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Original Article

Characteristics of Road-Kill Locations of San Clemente Island Foxes

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ABSTRACT Mortalities from collisions with vehicles have created concern for the welfare of the San Clemente Island fox (*Urocyon littoralis clementae*); 1 of only 6 genetically distinct subspecies of island fox. To find possible solutions for minimizing these mortalities, we compared 9 characteristics of roads and roadsides at kill-sites and control-sites to ascertain whether certain features were associated with risk of collisions. We found that kill-sites were positively associated with the volume of traffic, and negatively associated with the distance of motorists' visibility, which had not been previously identified for island foxes. Additionally, visual obstructions along roadsides (i.e., steep ditches and tall vegetation) showed some evidence of increasing mortalities. We also found that gravel mounds, a possible pseudo-barrier along roadsides, were associated with reduced mortalities. Speeds of vehicles, presence of drainages, cacti, and culverts, and seasonality showed minimal effects on road-kills. Our findings suggest that efforts to reduce mortalities should focus on roads with high volumes of traffic and high amounts of visual obstruction for motorists. Possible methods for reducing road-kills include installing signs and speed bumps on curves of roads, regular mowing of roadsides, constructing gravel-mound barriers along edges of roads, and educating motorists. © 2011 The Wildlife Society.

KEY WORDS animal–vehicle collisions, California, carnivores, island fox, mortality, road-kills, roads, *Urocyon littoralis clementae*.

Island foxes (*Urocyon littoralis*), the direct descendants of gray foxes (*U. cinereoargenteus*), have been isolated on 6 California Channel Islands (USA) for approximately 16,000 years, and evolved into distinct subspecies on each island (George and Wayne 1991, Rick et al. 2009). Recently, populations on 3 islands were reduced approximately 95% by newly colonizing golden eagles (*Aquila chrysaetos*; Roemer 1999, Coonan et al. 2005), and another population was reduced 90–95% by canine distemper virus (Kohlmann et al. 2005, Timm et al. 2009). Consequently, the United States Fish and Wildlife Service listed these 4 subspecies as endangered (U.S. Fish and Wildlife Service 2010), and the remaining 2 as species of concern, including the San Clemente Island (SCI) fox (*U. l. clementae*). The population on SCI is not known to have experienced a substantial decline; but road-kills of nearly 30 foxes per year since 2000 have caused concern for this subspecies (Snow 2009). Various types of mitigation including warning signs, reduced speed limits, and occasional mowing of vegetation along roadsides have been implemented in attempts to reduce road-kills, but a reduction in mortalities has not been observed (Spencer et al. 2006, Snow 2009).

Roads are a widespread feature on most landscapes (Trombulak and Frissell 2000). Some populations of wildlife

that suffer high incidence of road mortalities are known to experience considerable negative impacts to their persistence (van Langevelde and Jaarsma 2005, Fahrig and Rytwinski 2009). Road mortalities can directly affect a population's demography (Trombulak and Frissell 2000) and reduce abundance (Fahrig and Rytwinski 2009). For small populations, the effects from roads can be especially severe (Spellerberg 1998). For these reasons, roads are becoming recognized as a major contributor to loss of biodiversity (Benítez-López et al. 2010).

An important step in reducing the impacts of roads is to identify “road-kill hotspots,” where efforts to reduce mortalities can be most effectively concentrated (Litvaitis and Tash 2008). Road-kill hotspots have typically been identified along segments of road that were attractive to wildlife (e.g., high food availability, accumulation of minerals, near preferred habitat), or because topographic features funneled animals toward roads (Brockie 2007, Litvaitis and Tash 2008, Grilo et al. 2009). Roads with more traffic volume or higher speeds of vehicles have also been associated with increased road-kills (e.g., Rosen and Lowe 1994, Fahrig et al. 1995, Inbar and Mayer 1999, Klöcker et al. 2006, Danks and Porter 2010). Additionally, road-kills of red foxes (*Vulpes vulpes*; Grilo et al. 2009), roe deer (*Capreolus capreolus*; Hartwig 1993), and kangaroos (*Macropus* spp.; Klöcker et al. 2006) were more prevalent in locations where motorists had shortened sight of the upcoming road.

