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 2016, we used remote infrared cameras and a skunk-based lure on 177 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 three patch sizes and used 1–4 camera stations within each patch size and monitored each grid for 3 consecutive nights. We collected 227 unique swift fox detections from 15 August to 19 October, 2016. Across all patch sizes, detection probabilities varied by survey night and the average was $p = 0.553$ ($SE = 0.0398$, 95% CI 0.475–0.629). Probability of occupancy increased with patch size where occupancy of small patches (2.6–7.8 km^2) was $\hat{\psi} = 0.335$ (SE = 0.0526, 95% CI 0.241–0.445), for medium patches (7.8–12.9 km^2) $\hat{\psi} = 0.503$ (SE = 0.1124, 95% CI 0.295–0.710), and for grids (>12.9 km^2) $\hat{\psi} = 0.848$ (SE = 0.0649, 95% CI 0.675–0.937). Swift fox occupancy has remained stable with no change being detected over the past 20 years in eastern Colorado. We estimated the amount of short-grass prairie in eastern Colorado that is occupied by swift fox to be 33,696.0 km^2. Our estimate represents approximately 78% of the available short-grass prairie >2.6 km^2 and only 63% 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.

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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 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 (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 become increasingly 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). 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). Currently, the distribution of swift fox across eastern Colorado is 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 in previous surveys 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 limits our ability to map the species geographic distribution and establish a true baseline for comparison of swift fox occupancy across time.

Based on previous survey results and recommendations, in 2016, the survey design was further modified to focus exclusively in short-grass prairie habitat to provide a better determination of the true occupancy across eastern Colorado. Stratman (2012) speculated that the patch size of SGP was a determining factor in detecting swift fox in eastern Colorado. He noted that a minimum patch size of $\geq$2.6 km^2 was generally associated with all swift fox detections. Therefore, to estimate swift fox occupancy across the fragmented SGP landscape, we partitioned SGP into three size classes based on the contiguous patch size. We used remote cameras at scent stations as in the previous survey (Stratman and Apker 2014) to estimate swift fox occupancy rates of small (2.6–7.8 km^2) and medium (7.8–12.9 km^2) patches in more fragmented SGP and surveyed large patches (>12.9 km^2) for comparison with previous surveys (Martin et al. 2007, Stratman and Apker 2014).

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). 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 2014). Cattle production is common throughout the region and grazing intensity varies greatly.

There is roughly 53,114 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 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 Climatic Data Center 2011).

METHODS

Sampling Frame Selection

All short-grass prairie habitat identified from LANDFIRE vegetation classification data for eastern Colorado was stratified into three patch sizes; small (2.6–7.8 km^2), medium (7.8–12.9 km^2), and large (>12.9 km^2) to determine swift fox occupancy rates across the fragmented SGP landscape. In eastern Colorado, we identified 822 small patches, 205 medium patches, and 245 large patches encompassing approximately 42,903 km^2 that were available for survey sampling. Using a spatially-balanced sampling process employing Reversed Randomized Quadrant-Recursive Raster (RRQRR) algorithm (Theobald et al. 2007), we randomly selected 110 small patches and 26 medium patches to survey 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 in previous surveys (Martin et al. 2007, Stratman and Apker 2014) as well as this study to compare changes in occupancy and detection over time. To concentrate the survey in SGP habitat, we used 41 grids surveyed in 2011 that contained >12.9 km^2 of SGP as part of the initial large patch sampling frame. Using RRQRR, we randomly selected 11 additional grids bringing the total to 52 grids for sampling large patches. In addition, we also selected another 14 small patches, five medium patches, and eight grids to be used as alternative survey sites in case landowners denied access to the primary patches and grids.

For each 4.8 x 6.4 km^2 grid, we used an array of 4 infrared cameras (Reconyx, PC800, Holmen, WI) spaced a minimum of 3.2 km apart within each grid. For small patches, we used one camera site and for medium patches we used two camera sites. The number of cameras for each patch size was based on the average female 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 thru October 2016 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 inch) in height using a single screw. 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 (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, 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 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 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 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.

