STATUS OF SWIFT FOX 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 in short-grass prairie habitat using a non-invasive approach to evaluate the status of the swift fox in eastern Colorado. From August through October 2021, we used remote infrared cameras and a skunk-based lure on 94 patches of short-grass prairie habitat to estimate detection and occupancy rates of swift fox populations in eastern Colorado. We partitioned short-grass habitat into two patch sizes and used 2–4 camera stations within each patch and monitored each patch for 3 consecutive nights. We collected 162 unique swift fox detections from 24 August to 20 October, 2021. Across all patch sizes, detection probabilities varied by survey night and the average was $p = 0.501$ ($SE = 0.0461$, 95% CI 0.412–0.591). Probability of occupancy increased with patch size where occupancy for medium patches (7.8–12.9 km^2) $\hat{\psi} = 0.560$ (SE = 0.0908, 95% CI 0.382–0.723), and for grids (>12.9 km^2) $\hat{\psi} = 0.829$ (SE = 0.0731, 95% CI 0.638–0.930). We evaluated multiple survey years and due to the variability in those occupancy estimates, we were unable to detect a change over the last 15 years. We estimated the amount of short-grass prairie in eastern Colorado that is occupied by swift fox to be 32,478 km^2. Our estimate represents approximately 76% of the available short-grass prairie patches >2.6 km^2 in size and 61% of the total available short-grass prairie in eastern Colorado. Future surveys should continue to focus on additional fragmented short-grass prairie patches on the landscape to build on and refine our estimates of the distribution of occupied swift fox habitat. Reduction in the variability of detection rates via improved survey protocol consistency could be achieved by using a smaller dedicated survey team in future years.

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INTRODUCTION

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 Conservation Assessment and Conservation Strategy for Swift Fox in the United States (Kahn et al. 1997) to monitor the status of swift fox every 5 years, surveys began again in the fall/winter of 2004-05 to estimate occupancy and population size (Martin et al. 2007).

Legal harvest of swift fox in Colorado was suspended 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 (SGP) 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 has been increasingly important to assess any potential impacts through continued monitoring of the species.

Prior to 2011, mark-recapture techniques using cage traps to capture and mark each fox were used as the means to determine occupancy rates of swift fox across eastern Colorado (Finley et al. 2005, Martin et al. 2007). In 2011, a non-invasive survey technique using infrared cameras at scent stations was used to monitor occupancy rates for swift fox in eastern Colorado

(Stratman 2012, Stratman and Apker 2014). While our knowledge of occupied habitat on the eastern plains of Colorado has improved greatly since 2011, the extent of swift fox distribution is still not completely known. Stratman (2012) stated that the ability to accurately assess changes in swift fox occupancy requires a determination of what areas are actually occupied across the landscape. Despite the high dependence of swift fox on SGP, the sampling frame used prior to 2016 was inadequate for determining if all areas of short-grass prairie are truly occupied by swift fox due to the extent of fragmentation of SGP in eastern Colorado (Stratman 2012). This uncertainty limited our ability to map the species geographic distribution and establish a true baseline for comparison of swift fox occupancy across time.

In 2016, the survey design was modified to focus exclusively in SGP habitat to provide a better determination of the true occupancy across eastern Colorado. To estimate swift fox occupancy across the fragmented SGP landscape, SGP was partitioned into three size classes based on the contiguous patch size. Remote cameras at scent stations (Stratman and Apker 2014) were used to estimate swift fox occupancy rates of small (2.6–7.8 km^2) and medium (7.8–12.9 km^2) sized patches in more fragmented SGP. Grids (>12.9 km^2) in large contiguous SGP patches were surveyed for comparison with previous surveys (Martin et al. 2007, Stratman and Apker 2014).

In 2021, the survey design was refined to focus survey efforts only within medium sized (7.8–12.9 km^2) patches and grids (>12.9 km^2) within short-grass prairie habitat to compare with previous surveys (Stratman and Apker 2014, Stratman 2017). Small (2.6–7.8 km^2) patches of SGP were not surveyed in 2021 due to difficulties obtaining enough landowner permission for an adequate sample size and low rates of occupancy by swift fox observed in 2016. Swift fox occupancy in 2021 was determined using remote cameras at scent stations as in previous surveys

(Stratman and Apker 2014, Stratman 2017).

