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# SWIFT FOXES IN SOUTHWESTERN SOUTH DAKOTA:

# ASSESSING THE CURRENT STATUS OF A REINTRODUCED POPULATION


BY

SARAH ANN NEVISON


A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Wildlife and Fisheries Science

Specialization in Wildlife Sciences

South Dakota State University

2017

SWIFT FOXES IN SOUTHWESTERN SOUTH DAKOTA:

ASSESSING THE CURRENT STATUS OF A REINTRODUCED POPULATION

SARAH ANN NEVISON

This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science in Wildlife and Fisheries Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Dr. Jonathan A. Jenks, Ph.D. Date
Thesis Advisor

Dr. Michele R. Dudash, Ph.D. Date
Head, Department of Natural
Resource Management

Dean, Graduate School Date

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*"In the end, we will conserve only what we love;*

*we will love only what we understand;*

*and we will understand only what we are taught."*

*-Baba Dioum*

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# ABSTRACT

SWIFT FOXES IN SOUTHWESTERN SOUTH DAKOTA:

ASSESSING THE CURRENT STATUS OF A REINTRODUCED POPULATION

SARAH ANN NEVISON

2017

Swift foxes (*Vulpes velox*) were reintroduced into Badlands National Park between 2003 and 2006 after being nearly extirpated from South Dakota in the early 1900's. Genetic analysis provided strong evidence that the reintroduction was successful, but viability analysis indicated the population may be in jeopardy with a high probability of extinction. Recently, the population has declined due to various biotic and abiotic factors (e.g., recent weather patterns, effects of plague [*Yersinia pestis*], and increased coyote [*Canis latrans*] numbers). No information on the status of swift foxes has been collected since 2009. Between 2014 and 2016, the objectives of this study were to 1) document the current distribution of swift foxes in southwestern South Dakota; 2) estimate survival and cause-specific mortality; 3) document active dens to estimate reproductive success; and 4) assess the presence of swift foxes in areas affected by plague. Over 1,000 scent stations were deployed across a seven county area in southwest South Dakota; only 1.7% of the stations detected swift foxes, and in only two counties. Foxes were not detected in two of the counties that had presence within the last ten years. Forty-six swift foxes were trapped, radio-collared, and tracked around Badlands National

Park, and 12 natal dens were monitored. Yearly reproductive success was estimated using motion activated trail cameras, and averaged 4.3 ± 0.3 pups per mated pair. Natal dens had more holes (4.4 ± 0.7) than non-natal dens (2.2 ± 0.4) and were closer to roads (160.9 ± 57.0 m) and closer to anthropogenic features (105.8 ± 36.5 m) than random locations (roads: 557.4 ± 155.1 m; anthropogenic 341.2 ± 67.2 m). An additional objective 5) was added when pups from two orphaned dens were hand reared in an accredited zoo and subsequently returned to their natal dens; none of the foxes survived to become adults after release. Survival was estimated using the Kaplan-Meier procedure for staggered entry; apparent annual survival for collared adults was 0.51 (95% CI = 0.24–0.69; $n$ = 14), and for collared pups was 0.19 ($n$ = 8). Cause-specific mortality of collared foxes was attributed to vehicle collision ($n$ = 7; 33.3%), coyote ($n$ = 7; 33.3%), raptor ($n$ = 3; 14.3%), and unknown origin ($n$ = 4; 19.1%). Antibodies to *Y. pestis* were found in 69.9% of sampled foxes using enzyme-linked immunosorbent assay (ELISA) analysis. Data from this study raises concern for the status of the population. An apparent decline in distribution, a decline in numbers around Badlands National Park, a decreased survival rate in pups, and the presence of plague may lead this population to extinction in the near future. Another reintroduction is not recommended until biotic and abiotic factors correlated to the decline are mitigated and swift fox presence is determined in other regions of South Dakota.

# CHAPTER 1

# PRESENCE OF SWIFT FOXES (*VULPES VELOX*) IN SOUTHWESTERN SOUTH DAKOTA

## ABSTRACT

Reintroduction efforts to restore swift foxes (*Vulpes velox*) to their historic range in South Dakota have occurred in four locations since 2002. The current status of the species in southwest South Dakota is unknown, but has likely declined due to various biotic and abiotic factors. I used scent station surveys and live trapping to estimate presence of swift foxes in the seven southwest counties of the state. I focused heavily around Badlands National Park where 114 foxes were reintroduced between 2003 and 2006. Swift foxes were only detected on 18 of 1,070 (1.7%) scent stations, on three of 26 transects (11.5%), and in only two counties: Pennington and Fall River. A total of 46 individual foxes were live trapped in the focal area around Badlands National Park, with two additional foxes trapped in Fall River County. Foxes were present in Pennington, Jackson, Oglala Lakota, and Fall River counties, but there were no detections in Haakon, Bennett, or Custer counties, where historic accounts are present. This reduction in swift fox distribution in the seven counties, and decrease in swift fox presence around Badlands National Park, raises concerns for the viability of the species in this part of the state. Another reintroduction is not recommended until biotic and abiotic factors correlated to the decline are mitigated, and swift fox presence is determined in other regions of South Dakota.

## INTRODUCTION

The swift fox (*Vulpes velox*), once abundant throughout the Great Plains of North America, was nearly extirpated by the 1900’s due to habitat conversion, unregulated trapping, and poisoning programs (Kilgore 1969, Egoscue 1979, Carbyn 1994, Allardyce 2003). Precluded from listing by the U.S. Fish and Wildlife Service in 1994, the swift fox is listed as state threatened in South Dakota, having historically inhabited the entire state except for the easternmost counties (Egoscue 1979). Currently, a native remnant population inhabits the extreme southwestern corner of the state in Fall River County, and four reintroduction efforts occurred between 2002 and 2010 in South Dakota, west of the Missouri River, in an effort to bolster populations.

The Turner Endangered Species Fund initiated a swift fox reintroduction program on Bad River Ranches (BRR, Stanley and Jones counties) and in Haakon County in west-central South Dakota in 2002, releasing 179 translocated foxes from Wyoming over six years (Sasmal et al. 2015). Concurrently, between 2003 and 2006, Badlands National Park, in southwestern South Dakota, released 114 foxes translocated from Wyoming and Colorado (Schroeder 2007). Similarly, the Lower Brule Sioux Tribe (LBST) in west-central South Dakota reintroduced 119 foxes from Kansas between 2006 and 2009 (S. Grassel, LBST, personal communication), and the Oglala Sioux Parks and Recreation Authority (OSPRA) translocated 79 swift foxes from Colorado and Wyoming to their lands in southwestern South Dakota, south of Badlands National Park in 2009 and 2010 (Goodman et al. 2012).

Currently, there are no swift fox reintroduction efforts conducted on BRR or in Haakon County, with the most recent confirmed detection being a mortality in 2007 (D. Schwalm, TESF, personal communication). LBST does not have a swift fox monitoring program, though there were two confirmed mortalities in 2015 (S. Grassel, LBST, personal communication). The reintroductions by TESF and LBST did not establish a sustaining population, based on comments from individuals involved (Stratman 2015). OSPRA monitors swift foxes annually in the fall via spotlighting and trapping, but the population does not seem to be as robust compared to shortly after reintroduction (R. Goodman, OSPRA, personal communication). Staff at Badlands National Park surveyed Fall River County most recently in 2010, trapping 31 foxes in five days (G. Schroeder, National Park Service, personal communication). Three graduate students were intensely studying swift foxes around Badlands National Park from 2003 to 2009 (Russell 2006, Schroeder 2007, Sasmal 2011), and there were attempts by the National Park Service to annually trap for foxes in this population each fall, but no information on the status of swift foxes around Badlands National Park has been collected since 2009.

Genetic analysis provided strong evidence that the reintroduction of swift foxes around Badlands National Park between 2003 and 2006 was successful (Sasmal et al. 2013), but further analysis indicated the long-term viability of the population may be in jeopardy, with a high probability of extinction given current mortality rates (Sasmal 2011, Sasmal et al. 2016). There has been an apparent decline in this local population since reintroduction, which is likely due to several biotic and abiotic factors (e.g., effects of plague [*Yersinia pestis*], recent weather patterns, and increased coyote [*Canis latrans*] abundance). In 2008, sylvatic plague was detected in Conata Basin, immediately south of Badlands National Park, and is now present throughout western South Dakota. No comprehensive information on the status of swift foxes in southwestern South Dakota has been collected since the viability analysis was conducted by Sasmal (2011), which was based on data collected pre-colonization of plague.

Therefore, in 2014 I began a two-year research project to assess the current status of reintroduced swift fox around Badlands National Park and southwestern South Dakota. My objective was to estimate presence/absence of foxes in previously occupied areas in the seven southwest counties of South Dakota, with intense effort focused on the Badlands population. I used strategically placed scent stations and live trapping to confirm presence. Scent station surveys have reliably detected swift fox presence in studies across the country (e.g., Harrison et al. 2002, Schauster et al. 2002, Sargeant et al. 2003). Live trapping is a definitive method to confirm presence of swift foxes and provides additional information about population dynamics when trapped animals are radio-collared (Harrison et al. 2002, Schauster et al. 2002, Finley et al. 2005).

**STUDY AREA**

My study was conducted at two scales: intense effort and focus around Badlands National Park and surrounding Buffalo Gap National Grassland, hereafter, focal area (Figure 2), and broader effort in the seven southwest counties of South Dakota, hereafter, broad area (Figure 1). I monitored the population in the focal area continuously from May 2014 to August 2016, whereas I monitored the broad area during the time I deployed scent stations. I investigated reports of swift foxes outside of the focal area as they came to my attention.

The seven county broad study area in southwestern South Dakota included Bennett, Custer, Fall River, Haakon, Jackson, Oglala Lakota (formerly Shannon), and Pennington counties (Figure 1). The 2,600 $km^2$ focal study area included the North Unit of Badlands National Park and the surrounding area (Figure 2). Seventeen percent of the area was managed by the National Park Service, 36% by the United States Forest Service (Buffalo Gap National Grassland), and 47% was privately owned. Much of the surrounding land was used for cattle ranching, which is the major industry in the region (Schroeder 2007). The area has a continental climate with a mean annual precipitation of

40 cm. Temperatures vary between -23° C and 42° C. Elevation ranges from 691 to 989 m above mean sea level (Russell 2006). Soils in the study area are composed mostly of midway clay loam with a low water holding capacity (Whisenant and Uresk 1989). Badlands National Park is comprised of rugged geologic formations (e.g., buttes and pinnacles) along a wall running northwest to southeast through the North Unit of the park. On either side of the wall topography is flat to rolling mixed-grass prairie, dominated by buffalograss (*Buchloe dactyloides*), western wheatgrass (*Pascopyrum smithii*), and prickly pear cactus (*Opuntia polyacantha*), with minimal tree and brush species (Russell 2006).

## METHODS

*Scent stations:*

I deployed scent stations from February to April in 2015 and 2016, and September to December in 2015. The timing of scent stations aligned with the dispersal (September to December) and mating seasons (December to April) of swift foxes in this population, to maximize the chance of detections (Roughton and Sweeny 1982, Sargeant et al. 2003, Tannerfeldt et al. 2003). Surveyed areas were chosen based on previous swift fox reports or occupancy data, within suitable habitat, and were placed along roads (paved, gravel, or two-track) every 800 meters (0.5 mile), averaging 15 stations per transect (Roughton and Sweeny 1982, Dateo et al. 1996, Harrison et al. 2002).

The scent station technique consisted of identifying animal tracks found at baited locations made of cleared and maintained sand. The scent station sand was made by thoroughly mixing 22.7 kg (50 lbs) of fine silica sand (Granusil Industrial Quartz, Unimin Corporation, Ottawa, MN) with 3 cups of vegetable oil. I set scent stations by first clearing a 50 cm diameter circle of vegetation using a mattock tool, then smoothing approximately four liters (one gallon) of the sand mixture into the 50 cm circle with a plastic mortar trowel. I baited stations with approximately 57 grams (2 oz) of mashed Chicken of the Sea® Chub Mackerel in the late afternoon or evening to limit insect consumption and desiccation due to sun and wind. I maintained transects for three consecutive nights, or extended by one day for every day weather prevented accurate detections (i.e., rain). I checked stations in the morning and identified tracks. I took photos of all swift fox tracks and all unknown detections, and later verified or identified via Poppele (2012) and via personal communications with J. Evans (naturetracking.com). Tracks were identified to species when possible, but all small mammal detections (e.g., mice, voles) were classified as Rodentia and all bird detections were classified as Aves. If I detected swift foxes at a scent station, I subsequently trapped the area in an effort to collar individuals in the focal area or collect samples in the broad area.

*Trapping:*

I trapped foxes from May to November 2014 and May to September 2015 using 81.3 x 25.4 x 30.5 cm Tomahawk Live Traps (Professional Series model 108SS, Tomahawk, WI) with 2.5 x 1.3 cm, 14 gauge wire mesh. Traps were set in transects placed along roads or fence lines in areas with previous swift fox detections, or in suitable habitat, and were baited with quartered black-tailed prairie dog (*Cynomys ludovicianus*). I set traps shortly before sundown (1800–2000) and checked them shortly after sunrise (0500–0700), except for traps set in May and June, when traps were checked twice per night (2400–0100 and 0500–0700) because of the dependence of pups on lactating mothers (Egoscue 1962, Kilgore 1969). I removed traps in the morning and reset in the evening for a total of three consecutive nights. Incidental animal bycatch was released unharmed.

Trapped foxes were coaxed into a canvas sack, weighed (model 80210, Pesola® Macro-Line Spring scale, Baar, Switzerland), and scanned with an AVID PowerTracker (Avid Identification Systems, Inc., Norco, CA) to identify previously captured foxes that had been marked with PIT tags. Foxes were scruffed and physically restrained with thick leather gloves with one hand covering the eyes and ears, to minimize visual and auditory stimulation, and held with mouth closed to prevent bites. I recorded sex and body condition and aged foxes (pup < 1 year old; or adult ≥ 1 year old) based on tooth wear. Unmarked animals were PIT tagged (AVID FriendChip, Avid Identification Systems, Inc., Norco, CA) between the scapulae, and samples of blood, fleas, ticks, and hair were collected. VHF radio collars (M1830 40g, Advanced Telemetry Systems, Isanti, MN) equipped with 8 hour mortality sensors, were then attached. I released animals where they were captured to minimize stress. Animal trapping and handling methods were approved by the Institutional Animal Care and Use Committee at South Dakota State University (approval number 14-020A) and under compliance with the National Park Service (permit number BADL-2014-SCI-0020, and BADL-2014-SCI-0031.)

**RESULTS**

I deployed a total of 1,070 scent stations spanning 437.2 linear kilometers of the entire study area (Figure 1). Forty-six percent of stations were placed on gravel roads, 28% along paved roads, and 26% along two tracks. I deployed eight transects in Pennington County, four in Jackson County, four in Haakon County, three in Bennett

County, three in Custer County, two in Fall River County, and two in Oglala Lakota County (Table 1; Figure 1).

I detected swift foxes on 18 of 1,070 (1.7 %) scent stations, in Pennington (*n* = 9) and Fall River (*n* = 9) counties only (Table 1). Swift foxes were detected on three of 26 transects (11.5%), two transects in Pennington county and one transect in Fall River County. The most common detections were Rodentia (*n* = 459, 42.9%), Aves (*n* = 152, 14.2%), striped skink (*Mephitis mephitis*; *n* = 81, 7.6 %), and cottontail rabbit (*Sylvilagus* spp.; *n* = 62, 5.8 %; Table 2). Other species included domestic dog (*Canis lupus familiaris*; *n* = 22), domestic cat (*Felis catus*; *n* = 18), red fox (*Vulpes vulpes*; *n* = 14), raccoon (*Procyon lotor*; *n* = 12), American badger (*Taxidea taxus*; *n* = 10), coyote (*Canis latrans*; *n* = 8), cattle (*Bos taurus*; *n* = 6), deer (*Odocoileus* spp.; *n* = 3), horse (*Equus ferus caballus*; *n* = 2), and North American porcupine (*Erethizon dorsatum*; *n* = 1; Table 2).

Forty-eight foxes were captured during 1,711 trap nights over 52 days (0.92 foxes/day; Figure 2; Table 3). In 2014, I captured 24 individual foxes during 1,353 trap nights across 37 days (0.65 foxes/day): 10 pups and 14 adults. In 2015, I captured 24 new individual foxes during 358 trap nights spanning 15 days (1.60 foxes/day): 18 pups and 6 adults. Forty-six of the 48 foxes were trapped within the focal area (i.e., Pennington and Jackson counties), while the remaining two foxes were trapped in Fall River County after scent stations confirmed fox presence. Trap bycatch included *M. mephitis* (*n* = 17), *Sylvilagus* spp. (*n* = 4), *E. dorsatum* (*n* = 2), *F. catus* (*n* = 2), *C. lupus familiaris* (*n* = 1), and *Athene cunicularia* (*n* = 1).

*Pennington County: PRESENT*

Scent Stations- Swift foxes were detected. In Pennington County, eight transects were set covering 97.4 km for 303 trap nights. A total of nine swift fox detections were documented on two transects (Table 1).

Live Trapping- Swift foxes were trapped for 739 trap nights spanning 19 days in 2014 resulting in nine individuals (0.47 foxes/day), and for 270 trap nights spanning 10 days in 2015 resulting in 19 individuals (1.90 foxes/day; Table 3).

*Jackson County: PRESENT*

Scent Stations- Swift foxes were not detected. In Jackson County, four transects were set covering 61.0 km for 168 trap nights. No swift fox detections were documented (Table 1). Trapping subsequently occurred because of visual observations of swift foxes.

Live Trapping- Swift foxes were trapped for 614 trap nights spanning 18 days in 2014 resulting in 15 individuals (0.83 foxes/day), and for 28 trap nights spanning 2 days in 2015 resulting in three individuals (1.50 foxes/day; Table 3).

An additional five foxes were observed at an active den in 2014, but no foxes were trapped after repeated attempts.

*Fall River County: PRESENT*

Scent Stations- Swift foxes were detected. In Fall River County, two transects were set covering 39.0 km for 65 trap nights. A total of nine swift fox detections were documented on the transects (Table 1).

Live Trapping- Swift foxes were trapped for 60 trap nights spanning 3 days in 2015 resulting in two individuals (0.67 foxes/day; Table 3).

An additional 5 foxes were detected via remote trail camera in 2015, but no foxes were trapped after two attempts.

*Oglala Lakota County: PRESENT*

Scent Stations- Swift foxes were not detected. In Oglala Lakota County, two transects were set covering 30.1 km for 96 trap nights. No swift fox detections were documented (Table 1).

Live Trapping- Swift fox trapping was conducted by Oglala Sioux Parks and Recreation Authority during September 2015; one individual was captured. This fox was not included in the statistics and totals for this study because I was not involved in the trapping or processing of the fox, but the capture confirmed presence of swift foxes in this county during my study.

*Haakon County: ABSENT*

Scent Stations- Swift foxes were not detected. In Haakon County, four transects were set covering 83.6 km for 192 trap nights. No swift fox detections were documented (Table 1).

Live Trapping- This county was not trapped because no swift foxes were documented via scent stations nor via confirmed observations. The last confirmed swift fox in Haakon County was a mortality documented in December 2007 by the Turner Endangered Species Fund (D. Schwalm, TESF, personal communication). Unconfirmed reports by locals are as recent as 2016 (J. Hansen, personal communication).

*Bennett County: ABSENT*

Scent Stations- Swift foxes were not detected. In Bennett County, three transects were set covering 51.8 km for 128 trap nights. No swift fox detections were documented (Table 1).

Live Trapping- This county was not trapped because no swift foxes were documented via scent stations nor via confirmed observations. The last confirmed swift fox in Bennett County was a den in 2006 by OSPRA (R. Goodman, OSPRA, personal communication). Unconfirmed reports by locals are as recent as 2015.

*Custer County: ABSENT*

Scent Stations- Swift foxes were not detected. In Custer County, three transects were set covering 74.3 km for 118 trap nights. No swift fox detections were documented (Table 1).

Live Trapping- This county was not trapped because no swift foxes were documented via scent stations nor via confirmed observations. The only confirmed swift fox in Custer County was a collared fox by OSPRA in 2013 (T. Ecoffey, OSPRA, personal communication). This is the only documented swift fox in Custer County, South Dakota.

