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Optimizing Monitoring Efforts of Kit Fox (*Vulpes macrotis*) in Utah

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Optimizing Efforts to Monitor Kit Foxes (*Vulpes macrotis*) in Utah

Kelsey Alina Richards

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

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ABSTRACT

Optimizing Efforts to Monitor Kit Foxes (*Vulpes macrotis*) in Utah

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Master of Science

The kit fox (*Vulpes macrotis*) is a species of conservation concern in western North America. Recent methods for monitoring populations of kit fox include using lures and remote cameras in an occupancy-modeling framework and habitat modeling to predict areas of occupancy. In chapter one, we tested the optimal lure and movement procedure for scent stations to maximize visits and detection of foxes, thereby improving estimates of occupancy. Between May 2015 and October 2016, we placed remote cameras at 522 random locations throughout nine study areas in the Colorado Plateau, Great Basin Desert, and Mojave Desert. Each location was randomly assigned one of three methods (Scented Predator Survey Disks, cotton swabs, or hollowed golf ball) to broadcast one of three lure types (Red and Gray Fox liquid lure, Willey liquid lure, and fatty acid lure). After seven nights, half of all stations were moved 100 meters within the same sample grid cell, while the others remained in the same location. Stations were then monitored for an additional week. We used Program MARK and AIC model selection to identify optimal lure types and broadcast methods and to estimate rates of occupancy. Detection of kit foxes differed by method of scent deployment; cotton swabs were associated with the highest rates of visitation. Detection of kit foxes did not differ by lure type. Relocating the scent station after one week did not influence detection probability. We suggest that the use of cotton swabs maximizes detection, and therefore, the precision of estimates of occupancy.

For chapter two, we used resource selection functions to identify variables that best discriminated between locations where kit fox were detected and random locations. We then produced a habitat map that predicted the relative probability of kit foxes occurring across seven study areas throughout the state of Utah. We placed remote cameras at 458 randomly selected locations throughout the study areas in the Colorado Plateau, Great Basin Desert, and Mojave Desert. We detected kit foxes at 157 “use” points from these cameras between May 2015 and October 2016. We then compared the attributes of these “use” points to 14,742 available, randomly selected points located within the study areas using variables derived from a Geographic Information System (GIS). We used model selection and minimization of AIC values to determine key habitat characteristics that differentiated use and random locations. We identified slope, elevation, and soil type as significant variables ($P < 0.05$) in habitat selection of kit foxes. Kit foxes selected areas that were 1) less steep, 2) lower in elevation, and 3) classified as having silty soils. The identification of these specific variables from our modeling effort was generally consistent with kit fox ecology. Our study produced a habitat model that can serve as a foundation for future monitoring efforts of kit foxes in potential habitat across Utah.

Keywords: occupancy, detection probability, remote cameras, scent stations, resource selection, population monitoring, used-available study design

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CHAPTER 1

Optimizing Detection of a Desert Carnivore at Scent Stations

ABSTRACT

The kit fox (*Vulpes macrotis*) is a species of conservation concern in much of western North America and therefore, understanding trends in population size is fundamental for conservation. A relatively new method for monitoring wildlife, including kit foxes, uses scent stations (comprised of lures and remote cameras) in an occupancy-modeling framework. However, the utility of occupancy modeling is dependent on detection of individuals at scent stations. Different lures including fatty acid disks and liquid lures have been used to attract foxes and other carnivores. However, the effectiveness of the various lures and their dispersal methods have not been well tested. Additionally, changing the scent and moving scent stations a short distance within the sampled grid cell midway through sampling may increase detection probabilities by providing novel stimuli. Our objective was to identify the optimal lure, movement procedure, and duration of sampling period to maximize detection of foxes, thereby improving estimates of occupancy. We set up scent stations at 522 random locations throughout nine study areas in the Colorado Plateau, Great Basin Desert, and Mojave Desert. Each location was randomly assigned one of three methods (Scented Predator Survey Disks, cotton swabs, or hollowed golf ball) to disperse one of three lure types (Red and Gray Fox liquid lure, Willey liquid lure, and fatty acid lure). Additionally, half of all scent stations were moved approximately 100 meters within the same sample grid cell midway through sampling, while the others remained in the same location. To estimate rates of occupancy, we used Program MARK and AIC model selection. Detection probability for kit foxes differed by method of lure deployment with cotton swabs having the highest rate of visits. Detection probability of kit foxes did not differ among lure types. Additionally, relocating the scent station did not influence detection probability. We suggest that the use of cotton swabs or hollowed golf balls maximizes detection over Scented Predator Survey Disks, and therefore, the precision around estimates of occupancy.

INTRODUCTION

A critical component in the successful conservation of a species is monitoring of existing populations (Lindenmayer et al., 2013). Organized monitoring efforts provide information regarding population size and geographic distribution over both space and time. These data can then inform wildlife management policies designed to conserve imperiled species (Yoccoz et al., 2001). Assessment of distribution and population trends over time also helps define the geographic ranges and acceptable fluctuations in population size for species not currently listed as endangered. Thus, the information obtained from monitoring programs is crucial for the protection of endangered species and those that may be at risk in the future.

Kit foxes (*Vulpes macrotis*) are desert carnivores that were historically distributed throughout the semi-arid regions of western North America (McGrew, 1979). They ranged from northern Mexico across western Texas and extended west into New Mexico, Arizona, Nevada, Utah, and California. Kit foxes were reported as far north as Oregon and Idaho (O'Farrell, 1999). While the current distribution of this species includes much of their original range (except portions of California) (Meaney et al., 2006; O'Farrell, 1999), habitat loss, degradation, fragmentation, and interspecific competition with coyotes have resulted in declines of kit foxes (Arjo et al., 2007; Clark et al., 2005; Meaney et al., 2006). These declines have made kit fox a species of increased concern for state and federal agencies tasked with their conservation and management. Within the last fifty years, kit foxes have been listed as endangered in Colorado, threatened in California and Oregon, designated as a state sensitive species in Idaho, and a species of highest conservation concern in Utah (Dempsey et al., 2014). With increased concern for the conservation of this species, increased monitoring has also occurred.

Kit foxes, however, are difficult to monitor because they are broadly distributed, occur at relatively low density, and are largely nocturnal (Dempsey et al., 2014; Egoscue, 1956; Murdoch et al., 2003). Numerous methods have been developed in an attempt to more effectively and efficiently monitor this species. Previous studies have used scent stations and track plates (Warrick and Harris, 2001), radio collars (Cypher, 1997), spotlight surveys (Warrick and Harris, 2001), scat surveys (Smith et al., 2005), and live capture (Kozlowski et al., 2003) to determine abundance or distribution of kit foxes. Many of these methods, however, are time consuming, require advanced technical training, or are ineffective in inclement weather. As a result, the use of remote cameras to monitor kit foxes has increased (Constable et al., 2009; Hall et al., 2013; Kluever et al., 2013). This trend mirrors the rising popularity of remote cameras in wildlife monitoring generally, as cameras have become smaller, more durable, more reliable, and less expensive (Sanderson and Trolle 2005).

A variety of protocols using remote cameras and attractants have been employed in field research for predators such as kit foxes. Studies have used different attractants to draw in foxes, including cat food, canned fish, fatty acid, and liquid lures (Constable et al., 2009; Warrick and Harris, 2001; Hall et al., 2013). Additionally, researchers have used various broadcasting mechanisms to disperse the attractants. Some have used dried bone fragments (Milburn and Hiller, 2013) or Scented Predator Survey Disks (SPSD; Dempsey et al., 2014), while others used cotton swabs soaked in liquid lure (Hall et al., 2013). Furthermore, the remote cameras available for use in the field can capture pictures and video for various lengths of time (e.g., one to two weeks, or in some cases months at a time). Little standardization exists across studies (Constable et al., 2009), leading to an inability to compare results across space or time. Despite the growing trend in the use of remote cameras for carnivores including kit foxes, the relative efficacies of the various protocols have not been well characterized.

The objectives of this study were to identify the optimal dispersal mechanism, lure, relocation procedure, and duration of sampling for the detection of kit foxes. We hypothesized that the use of cotton swabs soaked in liquid lure, coupled with scent station relocation and lure change midway through sampling, would maximize detection of kit foxes. This hypothesis was based on the assumption that cotton swabs allow for the most even and rapid dispersal of lure. Because kit foxes are innately curious animals (Wauer, 1961), we predicted that changing the lure and relocating the scent stations a short distance within the same grid cell would increase the detection probability by providing a novel stimulus in a new location during the second half of the sampling period.

METHODS

Description of study areas

We conducted this research in three geographic regions of Utah: Colorado Plateau, Great Basin Desert, and Mojave Desert (Figure 1). These three regions cover a large portion of the state, and each contains territory included in the historical range of kit foxes (Armstrong *et al.* 1994). The Rocky Mountain geographic region which occurs in the north east portion of Utah was not included in the historic range of kit foxes and was therefore excluded from our study.

The Colorado Plateau is a vast region that encompasses land in western Colorado, eastern Utah, northern Arizona and northwestern New Mexico. It includes rugged territory with deep canyons. The climate is largely semi-arid, with hot-dry summers and below-freezing winter temperatures. Desert shrub species give way to pinyon-juniper as elevations increase (Durrenberger, 1972). Spruce (*Picea* sp.) and fir (*Abies* sp.) can be found at the highest elevations in this region (Durrenberger, 1972; Table 1). We selected three study areas in the Colorado Plateau, all of which were sampled in 2016 (Figure 1).

The Great Basin Desert is a large desert that extends across northern Nevada and most of the Western half of Utah. The topography of this region consists of wide valleys flanked by longitudinal mountain ranges. It is a high-elevation desert with hot, dry summers and cold, wet winters. Ecological communities vary with elevation, ranging from shadscale (*Atriplex confertifolia*) and greasewood (*Sarcobatus vermiculatus*) in the salty, dry valleys up to pinyon-juniper (*Pinus edulis* and *Juniperus* sp.) communities at higher elevations (Hall et al., 2013; King Top WSA, 2016; Table 1). Invasions of exotic plants and increased frequency of wildfire have led to a decrease in native species of vegetation. Exotic annuals such as cheatgrass (*Bromus tectorum*), Russian thistle (*Salsola iberica)*, and tumbling mustard (*Sisymbrium alissimum)* were common (Arjo et al., 2003). We sampled three study areas in the Great Basin Desert in both 2015 and 2016, and two additional areas in 2016 (Figure 1).