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 the one for small patches and estimated the probability of occupancy (ψ) and detection (*p*) for each using Program PRESENCE (Hines 2016). 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 2012). Therefore, we considered a set of *a priori* models that incorporated the three categorical patch sizes of SGP to model detection probabilities (*p*) and ψ (psi). We also used the modeled results of both *p* and ψ for the 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 of SGP occupied by swift fox in eastern Colorado using the SGP patch specific estimates for ψ from the minimum AIC_c

model corrected for small sample size. The proportion of occupied SGP was further refined using estimates from various geographic locations where significance differences were detected. Finally, using the results from this survey, as well as, those from 2011, we estimated the overall distribution of occupied swift fox habitat in eastern Colorado.

RESULTS

Survey Effort

We selected all of the alternative sites for small (*n* = 14) and medium (*n* = 5) patches and a few alternative grids (*n* = 4) because adequate landowner permission could not be obtained on the original sites (*n* = 28) or the habitat was not SGP (*n* = 20). We also surveyed several additional small (*n* = 12) and medium (*n* = 2) patches, as well as, three additional grids since landowner permission was obtained to further maintain or bolster sample sizes. Therefore, we surveyed 96 small patches, 24 medium patches, and 57 grids between 15 August and 19 October 2016 for a total survey sampling frame of 177 survey sites (Fig. 1).

We surveyed all sites for a minimum of three nights, although some (60 of 177) sites had cameras active for up to five consecutive nights before being removed. We completed the survey with 26 camera nights (CN) in which no data was collected. Grids accounted for 22 of the 26 inoperable camera nights. The inoperable camera nights resulted from battery failure (3 CN), livestock interference (8 CN), and human error (15 CN).

We collected 227 unique swift fox detections during the remaining 1,216 camera nights. We detected ≥1 swift fox on 45 of the 57 survey grids, 30 of the 96 small patches, and 12 of the 24 medium patches and the number varied from 1–10 unique detections per survey site. Of those 87 survey sites, we detected swift fox on 67% of the sites (58 of 87 sites) in the 1st night. After the 2nd night, 89% (77 of 87 sites) of the sites had obtained a swift fox detection and 98% (85 of

87 sites) of the sites had a confirmed detection by the end of the 3rd night.

Detection and Occupancy Estimation

Across all patch sizes, detection probabilities varied by night with the first survey night having the highest probability at p = 0.618 (SE = 0.0568, 95% CI 0.502–0.722) (Fig. 2). The average probability of detecting a swift fox across all nights was p = 0.553 (SE = 0.0398, 95% CI 0.475–0.629). Detection probabilities increased with patch size and generally declined over time (Fig. 2).

Model selection results for occupancy estimation are shown in Table 1. Compared to the top occupancy model with constant p, the patch size 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 size of SGP patch was an important influence on the probability of occupancy.

The overall estimated occupancy rate across all patch sizes was $\hat{\psi}$ = 0.524 (SE = 0.0436, 95% CI 0.439–0.608). When detection was allowed to vary by patch size the overall occupancy was $\hat{\psi}$ = 0.694 (SE = 0.0735, 95% CI 0.535–0.818). When the occupancy rates were estimated by patch size, occupancy of small patches was $\hat{\psi}$ = 0.335 (SE = 0.0526, 95% CI 0.241–0.445), for medium patches $\hat{\psi}$ = 0.503 (SE = 0.1124, 95% CI 0.295–0.710), and for grids $\hat{\psi}$ = 0.848 (SE = 0.0649, 95% CI 0.675–0.937). Among the small SGP patches surveyed, $\hat{\psi}$ = 0.137 (SE = 0.0578, 95% CI 0.058–0.293) for those in the northern and western portions of eastern Colorado compared to the small patches in the southeastern portion where $\hat{\psi}$ = 0.531 (SE = 0.1068, 95% CI 0.328–0.724).

Based on the entire set of 1,272 patches of SGP from which the 177 surveyed sites were selected, the amount of SGP in eastern Colorado occupied by swift foxes was estimated at 29,774.5 km^2 using the overall occupancy rate with detection varying by patch size and 33,555.1 km^2 using occupancy rates by patch size. When small patches of SGP were further partitioned by area, the amount of SGP estimated to be occupied was 33,696.0 km^2. Finally, based on survey results, the overall distribution of occupied swift fox habitat in eastern Colorado is estimated to encompass approximately 33,895 km^2 across portions of 22 counties (Fig. 3).