STUDY AREA

The survey area included all or portions of 25 counties in eastern Colorado, primarily east of Interstate 25, encompassing nearly 80,000 km^2 (Martin et al. 2007). Colorado's 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 2014). Cattle production is common throughout the region and grazing intensity varies greatly.

There is roughly 46,112 km^2 of short-grass prairie scattered across eastern Colorado. Dominant plant species in areas with SGP 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*), and prairie sandreed (*Calamovilfa longifolia*). 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 large daily and seasonal ranges 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 2011).

METHODS

Sampling Frame Selection

All short-grass prairie habitat identified from LANDFIRE vegetation classification data for eastern Colorado was stratified into two size classes; medium patches (7.8–12.9 km^2), and grids (>12.9 km^2) to determine swift fox occupancy rates across the SGP landscape. In eastern Colorado, we identified 159 medium patches, and 344 grids that were available for survey sampling. To maintain consistency, we used 19 medium patches surveyed in 2016 that contained 7.8–12.9 km^2 of SGP as part of the initial 2021 medium patch 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 21 medium patches to bolster our survey to 40 medium patches for our initial sample across eastern Colorado.

The survey grid size (4.8 x 6.4 km^2) and sample frame of 51 grids were initially established by Finley et al. (2005) and Martin et al. (2007) and has been maintained as the minimum sampling frame in subsequent surveys (Stratman and Apker 2014, Stratman 2017), including this study, to compare changes in occupancy and detection over time. We used 50 grids surveyed in 2016 that contained >12.9 km^2 of SGP as part of the initial 2021 large patch sampling frame. Using RRQRR, we randomly selected 3 additional grids bringing the total to 53 grids for our initial sample. Finally, we selected another 11 medium patches and eight grids to be used as alternative survey sites in case access couldn't be obtained to the primary patches and grids or ground observations showed the habitat was not suitable.

For each 4.8 x 6.4 km^2 grid, we used an array of 4 infrared cameras (Reconyx, PC800, PC900, HFX2, Holmen, WI) spaced a minimum of 3.2 km apart within each grid. For medium patches, we deployed cameras at two sites. The number of cameras for each patch size was based on an average female swift fox home range size (Finley et al. 2005). When necessary, we moved cameras within grids or patches 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 conducted the survey from August through October 2021 to coincide with juvenile dispersal and to maximize detection probabilities (Finley et al. 2005, Martin et al. 2007).

We attached cameras to light duty "U" posts measuring 0.91m (36 in) in height using a single screw or an L-shaped mounting bracket, depending on the style of camera. The "U" posts were equipped with pre-drilled holes spaced evenly along the shaft, which provided for quick attachment and consistent height reference. We placed a wooden stake 61 cm (24 in) approximately 3 m (10 ft) 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, Stratman and Apker 2014). We applied approximately 5–10 ml of lure to the top of each stake as an attractant.

We programmed the cameras to take three consecutive photos each time the camera was triggered and cameras were set to take pictures from 1 hour before sunset to 1 hour after sunrise. This timeframe takes advantage of peak swift fox activity (Kitchen et al. 1999, Moehrenschlager et al. 2003) and minimizes 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 or patch number. We left cameras active for three consecutive nights. On Day 4, 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 on each survey grid and patch. We categorized swift fox detections as separate and unique for all swift fox photos taken >2 hours 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.

Data Analysis

We combined data from the four cameras within each grid to develop an encounter history for each grid. We did the same for the two cameras within medium patches and estimated the probability of occupancy (ψ) and detection (p) for each patch size using Program PRESENCE (Hines 2021). The previous swift fox survey in Colorado reported that the size of the SGP patch was a factor associated with all swift fox detections (Stratman 2017). Therefore, we considered a set of *a priori* models that incorporated the two categorical patch sizes of SGP to model detection probabilities (p) and ψ (psi). We used the modeled results of both p and ψ for the medium patches and grids for comparison with previous surveys. We report model outputs which include ψ and up to three detection probabilities (p) for the three survey nights for each SGP patch size category.

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 distribution of SGP occupied by swift fox in eastern Colorado using the SGP specific estimates for ψ from the minimum AIC_c model.