The Mojave Desert is a rainshadow desert in the southwestern United States. A small portion of this high-elevation desert extends into southwestern Utah. The lower elevations are dominated by creosote *(Larrea tridentata),* blackbrush (*Coleogyne ramosissima*), and Joshua tree (*Yucca brevifolia*), whereas the higher elevations are home to pinyon-juniper (Nish, 1964; Hall et al., 2013; Table 1). The hot, dry climate, combined with the presence of invasive species such as cheatgrass and red brome (*Bromus rubens*) make the region vulnerable to wildfires. Several large fires have burned across much of this region in the past several decades. We sampled one study area in the Mojave Desert in both 2015 and 2016 (Figure 1).

Camera Methodology

We obtained general locations for study areas of interest to management agencies from the Bureau of Land Management (BLM), the Department of Defense at Dugway Proving Ground and Hill Air Force Base, and the Utah Division of Wildlife Resources (UDWR). Using a geographic information system (ArcMap, version 10.2, Environmental Systems Research Institute **®,** Redlands, California), we then created a uniform grid of sample cells with a forced minimum distance of either 1.61 or four km in these study areas. Due to safety concerns and a site-specific protocol, respectively, the forced minimum distance at Hill Air Force Base Testing Range and the BLM study area was restricted to 1.61 km. The forced minimum distance at the other seven study areas was four km (Hall et al., 2013). Given the potential of spatial dependency in detections, particularly for the cells spaced 1.61 km, we ran a Mantel test (Legendre and Legendre 1998). This test showed no spatial autocorrelation (Mantel test based on 9999 replicates, p = 1.00). Therefore, we did not incorporate spatial structure into the error component of the models used in analysis.

We placed Reconyx© PC900 infrared cameras (Holmen, Wisconsin, USA) within randomly selected cells throughout the nine study areas in the Colorado Plateau, Great Basin and Mojave Deserts. We programmed each of the cameras to take three consecutive photographs at one-second intervals each time the camera was triggered, followed by a 30 second quiet period (Stratman and Apker, 2014). Each camera trap was randomly assigned one of three possible methods to broadcast lure: SPSD (Pocatello Supply Depot, Pocatello, Idaho), bundle of nine cotton swabs, or a hollowed golf ball mounted on a wooden dowel. All of these dispersal methods have been used in prior work, but their relative efficacy in attracting kit foxes had not been previously studied. The broadcasting mechanism was set up approximately two meters from each camera trap.

During the first seven days, all camera traps assigned a broadcasting mechanism of either a bundle of cotton swabs or the hollowed golf ball were randomly scented with a Red and Gray Fox or Willey liquid lure (Murray's Lures, Walker, West Virginia). The SPSD came pre-scented with fatty acid lure. After seven days, we refreshed lures at each camera trap for each broadcasting mechanism. For the scent stations with liquid lure, half received (randomly) their original lure type of Red and Gray Fox or Willey lures, while the other half received the other lure. All scent stations assigned fatty acid lure received this same lure for the second half of sampling, as this was the only lure type available in SPSD form. Additionally, to determine whether moving scent stations increased their novelty and ability to attract kit foxes, half of the stations were relocated 100 meters, while the others remained in their same location (Table 2). Camera traps were then left in place for an additional seven days.

Data Analysis

After combining detection data from all study areas, we developed 63 generalized linear (occupancy) models that represented *a priori* hypotheses. These hypotheses incorporated variation in detection probability by lure type, method of lure deployment, whether the lure type changed in the second week of sampling, whether the scent station was relocated halfway through sampling, the season and year in which the sampling occurred, and whether the scent station detected coyotes during sampling. To estimate rates of occupancy, we evaluated hypotheses that included covariates for study area, season, year, and presence of coyotes. We used model selection and occupancy estimation within Program MARK v6.1 (White and Burnham 1999) to draw conclusions regarding the optimal scent station protocol for estimating detection probability and occupancy of kit foxes. We used a single-step modeling procedure to simultaneously calculate detection probability and rates of occupancy (MacKenzie et al, 2006). We analyzed relative model support by calculating the Aikake Information Criterion adjusted for small sample sizes (AICc; Burnham and Anderson, 2002) for each model.

In the event of model-selection uncertainty, we calculated model-averaged estimates of detection and occupancy for kit foxes in our study areas. We then determined the statistical significance and effect size of each covariate in the most supported models (Burnham and Anderson, 2002). We screened our list of supported models for uninformative parameters and used 85% confidence intervals to evaluate β coefficients (Arnold, 2010).

RESULTS

Between May 2015 and October 2016, our study included 7,308 camera trap nights. Kit foxes were present in all nine study areas. In total, we detected kit foxes at 162 of 522 sampled cells. We collected 599,027 photographs, and of these, 3,451 were images of kit foxes. All three dispersal methods attracted kit foxes.

The top model (AICc weight = 0.37) allowed for variation in detection by study week (i.e. week one vs. week two) and included dispersal method, year, and coyote detections as covariates (Table 3). The part of the model that assessed occupancy included variation between study areas (Table 3). The confidence intervals on our estimates of detection probability for kit foxes during week one of sampling (0.60 ± 0.05; 85% CI=0.53-0.67) overlapped estimates for week two of sampling (0.50 ± 0.05; 85% CI =0.44-0.57). Detection probabilities differed according to dispersal method. Both golf balls and cotton swabs had higher detection probabilities compared to SPSD in this model (β = 0.40 ± 0.21, 85% CI = 0.10 – 0.70 and β = 0.53 ± 0.32, 85% CI = 0.07 – 0.99, respectively). Based on the cumulative proportion of sites visited during the entire sampling period, 86 percent of visits to stations with cotton swabs occurred by the end of the first week (Figure 2). There was also a negative relationship between year and detection probability in our top model such that year two (2016; coded as a 1) was lower than year one (2015) (β = -1.05 ± 0.33, 85% CI = -1.53 - -0.57; Table 4). Additionally, there was a negative relationship between presence of coyotes during the first week and overall detection of kit foxes (-1.26 ± 0.44, 85% CI = -1.90 - -0.63). The apparent occupancy rates in our study areas ranged from 0.04 – 0.75 (Figure 3).

The second-ranked model (AICc weight = 0.15) also contained dispersal method, year, and coyote detections as covariates, but added relocation as an effect (Table 3). The 85% confidence interval for relocation, however, spanned zero (β = 0.18 ± 0.31, 85% CI = -0.27 - -0.62) and because this second-ranked model differed from the top model by only a single parameter we judged it as containing uninformative parameters (Arnold 2010). The third most supported model (AICc weight = 0.11) was similar to the second except that it did not account for variation in detection by week of sampling (Table 3). We found no relationship between lure type and detection probability with either Red and Gray lure or Willey lure.

DISCUSSION

The use of remote cameras to monitor species of conservation concern, including kit fox, is becoming a common survey methodology (Constable et al., 2009; Hall et al., 2013; Kluever et al., 2013). In this study, we demonstrated successful use of remote cameras to not only detect the presence of kit foxes, but also to estimate occupancy across a broad geographic area. Furthermore, we were able to identify a dispersal mechanism (cotton swabs) associated with increased detection probability. During our study, detection probabilities were relatively high in both the first and second week of sampling. The model-averaged estimates of detection probability for each week (0.601 and 0.50, respectively) were well above the benchmarks (often ≥ 0.30) for reasonable precision around estimates of occupancy. Although we conducted our study in only a portion of their known range, this methodology can likely be used in other areas where kit foxes occur.

Our study demonstrated the importance of scent dispersal method, not lure type, in the detection of kit foxes. SPSD have often been utilized to attract kit foxes and other carnivores (Hall et al., 2013; Milburn and Hiller, 2013; Warrick and Harris, 2001). However, we found that predator disks actually had the lowest detection probability of the dispersal methods and scent combinations that we tested. Instead, a bundle of cotton swabs with either lure was associated with higher detection probability. Lure type did not result in a difference in detection probability for cotton swabs or golf balls. Previous studies of kit foxes have used a variety of commercially available lures, such as: fatty acid (Cypher and Spencer, 1998; Sargeant et al., 2003) or Heck's Catch All and Heck's Loud Fox (Milburn and Hiller, 2013). Despite the use of different lures, scientists in each of these studies were able to successfully detect kit foxes. It is not surprising that a diverse range of lures could attract kit foxes considering the variation in their diet (Hawbecker, 1943; List and Cypher, 2004), and curious nature (Thacker and Flinders, 1999).

We hypothesized that relocating the scent station halfway through sampling would increase detection probability by creating a stimulus in a slightly different location. However, based on our results, the relocation of scent stations did not increase detection probability. Based on this result and the high cumulative detection rates observed by night seven, we conclude that only one week of sampling was sufficient to obtain adequate detection probabilities in our study years.

Sampling year was strongly associated with the detection probability of kit foxes. The average detection probability in the first year of sampling was 70.9%, while the average probability in 2016 was 43.8% (Figure 4). These probabilities were high enough in both years to produce reasonably precise estimates of occupancy; however, the cause of the decline in detection probability was not known. Kit foxes in California have a lifespan of 7 years (List and Cypher, 2004). By sampling in consecutive years, kit foxes that once visited a scent station may have been deterred from returning to a station again since no benefit of visiting was present. Another possibility is the influence of prey populations. Prey counts were not performed as part of our study. If prey abundance was higher in 2016 than in the previous year, kit foxes may not have been inclined to investigate scent stations as readily in order to find prey. Further research should be conducted to test these hypotheses.

There are a variety of methods used to estimate occupancy of wild animals such as kit foxes. Not all methods are equal in terms of cost and required effort (Long et al., 2008). The use of scent stations and remote cameras to monitor kit foxes can be a relatively cheap, yet reliable method (Larrucea et al., 2007b). For example, in a study comparing survey techniques for swift foxes, it was determined that remote cameras required less labor and were less expensive than scat surveys (Harrison et al., 2002). Our work validated the remote camera trap method in diverse locations throughout the state of Utah and refined a protocol to maximize detection of kit foxes. This method provides a way to produce information on occupancy of kit foxes that can be used by natural resource agencies to monitor populations of kit fox. A limitation of this approach, however, is the inability to easily estimate abundance, as identifying individuals can be difficult using remote cameras (Larrucea et al., 2007*a*; Negroes et al. 2010). Nonetheless, it can be done (Larrucea et al., 2007*b*), and as image acquisition and processing technologies continue to improve, remote camera traps will become an even more powerful tool for monitoring species of conservation concern.

