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Original Article

Capture Success Higher Near Roads for San Clemente Island Foxes

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ABSTRACT Recently, island fox (*Urocyon littoralis*) populations on 4 of 6 California Channel Islands (USA) were greatly reduced by colonizing golden eagles (*Aquila chrysaetos*) and a suspected outbreak of disease, creating concern for subspecies on all islands. Consequently, efforts of live-trapping foxes for research, monitoring, and vaccination has increased. Despite increased trapping efforts, evaluation of factors that influence capture success has not been conducted. We examined capture success of island foxes at 85 random trapping locations on San Clemente Island during 170 trap-nights during 2006–2007. We captured 98 island foxes, and found that traps placed ≤ 10 m from primary roads had higher overall capture success (i.e., 1.52 times more likely to capture foxes) than traps placed at random locations throughout the study area. We found no evidence to suggest that the density of edges between land-cover types (i.e., sum length of edges per 100-m buffered area [m/m^2]), nightly temperature, proportions of land-cover, or type of attractant tested ($n = 3$) affected capture success. All attractants captured similar proportions of sex and age classes of foxes. Our findings suggest that future trapping efforts would have the most success if conducted along roads. © 2013 The Wildlife Society.

KEY WORDS attractant, California Channel Islands, capture, island fox, roads, trapping, *Urocyon littoralis*.

Recent declines of 90–95% in populations of island foxes (*Urocyon littoralis*) have occurred on 4 of 6 California Channel Islands (USA) from hyper-predation by colonizing golden eagles (*Aquila chrysaetos*) and a suspected outbreak of canine distemper virus (Roemer 1999, Coonan et al. 2005, Timm et al. 2009). Consequently, 4 of 6 subspecies of island foxes are listed as critically endangered, and the other 2 subspecies are considered species of concern (USFWS 2010). The recent vulnerability of island foxes to stochastic events suggests that live-trapping will continue for conducting future research studies, population monitoring, and vaccination programs (e.g., Spencer et al. 2006). However, to our knowledge, no studies have been conducted to determine what factors influence success of live-traps for capturing island foxes.

Identifying factors that affect success of live-traps is important for eliminating biases when sampling foxes to make inferences about population dynamics (e.g., Snow et al. 2012), and for population monitoring (e.g., Spencer et al. 2006), especially when attempting to ascertain declines in populations. Resource managers also need information on capture rates for planning vaccination and emergency

protocols in response to potential introductions of diseases or predators. San Clemente Island (SCI) provides a good case study for examining factors that influence capture success of island foxes. Foxes on SCI (*U. l. clementae*) are not known to have experienced a significant decline in population from diseases or predators. Previous to this study, foxes on SCI had not been exposed to live-trapping for approximately 2 years; therefore, behaviors of foxes should be minimally impacted by previous experiences.

Previous methodology for trapping island foxes on California Channel Islands usually consisted of wire-mesh live-traps with burlap coverings, wet or dry cat food as nourishment for captured foxes, and a Very Berry–Loganberry paste (On Target A.D.C., Cortland, IL) as a fox attractant (Laughrin 1977, Garcelon et al. 1999, Coonan et al. 2005). Our objective was to follow a similar protocol for trapping foxes on SCI, and determine whether capture success was influenced by proximity to primary roads and type of attractant. We also explored whether ruggedness of terrain, surrounding land-cover types, the density of edges between land-cover types (i.e., calculated as the sum length of edges between cover types, divided by the area of the 100-m buffer [m/m^2]), and nightly temperatures influenced capture success. We predicted that capture success would be influenced by 1) placing traps along roads that may be used for travel or foraging, 2) placing traps in canyons and arroyos that may be used for cover, 3) placing traps in grassland and disturbed habitats used for foraging, 4) placing traps in areas with more edges between land-cover types, 5) nightly

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temperatures that may affect fox behavior, and 6) the types of attractants used inside traps. Our secondary objective was to determine whether 3 types of attractants captured similar age and sex classes of island foxes.