**DISCUSSION**

This study had low swift fox detection rates. It is possible some foxes went undetected; Sargeant et al. (2003) found evidence of swift foxes visiting scent stations that did not leave identifiable tracks. One way to overcome this constraint could be to use motion activated trail cameras, which would document foxes even if they did not leave tracks. I do not believe cameras would have increased detection rates, but it would have allowed me to cover more of the study area by allowing me time to set up additional transects. Some scent stations were over 160 km from my home base and I drove to these areas for four consecutive days (one to set and three to check). Given these potential constraints, I recommend against using scent stations and instead using camera surveys with lures to monitor swift foxes in the future. Although the upfront cost of motion activated trail cameras is high, the benefits are great, including one time set-up, continuous monitoring in all weather, more positive identification of visitors via multiple photos as opposed to tracks (Knox and Grenier 2010), and ability to monitor for longer periods of time. Camera surveys reduce the amount of time spent driving to the same location daily, increasing the potential for researchers to cover more area by setting out more camera stations than possible with scent stations. Stratman and Apker (2014) found an improvement in the precision of their occupancy estimates of swift foxes using infrared cameras compared to mark-recapture surveys of the same area. Cameras also provide temporal information, not known with scent stations. Finally, camera stations have been used to successfully detect swift foxes in northwestern South Dakota (E. Mitchell, South Dakota State University, personal communication).

The success rate of trapping foxes increased from 2014 to 2015. In 2014, I averaged 0.65 foxes/day (24 foxes/37 days), whereas I averaged 1.60 foxes/day (24 foxes/15 days) in 2015. That was a 246% increase in foxes per day from 2014 to 2015; I caught the same number of foxes in 2015 but required 40% less time to do so compared to 2014. I attribute this to increased awareness of swift fox locations via observations and local reports in the focal area, as well as improved methods for trapping foxes. In 2015, I had 100% success rate in trapping all known pups at dens by first ‘pre-baiting’ and then trapping the following night. For ‘pre-baiting’, I set out traps in a 10 m vicinity of the natal den, used nylon cable ties to lock doors in an open position, and baited half of the traps with quartered prairie dog. The following day, I cut the nylon cable ties, and baited and set all of the traps. I believe this greatly increased my success in trapping pups because it allowed the pups to familiarize themselves with the traps and reduce trap shyness with the baited and locked open doors. I highly recommend this ‘pre-baiting’ technique in areas where the locations of natal dens are known.

I confirmed presence of swift foxes in four of the seven southwest counties of South Dakota. Of the three counties where swift foxes were not detected, Haakon and Bennet counties had confirmed swift fox presence (reintroductions and/or active dens) in the last ten years, whereas Custer County had only one confirmed swift fox detection. This reduction in swift fox distribution raises concerns for the viability of the species in this part of the state. Especially concerning is the lack of swift fox detections in Haakon County, where a reintroduction occurred in the late 2000’s by the TESF. Much of the previously occupied areas of Haakon County still contain suitable habitat such as short native grassland or pasture land, and presence of suitable prey (e.g., small mammals, birds, and rabbit detections from scent stations). I detected coyote presence on three scent stations (1.6% of stations set in Haakon), which may be a factor leading to the extirpation of foxes in this county, because coyotes are known to kill swift foxes (e.g., Karki et al. 2007).

Additionally, swift foxes were detected in northwestern South Dakota (Stratman 2015, E. Mitchell, South Dakota State University, personal communication), though a reintroduction never occurred in this region. It is plausible that foxes from the TESF reintroduction dispersed to this part of the state (Stratman 2015). Long-distance dispersals between populations have been recorded on tagged swift foxes in South Dakota, and through genetic analysis. Sasmal et al. (2013) found genetic connectedness between the Badlands and Fall River County populations, and documented a collared fox from the Badlands population in the area of the Fall River County population, approximately a 100 km straight line distance away. Two foxes from the BRR population were detected in the Badlands population, distances dispersed of 100 and 126 km (Sovada et al. 2006). Additionally, a collared fox from the Badlands population was identified on LBST lands in 2015, a distance traveled of 217 km (personal observation, unpublished data).

The distribution and number of swift foxes around Badlands National Park and surrounding Buffalo Gap National Grassland has declined since 2009, when 177 pups were documented at 51 dens (G. Schroeder, National Park Service, personal communications). Areas that were previously inhabited by swift foxes were heavily surveyed with scent stations and live trapping, yet I only documented a total of 51 foxes (adults and pups) at 12 dens during 2014 and 2015. Only 14 foxes were known to remain alive when my study concluded in August 2016, 8 adults and 6 pups. A population viability analysis was performed in 2009 for the foxes around Badlands National Park based on the population conditions documented between 2003 and 2009 (Sasmal 2011). Results indicated a 100% chance of extinction within 10 years. Based on this drastic decrease in swift fox presence around Badlands National Park, I postulate that the population is still under threat of extinction.

Results from this study support the hypothesis that the apparent decline in swift foxes is related to biotic and abiotic factors. Recent weather patterns have included high precipitation (Amberg et al. 2012) leading to tall vegetation, which may impair fox visibility (Russell 2006). During the swift fox reintroduction, sarcoptic mange was present in the local coyote population, but has since recovered (E. Childers, National Park Service, R. Griebel, United States Forest Service, and G. Schroeder, National Park Service, personal communications). This potential increase in coyote numbers would likely have negative effects on the swift fox population, because coyotes are a known predator of foxes. Additionally, sylvatic plague is still present in prairie dog colonies in and around Badlands National Park (Livieri 2013, Mize and Britten 2016), resulting in great than a 60% reduction in prairie dog acreage within the park since the epizootic began in 2008 (Livieri 2013, E. Childers, National Park Service, personal communication). Swift foxes use prairie dog burrows for denning and prey on individuals for food (Russell 2006) so a reduction in prairie dog abundance would plausibly have a negative effect on the swift fox population.

## MANAGEMENT IMPLICATIONS

I strongly recommend continued swift fox surveys around Badlands National Park and the seven southwest counties of South Dakota. Live trapping allows for various samples to be collected and to potentially radio-collar and relocate foxes. If this is fiscally or temporally unavailable, motion activated trail cameras with scent lures should be used to document swift fox presence. There has been an evident reduction of swift fox numbers around Badlands National Park, and a decrease in swift fox presence throughout this area of the state. However, there is still an extant population of swift foxes present in Fall River County, and I recommend studying the population characteristics and habitat suitability of this population to better understand how and why this population was never extirpated. The reduction in swift fox distribution and decrease in swift fox presence raises concerns for the viability of the species in this part of the state. I do not recommend another reintroduction until biotic and abiotic factors correlated to the decline are mitigated, and swift fox presence is determined in other regions of South Dakota.

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**Table 1:** Swift fox detections on scent station transects in the seven southwest counties of South Dakota, 2014–2015. Swift foxes were detected on 18 of 1,070 scent stations (1.7%), 3 of 26 transects (11.5%), and in only Pennington and Fall River counties.

| County | Linear km | Scent Station Trap Nights | No. of Transects | No. of Swift Fox Detections |
|---|---|---|---|---|
| Pennington | 97.4 | 303 | 8 | 9 |
| Jackson | 61.0 | 168 | 4 | 0 |
| Fall River | 39.0 | 65 | 2 | 9 |
| Oglala Lakota | 30.1 | 96 | 2 | 0 |
| Haakon | 83.6 | 192 | 4 | 0 |
| Bennett | 51.8 | 128 | 3 | 0 |
| Custer | 74.3 | 118 | 3 | 0 |
| **TOTAL** | **437.2** | **1070** | **26** | **18** |

**Table 2**: Species detections on scent station transects deployed in southwestern South Dakota, 2014–2015. Swift foxes were detected on 18 of 1,070 stations (1.7%), in only 2 counties.

| Species | Total Station Detections | Detection Rate (1,070 stations) | Number of Counties (*n* = 7) |
|---|---|---|---|
| Rodentia | 459 | 42.9% | 7 |
| Aves | 152 | 14.2% | 7 |
| *M. mephitis* | 81 | 7.6% | 7 |
| *Sylvilagus* spp. | 62 | 5.8% | 6 |
| *C. lupus familiaris* | 22 | 2.1% | 5 |
| *F. catus* | 18 | 1.7% | 5 |
| *V. velox* | 18 | 1.7% | 2 |
| *V. vulpes* | 14 | 1.3% | 2 |
| *P. lotor* | 12 | 1.1% | 5 |
| *T. taxus* | 10 | 0.9% | 4 |
| *C. latrans* | 8 | 0.7% | 5 |
| *B. taurus* | 6 | 0.6% | 5 |
| *Odocoileus* spp. | 3 | 0.3% | 1 |
| *E. ferus caballus* | 2 | 0.2% | 1 |
| *E. dorsatum* | 1 | 0.1% | 1 |

**Table 3**: Trapping effort targeted at swift foxes in southwestern South Dakota, 2014–2015. A total of 48 individual foxes were trapped in 1,711 trap nights. Trapping success increased from 2014 to 2015.

| County | Year | No. of Days | Trap Nights | No. Trapped | Individuals | Foxes / Day |
|---|---|---|---|---|---|---|
| Pennington | 2014 | 19 | 739 | 11 | 9 | 0.47 [a] |
| Pennington | 2015 | 10 | 270 | 19 | 19 | 1.90 [b] |
| Jackson | 2014 | 18 | 614 | 16 | 15 | 0.83 [a] |
| Jackson | 2015 | 2 | 28 | 3 | 3 | 1.50 [b] |
| Fall River | 2015 | 3 | 60 | 2 | 2 | 0.67 [b] |
| **TOTAL** | | **52** | **1711** | **51** | **48** | |

[a] – 2014 averaged 0.65 foxes/day (24 foxes/37 days)

[b] – 2015 averaged 1.60 foxes/day (24 foxes/15 days)

**Figure 1**: Locations of scent station transects deployed across the seven southwest counties of South Dakota, "broad area," 2014–2015.

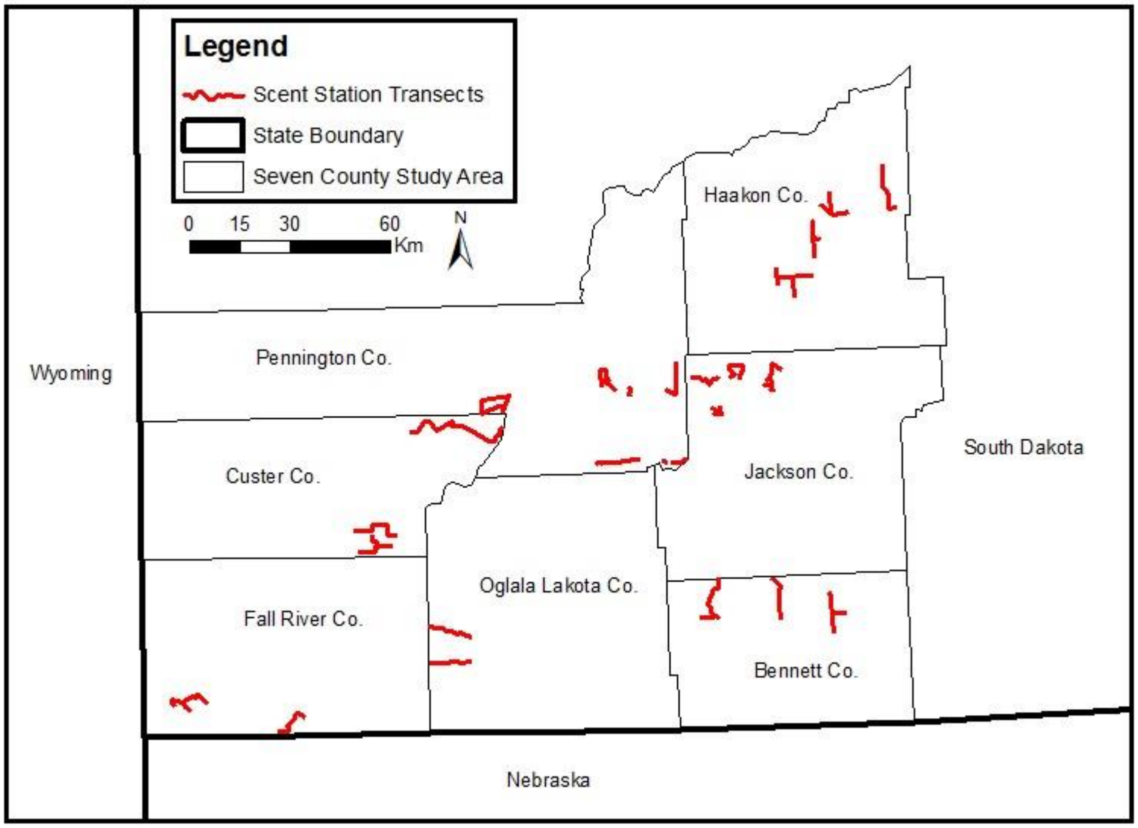
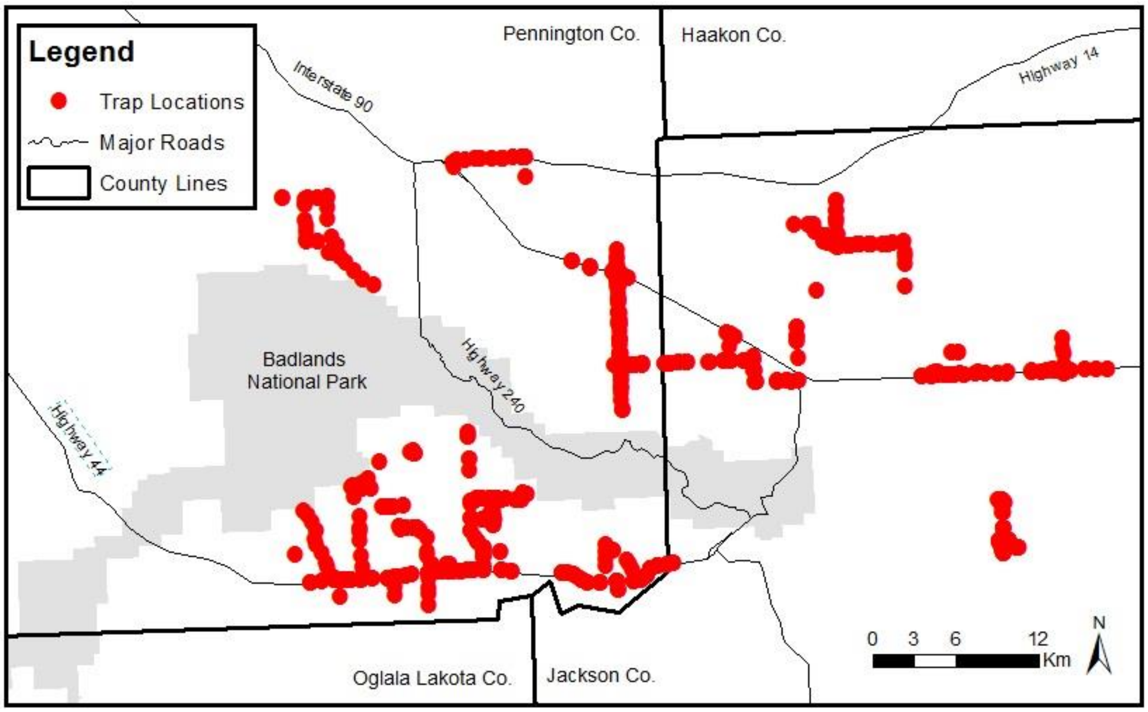


**Figure 2**: Trap locations targeting swift foxes around Badlands National Park, South Dakota, “focal area,” 2014–2015.



# CHAPTER 2

## SURVIVAL AND CAUSE-SPECIFIC MORTALITY OF SWIFT FOXES (*VULPES VELOX*) AROUND BADLANDS NATIONAL PARK, SOUTH DAKOTA

**ABSTRACT**

I estimated survival and cause-specific mortality for a reintroduced population of swift foxes (*Vulpes velox*) around Badlands National Park, South Dakota, from 2014 to 2016. Estimated annual adult survival ($n$ = 14) was 0.51 (95% CI = 0.24–0.69) using the Kaplan-Meier procedure for staggered entry. Annual pup survival ($n$ = 8) was estimated as 0.19. Twenty-one radio-collared swift fox mortalities were documented, of which 33.3% were attributed to vehicle collisions, 33.3% to coyote (*Canis latrans*) intraguild predation, 14.3% to raptor depredation, and 19.1% were of unknown cause. My study found higher rates of vehicular mortality compared to other studies, potentially caused by the high density and use of roads by swift foxes in this area. The month with the highest fox mortality was July (23.8%). There was no difference detected between the cause of mortality and either age or sex. Low survival rates and causes of mortality were similar to previous studies on this population and therefore raise concern for the longevity of this species in southwestern South Dakota.

**INTRODUCTION**

The swift fox, once abundant throughout the Great Plains of North America, was nearly extirpated by the 1900's due to habitat conversion, unregulated trapping, and poisoning programs (Kilgore 1969, Egoscue 1979, Carbyn 1994, Allardyce 2003). Precluded from listing by the US Fish and Wildlife Service in 1994, the swift fox is listed as state threatened in South Dakota. Currently, a remnant of the native population inhabits the extreme southwestern corner of South Dakota in Fall River County. In an effort to bolster swift fox populations in the state, 114 translocated swift foxes from Colorado and Wyoming were released at Badlands National Park between 2003 and 2006

(Schroeder 2007). Genetic analysis provided strong evidence that the reintroduction was successful (Sasmal et al. 2013), but further analysis indicated the long-term viability of the population may be in jeopardy with a high probability of extinction due to high mortality rates (Sasmal 2011, Sasmal et al. 2016).

There has been an apparent decline in this local population since the reintroduction, which is potentially due to several biotic and abiotic factors (e.g., effects of plague [*Yersinia pestis*], recent weather patterns, and possibly increased coyote abindance). In 2008, sylvatic plague was detected in black-tailed prairie dog (*Cynomys ludovicanus*) colonies in Conata Basin, immediately south of Badlands National Park, and is now evident throughout western South Dakota. This deadly bacterial disease is transmitted by fleas and frequently causes epizootics resulting in 90–100% mortality rates in infected prairie dog colonies (McGee et al. 2006). Swift foxes use prairie dog burrows for denning and consume prairie dogs as a food source, particularly during pup-rearing (Russell 2006). There has been a reduction in prairie dog acreage of over 60% within Badlands National Park since the epizootic began in 2008 (Livieri 2013, E. Childers, National Park Service, personal communication). However, no comprehensive information on the status of swift foxes in this region is available since the plague epizootic began.

To adhere these research needs, I began a three-year research project in 2014 to assess the current status of reintroduced swift fox in the Badlands population. My objectives were to estimate survival and cause-specific mortality of adult and pup swift foxes. These two variables are important to the understanding of population dynamics, and a high mortality rate was identified as the main contributor to population decline in this population (Sasmal 2011, Sasmal et al. 2016).

**STUDY AREA**

The 2,600 $km^2$ study area was located in southwestern South Dakota and includes the North Unit of Badlands National Park and the surrounding area (Figure 1). Seventeen percent of the area was managed by the National Park Service, 36% by the United States Forest Service (Buffalo Gap National Grassland), and 47% was privately owned. Much of the surrounding land was used for cattle ranching, which is the major industry in the region (Schroeder 2007). The area has a continental climate with a mean annual precipitation of 40 cm. Temperatures vary between -23° C and 42° C. Elevation ranges from 691 to 989 m above mean sea level (Russell 2006). Soils in the study area are composed mostly of midway clay loam with a low water holding capacity (Whisenant and Uresk 1989). Badlands National Park is comprised of rugged geologic formations (e.g., buttes and pinnacles) along a wall running northwest to southeast through the North Unit of the park. On either side of the wall topography is flat to rolling mixed-grass prairie, dominated by buffalograss (*Buchloe dactyloides*), western wheatgrass (*Pascopyrum smithii*), and prickly pear cactus (*Opuntia polyacantha*), with minimal tree and brush species (Russell 2006).

**METHODS**

I trapped and radio-collared foxes from May to November 2014 and May to September 2015, excluding June 2015. I trapped foxes using 81.3 x 25.4 x 30.5 cm Tomahawk Live Traps (Professional Series model 108SS, Tomahawk, WI) with 2.5 x 1.3 cm, 14 gauge wire mesh. Traps were set in pairs, back to back, and placed along roads or fence lines in areas with previous swift fox detections, or in suitable habitat. I baited traps with quartered black-tailed prairie dog, set shortly before sundown (1800–2000), and checked shortly after sunrise (0500–0700), except for traps set in May and June when traps were checked twice per night (2400–0100 and 0500–0700) because of the dependence of pups on lactating mothers at this time (Egoscue 1962, Kilgore 1969). Traps were removed in the morning and reset in the evening for a total of three consecutive nights, and I released any incidental animal bycatch unharmed.