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FIGURES

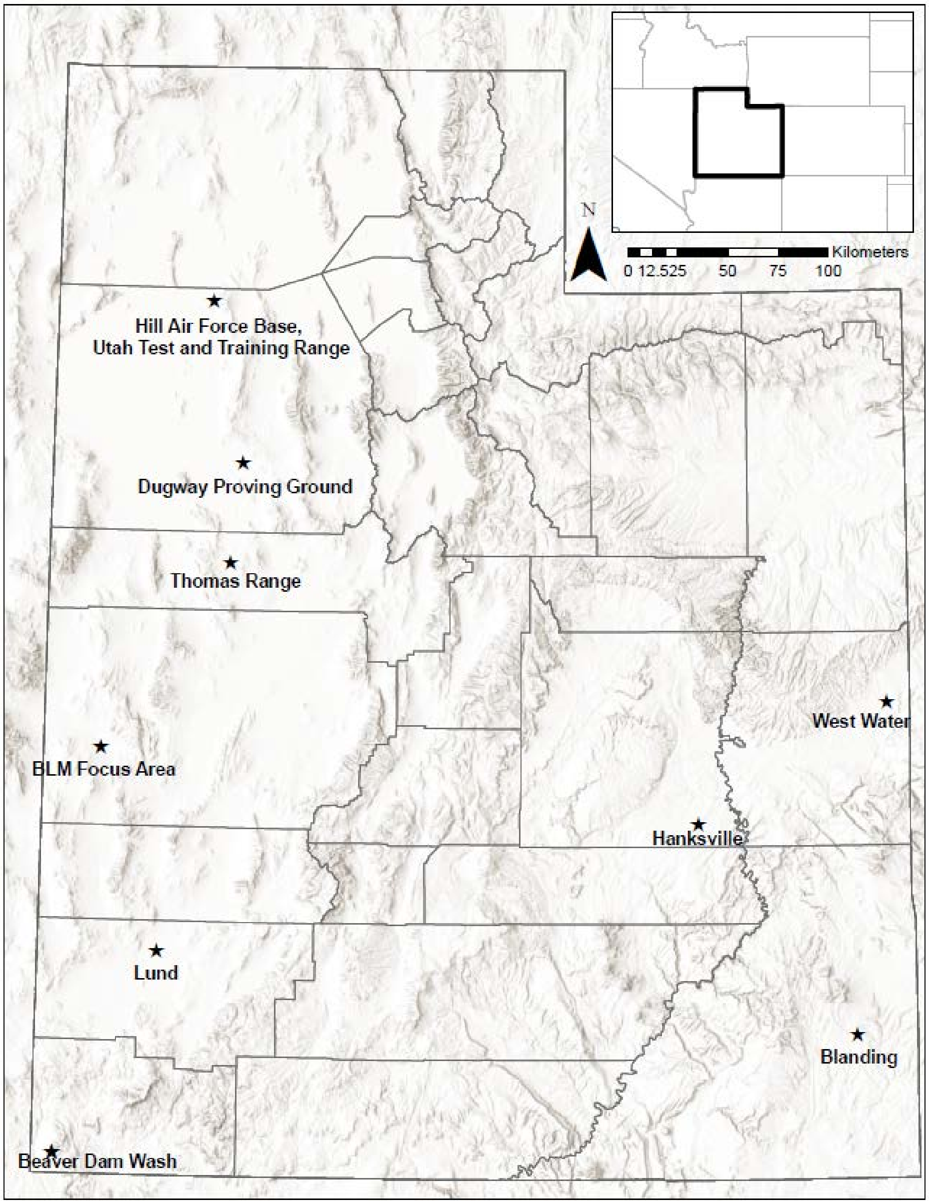

Figure 1-1. Locations of study areas where populations of kit fox (*Vulpes macrotis*) were surveyed using remote cameras between May 2015 and September 2016. The Great Basin Region includes the Bureau of Land Management focus area, Dugway Proving Ground, Hill Air Force Base Test and Training Range, Lund, and the Thomas Range. The Mojave Desert Region includes the Beaver Dam Wash. The Colorado Plateau Region includes Blanding, Hanksville, and West Water study areas.

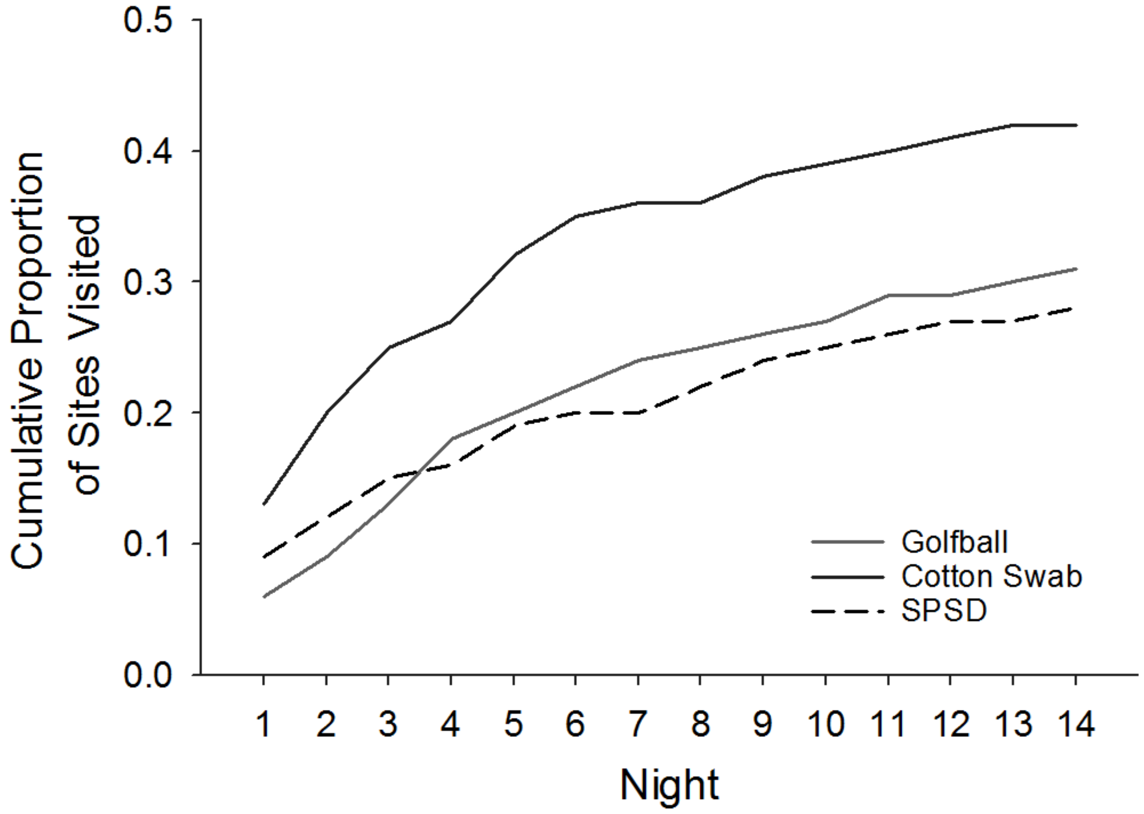

Figure 1-2. Cumulative proportion of sites visited by kit foxes (*Vulpes macrotis*) to remote cameras stratified by scent dispersal method in Utah, 2015-2016.

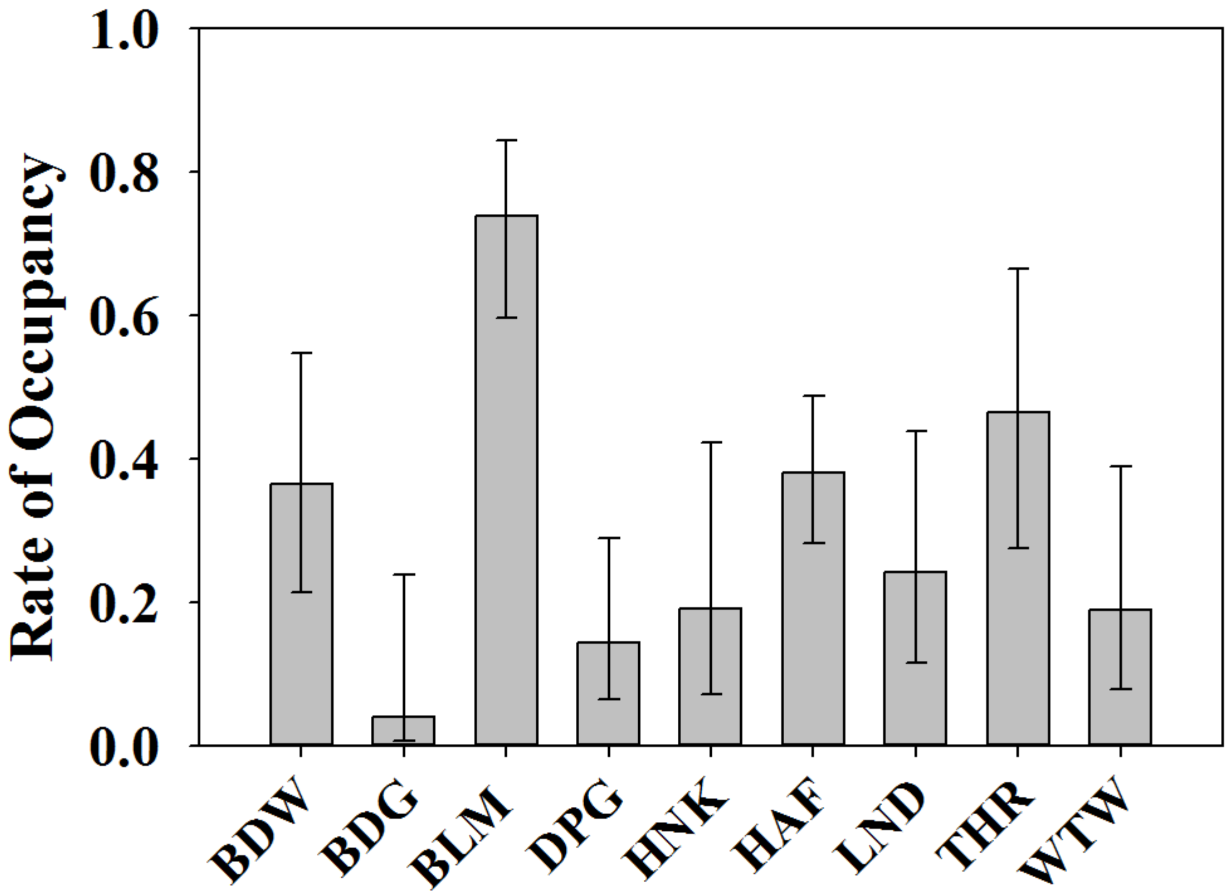

Figure 1-3. Mean rates of occupancy (±95% confidence intervals) for kit foxes (*Vulpes macrotis*) in nine study areas throughout Utah (2015 and 2016). Blanding (BDG), Bureau of Land Management focus area (BLM), Dugway Proving Ground (DPG), Hanksville (HNK), Hill Air Force Base Testing and Training Range (HAF), Lund (LND), Beaver Dam Wash (BDW). Thomas Range (THR), West Water (WTW).