STUDY AREA

San Clemente Island (146 km²) was the southernmost California Channel Island (33°1'22"N, -118°35'19"W), located approximately 109 km west of San Diego, CA, USA (Fig. 1). San Clemente was approximately 34 km long, 6.5 km wide, and rose 599 m above sea level. The mean temperature was 17°C and annual precipitation averaged 150–300 mm (Schoenherr et al. 1999), with 95% falling from November to April (Kimura 1974, Yoho et al. 1999). However, during the duration of this study, only 80 mm of rain were recorded (H. Cox, California State University Northridge, unpublished data), indicating drought conditions. San Clemente Island was owned and operated by the U.S. Navy. Our study area (80.6 km²; Fig. 1) covered the north-central portion of SCI, but excluded the extreme northern tip (2.1 km²) and the southern portion (55.9 km²) because of access restrictions, and excluded the steep eastern escarpment (7.4 km²) because of safety concerns.

Vegetation consisted primarily of maritime desert scrub (54%) and grassland (33%; Thorne 1976, Sward and Cohen 1980), although several other types of vegetation were interspersed (Roemer et al. 2004). Maritime desert scrub primarily consisted of California boxthorn (*Lycium californicum*), snake cactus (*Bergerocactus emoryi*), and prickly pear (*Opuntia littoralis*); whereas, grasslands were a mixture of perennial and annual grasses, including purple needlegrass (*Nassella pulchra*), ripgut grass (*Bromus diandrus*), and wild oats (*Avena fatua*; Raven 1963, Philbrick and Haller 1977, Baldwin et al. 2012). About 7% of the island was designated as disturbed with naval facilities and roads (Roemer et al. 2004). Three urban areas that comprised 1.1 km² were located in the north and north-central portions of SCI (Gould and Andelt 2011). Foxes occurred in all types of land-cover and land-use classes, although habitat-specific relationships and the relative importance of each are currently unknown.

The primary roads (i.e., study roads) on SCI included Ridge Road (24.3 km) that ran north–south through the center of the island, and Perimeter Road (7.9 km) that encircled the airfield at the northern tip of the island (Fig. 1). The maximum speed limit was 56 km/hr (35 mph), although 40 km/hr (25 mph) was posted in some urban areas and on some curved sections. Depending on the segment of road, speeds averaged 47–60 km/hr and the volume of traffic averaged 60–366 vehicles/day (Snow et al. 2011). Approximately, 90% of all traffic volume occurred during daytime (Snow 2009). During this study, these roads were a mixture of paved (76%) and gravel (24%) surface. The study roads were 2 lanes, and most did not have maintained shoulders and were slightly or not elevated above the surrounding landscape. Vegetation typically grew to the edge of the roads. Secondary roads were present, but were

infrequently used and were not developed or maintained, and therefore were not considered during our study.

METHODS

Trapping Foxes

We used the Reversed Randomized Quadrant-Recursive Raster algorithm (Theobald et al. 2007) within ArcGIS (v9.1) to generate random, and spatially balanced, trapping locations throughout the entire study area. We also divided the primary roads into 1.2-km segments (Snow et al. 2012), approximating the diameter of home ranges of island foxes on SCI (Resnik 2012). We randomly generated 1 trapping location/segment, ≤ 10 m from the study roads. We expected that trapping locations ≤ 10 m from roads were within the spatial proximity needed to detect whether roads influenced capture success. Our trapping protocol was also used to capture random samples of foxes for assessing the effects of roads on survival of foxes (see Snow et al. 2012).

During July–August 2006, we set traps in 58 random locations throughout the study area. During September 2006, we set traps in 13 random locations along roads. Finally during November 2006–July 2007, we set more traps in random locations throughout the study area ($n = 4$ locations) and along the roads ($n = 10$ locations) as needed for objectives of the interrelated survival study (see Snow et al. 2012).

We used wire-mesh cage-traps (Tomahawk Live Trap Co., Tomahawk, WI) equipped with acrylic glass sheets on the inside of doors and polyethylene tubing for chew bars inside the traps to reduce potential injuries to captured foxes. We covered the traps with burlap, and placed vegetation on the inside floor and on the tops of traps to protect foxes from exposure. We placed approximately 2 oz (approx. 57 g) of dry, fish-flavored cat food on a 9-cm $\times$ 9-cm piece of cardboard at the rear of every trap for nourishment. We oriented all traps so the doors opened downwind, and in particular, we oriented the traps along roads with the doors opening downwind and toward the road. We set all traps at each location before sunset of the evening of the first day, checked and closed the traps the next morning before noon, re-opened the traps the second evening, and re-checked and removed the traps the second morning. Traps were not set during the day to reduce the risk of heat stress for captured foxes. We also did not set traps during inclement weather (e.g., rain). We wore leather gloves while setting traps to minimize human odors. We verified that trapping procedures were consistent among members of the field crew at the beginning of the study.