Trapped foxes were coaxed into a canvas sack, weighed (model 80210; Pesola® Macro-Line Spring scale, Baar, Switzerland), and scanned with an AVID PowerTracker (Avid Identification Systems, Inc., Norco, CA) to identify previously captured foxes. Foxes were scruffed and physically restrained with thick leather gloves with one hand covering the eyes and ears, to minimize visual and auditory stimulation, and held with jaws closed to prevent bites. I recorded sex and body condition and aged foxes (pup < 1 year old; or adult > 1 year old) based on tooth wear. Unmarked animals were PIT tagged (AVID FriendChip, Avid Identification Systems, Inc., Norco, CA) between the scapulae, and samples of blood, fleas, ticks, and hair were collected. I then attached VHF radio-collars (M1830 40g, Advanced Telemetry Systems, Isanti, MN) equipped with 8 hour mortality sensors and released the animals where they were captured to minimize stress. Animal trapping and handling methods were approved by the Institutional Animal Care and Use Committee at South Dakota State University (Approval Number 14-020A) and under compliance with the National Park Service (Permit Number BADL-2014-SCI-0020, and BADL-2014-SCI-0031.)

I monitored radio-collared foxes one to five times per week using a truck mounted null-peak telemetry system (Advanced Telemetry Systems, Isanti, MN ) fitted with a digital compass (C100 Compass Engine, KVH Industries, Inc., Middleton, RI) between 2100 and 0600 hours (Brinkman et al. 2002). The telemetry system was calibrated using transmitters placed at known locations (Cox et al. 2002). To maintain temporal independence, I scheduled telemetry routes at different times each night and locations for individual foxes were collected at a minimum of 2 hours apart (e.g., Gese et al. 1990). I made attempts to collect locations uniformly distributed between 2100 and 0600 hours. Fox locations were estimated by collecting two to three bearings from different locations within a 10 minute period, and entered into Trimble TerraSync™ software on a handheld Trimble GeoExplorer 2008 GPS unit (Trimble®, Sunnyvale, CA). I corrected locations using real-time differential correction in TerraSync ™ software. Only bearings with an angle interception between 20° and 160° were used in order to reduce error (Gese et al. 1988). Aerial telemetry (Mech 1983) was used to locate dispersing foxes. If a mortality trigger was detected, my technicians or I investigated the location the following morning.

*Mortality:*

I determined cause of death either by examining the carcass in the field or via necropsy at South Dakota State University at a later date. Cause of death was attributed to 1) vehicle collision based on location of carcass and signs of impact (e.g., bulging eyeballs, split skin, broken limbs); 2) coyote intraguild predation based on saliva and dentition marks around the chest cavity, broken ribs, coyote tracks around the carcass, and lack of caching or feasting upon of the carcass; 3) raptor depredation based on the eviscerated state of the carcass, skin peeled back on the skull, and patches of fur surrounding the carcass; and 4) unknown if cause of death was undetermined after necropsy, or the carcass was too decomposed to attribute accurate cause of death. I used chi-square analysis to test for differences between cause of mortality and both age and sex.

*Survival:*

For adult foxes (≥ 1 year old), I estimated survival using the Kaplan-Meier procedure for staggered entry (Kaplan and Meier 1958, Pollock et al. 1989) in Microsoft Excel. Survival was estimated at the end of the two year (24 month) study, then estimated for annual survival by taking the square root of two year survival, $\sqrt[2]{\hat{S}(24)} = \hat{S}(12)$, or raising it to the ½ power, $\hat{S}(24)^{1/2} = \hat{S}(12)$. For pup survival (< 1 year), I estimated gross apparent seven month survival, which equated to the probability that the pup became an adult/one year old. All pups were collared in September of 2014 and 2015 and thus, became one year old (or achieved adult status) seven months later in April. I was not able to estimate annual survival for pups in 2015 because the study ended in August 2016, one month prior to one year of surveying. To overcome this constraint, I estimated monthly pup survival from the gross seven month survival $\sqrt[7]{\hat{S}(7)}$, then raised to the $12^{th}$ power to estimate annual pup survival. Only foxes with known fate were included in survival estimates.

**RESULTS**

*Mortality:*

I assessed cause-specific mortality for 21 collared swift foxes (14 adults, 7 pups), of which 7 (33.3%) were attributed to vehicle collisions, 7 (33.3%) to coyote intraguild predation, 3 (14.3%) to raptor depredation, and 4 (19.1%) were unknown (Figure 2). An additional eight, uncollared fox mortalities (3 adults, 5 pups) were detected in the study area, of which 7 (87.5%) were attributed to vehicle collisions, and 1 (12.5%) was unknown (Table 1). There was no statistical difference between pups ($n$ = 8) and adults ($n$ = 13) with regard to cause of mortality ($X^2 = 1.82$, $P = 0.61$). There was no statistical difference between females ($n$ = 10) and males ($n$ = 11) and cause of mortality ($X^2 = 1.58$, $P = 0.67$). I documented fox mortalities in every month of the year except for April and October (Figure 3). The month with highest fox mortality was July ($n$ = 5, 23.8%), followed by January ($n$ = 4, 19.0%).

*Survival:*

Adult survival ($n$ = 14) for the duration of the study (24 months) was 0.26 (95% CI = 0.06–0.47; Table 2; Figure 4). Annual adult survival was estimated as 0.51 (95% CI = 0.24–0.69). Seven month gross apparent survival for pups ($n$ = 8) was estimated as 0.38 (Table 3). Annual pup survival was estimated as 0.19.

**DISCUSSION**

*Mortality:*

Vehicle collisions and coyote intraguild predation were the main causes of swift fox mortality in this study. Sasmal et al. (2016) found similar mortality rates (vehicle 28.2% and coyote 21.5%) for the same population of swift foxes around Badlands National Park between 2004 and 2009. However, the percent of mortalities cause by vehicle collisions was higher than other studies of swift and kit fox (*Vulpes macrotis mutica*) mortality around the United States (Table 4). In my study, swift foxes selected den locations close to roads (Chapter 3) and were documented frequently traveling on roadways. I hypothesize that roads provide travel corridors through fox home ranges;

roads act as a food source, in vehicle-killed animals; and roads may allow for avoidance of coyotes (Chapter 3). Furthermore, I believe there may have been a change in swift fox behavior in this region as prairie dog acreage decreased due to the plague epizootic, causing foxes to shift their home ranges closer to roads. With the loss of prairie dog colonies, which provided a food source and quality habitat with low vegetation, foxes may have moved closer to roadways, which mimic the short vegetation of prairie dog colonies and also provide a food source (Russell 2006).

Of the eight uncollared fox mortalities located during this study, the majority was attributed to vehicular collision, likely due to the higher detection probabilities of vehicle collision opposed to raptor or coyote kills because of visible presence on the road. None of the collared foxes killed by raptor or coyote were located on roads. All unknown mortalities were too decomposed to determine cause of death.

The month with the highest fox mortality was July (Figure 3), which may correlate with adults spending more time and energy procuring food for pups. The care and parental demands of pups is highest June through August when they are above ground and require parents to provide food (Egoscue 1962); mothers may be particularly vulnerable because they are often nursing until mid-June (Kilgore 1969). The month with the second highest mortality was January, which correlates with the breeding season of swift foxes in South Dakota. Foxes disperse between December and March, and breed in February and March. Procuring food for pups or when dispersing to find mates may increase exposure of foxes to predation (Kamler et al. 2004) and vehicle collisions (Russell 2006).

All five of the adult radio-collared foxes that were killed by coyotes were killed within their 95% fixed kernel home range (unpublished data). This was drastically different than findings from Sovada et al. (1998), which located coyote depredation of swift foxes outside of or bordering their home ranges in western Kansas. This suggests that coyote and swift fox home ranges in the Badlands region may overlap, which is supported by findings from Schroeder (2007). In an experimental removal of coyotes from a study area in southeastern Colorado, Karki et al. (2007) documented an increase in pup survival and dispersal compared to the area without coyote removal. They recommended that coyote removal efforts be intense, occur in late-summer, and be sustained over time to have an effect on local swift fox populations. If a comparable removal program existed around Badlands National Park, it could have the potential to increase survival for this swift fox population.

*Survival:*

Annual survival of adults was higher than previously recorded by Sasmal (2011) and Sasmal et al. (2016) for the population of swift foxes around Badlands National Park. Between 2003 and 2009, survival of adult foxes was estimated as 0.39 (Sasmal 2011), compared to 0.51 between 2014 and 2016. In this study, annual pup survival was slightly lower (0.19) than previously recorded (0.22; Sasmal 2011). These differences may reflect a change in survival, but were estimated using different methods; Sasmal (2011) used Cormack-Jolly-Seber model estimates of capture-recapture data in Program MARK. In 2009, Program VORTEX 9.99b was used to assess the population viability of the foxes around Badlands National Park based on the population conditions documented between 2003 and 2009 (Sasmal 2011). Results indicated a 100% chance of extinction within 10 years, with the mortality rate being the major cause of the probability of extinction. The survival rates estimated between 2014 and 2016 are comparable to those documented 2003 to 2009, and therefore I postulate that the population is still under threat of extinction.

Adult survival in my study was much lower than rates from southeastern Colorado (Schauster et al. 2002), where estimated annual survival was 0.55 to 0.75. Fox mortalities in the Colorado study were attributed to predation (62.8%), unknown (28.6%), and other causes (8.6%), but no foxes died due to vehicular collision. The study was conducted at U.S. Army's Pinon Canyon Maneuver Site, a training site used 3–4 times per year (Karki et al. 2007), and otherwise infrequnetly used by the public (e.g., hunting). Their study area differed greatly from the area around Badlands National Park with regard to roads and vehicular traffic. The study area had three major highways: Interstate 90 in the north, State Highway 44 in the south, and State Highway 240 through Badlands National Park (Figure 1). Badlands National Park received nearly 400,000 vehicles per year between 2014 and 2016, with a peak in visitation between June and September (http://irma.nps.gov). Sixty percent of vehicle collisions in my study occurred in this 4 month timeframe. It is likely that the presence of heavily trafficked roads in my study area lead to the higher rates of vehicular-caused mortality compared to other studies (Schauster et al. 2002).

## MANAGEMENT IMPLICATIONS

I recommend continued monitoring of the population of swift foxes around Badlands National Park because of the potentially imminent extinction due to high mortality rates. Efforts should be made to reduce mortality, particularly during the high vehicle traffic season between June and September by increasing education and awareness of visitors to the National Park (e.g., wildlife crossing signs placed near swift fox home ranges). Coyote removal programs also could increase swift fox survival if implemented annually, and in late-summer. Cost and time required to implement these methods should be taken into consideration. Managers should continue to maintain suitable habitat, control disease, evaluate genetic diversity, and monitor populations in other parts of the state before another reintroduction occurs around Badlands National Park.

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**Table 3**: Cause-specific mortality of 29 foxes around Badlands National Park, South Dakota, 2014–2016. Cause: V = vehicle collision, C = coyote intraguild predation, R = raptor depredation, U = unknown cause. Collar: Y = fox was collared and monitored at death, N = fox was not collared or not monitored at death. Age: A = adult (≥ 1 year old), P = pup (< 1 year old). Sex: M = male, F = female, ? = unknown.

| ID | Cause | Collar | Age | Sex |
|---|---|---|---|---|
| 816 | V | Y | A | M |
| 1034 | V | Y | A | F |
| 1203 | V | Y | A | M |
| 1306 | V | Y | A | F |
| 1412 | V | Y | A | F |
| 1511 | V | Y | P | F |
| 1515 | V | Y | P | M |
| 944 | V | N | A | F |
| 1113 | V | N | A | M |
| 1217 | V | N | A | M |
| 1403 | V | N | P | M |
| 1407 | V | N | P | F |
| 1411 | V | N | P | F |
| 1601 | V | N | P | F |
| 857 | C | Y | A | M |

| ID | Cause | Collar | Age | Sex |
|---|---|---|---|---|
| 1210 | C | Y | A | F |
| 1214 | C | Y | A | F |
| 1215 | C | Y | A | M |
| 1216 | C | Y | A | F |
| 1512 | C | Y | P | M |
| 1514 | C | Y | P | F |
| 770 | R | Y | A | M |
| 1408 | R | Y | P | M |
| 1516 | R | Y | P | F |
| 1303 | U | Y | A | M |
| 1304 | U | Y | A | M |
| 1301 | U | Y | P | M |
| 1508 | U | Y | P | F |
| 1401 | U | N | P | ? |
| | | | | |

**Table 4**: Kaplan-Meier staggered entry survival estimates for adult (≥1 year old) swift foxes around Badlands National Park, South Dakota, 2014–2016. Two year (24 month) survival was 0.26 (95% CI = 0.06–0.47). Annual adult survival was estimated as 0.51 (95% CI = 0.24–0.69).

| **Month (*t*)** | **Date** | **No. at risk ($r_j$)** | **No. deaths ($d_j$)** | **No. censored** | **No. new added** | **Survival ($\hat{S}[t]$)** | **95% CI** |
|---|---|---|---|---|---|---|---|
| 1 | May-14 | 1 | 0 | 0 | 0 | 1.00 | 1.00 - 1.00 |
| 2 | Jun-14 | 5 | 1 | 0 | 4 | 0.80 | 0.75 - 0.85 |
| 3 | Jul-14 | 7 | 0 | 0 | 3 | 0.80 | 0.75 - 0.86 |
| 4 | Aug-14 | 8 | 0 | 0 | 1 | 0.80 | 0.74 - 0.86 |
| 5 | Sep-14 | 10 | 0 | 0 | 2 | 0.80 | 0.74 - 0.86 |
| 6 | Oct-14 | 12 | 0 | 0 | 2 | 0.80 | 0.74 - 0.86 |
| 7 | Nov-14 | 12 | 0 | 0 | 0 | 0.80 | 0.73 - 0.88 |
| 8 | Dec-14 | 12 | 1 | 0 | 0 | 0.73 | 0.64 - 0.83 |
| 9 | Jan-15 | 11 | 2 | 0 | 0 | 0.60 | 0.48 - 0.72 |
| 10 | Feb-15 | 9 | 2 | 0 | 0 | 0.47 | 0.34 - 0.60 |
| 11 | Mar-15 | 7 | 0 | 0 | 0 | 0.47 | 0.28 - 0.65 |
| 12 | Apr-15 | 7 | 0 | 0 | 0 | 0.47 | 0.27 - 0.67 |
| 13 | May-15 | 8 | 0 | 0 | 1 | 0.47 | 0.28 - 0.66 |
| 14 | Jun-15 | 8 | 1 | 0 | 0 | 0.41 | 0.24 - 0.58 |
| 15 | Jul-15 | 8 | 2 | 0 | 1 | 0.31 | 0.18 - 0.43 |
| 16 | Aug-15 | 6 | 0 | 0 | 0 | 0.31 | 0.13 - 0.48 |
| 17 | Sep-15 | 7 | 1 | 0 | 1 | 0.26 | 0.14 - 0.39 |
| 18 | Oct-15 | 6 | 0 | 0 | 0 | 0.26 | 0.11 - 0.42 |
| 19 | Nov-15 | 6 | 0 | 0 | 0 | 0.26 | 0.10 - 0.42 |
| 20 | Dec-15 | 6 | 0 | 0 | 0 | 0.26 | 0.09 - 0.43 |
| 21 | Jan-16 | 6 | 0 | 0 | 0 | 0.26 | 0.09 - 0.44 |
| 22 | Feb-16 | 6 | 0 | 0 | 0 | 0.26 | 0.08 - 0.45 |
| 23 | Mar-16 | 6 | 0 | 0 | 0 | 0.26 | 0.07 - 0.46 |
| 24 | Apr-16 | 6 | 0 | 0 | 0 | 0.26 | 0.06 - 0.47 |

**Table 5**: Seven month gross apparent survival of swift fox pups around Badlands National Park, South Dakota, 2014–2016. Pups were born in April and collared in September. Seven month survival equates to pups surviving to become adults. Seven month gross survival was 0.38 ($n$ = 8). Annual survival was estimated as 0.19.

* = Denotes fox was alive at the end of the study, August 2016.

| **ID** | **Sex** | **Collared Date (Mo-Yr)** | **Mortality Date (Mo-Yr)** | **Survival (Months)** |
|---|---|---|---|---|
| 1408 | M | Sep-14 | Sep-14 | 0 |
| 1301 | M | Sep-14 | Jun-15 | 9 |
| 1508 | F | Sep-15 | Mar-16 | 6 |
| 1509 | F | Sep-15 | NA* | 11 |
| 1511 | F | Sep-15 | Jan-16 | 4 |
| 1512 | M | Sep-15 | Jan-16 | 4 |
| 1513 | F | Sep-15 | NA* | 11 |
| 1516 | F | Sep-15 | Mar-16 | 6 |
| Pups Surviving ≥ 7 Months | | | | 3 |
| Total Pups | | | | 8 |

**Table 4:** Cause-specific mortality from six studies of swift foxes and one study of kit foxes around the United States. This study found 33.3% vehicle mortality, 33.3% coyote mortality, 14.3% raptor mortality, and 19.1% mortality of unknown cause. * Vehicle mortality around Badlands National Park from 2014 to 2016 was higher than any other study documented.

| **Location** | **Percent Mortality** | | | | **Years** | **Reference** |
|---|---|---|---|---|---|---|
| | **Vehicle** | **Coyote** | **Other Predator** | **Other or Unknown** | | |
| Badlands National Park | 28.2 | 21.5 | 0 | 50.3 | 2003–2009 | Sasmal et al. 2016 |
| Southeastern Wyoming | 3 | 46 | 29 | 23 | 1996–1999 | Olson and Lindzey 2002 |
| Western Kansas | 0 | 0 | 72.2 | 27.8 | 1996 | Sovada et al. 1998 |
| Northern Montana | 13 | 46 | 34 | 7 | 2003–2005 | Ausband and Foresman 2007 |
| California (Kit Foxes) | 4.5 | 0 | 50.0 | 45.5 | 2002–2004 | Cypher et al. 2009 |
| Southeastern Colorado | 0 | 0 | 62.8 | 37.2 | 1997–1998 | Schauster et al. 2002 |
| Eastern New Mexico | 12.5 | 0 | 62.5 | 25.0 | 1998–2001 | Harrison 2003 |
| **AVERAGE** | **8.7** | **16.2** | **44.4** | **30.8** | | |
| *Badlands National Park* | *33.3** | *33.3* | *14.3* | *19.1* | *2014–2016* | *This Study* |

**Figure 3:** Swift fox study area around Badlands National Park and Buffalo Gap National Grassland, South Dakota, 2014–2016. The three major highways through the study area are labeled: Interstate 90 in the north, State Highway 44 in the south, and State Highway 240 through Badlands National Park. NAD 1983 UTM Zone 13N

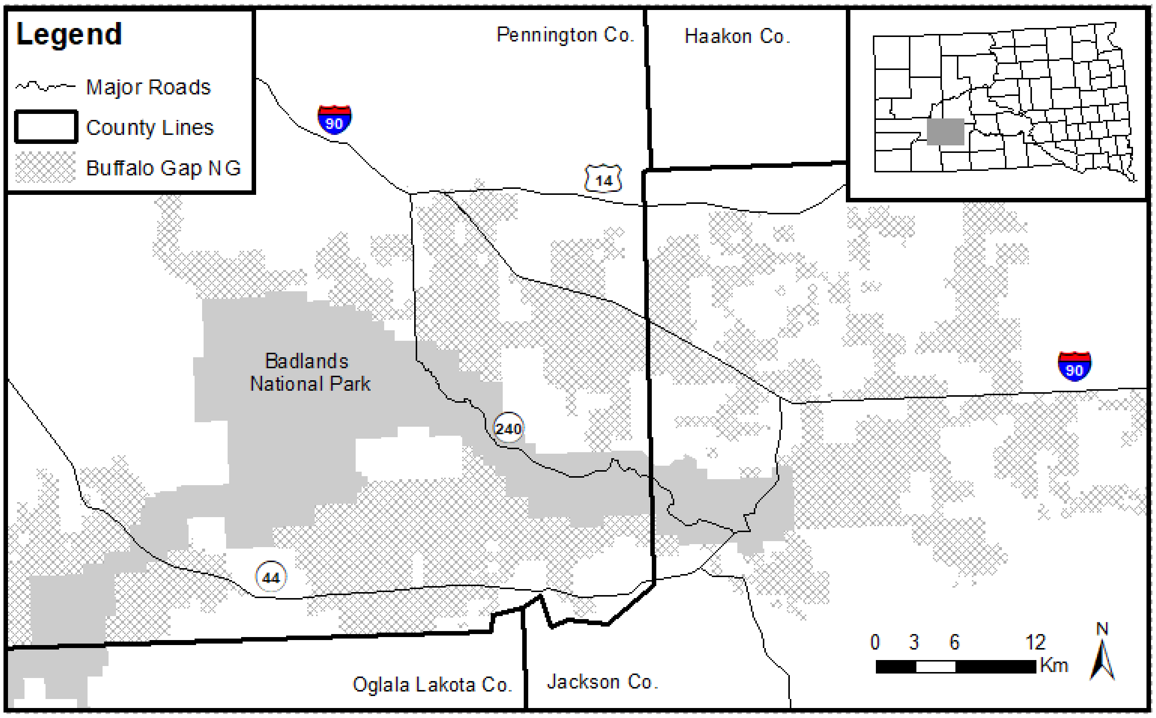


**Figure 4**: Cause-specific mortality for 21 radio-collared foxes around Badlands National Park, 2014–2016. One third (33.3%) of mortalities were deemed vehicle collision, an additional 33.3% were deemed coyote intrigued predation, 14.3% were deemed raptor depredation, and 19.1% were of unknown cause. There was no statistical difference between pups (< 1 year old) and adults (≥ 1 year old) with regard to cause of mortality ($X^2 = 1.82$, $P = 0.61$).