Shortly after roads were constructed on SCI, road-kills became recognized as a major source of mortality for foxes (Laughrin 1977, Moore and Collins 1995, Roemer et al.

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2004, Spencer et al. 2006, Snow 2009). During 2006–2007, road-kills represented the largest cause of mortality (29–57% of mortalities) and reduced survival of foxes with home ranges that encompassed roads on the northern two-thirds of SCI (Snow 2009). That population was estimated to be 386 (95% CI = 320–480) foxes during 2007 (Andelt et al. 2009), of which 3–8% was lost annually to road-kills (Snow 2009). It is unknown whether those mortalities were compensatory. Despite the high rate of road-kills, no studies have focused on identifying influential variables that explain where and when road-kills occur. Therefore, our objective was to better inform effective mitigation strategies by determining which characteristics of road-kill sites, compared to random sites, influenced the occurrence of road-kills on SCI. We also sought to determine whether certain times of year influenced the occurrence of road-kills.

We predicted that sites of road-kills would be located 1) on roads with higher volumes of traffic, 2) where vehicles drove at higher speeds, 3) where roads were paved, 4) where visibility of the upcoming road for motorists was more limited by hills or curves, 5) where visibility of roadsides to motorists was more obstructed from vegetation, boulders, and increased elevation change leading away from the roadside, 6) where there were no gravel mounds along the roadsides to act as pseudo-barriers, 7) where drainages were nearby and available as travel lanes, 8) where patches of prickly pear cactus (*Opuntia* spp.) fruits were nearby and available for food, 9) where culverts were nearby and available for cover, and 10) during the prebreeding season when young foxes may be dispersing.

STUDY AREA

San Clemente Island is the southernmost California Channel Island (33°1'22"N, –118°35'19"W), and is owned and operated by the United States Navy. It is located approximately 109 km west of San Diego, California, USA (Fig. 1), and is approximately 34 km long, 6.5 km wide, and rises to 597 m above sea level. Vegetation on the island was comprised primarily of maritime desert scrub (54.4%) and grassland (32.8%; Thorne 1976, Sward and Cohen 1980) although several other habitat types were interspersed (Roemer et al. 2004). About 7.4% of the island habitat was designated as “disturbed” with naval facilities and roads. Foxes occurred in all habitats of the island (Roemer et al. 2004), including much of the disturbed land. The mean temperature was 17° C and annual precipitation averaged 13 cm, with 95% falling from November through April (Kimura 1974, Yoho et al. 1999).

Roads were first constructed on SCI when the island became a Naval Auxiliary Air Station in 1942, although substantial activity did not occur on land until the 1960s (Sturgeon 1999). We focused our study on the primary roads including Ridge Road (24.3 km) that ran north–south through the center of the island, and Perimeter Road (7.9 km), which encircled the airfield at the northern tip of the island. At the beginning of the study, the surfaces of the roads were 76% paved and 24% gravel. During