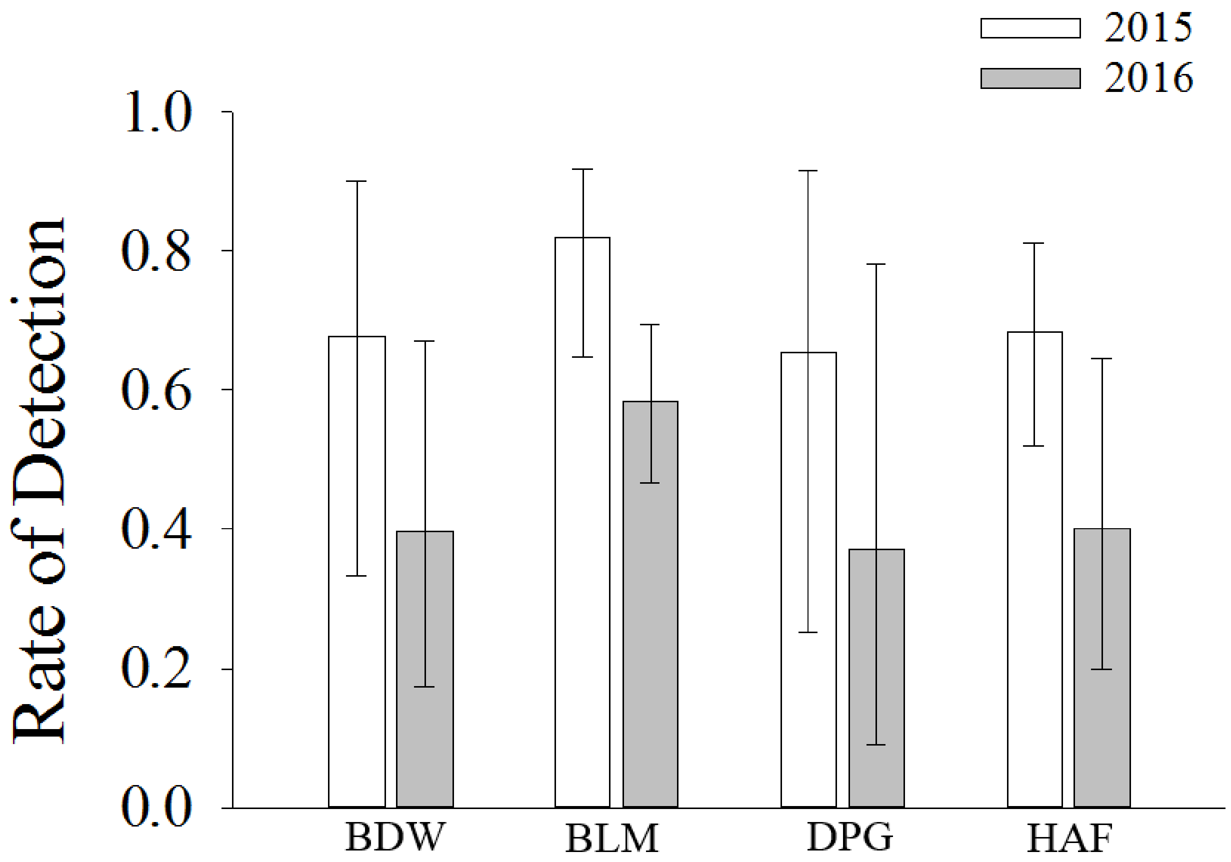

Figure 1-4. Rates of detection for kit fox (*Vulpes macrotis*) at remote cameras and scent stations by year from four study areas throughout Utah sampled in 2015 and 2016: Beaver Dam Wash (BDW), Bureau of Land Management focus area (BLM), Dugway Proving Ground (DPG), Hill Air Force Base Testing and Training Range (HAF).

TABLES

Table 1-1. Characteristics of nine study areas throughout Utah that were surveyed using remote cameras and scent stations for the presence of kit fox (*Vulpes macrotis*) between May 2015 and October 2016.

Study Area	**Region**	**Year Sampled**	**Location** (Easting Northing; see Figure 1)	**Area (km^2)**	**Elevation (m)**	**Mean Annual Air Temp. (°C)**	**Precipitation (cm)**	**Terrain**	**Dominant Vegetation**
Bureau of Land Management focus area	Great Basin Desert	2015 2016	264485 4312267	500	1527-2306	10.0[1]	6.8[1]	Mostly flat, with the Confusion Range to the east	broom snakeweed (*Guiterrezia sarothrae)* and black sagebrush (*Artemisia nova)* in the desert floor and pinyon-juniper woodlands at higher elevations[2]
Dugway Proving Ground	Great Basin Desert	2015 2016	334474 4453247	1354	1303-2137	24.0[1]	16.0[1]	Dune systems and alkaline flats; bordered on the northeast by the Cedar Mountains	black greasewood (*Sarcobatus vermiculatus*); juniper (*Juniperus utahensis*) and rabbitbrush (*Chyrsothamunus* sp.) in the mountains
Hill Air Force Base, Utah Test and Training Range	Great Basin Desert	2015 2016	315401 4514950	807	1281-1824	12.6[1]	6.89[1]	Dune systems and alkaline flats; several small mountain ranges	black greasewood, halogeton, (*Halogeton glomeratus*) pickleweed (*Salicornia* sp.)
Lund	Great Basin Desert	2016	28228 419586	1618	1541-2268	11.8[1]	11.9[1]	Mostly flat, with the Wah Wah Mountains to the northwest.	black greasewood, sagebrush (*Artemisia tridentata)*, broom snakeweed
Thomas Range	Great Basin Desert	2016	33034 439667	1618	1377-2226	10.6[1]	9.7[1]	Mountain ranges and adjacent valleys.	Ephedra (*Ephedra sinica*), halogeton, broom snakeweed, cheatgrass
Beaver Dam Wash	Mojave Desert	2015 2016	242945 4110128	710	1255-2268	18.0[1]	12.0[1]	Mountain ranges and adjacent basins	creosote, black-brush, Joshua tree; pinyon-juniper woodlands at higher elevations
West Water	Colorado Plateau	2016	65698 433449	1618	1255-2173	12.7[1]	18.1[1]	Mostly flat with the Colorado River to the southeast	cheatgrass, black greasewood, shadscale, Indian rice grass (*Achnatherum hymenoides)*
Hanksville	Colorado Plateau	2016	54678 426596	1618	1268-1897	4.8[1]	13.5[1]	Mostly flat	Indian rice grass, ephedra, silver sagebrush, broom snakeweed
Blanding	Colorado Plateau	2016	64028 413860	1618	1334-2759	9.8[1]	17.8[1]	Mostly flat with scattered mountains	Utah juniper, mountain mahogany (*Cercocarpus mountanus)*, prickly pear (*Opunita ficus-indica*), big sagebrush

1: MesoWest , Bureau of Land Management & Boise Interagency Fire Center
2: King Top WSA

Table 1-2. Scent assignment and relocation conditions for scent stations and remote cameras used to survey kit fox (*Vulpes macrotis*) in Utah between May 2015 and October 2016. RG: Red and Gray fox liquid lure; Willey: Willey liquid lure. At each study location, each scent station was randomly assigned to one of the different scent and relocation combinations.

Cotton Swabs and Golf Ball

	Condition 1	Condition 2	Condition 3	Condition 4	Condition 5	Condition 6	Condition 7	Condition 8
Week 1	RG	RG	RG	RG	Willey	Willey	Willey	Willey
Week 2 scent	Refreshed Willey	Refreshed RG	Refreshed Willey	Refreshed RG	Refreshed Willey	Refreshed RG	Refreshed Willey	Refreshed RG
Week 2 Movement	Relocated	Relocated	Not relocated	Not relocated	Relocated	Relocated	Not relocated	Not relocated

Scented Predator Survey Disks

	Condition 1	Condition 2	Condition 3	Condition 4	Condition 5	Condition 6	Condition 7	Condition 8
Week 1	Fatty acid	Fatty acid	Fatty acid	Fatty acid	Fatty acid	Fatty acid	Fatty acid	Fatty acid
Week 2 scent	Refreshed Fatty acid	Refreshed Fatty acid	Refreshed Fatty acid	Refreshed Fatty acid	Refreshed Fatty acid	Refreshed Fatty acid	Refreshed Fatty acid	Refreshed Fatty acid
Week 2 Movement	Not relocated	Not relocated	Not relocated	Not relocated	Relocated	Relocated	Relocated	Relocated

Table 1-3. Model selection results for kit fox (*Vulpes macrotis*) detection probability and occupancy in 9 study areas throughout Utah, 2015-2016, showing model structure, Akaike's Information Criterion (AICc), change in AICc from the most supported model (ΔAICc), model weight (w_i), model likelihood, number of parameters (*K*), and model deviance.

Model	AICc	ΔAICc	W_i	Model Likelihood	k	Deviance
p(Week_D + Deployment + Year + Coyotes), Psi(Site)	897.9627	0.0000	0.37195	1.0000	16	864.8769
p(Week_D + Deployment + Year + Move + Coyotes), Psi(Site)	899.7738	1.8111	0.15039	0.4043	17	864.5498
p(Week_S + Deployment + Year + Move + Coyotes), Psi(Site)	900.3457	2.3830	0.11299	0.3038	16	867.2599
p(Week_D + Deployment + Year + Coyotes), Psi(Site + Coyotes)	900.9942	3.0315	0.08170	0.2197	18	863.6235
p(Week_D + Deployment + Year), Psi(Site)	901.5466	3.5839	0.06198	0.1666	14	872.7116

Table 1-4. β estimates, SE, and 85% confidence intervals for parameters in the top model of detection probability and occupancy for kit fox (*Vulpes macrotis*) in 9 study areas throughout Utah, 2015 – 2016.