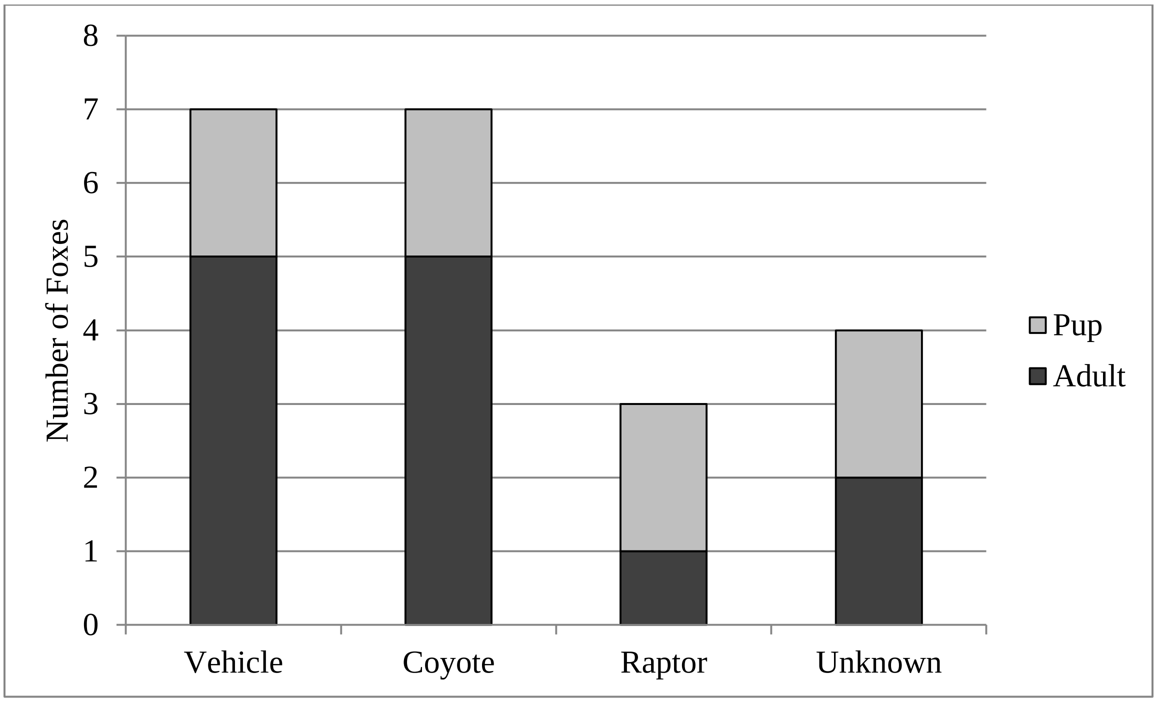


**Figure 3**: Swift fox mortality per month, combined from May 2014 through July 2016, around Badlands National Park, South Dakota.

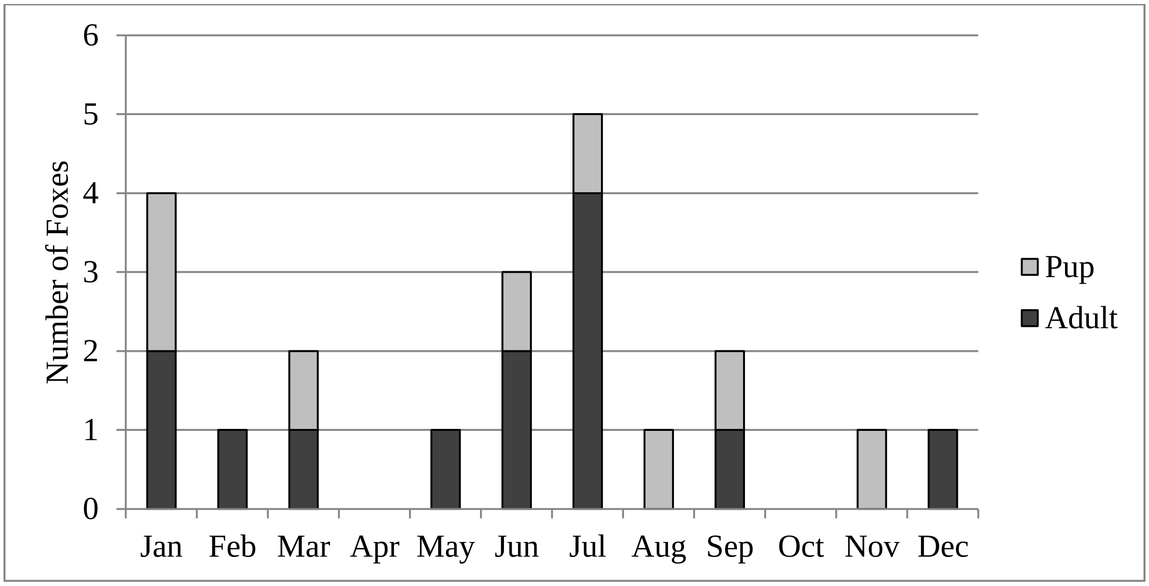
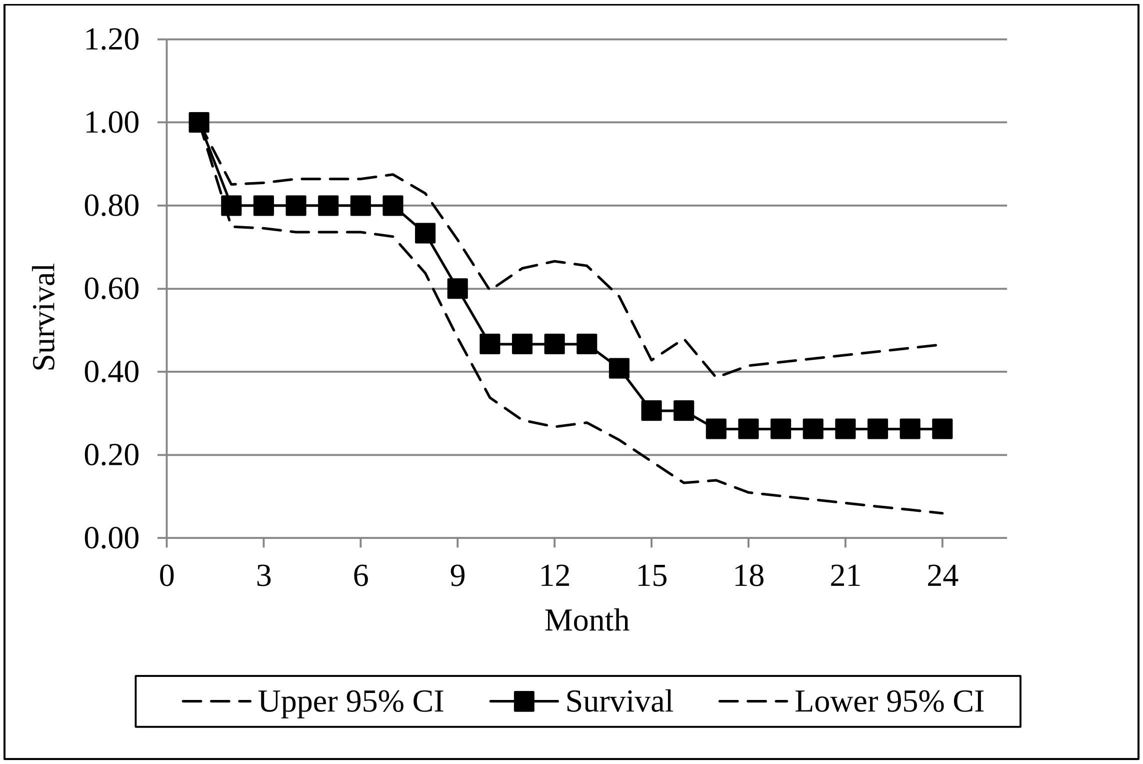


**Figure 4**: Kaplan-Meier staggered entry survival estimates with confidence limits for adult (≥ 1 year old) swift foxes around Badlands National Park, South Dakota, 2014–2016. Survival at the end of the study (24 months) was 0.26 (95% CI = 0.06–0.47). Annual adult survival was estimated as 0.51 (95% CI = 0.24–0.69).



# CHAPTER 3

# REPRODUCTIVE CHARACTERISTICS AND NATAL DEN SELECTION OF SWIFT FOXES (*VULPES VELOX*) AROUND BADLANDS NATIONAL PARK, SOUTH DAKOTA

## ABSTRACT

Swift foxes (*Vulpes velox*) are monoestrus, and often monogamous carnivores. Dens around Badlands National Park, South Dakota were monitored from 2014 to 2016 to estimate reproductive success and surveyed to better understand den site selection. I surveyed a total of 12 natal dens, 34 non-natal dens, and 12 randomly generated locations. ANOVA analysis indicated that non-natal dens had significantly ($P < 0.05$) fewer holes (2.2 ± 0.4) than natal dens (4.4 ± 0.7). Random locations were significantly farther from roads (557.4 ± 155.1 m) than natal dens (160.9 ± 57.0 m), and also significantly farther from the nearest anthropogenic feature (341.2 ± 67.2 m) than natal dens (105.8 ± 36.5 m). Only one (1.4%) historically occupied (2005–2008) den was occupied by swift foxes during this study. I used motion activated trail cameras to monitor secondary post-birth reproductive success, which averaged 4.3 ± 0.3 pups per den over the three-year period. I observed a decrease in the number of pups counted in the population, as well a decrease in total number of natal dens, from 2014 to 2016. I documented two instances of natal philopatry and alloparental care by older female siblings. I recommend using motion activated trail cameras to estimate reproductive success of swift foxes in future studies because of their accuracy and ability to document additional behaviors like parental care.

## INTRODUCTION

The swift fox (*Vulpes velox*), once abundant throughout the Great Plains of North America, was nearly extirpated by the 1900's due to habitat conversion, unregulated trapping, and poisoning programs (Kilgore 1969, Egoscue 1979, Carbyn 1994, Allardyce 2003). Precluded from listing by the United States Fish and Wildlife Service in 1994, the swift fox is listed as threatened in South Dakota. Currently, a remnant population inhabits the extreme southwestern corner of the state in Fall River County. In addition, between 2003 and 2006, 114 swift foxes were translocated from Colorado and Wyoming and released at Badlands National Park (Schroeder 2007). Genetic analysis has provided strong evidence that the reintroduction was successful (Sasmal et al. 2013), but further analysis indicated the long-term viability of the population may be in jeopardy with a high probability of extinction due to high mortality rates (Sasmal et al. 2016).

Since the reintroduction, there has been an apparent decline in this local population, which is potentially related to several biotic and abiotic factors (e.g., effects of plague [*Yersinia pestis*], recent weather patterns, and possibly increased coyote [*Canis latrans*] numbers). In 2008, sylvatic plague was detected in Conata Basin, immediately south of Badlands National Park, and is now evident throughout western South Dakota. No comprehensive information on the status of swift foxes in southwestern South Dakota has been collected since the viability analysis was conducted by Sasmal (2011), which was based on data collected pre-colonization of plague.

Swift foxes are monogamous, though polygyny has been documented (Ralls et al. 2001). Both genders are sexually mature to breed within their first year, and females are monoestrous with litters ranging from 3 to 7 pups (Asa 2003). Mating in South Dakota often occurs in February and March and parturition occurs in April and May (Tannerfeldt et al. 2003). Young either disperse during their first winter or exhibit natal philopatry and remain within their parent's home range (Ralls et al. 2001). Swift foxes rely on dens throughout the year and are thought to choose dens based on location and physical characteristics, which is especially important during the pup-rearing period of June to

August (Pruss 1999). They maintain numerous dens throughout the year, used for raising young, denning, and escaping predators (Tannerfeldt et al. 2003). No information has been collected regarding physical characteristics of natal swift fox dens in southwestern South Dakota. The objectives of this study were to estimate reproductive parameters and document natal den characteristics, which will provide critical information and reassessment of the current status of swift foxes in southwest South Dakota.

**STUDY AREA**

The 2,600 $km^2$ study area was located in southwestern South Dakota and included the North Unit of Badlands National Park and the surrounding area (Figure 1). Seventeen percent of the area was managed by the National Park Service, 36% by the United States Forest Service (Buffalo Gap National Grassland), and 47% was privately owned. Much of the surrounding land was used for cattle ranching, which is the major industry in the region (Schroeder 2007). The area has a continental climate with a mean annual precipitation of 40 cm. Temperatures vary between -23° C and 42° C. Elevation ranges from 691 to 989 m above mean sea level (Russell 2006). Soils in the study area are composed mostly of midway clay loam with a low water holding capacity (Whisenant and Uresk 1989). Badlands National Park is comprised of rugged geologic formations (e.g., buttes and pinnacles) along a wall running northwest to southeast through the North Unit of the Park. On either side of the wall topography is flat to rolling mixed-grass prairie, dominated by buffalograss (*Buchloe dactyloides*), western wheatgrass (*Pascopyrum smithii*), and prickly pear cactus (*Opuntia polyacantha*), with minimal tree and brush species (Russell 2006).

## METHODS

*Den Selection:*

I located dens by tracking radio-collared adults to dens during the day or incidental observations of pups or uncollared adults in the study area. Den surveys were conducted at all natal dens and non-natal dens at the time of detection. I considered dens 'natal' if it was the location where pups first emerged in the spring, and 'non-natal' if ≥ one fox (collared or not) was located at the den more than once within one month. Therefore, each fox family had only one natal den per year and multiple non-natal dens. For each natal den, a random location was also surveyed, to determine if there were variables that were selected more often than random. These points were generated from a random bearing (1–360°) and distance (200–2000 m; the approximate nearest and farthest distance between dens within an average fox home range, therefore generating a point that was likely within the utilized area of an average fox). Bearing and distance were generated using a random number generator (R N G Random Number Generator, Version 1.01, mobile application, A. Rutkowskij).

I measured six habitat variables at each den site (Table 1). I estimated the percent vegetative cover around each den site (% Veg), counted the number of holes (Holes), measured the slope of the den site (Slope [°]), distance to the nearest water source (Water [m]), distance to the nearest roadway (Road [m]), and distance to nearest anthropogenic feature (Anthro [m]). Holes were not counted at random locations. These variables were selected based on extensive behavioral observations and published research (Egoscue 1979, Pruss 1999, WWF 2010, Sasmal et al. 2011). I compared these attributes among den types and random locations using one-way analyses of variance (ANOVA; PROC

GLM; SAS Institute Inc., Cary, North Carolina). After logarithmic ($log_{10}$ +1) transformation, den attribute data met the assumptions homogeneity of variance and better approximated a standard normal distribution. If logarithmic transformation did not improve distribution, nonparametric approaches (Wilcoxin or Kruskal-Wallis) were used. Significance was determined at $\alpha = 0.05$. If differences were observed among treatment groups, I performed a Tukey's post-hoc test to isolate the source of variation.

*Historic Dens:*

In addition to locating active dens from collared foxes and incidental observation of uncollared foxes, I investigated GPS locations from 70 historic dens which were detected between 2005 and 2008 (E. Childers, National Park Service, unpublished data) to determine the current status of the den. If the den was currently occupied by swift foxes, I conducted a den survey as described above; if the den was not currently occupied by swift foxes, I recorded what species was occupying the den based on visual observation, size of hole, and animal tracks around the den (via Animal Tracks: Midwest Edition, by Jonathan Poppele, Adventure Publications, Inc., Cambridge, MN).

*Reproductive Characteristics:*

I defined reproductive success as secondary, or post-emergence, reproduction and estimated as number of pups per natal den. Because parturition occurs within dens and pups remain underground for approximately three weeks, it is unknown how many pups were born to each female (Asa 2003). Dens located after 9 July were not included in estimates of reproductive success because pups may have died before this time.

Counting pups for estimating reproductive success was based on two methods: 1) observing the den from a distance using binoculars for 90 minutes prior to sunset for maximum number of pups; 2) motion activated, infrared trail cameras (HC600 HyperFire Covert Camera, RECONYX, Holeman, WI) placed approximately 3–4 meters from the main natal den hole in late April or early May and checked weekly to determine the emergence date of pups, and to determine a total pup count for the den. Pictures were analyzed weekly and the maximum number of pups in one photo was used as the estimate of reproductive success. I did not observe a difference in fox behavior with either method; they maintained natural curiosity and unsuspicious behavior to both the camera and the observer (Egoscue 1979). During 2014, both methods were implemented and it was determined that trail cameras were more efficient and more accurate than observations because of the ability to monitor the den continuously as opposed to limited observations. For 2015 and 2016, I used trail cameras exclusively to monitor reproductive success.

## RESULTS

*Den Selection:*

I surveyed 12 natal dens and random locations, and 34 non-natal dens from 2014 to 2016. Fox families had 1 to 9 non-natal dens per year. There was no significant differences in the percentage of vegetation ($F_{2, 54} = 0.83$, $P = 0.44$), slope ($F_{2, 53} = 0.57$, $P = 0.57$), or distance to water ($F_{2, 54} = 0.13$, $P = 0.88$) among treatment groups (Table 2). Non-natal dens had significantly fewer holes ($M = 2$, $\bar{x} = 2.2 \pm 0.4$) than natal dens ($M = 4$, $\bar{x} = 4.4 \pm 0.7$; $F_{1, 43} = 7.3$, $P = 0.01$; Figure 2). The distance to roads ($F_{2, 54} = 3.6$, $P = 0.04$; Figure 3) and to the nearest anthropogenic feature ($F_{2, 54} = 6.6$, $P = 0.003$; Figure 4) differed significantly among treatment groups. Random sites ($\bar{x} = 557.4 \pm 155.1$ m) were approximately 3.5 times farther away from roadways than natal den sites ($\bar{x} = 160.9 \pm$

57.0 m; Tukey's HSD, $P < 0.05$). The distance to roads was not significantly different between natal and non-natal den sites or between random locations and non-natal sites (Figure 3). Random sites were significantly farther ($M = 300$, $\bar{x} = 341.2 \pm 67.2$ m) from nearby anthropogenic features than both natal ($M = 111$, $\bar{x} = 105.8 \pm 36.5$ m; Tukey's HSD, $P < 0.05$) and non-natal ($M = 101$, $\bar{x} = 150.3 \pm 28.2$ m; Tukey's HSD, $P < 0.05$) dens (Figure 4).

*Historic Dens:*

Of the 70 historic dens investigated, one (1.4%) was occupied by swift foxes during my study, as a natal den in 2016. Nine dens (12.9%) were occupied by other species (red fox [*Vulpes vulpes*], American badger [*Taxidea taxus*], coyote, striped skunk [*Mephitis mephitis*], rabbit [Leporidae], or prairie rattlesnake [*Crotalus viridis*]), and 60 historic dens (85.7%) were unoccupied.

*Reproductive Characteristics:*

My technicians and I analyzed 128,823 images from den cameras between April and August in 2015 and 2016; however, about one-third of images were discarded due to tall moving grass or cattle disturbance. Pups first emerged from dens between 14 May and 2 June; mean emergence date was 25 May in both 2015 and 2016. Most swift fox families vacated natal dens about two months after emergence. After vacating the natal den, pups were often moved to one non-natal den while the parents inhabited another. In two cases, mated pairs returned to the natal den they used the previous year to raise pups the current year.

I observed a decrease in the number of pups counted in the population, as well as a decrease in total number of natal dens, from 2014 to 2016 (Table 3). In 2014, eight dens with pups were detected, with a minimum of 23 pups. Secondary, post-birth reproductive success averaged 4.2 ± 0.4 pups per den ($n$ = 5). In 2015, six dens with pups were detected, accounting for a minimum of 21 pups. Secondary, post-birth reproductive success averaged 4.5 ± 0.6 pups per den ($n$ = 4). In 2016, only three dens with pups were detected, accounting for a minimum of 12 pups. Secondary, post-birth reproductive success averaged 4.0 ± 0.6 pups per den ($n$ = 3). Overall, the average reproductive success of swift foxes around Badlands National Park and Buffalo Gap National Grassland was 4.3 ± 0.3 pups per den between 2014 and 2016.