DISCUSSION

After the first survey night, overall detection probabilities declined on average by 16% for the remaining 2 nights of survey. In 2011, there was nearly a 14% decline 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). This rate of decline was also fairly consistent among the three patch sizes. In this study, there was also a significant difference in detection probabilities of small SGP patches between the northern and western portions of eastern Colorado compared to the southeasterly portion of the state. Although the size of the SGP patch did not improve detection probability over the top model with constant p, 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 5% between small and medium patches and increased another 18% between medium and large patches with a 24% increase in the probability of detecting a swift fox between small (2.6–7.8 km^2) and large (>12.9 km^2) patches of SGP, which supports a positive relationship.

There was no apparent effect from reducing the number of survey nights from five nights to three nights. Although there was a slight decline in the occupancy rates of the grids compared to 2011 (Stratman and Apker 2014), this change was not significant. However, the reduction to three survey nights did provide additional time needed to survey the other patch sizes. With the aid of additional equipment and manpower, we surveyed 177 patches and grids in the same amount of time (70 days) as was needed in 2011.

Comparing the minimum AIC_c models for the grids, the 2011 estimate was $\hat{\psi}$ = 0.872 (*SE* = 0.0528) compared to the current estimate of $\hat{\psi}$ = 0.848 (*SE* = 0.0649). The estimated change is -0.024, which is well within the sampling variation of the estimates. Therefore, we did not detect a change in swift fox occupancy since the previous survey and swift fox occupancy has remained stable with no change being detected over the past 20 years in eastern Colorado.

Partitioning SGP based on patch size greatly improved our estimates of swift fox distribution and occupancy across the landscape. As suspected, the size of the SGP patch did influence the probability of swift fox occupancy. On average, the probability of occupancy decreased by >50% as the patch size surveyed decreased. While there are numerous factors that ultimately determine whether a patch is occupied by swift fox, this is supporting evidence that habitat fragmentation and degree of isolation has a negative effect on swift fox occupancy on the landscape.

Determining the appropriate map layer to use to base the survey on proved more difficult than expected because of the inherent errors that are present with habitat classification derived from aerial or thermal imagery. To minimize these errors in our survey samples, we conducted an aerial survey of the initial sampling frame of small and medium-sized patches in July 2016 to identify patches that were misclassified as SGP. From this exercise, we identified 17 small and four medium patches from the northern one-third of the eastern plains, which were removed from survey consideration and new random patches were selected as their replacement. In addition, during the course of conducting the surveys, we identified another 14 small and six medium patches that were also misclassified and subsequently removed them from the sampling frames and additional replacements were selected. However, time constraints limited our ability to obtain landowner permission on some of those later replacement patches. Thus, our survey samples of small and medium patches were not as robust as originally intended. The majority of misclassifications (95%) occurred in the northern one-third of the eastern plains with sandsage (*Artemisia filifolia*) and CRP plantings being the most common habitats that were misidentified as SGP. Therefore, we encountered 35% of the small and medium SGP patches identified from the LANDFIRE data that were classified incorrectly across the northern portion of eastern Colorado. Habitat fragmentation and the small resolution of the data layer appear to be significant factors in the high misclassification rate we 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 were detected in SGP patches as small as 2.6 km^2 and the probability of occupancy increased as patch size increased. 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 previous surveys that surveyed across all habitat types. However, occupancy surveys continue to 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.

