THESIS

REPRODUCTION, DENNING ECOLOGY, AND BEHAVIOR OF THE SAN CLEMENTE ISLAND FOX (*UROCYON LITTORALIS CLEMENTE*)

Submitted by

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In partial fulfillment of the requirements

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY NICHOLAS P. GOULD ENTITLED REPRODUCTION, DENNING ECOLOGY, AND BEHAVIOR OF THE SAN CLEMENTE ISLAND FOX (*UROCYON LITTORALIS CLEMENTE*) BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

REPRODUCTION, DENNING ECOLOGY, AND BEHAVIOR OF THE SAN CLEMENTE ISLAND FOX (*UROCYON LITTORALIS CLEMENTE*)

Island foxes (*Urocyon littoralis*) have experienced severe reductions in populations on 4 of 6 California Channel Islands. While numbers of San Clemente Island (SCLI) foxes (*Urocyon littoralis clemente*) have remained relatively stable, additional data on reproductive success in urban and rural areas is necessary so that we can better manage the population if it sustains declines. We also need to know locations and characteristics of den sites in order to minimize possible impacts of military training activities on foxes.

I found that 5 of 6 urban females and 5 of 11 rural females produced at least 19 kits on the northern 2/3 of SCLI during 2008. Although foxes in urban areas may be reproducing more successfully than foxes in rural areas, urban foxes often selected den sites near roads which may expose them to increased mortalities. I located 23 den sites, on an average of 17–18° slopes with 40% having westerly-facing aspects. I recommend redirecting ground-disturbing military training maneuvers away from these areas during February through June which may minimize impacts of training activities on foxes.

Collisions with vehicles have created concern for the welfare of the endemic San Clemente Island fox. The small population on the northern 2/3 of SCLI has sustained an estimated annual mortality rate of 3–8% due to collisions with vehicles from 2000 through 2007. To identify potential management solutions for minimizing these mortalities, I examined behavioral responses of SCLI foxes to approaching vehicles on roads. I found that during 67% of 541 observations, foxes remained within 5 m of an approaching vehicle, and during 26% of 258 observations, foxes remained on the road as the vehicle passed suggesting many foxes were naïve toward vehicles. During 8% of 258 observations, foxes remained in the center of the road; thus, we were required to stop our vehicle to avoid hitting the fox.

I examined 5 main behaviors (running, walking, sitting, standing, and foraging) of foxes as a vehicle approached to ascertain if behaviors of foxes changed with distance. Foxes showed no trend towards avoidance behaviors (running or walking away) at closer distances (0, 5, 25 m) to the approaching vehicle. During 49 of 150 observations where foxes exhibited directional movements in response to our vehicle at 0, 5, 25, 50 and100 m, foxes approached our on-coming vehicle, further suggesting SCLI foxes exhibit naïve behaviors toward vehicles. I found no significant effects of road surface, biological season, day versus night, and foxes in urban versus rural areas on behaviors.

I recommend educating drivers on SCLI about the general lack of vehicle-avoidance behaviors of foxes, and recommend reducing the speed limit to minimize impacts of vehicles on island foxes.

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SAN CLEMENTE ISLAND FOX KIT (*UROCYON LITTORALIS CLEMENTE*)

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I owe a special thanks to Katie Andres and Elise Hinger who went above and beyond to ensure this project was a success.

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Lastly, I could not have done any of this without the love and support of my family, both here in Colorado and back east in Boston. You never showed anything but support, patience, and enthusiastic encouragement. I love all of you for that.

DEDICATION

This research is dedicated to my beautiful wife, Kelly Ann Gould, without whom I would not be the man I am today. Her presence alone makes me a better man and I couldn't imagine a day in this life without her. I also dedicate this work to the newest member of our family, Samantha Gray Gould, whose time and impact on this world has only just begun. I also hope that were my father alive, he would be proud.

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ABSTRACT Island foxes (*Urocyon littoralis*) have experienced severe reductions in populations on 4 of 6 California Channel Islands. Whereas numbers of foxes on San Clemente Island (SCLI) have remained relatively stable, additional data on reproductive success in urban and rural areas is necessary so that we can better manage the population if it sustains declines. We also need to know locations and characteristics of den sites in order to minimize possible impacts of military training activities on foxes.

I found that 5 of 6 urban females and 5 of 11 rural females produced at least 19 kits on the northern 2/3 of SCLI during 2008. Although foxes in urban areas may be reproducing more successfully than foxes in rural areas, urban foxes often selected den sites near roads which may expose them to increased mortalities. I located 23 den sites on an average of 17–18^{o} slopes with 40% having westerly-facing aspects. I recommend redirecting ground-disturbing military training maneuvers away from these areas from February through June which may minimize impacts of training activities on foxes.

1.1 INTRODUCTION

The island fox (*Urocyon littoralis*) is a diminutive descendant of the gray fox (*U. cinereoargenteus*), with an endemic subspecies on each of 6 of the 8 California Channel Islands. Genetic analyses and archeological findings suggest that island foxes were introduced from the northern Channel Islands to the southern Channel Islands between 2,200 and 5,200 years ago by Native Americans (Collins 1991a; Collins 1991b). Rapid population declines on 4 islands (Santa Rosa, Santa Catalina, Santa Cruz, and San Miguel) resulted in these 4 subspecies being listed as federally endangered (United States Fish and Wildlife Service 2004).

Reproduction and topographic and vegetative characteristics associated with den sites have not been well documented for island foxes. Island foxes breed once a year and parturition has been reported to occur in early April, but kits have been born as early as February on San Clemente Island (SCLI; Schmidt et al. 2001). During 2007 on SCLI, only 4 of 20 females were found associated with dens and kits (Snow et al. 2007), and Garcia and Associates (2007) found that of 112 adult females captured on 12 grids, only 11 (10%) were lactating, and only 1 of 203 foxes that were captured was a juvenile. Although Garcia and Associates collected these data late in the breeding season, these indicators of low reproduction might have been due to an extended period of drought (Snow et al. 2007).

Typical dens used by island foxes include rock piles, dense brush, and naturally occurring cavities in the ground or under tree trunks (Roemer et al. 2004). Snow et al. (2007) found that dens occurred primarily in large rock piles (either natural or man-made) and in lemonade berry bushes (*Rhus integrifolia*). San Clemente Island foxes may select den sites that are in close proximity to various human disturbances, and thus are more likely to encounter supplemental food resources (Snow et al. 2007, J. R. Resnik, *personal communication*).

Snow (1973) and Kintigh and Andersen (2004) found that den sites of swift fox (*Vulpes velox*) were located in areas with higher road densities than in random areas, but dens in the 2 locations did not differ significantly in distance to roads. Knowles (1991) suggested that roads and trails may be used as travel routes by swift fox because roads have been identified as common travel and dispersal corridors for other prairie species including prairie dogs (*Cynomys ludovicianus*; Knowles 1985). Slough (1999) suggested that den sites for Canada lynx (*Lynx canadensis*) are an important habitat feature which, along with foraging habitat, cover, and travel corridors, may enhance recruitment by lynx.

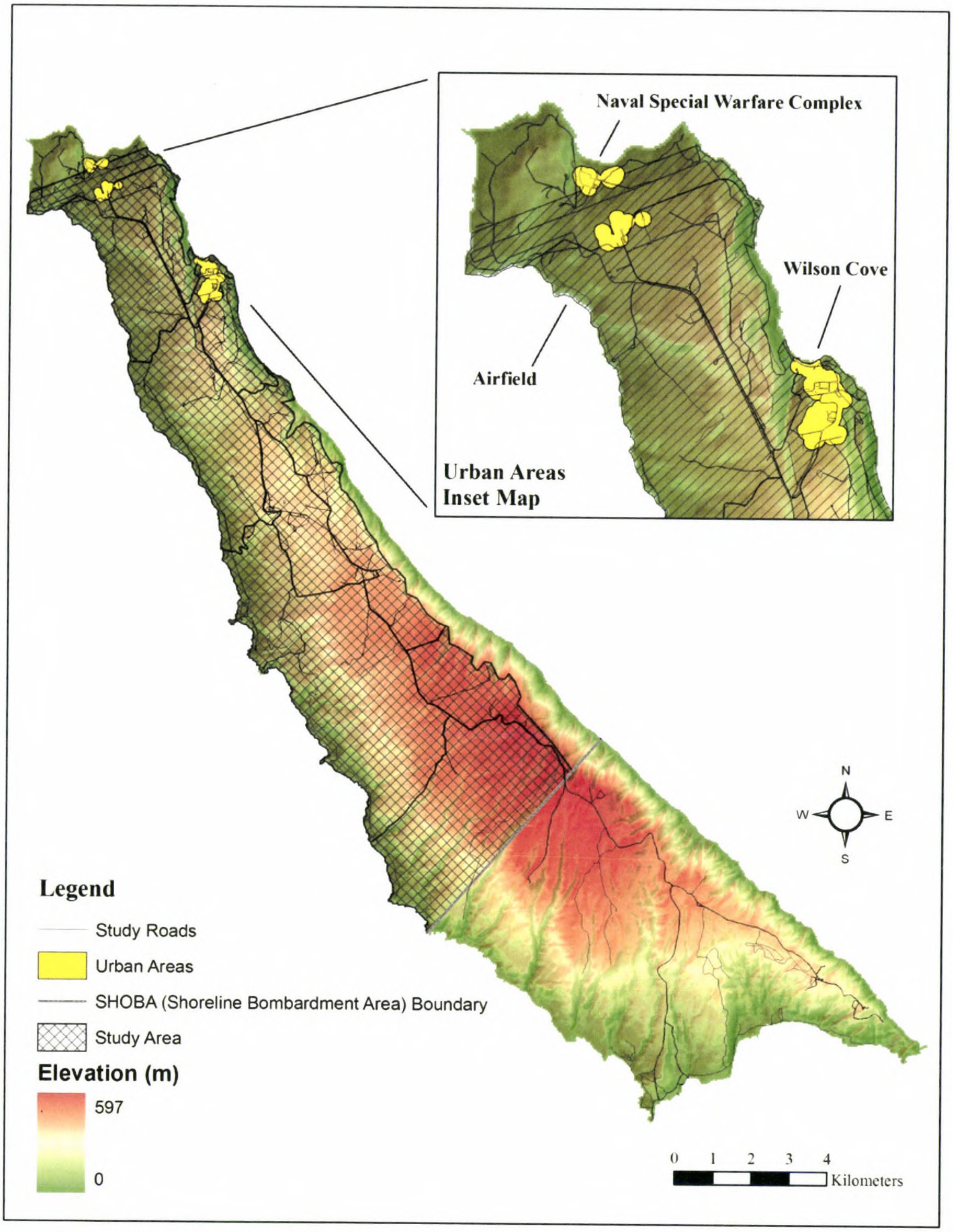
With little information currently known, and increasing expansion in military activities on SCLI, ascertaining where dens are located should be instrumental in assisting the Navy to manage disturbance to these areas. In addition, no studies have investigated differences between the denning ecology of urban and rural island foxes. My objectives were to: 1) ascertain reproduction and den site locations and characteristics for a random sample of foxes; and 2) compare reproduction and characteristics of den sites of foxes in urban and rural areas. I hypothesized that: 1) a greater proportion of females in urban compared to rural areas would reproduce; 2) urban foxes will have larger litter sizes; 3) den sites will be more frequently located in rock outcrops; and 4) slope, aspect, and orientation of den sites will not differ between the 2 groups of foxes.