I observed a decrease in the number of females producing a litter of pups from 2014 to 2016. In 2014, all known females (100% mated, $n$ = 7) located before 9 July were observed with litters. In 2015, 66.6% of known females ($n$ = 6) were observed with litters. Details of the two unmated females were: 1) Fox 1212 had a litter in 2014 but her mate died in January 2015 and subsequently no pups were observed at her den in 2015; 2) Fox 1404 was a pup in 2014 and remained within the home range of her parents and was observed assisting with raising of the offspring from 2015 (photographic evidence of alloparental care, e.g., cleaning, playing with, and providing food for the offspring, as well as guarding the den). In 2016, I observed 42.9% of known females ($n$ = 7) with litters. Details of the four unmated females were: 1) Fox 1212 remained unmated and she dispersed to a new home range approximately 24 km away from the 2014 natal site; 2) Fox 1404 remained unmated; she was observed at the natal den of her parents raising offspring of the current year (second consecutive year); 3) Fox 1509, a pup in 2015, was located at the same den site as Fox 1404; this fox also remained at the den to raise offspring (1404, 1509, and the parents raised the offspring in 2015); 4) Fox 1307 had a litter in 2015 but her mate died in September 2015 and subsequently no pups were observed at her den in 2016. All mated pairs produced litters in all three years.

**DISCUSSION**

*Den Selection:*

My findings support other studies in which natal dens were documented with greater numbers of holes than non-natal dens (Egoscue 1962, Hillman and Sharps 1978, Kilgore 1969). This is likely due to adults excavating more holes as escape routes for pups while at the den. My study also found that natal dens were located within close proximity to an anthropogenic feature (e.g., road ditch, scenic overlook, beneath an overpass, under shed) more often than random locations. The close relationship between foxes and human disturbance has been documented by Kilgore (1969), who found two dens located in a cemetery and one den located in a culvert under a road. Swift fox dens have been documented within plowed agricultural fields and also associated with fence rows (Sovada et al. 2003, Cutter 1958, Kilgore 1969).

In my study, natal dens were nearer to roads than random locations, which has been documented in other studies (Pruss 1999, Cypher et al. 2009, Harrison 2003). In New Mexico, swift foxes demonstrated a preference for dens to be nearer to roads and in areas with more roads than randomly selected locations (Harrison 2003). I hypothesize that swift foxes select den sites closer to roads for three reasons. First, roadways provide easy travel corridors for moving throughout home ranges, and vegetation is often shorter closer to roads than in the surrounding landscape (Russell 2006). Bjurlin and Cypher (2003) documented the closely related San Joaquin kit fox (*Vulpes macrotis mutica*) regularly crossing roads. I observed foxes crossing a four lane divided highway

(Interstate 90) on a regular basis. I also observed foxes consistently travelling on interstates, county roads, and two-track roads, some for nearly 1 km at a time, usually nocturnally while I collected locations on radio-collared foxes. These foxes often ran, trotted, or walked along roadways as observers followed them from behind with a spotlight. The second reason I hypothesis swift foxes select for natal den sites close to roads is that roadways act as a food source, providing vehicle-killed animals (e.g., rabbits, birds, snakes) for foxes to scavenge. Scavenging behavior in swift foxes has been documented by many studies (Sovada et al. 2001, Kilgore 1969, Hillman and Sharps 1978). Third, roadways may provide swift foxes in this area a way to avoid coyotes, which are a major source of mortality. Coyotes have been reported to avoid roadways in Canada (Roy and Dorrance 1985), and Mech (1989) documented an avoidance of roads by wolves (*Canis lupus*) in Minnesota. It has been suggested that kit foxes (*Vulpes macrotis*) and red foxes (*Vulpes velox*) may select dens close to roads to avoid coyote core areas (Voigt and Earle 1983, Ralls and White 1995).

Dens often had long tracks (up to 8 meters) of excavated dirt extending beyond the hole, created when adult foxes cleaned out the den and pulled material from underground up out of the hole. Natal dens were easiest to find mid-April to mid-June when new vegetation was growing on the grasslands. Though not analyzed in my study, vegetation at den entrances was noticeably taller and comprised of a different composition of grass and forb species than the surrounding grassland, which made them easy to identify (Egoscue 1962, Kilgore 1969). This vegetative characteristic at dens was documented by Gharajehdaghipour et al. (2016) at arctic fox (*Vulpes lagopus*) dens, which had higher nutrient levels in the soil (due to defecation and prey remains) than adjacent control sites. Arctic fox dens were surrounded by nearly three times as much biomass of lush green vegetation compared to the surrounding tundra.

*Historic Dens:*

Only one of 70 historically occupied den locations was inhabited by swift foxes during this study. This corroborates the findings of Chapter 1 which found an apparent decline in swift fox presence and numbers around Badlands National Park since the reintroduction. Likewise, this also correlates with the decline in the total number of dens documented, from 60 litters between 2004 and 2007 to 12 litters between 2014 and 2016.

*Reproductive Characteristics:*

Reproductive success, as defined as number of pups per den, average 4.3 ± 0.3; *n* = 12 litters) during this study. This result is consistent with average litter size estimated for the same population between 2004 and 2007: 4.0 ± 0.2 pups per den (*n* = 60 litters; G. Schroeder, National Park Service, unpublished data). Reproductive success of swift foxes around Badlands National Park is apparently higher than what has been reported for swift foxes in other regions (Table 4); the average mean litter size reported from eight other studies was 3.6 pups per litter (Olson and Lindzey 2002, Rongstad et al. 1989, Covell 1992, Karki 2007, Sovada et al. 2003, Kilgore 1969, Brechtel et al. 1993, Carbyn et al. 1994, Moehrenschlager 2000). Swift foxes around Badlands National Park may produce more offspring, but I hypothesize that the methods in this study provided a more accurate count of pups at dens. My study is the only study that used motion activated trail cameras to monitor reproductive success, whereas all other studies counted pups via visual observations from researchers present only temporarily at the den. This observation and counting method potentially misses individual pups if they did not happen to be above the den at the time of viewing. Placing cameras at the dens allowed me to monitor the dens on a continuous basis as opposed to a snapshot in time that viewing the den from afar provides. Therefore, I believe my methods better detected the true number of pups, including pups that perhaps came above the den much less often than their siblings. Cameras also documented male parental care (e.g., hunting, playing, guarding), to which the extent was previously unknown; as well as alloparental care by older siblings.

This study documented an annual decline in total number of pups, and a decline in percent of mated females, which correlates with notable declines in the overall population (Chapters 1 and 2). Significant effort was expended detecting fox presence via scent stations and trapping throughout the study (Chapter 1); therefore, I believe the decline of pups and percent of mated females accurately represents the dynamics of the population as a whole. Percent of mated females decreased from 100.0% to 66.6% to 42.9% from 2014 to 2016; however, I was unable to document an unmated male. Thus, all known males of breeding age mated, and all mated pairs produced a litter each year. This may indicate that a lack of breeding males is limiting the population. Sex ratios of captured swift fox pups were 13M:17F, which I interpret as not different from 1:1 and similar to that documented in other swift fox populations (Harrison 2003).

Two instances of natal philopatry resulting in kin selection (Hamilton 1963) and alloparental care (Wilson 1975) were documented in this population. In kin selection, individuals care for close relatives, resulting in improved survival of their genes. Both foxes exhibiting this behavior were from the same family group (sister from subsequent litters.) These behaviors have also been documented in the closely related kit fox

(Egoscue 1962, Ralls et al. 2001). Relative to my study, in 2015, a 1 year old female (Fox 1404) was observed at the natal den of her parents (she was trapped and marked at this den in 2014 as a pup), and assisted in raising pups in 2015. She returned again in 2016 and assisted in raising her parent's offspring as a 2 year old. At the same den in 2016, a female pup (Fox 1509) from 2015 remained at the den and assisted in provisioning and caring for offspring. Both the two year old (Fox 1404) and one year old (Fox 1509) were at the same den in 2016 as 'helpers' raising the litter. Trios of two females and one male at swift fox dens have been documented (Kitchen et al. 2006, Ralls et al. 2001), and my study negates the potential conclusion that the relationship is polygyny, but instead may be older offspring 'helpers.'

Coincidentally, the adult male at the den which exhibited natal philopatry died 14 May 2016. This event likely would have placed immense stress on the adult female had there not been two other mature females to assist in hunting for and raising the litter. A similar situation occurred in 2015 at two other dens (Chapter 5), where the males died in June resulting in lone adult females at dens to care for the pups. Both females subsequently died in July (one lived for 29 days, the other for 34 days) and I hypothesize that the additional stress of caring for litters alone contributed to these mortalities. The parental demands of pups is highest June through August when they are above ground and require parental care (Egoscue 1962), and especially on mothers who are often nursing until mid-June (Kilgore 1969). The survival of pups at the den with 'helpers' was 100.0% from emergence in 2015 to dispersal in March 2016, and in 2016, survival was 100% from emergence to when the foxes moved to a new den location in July. The survival of pups at the two dens where both parents died in 2015 (Chapter 5) was unquantifiable because the pups were removed and hand-reared at an Association of Zoos and Aquariums Certified zoo, which was deemed necessary by South Dakota Game, Fish and Parks due to the threatened status of the species in the state.

Swift foxes must weigh the risk of dispersing (and risking death, but potentially finding a mate and reproducing) with natal philopatry (and remaining within their parent's home range and raising the next year's litter/kin selection; Ausband and Moehrenschlager 2009). Of six known-fate pup dispersers, only one produced a litter (male pup 1301) the following spring, while the remaining five (2 males, 3 females) died between October and March (the dispersing and breeding season). I believe that the two females who exhibited natal philopatry remained at the den due to lack of potential mates. The nearest known foxes to this den were over 10 km away and to the north of the Badlands wall, requiring the foxes to find a path to scale the formation. This geologic formation may have prevented the foxes from dispersing due to an inability to cross the matrix (Saunders et al. 1991). The nearest foxes to the south of the wall were nearly 30 km away. The low abundance of foxes throughout the study area (Chapter 1) may favor natal philopatry over dispersal, and may have caused these foxes to opt to remain as 'helpers' rather than attempt to obtain mates.

An additional example of natal philopatry existed in another family group of swift foxes in this study area. A one year old female (Fox 1513) remained within her parent's home range, mated with an unrelated male, and produced 6 offspring in a natal den previously used by her parents. This den was 4.0 km from the natal den her parents used the same year. This supports the conclusion by Ralls et al. (2001) that neighboring foxes are often closely related. This also confirms that swift foxes are sexually mature and can bear young within their first year.

## MANAGEMENT IMPLICATIONS

Continued monitoring of swift foxes around Badlands National Park and Buffalo Gap National Grassland is highly recommended. Motion activated trail cameras should be used for future monitoring of swift fox dens because of their improved accuracy compared to visual observation. This study documented extensive male parental care, and two instances of alloparental care by older female offspring. Additional studies are recommended to estimate prevalence of these behaviors.

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**Table 1**: Habitat variables evaluated at natal dens, non-natal dens, and random sites around Badlands National Park, South Dakota, 2014–2016.

| **Variable** | **Definition** |
|---|---|
| % Veg | The estimated percent of vegetative cover (as opposed to bare ground, roadway, or water) in a 20 m radius circle around the den |
| Holes | Number of active holes at the den site; not recorded at random locations |
| Slope (°) | Angle of inclination (±1°) of the den site |
| Water (m) | Distance (±1 m) to the nearest water source |
| Road (m) | Distance (±1 m) to the nearest roadway, including paved, gravel, and two-track roads |
| Anthro (m) | Distance (±1 m) to the nearest anthropogenic feature (i.e., road ditch, scenic overlook, beneath an overpass, under shed) |

**Table 2:** Results for six habitat variables collected at natal den sites, non-natal den sites, and randomly generated locations around Badlands National Park, South Dakota, 2014–2016. * Denotes significant differences from natal den characteristics. Non-natal dens had significantly fewer active holes than natal dens ($F_{1, 43} = 7.3$, $P = 0.01$; see Figure 2). Random locations were significantly farther from roads than natal dens ($F_{2, 54} = 3.6$, $P = 0.04$; see Figure 3). Random locations were significantly farther from the nearest anthropogenic feature than natal dens ($F_{2, 54} = 6.6$, $P = 0.003$; see Figure 4).

| **Class** | **% Veg** | **Holes** | **Slope (°)** | **Water (m)** | **Road (m)** | **Anthro (m)** |
|---|---|---|---|---|---|---|
| **Natal Dens** | 81.9 ± 7.8 | 4.4 ± 0.7 | 10.4 ± 2.7 | 458.0 ± 51.8 | 160.9 ± 57.0 | 105.8 ± 36.5 |
| **Non-Natal Dens** | 71.4 ± 5.6 | 2.2 ± 0.4* | 6.8 ± 1.5 | 494.9 ± 54.2 | 259.6 ± 51.5 | 150.3 ± 28.2 |
| **Random Locations** | 81.0 ± 7.9 | -- | 7.5 ± 3.5 | 470.4 ± 82.7 | 557.4 ± 155.1* | 341.2 ± 67.2* |

**Table 3:** Reproductive characteristics of swift foxes around Badlands National Park, South Dakota. There was a decrease in the number of pups documented in the population, as well as a decrease in the number of total natal dens from 2014 to 2016. “Total” refers to all dens counted before or after 9 July. “Monitored” refers to dens documented before 9 July. The average number of monitored pups per monitored dens (reproductive success) is also included. The average pups per den for 2014–2016 was 4.3 ± 0.3.

| **Year** | **Total Pups** | **Total Dens** | **Monitored Pups** | **Monitored Dens** | **Average** |
|---|---|---|---|---|---|
| 2014 | 23 | 8 | 21 | 5 | 4.2 ± 0.4 |
| 2015 | 21 | 6 | 18 | 4 | 4.5 ± 0.6 |
| 2016 | 12 | 3 | 12 | 3 | 4.0 ± 0.6 |

**Table 4:** Mean litter size of swift foxes across the United States. This study found an average littler size of 4.3 ± 0.3, which is similar to previous years in the same population. This is apparently higher than litter size in other regions; the average from eight other studies was 3.6 pups per litter. I hypothesize my methods (motion activated trail cameras) provided a more accurate, and therefore higher, pup count than other studies (visual observation).

| **Location** | **Mean Litter Size** | **SE** | ***n* (Number of Litters)** | **Years** | **Reference** |
|---|---|---|---|---|---|
| Southeastern Wyoming | 4.6 | 0.4 | 25 | 1996–1999 | (Olson and Lindzey 2002) |
| Las Animas County, Colorado | 3.4 | --- | 5 | Prior to 1989 | (Rongstad et al. 1989) |
| Southeastern Colorado | 2.4 | --- | 13 | Prior to 1992 | (Covell 1992) |
| Southeastern Colorado | 2.5 | 1.9 | 51 | 1999–2000 | (Karki 2007) |
| Western Kansas | 3.1 | 0.4 | 10 | 1996 | (Sovada et al. 2003) |
| Beaver County, Oklahoma | 4.3 | 0.6 | 4 | 1965–1966 | (Kilgore 1969) |
| Alberta/Saskatchewan | 4.2 | --- | 12 | Prior to 1993 | (Brechtel et al. 1993, Carbyn et al. 1994) |
| Alberta/Saskatchewan | 3.9 | --- | 29 | Prior to 2000 | (Moehrenschlager 2000) |
| **AVERAGE** | **3.6** | | | | |
| *Badlands National Park* | *4.3* | *0.3* | *12* | *2014–2016* | *This Study* |
| *Badlands National Park* | *4.0* | *0.2* | *60* | *2004–2007* | *G. Schroeder, unpublished data* |

**Figure 5:** Swift fox study area around Badlands National Park and Buffalo Gap National Grassland, South Dakota, 2014–2016. NAD 1983 UTM Zone 13N

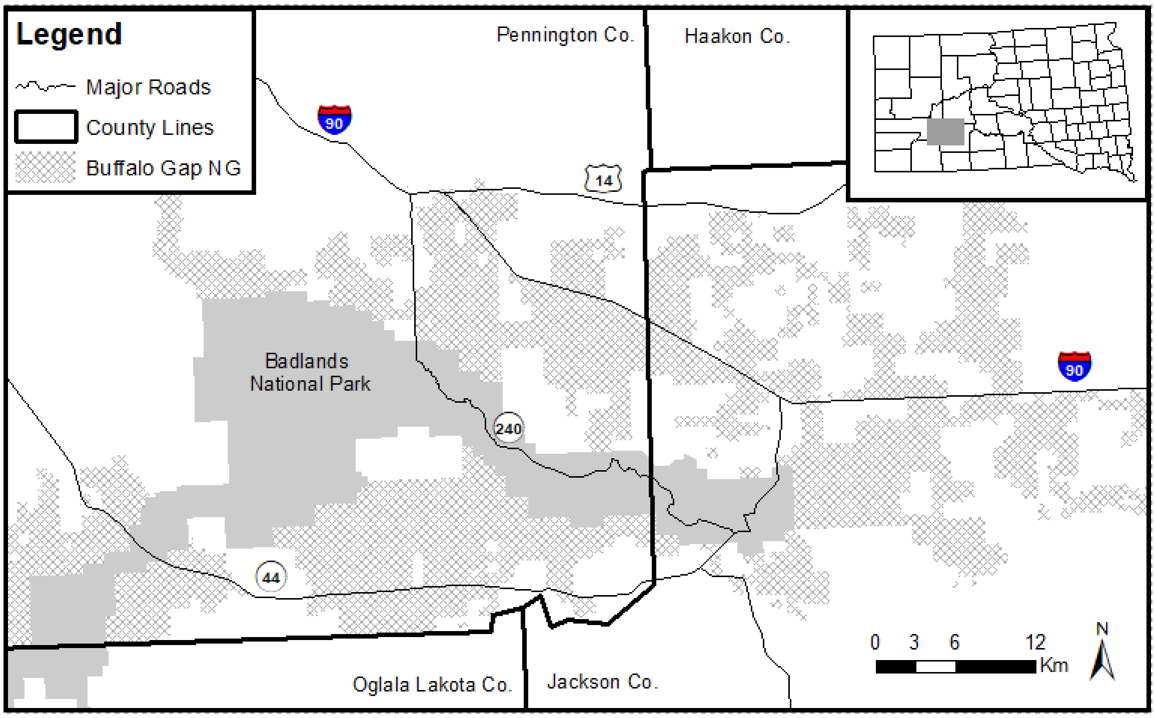


**Figure 2:** Number of active holes detected at natal and non-natal dens around Badlands National Park and Buffalo Gap National Grassland, South Dakota, 2014–2016. * Non-natal dens had significantly fewer holes ($M$ = 2, $\bar{x}$ = 2.2 ± 0.4) than natal dens ($M$ = 4, $\bar{x}$ = 4.4 ± 0.7; $F_{1, 43}$ = 7.3, $P$ = 0.01).

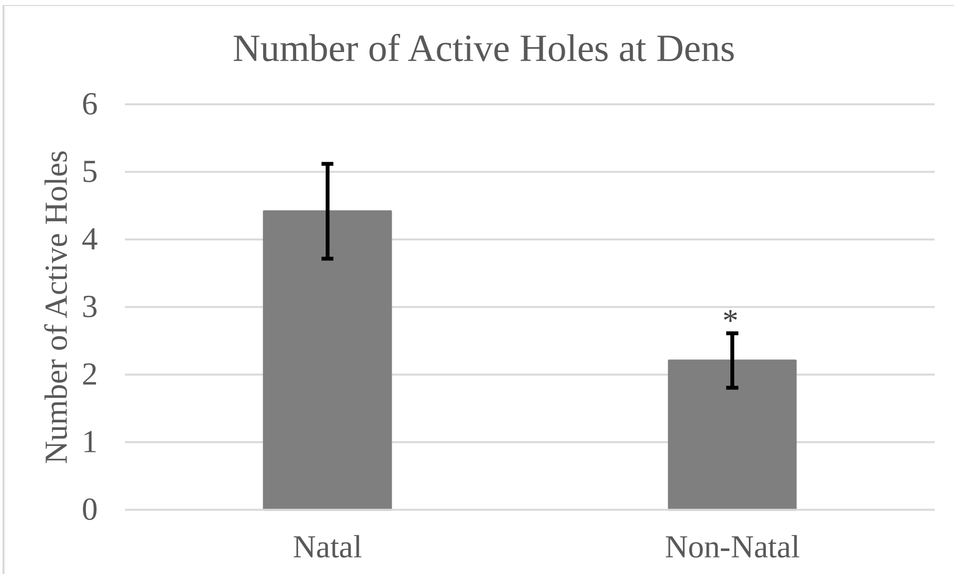


**Figure 3:** Distance to road (m) at natal dens, non-natal dens, and random locations around Badlands National Park and Buffalo Gap National Grassland, South Dakota, 2014–2016. * Random locations were significantly farther from roads ($\bar{x}$ = 557.4 ± 155.1 m) than natal dens ($\bar{x}$ = 160.9 ± 57.0 m; $F_{2, 54}$ = 3.6, $P$ = 0.04).