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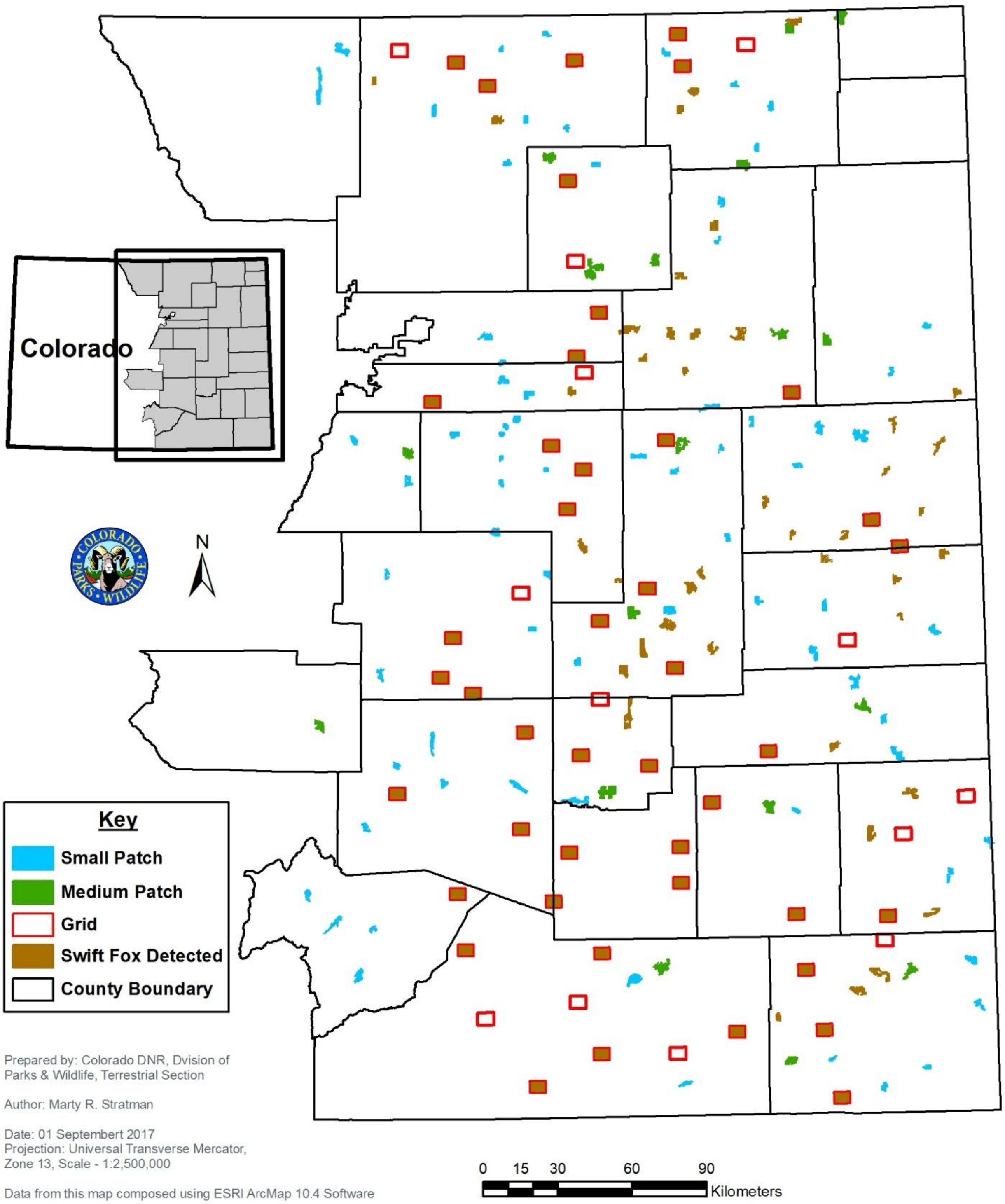

Figure 1. Distribution of swift fox monitoring patches and grids of short-grass prairie (SGP) in eastern Colorado, showing patch size and whether foxes were detected by cameras in each, August–October, 2016.

