MONITORING SWIFT FOX USING REMOTE CAMERAS IN EASTERN COLORADO

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ABSTRACT

Swift foxes (*Vulpes velox*) are a priority conservation species throughout the western prairie regions of the United States. A variety of methods has been used to survey and monitor the status of swift populations throughout the species range. We conducted surveys using a non-invasive approach to evaluate the status of the swift fox in eastern Colorado. From August through October 2011, we used remote infrared cameras and a skunk-based lure on 52 grids to estimate detection and occupancy rates of swift fox populations in eastern Colorado. We used 8 camera stations within a 4.8 x 6.4 km^2 area and monitored each grid for 5 consecutive nights. We collected 331 unique swift fox detections from 29 August to 28 October, 2011. Short-grass prairie habitat accounted for all swift fox detections. Detection probabilities varied by survey night and the average was p = 0.692 (*SE* = 0.0311, 95% CI 0.631–0.753). Probability of occupancy was highly correlated with the percent short-grass prairie within each grid and was estimated to be $\hat{\psi}$ = 0.868 (*SE* = 0.0475, 95% CI 0.775–0.961). These estimates are higher than those reported by Martin et al. (2007) for swift fox surveys conducted in 2004-05. We estimated the overall proportion of 4.8 x 6.4 km^2 grids occupied by swift foxes in eastern Colorado to be $\hat{\psi}$ = 0.765 (*SE* = 0.0341, 95% CI 0.698–0.832), with no evidence of a decline from the surveys reported by Martin et al. (2007) conducted in 2004-05. The use of cameras and a skunk-based lure was an efficient technique that provided reliable estimates of swift fox occupancy in eastern Colorado. Future surveys should be restricted to short-grass prairie habitat to establish a baseline of swift fox occupancy and further refine the species distribution in eastern Colorado.

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INTRODUCTION

The swift fox (*Vulpes velox*) is a small canid native to the short-grass (SGP) and mixed-grass prairie regions of southern Canada and west-central United States (Scott-Brown et al. 1987, Allardyce and Sovada 2003, Cypher 2003). The swift fox is closely related to the kit fox (*V. macrotis*) and there is evidence to suggest combining these species taxonomically (Mercure et al. 1993, Dragoo and Wayne 2003). However, many wildlife agencies still consider swift and kit foxes separate species due to the relatively small area of overlap in their geographic range.

Historically, swift fox occupied portions of 12 states (Montana, North Dakota, Minnesota, South Dakota, Wyoming, Nebraska, Iowa, Kansas, Colorado, Oklahoma, New Mexico, and Texas) and 4 Canadian provinces (British Columbia, Alberta, Manitoba, and Saskatchewan) (Carbyn et al. 1994). Habitat fragmentation and degradation from agricultural practices, urbanization, predation by coyotes (*Canis latrans*), competition with red fox (*V. vulpes*), and predator control efforts of the past century contributed to a significant decline in number and geographic range of the species over the past century (Allardyce and Sovada 2003). It is estimated that swift fox occupy approximately 44% of their historic range (Fig. 1) (Sovada et al. 2009). Habitat fragmentation and rodent control practices continue to threaten the available habitat for swift fox and many of their species of prey, including prairie dogs (*Cynomys* spp.) (Scott-Brown et al. 1987, Allardyce and Sovada 2003).

In 1992, the swift fox was petitioned to be listed as an endangered species under the Endangered Species Act of 1973. In 1994, the U.S. Fish and Wildlife Service (USFWS) concluded the swift fox warranted listing as threatened but precluded by higher priority species (Federal Register 1994). At the same time, the Swift Fox Conservation Team (SFCT) was formed, which included various Federal agencies and representatives from Canada and 10 States located within the historic range of the swift fox, to take a proactive approach to the status, conservation, and management of the species. Over the next decade, the SFCT produced the Conservation Assessment and Conservation Strategy for Swift Fox in the United States (CACS) (Kahn et al. 1997) and several annual reports (Allen et al. 1995, Luce and Lindzey 1996, Giddings 1997, Roy 1999, Schmitt 2000, Schmitt and Oakleaf 2001, Peek 2002). This compilation of existing information, collection of new biological data, and implementation of swift fox monitoring and management programs demonstrated that swift fox distribution was more widespread and continuous and that the species was more adaptable to various habitat types than previously believed. As a result, the USFWS found the petition for listing to be unwarranted and removed the swift fox from the candidate list in 2001. Since its inception, the SFCT has been instrumental in providing defensible data on swift fox abundance and distribution with a more coordinated approach to rangewide conservation and management of the species.

Prior to 1995, information on the distribution and population status of swift fox in Colorado was largely based on small-scale projects scattered across the eastern plains (Loy 1981, Cameron 1984, Rongstad et al. 1989, Covell 1992). These projects were of insufficient size to make range-wide assessments of the species in Colorado. This lack of information prompted research in 1995 to determine the population status and development of a monitoring program for swift fox across the species geographic range in eastern Colorado (Finley et al. 2005). As part of Colorado’s commitment in the 1997 CACS to monitor the status of swift fox every 5 years, surveys were again conducted in the fall/winter of 2004-05 to estimate occupancy and population size (Martin et al. 2007).

Legal harvest of swift fox in Colorado ended in 1995 with the closure of the hunting and trapping season and in 1998, the species was designated as non-game and listed as a Species of

Special Concern. Because of the extent of short-grass prairie on the eastern plains, Colorado is believed to have the largest distribution of swift fox within the species geographic range (Finley at al. 2005). In 2009, the swift fox was reclassified as a furbearer and a season was established authorizing regulated take. With harvest opportunity on swift fox reestablished in Colorado, it is important to assess the potential impacts through continued monitoring of the species.