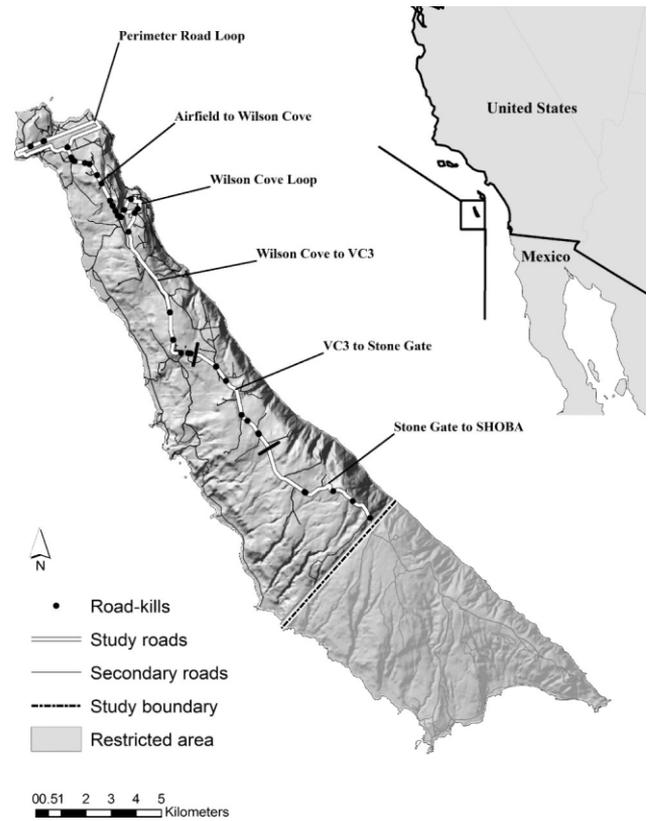


Figure 1. Study area and 6 segments of roads monitored for road-kills of island foxes on San Clemente Island (CA, USA) during July 2006–December 2008.

the middle of the study, some of the paved roads were temporarily converted into gravel, in preparation for future road improvement. The roads remained 43% paved and 57% gravel through the end of this study. Other secondary roads were present on SCI but were infrequently driven and usually not developed and, therefore, were not considered in this study. The maximum speed limit posted on study roads was 56 km/hr (35 mph), and 40 km/hr (25 mph) was posted in urban areas and on some curves. All study roads were 2 lanes, and most had no existing road shoulder. Vegetation typically grew to the edge of the road.

METHODS

Road-Kill and Control-Sites

We located road-kills by driving the study roads at ≤56 km/hr and scanning for any signs of dead foxes, primarily while conducting radiotelemetry, ≥4–7 times each week from July 2006 to December 2008. Because 4 out of 8 road-kills of radiocollared foxes on SCI moved, or were moved, off the road following a collision (Snow 2009), we suspect our observations of uncollared road-killed foxes were underestimates. Also, security personnel were instructed to report road-kills seen during nightly patrols, and other island residents were asked (via instructional pamphlets and meetings) to report road-kills. We recorded the Universal Transverse Mercator (UTM) locations of the kill-site using a handheld Global Positioning System unit.

We divided the entire length of study roads into 6 segments (range = 2.0–7.9 km long; Fig. 1) based on presumed uniformity of traffic volume due to few, if any, intersecting roads within each segment. For each kill-site, we selected 2 control-sites by dividing the entire road into 10-m increments, and extracted the UTM locations for the midpoints of each increment (ArcGIS v9.1). Then we randomly selected 1 midpoint from the entire length of roads, and a second midpoint from the segment of road where the road-kill occurred. We recorded measurements at all sites usually within 21 days from the date of the mortality. For the analysis, we excluded 7 control-sites that were located ≤ 50 m from a kill-site to reduce confounding the characteristics of kill-sites with control-sites.

Characteristics of Roads

We monitored traffic volume and speed with 3 configurable automatic traffic recorders (model 5710; Metrocount, Olney, MD). We placed the recorders at random locations within each segment of road, and rotated the recorders between 2 groups of 3 segments every 14 days from December 2006 to December 2007. We calculated the average volume of traffic per day and average speed for each segment of road. We also recorded whether each site was located on a paved or gravel surface of road.

We used a model of a fox, assembled based on measurements of an adult SCI fox, to determine the distances at which an approaching motorist would first recognize a fox on the road. At each site, we placed the model on the road and approached it from both directions in a pick-up truck, which was comparable to 71% of vehicles identified by our traffic counters. We recorded the distance between the model and the vehicle, when the model first was visible to the observer. We verified that distances were consistent among all observers at the beginning of the study. We also recorded the reason the model fox was not visible from a greater distance (e.g., curve, hill, or too far away). Assuming the greatest danger of road mortality would come from the direction with the shortest measured distance, we used the minimum distance (MinDist) at which the model fox was visible in our analyses. Because of safety restrictions, we were only able to measure the distances during daylight hours.