We randomly assigned 1 of 3 paste attractants to each trap: 1) a food-based attractant (i.e., fruit odor), Very Berry–Loganberry; 2) a curiosity-based attractant (i.e., peppermint odor), Gray Fox Candy Cane Special (O'Gorman Enterprises, Inc., Broadus, MT); and 3) a multi-attractant call lure (i.e., gland odor), Circle Maker (Russ Carman, New Milford, PA). We dipped wooden sticks (approx. 5 cm long) approximately 1.5 cm deep into each attractant paste.

Figure 1. Study area, primary roads, and trapping locations on San Clemente Island (CA, USA) during July 2006 to August 2007.

We hung the attractant stick inside the top of each trap, behind the treadle.

Captured foxes were not anesthetized during handling (for more details, see Snow et al. 2012). We determined the sex of all foxes captured. We assigned 1 of 5 age classes to each fox based upon general amount of wear on the first upper molar (Wood 1958, Collins 1993): 0–12 months (age class 0), 13–24 months (age class 1), 25–36 months (age class 2), 37–48 months (age class 3), and >49 months (age class 4). We verified and corrected age estimates using tooth cementum layers (Matson's Laboratory, Milltown, MT) for foxes found dead ($n = 15$), and cross-checked ages of foxes marked with Passive Integrated Transponders ($n = 35$) using databases from previous years (D. K. Garcelon, Institute for Wildlife Studies, unpublished data). We used corrected estimates of age classes to calculate continuous estimates of ages (Wood

1958), assuming an average birthdate of 21 February (Snow et al. 2011). We considered juvenile and young foxes as ≤ 2 years old, intermediate-aged foxes as 2–6 years old, and old foxes as >6 years old. Techniques for capturing and handling foxes were approved by Colorado State University's Institutional Animal Care and Use Committee (protocol 06-098A-01), and by a memorandum of understanding with California Department of Fish and Game.

Characteristics of Trapping Locations

We considered a number of putative explanatory variables to help explain variation in capture success. First, we considered 2 classes of trapping locations: 1) traps set ≤ 10 m from primary roads and 2) traps set at random locations throughout the study area, to examine for influences from roads on capture success of island foxes (ROAD). Then, we

buffered each trapping location in ArcGIS with a 100-m radius to examine for other influences on capture success. The buffered area (0.03 km²) approximated the core-use area for island foxes on SCI (Resnik 2012). We used a 10-m digital elevation map from the United States Geological Survey, National Elevation Dataset (Gesch et al. 2002, Gesch 2007) and Topography Tools for ArcGIS (Dilts 2010) to calculate the average Topographic Position Index (TPI) value within the buffer to examine for influences from topography on the capture success of foxes. The TPI value represented the difference between elevation of a central pixel and the mean of the surrounding cells. Large negative TPI values were associated with topographic depressions (e.g., canyons or arroyos), TPI values near 0 were associated with flat areas, and large positive TPI values were associated with topographic rises (e.g., ridges or hilltops).

We used the 2006 land-cover map from National Oceanic and Atmospheric Administration, Coastal Change Analysis Program, collected with Landsat 7 Thematic Mapper with 86.1% overall classification accuracy and 30-m resolution (NOAA Coastal Services Center 2009) to examine for influences from the surrounding land-cover and land-use on capture rates. We reclassified the cover types on SCI from 14 to 4 classes: grassland (75%), scrub-shrub (21%), disturbed (3%), and other (1%; e.g., unconsolidated shore, sand dunes, forests, water). We used the Fragstatsbatch extension in ArcGIS (Mitchell 2005), and Program FRAGSTATS v3.3 (McGarigal and Marks 1995), to calculate the proportions of grassland (GRASS), scrub-shrub (SHRUB), and disturbed (DISTURBED) cover types within the 100-m buffers. We also calculated the sum length of edges between land-cover types, divided by the area of the 100-m buffer (m/m²; EDGE).