1.2 METHODS

1.2.1 Study area

San Clemente Island is owned and operated by the United States Navy as a naval base for training activities. San Clemente Island is the southern most of the California Channel Islands, located approximately 109 km west of San Diego, California and is 146 km^2 in area (Olmstead 1958). My study was conducted on the northern 2/3 of SCLI (Figure 1.1).

Figure 1.1. Study area on the northern 2/3 of San Clemente Island, California, USA.



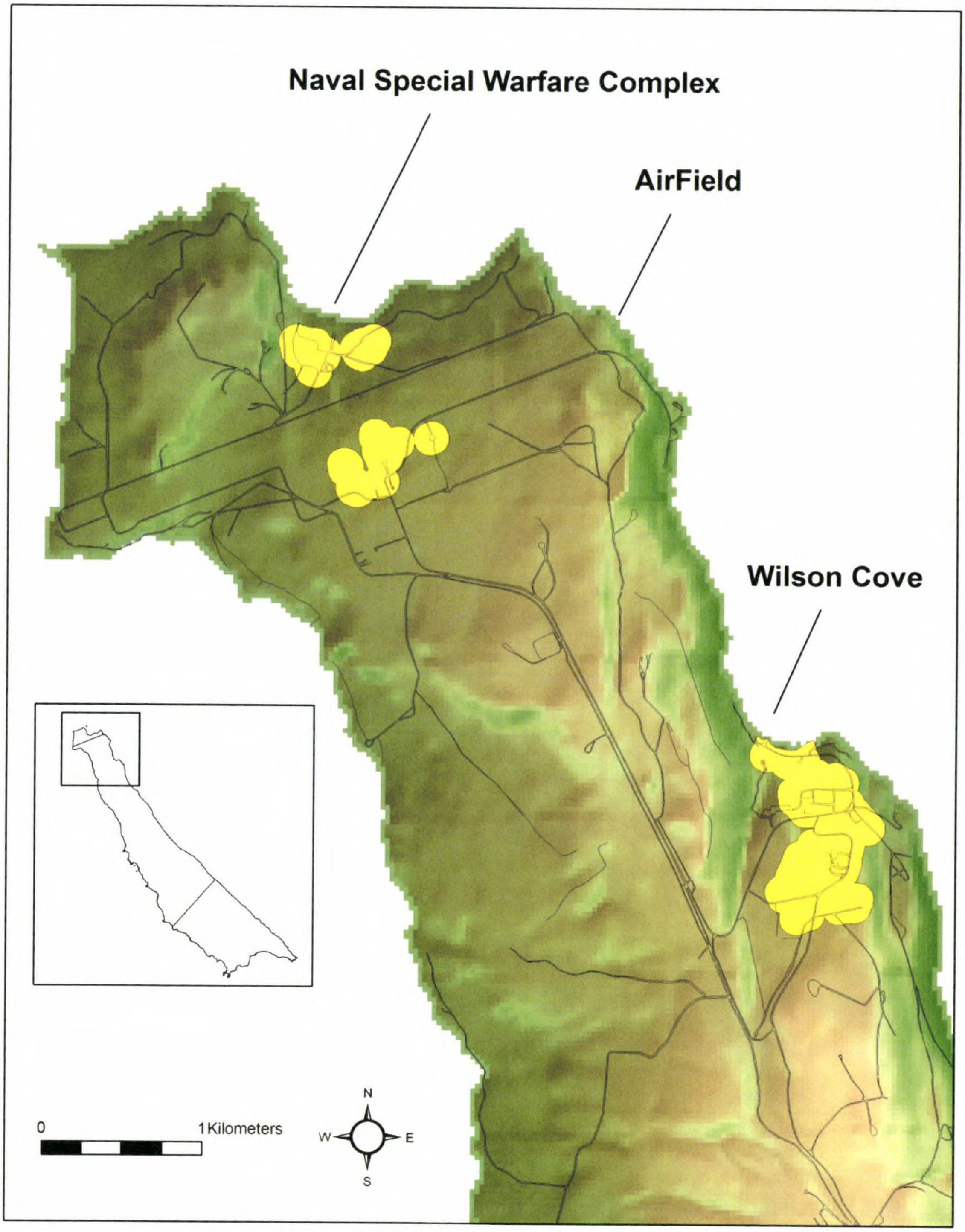
The vegetation on the island was comprised primarily of maritime desert scrub (54.4%), grassland (32.8%) (Thorne 1976, Sward and Cohen 1980), and "disturbed" (7.4%) with Navy facilities and roads (Schmidt et al. 2004). Foxes occur in all habitats of the island (Roemer et al. 2004). The average temperature was 17°C and annual precipitation averaged 13 cm with 95% falling during the wet season, November thru April (Kimura 1974, Yoho et al. 1999).

1.2.2 Defining urban and rural areas

I used Geographic Information Systems (GIS; ArcGIS; v9.2, Environmental Systems Research Institute, Inc., Redlands, CA) and the Reversed Randomized Quadrant-Recursive Raster (RRQRR) tool (Theobald et al. 2007) to produce random but spatially-balanced trapping locations throughout the study area. Additionally, I delineated urban area polygons based upon human habitation, human-associated food sources (e.g., a galley), and overall frequency of daily human use. There are approximately 400 people that have temporary living quarters on SCLI. These living quarters are limited to the 3 "urban" areas on SCLI that have housing: Wilson Cove (the main town area with central galley), the Airfield (where all personnel arrive to, and depart from, the island), and the Naval Special Warfare Complex (NSWC; classified Navy personnel training facilities).

The urban areas were divided into 3 polygons including the Wilson Cove (607,695 m^2), Airfield (230,194 m^2), and NSWC (182,370 m^2) areas (Figure 1.2). The polygons were created in GIS by placing a 100 m buffer around each building within these areas, and then "dissolving" the individual buffers into 1 larger connected polygon. I targeted these 3 areas based upon visual sightings of foxes frequently inhabiting the areas. All areas within the study area outside of these polygons were considered rural. Average Daily Traffic volume (ADT) was 244 vehicles for Wilson Cove, 132 vehicles for the Airfield, and 48 vehicles for NSWC. The main section of road connecting the Wilson Cove area to the Airfield area had an ADT of 303 vehicles.

Figure 1.2. Three urban areas on the northern 2/3 of San Clemente Island, California, USA.



1.2.3 Capturing random samples of foxes

I captured foxes using 23 x 23 x 66-cm cage traps (Tomahawk Live Trap Co., Tomahawk, WI) with 1.27 x 2.54-cm mesh, baited with ~ 57 g of dry cat food and a Berryberry scent (On Target A.D.C., Cortland, IL). I attached plexiglass to the inside of the front doors and attached a 46-cm-long polyethylene tube chew-bar along an inside wall of all traps (Coonan et. al. 2005) in an attempt to reduce potential trap-related injuries. The tops and sides of traps were covered with burlap and vegetation to protect foxes from exposure to sunlight. To avoid daytime heat and undue stress on foxes, traps were checked starting at sunrise, remained closed during the afternoon, and were reopened in the evening. Foxes were identified as male or female; weighed; aged as juveniles, yearlings, or adults by general size and tooth wear (Wood 1958, Collins 1993); and checked for reproductive status of females (size and pigmentation of teats) and general physical condition. Foxes were fitted with approximately 39.9 gram radio telemetry collars equipped with mortality sensors (Advanced Telemetry Systems, Isanti, MN), and then released at the point of capture. I inserted a pit tag (Biomark, Inc., Boise, ID) in each captured foxes that did not already have one.

I initially captured and radio-collared 19 random subadult (<1 year old) and adult (>1 year old) males and 12 subadult and adult females on the northwestern 2/3 of SCLI from January to mid-February 2008. These 31 foxes served as a random sample from which I determined reproduction and location of den sites to represent the fox population (n = ~348 animals; Andelt et al. 2009) on the northwestern 2/3 of SCLI. The balance of the urban sample was collected by using RRQRR to produce random trap locations within the urban area polygons. I apportioned the number of traps set in each urban area based upon the relative size of the 3 urban areas. This resulted in 12 subadult and adult urban males and 8 subadult and adult urban female foxes (4 foxes from the initial random sample of 31 foxes, and 16 foxes that were intentionally trapped in the 3 urban areas).

1.2.4 Locating den sites

All 18 females were located 4 times per week from 15 February through 30 June (the end of the island fox breeding season) using a vehicle-mounted antenna, and an additional 1–2 times per week on foot using a Yagi antenna to determine if a den site was used and where it was located. I retrieved a damaged collar for 1 female on 9 April 2008; thus, I excluded her from my sample, but included 17 of 18 females (6 urban, 11 rural) in my analyses of reproduction. I considered foxes to have reproduced when I observed a female at a den site with kits, or a female traveling inside her home-range with kits. I also excluded all male foxes from my analysis of reproduction because they were found opportunistically at dens, and thus equal den-searching effort was not placed on male foxes. However, all dens associated with radio-collared male foxes were included in my analyses of den site characteristics. The majority of dens where males were observed were located opportunistically due to 1) telemetry locations were close to the road (i.e., visible from the vehicle), 2) the fox crossed the road with kits into a nearby den site during a telemetry shift, or 3) by association with a denning female fox (i.e., a mate).

I "circled" female foxes at 20–50 m, depending on visibility, and viewed with binoculars to ascertain 1) if the female fox was with kits, 2) if the observed female had visibly darkened or swollen mammary glands, indicating lactation, and 3) to determine if the fox was exhibiting denning behavior (e.g., underground or in a rock outcrop versus foraging or "bedded down"). Den area characteristics were recorded on a data sheet along with a "den map" detailing the area and at least one telemetry bearing on the "den" site from a vantage point. This provided confirmation of the exact location of the den as well as an estimate of litter size. Litter size was based on the largest number of kits observed with the adult.

A den site was confirmed if kits were observed at the same site on 2 or more occasions. Den sites were not visited again until telemetry data indicated the den had been abandoned. Dens were generally thought to be abandoned by mid-summer (Moore and Collins 1995). I measured characteristics for 23 dens (15 primary dens and 8 secondary dens or rendezvous sites) between August and October due to time constraints and uncertainty that a female and her kits had abandoned the immediate area. Secondary dens were defined as rendezvous sites, or den sites, that were primarily used after the female and kits abandoned the primary den site. I obtained measurements of 31 characteristics on each den site.

I used the term canyon only for canyons on SCLI that were predefined as such prior to the start of my study. All areas scoured by heavy rainfall were considered drainages or washes. A supplemental food source was defined as a place where foxes were provisioned with food scraps directly (by being hand fed or with the placement of a "food bowl" near the door of a galley), or indirectly (foxes eating out of large refuse containers or garbage cans). Each of the 3 urban areas contained at least 1 of these supplemental food sources.

1.2.5 Data analysis

After examining the data for normality graphically, I compared reproduction between the rural and urban samples of radio-collared female foxes using Fisher's Exact Test (PROC FREQ, SAS Institute, Cary, NC) to adjust for small sample sizes. I used a square root transformation on number of kits observed and number of den entrances observed (i.e., count data) in order to obtain homogeneity of variances. I used a cosine and sine transformation on aspect and orientation of den openings to avoid obtaining an average value for these 2 attributes that was not represented by the data (e.g., a south-facing aspect if most dens were oriented east and west). I used a log transformation for the majority of the remaining attributes to obtain homogeneity of variances. Slope and the presence of bedding, fecal matter, and food scraps inside the den entrance were not transformed. I compared the means, their respective 95% C.I.'s, and the associated p-values for each attribute between the rural and urban samples of foxes (PROC MIXED, SAS Institute, Cary, NC). I used a random effect to account for lack of independence for the 8 foxes that had primary and secondary dens and modeled a group effect (i.e., urban or rural) for all 31 attributes. Each variable was modeled individually.