Prior to 2011, mark-recapture techniques using cage traps were used as the means to determine occupancy rates of swift fox across eastern Colorado (Finley et al. 2005, Martin et al. 2007). Although mark-recapture will yield population estimates, this technique can be labor intensive and increases the risk of injury to animals. Budgetary constraints may also preclude the large-scale use of this technique. Non-invasive techniques including scent stations, scat collection, track plates, spotlighting, and calling have been used as an alternative to estimate relative and absolute abundance of swift fox with mixed results.

Harrison et al. (2002) compared multiple non-invasive survey methods and found scent station surveys to be the most reliable method in detecting swift fox. Schauster et al. (2002) evaluated 6 non-invasive methods including catch-per-unit-effort, mark-recapture estimates, scent-post surveys, spotlight counts, scat deposition rates, and an activity index and concluded that all methods, except spotlight counts, were reliable and consistent for detecting swift fox presence. They also found that a combination of mark-recapture estimates and scent-post indices was the best predictor of swift fox density. Generally, scent stations and scat collection have become the most commonly used survey methods by states within swift fox range.

Knox and Grenier (2010) conducted a pilot study to evaluate the use of hair snares, live trapping, and infrared cameras at scent stations as potential survey methods for swift fox in eastern Wyoming and concluded that infrared cameras were the most efficient method for determining swift fox presence. They noted that infrared cameras detected swift fox when other methods failed to do so. Subsequently in 2010, this method was used across the species range in eastern Wyoming to estimate occupancy and update the species distribution in the state (Cudworth et al. 2011). Infrared cameras were also used to determine swift fox presence or absence in eastern Montana with similar results (Bly et al. 2010, Alexander 2011).

Therefore, in 2011, as part of Colorado's commitment to monitor the status of swift fox, we initiated a non-invasive survey technique using infrared cameras at scent stations to monitor occupancy rates for swift fox in eastern Colorado. We estimated swift fox occupancy rates of 4.8×6.4 km^2 (3×4 mi^2) grids and related occupancy and detection to presence of shortgrass prairie. We also compared parameter estimates to those from previous mark-recapture surveys (Martin et al. 2007).

STUDY AREA

The survey area included all or portions of 23 counties in eastern Colorado, primarily east of Interstate 25, encompassing nearly 80,000 km^2 (Martin et al. 2007). The eastern plains are dominated by short and mid-grass prairies, Conservation Reserve Program (CRP) plantings, and agricultural development. The terrain varies widely, from flat to rolling upland plains in the east-central to high plains and canyons in the southeast. Agricultural cropland is dominated by both irrigated and dryland corn and wheat (U.S. Department of Agriculture 2009). Cattle production is common throughout the region and grazing intensity varies greatly.

Dominant plant species in areas with short-grass prairie are blue grama (*Bouteloua gracilis*), buffalo grass (*Buchloe dactyloides*), scarlet globemallow (*Sphaeralcea coccinea*), prickly-pear cactus (*Opuntia polyacantha*), rabbitbrush (*Chrysothamnus nauseosa*), broom snakeweed (*Gutierrezia sarothrae*), and spreading buckwheat (*Eriogonum effusum*). In eastern

Colorado, CRP plantings contain a variety of native and non-native vegetation. Although composition varies by location, generally CRP plantings are dominated by western wheatgrass (*Pascopyrum smithii*), switchgrass (*Panicum virgatum*), blue grama, sand bluestem (*Andropogon hallii*), yellow indiangrass (*Sorghastrum nutans*), prairie sandreed (*Calamovilfa longifolia*), and green needlegrass (*Nassella viridula*). Pinyon pine (*Pinus edulis*) and one-seed juniper (*Juniper monosperma*) are common within and along canyon breaks, bluffs, and mesas in the southeastern part of the state.

The climate on the eastern plains is generally semi-arid and uniform across the region. It is characterized by low humidity, infrequent rains and snow, moderate to high wind movement, and a large daily and seasonal range in temperature (Pielke, et al. 2003). Winter precipitation is light and infrequent and most of the precipitation (70–80%) falls during the growing season from April through September. Annual precipitation ranges from less than 12 inches in the Arkansas Valley to nearly 18 inches in extreme northeastern and southeastern corners of the state (Pielke et al. 2003). Mean temperature from September thru November for the state is 7.0°C, and mean precipitation is 9.68 cm (1991-2011 data, National Oceanic and Atmospheric Administration National Climatic Data Center 2011).

METHODS

Grid Selection

The surveyed grid size (4.8 x 6.4 km^2) was initially established by Finley (1999) and has been maintained in previous surveys (Martin et al. 2007) as well as this study to compare changes in occupancy and detection over time. Finley et al. (2005) demonstrated that the composition of short-grass prairie in a grid was a reliable predictor for both the probability of occupancy (ψ) and probability of detection (p) for swift fox in eastern Colorado. Thus, in 2004, Martin et al. (2007) identified 2,566 available grids in eastern Colorado. They sorted the grids by the percentage of short-grass prairie contained in the grid based on Colorado Gap Analysis Program data and systematically selected every 50th grid for sampling swift foxes (Martin et al. 2007). This procedure resulted in a sample frame of 51 grids. The sample size of n = 51 was based on the power calculations provided by Finley et al. (2005) (Martin et al. 2007).

Survey Technique

For this study, we used the same 51 grids surveyed in 2004–05 as the initial sampling frame. Using a spatially-balanced sampling process employing Reversed Randomized Quadrant-Recursive Raster (RRQRR) algorithm (Theobald et al. 2007), we randomly selected an additional 51 grids to be used as alternatives survey sites in case landowners denied access to the primary grids. We conducted surveys from August thru October 2011 to coincide with juvenile dispersal and to maximize detection probabilities (Finley et al. 2005, Martin et al. 2007).