Characteristics of Roadsides

Because foxes on SCI are small (approx. 2 kg and about 22 cm at the shoulder), we suspected they could be easily obstructed from the view of approaching motorists. We measured visual obstruction readings (VOR) along roadsides at each site to reflect the height of visual obstruction a motorist would encounter. We placed a 1.5-m Robel pole, divided into 30 equal increments, at 0.5 m off the edge of the road (Robel et al. 1970, 1998). We measured the amount of the pole that was visible from 4 cardinal directions from 5 m away from the pole. We obtained VOR measurements on both sides of the road directly at each site, and at distances of 5 m up- and down-road from the site. We averaged these 6 readings to identify the amount of visual obstruction surrounding the road at each site.

We recognized that the depth of the ditches extending away from the edges of the road also could reduce visibility of foxes to a motorist. We used a clinometer to create a level measuring plane; then we measured the change in height from the edge of the road to a measuring stick placed 1 m off the road. For each site we averaged the change in elevation for both sides of the road.

We recorded whether mounds of excess gravel from routine road maintenance, and void of vegetation, were piled along the edges of roads at each site. We assumed that these mounds could serve as “pseudo-barriers” between vehicles and foxes using the edges of roads. Most pseudo-barriers were mounds of gravel (96%) that averaged 29 cm tall \times 76 cm wide. We also considered as pseudo-barriers small vertical rises (e.g., where the road cut into a bank; 4%) that averaged 22 cm tall.

While driving on the roads, we occasionally observed foxes using drainages for cover or travel, eating fruit of prickly pear cacti, and using culverts for cover or underpasses. Therefore, within 100 m in either direction along the road from each site, we recorded the presence of drainages that intersected the road, patches of prickly pear cactus (≥ 1 m in diam) < 5 m from road, and culverts under the road. Our study was approved by Colorado State University’s Institutional Animal Care and Use Committee (protocols 06-098A-01 and 06-098A-02).

Data Analyses

We conducted exploratory analyses of the data, and excluded the least biologically important variables from any correlated pair (i.e., $r \geq 0.70$; Proc Corr; SAS Institute, Cary, NC). We found that pseudo-barriers and the surface of roads were correlated ($r = -0.87$), indicating that pseudo-barriers were typically only present on gravel roads. Therefore, we excluded Surface, because a recent study showed that island foxes did not react differently to approaching vehicles on paved versus gravel roads (Gould 2010).

We used conditional, case-control, logistical regression (Proc Phreg) to ascertain whether the 9 remaining variables were associated with kill-sites versus control-sites. Case-control logistical regression allowed us to consider each set of case and control measurements as a separate stratum (Stokes et al. 2000). Because the characteristics of the roads and roadsides were dynamic through time, we could identify the within-stratum effects by conditioning out variability among measurements taken throughout different times of the study.

We used a balanced incomplete block design to construct a balanced set of 29 biologically meaningful models (Burnham and Anderson 2002). We included the variable Volume in every model to control for differences in traffic volume at each site, to better identify any effects from the other variables. The global model considered was:

$$[p(\text{Volume} + \text{MinDist} + \text{Elev} + \text{VOR} + \text{Barrier} + \text{Speed} + \text{Drainage} + \text{Cactus} + \text{Culvert})]$$

where p is the probability that a site was a kill-site. We used the minimum corrected Akaike Information Criterion

(AIC_c) to rank the models and calculate the model weights (Burnham and Anderson 2002). We also calculated the relative importance of each predictor variable, while controlling for Volume (Burnham and Anderson 2002). Variables with a relative importance weight of <0.30 were considered as having weak support for influencing locations of kill-sites (Burnham and Anderson 2002); therefore, we excluded those variables from further analysis. For the remaining variables, we constructed another model set using all combinations of the variables while controlling for Volume. We model-averaged the parameter estimates for each variable using the “shrinkage” technique and calculated the unconditional variance estimates and associated 95% confidence intervals (Burnham and Anderson 2002, Anderson 2008). We ascertained whether variables had strong influences on a site being a kill-site by examining whether the confidence intervals excluded zero.