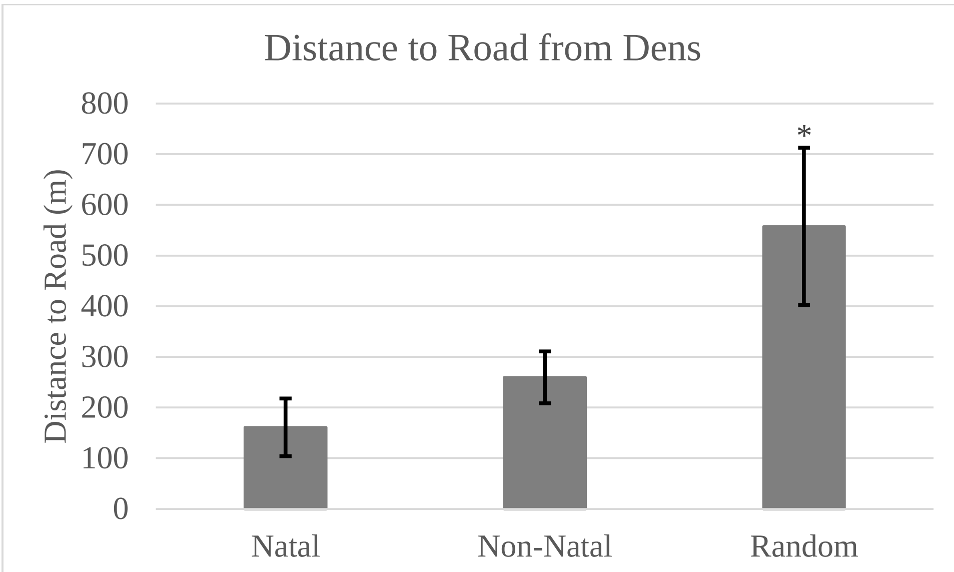
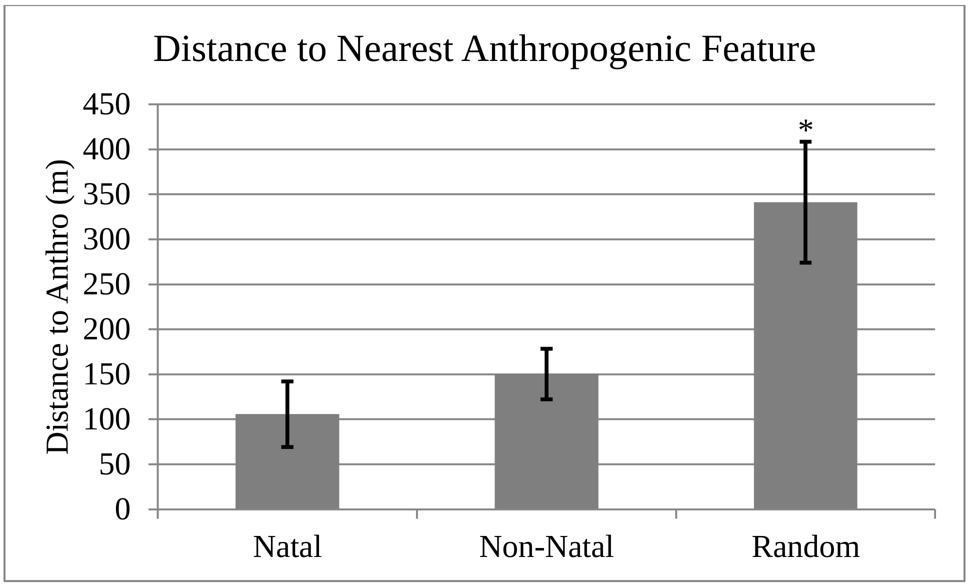


**Figure 4:** Distance (m) to nearest anthropogenic feature at natal dens, non-natal dens, and random locations around Badlands National Park and Buffalo Gap National Grassland, South Dakota, 2014–2016. * Random locations were significantly farther from anthropogenic features ($M$ = 300, $\bar{x}$ = 341.2 ± 67.2 m) than both natal ($M$ = 111, $\bar{x}$ = 105.8 ± 36.5 m; Tukey's HSD, P < 0.05) and non-natal ($M$ = 101, $\bar{x}$ = 150.3 ± 28.2 m; Tukey's HSD, $P$ < 0.05) dens.



# CHAPTER 4

## SEROLOGIC TESTING FOR PREVALENCE OF PLAGUE (*YERSINIA PESTIS*) IN SWIFT FOXES AROUND BADLANDS NATIONAL PARK, SOUTH DAKOTA

## ABSTRACT

Sylvatic plague (*Yersinia pestis*) was detected in black-tailed prairie dog (*Cynomys ludovicianus*) colonies in southwest South Dakota in 2008. No information on the status of reintroduced swift foxes (*Vulpes velox*) in this area has been collected since this epizootic began. Sixty-two blood samples were taken from swift foxes around Badlands National Park from 2014 to 2016. Blood saturated Nobuto filter paper strips were dried and stored at room temperature for 30–147 weeks prior to enzyme-linked immunosorbent assay (ELISA) analysis for F1 and LcrV antigens. A total of 69.6% of sampled foxes were seropositive for plague antibodies at some point during the study, which is higher than similar studies in the region. No difference was detected between seroprevalence and fox age or sex, nor was there a difference in distance to nearest prairie dog colony and seroprevalence. It is important to note that negative correlations were detected between storage time and both the elution score and dilution concentration, indicating that the storage of samples may have had a negative impact on sample integrity. I highly recommended Nobuto samples be stored in a freezer until ELISA analysis is conducted to preserve the quality of the samples.

## INTRODUCTION

Since establishing that reintroduced swift fox (*Vulpes velox*) populations in southwestern South Dakota were in jeopardy of extinction due to high potential mortality (Sasmal et al. 2013, Sasmal et al. 2016), an additional factor that could further affect population viability of swift foxes has colonized rangeland within the distribution of the species. Sylvatic plague is now evident within black-tailed prairie dog (*Cynomys ludovicianus*) colonies throughout western South Dakota. Although the relationship between swift foxes and prairie dogs is controversial, swift foxes have been documented consuming prairie dogs and living in prairie dog colonies (e.g., Russell 2006). Furthermore, swift foxes prefer shorter vegetation structure; taller vegetation height likely impacts the ability of swift foxes to detect predators (i.e., coyote [*Canis latrans*]), greatly affecting survival (Russell 2006, Sasmal et al. 2016, Sovada et al. 1998, Karki et al. 2007). Since the reintroduction in this area, there has been an apparent decline in the local swift fox population which is potentially related to plague, recent weather patterns, and possibly increased coyote numbers. Nevertheless, no information on the status of swift foxes in southwestern South Dakota has been collected since a viability analysis was completed in 2011 (Sasmal 2011, Sasmal et al. 2016), which was based on data collected pre-colonization of plague. Consequently, no comprehensive information is available regarding the status of swift foxes in areas where prairie dog colonies have been decimated by plague.

Plague is caused by the bacterium *Y. pestis* and is not native to North America. This deadly bacterial disease is transmitted by fleas and frequently causes epizootics resulting in 90–100% mortality rates in infected prairie dog colonies (McGee et al. 2006), though many other mammals, including rodents, felines, and endangered black-footed ferrets (*Mustela nigripes*) are susceptible to the disease. Swift foxes use prairie dog burrows for denning and consume prairie dogs as a food source, particularly during pup-rearing (Russell 2006). Carnivores likely contract the disease from consuming infected prey or by flea bites (Baeten et al. 2013, Malmlov et al. 2014), though they are not the primary host for the flea that carries plague (*Pulex simulans*; Pence et al. 2004). Swift foxes are presumed resistant to the development of clinical disease and mortality, seeing as they seroconvert when exposed, similar to coyotes (Gage and Kosoy 2005, Malmlov et al. 2014).

In May 2008, plague was documented in prairie dog colonies in Conata Basin, south of Badlands National Park (Figure 1). In an effort to protect the endangered black-footed ferret, which is an obligate carnivore to prairie dogs for prey and burrow systems (Biggins et al. 2006), federal agencies (US Forest Service, National Park Service, and US Fish & Wildlife Service) began dusting prairie dog colonies. DeltaDust® (0.05% deltamethrin; Bayer, Montvale, New Jersey) is an insecticide that kills fleas, a vector of plague, and is applied via mechanical dust dispensers (Technidusters, Technicide, San Clemente, California; Livieri 2013) annually to individual prairie dog burrows in specified colonies throughout the study area. Even with intense management, there has been a loss of over 60% of the prairie dog colony acreage within the study area since 2008 (Livieri 2013).

In 2014, I began a three-year research project to assess the current status of reintroduced swift fox in the Badlands region of South Dakota. The objectives of this study were to estimate the seroprevalence of *Y. pestis* in the swift fox population, indicating exposure to plague, and to assess the biogeography of swift foxes in areas affected by plague.

## STUDY AREA

The 2,600 $km^2$ study area was located in southwestern South Dakota and included the North Unit of Badlands National Park and the surrounding Buffalo Gap National Grassland (Figure 1). Seventeen percent of the area was managed by the National Park Service, 36% by the United States Forest Service (Buffalo Gap National Grassland), and

47% was privately owned. Much of the surrounding land was used for cattle ranching, which is the major industry in the region (Schroeder 2007). The area has a continental climate with a mean annual precipitation of 40 cm. Temperatures vary between -23° C and 42° C. Elevation ranges from 691 to 989 m above mean sea level (Russell 2006). Soils in the study area are composed mostly of midway clay loam with a low water holding capacity (Whisenant and Uresk 1989). Badlands National Park is comprised of rugged geologic formations (e.g., buttes and pinnacles) along a wall running northwest to southeast through the North Unit of the park. On either side of the wall topography is flat to rolling mixed-grass prairie, dominated by buffalograss (*Buchloe dactyloides*), western wheatgrass (*Pascopyrum smithii*), and prickly pear cactus (*Opuntia polyacantha*), with minimal tree and brush species (Russell 2006).

**METHODS**

*Serology:*

I trapped foxes in Tomahawk Live Traps (Professional Series model 108SS, Tomahawk, WI) from May to November 2014, May to September 2015, and August 2016. Trapped foxes were coaxed into a canvas sack and scanned with an AVID PowerTracker (Avid Identification Systems, Inc., Norco, CA) to identify previously captured foxes. Foxes were scruffed and physically restrained with thick leather gloves with one hand covering the eyes and ears, to minimize visual and auditory stimulation, and held with jaws closed to prevent bites. I recorded sex and aged foxes (pup < 1 year old; or adult > 1 year old) based on tooth wear. Unmarked animals were PIT tagged (AVID FriendChip, Avid Identification Systems, Inc., Norco, CA) between the scapulae, and I collected samples of blood, fleas, ticks, and hair.

I drew blood from the cephalic vein of the front leg of each swift fox with a 25 gauge, ¾ inch needle. I collected 1 cc of whole blood, then expelled it carefully onto two Nobuto blood filter strips (Toyo Roshi Kaisha, Ltd., Tokyo, Japan), fully saturating both sides of the strips. After strips were dry, I placed them in paper coin envelopes and stored at ambient room temperature and humidity until they were assayed (4 March 2017). Animal trapping and handling methods were approved by the Institutional Animal Care and Use Committee at South Dakota State University (Approval Number 14-020A) and under compliance with the National Park Service (Permit Number BADL-2014-SCI-0020, and BADL-2014-SCI-0031).

I also collected blood samples from swift fox mortalities. If a freshly dead (< 24 hours) swift fox was located, I cut open their chest cavity and dipped two Nobuto filter strips into the blood in and around the heart, being sure to avoid areas that may have been contaminated from other bodily fluids or material.

Antibody titers of fraction 1 capsular antigen protein (F1) and low calcium response V antigen protein (LcrV) were determined using enzyme-linked immunosorbent assay (ELISA) for immunoglobin G (IgG) as described by Rocke et al. (2004), with modifications, at Colorado State University, Fort Collins, Colorado. Briefly, modifications included the use of recombinant antigens F1 and LcrV (BEI Resources, Manassas, VA) to coat plates and horseradish peroxidase conjugated Protein A/G (at 1:10,000; Pierce Biotechnology, Rockford, IL) used for the secondary antibody. Presence of either of the two antigens indicates presence of plague antibodies in the blood and therefore, exposure to the *Y. pestis* bacterium (Gomes-Solecki et al. 2005). The F1 antigen was previously believed to be an important virulence factor adding to the effectiveness of *Y. pestis* immunosuppression, but F1-negative strains of *Y. pestis* have been reported (Gomes-Solecki et al. 2005). Therefore, samples were also tested for the presence of the LcrV antigen, which has been confirmed to be an essential virulence factor in *Y. pestis* (Gomes-Solecki et al. 2005). A sample can be negative for F1 but still carry plague, so an additional test was used for LcrV, which is a newer and more accurate antigen when detecting antibodies to plague.

A positive plague titer was considered ≥ 1:50 dilution concentration (L. Baeten, Colorado State University, personal communication). If a positive titer was detected at 1:50, the sample was subsequently diluted to 1:150 or 1:450 to assess highest concentration, with 1:450 being the most concentrated. Elution scores (1–4) were assessed visually based on the color change after samples were eluted in ELISA buffer. Elution scores of 3 and 4 are considered reliable for negative titer results, while elution scores of 1 and 2 can produce false negatives because of the lower quality of the sample (L. Baeten, Colorado State University, personal communication). A positive result at any elution score is considered reliable. Chi-square analysis was used to test for differences between seroprevalence and both age and sex. Only negative results with elution score of 3 and 4 were analyzed to eliminate potential false negatives, along with all positive titer results.

*Biogeography:*

The United States Forest Service (Buffalo Gap National Grassland, Wall, South Dakota) and the National Park Service (Badlands National Park, Interior, South Dakota) have monitored hectares and activity (i.e., extinct or active) of prairie dog colonies since 1993, and annually since 2003. The agencies map colonies in Trimble TerraSync™

software on a handheld Trimble GeoExplorer 2008 GPS unit (Trimble®, Sunnyvale, CA) and incorporate the data into a Geographic Information System (GIS) using various versions of Environmental Systems Research Institute (ESRI; Redlands, California) software.

Dusting status of colonies during this study was provided by Buffalo Gap National Grassland and Badlands National Park. I estimated the distance to nearest prairie dog colony in ArcMap 10.3.1 (Envrionmental Systems Research Institute, Redlands, California) as shortest straight line distance from capture location to the nearest edge of a prairie dog colony polygon. I used a *t*-test to compare distance to nearest prairie dog colony and seroprevalence; only negative results with elution score of 3 and 4 were analyzed, along with all positive titer results.

**RESULTS**

*Serology:*

Sixty-two samples from fifty-six foxes were analyzed for exposure to *Y. pestis*. Sixteen samples (25.8%) produced a positive result for F1 and/or LcrV titers (Table 1). Of the remaining 46 samples, nine had reliable elution scores (3 or 4) to indicate a negative result. The remaining 37 samples produced negative results, but the elution scores were too low (1 or 2) to be reliable, indicating the potential that these could be false negatives. Therefore, of all seropositive foxes and all reliable negative elution scores, 16/25 samples (64.0%) were positive and 16/23 individual foxes (69.6%) were positive.

Six foxes had blood collected twice during the study (Table 1: Fox ID 951, 1034, 1211, 1213, 1305, 1306). Of these, two (Fox ID 1305 and 1306) had high enough elution scores to compare the two different dates and results. Both of these foxes had negative results the first time blood was drawn and positive results the second time blood was drawn (Table 1: Sample ID 43 and 54, 44 and 52), 322 and 25 days apart, respectively.

There was no statistical difference between pups (< 1 year old) and adults (≥ 1 year old) with regard to positive titer results ($X^2 = 0.07$, $P = 0.79$). I sampled near equal numbers of pups ($n = 13$) and adults ($n = 12$) and found equal numbers of positive plague titers ($n = 8$). There was no statistical difference ($X^2 = 0.62$, $P = 0.43$) between male ($n = 8$; 75.0% positive) and female ($n = 17$; 58.8% positive) foxes and seroprevalence. All three samples taken from freshly dead swift foxes produced reliable elution scores (Table 1: Sample ID 26, 27, 52).

*Biogeography:*

The average distance to the nearest prairie dog colony for seropositive foxes ($n = 16$; $\bar{x} = 1.03 \pm 0.20$ km) was not statistically different ($t_{23} = 1.07$, $P = 0.29$) than seronegative foxes ($n = 9$; $\bar{x} = 1.78 \pm 0.87$ km). Only one of the nearest colonies had been dusted during the duration of the project; both foxes found nearest to this colony were negative for plague titers, with elution scores of 2 indicating potential for a false negative.

## DISCUSSION

*Serology:*

In the population of swift foxes surrounding Badlands National Park, 69.6% of sampled foxes were seropositive for plague antibodies. This level of plague exposure is higher than similar studies of swift foxes in Colorado, which ranged from 0% to 57%

(Salkeld et al. 2007, Gese et al. 2004, Miller et al. 2000). With a recent epizootic and *Y. pestis* still present in prairie dog colonies (Mize and Britten 2016, Livieri 2013), it is not surprising that so many foxes tested positive for plague.

I found no relationship or difference between age and seropositive foxes; pups were equally as likely to be seropositive as were adults. Pups trapped as early as 3 August, approximately 3 months old, were positive for plague antibodies indicating exposure. However, Salkeld et al. (2007) found a significant positive relationship between fox weight (which the authors used as an indicator of age) and seroprevalence of *Y. pestis*. Gese et al. (1997) found a similar relationship between seroprevalence and age in coyotes.

Blood samples collected from freshly dead (< 24 hours) swift foxes produced reliable elution scores and results (Table 1: Sample ID 26, 27, 52). This corroborates findings by Bevins et al. (2016) that posteuthanasia samples collected from the body cavity did not significantly affect antibody titer compared to samples collected directly from venous blood of live specimens.

There was a correlation between the date samples were collected and the elution score, with older samples having lower scores than newer samples (Figure 2). Of the 2014 samples, only 7.7% (2/26) had elution scores of 3 or 4. Of the 2015 samples, 34.6% (9/26) had elution scores of 3 or 4. While in 2016, 100% (10/10) had elution scores of 3 or 4. Similarly, there was a correlation between the date samples were collected and the dilution concentrations, with older samples being less concentrated than newer samples (Figure 3). Of the 2014 samples, only one was seropositive for the LcrV antigen, and was detected the lowest dilution concentration: 1:50. In 2015, six samples were positive, 83.3% of which were the lowest concentration and 16.7% were at the mid-range concentration: 1:150. In 2016, nine samples were positive, with 11.1% mid-range and the remaining 88.9% in the highest dilution concentration: 1:450. With this negative correlation between both elution score and concentration of plague anitgens with the age of the samples, I believe the storage time and conditions had an effect on the quality of the samples. Therefore, my results indicating 69.6% of foxes were seropositive for plague may be an underestimate, with poor storage methods potentially creating many false negatives.

The Nobuto filter paper manufacturer recommends avoiding sunlight, ultraviolet light, water, extreme temperatures, and moisture, and to store samples “in a clean indoor space” (Toyo Roshi Kaisha, Ltd., Curry et al. 2014). However, more specific storage parameters have been recommended in recent publications (e.g., Bevins et al. 2016, Dusek et al. 2011, Curry et al. 2014) depending on assay and length of storage. It became clear after analyzing the results and apparent correlations between holding time and elution and dilution variables that the swift fox blood samples should have been stored in refrigeration (4° C) or a freezer (-20° C) with desiccant, and not at ambient room temperature and humidity. Although the means of analysis (i.e., ELISA) may determine specific parameters for storage, current publications recommend the length of time to store Nobuto samples at room temperature is 10–12 weeks before analysis (Bevins et al. 2016, Dusek et al. 2011, Curry et al. 2014). My samples were stored for 30–147 weeks. Results from this study show reliable plague titers (elution score of 4) can be obtained by ELISA analysis of Nobuto strips if stored at room temperature for 30 weeks (214 days; Table 1: Sample ID 53–62). The longest storage time with a reliable elution score of 3 was 125 weeks (877 days; approximately 2 years 5 months: Table 1: Sample ID 23). Even with these results, I highly recommend that future studies store Nobuto blood samples in a freezer (-20° C) with desiccant until analysis to prevent degradation to the quality of the samples.