Parameter	β	SE	Lower 85% CI	Upper 85% CI
Detection				
Golf ball (intercept)	0.40	0.21	0.09	0.71
SPSD	-0.73	0.33	-1.21	-0.26
Cotton Swab	0.53	0.32	0.07	1.00
Year	-1.05	0.33	-1.53	-0.57
Coyote Visit Week 1	-1.26	0.44	-1.90	-0.62
Coyote Visit Week 2	-0.05	0.43	-0.67	0.57
Occupancy				
BLM (intercept)	-1.04	0.47	-1.72	-0.37
Dugway	2.14	0.56	1.34	2.95
Hill Air Force	-0.69	0.64	-1.62	0.24
Beaver Dam Wash	0.54	0.51	-0.20	1.28
West Water	0.41	0.60	-0.46	1.28
Hanksville	-0.39	0.69	-1.37	0.60
Blanding	-0.36	0.74	-1.42	0.70
Thomas Range	-2.14	1.12	-3.76	-0.52
Lund	0.91	0.61	0.03	1.79

CHAPTER 2

Developing a Habitat Model for Kit Fox in Utah

ABSTRACT

The kit fox (*Vulpes macrotis*) is a species of conservation concern in western North America, and monitoring their populations has become a priority for natural resource agencies. Effective monitoring, however, is enhanced with information on preferred habitats and resource selection. By using ecological parameters from locations where animals are detected, biologists can create quantitative models that predict the likelihood of species occurring across large geographic areas. With this information, agencies can more effectively manage their money and time devoted to conservation efforts. Our objective was to create a habitat model for kit foxes in seven study areas throughout the state of Utah. We placed remote cameras at 458 randomly selected locations throughout our study areas in the Colorado Plateau, Great Basin Desert, and Mojave Desert. We obtained 157 “use” points where kit fox were observed from these cameras between May 2015 and October 2016. We then compared these “use” points to 14,742 available points (randomly selected) within our study areas. We used model selection and minimization of AIC values to determine key habitat characteristics of kit foxes. We identified slope, elevation, and soil type as important influences in habitat selection of kit foxes. Kit foxes selected areas that were 1) less steep, 2) lower in elevation, and 3) classified as silty soils. The identification of these specific explanatory variables from our modeling effort was generally consistent with kit fox ecology. Our study produced a habitat model that can serve as a foundation for future monitoring efforts of kit foxes in potential habitat across Utah. More “use” points from future

fieldwork, as well as new or improved layers (e.g., vegetation) can be included to improve the model in the future, thereby helping with the conservation of this species.

INTRODUCTION

Global climate change, human activity, and population expansion are contributing to the decline and demise of many species (Cafaro 2015; Pyke 2004). Some consider the current reduction in distribution, density, and diversity of species to be a sixth mass extinction event (Thomas et al. 2004). Some have predicted that by the end of this century, two-thirds of existing terrestrial species will be extinct (Raven et al. 2011). However, this loss of biodiversity will not be uniform, as species in different habitat types experience variable extinction rates. Ecosystems with high species diversity (e.g. coral reefs and tropical rain forests) will experience lower rates of extinction, while ecosystems with low species diversity (e.g. deserts and open oceans) will have higher rates (Morgan 1987). Despite these differences, habitat loss is consistently one of the major driving forces of mass extinction across regions. Identifying remaining suitable habitats for conservation planning is thus one of the most pressing needs in the effort to preserve the biodiversity of our planet.

Habitat modeling is a powerful approach to identify geographic areas best suited to meet the needs for species of conservation concern. Quantitative habitat models use ecological parameters from locations where species occur to predict the likelihood of occupancy across larger regions (Cypher et al. 2013). These models help identify the suitability of areas for species of interest which informs management and conservation planning. Because large-scale monitoring is expensive and time-consuming (Constable et al., 2009), habitat modeling can improve the efficiency of conservation efforts by informing the allocation of resources towards regions of greatest potential impact (Gerrard et al. 2001).

Kit foxes (*Vulpes macrotis*) are mesocarnivores of conservation concern for which agencies are working on or have developed conservation plans. Kit foxes live in the deserts of the southwestern region of North America. Historically, their range extended from northern Mexico (including Baja California) and southwestern Texas through the states of Arizona, California, Nevada, New Mexico and Utah (Armstrong et al. 1994). The primary habitat for this species in this region is semiarid desert (O'Farrell 1999). Kit foxes are well adapted to this environment, as they are not dependent on water sources; they can obtain the hydration they need from their prey (Girard 1998). They prefer relatively deep clay-loam soils in which they dig their dens (List and Cypher 2004; McGrew et al. 1977). In the western half of Utah, kit fox are found mainly in flat areas with little ground cover (Egoscue 1956).

Although their geographic distribution has changed very little over time, the density of kit foxes has decreased (Meaney et al. 2006; Thacker et al. 1995). Much of this decline has been attributed to degradation, fragmentation, and loss of habitat, in addition to interspecific competition with coyotes (Arjo et al. 2007; Clark et al. 2005; Egoscue et al.1956; Meaney et al. 2006). The decline in the number of kit foxes has led to their classification as a species of conservation concern in several states, as well as a federal listing (endangered) in the San Joaquin Valley of California. Thus, several organizations are now monitoring the species. A variety of methods, including human observation (Murdoch et al. 2003), live capture (Arjo et al. 2003; Kozlowski et al. 2003) and, more recently, remote cameras coupled with scent stations (Hall et al. 2013), have been deployed in this effort.

Each of these methods, however, is labor-intensive and expensive (Shauster et al. 2002). Furthermore, studying kit foxes is difficult because they occur in low densities, have a broad distribution, and are largely nocturnal (Warrick and Harris 2001). A predictive habitat model could reduce costs by allocating resources to areas of highest potential impact. This would enable habitat evaluations and impact assessments, allow for the development of management and mitigation plans, direct research, and help assess future threats to the habitat of kit foxes (Schamberger and Turner 1986). With the advancement of geographic information system (GIS) software and open access to extensive environmental data (Dempsey et al. 2015), developing useful habitat models has become easier. This type of modeling is also dynamic, as it can be continually refined with new geographic data or new location data for the species of interest (Gerrard et al. 2001). A cyclical pattern of model modification and population surveys in the field will lead to a reasonably accurate map of the distribution of kit foxes in the state of Utah.

Our objective was to create a model of habitat selection by kit foxes in seven study areas throughout the state of Utah. Based on the ecology of kit foxes, we predicted that they would select for areas of flat terrain at low elevations. Additionally, we hypothesized that habitats with clay-loam soils would have a higher likelihood of use. In creating our model, we built on previous work for specific locations such as Dugway Proving Ground (Dempsey et al. 2015) and Moab (BLM, unpublished data). These other models have proven very useful in the monitoring of localized populations of kit foxes. However, a model that includes more of the historic range of kit foxes in the state has never been attempted. The model we generate may become a valuable tool that can be used and refined in future years to help with the monitoring of this species of conservation concern in Utah.

METHODS

Description of study areas

We conducted this research at multiple study areas located in three geographic regions of Utah: the Colorado Plateau, the Great Basin Desert, and the Mojave Desert. These three regions cover a large portion of the state, and each contains territory included in the historical range of kit fox (Armstrong et al. 1994). Although the Rocky Mountain geographic region also occurs in Utah, it was not part of the historic range for this species and was therefore excluded from our study.

The Colorado Plateau is a vast region that encompasses land in western Colorado, eastern Utah, northern Arizona and northwestern New Mexico. It is rugged territory with many canyons. The climate is largely semi-arid, with hot-dry summers and below-freezing winter temperatures. Desert shrub species give way to pinyon-juniper as elevation increases. Spruce (*Picea* sp.) and fir (*Abies* sp.) can be found at the highest elevations (Durrenberger 1972; Table 1). We sampled one study area in the Colorado Plateau (Figure 1).

The Great Basin Desert is a large desert that extends across northern Nevada to the Western half of Utah. The topography of this region consists of wide valleys flanked by longitudinal mountain ranges. It is a high-elevation desert with hot, dry summers and cold, wet winters. Ecological communities vary with elevation, ranging from shadscale (*Atriplex confertifolia*) and greasewood (*Sarcobatus* sp.) in the salty, dry valleys up to pinyon-juniper (*Pinus* sp. and *Juniperus* sp.) communities at higher elevations (Hall et al. 2013; Comstock and Ehleringer 1992; Table 1). Disturbances from wildfires have led to a decrease in natural vegetation, resulting in the expansion of exotic annuals such as cheatgrass (*Bromus tectorum*), Russian thistle (*Salsola iberica)*, and tumbling mustard (*Sisymbrium alissimum)* (Argo et al. 2003). We sampled five areas in the Great Basin Desert (Figure 1).

The Mojave Desert is a rainshadow desert in the southwestern United States. A small portion of this high-elevation desert extends into southwestern Utah. The lower elevations are dominated by creosote *(Larrea divaricate),* black-brush (*Coleogyne ramosissima*), and Joshua tree (*Yucca brevifolia*), whereas the higher elevations are home to pinyon-juniper (Nish 1964;

Hall et al. 2013; Table 1). The hot, dry climate and presence of invasive species such as cheatgrass and red brome (*Bromus rubens*) make the region prone to wildfires. Several large fires have burned in this region over the past several decades. We selected one study area in the Mojave Desert (Figure 1).

Grid Establishment within Study Areas

In order to create a habitat model for kit fox, we started with polygons outlining each of the seven study areas. We then used a geographic information system (ArcMap, version 10.2, Environmental Systems Research Institute, Redlands, California) to create a uniform grid of sample cells with a forced minimum distance of either 1.61 or 4 km within each polygon for the study areas. Due to safety concerns and a site-specific protocol, respectively, the forced minimum distance at Hill Air Force Base Testing Range and the BLM study area was restricted to 1.61 km. The forced minimum distance at the other five study areas was 4 km (Hall et al. 2013). Given the potential of spatial non-independence of camera sampling, particularly for the cells spaced 1.61 km, we ran a Mantel test (Legendre and Legendre 1998). The test results indicate limited spatial autocorrelation (Mantel test based on 9999 replicates, $p = 1.00$). Therefore, we did not incorporate spatial structure into the error component of our models.

Camera Traps

To gather current data on the distribution of kit foxes in the study areas, we deployed scent stations and remote cameras (camera traps) in randomly selected cells from the uniform grid in each of the study areas. We left cameras at scent stations for discrete two-week periods between May 2015 and October 2016. To ensure scent station independence, we placed each camera trap within 300 m of the selected cell's centroid. Scent stations were comprised of a Reconyx© PC900 infrared camera mounted to a small metal post positioned 27 cm above the ground and fox lure located 2.5 m away from the camera. Following retrieval of cameras, we analyzed photographs for detection of kit foxes. The locations at which camera traps detected kit fox were then considered "use" points in a resource selection function.