Seasonal Analysis

We identified seasonal periods based on annual reproductive activities of foxes on SCI using observations of offspring at den-sites during 2007–2009 (Gould 2010; J. R. Resnik and E. E. Hamblen, Colorado State University, personal communication) and reports of reproduction on some northern California Channel Islands (Moore and Collins 1995, Garcelon et al. 1999, Asa et al. 2007, Clifford et al. 2007). We identified 1 December to 20 February as the Breeding and Gestation season; 21 February to 15 June as the Parturition, Pup nursing, and Weaning season; 16 June to 15 September as the Postnursing season; and 16 September to 30 November as the Prebreeding season. We calculated the expected proportion of road-kills each season by dividing the total number of mortalities observed by the number of days in a season. Then, we compared the expected to the actual proportion of road-kills using a chi-square test (Proc Freq). To ensure that seasons were not confounded with changes in traffic, we examined whether Volume varied among seasons using an analysis of variance (ANOVA; Proc GLM).

RESULTS

We monitored roads for 914 days, and found 72 road-kills. Forty-three of the road-kills occurred on the study roads. We identified the exact location of 39 of the road-kills, and recorded measurements at those kill-sites and at 71 control-sites for analysis.

The Airfield to Wilson Cove segment had the highest volume of traffic (along with the Wilson Cove Loop), the highest average speed of vehicles, the highest proportion of vehicles traveling above the speed limit, and the highest rate of road-kills/km (Table 1; Fig. 1). The Airfield to Wilson Cove and Wilson Cove Loop segments combined contained about 44% of the road-kills, but only 19% of the length of study roads.

Results from the 9-variable model-set (model-set 1; Table 2) indicated that Volume, MinDist, Elev, VOR, and Barrier were the only variables sufficiently important for continued analysis (Fig. 2). Speed of vehicles, Drainage, Cactus, and Culvert showed minimal effects on road mortalities.

No model in our second model-set held a majority of the model-set weight (model set 2; Table 2). However, when we model-averaged the parameter estimates, we found that the 95% confidence interval for Volume excluded zero, thus showing strong evidence of being positively associated with kill-sites (Table 3). The 95% confidence interval for MinDist had only slight overlap on zero, suggesting that the minimal distance at which a fox was first visible to motorists had some influence on the locations of road-kills. On average, the minimum distance at which a model fox was visible to an approaching motorist was 0.86 times shorter at kill-sites than at control-sites (Table 3). Reasons for not seeing the model fox from a farther distance included curves (42%), too far away (32%), and hills (26%).

The 95% confidence intervals for Elev, VOR, and Barrier overlapped zero, but the estimates followed our predictions. On average, ditches along the roadsides were 4.4 times deeper, and VOR measurements were 1.2 times taller at kill-sites than at control-sites. Pseudo-barriers were also 1.8 times less likely to be located at kill-sites. We also found an average of 0.78 road-kills/km on paved roads and 0.26 road-kills/km on gravel roads.

We did not detect an effect of reproductive seasons on frequencies of road-kills ($\chi^2_3 = 1.54$, $P = 0.672$). We also found that traffic volume did not vary by season ($F_{3,9} = 0.96$, $P = 0.453$).

DISCUSSION

Our finding that road-kills were influenced by the volume of traffic was expected, primarily because Snow (2009) found that foxes readily used and crossed all segments of roads

Table 1. Average daily volume of traffic (vehicles/day), speed (km/hr), and annual road-kills/km of island foxes on 6 segments of roads on San Clemente Island (CA, USA) during July 2006–December 2008.

Segment	Vehicles/day	Speed (km/hr)		Annual road-kills/km
		\bar{x}	Prop. \geq max speed lim ^a	
Airfield to Wilson Cove	360	60	0.63	1.39
VC3 to Stone Gate	100	47	0.25	0.61
Wilson Cove Loop	366	42	0.59	0.60
Wilson Cove to VC3	190	54	0.42	0.37
Stone Gate to SHOBA Gate	60	42	0.12	0.32
Perimeter Road	71	56	0.45	0.15

^a Max. speed lim on all segments was 56 km/hr (35 mph), except Wilson Cove Loop was 40 km/hr (25 mph).