After the analyses were complete, I exponentiated the difference between the means for each attribute to obtain a ratio of rural to urban (e.g., distance to a paved road for foxes in rural areas were X times greater than for foxes in urban areas) in order to effectively present the results (P. L. Chapman, *personal communication*). I excluded from my analyses 2 den sites because the fox was observed only once with kits at each site. I also excluded 1 den site because the female fox was captured outside of the breeding season, on 26 June 2008, and thus, den searching efforts had ceased for all other remaining foxes where no den had been found. For ease of interpretation and when appropriate, I present actual means although I primarily conducted analyses on transformed data.

1.3 RESULTS

1.3.1 Reproduction

I recorded 331 hand-held telemetry locations, in addition to 4 weekly telemetry locations per fox from vehicles during 1 season of island fox breeding (1 March through 30 June). I observed 24 foxes (14 urban, 10 rural) associated with litters, and located 23 den sites (Figure 1.3). Within the urban sample, 5 of 6 (83.3%) female foxes that were captured in January or February 2008 were associated with dens, and all were observed with kits at a den site. Within the rural sample, 3 of 11 female foxes were associated with kits at den sites; however, 5 of the 11 (45.5%) were observed with kits, either at a den site or away from a den. I found weak evidence of a trend that a greater proportion of urban foxes (5 of 6) reproduced compared to rural foxes (5 of 11; $P = 0.152$, 1-tailed test; Table 1.1). Contrary to my hypothesis, I also found weak supporting evidence that rural foxes had larger litters ($\bar{x} = 2.3$ kits; range = 1–4) than urban foxes ($\bar{x} = 1.9$ kits; range = 1–4) when I included male and female foxes ($n = 17$) that were associated with successful litters ($F_{1,15} = 2.24$, $P = 0.155$, 1-tailed test). Among only female foxes ($n = 10$), I found similar results ($F_{1,8} = 2.67$, $P = 0.141$, 1-tailed test).

Figure 1.3. Locations of 23 dens (including dens of 8 island foxes that relocated to a secondary den) from the urban and rural samples of foxes on the northern 2/3 of San Clemente Island, California, USA, during 2008.

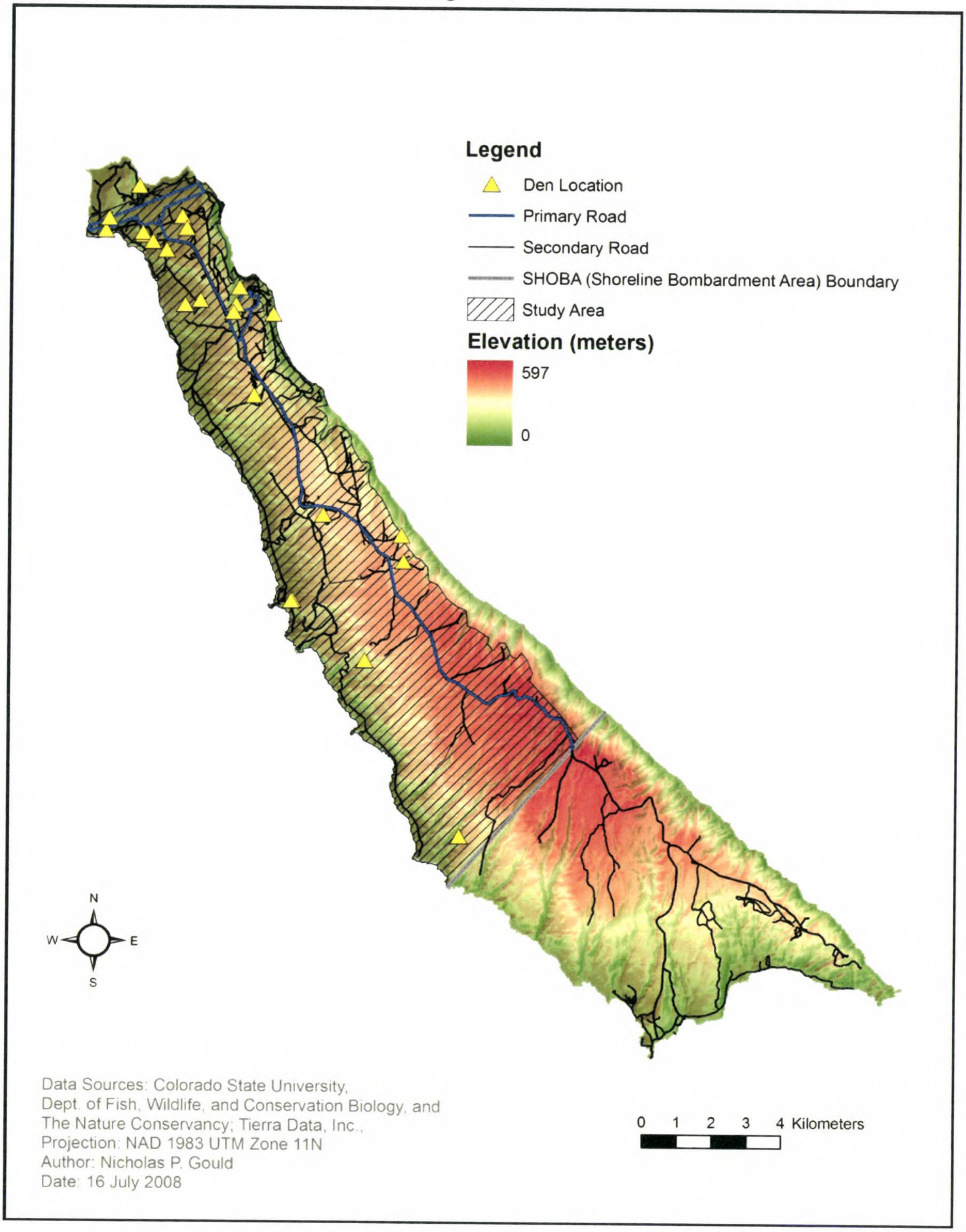


Table 1.1. Reproductive success by island foxes on San Clemente Island, California, USA, 15 February through 30 June 2008.

	No. females	No. females reproduced	No. males[a]	No. males reproduced	Total
Random[b]	12	6 (50%)	19	6 (32%)	12 (39%)
Urban	10	7 (70%)	16	7 (44%)	14 (54%)
Rural	11	5 (46%)	17	5 (29%)	10 (36%)
Total	21	12 (57%)	33	12 (36%)	24 (44%)

[a]Males were found as part of a male/female pair, or opportunistically during telemetry shifts.

[b]11 female foxes and 17 male foxes were also in the rural sample, and 1 female and 2 males were also in the urban sample; 2 foxes reproduced of 4 foxes captured on 26 June 2008.

1.3.2 Den site characteristics

Within the random sample of foxes where dens were discovered, 9/23 (39%) were distributed throughout the study area, with 5/13 (39%) of the dens occurring between Wilson Cove and the Airfield. Pooling data for foxes in the urban and rural samples, 8/23 (35%) dens were located in canyons or drainages, 6/23 (26%) were located in or near rock outcrops or rock piles, 5/23 (22%) were located solely in underground holes, and 4/23 (17%) were in or near vegetation (e.g., lemonade berry bush thickets). I found little to no difference in numbers of den entrances between foxes in urban (range = 1–3) versus rural (range = 1–2) areas ($F_{1,12} = 1.85$, $P = 0.199$; Table 1.2).

Table 1.2. Characteristics for 23 island fox dens on the northern 2/3 San Clemente Island, California, USA, during 2008.[a]

	Random		Urban		Rural	
Measurement	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Den entrances (*n*)	1.3	0.2	1.5	0.3	1.1	0.1
Aspect (°)[b]	220	26.4	183	33	217	27.5
Slope (°)	16	2.6	18	1.6	17	3.6
Den orientation (°)[c]	143	27	184	31	113.5	28.9
Distance (m) from nearest:						
Paved road	786	220	199	51	857	261
Two-track	320	143	120	21	365	169
Canyon	874	311	2,906	531	458	161
Urban area	6,118	1,425	580	132	7,228	1,469
Drainage/wash	117	27	255	60	124	30
Culvert	705	313	314	72	767	375
Supplemental food	6,465	1,433	768	117	7,564	1,486
Den opening #1 (cm):						
Height	21.0	3.1	30.1	5.3	19.7	3.6
Width	33.0	2.3	31.5	3.6	32.9	2.8
Depth	97.0	5.7	123.5	26.9	97.3	6.4

Den opening #2 (cm):						
Height	31.0	12.6	25.3	8.5	19.5	6.8
Width	34.6	14.4	33.3	9.3	20.5	4.3
Depth	69.0	16.3	86.7	13.9	53.5	8.6
Den opening #3 (cm):						
Height	23.0		19.8	2.9		
Width	37.0		30.0	5.0		
Depth	91.5		81.2	10.6		
Vegetation density VOR (dm):						
North	9.6	1.3	9.6	1.0	9.4	1.7
South	9.7	1.2	8.4	1.1	10.5	1.2
East	11.1	1.0	9.6	0.9	12.1	1.2
West	8.7	1.2	9.3	0.8	8.7	1.6
Den interior (cm):						
Length	104	14.2	98	14.4	103	15.8
Width	54	18.7	31	14.4	53	21.2
Height	34	10.3	27	1.5	35	11.6
Proportion						

dens with:						
Bedding	0.8	0.1	0.3	0.2	0.9	0.1
Fecal matter	0.3	0.1	0.3	0.2	0.3	0.2
Food scraps	0.8	0.1	0.5	0.2	0.8	0.1

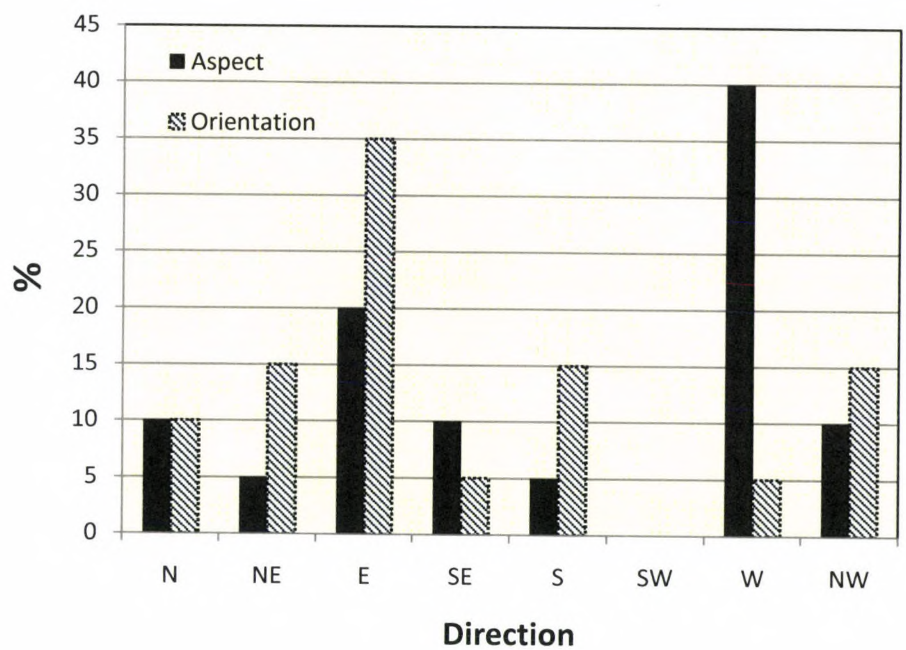
[a]Standard errors were not cosine or sine transformed.