We conducted an additional analysis in program MARK (White and Burnham 1999) to evaluate p and ψ across years. We used data collected from grids (i.e., large patches only) in 2011, 2016, and 2021 and incorporated year as a covariate to estimate annual differences in p and ψ. We could not include medium and small patches because they were not sampled often enough. Our total sample size was 57 grids, 52 of which were sampled each year, two of which were sampled in 2016 and 2021, and three of which were sampled in 2016 only. We included models that fit the covariates *night*, *year* and camera deployment *crew* (NE Region, Area 11, Area 12 or Area 14) to p and year to ψ. We also modeled whether fox *behavior* might affect detection probability, which fit the 2nd and 3rd nights (p) as equal but the 1st night of a capture period as different than the latter two nights. Swift fox behavior in relation to the camera/lure site over subsequent nights is thus nested within visit so the global model we considered was p (*night* * *year* * *crew*) ψ (year). We considered only interaction models because we wanted to keep the year terms as independent as possible to estimate change in occupancy across years; for the same reason we always included a year term for *p*. This resulted in a set of six total models.

RESULTS

Survey Effort

We surveyed two alternative sites each for medium patches and grids because adequate landowner permission could not be obtained on the original sites. We also surveyed one additional medium patch and one additional grid since landowner permission was obtained to further bolster sample sizes. Therefore, we surveyed 40 medium patches and 54 grids between 24 August and 20 October 2021 for a total survey sampling frame of 94 survey sites (Fig. 1).

We surveyed all sites for a minimum of three nights, although some (12 of 94) sites had cameras active for up to six consecutive nights before being removed. We completed the survey with 962 total camera nights (CN) and no data was collected on 33 CNs (3.4%). The CNs with no data were due to livestock interference (27 CN) and human error (6 CN).

We collected 162 unique swift fox detections during the remaining 929 CNs. We detected ≥1 swift fox on 40 of the 54 survey grids and 20 of the 40 medium patches and the number varied from 1–10 unique detections per survey site. Of those 60 survey sites with observations, we detected swift fox on 75% of the sites (45 of 60 sites) in the 1st night. After the 2nd night, 88% (53 of 60 sites) of the sites had obtained a swift fox detection.

Detection and Occupancy Estimation

Across both patches and grids, detection probabilities varied by night with the first survey night having the highest probability at $p = 0.655$ ($SE = 0.068$, 95% CI 0.512–0.774) (Fig. 2). The probability of detecting a swift fox in a single night averaged across all nights was $p = 0.501$ ($SE = 0.046$, 95% CI 0.412–0.591). Detection probabilities increased with patch size and generally declined over time (Fig. 2).

Model selection results for occupancy estimation in 2021 are shown in Table 1. Compared to the top occupancy model with *p* varying by night, the patch size of SGP did not improve model fit of detection probabilities, although there was evidence that suggested it did have a small influence on detection. However, the size of SGP patch was an important influence on the probability of occupancy.

The overall estimated occupancy rate in 2021 across both patches and grids was $\hat{\psi}$ = 0.714 (SE = 0.061, 95% CI 0.582–0.818). When detection was allowed to vary by patch size the overall occupancy was $\hat{\psi}$ = 0.781 (SE = 0.070, 95% CI 0.616–0.888). When the 2021 occupancy rates were estimated by patch size, occupancy for medium patches was $\hat{\psi}$ = 0.560 (SE = 0.091, 95% CI 0.382–0.723), and for grids was $\hat{\psi}$ = 0.829 (SE = 0.073, 95% CI 0.638–0.930).

Based on the entire set of 503 patches of SGP from which the 94 surveyed sites were selected, the amount of SGP in eastern Colorado occupied by swift foxes was estimated at 31,056 km^2 using the overall occupancy rate with detection varying by patch size. Occupancy was estimated at 32,478 km^2 using occupancy rates varying by patch size. Finally, based on survey results, the overall distribution of occupied swift fox habitat in eastern Colorado was estimated to encompass approximately 33,794 km^2 across portions of 21 counties (Fig. 3).

For the analysis across years, the low-AICc model was *p* (*behavior* * *year*) ψ (*year*) and was 6.48 AICc units lower than the most closely ranked model. With detection varying by *year* and first night vs the final two nights, occupancy was $\hat{\psi}$ = 0.869 (SE = 0.054, 95% CI 0.728–0.942) in 2011, $\hat{\psi}$ = 0.825 (SE = 0.063, 95% CI 0.666–0.917) in 2016, and $\hat{\psi}$ = 0.801 (SE = 0.070, 95% CI 0.631–0.905) in 2021. Detection probabilities ranged from 0.659 – 0.797 for the

1st night and 0.462 – 0.642 for the 2nd and 3rd nights pooled.

