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*Research Article*

# Off-Highway Vehicle Road Networks and Kit Fox Space Use

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**ABSTRACT** Off-highway vehicle (OHV) use is popular for outdoor recreation across the United States, with especially high levels of participation in Arizona and the American Southwest. Road networks related to OHV recreation have the potential to influence kit fox (*Vulpes macrotis*) space use intensity. To evaluate the potential impacts of OHV road networks to kit fox space use, we conducted a study during 2010–2013 in 2 areas of the Sonoran Desert in central Arizona. We used an observational approach to determine the importance of road density to kit fox space use, relative to other measured environmental variables. We monitored 22 collared individuals and used linear mixed models and an information-theoretic approach to develop models of intensity of space use for seasons of relatively low (e.g., 33% of yearly OHV use observed) and high (e.g., 67% of yearly OHV use observed) OHV use. We found road density to be the most important predictor of space use for kit foxes, relative to other measured environmental variables. Space use was negatively associated with road density during winter (Oct–Mar), which coincided with kit fox breeding, denning, and pupping activities and was the season of relatively higher OHV use. Road density in OHV use areas is an important seasonal predictor of, and can negatively influence, kit fox space use. OHV road networks may lead to effective habitat loss for kit foxes and managers must consider how OHV recreational opportunities should be balanced with habitat conservation for species like kit fox. © 2016 The Wildlife Society.

**KEY WORDS** Arizona, disturbance, kit fox, off-highway vehicle, roads, *Vulpes macrotis*.

Kit foxes (*Vulpes macrotis*) in Arizona occupy desert scrub and grasslands in arid regions of the state and are most common in low-elevation habitats (Hoffmeister 1986). Areas occupied by kit foxes have undergone extensive modification, including agricultural, mineral, industrial, and urban developments (O'Farrell and Gilbertson 1986). Consequently, kit fox populations have declined in many parts of the Southwest (Zoellick et al. 1989), with the San Joaquin kit fox (*V. m. mutica*) listed as Federally Endangered because of loss and degradation of habitat by agricultural and industrial developments and urbanization (U.S. Fish and Wildlife Service 1998).

Off-highway vehicle (OHV; e.g., all-terrain vehicles, dirt bikes) recreation may pose an additional threat to kit fox populations already affected by land use changes (Cypher et al. 2009). This may especially be the case in Arizona because of the popularity of OHV recreation. Roughly 25% of Arizona residents participate in OHV activities ≥1 time/year (Cordell et al. 2005) and the number of registered OHVs increased nearly 6 times during 1998–2014 (Arizona Department of Transportation 2015). This increase in OHV activity can quickly lead to an increase in the density and distribution of off-road networks. Roads open to OHV recreation may provide opportunities for riders to engage in off-trail use, which can expand road networks over time (Matchett et al. 2004), especially in the arid and semi-arid Southwest where the vegetation structure allows for the ready expansion into roadless areas (Brooks and Lair 2005). In addition, increased vehicle traffic results in soil disruption and compaction (Iverson et al. 1981, Adams et al. 1982), which leads to a decrease in the ability of vehicles to move across soil surfaces (Karafiath and Nowatzki 1978). Eventually, this can also lead to expansion of the road network when recreationists avoid degraded roadways by riding parallel to open roads or creating new routes.

A limited number of studies have evaluated the direct influence of OHV disturbance to wildlife, such as alteration of movement patterns (Preisler et al. 2006, St-Louis et al. 2012), decreased feeding activity (Naylor et al. 2009), altered nesting activity (McGowan and Simons 2006), decreased reproductive success (Yarmoloy et al. 1988), and decreased