[b]Mean aspect at den sites was 0.30 (cosine transformation) and 0.35 (sine tranformation), or ~319^0 (i.e., west/northwest-facing) for the urban sample and 0.29 (cosine transformation) and 0.12 (sine transformation), or ~254^0 (i.e., west/southwest-facing) for the rural sample of foxes.

[c]The mean orientation of den sites were -0.06 (cosine transformation) and 0.03 (sine transformation), ~28^0 (i.e., north/northeast-facing) for the urban group, and -0.01 (cosine transformation) and 0.09 (sine transformation), ~73^0 (i.e., east/northeast-facing) for the rural group.

I found no differences in aspect ($F_{1,12} = 0.00$, $P = 0.980$ cosine transformation; $F_{1,12} = 0.76$, $P = 0.400$ sine transformation), slope ($F_{1,12} = 0.08$, $P = 0.786$) or orientation of openings of den entrances ($F_{1,12} = 0.03$, $P = 0.873$ cosine transformation; $F_{1,12} = 0.02$, $P = 0.889$ sine transformation) between the 2 groups. When pooled together, foxes in both urban and rural areas selected for west-facing aspects (40%) and an east-facing direction for den entrance openings (35%). No foxes selected den sites with southwest-facing aspects or den entrances with a southwest-facing orientation (Figure 1.4).

Figure 1.4. Percentage of dens with aspect and den entrance orientation in 8 directions on the northern 2/3 of San Clemente Island, California, USA, during 2008.



The average distance of den sites to the nearest paved road was 5.6 times greater for foxes in rural areas than for foxes in urban areas ($F_{1,12} = 7.50$, $P = 0.018$; Table 1.2). The distance to the nearest urban area was 12.9 times greater ($F_{1,12} = 38.6$, $P = <0.001$) for foxes in rural areas, and the distance to the nearest supplemental food source was 9.1 times greater for foxes in rural areas ($F_{1,12} = 38.79$, $P = <0.001$). Lastly, the distance to nearest canyon ($F_{1,10} = 1.37$, $P = 0.270$), drainage ($F_{1,11} = 1.61$, $P = 0.231$) and distance to nearest culvert ($F_{1,12} = 1.21$, $P = 0.294$) did not differ for foxes in urban and rural areas.

I found some evidence that heights of den entrance openings were greater for foxes in urban versus rural areas ($F_{1,12} = 4.06$, $P = 0.067$). I found no difference in width ($F_{1,12} = 0.17$, $P = 0.690$) and depth ($F_{1,12} = 0.40$, $P = 0.541$) of den entrance openings or height of vegetation ($F_{1,12} = 1.81$, $P = 0.203$) as reflected by the Visual Obstruction Reading (e.g., vegetation or boulders; Robel, 1970) at entrance to dens between foxes in urban and rural areas, likely suggesting that foxes in both groups exhibit similar behavior in choosing den sites to whelp kits. Length ($F_{1,10} = 0.01$, $P = 0.941$), width ($F_{1,7} = 1.01$, $P = 0.348$), and height ($F_{1,7} = 0.00$, $P = 0.948$) of internal den measurements also did not differ between the 2 groups. I found some evidence of bedding (i.e., dried grasses) inside a greater proportion of dens of foxes in rural compared to urban areas (Fisher's Exact Test, $P = 0.070$), and no difference in the presence of fecal matter or food scraps at den sites between foxes in the 2 groups.

1.4 DISCUSSION

1.4.1 Reproduction and supplemental feeding

I found weak evidence that a greater proportion of female foxes in urban versus rural areas reproduced. Even though not significant at the alpha = 0.05 level, I expect that with larger sample sizes I might have observed a more significant difference in reproduction between the 2 groups of foxes.

I observed 2 females and 1 male near 1 den that was located near the Naval Special Warfare Complex urban area. One female was visibly pregnant when captured in February 2008 and the other female was observed with swollen and darkened mammary glands on 29 March 2008, indicating she had recently been lactating. All 3 animals were observed entering and exiting the same den. It is unclear which female, or if both females reproduced. Thus, if there were >1 females associated with other dens, I may have over-estimated the number of foxes that reproduced. However, because this is the only instance where I observed >1 female near a den, coupled with the fact that I likely did not locate all successful dens, I surmise that my data indicates a minimum proportion of females that reproduced on SCLI.

Island foxes in urban areas weighed more than foxes in rural areas of SCLI (Gould 2009, unpublished data) possibly due to their close proximity to supplemental food sources (e.g., a galley, refuse, outdoor cooking facilities, etc) that could have contributed to slightly better health and an increase in the proportion of females that reproduced. Banded mongooses (*Mungo mungo*) that fed on refuse also were heavier and in better condition than individuals of the same sex that did not feed on refuse (Otali and Gilchrist 2004). On SCLI, supplemental food sources (in the form of feed-stations) could be made available to island foxes (in the short-term) if this sub-species ever sustains a significant population decline in the future. Numerous studies have demonstrated the benefits of supplementary feeding in enhancing populations of endangered species (Wilbur et al. 1974; O'Leary and Jones, 2006). Warrick et al (1999) found that supplementally-fed kit fox (*Vulpes velox*) pups and adults had significantly higher survival and a greater proportion of females bred than corresponding control foxes. Other benefits include enhanced physical condition and greater resilience to disease, parasites, and predation (Brittingham 1991, O'Leary and Jones, 2006). However, this habituation may increase fox roadkills as well as fox aggression towards one another, and also increase the probability of humans being bitten when hand-feeding island foxes (N. P. Snow, Colorado State University, unpublished data) and other wildlife (Jones and Witham, 1990; Knight and Temple, 1995; Whittaker and Knight, 1998; Kloppers et al., 2005; George and Crooks, 2006). The availability of supplemental food sources may also increase the potential for disease transmission through direct, fox to fox contact and possibly through vectors such as food stations (Clifford et al 2006).

1.4.2 Litter size and age of foxes

The average litter size (2.3 kits) for my random sample of adult female foxes is consistent with findings on the other Channel Islands (Laughrin 1977; Moore and Collins 1995; Coonan 2002; Roemer et al 2004; Clifford et al 2007). Given that my data suggest a greater proportion of female foxes in urban compared to rural areas reproduced, it is unclear why litter sizes appear to be larger for foxes in rural areas. My data suggest that foxes in urban areas that reproduced successfully were younger (4/5, or 80% were $\leq$ age class 2) than foxes that reproduced in rural areas (1/5, or 20% were $\leq$ age class 2). Younger island foxes may produce fewer pups per litter as has been reported in grizzly bears (*Ursus arctos*; Schwartz et al 2006), farm-raised Finnish mink (*Neovison vison*; Koivula et al. 2010), and farm-raised Finnish blue fox (*Alopex lagopus*; Peura et al.2007).

1.4.3 Den site characteristics

My finding that slope, aspect, and den entrance orientation did not differ between rural and urban foxes suggests that foxes on SCLI may be exhibiting specific search behavior for these 3 attributes when selecting for a den site. Swift foxes in New Mexico also selected for similar western slope aspects and east-facing orientation for den entrance openings (Harrison 2003). Conversely, Unger (1999) and Trapp (2004) found that wolves (*Canis lupus)* did not select for any particular aspect when choosing a den site, whereas Matteson (1992) found a moderate preference by wolves for south and east facing slopes. Szor et al. (2008) found that arctic foxes (*Alopex lagopus*) preferred steep and southerly exposed dens.

My finding that foxes in urban areas had den sites much closer to paved roads, urban areas, and supplemental food sources was expected, because by definition, urban foxes had a much higher probability of being closer to roads and areas of human habitation than did foxes in rural areas. These differences also confirmed my definition and placement of foxes into 2 classes. Nonetheless, foxes that reproduced in, or near, urban areas that support a larger network of roads, higher traffic volumes (Snow 2009, unpublished data), and additional supplemental feeding reserves may also be predisposed to higher risks of mortalities via road-kill (Jaeger et al 2005, George and Crooks 2006, Riley 2006, Baker et al 2007, Snow 2009). This is of particular concern during pup-rearing when younger urban foxes are beginning to explore areas beyond the immediate den area or when adults are still provisioning their young, and thus likely encountering more roads. Grilo et al. (2009) found that higher road casualties were observed when red fox (*Vulpes vulpes*) and stone marten (*Martes nivalis*) were provisioning young.

Foxes in urban areas selected for taller den entrance heights and foxes in rural areas had bedding, in the form of dried grasses, inside their den entrances; however, these findings may be a product of small sample sizes.

1.5 CONCLUSIONS

My study suggests that because a greater proportion of foxes in urban areas may have been reproducing and in closer proximity to roads, that possible management efforts be implemented that may reduce the threat of road mortalities for foxes in urban areas such as additional signage alerting drivers of a possible "denning area" for foxes, and to "stop for foxes on roadways".

My data also indicated that foxes were more likely to den in canyons/drainages or some form of rock piles, suggesting that impacts or alterations to these areas should be minimized, if not restricted. I suspect that these types of sites generally provided the most durable cover and protection, and canyons and drainages likely served as travel corridors. Grubbs and Krausman (2009) also suspected that washes provided important cover and were important travel lanes for urban coyotes (*Canis latrans*) in Tucson, Arizona. Thus, creating additional rock piles, provided that they are limiting to foxes, might enhance recruitment of young. I also recommend avoiding ground-disturbing activities on 15–20° slopes, and primarily on westerly-facing aspects during the parental care season (15 February though 20 June). However, increasing the numbers of dens sampled, in concert with determining what is available for foxes to select with regard to aspect and slope would be useful before implementing this recommendation. I also suggest that additional research should be conducted to ascertain if daughters or siblings of females serve as "helpers" or if both females in a group reproduce to correct estimates of reproduction on SCLI.

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2 BEHAVIORAL ECOLOGY OF THE SAN CLEMENTE ISLAND FOX ON ROADS

ABSTRACT Collisions with vehicles have created concern for the welfare of the endemic San Clemente Island fox (*Urocyon littoralis clementae*). The population on the northern 2/3 of San Clemente Island (SCLI) has sustained an estimated annual mortality rate of 3–8% due to collisions with vehicles from 2000 through 2007. To identify potential management solutions for minimizing these mortalities, I examined behavioral responses of SCLI foxes to approaching vehicles on roads. I found that during 67% of 541 observations, foxes remained within 5 m of an approaching vehicle, and during 26% of 258 observations, foxes remained on the road as the vehicle passed suggesting many foxes were naïve toward vehicles. During 8% of 258 observations, foxes remained in the center of the road; thus, we were required to stop our vehicle to avoid hitting the fox.

I examined 5 main behaviors (running, walking, sitting, standing, and foraging) of foxes as a vehicle approached to ascertain if behaviors of foxes changed with distance. Foxes showed no trend toward avoidance behaviors (running or walking away) at closer distances (0, 5, 25 m) to the approaching vehicle. During 49 of 150 observations where foxes exhibited directional movements in response to our vehicle at 0, 5, 25, 50 and 100 m, foxes approached our on-coming vehicle, further suggesting SCLI foxes exhibit naïve

behaviors toward vehicles. I found no significant effects of road surface, biological season, day versus night, and foxes in urban versus rural areas on behaviors. I recommend educating drivers on SCLI about the general lack of vehicle-avoidance behaviors of foxes, as well as installing additional signage alerting drivers that "foxes are naïve to vehicles", and to "stop for foxes on roadways" to minimize impacts of vehicles on island foxes.