Lastly, we used nightly temperatures (°C) recorded at the Hoeppel weather station in the central-interior region of SCI by the SCI Climatic Monitoring Program (H. Cox, unpublished data) to examine for influences of temperature on capture success. Climatic factors have affected the trapping success of some small mammals (e.g., Gosling 1981, van Hensbergen and Martin 1993), but no studies have demonstrated this for foxes. For each trap location, we used the average temperature recorded at midnight during the 2 consecutive trap-nights (TEMP).

Data Analyses

We considered the total count of foxes captured within 2 trap-nights at each location as the response variable in order to avoid pseudo-replicating trap-nights at each location. We excluded instances where an individual fox was captured during 2 consecutive trap-nights, to reduce influences from trap-happy animals. We conducted exploratory analyses of the data, and excluded the less biologically important explanatory variable(s) from any correlated pair (i.e., $r \geq |0.70|$; Program R v2.12.1; R Development Core Team).

To examine for influences from the 7 remaining explanatory variables on the count of captures, we used a maximum-likelihood approach with generalized linear

models with a Poisson error term and logarithm-link function in Program R. We constructed a set of 18 *a priori*, balanced, and biologically meaningful models (Burnham and Anderson 2002, Anderson 2008) using an incomplete block design of 7 variables. The global model considered was: $c = \text{ROAD} + \text{TPI} + \text{EDGE} + \text{TEMP} + \text{DISTURBED} + \text{GRASS} + \text{ATTRACTANT}$, where c was the count of captures at each location. We investigated our data for over-dispersion by comparing the residual deviance of the global model with the residual degrees of freedom. We also compared the fit of standard Poisson and fit of negative binomial modeling approaches for the global model using glm.nb (Package MASS; Zeileis et al. 2008) and the odTest function (Package pscl; Jackman et al. 2007) to test the null hypothesis that the data followed a Poisson distribution ($P < 0.05$).

We used the Akaike Information Criterion adjusted for small sample size (AIC_c) to rank models and calculate model weights (Burnham and Anderson 2002). Following methodology of Snow et al. (2011), we calculated the relative importance of each explanatory variable, and variables with weights <0.30 were considered as having weak support for influencing the count of captures (Burnham and Anderson 2002); therefore, we excluded those variables from further analysis. For the remaining variables (ROAD and TPI), we constructed a second, reduced set of balanced models. We model-averaged across the reduced set to provide robust estimates of coefficients using the shrinkage technique, and calculated the unconditional variance estimates and associated 95% confidence intervals (Burnham and Anderson 2002, Anderson 2008). We examined the model-averaged coefficients ($\hat{\beta}$) and 95% confidence intervals to ascertain the strength and directionality of influences on captures. We examined residuals from the model-averaged model for spatial autocorrelation using a correlogram (Package ncf, v1.3; Bjornstad 2012) and a semivariogram (Package gstat, v1.8; Pebesma and Wesseling 1998).

We calculated the incidence-rate ratio from the main effect model of ROAD to determine the change in capture rate based on trap placement near roads (Package msm, v1.1.1; Jackson 2011). This rate was considered the relative change in the capture rate between trapping sites near roads, and all other sites. We calculated the associated standard errors and confidence intervals for the incident rate ratios using the Delta method. We also conducted a *post hoc* analysis using a generalized linear model to compare the capture success at sites near roads (≤ 10 m) relative to capture success at sites away from roads (> 10 m).

Finally, we examined whether the type of attractant influenced the proportions of foxes captured by sex and by age. We used logistic regression with a binomial distribution and logit-link to determine whether the probability of capturing a male varied by attractant type. We also used linear regression with a Gaussian distribution and identity-link to determine whether the ages of the foxes captured varied by attractant type. For each regression, we considered the Very Berry-Loganberry attractant as our reference

attractant, because this attractant was most commonly used on SCI.