For each 4.8 x 6.4 km^2 grid, we used an array of 8 infrared cameras (Reconyx, PC800, Holmen, WI); 3 cameras spaced at 3.2 km intervals across the top and bottom of each grid and 2 cameras centered north to south, spaced 3.2 apart, and 1.6 km from the east and west edge of the survey grid. When necessary, we moved cameras within the grid to accommodate landowners who denied access. In most cases, we moved cameras ≤ 0.8 km. We placed cameras along fence rows, powerlines, and trails, which are common travel routes for canids including swift fox.

We attached cameras to either light duty “U” posts measuring 0.91m (36 inch) in height using a single screw, or 1.27 cm (0.5 in) rebar measuring 76 cm (30 in) in length using a 1.27 cm rubber-lined, pipe clamp. The “U” posts were equipped with pre-drilled holes spaced evenly along the shaft, which provided for quick attachment and consistent height reference. We used rebar primarily in areas adjacent to public roads to conceal cameras from public view and reduce potential theft. We placed a wooden stake (24 in) approximately 3 m in front of each camera to serve as a base for the lure and a focal point for the camera. We placed both the camera and survey stake at a height of 38–40 cm using the length of a hammer as a guide. We created a skunk-based lure by heating 385 ml of petroleum jelly to liquid form, adding 8 ml of skunk essence (Schmitt Enterprises, Inc., New Ulm, MN), and allowing the lure to solidify (Cudworth et al. 2011). We applied approximately 5–10 ml of lure to the top of each stake as an attractant.

We programmed the cameras to take 3 consecutive photos each time the camera was triggered and cameras were set to take pictures 1 hr before sunset to 1 hr after sunrise to take advantage of peak swift fox activity (Kitchen et al. 1999, Moehrenschlager et al. 2003) and minimize extraneous non-target photos (e.g. livestock and vegetation movement). We programmed photos to be stamped with the date, time, temperature, camera number, and grid number. We left cameras active for 5 consecutive nights. On Day 6, we collected cameras, downloaded pictures, and erased and re-programmed memory cards for the next array. We recorded all target and non-target species and the number of swift fox detections from each camera and survey grid. We categorized swift fox detections as separate and unique for all swift fox photos taken >2 hr apart. We used a Global Positioning System (GPS) set to North American Datum 1983 (NAD83) to collect Universal Transverse Mercator (UTM) coordinates for each camera location.

Because the distance and direction from which detected swift fox came from was unknown, after completion of the survey effort, we used ArcMap 10.0 (ESRI, Redlands, California) to buffer each grid by 1.6 km, which was one-half the average inter-camera distance to account for swift foxes that may have originated outside the sampled grid (Martin et al. 2007).

We recalculated the percent short-grass prairie for each 8.0 × 9.6 km^2 (buffered) grid in ArcMap using Southwest ReGap Vegetation Classification data.

Data Analysis

We combined data from the eight cameras within each grid to develop an encounter history for each grid and estimated the probability of occupancy (ψ) and detection (p) using Program PRESENCE (Hines 2011). Previous swift fox surveys in Colorado demonstrated that percentage of SGP was an important factor influencing detection probabilities (p) and ψ (psi) (Finley et al. 2005, Martin et al. 2007). Therefore, we considered a set of *a priori* models that incorporated the percentage of SGP within the survey grid to model both. We standardized the covariate (SGP) before inclusion in the models (Franklin 2001). We modeled both p and ψ for the complete survey period and only the first 3 nights for comparison with previous surveys. We report model outputs which include ψ and up to five detection probabilities (p) for the five survey nights.

We evaluated occupancy models using Akaike's Information Criterion adjusted for small sample sizes (AIC_c) to perform model selection in an information-theoretic framework (Burnham and Anderson 2002). We considered models with ΔAIC_c values ≤1.5 to be equally parsimonious and used Akaike weights (w_i) to assess relative support for different models. For the top models selected, we performed a MacKenzie-Bailey goodness of fit test (MacKenzie and Bailey 2004) to test for overdispersion. We estimated occupancy and detection probabilities from the minimum AIC_c model and used model averaging when more than 1 model was supported (Burnham and Anderson 2002, MacKenzie et al. 2006).

We estimated the proportion and number of grids occupied by swift fox in eastern Colorado using the logistic equation with estimates from the minimum AIC_c model corrected for small sample size with the grid specific covariate SGP $\hat{\psi}_i = \frac{\exp(\hat{\beta}_0 + \hat{\beta}_1 x_i)}{1 + \exp(\hat{\beta}_0 + \hat{\beta}_1 x_i)}$, where the covariate value of SGP for grid i (i = 1,... 2,566) is x_i and the estimates from Program PRESENCE are the intercept ($\hat{\beta}_0$) and slope parameter ($\hat{\beta}_1$). The number of occupied grids is estimated by $\hat{O} = \sum_{i=1}^{2,566} \hat{\psi}_i$ with variance estimated by the sum of the elements of the 2,566 x 2,566 estimated variance-covariance matrix of the $\hat{\psi}_i$ (Martin et al. 2007).

RESULTS

Survey Effort

We initially surveyed 4 grids between 1 August and 9 August 2011 as a pilot survey to estimate detection probabilities (*p*) to determine if the sampling frame was adequate for comparison with mark-recapture surveys conducted by Finley et al. (2005) and Martin et al. (2007). Swift fox detections on 3 of 4 grids indicated that no changes to the sampling frame were necessary. We selected a small number of alternative survey grids (n = 5) because adequate landowner permission could not be obtained on the original grids. We also surveyed one additional alternative grid since landowner permission was obtained. Therefore, we surveyed the remaining 48 grids between 29 August and 28 October 2011 for a total survey sampling frame of 52 grids.