2.1 INTRODUCTION

The Island fox (*Urocyon littoralis*) is a diminutive descendant of the gray fox (*U. cinereoargenteus*), with an endemic subspecies on each of 6 of the 8 California Channel Islands. Island foxes are known for their docile nature and general lack of fear of humans (Blake 1887; Grinnell et al. 1937; Laughrin 1977; Moore and Collins 1995). Island foxes can be easily tamed and have been known to approach within a meter of a person to retrieve scraps of food (Blake 1887). The docile behavior and diurnal habits exhibited by island foxes probably result from an absence of large predators (Laughrin 1977). Isolation on islands can result in ecological naïveté (Clevenger 1994; Blumstein and Daniel 2005), island tameness (Goltsman et al. 2005; Rodl et al. 2007), and less vigilance (Blumstein and Daniel 2005; Mills 2007; Snow 2009). In general, most vertebrates inhabiting islands are characterized by fearlessness and tame behavior which make them vulnerable to humans and introduced predators (Pimm 1987; Atkinson 1989; Case et al. 1992; Blazquez et al. 1997; Rodl et al. 2007). Consequently, populations of endemic wildlife on some islands have been decimated (Diamond 1989; Blumstein and Daniel 2005; Mills 2007). For small populations that are isolated on islands, naïveté could be problematic when roads and vehicles are introduced (Snow 2009).

Genetic analyses and archeological findings suggest that island foxes were introduced from the northern Channel Islands to the southern Channel Islands between 2,200 and 5,200 years ago by Native Americans (Collins 1991a, b). Rapid population declines on 4 islands (Santa Rosa, Santa Catalina, Santa Cruz, and San Miguel) resulted in these 4 subspecies being listed as federally endangered (United States Fish and Wildlife Service 2004; Clifford et al. 2007). While numbers of foxes on San Clemente Island (SCLI) have remained relatively stable, SCLI has experienced an average of 27 road-kills per year from 2000 through 2007, an estimated 3–8% of the population on the northern 2/3 of SCLI (Andelt et al. 2009; Snow 2009; see also Roemer et al. 2004; Spencer et al. 2006).

The main concern among conservationists is that roads and traffic may be reducing or even eliminating wildlife populations (Trombulak and Frissell 2000; Forman et al. 2003; Fahrig and Rytwinski 2009). Roads can have detrimental effects on small populations of wildlife (Spellerberg 1998) especially on small islands (Lin 2006). These effects include loss and fragmentation of habitat, injury and death of wildlife attempting to cross roads, pollution of air, water, and soil, and contraints on acoustic communication in areas affected by traffic noise (Parris and Schneider 2009).

Road-kills can also alter the demography and structures of populations of wildlife (Bangs et al. 1989; Fahrig et al. 1995; Trombulak and Frissell 2000; Baker et al. 2007). Several factors combine to make a species vulnerable to road mortality. Species that are either attracted to roads or do not avoid roads, and that show low car avoidance of vehicles (e.g., naïve species) also have higher rates of mortality, and thus are particularly vulnerable (van Langevelde and Jaarsma 2005; Klocker et al. 2006; Brockie 2007; Fahrig and Rytwinksi 2009; Snow 2009). Some species, including frogs (*Pseudacris sp.*), actually respond to traffic on the road by stopping, thus increasing the time spent on the road and making them even more likely to be killed (Andrews and Gibbons 2005; Mazerolle et al. 2005; Fahrig and Rytwinski 2009). Gray foxes on mainland California, USA, readily accessed abundant resources near roads and urban areas, likely predisposing them to increased human-associated risks including collisions with vehicles (Riley 2006).

To my knowledge, no studies have investigated behavioral responses of island foxes to approaching vehicles. With increasing expansion in military traffic and activities expected on SCLI (M. Booker, *personal communication*), my objective was to ascertain behavioral responses of foxes to approaching vehicles which might lead to recommendations for reducing road-kills. I hypothesized that: 1) foxes will begin running and walking away from vehicles at farther distances on gravel surfaces than on paved or dirt surfaces because of additional noise from vehicles; 2) due to habituation, foxes in urban compared to rural areas will exhibit more "naïve" behaviors on roads such as sitting, standing, and foraging at closer distances to approaching vehicles; 3) foxes will show more avoidance behaviors at closer versus farther distances; 4) foxes will forage a greater proportion of the time during the pup-rearing season; 5) foxes will more frequently utilize roads during the pup-rearing and breeding seasons; 6) foxes will forage a greater proportion of time during night versus daytime; and 7) foxes will run away from vehicles a greater proportion of time during the day versus night.

2.2 METHODS

2.2.1 Study Area

San Clemente Island is owned and operated by the United States Navy as a naval base for training activities. San Clemente Island is the southern most of the California Channel Islands, located approximately 109 km west of San Diego, California and is 146 km^2 in area (Olmstead 1958). The vegetation on the island was comprised primarily of maritime desert scrub (54.4%), grassland (32.8%) (Thorne 1976; Sward and Cohen 1980), and "disturbed" (7.4%) with Navy facilities and roads (Schmidt et al. 2004). Foxes occur in all habitats on the island (Roemer et al. 2004). Temperature averaged 17°C and annual precipitation averaged 13 cm with 95% falling during the wet season, November thru April (Kimura 1974; Yoho et al. 1999).

My study area was 80.6 km^2 and was located on the northern 2/3 of SCLI except for the extreme northern tip (2.1 km^2), because of U.S. Navy restrictions, and except for the steep eastern escarpment (7.4 km^2; JR Resnik, personal communication; see Chapter 1). I studied behavioral responses of foxes on the primary roads including Ridge Road which was 18.1 km and ran north-south through the center of the island and Perimeter Road which was 7.9 km and encircled the airfield at the north end of the island, resulting in a density of 0.32 km of primary roads/km^2. All primary roads were 2 lanes and the maximum speed limit was 56 kph (Snow 2009). Approximately 2 km of San Clemente Ridge Road looped through 1 of 3 urban areas (Wilson Cove) and had a speed limit of 48 kph. At the beginning of the study, Ridge Road consisted of interspersed sections of gravel (32%) and asphalt (68%) whereas Perimeter Road was entirely asphalt. After road construction approximately half way through the study, Ridge Road became, and remained, nearly 75% gravel. I also studied behavioral responses of foxes on secondary roads. Secondary roads were dirt roads with little to no maintenance that branched off of the main roads.

2.2.2 Defining urban polygons

I used Geographic Information Systems (GIS; ArcGIS; v9.2, Environmental Systems Research Institute, Inc., Redlands, CA) to delineate urban area polygons which contained human habitation, human-associated food sources (e.g., a galley), and daily human use. Urban areas were divided into 3 polygons including Wilson Cove, the Airfield, and the Naval Special Warfare Complex (NSWC; see Chapter 1). I placed a 100 m buffer around all buildings within each urban area, and then "dissolved" the individual buffers to create 1 larger connected polygon. I targeted these 3 known areas of human habitation based upon frequent sightings of foxes and expectations that behaviors might differ between urban and all areas outside these polygons (rural areas).

2.2.3 Measuring fox observations

All data collected were opportunistic encounters of foxes on roads. When I observed a fox on the road, I determined if the fox was influenced by the presence of our vehicle (i.e., the fox looked at the vehicle). If the fox was influenced by the vehicle, we drove toward the fox at, or below, the specified speed limit (24 to 56 kph) depending on road and surface type, but were prepared to stop if it appeared that we might hit the fox. Observers recorded date, time, location (Garmin eTrex Vista; NAD 83, Universal Trans Mercator Zone 11), initial vehicle speed, surface type (paved, gravel, or dirt), road name, if the fox was wearing a radio-collar, and if the observation was located in 1 of the 3 urban areas. I classified behavioral observations of foxes as either running, walking, sitting, standing, foraging, laying, or scent-marking at distances of 100 m, 50 m, 25 m, 5 m, and 0 m from the approaching vehicle. I also recorded: 1) if the fox approached the vehicle, 2) if the fox was located in the middle or near the edge of the road, and 3) location and distance of the fox from the vehicle as it passed. Each field technician was trained to estimate the 5 distances and to ascertain if the fox was influenced by the vehicle prior to collecting observations.

2.2.4 Day, night, and seasonal effects

I drove the roads on SCLI throughout three 8-hour periods (0000–0800, 0800–1600, 1600–2400) every 3 weeks. This allowed us to observe foxes on roads during a 24-hour period, thus I collected behavioral observations during both daytime and nighttime hours. I used the National Oceanic and Atmospheric Administration records to categorized behavioral observations as "day" (sunrise to sunset) or "night". I used GIS to confirm if behavioral observations were located within or outside the urban polygons.

I examined the effect of seasonal periods of annual reproductive activities (see Andelt 1985 and Zoellick and Smith 1992) on the behavioral responses of foxes to approaching vehicles, similar to the methods of. Based on observations of pups at dens on SCLI during 2007–2009 (Snow et al. 2007; Gould et al. 2009) and reports of periods of reproduction for island foxes on other islands (Moore and Collins 1995; Garcelon et al. 1999; Asa et al. 2007; Clifford et al. 2007), I defined 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 Post-nursing season; and 16 September to 30 November as the Pre-Breeding season.

2.2.5 Data analyses

I used a mixed model regression analysis (Proc Glimmix; SAS Institute, Cary, NC) with binary categorical responses that coded if the specified behaviors occurred at each of the 5 distances. Explanatory variables indicated if the observation occurred within an urban or rural area, was during the day or night, if the road surface was paved, gravel, or dirt, and if the biological season was Breeding and Gestation; Parturition, Pup-nursing and Weaning; Post-nursing; or Pre-Breeding. We assumed that each observation of a fox was an independent observation even though we had ≤ 3 repeated observations of the same individual fox across the 5 distances. Prior to the analyses, I excluded data on foxes that were not observed directly on the road (e.g., "foraging off road", "sitting off road", running off road", etc). I accounted for this potentially confounding effect by ascertaining the proportions of each behavior at each distance for the data that were discarded.

I ascertained the effects of urban versus rural area, day versus night, and road surface on 5 main fox behaviors. I selected these biologically important predictor variables *a priori* to determine if these variables explained changes in fox behavior toward an approaching vehicle. I elected not to examine all possible combinations of models in order to specifically address predictor variables that may more directly influence road mortality of foxes. I did not evaluate interactions between these variables because I felt that the main effects were more biologically important. To ascertain if there was an effect of distance on fox behaviors, I used the previous model in the logit scale with only an intercept and no covariates to obtain probabilities and associated standard errors for each behavior at each of the 5 distances. I used the logit scale to construct confidence intervals around pairwise differences in the coefficients which I compared to zero to ascertain if the probability of each behavior changed with distance.

I also ascertained if distance affected the probability of foxes displaying "vehicle-avoidance" (i.e. running and walking away) or "vehicle-naïve" (i.e. running and walking toward) behaviors in response to an approaching vehicle. I compared these categories at each of the 5 distances separately. I used pairwise comparisons in the logit scale to determine if a fox was more likely to approach an on-coming vehicle at closer distances compared to farther distances. Lastly, I examined the effect of season on foraging versus all other behaviors of foxes combined because I ascertained *a priori* that foraging was the primary behavior that might be affected by season. I compared these categories at each of the 5 distances separately. I again used pairwise comparisons in the logit scale to determine if a fox foraged less at closer distances to the approaching vehicle. However, I did not have data for the 50 and 100 m categories, respectively, for this model.