RESULTS

We set traps at 85 locations (23 locations near roads, and 62 random locations throughout SCI), for 170 total trap-nights. We captured 98 foxes for an overall capture success of 57.6%. We excluded one instance of a second-capture because the fox was captured at the same location twice during 2 consecutive nights. We identified that SHRUB was correlated with GRASS ($r = -0.71$) and EDGE ($r = -0.71$); therefore, we excluded SHRUB from further analysis. The residual degrees of freedom of the global model ($df = 76$) was only 1.2 times greater than the residual deviance ($dev. = 62.9$), and the over-dispersion test confirmed a lack of over-dispersion by not rejecting the null hypothesis that the data had a Poisson distribution ($\chi^2 = -0.001$; $P = 0.5$). From the full model set, we found ROAD and TPI were the only explanatory variables showing evidence of influencing the success of captures ($w_{ROAD} = 0.56$ and $w_{TPI} = 0.32$). All other variables showed little evidence of influencing the success of captures ($w_{EDGE} = 0.19$, $w_{TEMP} = 0.14$, $w_{DISTURBED} = 0.13$, $w_{GRASS} = 0.10$, and $w_{ATTRACTANT} = 0.07$).

We considered all models from the reduced model set as being plausible (Table 1). The model-averaged estimate from the reduced model set indicated that capture success was higher along roads than at random ($\hat{\beta}_{ROAD} = 0.36$, 95% CI = -0.07 – 0.79 ; Fig. 2), although the confidence interval slightly overlapped zero. The incidence-rate ratio indicated that the predicted rate of capture along roads was 1.52 (95% CI = 1.16 – 2.00) times greater than the rate for other sites. The *post hoc* analysis produced similar results that capture success was higher near roads ($n = 25$) than away from roads ($n = 60$; $\hat{\beta} = 0.39$, 95% CI = -0.03 – 0.80).

We found that TPI had little influence on capture success ($\hat{\beta}_{TPI} = -0.04$, 95% CI = -0.21 – 0.12 ; Fig. 2). The residuals from the model-averaged model showed no indication of spatial autocorrelation among trap locations; therefore, no correction for autocorrelation was required.

We found no evidence that the type of attractant affected the sex or age classes of foxes captured. We estimated 33 of 63 (52%) foxes captured in the random, and spatially balanced trapping locations throughout SCI were <2 years old, and therefore not exposed to traps previous to this study.

Similarly, 18 of 35 (51%) foxes captured in traps intentionally set near roads were estimated as <2 years old.

DISCUSSION

Placing traps along primary roads was the most influential variable we examined that affected capture success of island foxes. Although the parameter estimate for ROAD was not statistically significant, the incidence-rate ratio indicated the directionality of the effect was unlikely to be from random chance alone, and therefore suggested biological significance. Plausible explanations include: foxes used areas near roads more than surrounding areas (e.g., higher density of foxes near primary roads), traps were more easily detected near roads, or both of these. Our placement of traps near roads was specifically designed to attract foxes from roads (i.e., trap placed upwind from road with door facing road); therefore, we cannot discern whether capture rates were higher because more foxes were using the roads, or because traps were more easily detected there. Foxes on SCI were occasionally observed foraging, traveling, and scent-marking along roads (Gould 2010); thus, we suspect foxes encountered traps more frequently near roads than at random locations where foxes may not have traveled as often.

Roads may represent desirable habitat features for island foxes, because roads create edges that many generalist mammalian predators prefer (Heske et al. 1999, Dijak and Thompson 2000, Svobodová et al. 2011). Swift foxes (*Vulpes velox*) used roadsides for denning (Harrison and Whitaker-Hoagland 2003) and San Joaquin kit foxes (*V. macrotis mutica*) possibly used roads to obtain food (e.g., road-kill; Cypher et al. 2009). Red foxes (*V. vulpes*; Macdonald 1985) and Iberian wolves (*Canis lupus signatus*; Macdonald 1985, Barja et al. 2005) placed their scats on roadways so that they may be visible and easily detected by conspecifics. Similarly, gray wolves (*C. lupus*) in Alberta, Canada used roads for travel lanes (Whittington et al. 2005). Snow et al. (2012) found that foxes on SCI used areas <100 m and >100 m from roads in similar proportions, but the scale of that study was too large to infer frequency of use <10 m from roads, as was the scale in this study. Coinciding with the nightly setting of our traps, foxes moved across roads more at night, which also coincided with periods of higher fox-activity and lower volumes of traffic (Snow et al. 2012). Determining how island foxes use roads appears to be an important line of future research on SCI.

Table 1. Model selection results for examining captures of island foxes during two consecutive trap-nights at locations ($n = 85$) on San Clemente Island, CA, USA, July 2006 to August 2007. Candidate models were ranked using change in Akaike's Information Criterion (ΔAIC_c) and Akaike weight (w_i).