We completed the survey with 95 camera nights (CN) in which no data was collected. The initial pilot survey in early August accounted for 26% of the total inoperable camera nights, all from livestock interference. The remaining inoperable camera nights resulted from battery failure (20 CN), camera theft (15 CN), livestock interference (15 CN), camera destruction (10 CN), and human error (10 CN).

We collected 331 unique swift fox detections during the remaining 1,985 camera nights. We detected ≥1 swift fox on 45 of the 52 survey grids and the number varied from 1–18 unique detections per grid (Fig. 2). Of those 45 grids, we detected swift fox on 80% of the grids (36 of 45 grids) in the 1st night. After the 2nd night, 91% (41 of 45 grids) of the grids had obtained a swift fox detection and 98% (44 of 45 grids) of the grids had a confirmed detection by the end of the 3rd night. In addition to swift fox, we detected 20 other mammalian species and 9 species of birds (Table 1).

Detection and Occupancy Estimation

Detection probabilities varied by night with the first survey night having the highest probability at p = 0.799 (*SE* = 0.0599, 95% CI 0.681–0.916) (Fig. 3). The average probability of detecting a swift fox across all nights was p = 0.692 (*SE* = 0.0311, 95% CI 0.631–0.753). To compare with previous surveys, the average detection probability for the first 3 nights of the survey was p = 0.700 (*SE* = 0.0425, 95% CI 0.617–0.783).

Model selection results for occupancy estimation are shown in Table 2. Compared to the top occupancy model with constant p, the percentage of SGP did not improve model fit of detection probabilities, although there was evidence that suggested it does have a small influence on detection. However, the percentage of SGP did provide an important predictor of occupancy (Fig. 4) with the logit predictive equation: Occupancy Probability = $\frac{\exp[\hat{\beta}_0 + \hat{\beta}_1(\text{SGP\%})]}{1 + \exp[\hat{\beta}_0 + \hat{\beta}_1(\text{SGP\%})]}$,

where $\hat{\beta}_0$ = –1.631 (*SE* = 1.123, 95% CI –3.833 to 0.571) and $\hat{\beta}_1$ = 9.765 (*SE* = 3.957, 95% CI 2.009 to 17.521).

The overall estimated occupancy rate using the average amount of SGP found on the 52 grids sampled was $\hat{\psi}$ = 0.868 (*SE* = 0.0475, 95% CI 0.775–0.961). When the estimated occupancy was summed across the 52 grids using the observed amount of SGP on each grid, $\hat{\psi}$ = 0.867 (*SE* = 0.0507, 95% CI 0.767–0.966). When the occupancy rate was estimated from only the first 3 nights of the survey, $\hat{\psi}$ = 0.872 (*SE* = 0.0528, 95% CI 0.768–0.975) using the average amount of SGP on the grids and $\hat{\psi}$ = 0.861 (*SE* = 0.0574, 95% CI 0.748–0.973) when occupancy was summed across all grids using the observed amount of SGP. Finally, based on the entire set of 2,566 grids from which the 52 surveyed grids were selected, the number of grids in eastern Colorado occupied by swift foxes was estimated at 1,963.1 grids (SE = 87.5, 95% CI 1,791.7–2,134.5). Thus, the estimated proportion of occupied grids in eastern Colorado is $\hat{\psi}$ = 0.765 (*SE* = 0.0341, 95% CI 0.698–0.832).

DISCUSSION

After the first survey night, detection probabilities declined on average by nearly 14% for the remaining 4 nights of survey. In Wyoming, Cudworth et al. (2011) found nearly a 10% decline after the first detection and hypothesized that it was due to a lack of curiosity in the lure after the initial swift fox investigation. In this study, swift fox tended to also show a pattern of visitation over time, suggesting that swift fox may have a movement routine that does not involve monitoring all areas within their home range on a daily basis. Although the percentage of SGP did not improve detection probability over the top model with constant *p*, there was model evidence to suggest SGP has a positive influence on detection probability. In Wyoming, detection probability was influenced by the percentage of grassland in the grids, which included SGP (Cudworth et al. 2011). Cameras placed within or on the edge of short-grass prairie habitat accounted for all of the swift fox detections in this survey, which strongly supports a positive relationship.

Comparing the minimum AIC_c models for the average percentage of SGP in the grids, the 2004–05 estimate, from 3 days of mark-recapture, was $\hat{\psi}$ = 0.777 (*SE* = 0.0786) compared to the current 3-day estimate of $\hat{\psi}$ = 0.872 (*SE* = 0.0528). The estimated change is +0.095. Summing the predicted occupancy values across the sampled grids provided a similar conclusion: Martin et al. (2007) found $\hat{\psi}$ = 0.742 (*SE* = 0.0869), whereas this study found $\hat{\psi}$ = 0.861 (*SE* = 0.0574), providing an estimated change of +0.119. Despite the significant increase in occupancy probabilities, I conclude that these differences are the outcome of changing to a more effective survey methodology which resulted in more accurate estimates of occupancy than previously reported.

Based on the results from the 2004-05 surveys, Martin et al. (2007) estimated 1,824.6 grids were occupied by swift fox across eastern Colorado. My results represent an increase of 138.5 additional grids estimated to be occupied by swift fox. Martin et al. (2007) estimated overall $\hat{\psi}$ = 0.711 (*SE* = 0.069) for the 2,566 grids, whereas this study found $\hat{\psi}$ = 0.765 (*SE* = 0.034), providing an estimated change of +0.054. However, these differences are within the sampling variation of the estimates, thus a significant change in swift fox occupancy in eastern Colorado was not detected. Therefore, my estimates of the percent of grids occupied by swift foxes only reflect updated figures from the previous survey conducted in 2004–05.

