THESIS

HOME RANGE, SITE FIDELITY, REPRODUCTIVE ECOLOGY, AND DEN SITE CHARACTERISTICS OF THE SAN CLEMENTE ISLAND FOX

Submitted by

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ABSTRACT

HOME RANGE, SITE FIDELITY, REPRODUCTIVE ECOLOGY, AND DEN SITE CHARACTERISTICS OF THE SAN CLEMENTE ISLAND FOX

Since 2004, the endangered status of 4 island fox (*Urocyon littoralis*) subspecies has prompted increased efforts to understand and manage island foxes on all 6 islands where they occur. High rates of vehicle-related mortalities and potential for exposure to pathogens are of particular concern on San Clemente Island, California. Basic spatial ecology of the San Clemente Island fox (*U. l. clementae*) is needed for effective management but is currently inferred from home range studies on other island fox populations. Additionally, little is known about reproduction and denning of this subspecies, and island foxes in general. To better inform management strategies, I studied the spatial and reproductive ecology of this subspecies.

During 2006–2007, I collected telemetry locations throughout the diel period for a random sample of foxes (n = 29), a sample with home ranges that included roads (n = 18) and a sample with home ranges that excluded roads (n = 19). I also monitored the movements of females in the random sample during 2007 to determine the proportion producing litters, number of kits in weaned litters, chronology of reproduction, and den site characteristics. I found that San Clemente Island foxes had home ranges ($\bar{x}$ = 0.75 km^2, SE = 0.9) and core areas ($\bar{x}$ = 0.19 km^2, SE = 0.03) 36–116% larger than reported in published studies for other island fox subspecies. Home ranges were largest during the pup-independence season ($\bar{x}$ = 0.76 km^2, SE = 0.07), but did not vary between pup-dependence ($\bar{x}$ = 0.68 km^2, SE = 0.11) and breeding ($\bar{x}$ = 0.66 km^2, SE = 0.10) seasons. Core area sizes were similar among all seasons. Annual home ranges and core areas for foxes living near roads were 77% and 82% larger compared to non-road foxes. Seasonal home ranges were larger for road foxes than for non-road foxes during the pup-independence and breeding seasons, but were similar in size during the pup-dependence season. Site fidelity between seasons ranged from 18–50%, was greater for home ranges of males than females, and was not different between genders for core areas. I did not detect dispersal during the home range study.

Only 3 or 4 of 23 females produced a total of 6 pups. Of 13 females recaptured and examined for reproductive status, most had lactated in previous years (*n* = 7), or had some evidence of lactating but not weaning pups (*n* = 4); two females had never lactated. Breeding and parturition occurred two months earlier than reported for other island fox subspecies in wild-born or captive breeding populations since the 1970s. Females used two or three dens in succession and dens were almost exclusively found in rock crevices. Five of 23 foxes had home ranges that included supplemental food sources and human habitation, including all four females observed with pups, suggesting this could be a factor in reproductive success. I recommend caution when generalizing findings from other island fox subspecies and suggest managers establish subspecies-specific information to better inform conservation strategies on the different islands.

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HOME RANGE AND SITE FIDELITY OF THE SAN CLEMENTE ISLAND FOX

Since 2004, the endangered status of 4 island fox (*Urocyon littoralis*) subspecies has prompted increased efforts to understand and manage island foxes on all 6 islands where they occur. High rates of vehicle-related mortalities and potential for exposure to pathogens are of particular concern on San Clemente Island, California, USA. To better inform management strategies for the San Clemente Island fox (*U. l. clementae*), I studied the spatial ecology of this subspecies.