Habitat Variables

Using ArcGIS, we calculated slope (degrees), aspect, and topographic curvature using a 30-meter Digital Elevation Model (DEM) for Utah. To calculate Topographic Position Index (TPI), we used the DEM and a 3-pixel neighborhood size. We used the Benthic Terrain Modeler (BTM) to generate a Vector Ruggedness Measure (VRM). We also obtained data for vegetation type, vegetation cover, and vegetation height from the United States Geological Survey's Landfire program (Landfire 2008). Additionally, we utilized soil data from the Utah Automated Geographic Reference Center. Following the reclassification by Dempsey et al. (2015), we classified soils within the study areas into four major classes based on average grain size: ultrafine, fine, intermediate, and course. Soils were classified this way because grain size has been shown to affect den site selection (Dempsey 2015).

We then generated 14,742 "available" random points within the study boundaries. This number of "available" random points was selected because it adequately captured availability based on comparison of sample means and confidence intervals to average values for the covariates derived from all pixels within the study areas (Baxter 2017). We then intersected the topographical and vegetation layers with our points of interest (use and available) to determine the values of aspect, curvature, elevation, slope, TPI, vegetation cover, vegetation height, vegetation type, and VRM. We then calculated the distance to the nearest road for each location.

Model Generation

Within a used-available study design (Manly et al. 2002), we then analyzed habitat selection by kit foxes at the population level (i.e. Johnson's second order; Johnson 1980). We used the statistical package R 3.1.3 (R Core Team 2015) to run fixed-effects logistic regression models where "use" sites were coded as a 1 and "available" points were coded as a 0. Slope, aspect, curvature, elevation, TPI, VRM, and distance to roads were continuous variables; vegetation cover, vegetation height, vegetation type, and soil type were categorical variables (Table 2). We down-weighted the random locations to have the same weight as locations that detected kit foxes (Hirzel et al. 2006). Before the regression, we performed Pearson correlations and removed correlated variables ($r \geq |0.65|$). We developed 28 *a priori* hypotheses (models) regarding the influence of the habitat variables on the presence of kit foxes and determined which models were most competitive based on their Aikake information criterion (AIC) values. We reported all models with ≥5% of total AIC weight. We then evaluated the AIC values and model composition to determine whether all variables included in supported models were informative (Arnold 2010). In the case of model selection uncertainty, we used the MuMIn package in program R to calculate model-averaged coefficients.

We then used the model coefficients to make a prediction for each 30 m x 30 m pixel that corresponded to the relative probability of occurrence for kit foxes. We categorized these values into five probability groups of equal area, ranging from low to high relative probability. We then used ArcGIS to project these values across our study area and generate a probability map for the area within the study area boundaries.

Model Validation

To validate the final models, we used variance inflation factors (VIF) to test for multicollinearity among variables. We considered VIF > 10 to indicate evidence of multicollinearity (O'Brien 2007). To assess the predictive ability of our top model, we used k-fold cross validation with k=7 for practical constraints of required computing time (Long et al. 2009). We divided each of the kit fox data points randomly into seven groups, with an approximately equal number of locations in each group. For each of the seven iterations of the cross-validation, six groups (86% of the data) were used as the training set to estimate model coefficients and one group (14% of the data) was used as the test set to validate the model. We repeated this procedure until all seven groups had been used as the test set.

RESULTS

Between May 2015 and October 2016, our study included 6,412 camera trap nights. Kit foxes were present in all seven study areas. In total, we detected kit foxes at 157 of 458 sampled cells. We collected 584,127 photographs, and of these, 3,408 were images of kit foxes.

The top four models accounted for 91% of AIC weight (Table 3) and were model-averaged. The top model (AICc weight = 0.69) contained only slope (Table 3; $P < 0.05$). Kit foxes strongly selected for areas with less steep slope. Relative probability of use declined exponentially as slope increased (Figure 3). The second-ranked model (AICc weight = 0.12) contained elevation and soil type, both of which were statistically significant ($P < 0.05$). Kit foxes strongly selected for lower elevations and silty soils. Relative probability of use declined as elevation increased (Figure 4). Explanatory variables that were not in the top models included aspect, curvature, VRM, vegetation cover, height, and type.

Predictive ability of the top model from the seven-fold cross validation was high (Spearman $\rho = 0.85$; $P < 0.02$). We found no evidence for multicollinearity in any of our top models (VIF < 1.2). Of the 157 points with detections, 98.7% were in the high or medium-high categories for relative probability of use. The remaining 1.3% were in the medium category. By contrast, the distribution of the 14,742 "available" random points was relatively even across the five categories (low 14.7%, medium-low 9.9%, medium 15.4%, medium-high 24.8%, high 35.2%).

DISCUSSION

The use of habitat modeling to identify areas likely inhabited by species of conservation concern, including kit foxes, has recently grown in popularity (Dempsey et al. 2015; Gerrard et al. 2001). Historical data regarding the range of kit foxes in the state of Utah suggest a widespread distribution. However, most monitoring efforts have concentrated primarily on the western half of the state (Kluever et al. 2013; Thacker et al. 1995). We sampled for kit foxes in seven study areas throughout Utah and were successful in creating a habitat model that predicted occupancy across three distinct geographic regions that span much of the state.

Explanatory variables in our top models were generally consistent with kit fox ecology. Slope was an important discriminant in our habitat model for kit fox. This species inhabits flats areas and generally avoids steep slopes (Grinnel et al. 1937; Daneke et al. 1984; Zoellick and Smith 1992). Previous work on swift foxes and San Joaquin kit foxes suggests that areas of complex topography are avoided due to interspecific competition with other predators (Kitchen et al. 1999; Schauster et al. 2002; Warrick and Cypher 1998). Furthermore, the availability of dominant prey species may be highest in flat areas (Kozlowski et al. 2008). Kit foxes also selected areas of lower elevation. Similar results were found by Dempsey et al (2015), who suggested that elevation's substantial weight in models might be a result of its relationship to other environmental variables that were not accounted for, such as: rainfall, availability of water, and other climatic factors.

Kit foxes were also found to occur more frequently in areas where fine soils were present. Fine soils such as silty clay is preferred by kit foxes, as they are fossorial canids (Egoscue 1956). By selecting for soils with small particle sizes, kit foxes are able to more easily dig a den that provides protection from predators, shelter from high temperatures, and a location to bear young (Argo et al. 2003; McGrew 1977). Additionally, kit foxes were found to occur more frequently in areas closer to roads (Figure 5). A previous study suggests that kit fox select for areas near roadways because they are a source of carrion (Cypher et al. 2009). Other work proposes that roadways more frequently occur in areas of lower elevation with low slopes and are not directly selected for (Orloff et al. 1986). Alternatively, kit foxes may select areas near roadways to avoid coyotes if they select areas away from roads.

Variables that were absent from our top models included aspect, curvature, VRM, vegetation cover, vegetation height, and vegetation type. The three variables associated with vegetation may have received only limited support in our modeling effort because they can be indirectly influenced by variation in other, more supported variables such as elevation or slope (McGrew 1976, Fitzgerald 1996). Aspect is considered an important variable for kit foxes when selecting natal den sites (Arjo et al. 2003), but may not be as influential when selecting overall habitat.

In summary, similar to previous studies, our results demonstrated selection by kit foxes for flat terrain, lower elevations, and fine, silty soils (Link 1995; List and Cypher 2004). We recognize that performing a mixed-effects logistic regression analysis would have strengthened our findings by allowing for inclusion of random effects. However, due to the limited number of detections in several of our study areas, we were unable to perform such an analysis. Future studies that compile data gathered from multiple samplings of study areas with low detection rates would allow for mixed-effects logistic regression analysis and refinement of our habitat model. Furthermore, the addition of variables for densities of prey and predator species could also strengthen the model. Kangaroo rats are the preferred prey of kit foxes, so habitats with a high density of this prey species may be more suitable for kit foxes (Cypher et al. 2013). On the other hand, coyotes are the primary predator of kit foxes, and recent studies suggest that kit foxes are less likely to be found in locations with greater coyote activity (Lonsinger et al. 2017).

This study produced a model that may serve as a basis for future monitoring efforts of kit foxes in potential habitat across Utah. One advantage of habitat modeling is that it is iterative; models can be improved as new geographic information or kit fox detection points become available (Schamberger and Turner 1986). As continued fieldwork produces more biological information on kit foxes, this habitat model will be improved and can become a valuable tool in the effort to conserve this species.