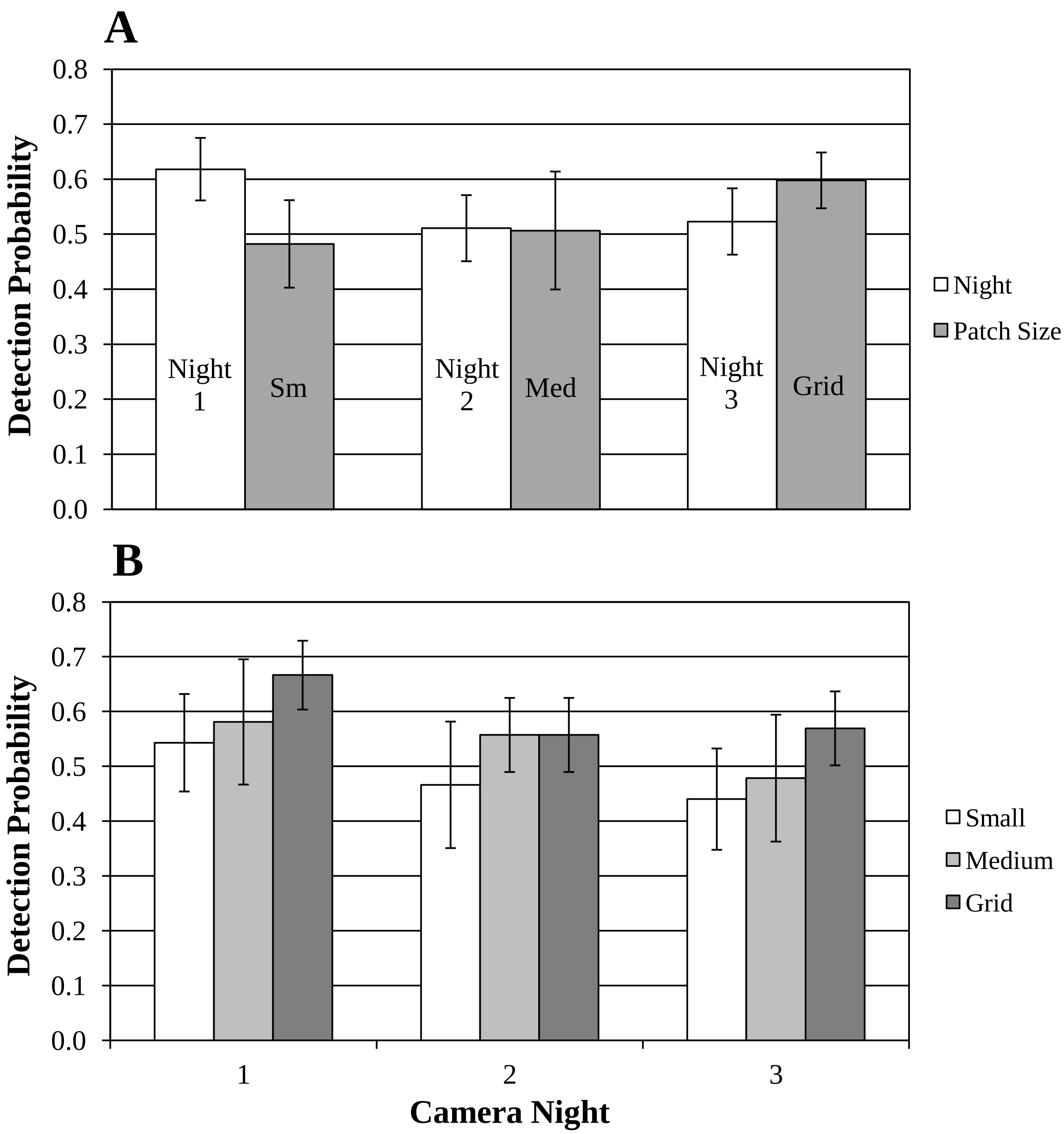

Figure 2. Probability of detecting swift foxes by A) camera night and patch size and B) by camera night on the small (2.6–7.8 km^2) and medium (7.8–12.9 km^2) survey patches, and grids (>12.9 km^2) of short-grass prairie in eastern Colorado, August through October, 2016. Error bars represent ±1 *SE*.