During 2006–2007, I collected telemetry locations throughout the diel period for a random sample of foxes (n = 29), a sample with home ranges that included roads (n = 18) and a sample with home ranges that excluded roads (n = 19). I found San Clemente Island foxes had home ranges ($\bar{x}$ = 0.75 km^2, SE = 0.9) and core areas ($\bar{x}$ = 0.19 km^2, SE = 0.03) 36–116% larger than reported in published studies for other island fox subspecies. Home ranges were largest during the pup-independence season ($\bar{x}$ = 0.76 km^2, SE = 0.07), but did not vary between pup-dependence ($\bar{x}$ = 0.68 km^2, SE = 0.11) and breeding ($\bar{x}$ = 0.66 km^2, SE = 0.10) seasons. Core area sizes were similar among all seasons. Annual home ranges and core areas for foxes that lived near roads were 77% and 82% larger compared to non-road foxes. Seasonal home ranges were larger for road foxes than for non-road foxes during the pup-independence and breeding seasons, but were similar in size during the pup-dependence season. Site fidelity between seasons ranged from 18–50%, was greater for home ranges of males compared to females, and was not different between genders for core areas. I did not detect dispersal during the home range study. I recommend caution when generalizing findings from other island fox subspecies and suggest managers establish subspecies-specific home range information to better inform conservation strategies on the different islands.

INTRODUCTION

The island fox (*Urocyon littoralis*) occurs as genetically and morphologically distinct subspecies on 6 of California's 8 Channel Islands (Collins 1987, Wayne et al. 1991). Four subspecies (*U. l. catalinae, U. l. littoralis, U. l. santacruzae, U. l. santarosae*) were placed on the federal endangered species list in 2004 because of population declines attributed to golden eagle (*Aquila chrysaetos)* predation on 3 islands (Roemer et al. 2001*a, b*), and canine distemper on the fourth (Kohlmann et al. 2005, Timm et al. 2009). The remaining 2 subspecies (*U. l. dickey, U. l. clementae*) occur on San Nicholas Island and San Clemente Island, respectively, which are owned and managed by the United States (U.S.) Navy. These 2 subspecies have been considered Species of Concern by the U.S. Fish and Wildlife Service since 2003, the same year they entered the Department of Defense Legacy Species at Risk Program. Subsequently, in 2008 the International Union for the Conservation of Nature red-listed the entire species as critically endangered throughout its range.

The San Clemente Island fox population is relatively stable compared to the 4 federally-endangered subspecies. However, biologists and managers have expressed concern for this subspecies due to a possible population decline during 1988 to 2002

(Roemer et al. 2001*a, b*; Coonan 2003), lack of resistance to disease (Garcelon et al. 1992; Rubin et al. 2007), possibility of immigration by golden eagles from other Channel Islands (34–191 km) or the mainland (100 km), and the general vulnerability of island species to stochastic events. Foxes on San Clemente Island also sustain a high rate of vehicle-related mortalities (Laughrin 1977, Snow et al. 2011). Risk of exposure for San Clemente Island foxes to rabies and canine distemper (Clifford et al. 2006) prompted the initiation of a vaccination program for these pathogens in 2007. Guidelines developed by the U.S. Fish and Wildlife Service (Vissman 2004) and a monitoring plan for the San Clemente Island fox (Spencer et al. 2006) recommended additional research, including investigating the basic spatial ecology of foxes on San Clemente Island.   No studies have been published on home range and site fidelity for this subspecies, and few data are available on dispersal of island foxes.

Understanding space use has several applications for management. Home range size is used to model probabilities of contact for rabies in red foxes (*Vulpes vulpes*; Macdonald and Bacon 1982, White et al. 1995) and to determine the rate of spread of rabies and width of control zones (Roscoe et al. 1998, Rosatte et al. 2010). Dispersal in foxes also affects the rate of spread of rabies (Artois and Andral 1980, Wandeler 1980). Home ranges provide information about the extent of movements during an individual's normal activities of food gathering, mating, and caring for young (Burt 1943) but they focus on boundary estimation while ignoring the internal anatomy of the home range (Adams and Davis 1967). Core areas identify centers of activity within a home range (Hayne 1949) that probably contain the principle home sites, refuges, and most dependable food sources (Kaufmann 1962).