The skunk-based lure used in this and other studies (Cudworth et al. 2011) was very effective in attracting swift fox because of its aromatic potency that persisted over time. The lure elicited investigative responses from more animals than previous surveys that used traditional baits. I used 12 fewer survey stations per grid and averaged 4.1 detections per grid compared to 2.7 detections per grid from the 2004–05 surveys that used 20 cage traps and traditional bait products (Martin et al. 2007). The attractant was also effective in presumably lower density areas where I documented swift fox on 7 grids that previously had no detections from the use of cage traps. I believe the change to using a skunk-based lure, instead of traditional baits and attractants consisting of meat and fish-based products, is the primary reason this survey was so successful compared to other swift fox, scent station surveys reported in literature (Harrison et al. 2002, Harrison and Schmitt 2003, Olsen et al. 2003, Sargeant et al. 2003, Martin et al. 2007).

Cameras provided an effective mode of detection because swift fox could be detected more easily than they would be using cage traps. Generally there is some degree of bias associated with cage traps when animals are present but never captured which results in underestimation of both detection and occupancy. With cameras, the negative trap response is virtually eliminated because animals were not required to be captured to verify their presence. In addition, Martin et al. (2007) reported the capture of 73 non-target animals making the traps inoperable to detect swift fox for the remainder of those survey nights. In contrast, cameras provided continuous detection throughout the nightly survey period, irrespective of non-target species present.

The use of cameras in this study was not only a more efficient mode of detection but less labor intensive than the use of cage traps. Comparing the first 3 days of this study to the 2004–05 survey that used cage traps, we documented 78 more swift fox detections on 25% more grids, while reduced the total survey time by 100 days. Although the increase in detection and occupancy estimates may be the result of an increase in the distribution and population of swift fox in Colorado, the effectiveness of the camera and lure design to attract and detect the presence of swift fox in this study cannot be discounted. Regardless of the rationale for the increase, these results provide convincing evidence that swift fox occupy more areas in eastern Colorado than previously reported.

MANAGEMENT IMPLICATIONS

In Colorado, swift fox are highly dependent on short-grass prairie habitat. All swift fox detections were collected from cameras placed within or on the edge of short-grass prairie pastures. It was also apparent that swift fox occupancy was dependent on the size of the SGP tracts within the grids. Swift fox were detected on grids containing as little as 16% SGP, as long as there was a contiguous tract of SGP $\geq$ 640 acres within and/or adjacent to the grid. This apparent minimum threshold could be used for future surveys to partition the sampling frame and refine the geographic distribution of available swift fox habitat in Colorado.

In this study, the use of cameras and scent stations was highly effective in refining detection and swift fox occupancy estimates compared to previous surveys that used mark-recapture techniques. However, occupancy surveys have their limitations since it can only be used to assess changes in geographic distribution of animals. Because population or density estimates are not derived from this type of survey, it is possible that substantial changes in the population may go undetected. Since occupancy modeling, as conducted in this survey, only requires the detection of a single animal, it should not be used as the sole indicator of the status of swift fox. I recommend exploring other non-invasive techniques, such as scat or hair collection, along with occupancy surveys to monitor both occupancy and population status. The advancements in DNA extraction and genotyping from hair and scat have progressed in recent years and processing costs continue to decline making this a potential option for future surveys.

The ability to accurately assess changes in swift fox occupancy requires a determination of what areas are actually occupied across the landscape. Currently, the distribution of swift fox across eastern Colorado is not completely known. Despite the high dependence of swift fox on short-grass prairie, the sampling frame used in this and previous surveys is inadequate for determining if all areas of short-grass prairie are truly occupied by swift fox. This uncertainty limits our ability to map the species geographic distribution and establish a true baseline for comparison of swift fox occupancy across time. The sampling frame necessary to achieve this level of accuracy, using the current design, would number in the hundreds due to the extent of fragmentation of short-grass prairie in eastern Colorado, making it both time and cost prohibitive to implement on a landscape scale.

Because of the high dependence of swift fox on short-grass prairie in Colorado, I recommend that future surveys focus primarily within this habitat type. In addition, I suggest using the camera stations as point counts within a transect framework to survey all SGP areas on the eastern plains. Future surveys would still be comparable with the current results because swift fox were only detected in short-grass habitat; therefore, the current estimates of occupancy are essentially an estimate of the proportion of occupied short-grass prairie. These changes would provide a better assessment of the true occupancy of short-grass prairie across all areas in eastern Colorado. In addition, swift fox occupancy of fragmented portions of short-grass prairie could be determined without the need to survey less desirable habitats. Regardless of the survey design, I recommend reducing the survey period from 5 nights to 3 nights, since 98% (44 of 45) of the grids detected swift fox within the first 3 nights of the survey and there was no significant difference in detection or occupancy probabilities between the two timeframes. This change would improve survey efficiency and provide opportunity to survey more areas within the same timeframe.

There is little argument that a skunk's scent is one of the most pungent of all scents in the natural world. I believe this was the reason detection rates in this survey were among the highest ever documented for a scent station survey on swift fox. The common use of meat products, fish oil, or other fish-based lures, which is inferior in odor to skunk, has generally resulted in speculative recommendations that scent station surveys are a reliable technique for detecting swift fox. The positive results from this study and those reported by Cudworth et al. (2011) evoke a renewed optimism about the efficacy of scent station surveys to detect swift fox. Because the dynamics of swift fox populations vary across the species range, further research is needed to determine if a skunk-based lure improves swift fox detections in other regions of the species range.