DISCUSSION

After the first survey night in 2021, overall detection probabilities declined on average by 35% for the remaining 2 nights of survey. In 2011 and 2016, there was a 14% and 16% decline, respectively, after the first night and it is likely due to a lack of curiosity in the lure after the initial swift fox investigation (Cudworth et al. 2011, Stratman and Apker 2014). In 2021, the rate of decline was more pronounced for medium patches than grids, which was not observed in 2016 when the rate of decline was fairly consistent across the patch sizes (Stratman 2017). Although the size of the SGP patch did not improve detection probability over the top model with p varying by night, there was model evidence to suggest that the size of the SGP patch has a positive influence on detection probability. Detection probabilities increased by more than 60% between medium patches and large patches, compared to only an 18% increase reported in 2016 (Stratman 2017). This change over time demonstrates the positive relationship between SGP patch size and swift fox detection.

For the analysis across all 3 years on the grids (i.e., large patches) only, the 2011 estimate was $\hat{\psi}$ = 0.869 (*SE* = 0.052) and the 2016 estimate was $\hat{\psi}$ = 0.825 (*SE* = 0.063) compared to the current estimate of $\hat{\psi}$ = 0.801 (*SE* = 0.070). Because of the variance in these estimates, we did not detect a change in swift fox occupancy between 2011-2021.

There was a slight difference in point and *SE* estimates between the single year 2021 analysis and the multi-year analysis due to a slightly different modeling approach with fox *behavior* being modeled for p. When the same model structure was used for the multi-year analysis, estimates were nearly identical to the 2021 grid results.

Partitioning SGP based on patch size continues to show that the estimates of swift fox distribution and occupancy across the landscape have improved. As in 2016, the size of the SGP patch did influence the probability of swift fox occupancy. On average, the probability of occupancy decreased by 48% between large and medium patch sizes surveyed, which was similar to the decrease found in 2016. While there are numerous factors that ultimately determine whether a patch is occupied by swift fox, this continues to show the negative effect of habitat fragmentation on swift fox occupancy in eastern Colorado.

Stratman (2017) reported the inherent errors that are present with habitat classification derived from aerial or thermal imagery. He encountered 35% of the small and medium SGP patches identified from the 2016 LANDFIRE data that were classified incorrectly across the northern portion of eastern Colorado. During the 2021 surveys, we identified seven medium patches (17%) that were misclassified as SGP, but only two were removed from the sampling frame, due to time constraints that limited our ability to obtain landowner permission on replacement patches. All of the misclassifications were sandsage (*Artemisia filifolia*) and CRP plantings being the habitats misidentified as SGP. Habitat fragmentation and the small resolution of the data layer appear to be the leading factors in the misclassification rate encountered in this region of the state.

MANAGEMENT IMPLICATIONS

In Colorado, swift fox are highly dependent on short-grass prairie habitat and swift fox occupancy varies considerably depending on the size of the SGP patch and proximity to other patches across the landscape. Swift fox have been detected in SGP patches as small as 2.6 km^2 (Stratman 2017) and the probability of occupancy has been shown to increase as the patch size of SGP increases. This provides the baseline data needed to continue to refine the geographic distribution of available swift fox habitat in Colorado. The sampling frame used in this survey was adequate for determining which areas of short-grass prairie are truly occupied by swift fox. However, the extent of fragmentation of short-grass prairie in eastern Colorado makes it time and cost prohibitive to survey all areas on the landscape in a single survey. Future surveys should continue to focus on additional fragmented SGP patches on the landscape to build on our estimates of the distribution of occupied swift fox habitat.

In this study, surveying exclusively within SGP and partitioning the habitat by patch size was effective in refining the distribution of swift fox and their primary occupied habitat compared to some of the previous surveys that surveyed across all habitat types. However, we recommend that investigators conduct ground and/or aerial surveys to identify the SGP patches that are misclassified in the data layer imagery that is used. This would provide a uniform sampling frame to increase efficiency of staff time and effort prior to surveying, and ultimately improving the precision and accuracy of the survey estimates. Because population or density estimates are not derived from this type of survey, it is possible that smaller or gradual changes in swift fox abundance could go undetected. Thus, occupancy should only be considered one indicator of the status of swift fox.