The basic spatial ecology of all subspecies of island fox is largely inferred from published research on the subspecies occurring on Santa Cruz Island (Laughrin 1977, Fausett 1982, Crooks and Van Vuren 1996, Roemer et al. 2001*b*). Home ranges and core areas were not found to differ between genders (Crooks and Van Vuren 1996, Roemer et al. 2001*b*) and dispersal rates were low (Roemer et al. 2001*b*) for Santa Cruz Island foxes. Seasonal home range sizes were estimated for wet and dry seasons (Crooks and Van Vuren 1996) but not for seasons based on energetic demands or behavioral characteristics (Roemer et al. 2001*b*). Seasonal site fidelity and home range size relative to age remains unknown for all island foxes. The Channel Islands vary in size, diversity of habitat, diversity of species, and microclimate (Schoenherr et al. 1999, Yoho et al. 1999). Laughrin (1977) speculated that these variations might result in differences in abundance, habitat use, and age structure among island fox populations.

My objectives were to estimate annual and seasonal home ranges and core areas as a function of gender, age, and season; assess seasonal site fidelity as a function of gender, age, and season; and determine dispersal rates and distances for the San Clemente Island fox. Because of the high incidence of vehicle-related mortalities, I also compared home range and core areas for foxes with home ranges that included and excluded primary roads.

STUDY AREA

I conducted my study on the northern two-thirds of San Clemente Island, but excluded portions on the eastern escarpment with >25° slope, above a northern boundary 300 m north of the airport runway, and below a southern boundary designated by a Navy training area (Figure 1). My study area comprised 81 of 146 km^2 of the island. San

Clemente Island is the southernmost Channel Island located approximately 109 km west-northwest of San Diego. It is 34 km long, up to 6.4 km wide, and characterized by steep cliffs on the eastern slope, a gentler western slope with marine terraces, and deep canyons running from the upper plateau (maximum elevation = 599 m) to the shoreline on both sides of the island (Olmstead 1958, Schoenherr et al. 1999). Maritime desert scrub (55%) and grassland (33%) comprised the majority of plant communities on San Clemente, and 7% of the island is disturbed (U.S. Department of the Navy, unpublished report). Mean summer and winter temperatures on the island are 18 and 13˚C, respectively, with average annual rainfall varying between 150 and 300 mm depending on the location on the island (Schoenherr et al. 1999). Weather station data from San Clemente Island indicate drought conditions were present during my study period; mean temperature was 16 ˚C with total rainfall of 80 mm from August 2006 to December 2007 (California State University Northridge 2011). Primary roads within my study area consisted of approximately 41 km of maintained, 2-lane paved or graded gravel roads 5.5–7.5 m wide. A single primary road extended the length of the island, from below the airport on northern end to the southern tip of the island. There are typically about 500 military personnel and civilian subcontractors on the island (U.S. Department of the Navy, unpublished report).

METHODS

Capturing Foxes

I used the Reversed Randomized Quadrant-Recursive Raster algorithm (Theobald et al. 2007, Theobald and Norman 2006) in ArcGIS 9.2 at 30 m resolution to produce spatially balanced random trapping locations throughout the study area (Figure 2). This probability-based survey design assumed uniform density of the fox population. I live-trapped foxes using 23 x 23 x 66-cm cage traps (Tomahawk Live Trap Co., Tomahawk, WI) with either 2.54 x 2.54 cm-mesh or 1.27 x 2.54-cm mesh, baited with dry cat food and a lure. Plexiglass was attached to the inside of the front doors, and a 46-cm-long polyethylene tube chew-bar installed on the inside of traps to minimize trap-related injures (Coonan et al. 2005). For protection from the elements, sides and tops of traps were covered with burlap and vegetation. Traps were set in the evening and checked starting at sunrise.