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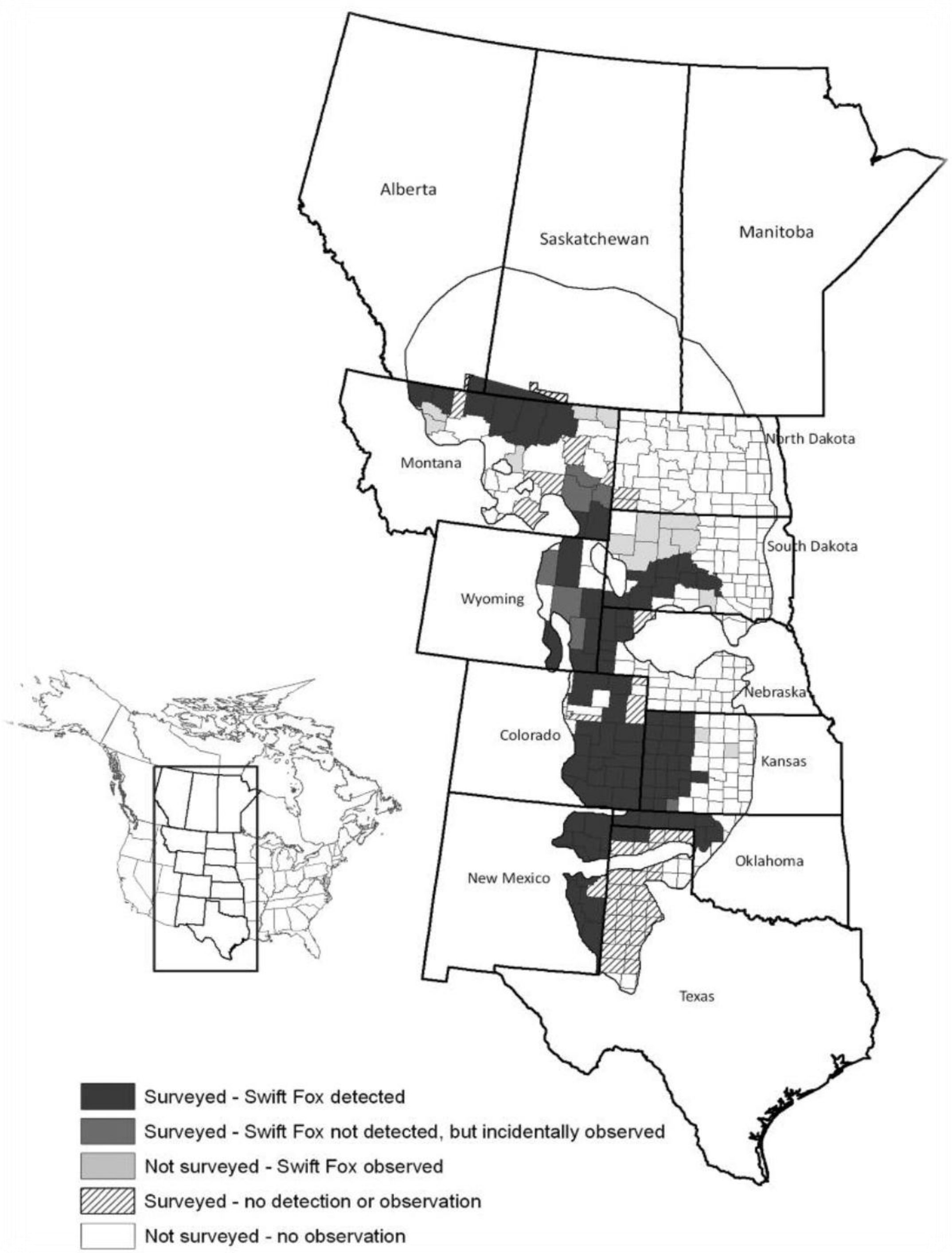

Figure 1. Recent occurrences of swift fox by county in the United States and the area surveyed in Canada, bounded by the species' estimated historical range. Swift fox occurrences in the United States are from survey results, confirmed observations, and fur-harvest records, 2001–2006. Swift fox occurrences in Canada are from live-trap surveys and incidental observations, 2005–2006 (Adapted from Sovada et al. 2009).