*Biogeography:*

The distance to the nearest prairie dog colony had no apparent effect on seroprevalence. This is quite different than results by Salked et al. (2007) who found a strong association between exposure to plague and distance to nearest colony that experienced a plague epizootic. This study area experienced a recent epizootic of *Y. pestis* in prairie dog colonies (Mize and Britten 2016, Livieri 2013), but the bacterium can be found in a broad range of hosts, especially rodents of the families Cricetidae, Muridae, and Sciuridae (Gage and Kosoy 2005). Therefore, I do not believe distance to prairie dog colony is a key variable in predicting seroprevalence in swift foxes because rodents throughout the study area may carry *Y. pestis*.

I only had two foxes for which the nearest colony had been dusted, and both foxes were negative for plague titers, with elution scores of 2. Because of this small sample size and swift fox behavior, I do not consider the dusted status of the colony as having an effect on the serological results. Swift foxes in this region may cover multiple prairie dog colonies because of the fragmented distribution of colonies across the landscape, particularly in Conata Basin where this dusted colony was located. These two foxes likely spent time hunting, scavenging, or even living in another colony that had not been dusted.

## MANAGEMENT IMPLICATIONS

I do not believe that swift foxes play a significant role as a vector in dissemination of *Y. pestis* in the Badlands region, similar to the conclusions of McGee et al. (2006) and Salkeld et al. (2007). Management of plague should continue by dusting and monitoring prairie dog colonies. The population of swift foxes around the Badlands region should continue to be monitored, and if blood is taken, it should be stored on Nuboto filter strips in a freezer until ELISA analysis to maintain sample integrity.

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**Table 6**: Plague titer results for 62 swift fox blood samples from southwestern South Dakota, 2014–2016.

[T] = Fox was sampled twice during study; [M] = Sample was collected as a mortality

* = Indicated reliable negative elution score; all other negative results could be false negatives.

A = Adult (≥ 1 year old); P = Pup (< 1 year old)

F1 = Concentration of F1 antigen; LcrV = Concentration of LcrV antigen

Neg = Negative for corresponding plague antigen

| Sample ID | Fox ID | Sex | Age | Nobuto Collected | Days Until Analysis | Elution Score | F1 | LcrV |
|---|---|---|---|---|---|---|---|---|
| 1 | 1208 | F | A | 5/9/2014 | 1030 | 2 | Neg | Neg |
| 2 | 1209 | M | A | 5/10/2014 | 1029 | 2 | Neg | Neg |
| 3 | 1210 | M | A | 5/10/2014 | 1029 | 1 | Neg | Neg |
| 4 | 951[T] | F | A | 6/19/2014 | 989 | 1 | Neg | Neg |
| 5 | 1211[T] | M | A | 6/19/2014 | 989 | 1 | Neg | Neg |
| 6 | 857 | M | A | 6/24/2014 | 984 | 2 | Neg | Neg |
| 7 | 1034[T] | F | A | 6/24/2014 | 984 | 2 | Neg | Neg |
| 8 | 1212 | F | A | 7/3/2014 | 975 | 2 | Neg | Neg |
| 9 | 1402 | F | P | 7/3/2014 | 975 | 1 | Neg | Neg |
| 10 | 816 | M | A | 7/23/2014 | 955 | 2 | Neg | Neg |
| 11 | 770 | M | A | 7/24/2014 | 954 | 1 | Neg | Neg |
| 12 | 1213[T] | F | A | 8/12/2014 | 935 | 2 | Neg | Neg |
| 13 | 1404 | F | P | 8/12/2014 | 935 | 2 | Neg | Neg |
| 14 | 1405 | M | P | 8/12/2014 | 935 | 1 | Neg | Neg |
| 15 | 1406 | M | P | 8/12/2014 | 935 | 2 | Neg | Neg |
| 16 | 1034[T] | F | A | 9/2/2014 | 914 | 2 | Neg | Neg |
| 17 | 1408 | M | P | 9/5/2014 | 911 | 2 | Neg | Neg |
| 18 | 1301 | M | A | 9/12/2014 | 904 | 1 | Neg | Neg |
| 19 | 1409 | F | P | 9/12/2014 | 904 | 2 | Neg | Neg |
| 20 | 1214 | F | A | 9/13/2014 | 903 | 2 | Neg | Neg |
| 21 | 1215 | M | A | 9/13/2014 | 903 | 2 | Neg | Neg |
| 22 | 1410 | M | P | 9/13/2014 | 903 | 2 | Neg | Neg |
| 23 | 1216 | F | A | 10/9/2014 | 877 | 3 | Neg* | Neg* |

| Sample ID | Fox ID | Sex | Age | Nobuto Collected | Days Until Analysis | Elution Score | F1 | LcrV |
|---|---|---|---|---|---|---|---|---|
| 24 | 1302 | M | A | 10/10/2014 | 876 | 2 | Neg | Neg |
| 25 | 1303 | M | A | 11/5/2014 | 850 | 1 | Neg | Neg |
| 26 | 1411 [M] | F | P | 11/8/2014 | 847 | 3 | Neg* | Neg* |
| 27 | 1113 [M] | M | A | 3/17/2015 | 718 | 3 | 1:50 | 1:50 |
| 28 | 1203 | M | A | 5/28/2015 | 646 | 2 | Neg | Neg |
| 29 | 1304 | M | A | 7/21/2015 | 592 | 3 | Neg* | Neg* |
| 30 | 1501 | F | P | 8/4/2015 | 578 | 2 | Neg | Neg |
| 31 | 1502 | F | P | 8/4/2015 | 578 | 2 | Neg | Neg |
| 32 | 1503 | F | P | 8/4/2015 | 578 | 3 | Neg* | Neg* |
| 33 | 1504 | M | P | 8/4/2015 | 578 | 2 | Neg | Neg |
| 34 | 1505 | M | P | 8/4/2015 | 578 | 2 | Neg | Neg |
| 35 | 1506 | M | P | 8/4/2015 | 578 | 2 | Neg | Neg |
| 36 | 1507 | M | P | 8/4/2015 | 578 | 1 | Neg | Neg |
| 37 | 1508 | F | P | 9/3/2015 | 548 | 1 | Neg | Neg |
| 38 | 1509 | F | P | 9/3/2015 | 548 | 3 | Neg* | Neg* |
| 39 | 1510 | F | P | 9/3/2015 | 548 | 2 | Neg | Neg |
| 40 | 1511 | F | P | 9/5/2015 | 546 | 2 | Neg | Neg |
| 41 | 1512 | M | P | 9/5/2015 | 546 | 2 | Neg | Neg |
| 42 | 1513 | F | P | 9/5/2015 | 546 | 3 | Neg* | Neg* |
| 43 | 1305 [T] | M | A | 9/15/2015 | 536 | 3 | Neg* | Neg* |
| 44 | 1306 [T] | F | A | 9/15/2015 | 536 | 3 | Neg* | Neg* |
| 45 | 1412 | F | A | 9/15/2015 | 536 | 2 | Neg | 1:50 |
| 46 | 1514 | F | P | 9/15/2015 | 536 | 2 | 1:50 | 1:50 |
| 47 | 1515 | M | P | 9/15/2015 | 536 | 2 | 1:150 | 1:150 |
| 48 | 1307 | F | A | 9/21/2015 | 530 | 2 | 1:50 | 1:50 |
| 49 | 1516 | F | P | 9/21/2015 | 530 | 3 | Neg* | 1:50 |
| 50 | 1308 | F | A | 9/26/2015 | 525 | 2 | Neg | Neg |
| 51 | 1517 | M | P | 9/26/2015 | 525 | 2 | Neg | Neg |
| 52 | 1306 [M T] | F | A | 10/10/2015 | 511 | 3 | 1:50 | 1:50 |
| 53 | 1211 [T] | M | A | 8/2/2016 | 214 | 4 | 1:150 | 1:450 |
| 54 | 1305 [T] | M | A | 8/2/2016 | 214 | 4 | 1:150 | 1:450 |
| 55 | 1602 | F | P | 8/2/2016 | 214 | 4 | 1:50 | 1:450 |
| 56 | 1603 | F | P | 8/2/2016 | 214 | 3 | Neg* | Neg* |
| 57 | 1604 | F | P | 8/2/2016 | 214 | 4 | 1:450 | 1:450 |
| 58 | 951 [T] | F | A | 8/3/2016 | 213 | 4 | 1:150 | 1:450 |
| 59 | 1213 [T] | F | A | 8/3/2016 | 213 | 4 | 1:50 | 1:150 |
| 60 | 1605 | F | P | 8/3/2016 | 213 | 4 | 1:450 | 1:450 |
| 61 | 1606 | M | P | 8/3/2016 | 213 | 4 | 1:450 | 1:450 |
| 62 | 1607 | M | P | 8/3/2016 | 213 | 4 | 1:450 | 1:450 |

**Figure 6:** Swift fox study area around Badlands National Park and Buffalo Gap National Grassland, South Dakota, 2014–2016. Conata Basin, where plague was first detected in 2008, is denoted. NAD 1983 UTM Zone 13N

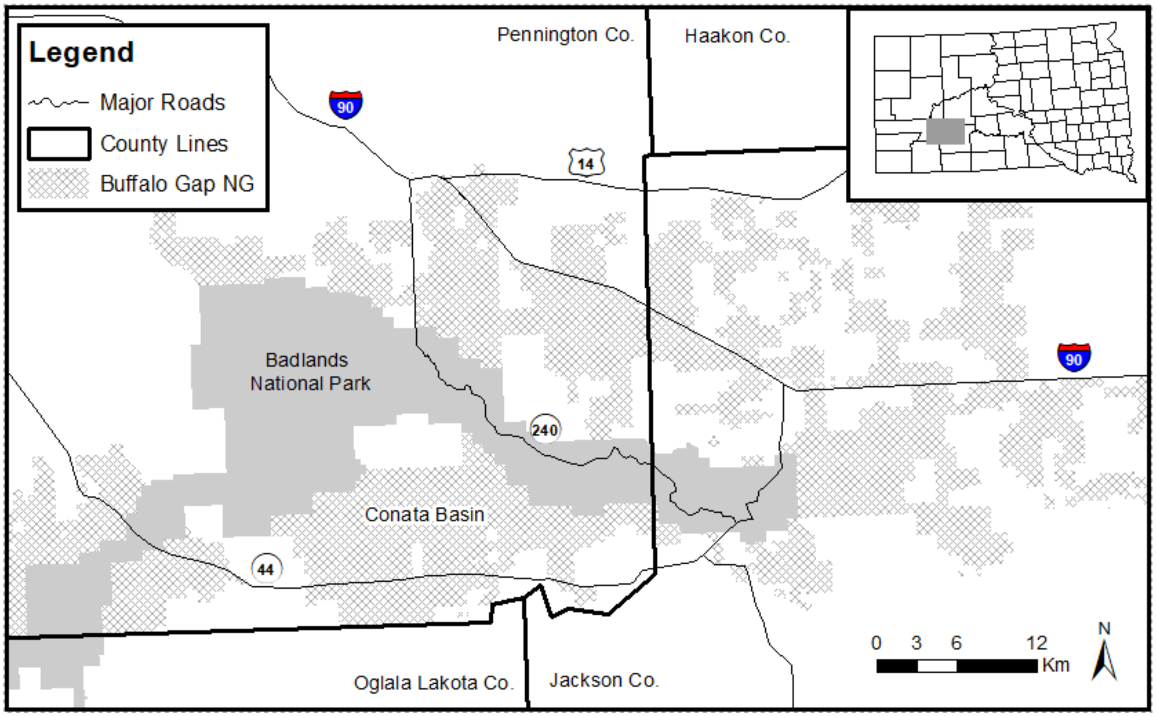


**Figure 7:** Elution score (1: lowest, 4: highest) for blood samples collected from swift foxes in southwest South Dakota and stored on Nuboto filter paper. Elution scores of 3 and 4 are considered reliable for negatives, while elution scores of 1 and 2 may produce false negatives. Only 7.7% (2/26) of samples collected in 2014 provided reliable elution scores; 34.6% (9/26) of samples collected in 2015 provided reliable elution scores; while 100.0% (10/10) of samples collected in 2016 provided reliable elution scores.

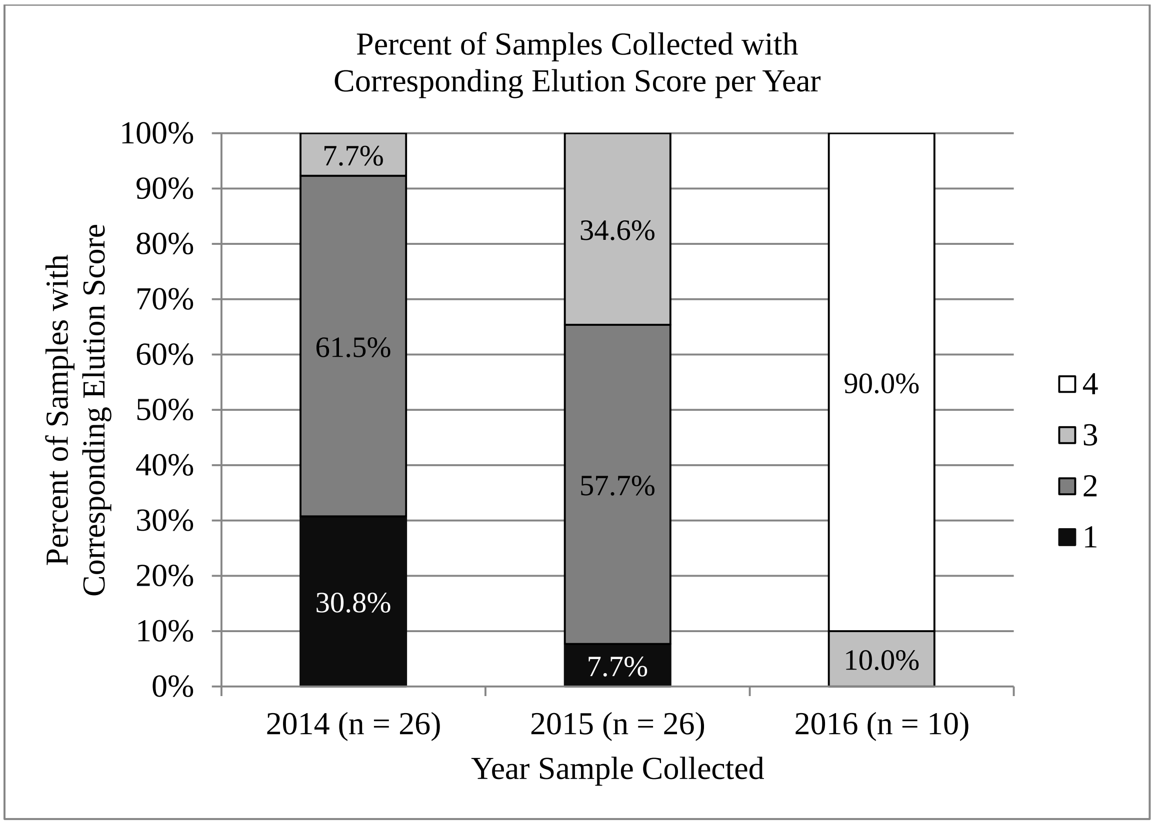
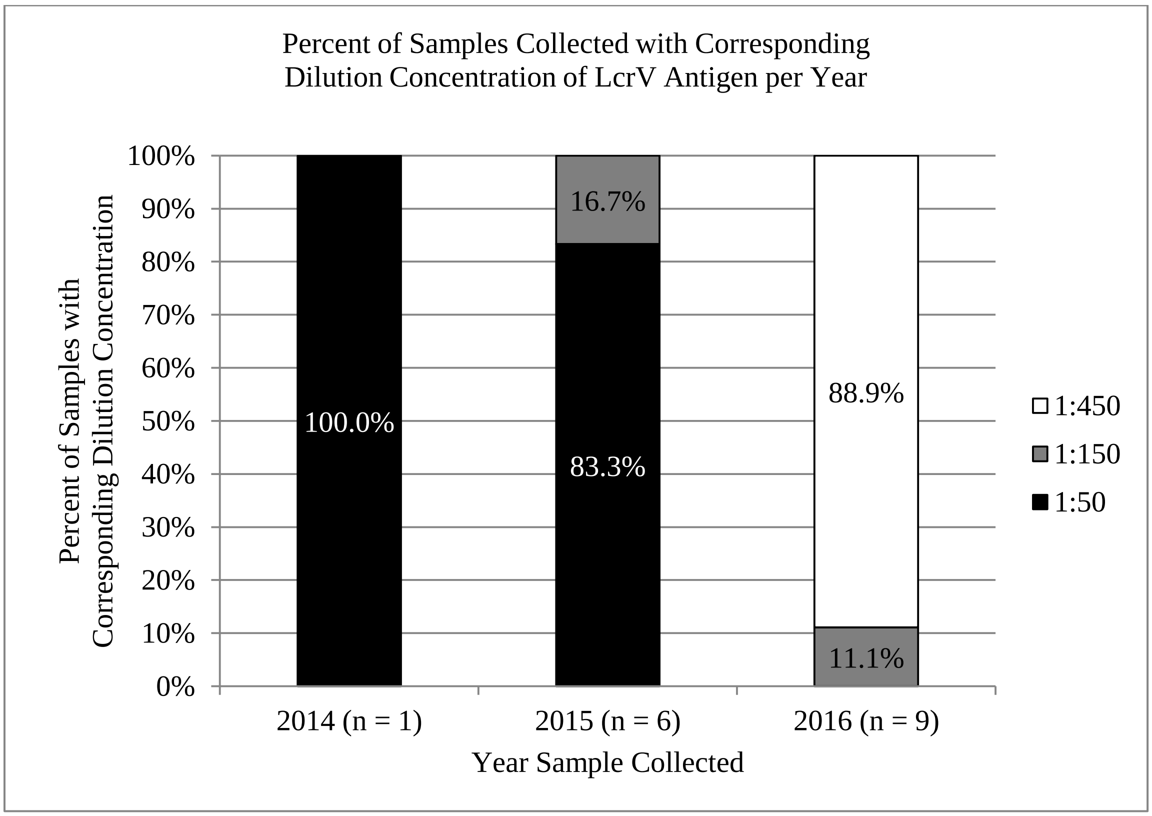


**Figure 8:** Dilution concentration of LcrV antigen in blood samples collected from swift foxes in southwest South Dakota. A dilution concentration of 1:50 is the lowest concentration considered positive for LcrV antigen, and therefore positive for plague exposure. Only one sample was seropositive in 2014, and had the lowest dilution concentration of 1:50. In 2015, concentrations were slightly higher, with 16.7% having mid-range dilution concentrations of 1:150. Samples collected in 2016 had the highest dilution concentrations with most samples (88.9%) at 1:450.



# CHAPTER 5

# EVALUATION OF AN ATTEMPT TO HAND-REAR AND RELEASE WILD SWIFT FOXES (*VULPES VELOX*) AS A TOOL FOR CONSERVATION OF A STATE THREATENED SPECIES IN SOUTH DAKOTA

## ABSTRACT

In July 2015, two dens of swift fox (*Vulpes velox*) pups became orphaned in the reintroduced population established around Badlands National Park, South Dakota, when both sets of parents died. A team of biologists decided to trap, hand-rear, and release the pups back into the population as a tool for conservation of this state threatened species. The seven orphaned pups were transported to Dakota Zoo in Bismarck, North Dakota and hand-reared for 55 days, at which time they were fitted with VHF radio-collars and released back into their natal dens. Survival after one year was 0.00. Mortality was attributed to vehicular collision for five pups (71%), and coyotes (*Canis latrans*) for two pups (29%), with a significant difference in longevity post-release between foxes killed by vehicles ($\mu$ = 13 ± 4 days) and those killed by coyotes ($\mu$ = 140 ± 43 days). Two foxes lived well beyond the average for the released pups and thus, the hand-rearing and release method may potentially be deemed successful for these two foxes. Although sample size in this investigation was limited, results indicated that the chance of success of this method of fostering abandoned swift fox pups is low.

## INTRODUCTION

The swift fox, once abundant throughout the Great Plains of North America, was nearly extirpated by the 1900's due to habitat conversion, unregulated trapping, and poisoning programs (Kilgore 1969, Egoscue 1979, Carbyn 1994, Allardyce 2003). Precluded from listing by the US Fish and Wildlife Service in 1994, the swift fox is listed as threatened in South Dakota. Currently, a remnant population inhabits the extreme southwestern corner of the state in Fall River County. In addition, between 2003 and 2006, a total of 114 translocated swift foxes from Colorado and Wyoming were released at Badlands National Park (Schroeder 2007). Genetic analysis provided strong evidence that the reintroduction was successful (Sasmal et al. 2013), but further analysis indicated the long-term viability of the population may be in jeopardy with a high probability of extinction due to high mortality rates (Sasmal 2011, Sasmal et al. 2016).