During 18 July–24 August 2006, 1 trap was set at each location for 2 nights and ≤2 foxes collared at each location until I obtained a random sample of 50 foxes (Figure 2). Foxes were aged upon capture, weighed, checked for reproductive status, and examined for general physical condition. They were assigned to 1 of 5 age classes according to amount of wear on the first upper molar (Wood 1958, Collins 1987): 0–12 months (age class 0), 13–24 months (age class 1), 25–36 months (age class 2), 37–48 months (age class 3), and ≥49 months (age class 4). Due to minimum body mass restrictions, only 1 fox in the youngest age class (age class 0) was radio-collared during my study. Similar to Crooks (1994), I recognized the subjectivity of categorizing continuous tooth wear into discrete age classes and later pooled the age classes into 3 age groups comprised of young foxes (age classes 0 and 1), adults (age classes 2 and 3), and old adults (age class 4). I used trap records (*n* = 33) from previous years when possible (Institute for Wildlife Studies, unpublished data), and cementum annulation (*n* = 15; Matson’s Laboratory, Milltown, MT) if foxes died during or after my study, to improve estimates of age. Foxes were fitted with 45-g radio-telemetry collars (Advanced

Telemetry Systems, Isanti, MN) and released at the site of capture; collars comprised 2.4% of average body weight of foxes. I also implanted a Passive Integrated Transponder tag (Biomark, Boise, ID) between and just anterior to the scapulae. Capture, handling, collaring, and monitoring protocols were approved by Colorado State University's Institutional Animal Care and Use Committee (protocol 06-098A-01) and California Department of Fish and Game.

The 33 km of primary roads on which ≥70% of vehicle-related fox mortalities occurred during 2000–2006 (Institute for Wildlife Studies, unpublished data) constituted my study roads, and included the road surrounding the airport and the main artery extending the length of the island (Figure 1). Between mid-August and early September 2006, ≥30 telemetry locations per fox were obtained stratified across the diel period to determine if home ranges for foxes in the random sample appeared to include one of the study roads. Foxes (n = 10) found on both sides of one of the study roads were included in the "road" sample; all other foxes comprised the "non-road" sample. The study roads were then divided into 20 1.2-km sections from the north end of the island to Stone Gate (Figure 1) and 1 trap was set for 2 nights at the midpoint of each of the 12 road sections where a road fox had not already been collared. If this did not yield a fox, successive traps were placed at quarter-points (in randomly-selected order) of road sections; a fox was captured within 6 trap nights in all cases. A maximum of 1 fox was radio-collared in each of the road sections from 09–14 September. When 3 foxes in the random sample were later located on both sides of a study road, they were re-classified as road foxes. One fox that was captured for the road sample never returned to the study roads and was thus included in the non-road sample. Foxes that died before December 2006 were replaced by capturing and radio-collaring additional foxes at random locations (for the random sample) or in the vacated road segment (for the road sample).

Radio-telemetry

Foxes were monitored from mid-August 2006 to mid-December 2007. During 15 October 2006–14 October 2007, I radio-located foxes every 2 hrs during 1 8-hr period (0000–0759, 0800–1559, 1600–2359) that rotated every 1–1.5 weeks. I minimized autocorrelation between successive radio-locations (Swihart and Slade 1985*a,b*) by spacing location attempts 2 h apart (Harris et al. 1990, Salvatori et al. 1999). Prior to the home range study (i.e., 18 August – 14 October 2006), foxes were radio-located opportunistically. After the home range study (15 October – 08 December 2007), 1 location was obtained on each fox every 1–2 weeks.

I established Universal Transverse Mercator (UTM) coordinates (North American Datum 1983, UTM Zone 11N) for >350 tracking stations along all roads in the study area to facilitate recording data (Figure 3). I monitored radio signals with a receiver (Advanced Telemetry Systems, Isanti, Minnesota) connected to a vehicle-mounted, stacked-array of 2 6-element antennae using a null-peak system. Foxes were located from 1 vehicle and directional azimuths were obtained in succession from 3 locations (i.e., “triangulated”). Inherent in radio-telemetry data collection is increased likelihood for error with increased distance from the source of the signal (White and Garrott 1990). I minimized locational error and elapsed time between telemetry bearings by obtaining bearings >20˚ and <160˚ apart and striving to obtain consecutive bearings ≤5 minutes apart. Most of my triangulations were completed within 15 min and I discarded locations >20 minutes apart (Crooks and Van Vuren 1996).