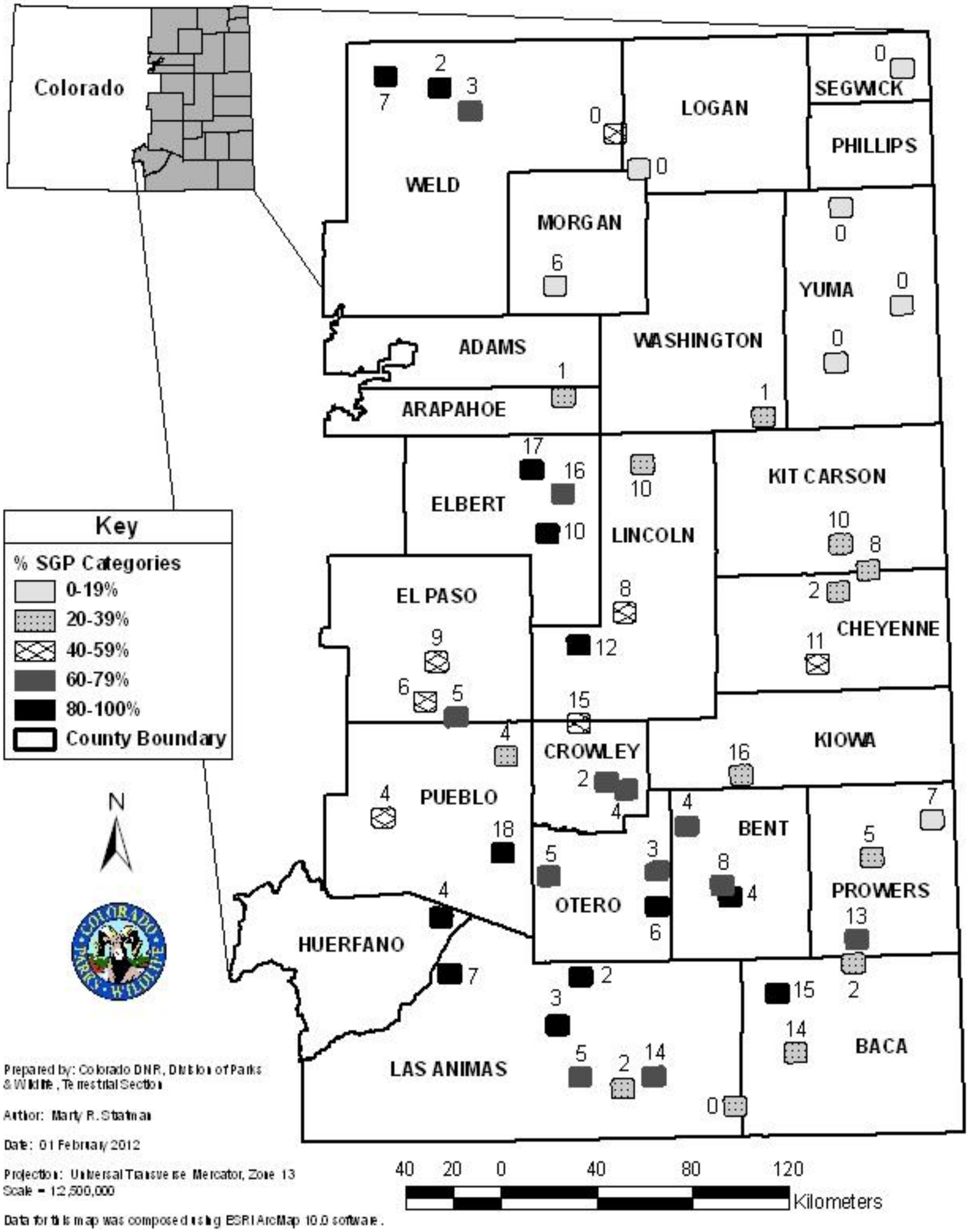

Figure 2. Distribution of swift fox monitoring grids in eastern Colorado, showing percent short-grass prairie (SGP) category and number of foxes detected by cameras in each, August–October, 2011.

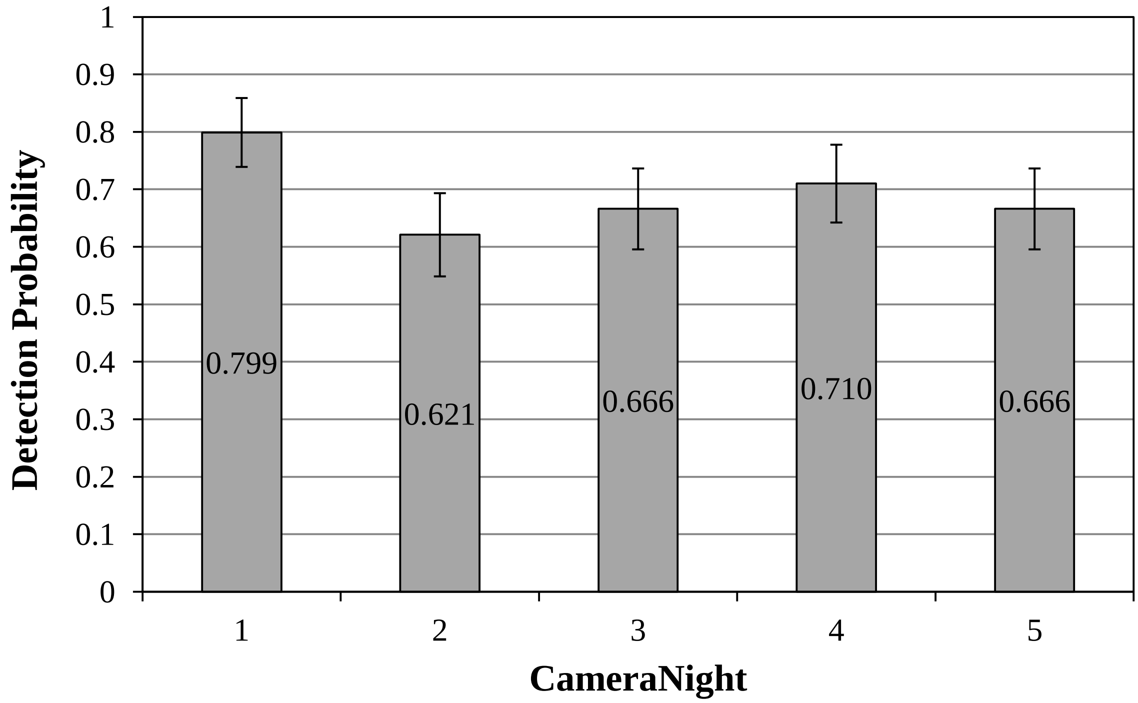

Figure 3. Probability of detecting swift foxes by camera night on the 30.7 km^2 survey grids in eastern Colorado, August through October, 2011. Error bars represent ±1 *SE*.