Table 2. Model selection results using the minimum corrected Akaike's Information Criterion (AIC_c) showing plausible models ($\Delta AIC_c < 2.0$) for predicting the locations of road-kills for San Clemente Island (CA, USA) foxes during July 2006–December 2008.

Candidate model organized by model set ^a	AIC _c	ΔAIC_c	Model wt	Model likelihood	K ^b	Deviance
Model-set 1 (all variables)						
[p (global)]	68.80	0.00	0.156	1.000	9	62.50
[p (Vol. + MinDist + Elev)]	69.21	0.42	0.127	0.812	3	67.49
[p (Vol. + VOR + Barrier)]	69.33	0.54	0.120	0.765	3	67.61
[p (Vol. + MinDist + Speed)]	70.60	1.81	0.063	0.405	3	68.88
[p (Vol. + MinDist + Elev + VOR)]	70.76	1.96	0.059	0.375	4	68.38
[p (Vol. + MinDist)]	70.80	2.00	0.057	0.367	2	69.69
Model-set 2 (relatively important variables)						
[p (Vol. + MinDist + VOR + Barrier)]	68.96	0.00	0.141	1.000	4	66.58
[p (Vol. + MinDist + Elev)]	69.21	0.26	0.124	0.880	3	67.49
[p (Vol. + VOR + Barrier)]	69.33	0.38	0.117	0.829	3	67.61
[p (Vol. + MinDist + Elev + Barrier)]	69.49	0.53	0.108	0.767	4	67.11
[p (Vol. + MinDist + Elev + VOR + Barrier)]	69.80	0.85	0.092	0.655	5	66.73
[p (Vol. + MinDist + Barrier)]	70.39	1.43	0.069	0.488	3	68.67
[p (Vol. + MinDist + Elev + VOR)]	70.76	1.80	0.057	0.407	4	68.38
[p (Vol. + MinDist)]	70.80	1.84	0.056	0.398	2	69.69

^a p = probability of kill-site. Conditional logistic regression variables: Vol. = average daily vol. of traffic, MinDist = min. distance a model fox was visible on the road from an approaching vehicle, Elev = elevation change 1 m from roadside, VOR = visual obstruction readings 0.5 m from roadside, Barrier = presence of barrier along road edge, Speed = average traffic speed. Other variables tested but not shown in model-set 1 include: Drainage = presence of drainage intersecting road, Cactus = presence of cactus patch ≤ 5 m from the roadside, and Culvert = presence of culvert under road.

^b No. of estimable parameters.

on SCI, regardless of the volume of traffic. The volume of traffic on SCI (60–366 vehicles/day) was relatively low compared to studies conducted on other species of foxes, where reported effects of traffic have varied. For instance, Grilo et al. (2009) found that red foxes avoided roads with up to 2,161 vehicles/day, and road-kills were highest on roads with intermediate and lower volumes of traffic. Additionally, urban red foxes in Bristol, United Kingdom suffered high rates of road mortality when crossing major roads (e.g., 6-lane highways), and some foxes altered their behaviors to avoid crossing those roads (Baker et al. 2007). In contrast, San Joaquin kit foxes (*V. macrotis mutica*) in California frequently crossed roads with 800–1,500 vehicles/day, but the occurrence of road-kills for the population was nearly undetectable (Cypher et al. 2009). Combined with our findings, these studies suggest that multiple features of the roads and different behaviors by foxes influence the probabilities of road-kills.

Two explanations exist for why the relatively low volume of traffic on SCI strongly influenced road-kills. The seg-

ments of roads with the highest volumes of traffic may not have been disturbing enough to elicit avoidance behaviors by foxes. Another explanation could be related to island foxes evolving with reduced avoidance behaviors. Avoidance behaviors can be lost through evolutionary isolation from predators (see Griffin et al. 2000), as experienced by island foxes. Island foxes generally were considered to lack fear of humans (Blake 1887, Grinnell et al. 1937, Laughrin 1977, Moore and Collins 1995), were considered naïve of novel threats (Roemer et al. 2001, Swarts et al. 2009), and have shown reduced avoidance of vehicles (Gould 2010). Contrary to foxes on SCI, San Joaquin kit foxes have been exposed to high intra-guild predation (Ralls and White 1995), and did not suffer from frequent road-kills (Cypher et al. 2009). The susceptibility of foxes to collisions with vehicles on SCI may become more problematic in upcoming years, because naval training activities are expected to increase (M. A. Booker, United States Navy Wildlife Biologist, personal communication).

