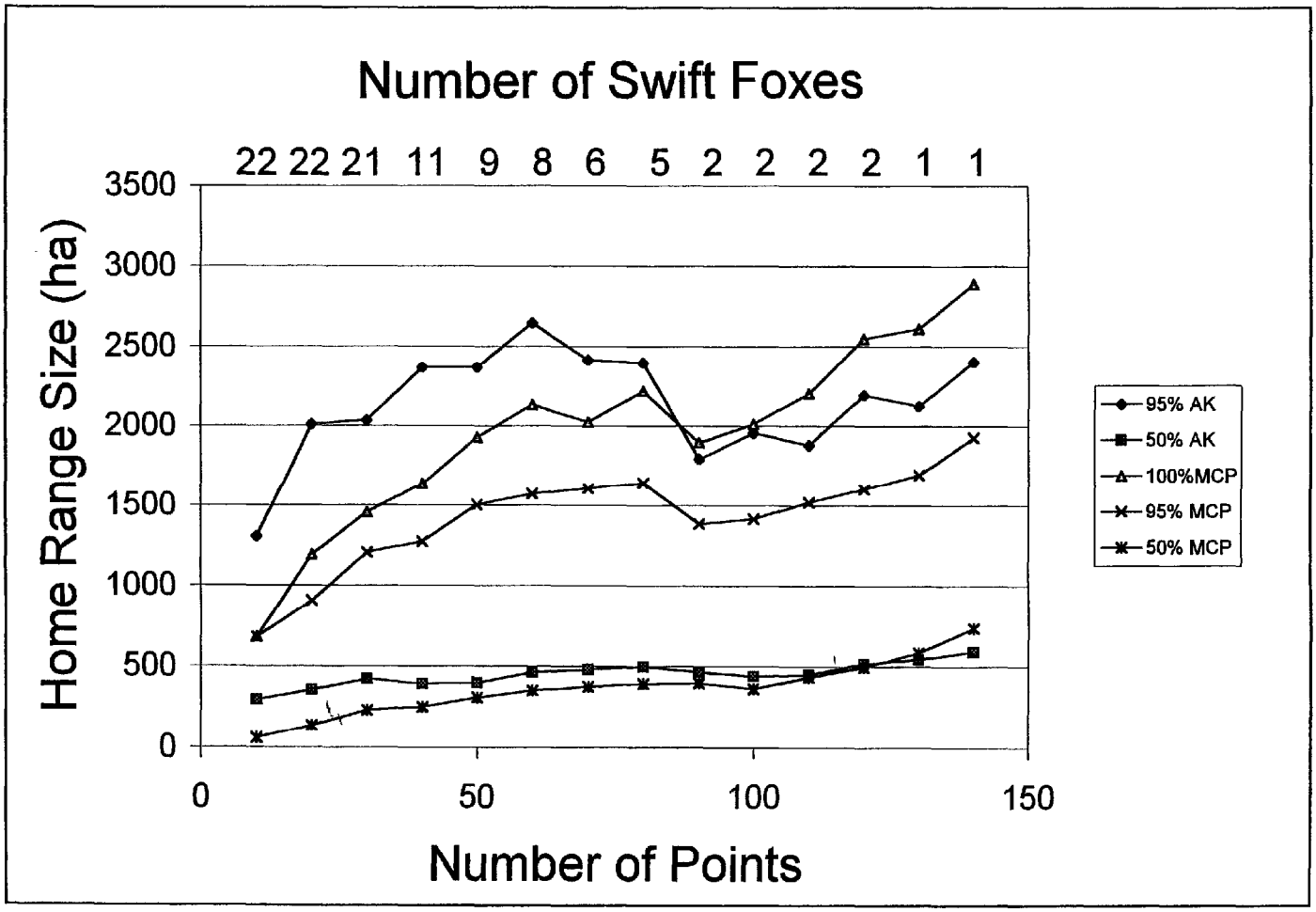
Number of Swift Foxes
22 22 21 11 9 8 6 5 2 2 2 2 1 1
Home Range Size (ha)
3500
3000
2500
2000
1500
1000
500
0
0
50
100
150
Number of Points
95% AK
50% AK
100%MCP
95% MCP
50% MCP

Figure 4.