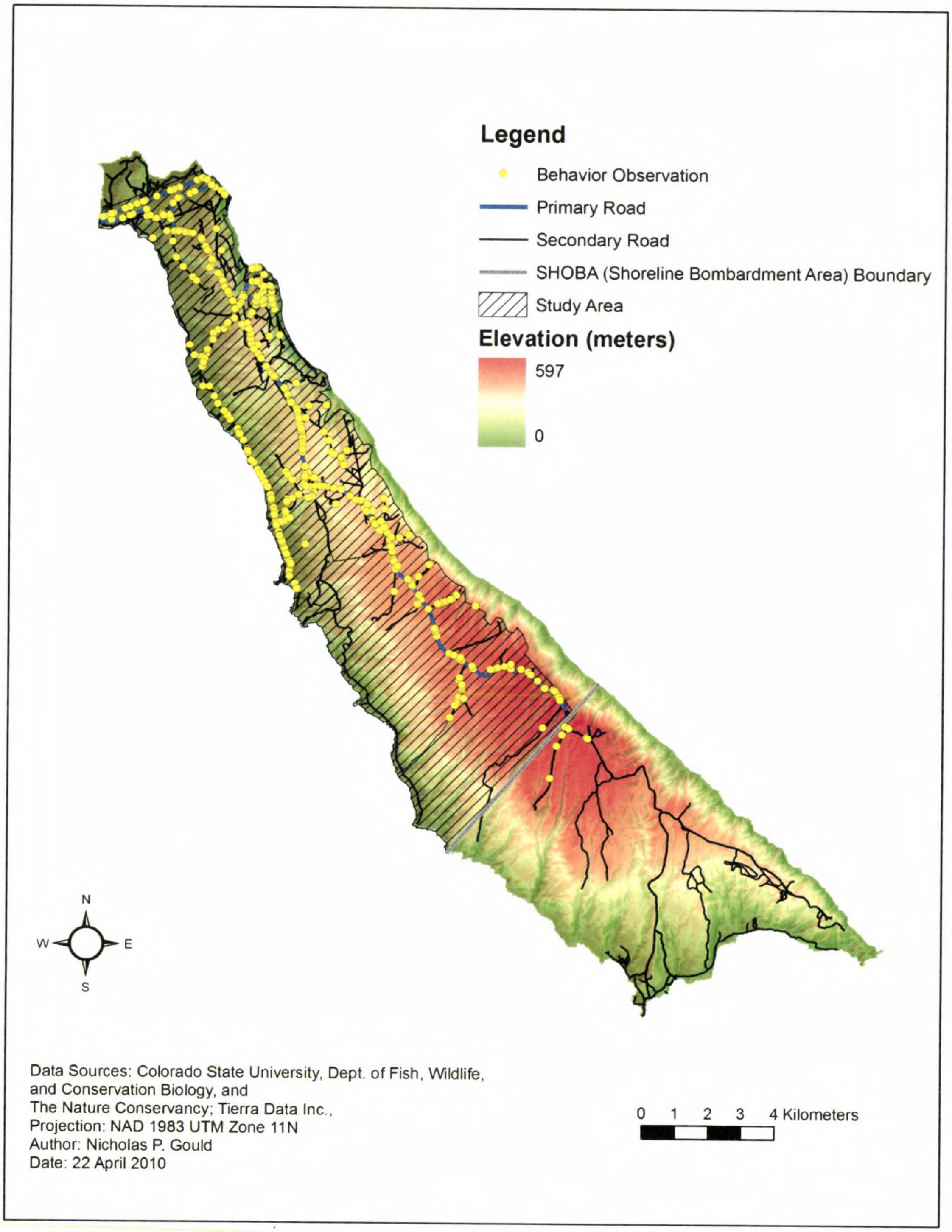
I treated my comparisons of fox behaviors across distances as independent observations, when in fact they were predominantly 5 repeated measures on 541 individual foxes. I knew of no way to address orthogonal polynomials to correct for this potential bias. However, even though my approach appears liberal (T. Stanley, personal communication), because it reflects more variance within distances, with an appropriate repeated measures analysis, my predominantly non-significant results would have been even more non-significant than presented.

2.3 RESULTS

2.3.1 Main fox behaviors

I observed behaviors of foxes toward approaching vehicles on 541 occasions (Figure 2.1). A total of 283 (52%) and 258 (48%) of 541 observations were on primary and secondary roads, respectively. I observed that 287 (67.4%) and 377 (88.5%) of 541 foxes remained within 5 and 10 m, respectively, of the vehicle as it passed. I also found that 66 of 258 (25.6%) foxes remained on the road as the vehicle passed, and 21 of 258 (8.1%) foxes remained in the center of the road; thus, causing the vehicle to stop to avoid hitting the fox.

Figure 2.1. Locations of 541observations of island foxes on roads on San Clemente Island, California, USA, July 2006 through February 2009.



I found no overall significant evidence that urban versus rural, day versus night, and surface affected the 5 main behaviors of foxes (Table 2.1). The probability that a fox displayed an "active" (e.g., running or walking) versus "passive" behavior did not differ significantly among the 5 distances (Figure 2.2; Table 2.2; Appendix A). In fact, as a vehicle approached a fox, there was a non-significant trend that a fox displayed passive behaviors at closer distances (0, 5, 25 m) than at farther distances (50 and 100 m; Figure 2.2), further suggesting that foxes exhibit naïve behaviors toward approaching vehicles. The probability of running at 0 m was significantly lower than the probability of running at 5 m (Table 2.2), suggesting that foxes may be returning to a passive behavior at 0 m without leaving the road. The percentages of excluded observations (3–15 %) of foxes not directly on the road at 0, 5, 25, 50, and 100 m were evenly distributed among behaviors and distances.

Table 2.1. Effect of road surface, day versus night, and urban versus rural on the probability that island foxes displayed 5 main behaviors on San Clemente Island, California, USA during July 2006 through February 2009.

Distance (m)	Surface			Day versus Night			Urban versus Rural		
	df	*F*	*P*	df	*F*	*P*	df	*F*	*P*
Run, 0	2,201	0.48	0.617	1,201	0.04	0.884	1,201	1.05	0.306
Run, 5	2,264	2.91	0.262	1,264	2.91	0.089	1,264	4.08	0.044
Run, 25	2,291	2.26	0.106	1,264	6.44	0.012	1,264	0.02	0.890
Run, 50	2,92	1.70	0.188	1,92	5.94	0.017	1,92	2.25	0.137
Run, 100	2,41	2.02	0.146	1,41	0.00	0.947	1,41	0.00	0.974
Walk, 0	2,201	1.03	0.359	1,201	0.01	0.927	1,201	0.00	0.975
Walk, 5	2,264	4.29	0.015	1,264	0.43	0.513	1,264	2.14	0.145
Walk, 25	2,291	1.25	0.288	1,264	7.76	0.006	1,264	0.03	0.857
Walk, 50	2,92	0.05	0.953	1,92	4.94	0.029	1,92	0.00	0.977
Walk, 100	2,41	1.67	0.199	1,41	0.65	0.426	1,41	0.00	0.992
Forage, 0	2,201	0.05	0.953	1,201	0.01	0.926	1,201	0.00	0.988
Forage, 5	2,264	0.96	0.383	1,264	0.26	0.609	1,264	0.29	0.590
Forage, 25	2,291	1.75	0.176	1,264	0.00	0.970	1,264	3.49	0.063
Sit, 0	2,201	5.88	0.003	1,201	5.18	0.024	1,201	1.85	0.175
Sit, 5	2,264	5.66	0.004	1,264	3.87	0.050	1,264	0.13	0.717
Sit, 25	2,291	7.18	0.001	1,264	0.31	0.580	1,264	0.03	0.871
Sit, 50	2,92	5.32	0.007	1,92	1.02	0.314	1,92	1.54	0.218
Sit, 100	2,41	6.71	0.003	1,41	1.41	0.241	1,41	0.00	0.966

Stand, 0	2,201	4.13	0.017	1,201	4.10	0.044	1,201	2.98	0.086
Stand, 5	2,264	3.08	0.048	1,264	0.53	0.468	1,264	1.71	0.193
Stand, 25	2,291	0.75	0.474	1,264	1.70	0.194	1,264	0.43	0.511
Stand, 50	2,92	0.56	0.572	1,92	0.77	0.383	1,92	0.00	0.978
Stand, 100	2,41	0.17	0.846	1,41	0.02	0.893	1,41	0.00	0.993

Figure 2.2. Probabilities for running, walking, foraging, standing, and sitting behaviors of island foxes on roads on San Clemente Island, California, USA, during July 2006 through February 2009.

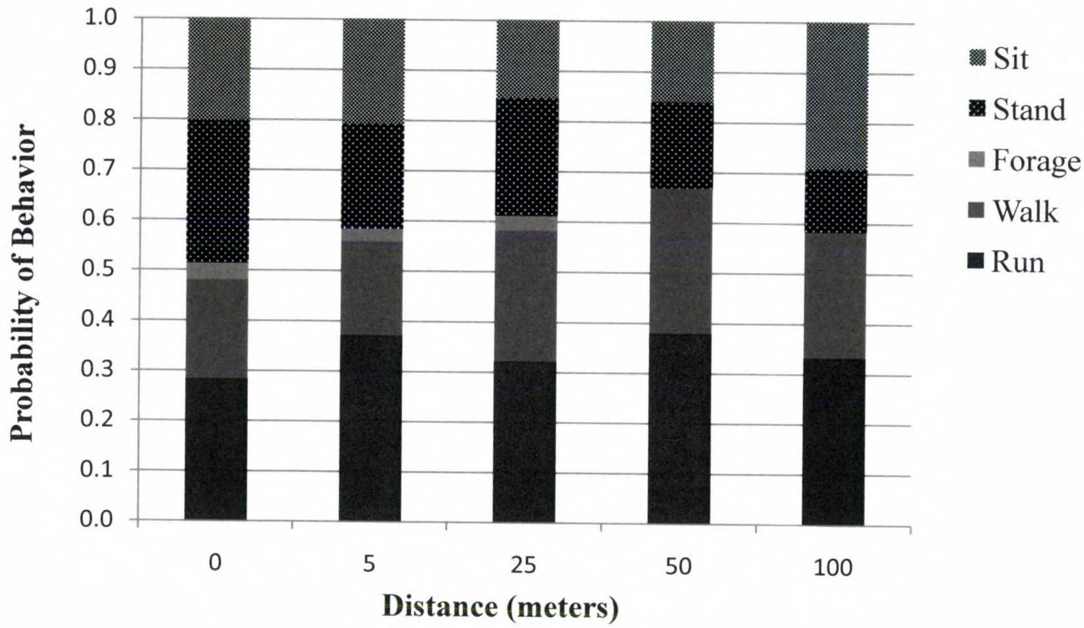


Table 2.2. Effect of distance on probability of island foxes displaying 5 behaviors when vehicles approached foxes on San Clemente Island, California, USA, during July 2006 through February 2009.