The association between road-kills and reduced visibility of the upcoming road for motorists was likely related to less reaction time for motorists to avoid foxes. We found that curves in the road were the most common factor that reduced visibility. Curved sections of roads in Germany (Hartwig 1993), Australia (Klöcker et al. 2006), and Portugal (Grilo et al. 2009) also were found to have higher incidence of road-kills. Motorists also might have been less likely to take evasive maneuvers on curves, because of limited visibility of approaching traffic, or aversion to risking a rollover accident.

Even though VOR, Elev, and Barrier lacked a strong influence on the probability of road-kills, they may provide useful information on associations with road-kills. The average VOR of 22 cm at kill-sites approximated the average shoulder height of foxes on SCI, suggesting

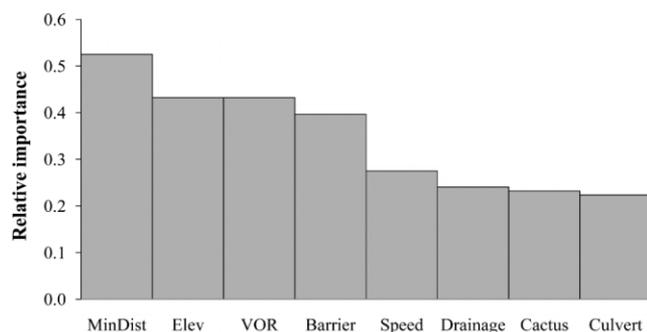


Figure 2. Relative importance of variables for predicting locations of road-kills of San Clemente Island (CA, USA) foxes during July 2006–December 2008.

Table 3. Influences of 9 variables on locations of road-kills for San Clemente Island (CA, USA) foxes during July 2006–December 2008.

Variable ^a	Kill-sites		Control-sites		Model-averaged parameter estimate			
	\bar{x}	SE	\bar{x}	SE	Parameter estimate ^b	Unconditional SE	95% CI	
							Lower	Upper
Vol. (vehicles/day)	222.42	20.80	171.42	13.94	0.008	0.004	<0.001	0.016
MinDist (m)	132.28	10.47	152.97	8.02	-0.005	0.005	-0.015	0.004
Elev change (cm)	-10.55	1.94	-2.38	2.82	-0.015	0.028	-0.071	0.040
VOR (cm)	22.74	3.21	18.90	1.88	0.014	0.021	-0.027	0.055
Barrier present (%)	0.18	0.06	0.32	0.06	-0.953	1.100	-3.109	1.203
Speed (km/hr)	32.66	0.70	31.98	0.49	NA			
Drainage present (%)	0.28	0.07	0.39	0.06	NA			
Cactus present (%)	0.49	0.08	0.46	0.06	NA			
Culvert present (%)	0.41	0.08	0.35	0.06	NA			

^a Vol. = average daily vol. of traffic, MinDist = min. distance a model fox was visible on the road from an approaching vehicle (m), Elev change = elevation change 1 m from the roadside (cm), VOR = visual obstruction readings 0.5 m from the roadside (cm), Barrier(s) present = proportion of sites with a gravel mound or vertical rise on the roadside, Speed = average speed of traffic (km/hr), Drainage present = proportion of sites with a drainage intersecting road, Cactus Present = proportion of sites with patch of prickly pear cactus ≤ 5 m from the roadside, Culvert present = Proportion of sites with culvert under road.