Since the reintroduction, there has been an apparent decline in this local population, which is potentially related to many biotic and abiotic factors (e.g., effects of plague [*Yersinia pestis*], recent weather patterns, and possibly increased coyote numbers). In 2008, sylvatic plague was detected in Conata Basin, immediately south of Badlands National Park, and is now evident throughout western South Dakota. No comprehensive information on the status of swift foxes in southwestern South Dakota has been collected since the viability analysis was conducted in 2011, which was based on data collected pre-colonization of plague (Sasmal 2011, Sasmal et al. 2016).

In 2014, I began a three-year research project to assess the current status of reintroduced swift fox in the Badlands population. This region of the state is within the historic distribution of the species and is representative of the area of effect of previous restoration efforts during the past decade. As part of this research, adult foxes were trapped, VHF radio-collared, and located ≤ 5 times per week.

In June 2015, two adult male swift foxes from different dens died, leaving lone adult female foxes to care for litters. Both females subsequently died in July, leaving seven orphaned swift foxes in the Badlands population. With no official protocol previously in place, a team of seven biologists decided to trap and hand-rear these foxes at an accredited zoo and release them back into their native home range when they were at a self-sustaining age. This paper describes the methods, decisions process, results, and recommendations of this hand-rear and release method as a tool for conservation of this state threatened species.

**STUDY AREA**

The 2,600 $km^2$ study area was located in southwestern South Dakota and included the North Unit of Badlands National Park and the surrounding area (Figure 1). Seventeen percent of the area is managed by the National Park Service, 36% by the United States Forest Service (Buffalo Gap National Grassland), and 47% is privately owned. Much of the surrounding land is used for cattle ranching, which is the major industry in the region (Schroeder 2007). The area has a continental climate with a mean annual precipitation of 40 cm. Temperatures vary between -23° C and 42° C. Elevation ranges from 691 to 989 m above mean sea level (Russell 2006). Soils in the study area are composed mostly of midway clay loam with a low water holding capacity (Whisenant and Uresk 1989). Badlands National Park is comprised of rugged geologic formations (e.g., buttes and pinnacles) along a wall running northwest to southeast through the North Unit of the Park. On either side of the wall topography is flat to rolling mixed-grass prairie, dominated by buffalograss (*Buchloe dactyloides*), western wheatgrass (*Pascopyrum smithii*), and prickly pear cactus (*Opuntia polyacantha*), with minimal tree and brush species (Russell 2006).

**METHODS**

On 3 June 2015, an adult male swift fox “Conata Male” died from vehicular collision on Highway 44 west of Interior, South Dakota in Conata Basin (Figure 1). This left his mate “Conata Female” alone to raise their 5 pups. Conata Female died on 2 July 2015, 29 days later, on Highway 44 west of Interior, South Dakota in Conata Basin.

Thus, the 5 pups, approximately 8 weeks old, were orphaned at the Conata Den, located on United States Forest Service property; Buffalo Gap National Grassland (Figure 1).

On 6 June 2015, an adult male swift fox “Quinn Male” died from unknown causes near Highway 14 west of Quinn, South Dakota (Figure 1). This left his mate “Quinn Female” alone to raise their 2 pups. Quinn Female died on 10 July 2015, 34 days later, from coyote intraguild predation. As a result, the 2 pups, approximately 9 weeks old, were orphaned at the Quinn Den, located on private land, north of Badlands National Park.

I hypothesize that the deaths of both females was due in part to the additional stress of caring for litters without assistance from a mate. The parental demands of pups is highest June through August when they are above ground and require parental care, including procuring food for the litter (Egoscue 1962).

There existed no official protocol for this situation with any participating agency; South Dakota Game, Fish & Parks (SDGFP), South Dakota State University (SDSU), United States Forest Service (USFS), or National Park Service (NPS). A team of seven biologists from SDGFP, SDSU, USFS, and the Swift Fox Species Survival Plan® (SSP) Coordinator held a conference call on 27 July 2015 to determine the fate of the orphaned pups. It was decided that the foxes would be trapped and hand-reared at Dakota Zoo in Bismarck, North Dakota, then released back at their natal dens when the pups were of independent age. This decision was based on the threatened status of swift foxes in South Dakota, the fragile state of the Badlands population, and the understanding that swift fox pups are not usually independent until the end of August (Egoscue 1979, Kilgore 1969), meaning that if we did not intervene, the pups would have a low chance of survival. The estimated age of the pups at the time of the conference call was 12 weeks (Chapter 3), and behavioral observations indicated the pups were not yet leaving the den area to explore or hunt. Dakota Zoo was chosen based on its current Association of Zoos and Aquariums (AZA) Accreditation, its history with hand-rearing swift fox pups and adults in the past for management and conservation purposes, its current resident swift foxes and staff trained in caring for the species, and its proximity to the Badlands population. It also was determined at the time of the conference call that the survival of these pups would be censored from the estimates provided for pups that remained in the wild.

Between the dates when the foxes became orphaned and when the hand-rearing plan was discussed, pups were supplementally fed at their dens; 25 days for Conata pups and 17 days for Quinn pups. This was decided between me and the biologists at SDSU and NPS until we would arrange for a formal conference call with the entire team. Food included black-tailed prairie dogs (*Cynomys ludovicianus*) provided by Badlands National Park, and vehicle killed white-tailed jackrabbits (*Lepus townsendii*), which are part of the native diet of swift foxes in this area (Uresk and Sharps 1986). Foxes were supplementally fed (averaging 1000–1750 grams/fox/week) twice per week to minimize human disturbance (i.e., imprinting). I also monitored dens continuously with motion activated trail cameras (HC600 HyperFire Covert Camera, RECONYX, Holeman, WI) placed 3–4 meters from the main natal den hole, which were checked each time the foxes were fed. This allowed me to monitor of the health of the foxes, playing behaviors, and food consumption, which was important considering they were never observed above ground when food was delivered.

On 4 August 2015, all seven foxes were trapped in 81.3 x 25.4 x 30.5 cm Tomahawk Live Traps (Professional Series model 108SS, Tomahawk, WI) with 2.5 x 1.3 cm, 14 gauge wire mesh, set directly at the dens. Traps were baited with quartered black-tailed prairie dog, set shortly before sundown (1800–2000), and checked shortly after sunrise (0500–0700). All seven pups were trapped in one night. Foxes were coaxed into a canvas sack and weighed (model 80210; Pesola® Macro-Line Spring scale, Baar, Switzerland). Foxes were scruffed and physically restrained with thick leather gloves with one hand covering the eyes and ears, to minimize visual and auditory stimulation, and held with jaws closed to prevent bites. Sex and body condition were recorded, pups were PIT tagged (AVID FriendChip, Avid Identification Systems, Inc., Norco, CA) between the scapulae, and samples of blood, fleas, ticks, and hair were collected. Flea and tick powder (Zodiac, Schaumburg, Illinois) was applied to reduce vector dissemination of ectoparasites. Pups were placed with siblings in large 66 x 38 x 47 cm canine crates lined with hay. Den cameras were removed at this time.

Animal trapping and handling methods were approved by the Institutional Animal Care and Use Committee at South Dakota State University (Approval Number 14-020A) and under compliance with the National Park Service (Permit Number BADL-2014-SCI-0020, and BADL-2014-SCI-0031.) A Director's Permit was obtained from the North Dakota Game and Fish Department (Permit Number 6368) for Dakota Zoo to care for the seven pups until they were returned to South Dakota Game, Fish and Parks. Foxes were then inspected and certified by a veterinarian for transport to Dakota Zoo in North Dakota. They received the Nobivac® Puppy-DPv vaccination for canine distemper and canine parvovirus, and the IMRAB® rabies vaccine at this time.

On 5 August 2015, pups were transported to Dakota Zoo and housed together in a 6 x 6 x 2 meter outdoor pen with two underground dens. The pen was entered once per day by zoo staff to feed and water, no human voice communication was made, and the pups were generally underground during visitations. Freshly harvested thirteen-lined ground squirrels (*Spermophilus tridecemlineatus*) were provided as supplies were available (approximately 1 per fox, 2–3 times per week). On days when squirrels were not provided, seven 8 oz. balls of Feline Complete Diet (Triple A Brand Meat Company, Burlington, Colorado), composed of ground beef muscle meat with a complete vitamin and mineral premix, were spaced throughout the pen.

On 26 and 27 September 2015, foxes were live trapped and moved to a boxed-in, indoor holding pen, allowing for easier capture and loading for the transport back to South Dakota. On 28 September 2015, after 55 days of hand-rearing and behavioral observations demonstrating adult behaviors (e.g., digging new dens, play fighting, and attempts at mating), foxes were captured and placed in individual kennels. Foxes were scanned with an AVID PowerTracker (Avid Identification Systems, Inc., Norco, CA) to identify individuals, and one individual received a new AVID FriendChip because no transponder was detected. All seven pups were transported back to the Badlands population, where researchers attached VHF radio-collars (M1830 40g, Advanced Telemetry Systems, Isanti, MN) using the same handling methods that were used during their original capture. Individuals were released into the same den where they were trapped: 5 pups at the Conata Den (Fox ID numbers: 1501, 1502, 1503, 1504, and 1505) and 2 pups at the Quinn Den (Fox ID numbers: 1506 and 1507). Supplemental feeding was discontinued.

Foxes were monitored twice per night for the first month and ≤ five times per week thereafter, using a truck mounted null-peak telemetry system (Brinkman et al. 2002), between 2100 and 0600 hours. Aerial telemetry was used for dispersing foxes (Mech 1983). Cause of death was determined in the field and attributed to vehicle collision based on location and signs of impact, and coyote intraguild predation based on saliva and dentition marks on the carcass, coyote tracks around the carcass, and lack of caching or feasting upon the carcass.

**RESULTS**

All seven foxes died within their first year, resulting in an annual survival rate of 0.00. This survival rate was lower than the estimated 0.19 gross apparent survival rate of swift fox pups in the population during this time (Chapter 2). Vehicle collision was determined to be the cause of death for 71% of the foxes ($N = 5$) and coyote intraguild predation was deemed cause of death for 29% ($N = 2$, Table 1). Causes and frequency of mortality were similar to other pups in the population at this time (Chapter 2): vehicles accounted for 25% ($n = 2$) of mortalities, coyotes accounted for 25% ($n = 2$), raptors accounted for 25% ($n = 2$), and cause of death was unknown for 25% ($n = 2$).

Foxes survived a mean of 49 ± 25.4 days post-release; however, there was a significant ($P = 0.003$, $t_5 = 5.37$) difference between longevity of foxes killed by vehicle collision and those killed by coyotes (Table 1). Vehicle collisions occurred 13 ± 4 days post-release, while coyote mortalities occurred 140 ± 43 days post-release. Mean distance between mortality location and release den was 2.44 ± 0.84 km. However, distance between release dens and vehicle mortalities differed significantly ($P = 0.013$, $t_5 = 3.77$) from distance between release dens and coyote mortalities. Vehicle mortalities averaged 1.31 ± 0.61 km from release dens whereas coyote mortalities averaged 5.24 ± 0.39 km from release dens (Table 1).

**DISCUSSION**

*Alternative Options Considered:*

Multiple options were discussed during the conference call before deciding to hand-rear and release the orphaned foxes. These Alternative Options included: 1) supplementally feeding the pups until the end of August (estimated age of independence (Egoscue 1979, Kilgore 1969)), then trapping and collaring the pups that remained and monitoring them via telemetry. This option was dismissed due to the significant effort required to feed the pups for that duration, and the lack of stored food resources. Alternative Option 2): stop supplementally feeding the pups immediately, then trap the dens in August when the pups were full grown, collar the remaining pups, and monitor them via telemetry. This option was dismissed because we had already intervened (SDSU, NPS, and I agreed that I should supplementally feed the pups, and this had been occurring for approximately three weeks) and thus, ceasing feeding and assessing survival of the orphans would likely not depict the natural result had we not intervened. Alternative Option 3): trap and remove the pups from the study area, and hand-rear at the SDSU Wildlife and Fisheries Research Facility, Brookings, South Dakota, until permanent/resident placement in an AZA accredited zoo. This was dismissed due to the fact that no zoos had come forward requesting swift fox pups (T. Rein, Swift Fox SSP Coordinator, personal communication, July 2015), which would lead to a stay of unknown length at the SDSU Facility, which did not have the immediate resources to hand-rear the pups. Both Alternative Options 1 and 2 kept the foxes in the Badlands population, while Alternative Option 3 removed the foxes completely.

Alternative Option 4) was also discussed: cross-foster the pups at other dens within the Badlands population. Cross-fostering (or facilitated adoption) has been used for multiple canid species, including 1) an experiment with captive coyotes (Kitchen and Knowlton 2005), 2) in a wild population of gray wolves [(*Canis lupus*) (Schultz et al. 2007)] and 3) captive gray wolves (Scharis and Amundin 2015), and 4) is part of the SSP management program for critically endangered red wolves (*Canis rufus*/*Canis lupus rufus*) both captive and wild (Waddell et al. 2002), and 5) a free-ranging population of endangered wild dogs ([*Lycaon pictus*] (McNutt et al. 2008)]. The catalyst for the aforementioned studies varied from conservation of wild species to use of captive animals for research purposes. The ages of the cross-fostered pups in the studies also varied from < 1 week in captive coyotes and gray wolves (Kitchen and Knowlton 2005, Scharis and Amundin 2015) to 18–19 weeks in wild gray wolves (Schultz et al. 2007).

These cross-foster studies had varying levels of success. All litters ($n$ = 8, 100%) up to 10 days old that were cross-fostered survived (Kitchen and Knowlton 2005, Scharis and Amundin 2015, Waddell et al. 2002), two of the three litters (66.7%) aged 3–4 weeks survived (Kitchen and Knowlton 2005), three of the five litters (60.0%) aged 6–7 weeks survived (Kitchen and Knowlton 2005, McNutt et al. 2008), and one of four (25.0%) wild gray wolf pups survived (Schultz et al. 2007). This option was considered after Alternative Options 1, 2, and 3 were dismissed, because the foxes would remain within the population and have the potential to learn behaviors (i.e., hunting, vehicle avoidance) from the foster parents. However, this option was dismissed because 1) cross-fostering had never been attempted in swift foxes, 2) the age of the pups (approximately 12 weeks) was older than the successful ages of cross-fostered pups in previous canid studies, 3) the potential effects to the natal pups and parents at the fostering dens were unknown, and 4) the genetic relatedness of the orphans and foster parents/litters was unknown.

*Hand-Rearing Success:*

During the original reintroduction of swift foxes around Badlands National Park, movement and survival of released swift foxes was determined after a 50 day period (Schroeder 2007). This was because a previous reintroduction in Canada (Moehrenschlager and Macdonald 2003) found no difference in movement between resident and translocated swift foxes after 50 days. Schroeder (2007) used this time frame to surmise that survival and movement would not be affected after 50 days based on the varying release methods used in the reintroduction of the Badlands population. Therefore, I also presumed that the effect of hand-rearing and releasing pups on their movement and survival would also be negligible after 50 days. Using this parameter, it can be stated that the hand-rearing and release of the pups was successful for 2 of the 7 pups, or 28.6%. One pup from each den survived past 50 days: Female 1501, Conata Den, survived 182 days before death by coyote 5.63 km from release den; and Male 1507, Quinn Den, survived 97 days before death by coyote 4.85 km from release den (Table 1).

The activity patterns and behavioral observations of these two individuals (1501 and 1507) further support that the release was successful: 1501 remained at the release/natal den and visual observations documented her walking and lying on or in the ditch along Highway 44 but she was never mortally wounded by a vehicle. I also visually documented Female 1501 eating prey and maintaining a healthy body condition. Fox 1507 was located in a new den outside of his parent's home range after 66 days (3.52 km from release/natal den) where he remained until his death by coyote 97 days post-release. Male 1507 was frequently seen along Interstate 90, walking on the road, in the median, and in the ditch, and he also maintained a healthy body condition (visual observations). Considering the other five orphaned pups died from vehicular collision, while 1501 and 1507 were frequently observed using roads, suggests that they learned how to avoid vehicles while continuing to use roadways. Deaths of foxes 1501 and 1507 were therefore likely not due to their history as hand-reared and released orphans.

*Modification to the Methods:*

Vehicular collision was the most common cause of mortality, and occurred soon after the release ($\mu$ = 13 ± 4 days) and close to the release den ($\mu$ = 1.31 ± 0.61 km). If this conservation experiment were to be repeated again, one modification would be to attempt experimental operant conditioning using positive punishment of vehicles in an attempt to teach foxes to avoid vehicles, reduce vehicular mortality, and potentially increase survival of hand-reared pups. This training could be done at a zoo or hand-rearing facility by driving various vehicles near the pen and honking a horn, hitting the brakes abruptly, or accelerating past the pen. Once released, this operant conditioning may have the potential to reduce vehicular mortality.

**MANAGEMENT IMPLICATIONS**

Although the hand-rearing and release of these wild-born pups may potentially be deemed successful for 2 of the 7 due to their longevity, I do not recommend this option if an orphaned swift fox situation occurs again in this population. The survival of the pups was 0.00 after one year, which was less than the estimated 0.19 gross apparent pup survival for this population at the time (Chapter 2). The amount of time, energy, and money put forth by the various organizations demonstrates immense collaboration, but this may not be feasible in other populations or in the future of this population. The time and money spent to supplementally feed, trap, transport, provide veterinary care, and food and staffing at the zoo may outweigh the results of this experimental conservation tool.

If orphaned pups are located within the Badlands population in the future, I recommend monitoring the den with trail cameras to document activity and health of the pups. If VHF collars are available, it would be ideal to trap the pups when they are full grown at the end of August or later in the fall to monitor survival. I do not recommend supplementally feeding, hand-rearing, and releasing the pups.

If orphaned swift fox pups are located in other populations, I recommend a thorough assessment of potential options, including but not limited to: no intervention, monitoring via cameras with no further intervention, collaring of foxes once full grown and monitoring survival, cross-fostering with other swift fox families in the area, or hand-rearing with the goal of release back into the wild or permanent residency at a zoo. Factors to consider include but are not limited to: status of the population in the area, the species' state listing, age and behavior of the orphaned pups, and availability of resources (for feeding, hand-rearing, or cross-fostering). The option with the least intervention should be favored to maintain natural instincts of the animals.

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**Table 7:** Life history and mortality of seven orphaned swift fox pups hand-reared and released in the Badlands population, South Dakota, 2015–2016.

| Fox ID | Den Name | Sex | Mortality Date | Days Survived | Cause of Mortality | Distance from den (km) | Comments |
|---|---|---|---|---|---|---|---|
| 1501 | Conata | F | 28-Mar-16 | 182[a] | Coyote | 5.63[b] | Remained at natal den. Frequent visual observations of her on Highway 44. Mortality was very far from last known point, 5.58 km. |
| 1502 | Conata | F | 29-Sep-15 | 1 | Vehicle | 0.30 | Mortality on Highway 44 directly north of release den. |
| 1503 | Conata | F | 18-Oct-15 | 20 | Vehicle | 0.09 | Mortality on Highway 44 directly north of release den. |
| 1504 | Conata | M | 1-Oct-15 | 3 | Vehicle | 0.80 | Mortality on Highway 44 just east of release den. |
| 1505 | Conata | M | 18-Oct-15 | 20 | Vehicle | 3.35 | Did not locate carcass, but collar was found at a gut pile on Highway 44, technician who discovered the carcass believes it was scavenged. |
| 1506 | Quinn | M | 17-Oct-15 | 19 | Vehicle | 2.03 | Mortality on Highway 14 west of release den. |
| 1507 | Quinn | M | 3-Jan-15 | 97[a] | Coyote | 4.85[b] | Was located at a new den outside of his parent's home range after 66 days (mortality was 1.94 km from this new den). Frequent visual observations indicated good health until death. |

[a] = Pups killed by coyotes survived significantly longer (140 ± 43 days post-release) than those killed by vehicles (13 ± 4 days post-release) ($P$ = 0.003, $t_5$ = 5.37).

[b] = Pups killed by coyotes were recovered significantly farther (5.24 ± 0.39 km) from the release den than those killed by vehicles (1.31 ± 0.61 km) ($P$ = 0.013, $t_5$ = 3.77).

**Figure 9:** Swift fox study area around Badlands National Park and Buffalo Gap National Grassland, South Dakota, 2015–2016. Orphan den locations are labeled.

NAD 1983 UTM Zone 13N