Distance	Probability	S.E.	Contrasts	Confidence Interval		Contrasts	Confidence Interval	
Running								
0	0.284	0.154	0 vs 5	-0.792	-0.015	5 vs 25	-0.123	0.564
5	0.372	0.125	0 vs 25	-0.569	0.202	5 vs 50	-0.505	0.439
25	0.322	0.123	0 vs 50	-0.941	0.067	5 vs 100	-0.478	0.819
50	0.380	0.206	0 vs 100	-0.905	0.438	25 vs 50	-0.723	0.217
100	0.333	0.306				25 vs 100	-0.696	0.597
						50 vs 100	-0.520	0.927
Walking								
0	0.197	0.174	0 vs 5	-0.387	0.528	5 vs 25	-0.826	-0.031
5	0.186	0.155	0 vs 25	-0.785	0.069	5 vs 50	-1.108	-0.052
25	0.260	0.131	0 vs 50	-1.060	0.042	5 vs 100	-1.097	0.344
50	0.290	0.220	0 vs 100	-1.043	0.431	25 vs 50	-0.654	0.351
100	0.250	0.333				25 vs 100	-0.650	0.754
						50 vs 100	-0.580	0.986
Foraging								
0	0.034	0.385	0 vs 5	-0.780	1.347			
5	0.026	0.383	0 vs 25	-0.872	1.136			
25	0.030	0.338	5 vs 25	-1.153	0.850			
50								
100								
Sitting								
0	0.202	0.173	0 vs 5	-0.484	0.409	5 vs 25	-0.064	0.788
5	0.208	0.149	0 vs 25	-0.135	0.784	5 vs 50	-0.288	0.930

25	0.155	0.159	0 vs 50	-0.349	0.917	5 vs 100	-1.137	0.238
50	0.160	0.273	0 vs 100	-1.196	0.222	25 vs 50	-0.659	0.578
100	0.292	0.318				25 vs 100	-1.507	-0.116
						50 vs 100	-1.592	0.050
Standing								
0	0.284	0.154	0 vs 5	-0.009	0.830	5 vs 25	-0.543	0.246
5	0.208	0.149	0 vs 25	-0.140	0.664	5 vs 50	-0.349	0.847
25	0.234	0.136	0 vs 50	0.057	1.262	5 vs 100	-0.295	1.513
50	0.170	0.266	0 vs 100	0.113	1.926	25 vs 50	-0.188	0.983
100	0.125	0.436				25 vs 100	-0.138	1.653
						50 vs 100	-0.642	1.362

2.3.3 Vehicle-avoidance versus vehicle-naïveté

I found no effect of surface, day versus night, or urban versus rural on whether or not foxes exhibited vehicle-avoidance or vehicle-naive behaviors at each of the 5 distances (Table 2.3). Forty-nine of 150 (32.7%) foxes approached our on-coming vehicles, whereas 67.3% of foxes ran or walked away from the vehicle. I also found no affect of distance on the probability that foxes displayed vehicle-avoidance or vehicle-naïve behaviors. However, the largest probability (19/51) that foxes approached an on-coming vehicle occurred at 5 m (Table 2.4; Figure 2.3). I found no effect of seasons on the probability that foxes were foraging.

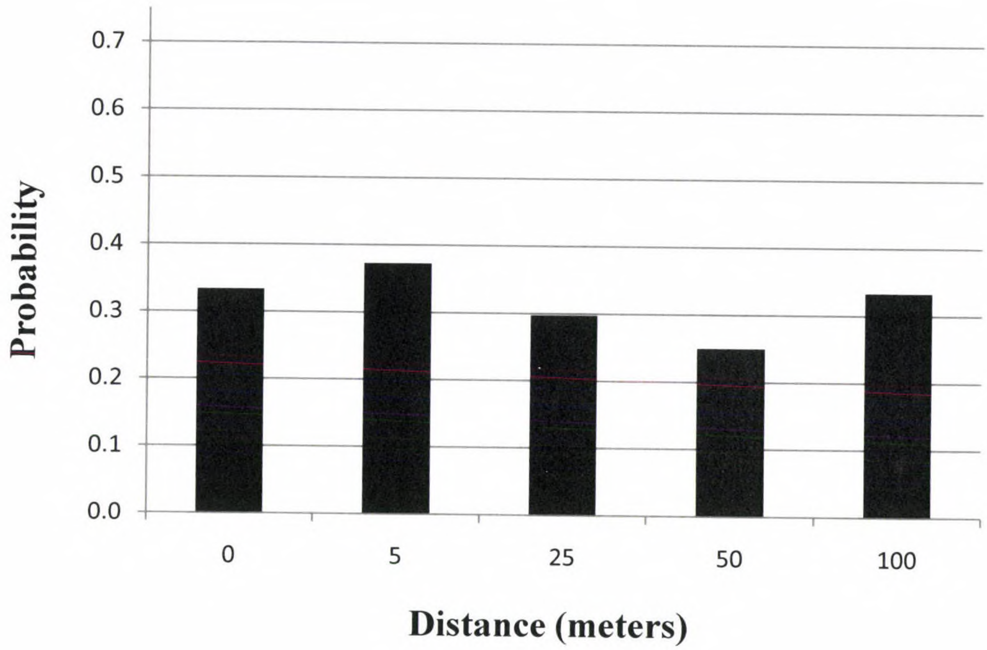
Table 2.3. Effect of road surface, day versus night, and urban versus rural on probability that island foxes displayed vehicle-naïve (running or walking towards a vehicle) behaviors on San Clemente Island, California, USA, during July 2006 through February 2009.

	Surface			Day versus Night			Urban versus Rural		
Distance (m)	**df**	***F***	***P***	**df**	***F***	***P***	**df**	***F***	***P***
0	2,26	0.510	0.681	1,26	0.930	0.344	.	.	.
5	2,46	1.520	0.230	1,46	0.060	0.800	1,46	0.760	0.389
25	2,31	0.120	0.891	1,31	1.200	0.282	.	.	.
50	2,14	0.010	0.993	1,14	0.000	0.964	.	.	.
100	1,8	0.000	0.971	1,8	0.000	0.960	.	.	.

Table 2.4. Effect of distance on probability that island foxes displayed vehicle-naïve (running or walking towards a vehicle) behaviors on San Clemente Island, California, USA, during July 2006 through February 2009.

Distance (m)	Probability	S.E.	Contrasts	Confidence Interval	
0	0.333	0.387	0 vs 5	-1.120	0.776
5	0.373	0.290	0 vs 25	-0.869	1.203
25	0.297	0.360	0 vs 50	-0.860	1.671
50	0.250	0.516	0 vs 100	-1.420	1.420
100	0.333	0.612	5 vs 25	-0.566	1.244
			5 vs 50	-0.583	1.738
			5 vs 100	-1.156	1.500
			25 vs 50	-0.995	1.472
			25 vs 100	-1.559	1.225
			50 vs 100	-1.976	1.165

Figure 2.3. Probability that an island fox approached an on-coming vehicle on San Clemente Island, California, USA, during July 2006 through February 2009.



2.4 DISCUSSION

Numerous studies have documented direct and indirect negative effects that roads, and exposure to other human activity (e.g., ATVs, snow mobiles, helicopter or airplane surveys, etc), can have on wildlife. The most obvious direct effects are injury (Cote 1996; Tracey and Fleming 2007) and mortality (Harris 1981; Harris and Trewhella 1988; Gosselink et al. 2007; Cypher et al. 2009) from collisions with motorized vehicles. The indirect, and potentially prolonged, impacts from exposure to roads or other human activity can result in fitness costs, such as decreased survival and reproduction (Andrews and Gibbons 2005; Borkowski et al. 2006; Snow 2009), reduced dispersal and colonization (Spellerberg 1998; Trombulak and Frissell 2000; Forman et al. 2003), changes in flight-response behavior (Tracey 1977; Singer and Beattie 1986), and reduced gene flow (Andrews and Gibbons 2005; Mazerolle et al. 2005) when roads serve as barriers to movement (Clarke et al. 1998; Klar et al. 2009). However, inherent in most of these studies is the notion that wildlife species will respond by avoiding, or fleeing, from these perceived threats, with research aimed at ascertaining the negative effects inflicted upon the study species by these human activities. There are few studies documenting the naïveté of wildlife species to these perceived threats, particularly on islands.

My finding that foxes did not change their behaviors from "passive" (i.e., sitting and standing) to "active" (i.e., walking or running) with decreasing distance to an approaching vehicle, coupled with foxes remaining in close proximity to passing vehicles (i.e., 67% within 5 m) and 32.7% of 150 observations of foxes approaching the oncoming vehicle, suggests that foxes on SCLI were naïve to threats posed by vehicles. I suggest that the reported lack of fear by island foxes of humans (Blake 1887; Grinnell et al 1937; Laughrin 1977; Moore and Collins 1995) extends to a lack of fear of vehicles on roads. In concert with a lack of fear of human activity, there are no predators of adult-aged island foxes on SCLI, thus the development of this naïveté, or lack of anti-predator behavior towards vehicles is further supported. Although I found few significant differences (Table 2.2), most of those differences indicated that foxes exhibited passive behaviors at closer distances. These results are far from intuitive, and they do not support my research hypothesis that foxes would exhibit appropriate avoidance behaviors with increasing proximity to an approaching vehicle.

In concert with foxes exhibiting no difference in active and passive behaviors as vehicles approached, my finding that the probability of foxes avoiding an on-coming vehicle did not differ with distance further amplifies the severity of potential mortality from collisions with vehicles on SCLI. Snow (2009) found no evidence that foxes on SCLI avoided roads, even though collisions with vehicles represented their main source of mortality. Many of these deaths likely resulted from a lack of fear of vehicles by foxes, juxtaposed on a network of roads with more traffic than has been found on other California Channel Islands.

Jaeger et al. (2005) suggest that there are three behavioral responses to roads and traffic: avoidance of the road surface; avoidance of traffic emissions and disturbance; and the ability of an animal to move out of the path of an on-coming vehicle (car avoidance). However, Forman et al. (2003) suggest that another behavioral response to roads is an attraction to the road, which increases the frequency with which animals enter the road and, therefore, increases the mortality risk. Whittington et al (2004), found that wolves (*Canis lupis*) appeared to either not recognize, or had difficultly learning about, the danger posed by vehicles. If foxes are approaching on-coming vehicles on SCLI, it is likely that personnel and employees on SCLI, apart from our field crew, may not realize that stopping for foxes is the only solution; thus awareness and education of fox behaviors on roads is likely one of the best management options available.

Moore and Collins (1995) reported that island foxes exhibit more daytime activity than gray foxes. I found that although proportion of various behaviors did not differ between day and night, 432 of the 541 (80%) observations occurred at nighttime, even though I spent more time observing behaviors during daytime, suggesting that SCLI foxes are considerably more active at night. It is possible that foxes were more active at night to increase foraging efficiency or perhaps to avoid warmer temperatures that occur during the day.

2.5 CONCLUSIONS

Mazerolle et al. (2005) suggests that mortality on roads is not only due to external factors such as traffic volume, traffic speed, surface type, etc, but depends on the behavior of the animals in response to vehicles. My study highlights the importance of determining threats to wildlife, and the responses of wildlife to those threats, prior to detecting a decline in the population. Road-kills pose a threat to foxes on SCLI (Laughrin 1977; Moore and Collins 1995; Snow 2009). Our finding that foxes are naïve to approaching vehicles identifies at least part of the reason why road-kills are common on SCLI. Given that traffic volume and activity are expected to increase on SCLI in the future (MA Booker, personal communication) the risk that vehicles pose to foxes likely will be amplified.

I suggest possible mitigation efforts that may reduce the threat of road mortalities for foxes on SCLI such as an education program for new drivers that emphasize the naïveté of foxes toward vehicles. I also recommend installing additional signage alerting drivers that "foxes are naïve to vehicles", and to "stop for foxes on roadways". Rotating these signs during the year, may reduce driver habituation to the signs, and thus, may increase overall driver awareness (Huijser and McGowen 2003). Lastly, in addition to the warning signs and “rumble strips” that are currently in place, I further recommend reducing speed limits or constructing additional speed bumps to allow greater reaction time for drivers to avoid foxes on roads.