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abundance (Busack and Bury 1974, Bury and Luckenbach 2002). A different approach to measure the potential effects of OHV recreation is to evaluate how road networks associated with OHV recreation may influence wildlife space use patterns. Kit foxes are semi-fossorial and depend on their dens throughout the year (Koopman et al. 1998) and may be directly affected by OHV use through den destruction, vehicle strikes, and noise disturbance. Kit fox populations can also be indirectly affected by OHV road networks, which may alter their prey base by reducing small-mammal abundance (Bury et al. 1977) and modify vegetation structure, composition, or density (Adams et al. 1982, Luckenbach and Bury 1983, Groom et al. 2007). Although OHV road networks have the potential to negatively affect kit foxes, there is scant empirical evidence documenting impacts and, to our knowledge, no previous studies have evaluated the influence of OHV road networks on kit fox space use. We conducted a study to determine whether kit fox space use intensity (space use) is influenced by OHV road density.

## STUDY AREA

We conducted this study at 2 sites in the Sonoran Desert of Arizona and both study sites were approximately 78 km$^2$ (Fig. 1). The first site was located southwest of Tonopah, Arizona, on land administered by the Bureau of Land Management (BLM) between Saddle Mountain and the Palo Verde Hills (PV). The second site was located on Arizona State Trust lands in the Desert Wells Multiuse Area east of Apache Junction, Arizona (DW). Both study areas were characterized by 2 primary plant communities: a creosote bush-burrobush (*Larrea tridentata-Ambrosia dumosa*) series of the Lower Colorado River Valley subdivision, and a palo verde (*Parkinsonia* sp.)-cacti-mixed scrub series of the Arizona Upland subdivision (Brown 1994). At both sites, the lower bajadas, flats, and desert arroyo areas were dominated by creosote-burrobush vegetation, whereas higher elevations and the more rugged mountainous terrain were dominated by palo verde-cacti-mixed scrub communities, including palo verde, cholla (*Cylindropuntia* sp.), and mesquite (*Prosopis* sp.; Brown 1994). Elevations at both sites were similar, ranging from 244 m to 488 m. Average high temperatures at the sites were 38°C and 25°C in summer and winter, respectively, during 1992–2008, with yearly rainfall averaging 15.5 cm (Western Regional Climate Center 2009). Primary predators at each site included coyotes (*Canis latrans*) and bobcats (*Lynx rufus*). Domestic cattle inhabited both areas. An industrial gravel-mining operation approximately 0.46 km$^2$ in area was located on the eastern edge of the DW study area, and a low-density residential housing development was located in the northeastern section of the PV study area. Off-highway vehicle use at the PV study area was enforced by the Arizona Game and Fish Department (AGFD) and the BLM. Off-highway vehicle recreation at the DW study area was enforced by the AGFD and the Arizona State Land Department. Surveys of OHV use showed that in the winter (i.e., Oct–Mar) at both study sites, observed OHV use was approximately double the OHV use observed during the summer (i.e., Apr–Sep).

## METHODS

### Kit Fox Monitoring

We trapped foxes between March 2010 and September 2012 using 91 × 28 × 30 cm, single-door box traps (Safe Guard, New Holland, PA, USA) baited with mackerel and commercial scent lure. We distributed trapping evenly across study sites in areas within 2 km from roads. We re-trapped