Since 2011, occupancy point estimates have varied across surveys. However, this is likely a product of the increase in survey and observer variability that was introduced in 2016. In 2011, the entire survey was conducted by two observers, which maintained consistency throughout the survey. In 2016 and 2021, survey responsibility was distributed among various agency personnel stationed across the eastern plains. This increased the number of observers to >8 different people each year, which has increased the variability of detection rates in the survey results. Because of the wide array of knowledge, experience, and effort levels inherent with using multiple observers, in the future we recommend establishing a fixed and consistent pool of observers to conduct all surveys, as well as provide additional training to improve the consistency of protocol implementation among those individuals selected. This could best be accomplished by hiring a survey crew of 3-4 observers, whose sole focus is conducting the survey. This would establish more consistency throughout the survey while reducing the number of days needed to complete the work. In turn, this would provide opportunities to expand the sampling frame into more fragmented SGP patches across the eastern plains, while still completing the survey in the same time frame as in the past.

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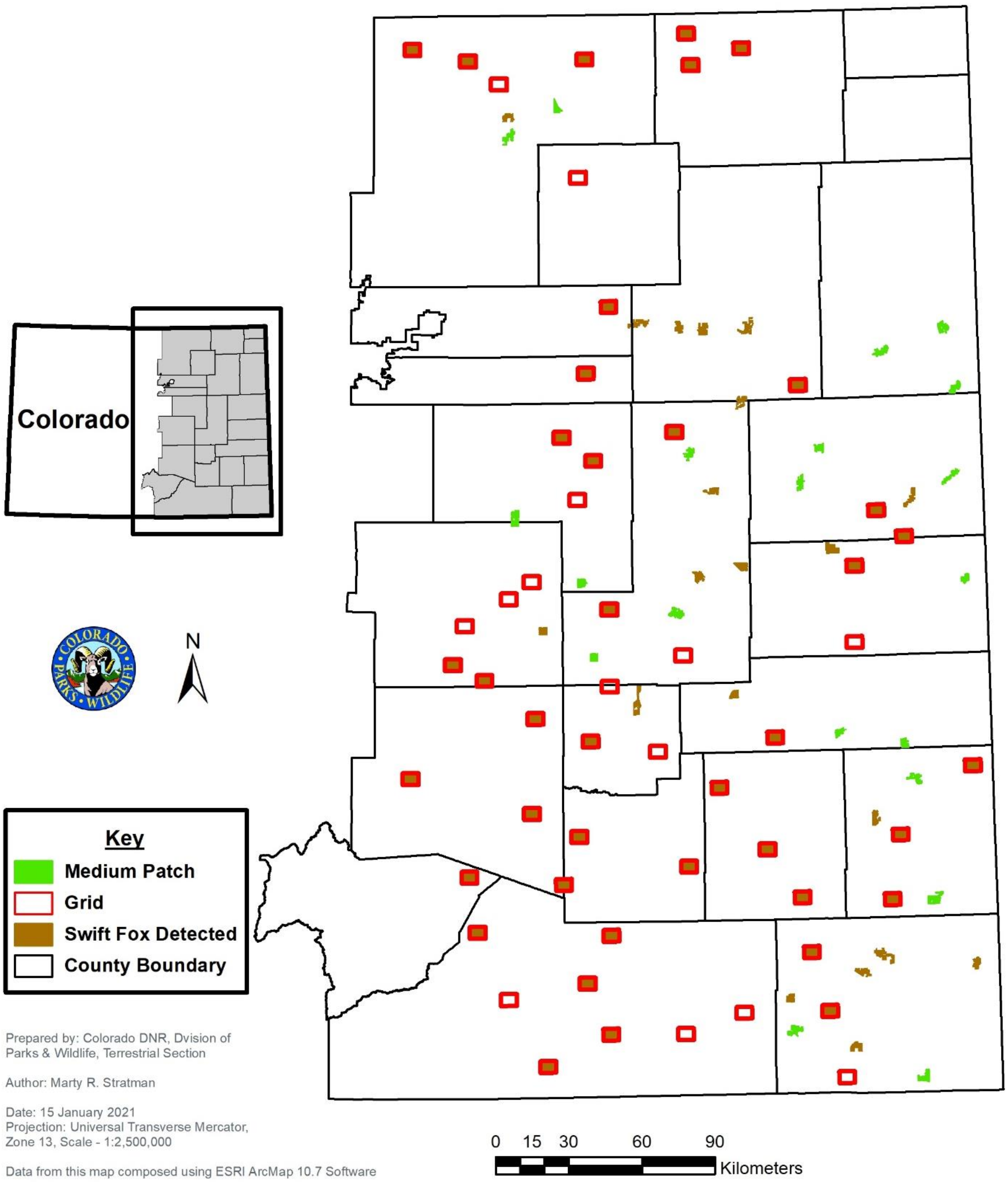