^b NA = not applicable because variable showed little evidence of influencing locations of road-kills.

the body of a fox was almost completely obstructed. Elevation changes leading away from the roadsides were also steeper at kill-sites, and likely limited the visibility of foxes to motorists. Other studies have also found that wildlife–vehicle collisions increased with density of vegetation along roads and changes in slope (Taylor and Goldingay 2004, Klöcker et al. 2006).

We surmised that mounds of gravel were partially effective barriers for reducing road-kills, because they likely provided a buffer between the road and surrounding habitat. Foxes that utilized the roadside vegetation would have been located on the side of the mound away from the road and, thus, farther away from passing vehicles. Additionally, foxes standing on the mounds may have been more visible to approaching motorists.

Given that other wildlife have experienced increased road-kills along roads with increased speeds (e.g., Philcox et al. 1999, Seiler 2005, Baker et al. 2007), we were surprised to find that speeds on SCI showed little evidence of influencing the occurrence of road-kills in our analyses. This could be related to the relatively low and uniform speed limits on SCI. Importantly, we were unable to determine the speed of the vehicles that actually struck foxes; thus, speeding vehicles could have been responsible for a greater proportion of road-kills.

Drainages, cacti, and culverts near or under roads apparently were not attractive enough to foxes to increase road-kills. Also, our suspected effects of reproductive seasons either did not exist or were not strong enough to influence frequencies of road-kills. In contrast, Grilo et al. (2009) reported that road-kills were more frequent when red foxes were provisioning young. Finally, we did not discern whether road-kills were more prevalent during the day or night because the time of a collision was often unknown; however, we observed that road-kills occurred during both the day and night. Approximately 72% of all road crossings by foxes occurred at night while the foxes were most active (N. P. Snow, Michigan State University, unpublished manuscript). Also, about 10% of the volume of traffic occurred at night

(Snow 2009). The distribution of road-kills of kangaroos in New South Wales, Australia, showed that mortalities were dependent on the intensity of nightly traffic (Klöcker et al. 2006).

Densities of island foxes along the primary roads of SCI are largely unknown, and Roemer et al. (2004) suggested that there are no clear relationships between densities and habitat. Density has not always been a reliable predictor of road-kill locations in other studies (e.g., Klöcker et al. 2006, Danks and Porter 2010); therefore, mitigation efforts likely should focus on the primary roads throughout the entire island, regardless of possible fluctuations in densities.

MANAGEMENT IMPLICATIONS

We acknowledge that reducing the volume of traffic on SCI likely would interfere with naval training activities and, thus, may not be a feasible method for minimizing road-kills. Therefore, focusing other strategies on segments of roads with the highest volume of traffic and with limited visibility may be better options. On segments of roads with reduced visibility, such as curves and hills, we recommend placing reduced speed limit signs and speed bumps to slow traffic so that motorists have more time to avoid foxes (see Clevenger et al. 2001a, Sullivan et al. 2004, McShea et al. 2008). Although static warning signs have already been placed on some roads to remind motorists to be vigilant for foxes, the signs have not been located in the most crucial areas. Therefore, relocating signs to high-risk areas may maximize their effectiveness. Dynamic warning signs may be more effective, especially where the risks of collisions are highest (see Sullivan et al. 2004, Tay and de Barros 2008). Additionally, upon arrival to SCI, we recommend that all motorists be given oral and written information on the importance of being vigilant for foxes on roads, especially where visibility is limited.

Fencing along roads and underpasses has reduced wildlife–vehicle collisions for a number of species (Clevenger et al. 2001a,b); thus, these methods should be considered for

island foxes. However, fencing on islands can have unwanted impacts, such as habitat fragmentation for an already small population. Therefore, preliminary trials should be conducted to ensure underpasses provide effective movement corridors for the population.

Finally, intermittent mowing of roadsides was implemented in 2007, but has not occurred frequently enough to keep the vegetation consistently short. Height of vegetation likely should be maintained at ≤ 12 cm (i.e., lower than the chest ht of an island fox), to increase visibility of foxes along roadsides. New road construction likely should include wider shoulders and ditches that gradually slope away from roads to help increase the visibility of foxes. Constructing pseudo-barriers along the edges of high-risk roads may also reduce the frequency of mortalities.

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