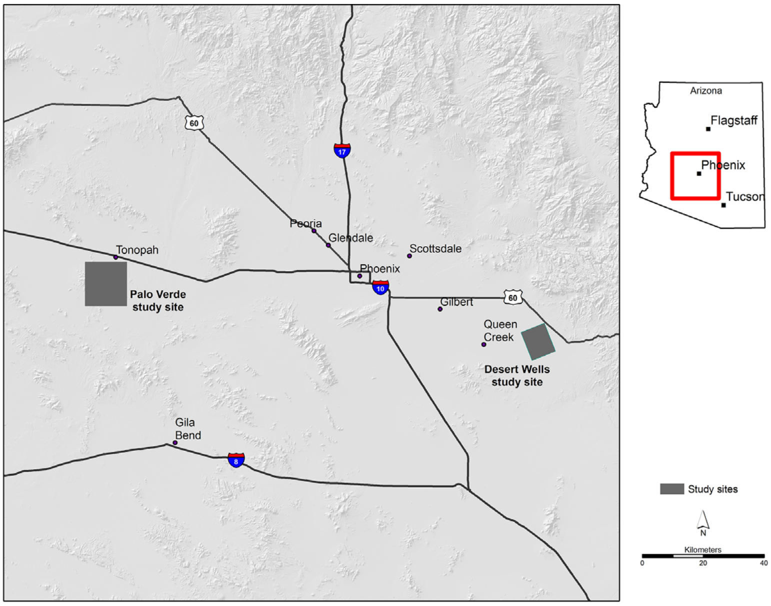

**Figure 1.** Study areas in the Sonoran Desert, central Arizona, USA, used to examine patterns of space use by kit fox relative to off-highway vehicle road networks, 2010–1013.

foxes approximately every 8 months to replace collars before the batteries expired. We fitted foxes with global positioning system (GPS) collars from Telemetry Solutions (Concord, CA, USA), programmed to attempt a locational fix every 5 hours. We collared only adult males to avoid collaring animals of the same pair, to reduce added variation due to sex-based differences in space use, and because yearling space use may be dependent on space use of adults. We monitored collar signals from the ground or air approximately every 2 weeks, and we uploaded data remotely or when we recovered collars following mortalities or re-trapping. We did not incorporate any fix-rate bias because of the open terrain and vegetation structure of our study sites. Additionally, we ground-truthed GPS data to verify that locations of dens, where fix-rate bias was most likely to occur, were accurately recorded.

### Environmental Variables and OHV Road Density

We used a geographic information system (GIS; ArcGIS v. 9.3, Environmental Systems Research Institute, Redlands, CA, USA) to define a 78-km$^2$ rectangular grid at the PV and DW study areas. To assign road density and values for environmental variables to cells, we divided each 78-km$^2$ rectangular grid into 0.16-km$^2$ cells. We measured field-based environmental variables 2 times/year at the end of each season, once in late winter and once in late summer, from March 2010 to September 2012. This resulted in 5 year–season study periods at each study area: summers 2010–2012 and winters 2011–2012.

In addition to road density, we hypothesized that several environmental variables affected kit fox space use: rodent abundance, lagomorph abundance, cattle presence, soil type, predator presence, slope, ruggedness, vegetative cover, distance to water, and distance to development (Table 1). Two observers walked parallel 400-m transects separated by 30 m across the center of each 0.16-km$^2$ cell and collected indices of rodent abundance, lagomorph abundance, cattle presence, predator presence, and data on dominant substrate. Observers recorded the number of rodent burrows (burrows $\geq$5.1 cm in diameter and with signs of recent activity), lagomorph pellet groups, bovine manure piles, predator scats (coyote, bobcat), and dominant soil type (a numerical interval based on soil particle size; Krumbein 1934) observed within 2.5 m of either side of each transect. We also conducted arroyo transects to provide an additional index of predator presence. For the arroyo transects, we searched for predator scats in the first 400 m of the largest arroyo found along the western edge of each 0.16-km$^2$ cell, with each starting point selected via GIS. We summed counts for rodent burrows, lagomorph pellet groups, and bovine manure piles between the 2 observers for each transect and assigned counts to the appropriate cell. We combined coyote and bobcat scat counts into a single predator scat count, then summed the counts from both transect methods and assigned counts to the appropriate cell.

Rodent burrow counts have been used successfully as an index of rodent abundance (O'Farrell 1992, Diffendorfer and Deutschman 2002). We tested and confirmed the applicability of this method with a field trial on a nearby Sonoran Desert site, where we compared abundance estimates calculated from mark-recapture data and counts of rodent burrows (A. Jones, Arizona Game and Fish Department, unpublished data). Similarly, pellet counts have previously been reported to be positively correlated with lagomorph abundance (Fuller and Heisey 1986, McCann et al. 2007) and scat counts have been correlated with predator abundance (Schauster et al. 2002, Gompper et al. 2006, Kays et al. 2008).