Figure 1. Distribution of swift fox monitoring patches and grids of short-grass prairie (SGP) in eastern Colorado, showing patch size and whether foxes were detected by cameras in each, August–October, 2021.

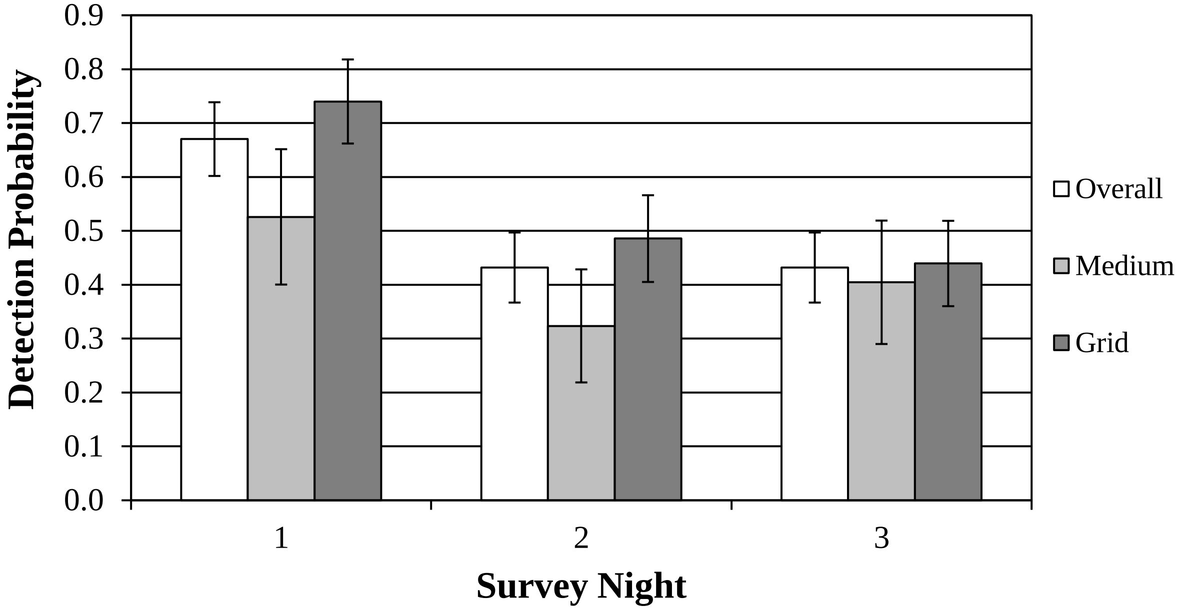

Figure 2. Probability of detecting swift fox on medium (7.8–12.9 km^2) patches and grids (>12.9 km^2) of short-grass prairie by survey night in eastern Colorado, August through October, 2021. Standard error (SE) bars shown on (*p*).