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FIGURES

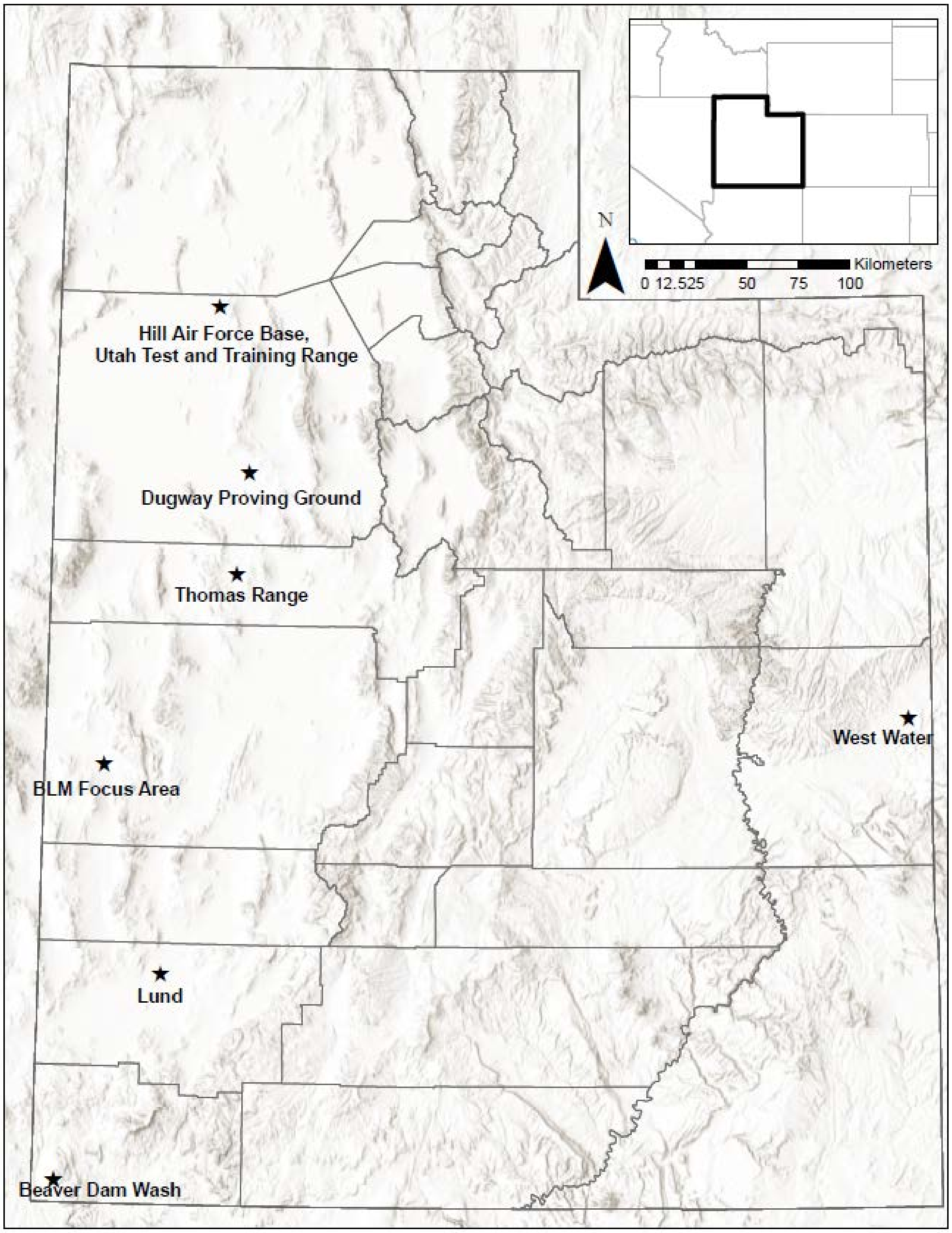

Figure 2-1. Study area locations where populations of kit foxes (*Vulpes macrotis*) were surveyed using remote cameras between May 2015 and September 2016. The Colorado Plateau region includes West Water. The Great Basin region includes the study areas of the BLM focus area, Hill Air Force Base Test and Training Range, Dugway Proving Ground, Lund, and Thomas Range. The Mojave Desert region includes the Beaver Dam Wash.

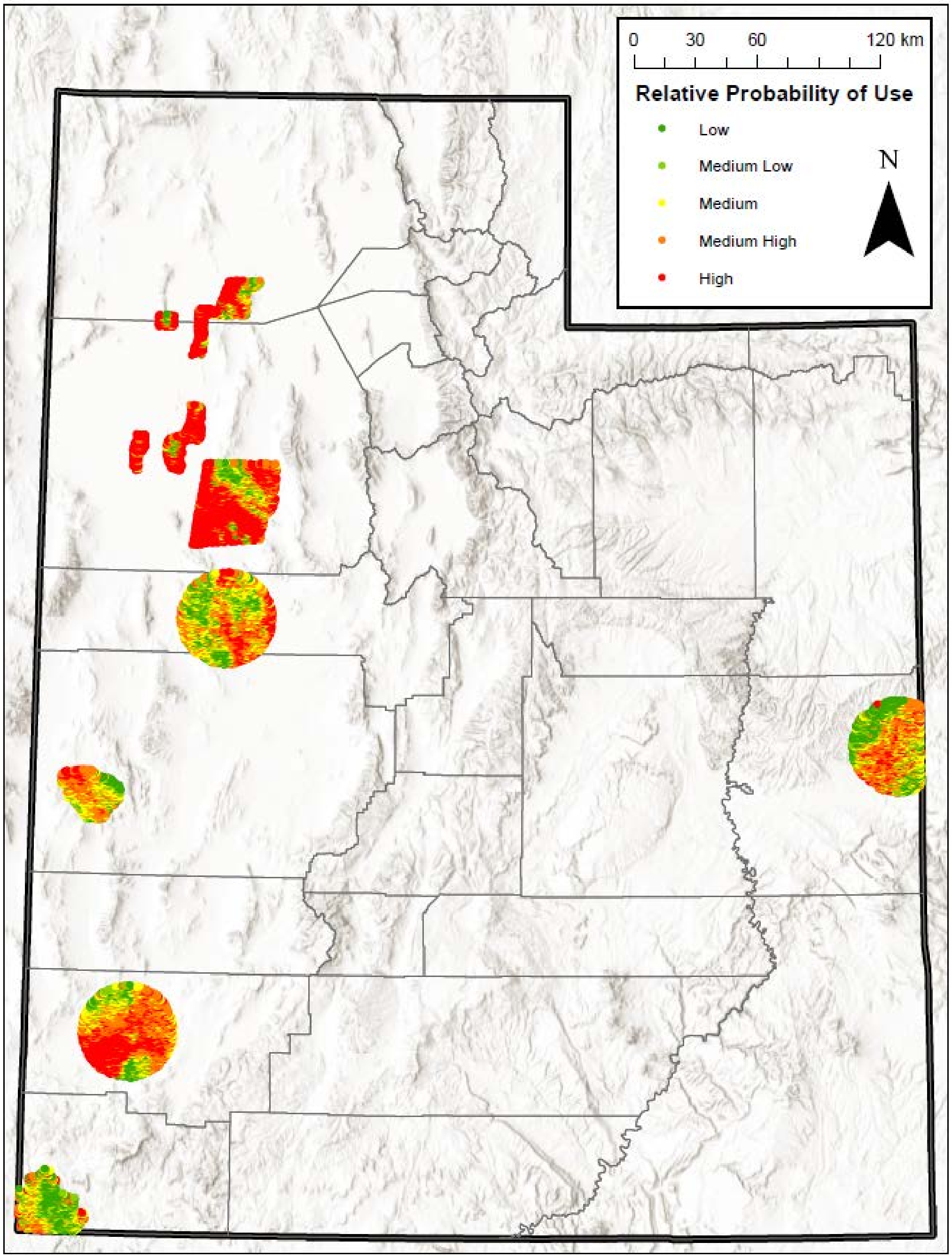

Figure 2-2. Relative probability of selection by kit foxes (*Vulpes macrotis*) across seven study areas throughout Utah, USA based on a resource selection function. Relative probability of use was binned into 5 categories, from low (dark green) to high (red).

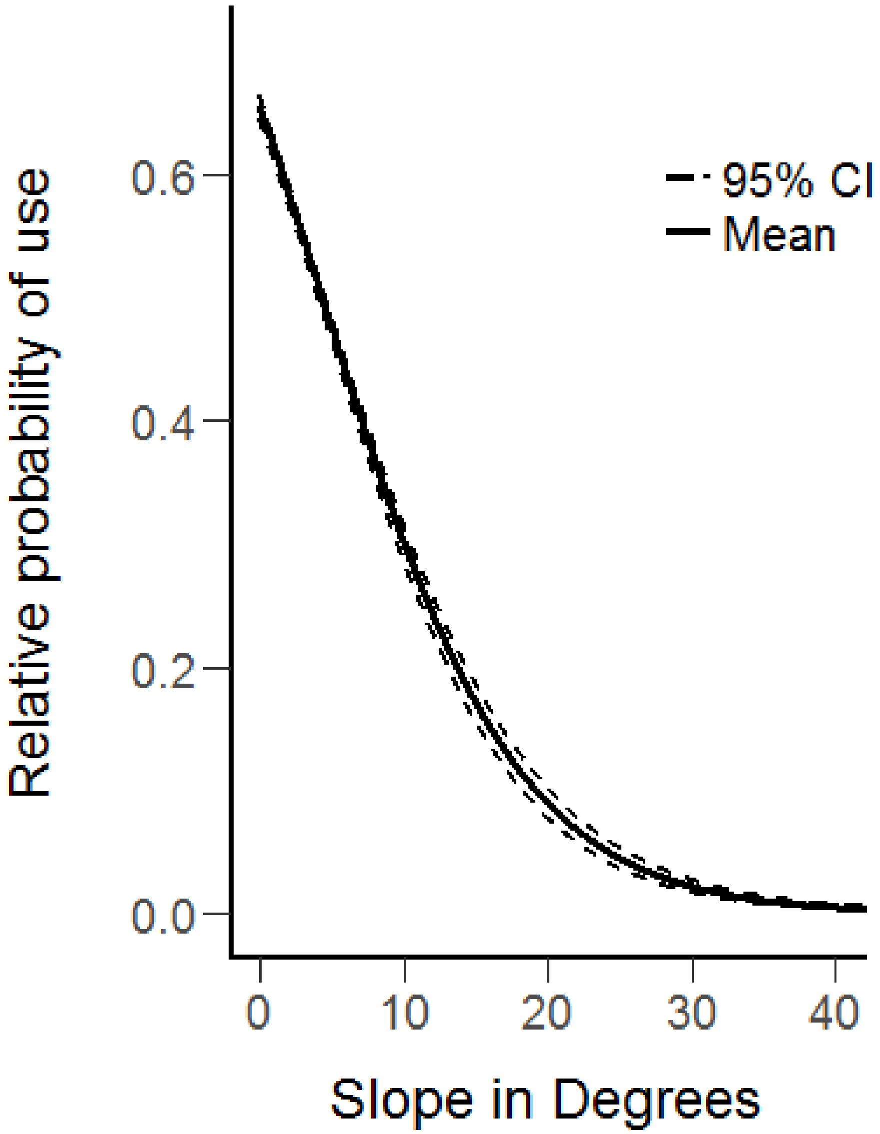

Figure 2-3. Modeled relationship between relative probability of use by kit foxes (*Vulpes macrotis*) and slope (degrees) from a resource selection, Utah 2015-2016.