For the slope variable, we used a 30-m resolution digital elevation model (DEM) to calculate the percent slope for each 0.16-km$^2$ cell. For the ruggedness variable, we used a 30-m resolution DEM and the vector ruggedness measure (VRM; Sappington et al. 2007) within a GIS. We calculated VRM at a 30-m pixel resolution using a moving neighborhood window of 150 m. After calculating VRM values for each 30-m pixel, we assigned a median VRM value to each 0.16-km$^2$ cell based on the median value of 30-m pixels falling within each 0.16-km$^2$ cell.

In a GIS, we visually identified arroyos using 2013 aerial photos of each study site at a 30-m resolution obtained from the National Agriculture Imagery Program (NAIP). After visually identifying arroyo areas, we manually traced the boundaries of these features in a GIS (hand-digitized). After hand-digitizing arroyo areas, we calculated the percent arroyo present in each 0.16-km$^2$ cell. We included percent arroyo as an environmental variable because arroyo areas represent important microhabitats with vegetative cover and structure that differs from the relatively flat and homogenous landscape dominated by creosote-burrobush vegetation, and arroyo areas may influence kit fox space use as foraging areas or travel corridors (Zoellick et al. 1989).

**Table 1.** Environmental variables considered for models of space use intensity by kit fox, central Arizona, USA, 2010–2013.

| Environmental variable | Unit of measure | Source of data | Frequency and timing of measurement |
|---|---|---|---|
| Slope | % | 30-m digital elevation model | Once during study |
| Ruggedness | Index | 30-m digital elevation model | Once during study |
| Water | Distance to (km) | National Aerial Imagery Program | Once during study |
| Percent arroyo | % | National Aerial Imagery Program | Once during study |
| Developed areas | Distance to (km) | National Aerial Imagery Program | Once during study |
| Off-highway vehicle use | Road density (km$^2$/0.16-km$^2$) | National Aerial Imagery Program | Once after completion of field activities |
| Soil type | Soil particle size (mm) | Categorized during transects | Once during study |
| Rodent abundance | Index | No. burrows counted on transects | Twice a year at the end of season |
| Lagomorph abundance | Index | No. pellet groups counted on transects | Twice a year at the end of season |
| Cattle presence | Index | No. manure piles counted on transects | Twice a year at the end of season |
| Predator presence | Index | No. predator scats counted on transects | Twice a year at the end of season |

We characterized distance to water by locating earthen stock tanks and water catchments with the aid of AGFD personnel, aerial imagery, and ground searches. We measured distance to water as the Euclidean distance from the center of each 0.16-km$^2$ cell to the nearest earthen stock tank or water catchment. We checked earthen stock tanks and water catchments monthly to verify that water was available at each source year-round.

To account for potential disturbance effects from the mining operation at DW and the residential housing at PV, we considered an open gravel pit, a graded gravel road, and residential housing to be development features. We calculated distance to development by measuring the Euclidean distance from the center of each 0.16-km$^2$ cell to the nearest development feature.

To measure OHV road density, we visually inspected in a GIS 30-m resolution aerial photos obtained from the NAIP, taken in 2013. After visual identification of road features, we manually traced the boundaries of these features in a GIS (hand-digitized). After hand-digitizing OHV road features, we calculated road density by dividing total area of OHV road features in each 0.16-km$^2$ cell by the area of the cell. To confirm the validity of road density as an index of OHV use, we flew each of the 2 study sites systematically via a series of flight transects 800 m apart, using a fixed-wing aircraft flying approximately 100–150 m above the ground, which allowed for the entire study area to be surveyed on each flight. We conducted flights during 6 weekend days each year in 2010, 2011, and 2012, with flights scheduled approximately every other month. We recorded data via direct counts of vehicles georeferenced with a GPS unit. We used a 2-tailed Pearson's correlation coefficient (test statistic $= r$, alpha $= 0.05$) to test for a relationship between the number of OHVs observed and road density in each 0.16-km$^2$ cell. Additionally, during the first year of the study, we placed 8 TrafX counters (Trafx Research Ltd., Canmore, Alberta, Canada) on main roads at each study site to assess relative levels of OHV use.