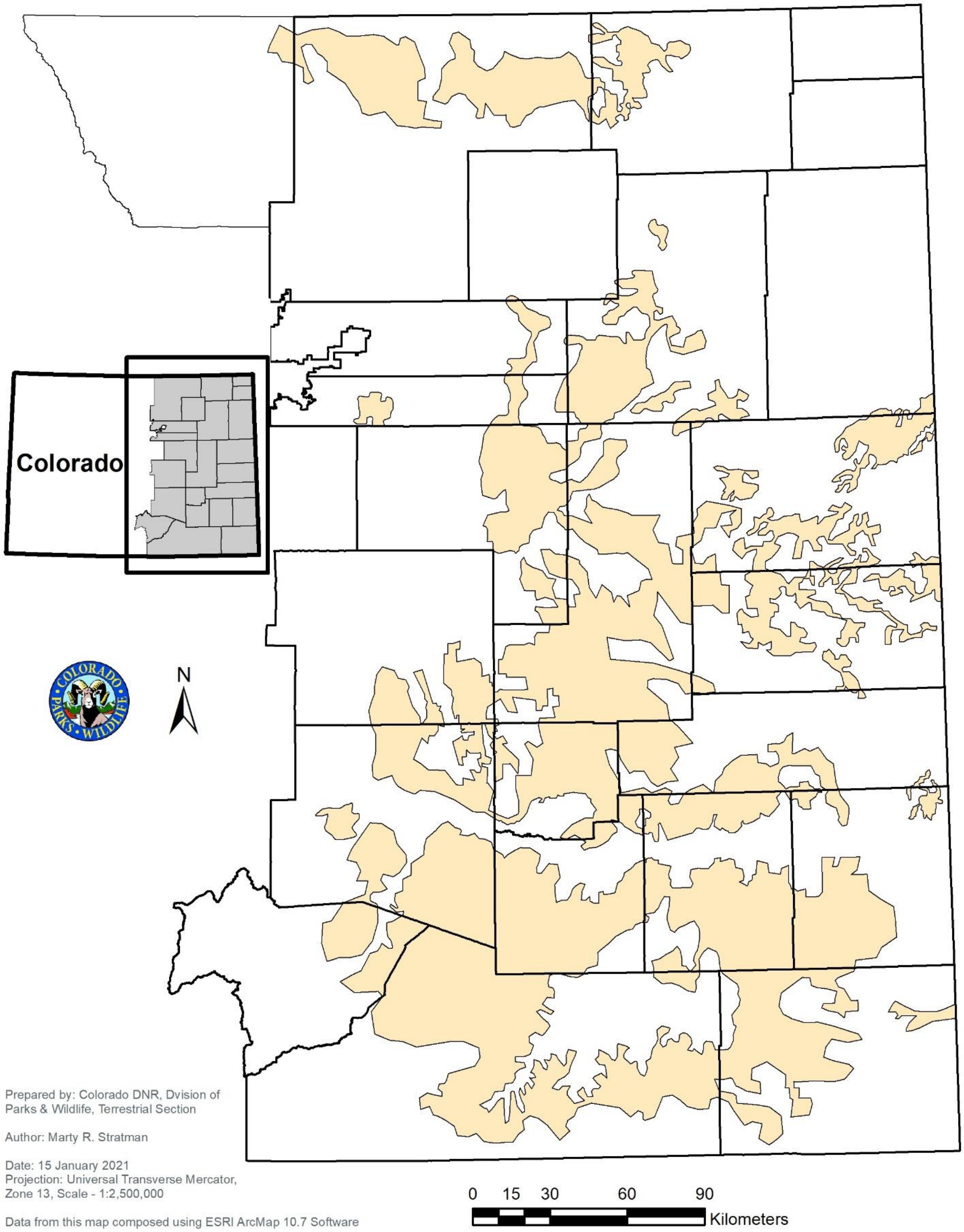

Figure 3. Estimated distribution of occupied swift fox habitat in eastern Colorado based on survey results collected in 2016 and 2021.

Table 1. Model selection results for 94 patches of short-grass prairie surveyed for swift fox presence in eastern Colorado, USA, August–October, 2021. Variable definitions are: ψ = occupancy probability, *p* = detection probability, Psize = patch size of short-grass prairie surveyed, Night = detection varied by night.

Model	AIC_c[a]	ΔAIC_c	w_i[b]	Likelihood	k[c]	Deviance
{ψ(Psize) *p*(Night)}	351.217	0.000	0.530	1.000	5	340.550
{ψ(.) *p*(Night × Psize)}	353.574	2.357	0.163	0.308	6	340.630
{ψ(Psize) *p*(Night × Psize)}	354.063	2.846	0.128	0.241	7	338.790
{ψ(.) *p*(Night)}	354.760	3.543	0.090	0.170	4	346.320
{ψ(.) *p*(Psize)}	356.811	5.594	0.032	0.061	3	350.550
{ψ(Psize) *p*(.)}	357.031	5.814	0.029	0.055	3	350.770
{ψ(Psize) *p*(Psize)}	357.470	6.253	0.023	0.044	4	349.030
{ψ(.) *p*(.)}	360.659	9.442	0.005	0.009	2	356.530

[a] Akaike Information Criterion for small samples.

[b] Akaike weight.

[c] Number of parameters.