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APPENDIX A: Individual graphs for the probability of running, walking, foraging, standing, and sitting behaviors of island foxes at 5 separate distances on San Clemente Island, California, USA, during July 2006 through February 2009.

Figure A.1 (Appendix A). Probability that an island fox exhibited a running behavior at various distances in response to an approaching vehicle on San Clemente Island, California, USA, during July 2006 through February 2009.

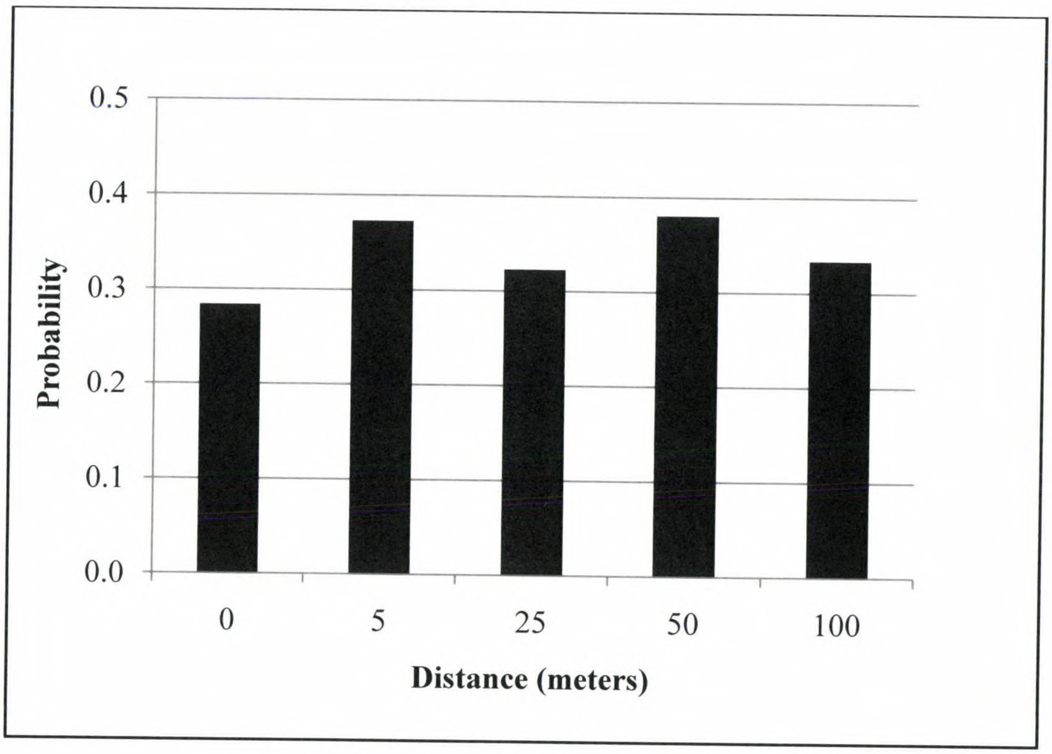

Figure A.2 (Appendix A). Probability that an island fox exhibited a walking behavior at various distances in response to an approaching vehicle on San Clemente Island, California, USA, during July 2006 through February 2009.

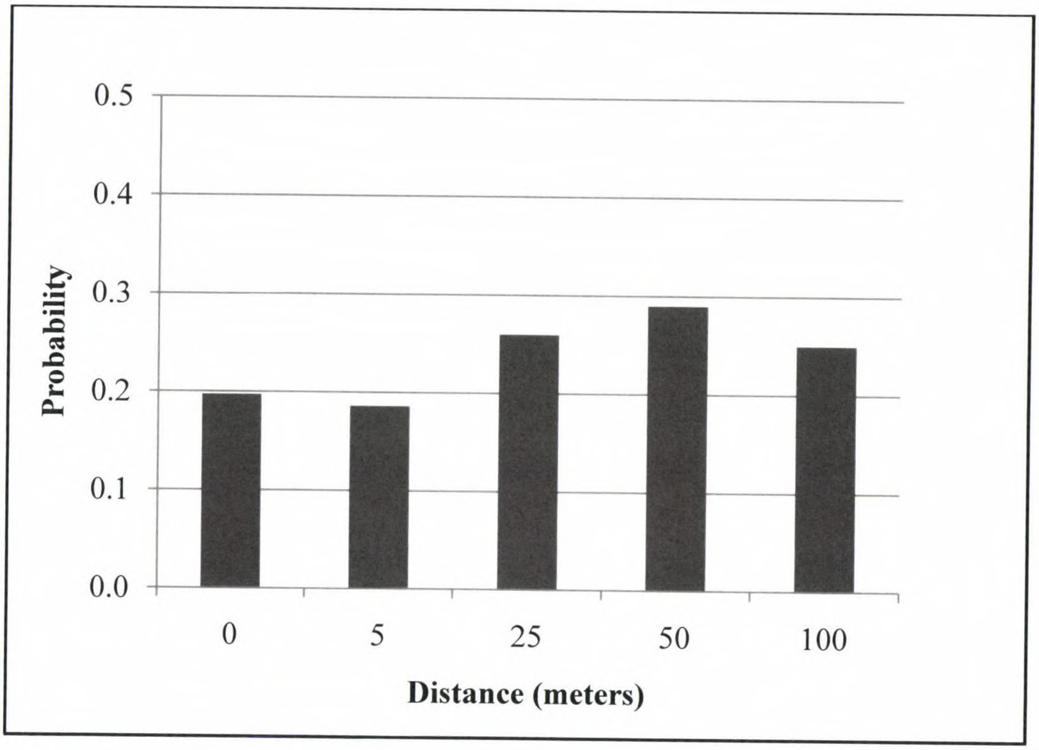

Figure A.3 (Appendix A). Probability that an island fox exhibited a foraging behavior at various distances in response to an approaching vehicle on San Clemente Island, California, USA, during July 2006 through February 2009.

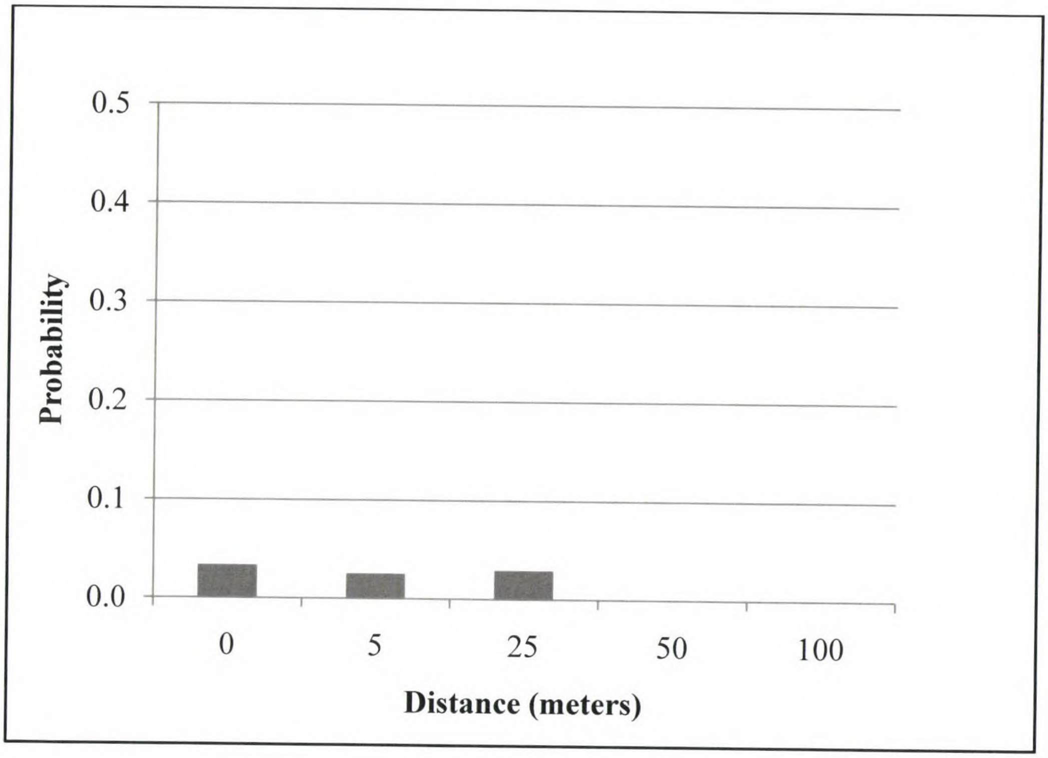

Figure A.4 (Appendix A). Probability that an island fox exhibited a standing behavior at various distances in response to an approaching vehicle on San Clemente Island, California, USA, during July 2006 through February 2009.

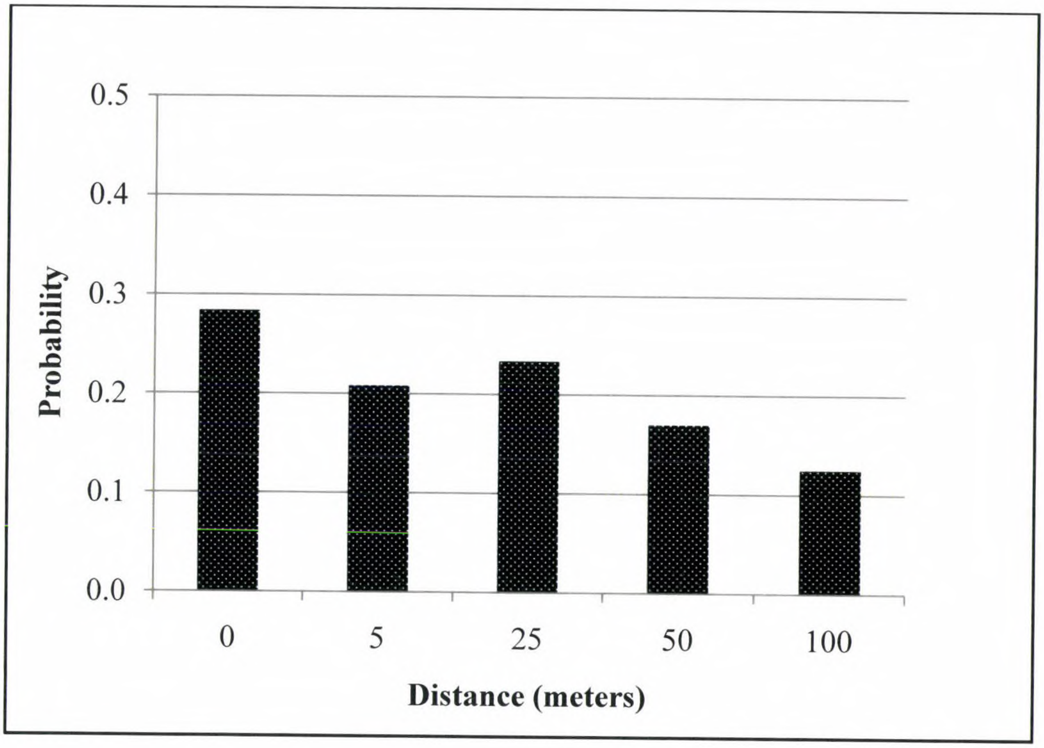

Figure A.5 (Appendix A). Probability that an island fox exhibited a sitting behavior at various distances in response to an approaching vehicle on San Clemente Island, California, USA, during July 2006 through February 2009.