### Models of Space Use Intensity

We estimated space use for each fox with $\geq$30 GPS locations (Seaman et al. 1999) in each winter and summer season using a utilization distribution (UD; Van Winkle 1975). We used a fixed kernel home range estimator, a likelihood-based smoothing parameter (cvh; Horne and Garton 2006), and a 30-m resolution grid cell size using the ks package (Duong 2014) in the R statistical environment (v3.0.2; R Core Team 2013).

We used the UD value at each telemetry location as an estimate of the relative intensity of space use (Horncastle et al. 2013, Dickson et al. 2015) and treated it as the dependent variable in our statistical models. We treated the environmental variables (Table 1) as independent variables to construct a model of space use using linear mixed-models and a hierarchical approach to quantify patterns of individual habitat use as a function of the habitat covariates (Burnham and Anderson 2002). Prior to modeling, we centered and standardized values for all continuous variables based on Schielzeth (2010). We diagnosed multicollinearity among environmental variables using a variance inflation factor (VIF; Neter et al. 1996). We assessed univariate correlations using a correlation matrix. We found no variables with VIF >10.0 and eliminated one in a pair of variables if Pearson's correlation coefficient >0.60. We treated measured environmental variables (Table 1) as fixed effects. We used the interaction of road density and season to evaluate differential space use intensity in response to differential OHV use, based on observed higher OHV use in the winter period. We included the interaction of site and season in our models as fixed effects to account for site and seasonal differences in space use intensity not related to OHV use. We included a random intercept variable, grouped by each individual within each season, to account for variation in use intensity among individuals. We used an exponential spatial covariance structure (Zuur et al. 2009) to model positive spatial autocorrelation among points. We used the Huber–White sandwich estimator to calculate standard errors (Huber 1967, Wooldridge 2009) to account for any remaining subject-level heterogeneity among points.

We used multi-model inference to estimate model-averaged regression coefficients ($\tilde{\tilde{\beta}}$) and unconditional standard errors (Burnham and Anderson 2002). Using Akaike's Information Criterion (AIC), we computed AIC weights ($w_i$) to rank and evaluate evidence in favor of a variable, given all possible models (i.e., all possible combinations of the fixed effects; Burnham and Anderson 2002). We then summed these weights across all models in which a given variable, $j$, occurred, to produce an importance value (Burnham and Anderson 2002). We considered an importance value $\geq$0.50 to suggest a relatively strong predictor of intensity of space use for a given environmental variable (Barbieri and Berger 2004). Additionally, we ranked the top 10 models, given all possible models, according to differences in their AIC values and considered models with the lowest relative values for AIC to be those that best approximated the data (Anderson 2008). We estimated all models in SAS PROC MIXED (v9.3, SAS Institute, Cary, NC, USA). Finally, to gain insight into the consequences of space use in relation to OHV road density, we used a 2-tailed Pearson's correlation coefficient (test statistic $= r$, alpha $= 0.05$) to test for relationships between all measured environmental variables and road density.

## RESULTS

We monitored 22 adult male foxes and gathered GPS location data on 14 individuals for 1 season, 3 individuals for 2 seasons, 3 for 3 seasons, no individuals for 4 seasons, and 2 individuals for 5 seasons. Most individuals had location data for only 1 season because of mortalities or collar failures. Five individuals died as a result of coyote predation (indicated by canine punctures in the skull and deposited coyote scats) and 4 died of unknown causes. Additionally, GPS collars failed on 2 individuals and we were unable to recapture them to retrieve data. Our final dataset to address the first objective (i.e., if space use is influenced by OHV road density) included 14,451 locations for kit fox in all years.