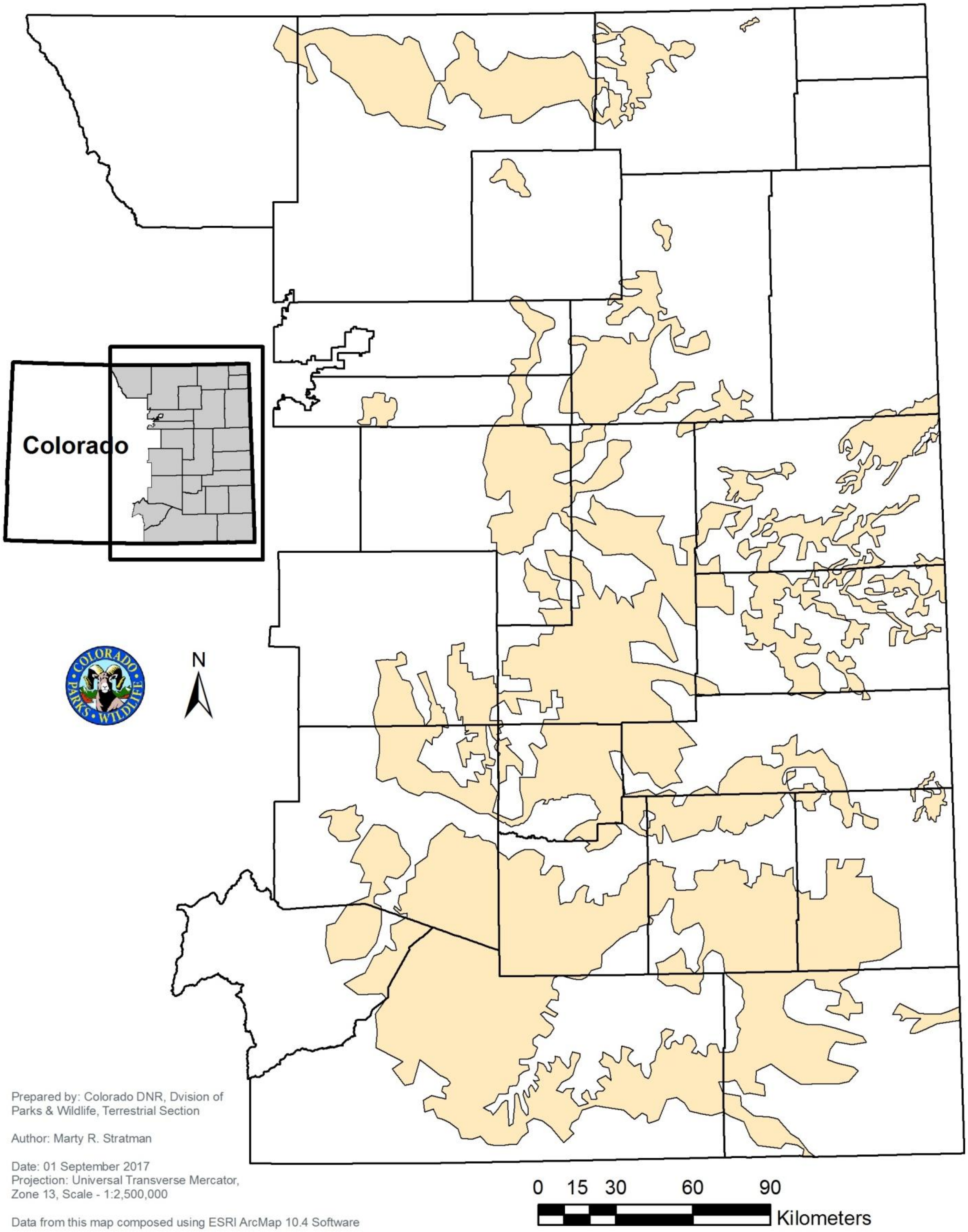

Figure 3. Estimated distribution of occupied swift fox habitat in eastern Colorado based on survey results collected in 2011 and 2016.

Table 1. Model selection results for 177 patches of short-grass prairie surveyed for swift fox presence in eastern Colorado, USA, August–October, 2016. Variable definitions are: ψ = occupancy probability, *p* = detection probability, Psize = patch size of short-grass prairie surveyed, day = detection varied by day.

Model	AIC_c[a]	ΔAIC_c	w_i[b]	Likelihood	k[c]	Deviance
{ψ(Psize) *p*(.)}	516.901	0.000	0.573	1.000	4	508.670
{ψ(Psize) *p*(Day)}	518.671	1.770	0.237	0.413	6	506.180
{ψ(Psize) *p*(Psize)}	519.391	2.490	0.165	0.288	6	506.900
{ψ(Psize) *p*(Day × Psize)}	523.201	6.300	0.025	0.043	9	504.130
{ψ(.) *p*(Psize)}	532.821	15.920	0.000	0.000	4	524.590
{ψ(.) *p*(Day × Psize)}	535.819	18.918	0.000	0.000	7	521.160
{ψ(.) *p*(.)}	545.149	28.247	0.000	0.000	2	541.080
{ψ(.) *p*(Day)}	546.831	29.930	0.000	0.000	4	538.600

[a] Akaike Information Criterion for small samples.

[b] Akaike weight.

[c] Number of parameters.