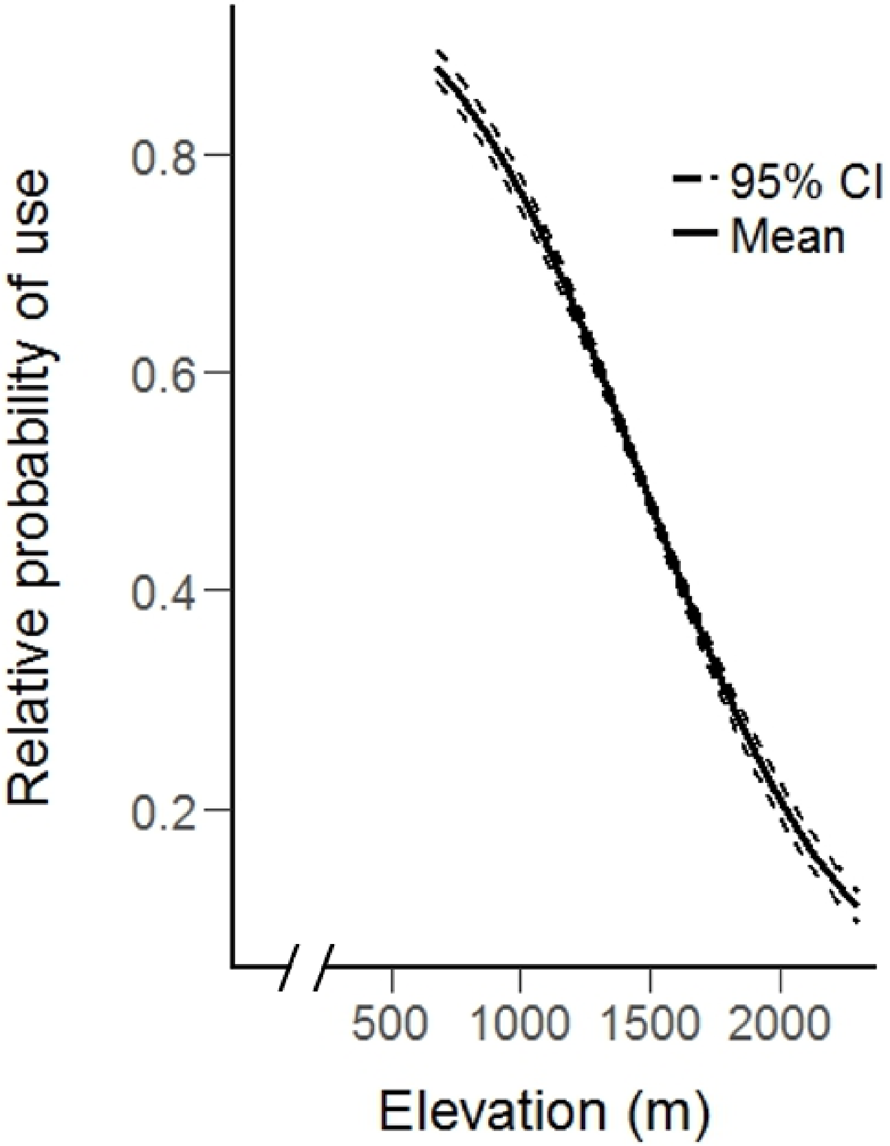

Figure 2-4. Modeled relationship between relative probability of use by kit foxes (*Vulpes macrotis*) and elevation (m) from a resource selection function, Utah 2015-2016.

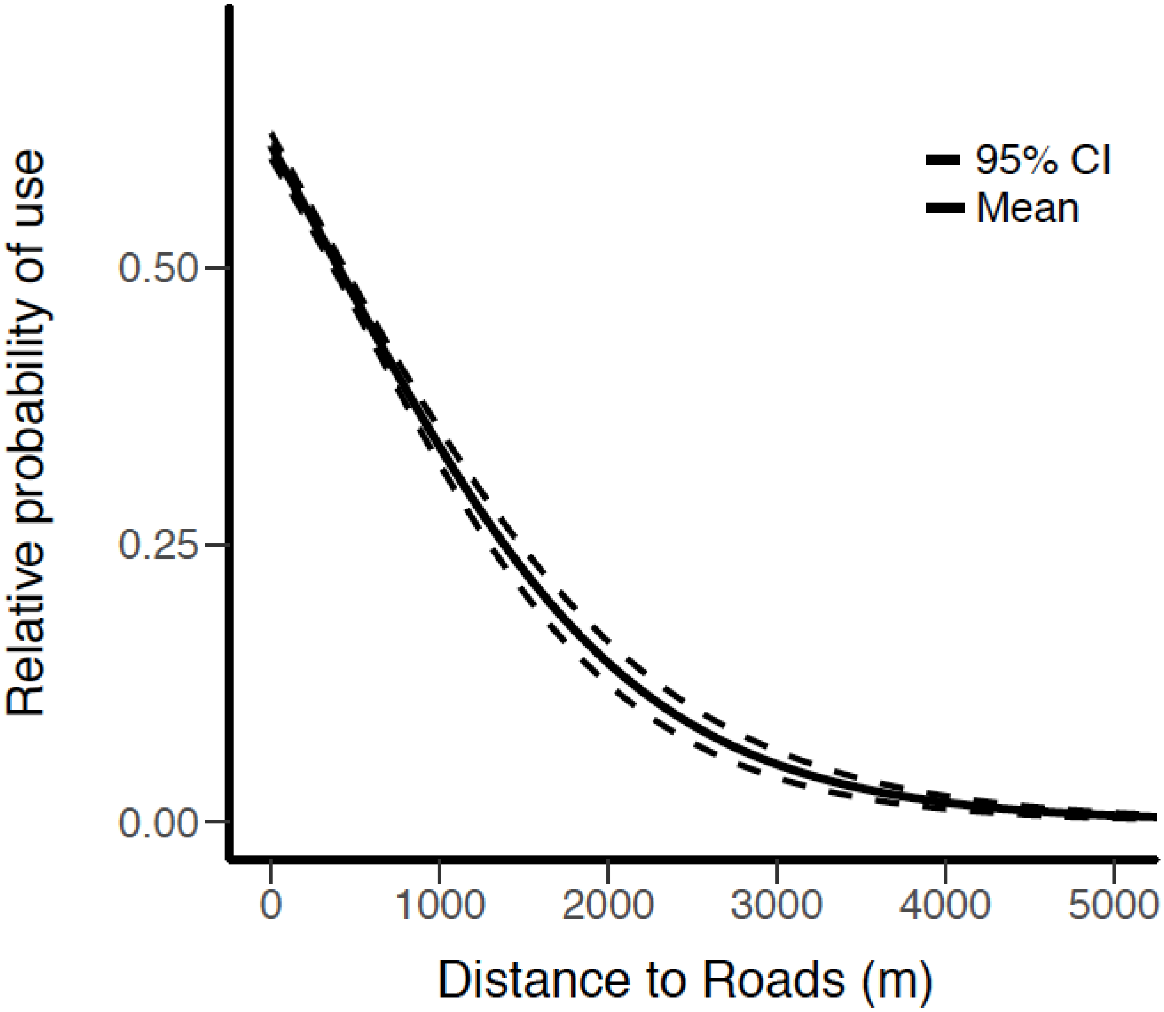

Figure 2-5. Modeled relationship between relative probability of use by kit foxes (*Vulpes macrotis*) and distance to roads (m) from a resource selection function, Utah 2015-2016.

TABLES

Table 2-1. Characteristics of the seven study areas throughout Utah surveyed using remote cameras and scent stations for the presence of kit foxes (*Vulpes macrotis*) between May 2015 and October 2016.

Study Area	**Region**	**Year Sampled**	**Location** (Easting Northing; see Figure 1)	**Area (km^2)**	**Elevation (m)**	**Mean Annual Air Temp. (°C)**	**Precipitation (cm)**	**Terrain**	**Dominant Vegetation**
Bureau of Land Management focus area	Great Basin Desert	2015 2016	264485 4312267	500	1527-2306	10.0[1]	6.8[1]	Mostly flat, with the Confusion Range to the east	broom snakeweed (*Guiterrezia sarothrae)* and black sagebrush (*Artemisia nova)* in the desert floor and pinyon-juniper woodlands at higher elevations[2]
Dugway Proving Ground	Great Basin Desert	2015 2016	334474 4453247	1354	1303-2137	24.0[1]	16.0[1]	Dune systems and alkaline flats; bordered on the northeast by the Cedar Mountains	black greasewood (*Sarcobatus vermiculatus*); juniper (*Juniperus utahensis*) and rabbitbrush (*Chyrsothamunus* sp.) in the mountains
Hill Air Force Base, Utah Test and Training Range	Great Basin Desert	2015 2016	315401 4514950	807	1281-1824	12.6[1]	6.89[1]	Dune systems and alkaline flats; several small mountain ranges	black greasewood, halogeton, (*Halogeton glomeratus*) pickleweed (*Salicornia* sp.)
Lund	Great Basin Desert	2016	28228 419586	1618	1541-2268	11.8[1]	11.9[1]	Mostly flat, with the Wah Wah Mountains to the northwest.	black greasewood, sagebrush (*Artemisia tridentata)*, broom snakeweed
Thomas Range	Great Basin Desert	2016	33034 439667	1618	1377-2226	10.6[1]	9.7[1]	Mountain ranges and adjacent valleys.	Ephedra (*Ephedra sinica*), halogeton, broom snakeweed, cheatgrass
Beaver Dam Wash	Mojave Desert	2015 2016	242945 4110128	710	1255-2268	18.0[1]	12.0[1]	Mountain ranges and adjacent basins	creosote, black-brush, Joshua tree; pinyon-juniper woodlands at higher elevations
West Water	Colorado Plateau	2016	65698 433449	1618	1255-2173	12.7[1]	18.1[1]	Mostly flat with the Colorado River to the southeast	cheatgrass, black greasewood, shadscale, Indian rice grass (*Achnatherum hymenoides)*

1: MesoWest , Bureau of Land Management & Boise Interagency Fire Center

2:Comstock and Ehleringer 1992

Table 2-2. Geographic information system (GIS) predictor variables potentially associated with occurrence of kit foxes (*Vulpes macrotis*) in seven study areas in Utah, USA 2015-2016.

Variable name	**Description**
Topographic	
SIN_ASPECT	Sine of aspect angle
COS_ASPECT	Cosine of aspect angle
ELEVATION	Elevation in meters
SLOPE	Slope in degrees
CURVE	Curvature
TPI	Topographic Position Index with a 3-pixel cell neighborhood
VRM	Vector Ruggedness Measure
Anthropogenic	
ALL_ROADS	Distance to road
Vegetative	
VC	Existing Vegetation Cover in percent
VH	Average Existing Vegetation Height
VT	Existing Vegetation Type of plant communities
SOIL	Four grouped classes of soil

Table 2-3. Model ranking (models with ≥ 5% of model weight) of habitat selection by kit foxes (*Vulpes macrotis*) across seven study areas in Utah, USA 2015-2016. Includes number of parameters (K), corrected Akaike's Information Criterion (AIC_c), ΔAIC_c, model weight (ω), and log likelihood (LL). Variable names match those in Table 2.

Model	Structure	K	AIC_c	ΔAIC_c	ω	LL
9	SLOPE	2	176.50	0.00	0.69	-86.25
18	ELEVATION + SOIL	5	180.04	3.54	0.12	-85.02
22	ELEVATION + SOIL + ALL_ROADS	6	181.79	5.29	0.05	-84.89
19	ELEVATION + SOIL + TPI	6	181.90	5.40	0.05	-84.95