**Table 2.** The 10 highest ranking models of kit fox space use at the Desert Wells (DW) and Palo Verde (PV) study areas, central Arizona, USA, 2010–2013, as judged by difference in Akaike's Information Criterion (ΔAIC), with fixed effects (model), number of parameters ($K$), and AIC weight ($w_i$; weight of evidence in favor of a given model). The full model set included all possible combinations of 12 environmental variables.

| Model | $K$ | AIC | ΔAIC | $w_i$ |
|---|---|---|---|---|
| Road density in winter | 4 | 58,449.0 | 0.0 | 0.02 |
| Road density in winter + lagomorph abundance | 5 | 58,449.6 | 0.6 | 0.01 |
| Road density in winter + slope | 5 | 58,450.6 | 1.6 | 0.01 |
| Road density in winter + percent arroyo | 5 | 58,450.6 | 1.6 | 0.01 |
| Road density in winter + DW site in winter | 5 | 58,450.7 | 1.7 | 0.01 |
| Road density in winter + PV site in winter | 5 | 58,450.7 | 1.7 | 0.01 |
| Road density in winter + ruggedness | 5 | 58,450.8 | 1.8 | 0.01 |
| Road density in winter + DW site in summer | 5 | 58,450.9 | 1.9 | 0.01 |
| Road density | 5 | 58,450.9 | 1.9 | 0.01 |
| Road density in winter + distance to development | 5 | 58,450.9 | 1.9 | 0.01 |

We conducted 18 aerial surveys and recorded 191 recreationists at the 2 study sites over a 3-year period. The majority (89%) of vehicles were 4-wheelers or dirt bikes, though some 4×4 trucks were also observed on roads. Of the 191 total observations, 128 (67%) were recorded during the winter and 63 were recorded during the summer (33%). We found road density to be strongly positively correlated ($r = 0.65$, $P \leq 0.001$) with aerial observations of OHV recreationists. TrafX counter data also showed that at both study sites, relatively lower OHV use coincided with summer (i.e., Apr–Sep) and relatively higher OHV use occurred during winter (i.e., Oct–Mar). For example at DW, summed across all 8 counters, the average number of hits per month was 1,045 in winter and 732 in summer. At PV, summed across all 8 counters, the average number of hits per month was 311 in winter and 193 in summer.

Our final set of environmental variables (independent variables) we used for models of space use by kit foxes included slope, ruggedness, percent arroyo, rodent abundance, lagomorph abundance, distance to water, distance to development, road density, and site variables identifying locations on the DW site in the winter and summer seasons and the PV site in the winter season. We excluded variables representing predator presence, soil type, and cattle presence from our analyses. We excluded the variable representing predator presence because the predator scat counts were zero-inflated on transects, and unvarying among analysis units. We excluded soil type because this variable was correlated with ruggedness and we considered ruggedness to be a more useful predictor of kit fox space use than our relatively coarse classification of soil type. We excluded our index of cattle presence because counts were unvarying between cells and cattle manure was recorded in nearly every 0.16-km$^2$ cell.

Road density in the winter season was included in each of the top 10 models, as ranked by ΔAIC (Table 2), and the best model included only road density in the winter season. Other top competing models included lagomorph abundance, slope, percent arroyo, ruggedness, and distance to development. Using a model-averaging approach and ranking by relative importance values, we found road density during winter to be the strongest predictor of space use intensity, with decreased space use intensity with increasing road density (Table 3). The relative importance of road density, compared to all other fixed effects in winter demonstrates that road density negatively influences kit fox space use during this time. Although they had a lower relative importance than road density, covariates for lagomorph abundance, slope, and percent arroyo were the next strongest predictors of space use intensity (Table 3). Correlations between environmental variables and road density were all significant ($P \leq 0.001$) but weakly correlated. This included the correlations between road density and slope ($r = -0.14$), ruggedness ($r = -0.14$), percent arroyo ($r = 0.03$), rodent abundance ($r = -0.09$), lagomorph abundance ($r = -0.05$), distance to water ($r = -0.03$), and distance to development ($r = 0.35$).