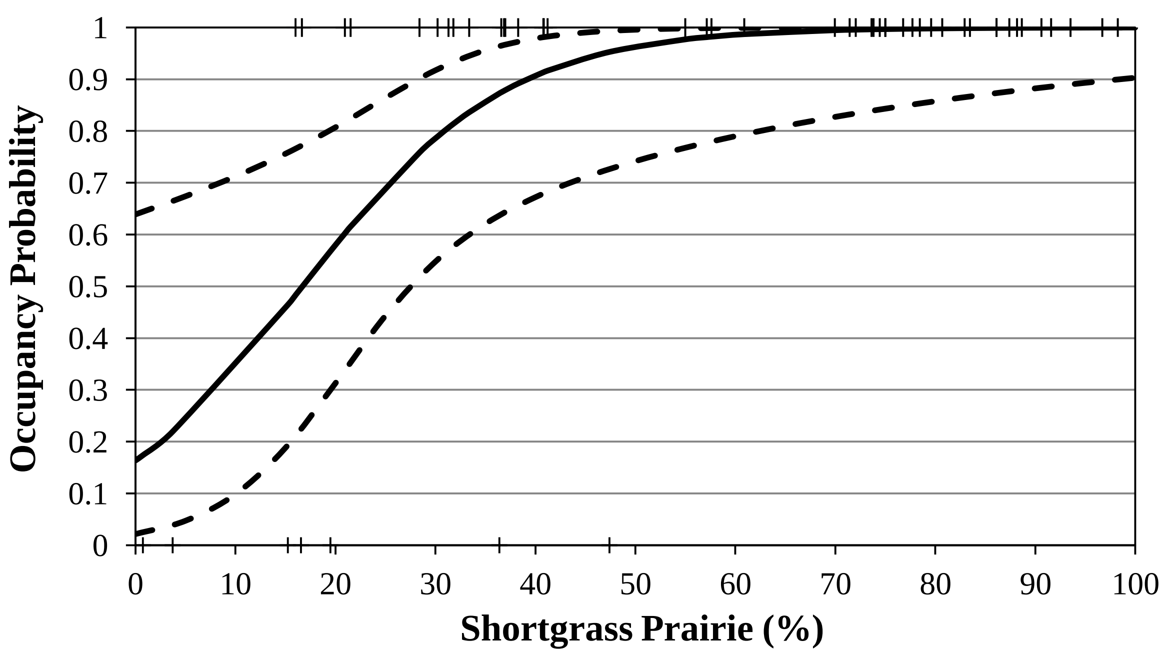

Figure 4. Prediction of the probability of occupancy by swift foxes as a function of the percentage of short-grass prairie on the 30.7 km^2 survey grids with 95% confidence intervals. Crosses on the 0 and 1 lines indicate the status of the 52 survey grids, with 45 of the grids recording foxes detected.

Table 1. Frequency of species detected from cameras set for swift foxes in eastern Colorado, 29 August to 28 October 2011.

Species		No. Individuals	No. Grids
Coyote	*Canis latrans*	NA[1]	52
Swift Fox	*Vulpes velox*	331	45
Black-tailed Jackrabbit	*Lepus californicus*	NA	40
Cottontail Rabbit	*Sylvilagus* spp.	NA	31
Badger	*Taxidea taxus*	48	27
Domestic Cow	*Bos* sp.	NA	25
Striped Skunk	*Mephitis mephitis*	85	24
Raccoon	*Procyon lotor*	15	9
American Crow	*Corvus brachyrhynchos*	5	5
Pronghorn Antelope	*Antilocapra americana*	6	4
Domestic Horse	*Equus* sp.	4	4
Mule Deer	*Odocoileus hemionus*	4	3
Kangaroo Rat	*Dipodomys* spp.	4	3
Western Meadowlark	*Sturnella neglecta*	3	3
Swainson's Hawk	*Buteo swainsoni*	3	3
Burrowing Owl	*Speotyto cunicularia*	3	3
White-tailed Deer	*Odocoileus virginianus*	2	2
Black-tailed Prairie Dog	*Cynomys ludovicianus*	3	2
Common Nighthawk	*Chordeiles minor*	2	2
Common Raven	*Corvus corax*	2	2
Gray Fox	*Urocyon cinereoargenteus*	1	1
Bobcat	*Felis rufus*	1	1
Porcupine	*Erethizon dorsatum*	1	1
Long-tailed Weasel	*Mustela frenata*	1	1
Domestic Cat	*Felis* sp.	1	1
Domestic Dog	*Canis* sp.	1	1
Bat	*Myotis* spp.	1	1
Scaled Quail	*Callipepla squamata*	1	1
Northern Bobwhite Quail	*Colinus virginianus*	1	1
Ring-necked Pheasant	*Phasianus colchicus*	1	1

[1]NA - No individual count was conducted.

Table 2. Occupancy model selection results for 52 swift fox grids surveyed in eastern Colorado, August thru October, 2011. Variable definitions are: *p* = detection probability, ψ = occupancy probability, SGP = percent short-grass prairie in the grid, day = detection varied by day.

Model	AIC_c	ΔAIC_c	AIC_c Weights	Model Likelihood	No. Par.[a]	Deviance
{ψ(SGP) *p*(.)}	307.96	0	0.68443	1	3	301.48
{ψ(SGP) *p*(SGP)}	309.83	1.8663	0.26919	0.39331	4	301.01
{ψ(SGP) *p*(Day)}	313.92	5.9648	0.03468	0.05067	7	297.49
{ψ(SGP) *p*(Day + SGP)}	316.23	8.2700	0.01095	0.01600	8	297.03
{ψ(.) *p*(.)}	322.46	14.4953	0.00049	0.00071	2	318.22
{ψ(.) *p*(SGP)}	324.07	16.1100	0.00022	0.00032	3	317.59
{ψ(.) *p*(Day)}	328.03	20.0672	0.00003	0.00004	6	314.24
{ψ(.) *p*(Day + SGP)}	330.06	22.1048	0.00001	0.00002	7	313.63

[a]No. Par. = Number of parameters used in each model.