Model ^a	K^b	ΔAIC_c	AIC_c w_i	Model likelihood	Residual deviance
ROAD	2	0.00	0.48	1.00	70.42
ROAD + TPI	3	0.53	0.37	0.77	68.80
TPI	2	2.32	0.15	0.31	72.74

^a Models named by associated explanatory variable(s): ROAD = 2 classes of trapping locations: traps set near primary roads, and traps set at random locations throughout the study area. TPI = topographic position index of trapping locations.

^b No. of parameters including an intercept.

Figure 2. Predicted (model-averaged) relationship and 95% confidence intervals (CIs) for the rate of capture of San Clemente Island (SCI; CA, USA) foxes during two consecutive trap-nights, July 2006 to August 2007.

Variation in population density of foxes on SCI, with regard to roads, is not well-understood. Population monitoring during 2009 estimated higher densities near primary and secondary roads, but not during 2007, 2008, 2010, and 2011 (Garcia and Associates, unpublished reports; N. C. Gregory, Institute for Wildlife Studies, unpublished report). We found 67% capture success for all traps set ≤ 100 m from primary and secondary roads, 46% success for all traps set > 100 m from roads, and 30% success at all traps set > 500 m from roads, suggesting that considerable numbers of foxes likely inhabit most areas. Regardless, it is clear that roads play substantial roles in the population dynamics of foxes on SCI. Road-kills are the leading cause of mortality, effectively reducing the survival rate of foxes living near roads (Snow et al. 2012). Our findings support recent evidence that roads are a focal feature on the island landscape affecting the population of foxes on SCI.

Although TPI indicated relative importance for influencing captures, canyons and arroyos showed little evidence of increasing capture success. No other variables tested influenced the success of capturing foxes, yet our capture rates were quite high for a carnivore species. Foxes that were not previously exposed to traps (< 2 years old) did not appear to bias our results, because similar proportions of foxes < 2 years old were also captured in a later study when trapping efforts had occurred for 5 previous years (N. C. Gregory, Institute for Wildlife Studies, unpublished report). The drought conditions on SCI during this study may have increased our capture success, because available food resources were limited. Additionally, our placement of dry cat food inside traps may have enticed foxes for supplemental feeding. We did not attempt to capture foxes without food

inside traps because of concerns for the welfare of captured foxes, and therefore we do not know whether food influenced captures. The attractants we tested did not appear to affect the age and sex classes of island foxes that we captured, suggesting that the attractiveness of food was modified by each attractant in a similar manner. Similarly, gray foxes on the mainland showed no preference to specific attractants (Steelman et al. 2000), although this was not the case for all wildlife (Andelt and Woolley 1996).

Another reason explaining our high capture success could be related to island foxes evolving in isolation, and therefore exhibiting ecologically naïve behavior. In the absence of predators, island foxes developed reduced avoidance behaviors (Swarts et al. 2009) similar to other species (e.g., Griffin et al. 2000). Island foxes reportedly lack fear of humans (Laughrin 1977, Moore and Collins 1995), are naïve of novel predators (Roemer et al. 2001, Swarts et al. 2009), and show low avoidance toward approaching vehicles (Gould 2010). We expect this phenotypic trait may extend to decreased wariness of traps, and may have resulted in higher capture success when compared with non-naïve species.

The timing of our trapping events was not evenly spaced throughout the study. The majority of traps placed along roads were operated approximately 1 month after the majority of traps placed at random locations throughout the study area, thus, potentially confounding our data. We also did not trap enough during both wet and dry seasons, or during each biological season to examine for seasonal effects. We expect that more evenly spaced trapping events among biological seasons could better identify whether capture success varies throughout the year.

MANAGEMENT IMPLICATIONS

Future trapping efforts likely will have highest success if conducted along roads. Research studies, population monitoring, and vaccination programs that involve live-trapping island foxes should consider biases from higher capture success near primary roads. Our results also demonstrate the utility of trapping efforts away from roads. For disease control purposes, it is important to place traps near to, and far from, roads to vaccinate a target percentage of the population; because foxes have demonstrated a strong affinity for a given area (Resnik 2012). All 3 attractants tested should capture balanced sex and age classes of foxes. Determining how foxes use roads and the densities of foxes in relation to roads appear to be important lines of future research on SCI.

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