## DISCUSSION

Our results indicate that for kit foxes, space use is negatively associated with road density during winter and road density in the winter was the most important predictor of space use. During summer, space use was also negatively associated with road density; however, the relationship was relatively weak. This pattern may be due to seasonally higher OHV activity levels during winter, greater sensitivity of kit foxes to disturbance during the breeding and pup-rearing season (winter), or a combination of these factors. For example, kit

**Table 3.** Relative importance ($w_+(j)$), model-averaged regression coefficient ($\tilde{\tilde{\beta}}$), and unconditional standard error values (SE) for environmental variables used to estimate intensity of space use by kit fox at the Desert Wells (DW) and Palo Verde (PV) study areas, central Arizona, USA, 2010–2013. Cumulative Akaike Information Criterion weights ≥0.5 for a given variable were indicative of a strong response. All parameter values were standardized.

| Environmental variable | $w_+(j)$ | $\tilde{\tilde{\beta}}$ | SE |
|---|---|---|---|
| Road density in winter | 1.00 | −2.08 | 1.24 |
| Lagomorph abundance | 0.42 | 0.15 | 0.22 |
| Slope | 0.31 | −0.03 | 0.08 |
| Percent arroyo | 0.30 | 0.04 | 0.11 |
| Site × season: PV in winter | 0.29 | 0.58 | 2.70 |
| Ruggedness | 0.29 | −0.03 | 0.07 |
| Site × season: DW in winter | 0.29 | −0.66 | 1.59 |
| Rodent abundance | 0.28 | 0.03 | 0.13 |
| Distance to water | 0.27 | 0.06 | 0.26 |
| Distance to development | 0.27 | 0.08 | 0.22 |
| Road density in summer | 0.27 | −0.01 | 0.27 |
| Site × season: DW in summer | 0.27 | −0.02 | 1.21 |

foxes rely on dens for security from predators and may use many dens in their home ranges. They have been observed to use 7–13 different dens during the non-pupping season (Cypher et al. 2009). However, during the pup-rearing season, kit foxes may use fewer dens and switch dens less often (Morrell 1972, Koopman et al. 1998) and dens may be especially important during this season when pups are most vulnerable (Rodrick and Mathews 1999). Reproductive females begin searching for and preparing natal dens during pair formation in September and October, males may join females at natal dens in October or November (Zoellick 1990), and pups are typically born during February and March (Morrell 1972). Thus, in Arizona deserts, activities surrounding kit fox reproduction coincide with increased OHV use in fall and winter. Kit foxes might therefore perceive a higher risk from areas with a high-density of roads during these months, and choose habitats in efforts to mitigate this risk (Warrick and Cypher 1998). Kit foxes may use areas with higher density of roads more readily in the summer as pups begin to disperse (Koopman et al. 1998). The lower relative importance of road density on fox space use during summer may have been due to reduced OHV activity during these months but may also have been influenced by behavioral changes in fox habitat use during these months.

The interpretation that kit fox space use may be negatively related to road density because of reproductive behavior associated with natal den sites is not unequivocal. For example, Pruss (1999) reported that den sites occupied by swift fox (*Vulpes velox*) were located closer to roads than unoccupied dens. However, when occupied and unoccupied dens were pooled, there was a weakly negative correlation between roads and dens. Harrison (2003) also reported that swift fox dens were recorded closer to primary or secondary roads than random locations. In an evaluation of the effects of 2-lane roads on San Joaquin kit foxes, Cypher et al. (2009) reported that, although not statistically significant, locations of pupping dens were, on average, closer to roads than non-pupping dens. However, dens of all types (natal and non-natal) for radio-marked kit foxes were farther from roads than nocturnal locations, suggesting that kit foxes were avoiding roads at some scale when selecting den sites.

We examined correlations between road density and all other measured environmental variables to consider the possible consequences of increased road density on kit fox habitat. For example, high rodent abundance might be a characteristic of high-quality habitat for kit foxes and if a strong positive correlation existed between rodent abundance and road density, it could be hypothesized that kit fox avoidance of high-density road areas would lead to a decrease in fitness. However, the weak correlations between road density and all other measured environmental variables do not provide evidence for how decreased space use intensity in areas with high road density may affect kit foxes. Although we cannot infer specific consequences, our results do suggest that OHV road networks create a road-effect zone where the ecological effects of roads extend beyond the physical edge of roads (Forman et al. 1997). Given decreased space use in relation to roads, increasing road densities over time could effectively remove areas available to kit foxes, similar to effects from urbanization or habitat alteration.

To our knowledge, our study is the first to evaluate the influence of OHV road density to kit fox space use. Previous studies have evaluated other forms of disturbance to kit fox space use and ecology (Cypher et al. 2009) or the influence of OHV use to kit fox survival and density (O'Farrell and Gilbertson 1986). Both studies concluded no negative effects to kit fox survival and density could be linked to human activities, including OHV use or 2-lane roads. However, our study addressed only space use and did not directly evaluate the influence of OHV disturbance to kit fox survival or reproduction. Notably, Cypher et al. (2009) did evaluate the influence of 2-lane roads on kit fox space use. These authors, using distances between nightly fox re-locations, found space use was not influenced by 2-lane roads. Importantly, our approach to evaluating kit fox space use differed from this approach because our UD and modeling approach incorporated both movements and day-time denning and resting locations within a single model.

Relative to road density in winter, all other environmental variables were weak predictors of space use. However, the weak positive relationship between space use and rodent abundance and lagomorph abundance are consistent with established kit fox ecology. For example, prey availability may exert a strong influence on population dynamics of kit foxes (White and Garrott 1997), and kit fox density and finite growth rates have been reported to positively correlate with prey abundance, whereas home range size of kit foxes has been reported to be negatively correlated with relative abundance of prey (White and Garrott 1997, White and Garrott 1999, Cypher et al. 2000). However, associations between kit foxes and habitat factors may also be somewhat flexible, such that the spatial distribution of kit foxes may not be determined primarily by prey abundance, and prey availability may, in fact, be a relatively weak predictor of space use within the home range (Warrick and Cypher 1998).

Slope and ruggedness were also considered relatively weak predictors in our model. However, the negative association between these topographic measures and kit fox space use is similar to findings by Warrick and Cypher (1998) who reported that kit fox capture rates were always negatively associated with ruggedness and Dempsey et al. (2015) who found a negative relationship between kit fox space use and slope. We also identified a relatively weak but positive association with distance to development. Kit foxes have been reported to occur in developed areas in other parts of the Southwest (Cypher and Frost 1999, Cypher et al. 2000). However, the forms of development present on our study sites were different than more developed urban areas, which can provide advantages (e.g., higher food availability; Cypher and Frost 1999). We found a relatively weak but positive association with distance to water. Kit fox water budgets are partly met through metabolic water but this must be supplemented by preformed water (Golightly and Ohmart 1984). The weak association with distance to water suggests that kit fox water requirements were not high enough at our study sites to influence space use. Finally, we found a relatively weak but positive association with percent arroyo, which is consistent with findings that although kit foxes den in creosote bush flats, they do not avoid more densely vegetated arroyo areas (Zoellick et al. 1989).

## MANAGEMENT IMPLICATIONS

The negative relationship between kit fox space use and road density shows that road networks may decrease the amount of habitat available to kit foxes. In areas like the Southwest where OHV road networks are expanding over time, increased road networks will likely result in effective habitat loss for kit foxes. In areas where the goal is no net loss of wildlife habitat, focus should be directed toward limiting the expansion of road networks over time. Practical solutions to limiting road network expansion include education and strict enforcement to restrict OHV access to established roads. Managers will ultimately need to determine whether adequate recreational opportunities exist in a given area for OHV recreationists and how recreational needs must be balanced with conserving habitat for species like the kit fox.

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