To minimize error from radio-tracking equipment, I tested equipment monthly and corrected my data by the average difference between antenna bearing and true bearing to a reference radio collar. I averaged the differences for each of the 2 vehicle-mounted tracking units over the study period (n_1 = 45, $\bar{x}_1$ = 1.24°, SD_1 = 1.55; n_2 = 38 $\bar{x}_2$ = −0.76°, SD_2 = 1.56) and used a slightly more conservative estimate (SD = 2) to represent bearing error when estimating UTM locations of foxes. I also corrected my data by the average magnetic declination (12.817°) during the study period.

Home Range Estimation

I used Location of a Signal software (Ecological Software Solutions, Urnäsch, Switzerland) to estimate UTM locations of foxes (Figure 7). I used the Andrews M-Estimator, a modification of the Maximum Likelihood Estimator (MLE; Lenth 1981*a, b*) that rejects aberrant bearings, because it is considered the best method when triangulating with ≥3 bearings (Garrott et al. 1986, White and Garrott 1990). If the Andrews M-Estimator failed to produce a location, I secondarily used MLE, and lastly used the best biangulation. I calculated an error ellipse ($\bar{x}$ = 10,150 m^2, SE = 738) or error polygon ($\bar{x}$ = 30,496 m^2, SE = 8,528) for each location estimate and established a maximum confidence error ellipse (>52,500 m^2; Figure 4) and error polygon (>22,711 m^2; Figure 5) as a means of setting objective thresholds for including data (White and Garrott 1990, Saltz 1994).

To produce representative home ranges, I included only foxes for which ≥80% of attempts to radio-locate a fox were successful. I estimated home ranges using the 95% isopleth (White and Garrott 1990, Laver and Kelly 2008) of the utilization distribution (UD; Van Winkle 1975) excluding excursions, which can greatly influence home range estimates (Dunn and Gipson 1977, Kernohan et al. 2001) and bias them to include largely unused areas (Kenward 2001). I defined an excursion as a temporary movement ≥1 km from the nearest location within the 95% UD isopleth calculated with all excursions included (Adams et al. 2008, Skuldt et al. 2008). For 2 foxes that used 2 distinct (i.e., split) home ranges throughout the monitoring period, I estimated separate UDs then combined them into a cumulative home range. Home ranges that overlapped the ocean were clipped at the shoreline. I defined a core area as the inflection point on a plot of area against fixed-kernel UD isopleths (Harris et al. 1990, Bingham and Noon 1997). Following Roemer et al. (2001*b*) and Kitchen et al. (2005), I identified 3 seasons corresponding with the reproductive chronology of San Clemente Island foxes (Resnik and Andelt 2011): breeding and gestation ("Breeding"; 15 October 2006–14 February 2007), parturition and pup-dependence ("Pup-dependence"; 15 February–14 June 2007), and pup-independence and dispersal ("Pup-independence"; 15 June–14 October 2007).

Seaman et al. (1999) recommended ≥30 observations per animal and preferably ≥50 to produce a reliable kernel estimate of a home range. However, several studies claim to have found accurate estimates using 10–20 fixes (Powell 2000, Said et al. 2005, Borger et al. 2006). I used ≥30 locations (Kernohan et al. 2001) and foxes located >2/3 of a given season to estimate seasonal home ranges and core areas. I constructed observation-area curves (Cain 1938, Odum and Kuenzler 1955) using the 95% UD isopleth and chronological increments of 5 consecutive locations (Harris et al. 1990) to ascertain that an asymptote was reached at approximately 60 locations (Figure 6). I estimated annual home ranges for foxes that were monitored during all 3 seasons and therefore had ≥90 total locations. To avoid confounding my comparisons between the road and non-road samples, I used PROC TTEST (SAS Institute, Cary, NC) to assess whether error ellipses, number of locations used to estimate the 95% UD, or least-squares cross-validation (LSCV) bandwidth differed ($P < 0.05$) between samples. I also considered the possibility of correlation between number of locations, LSCV bandwidth, and 95% UD ($P < 0.05$; PROC CORR).

I estimated home ranges (Figures 8–10) using Animal Movement SA Extension (Hooge and Eichenlaub 2000) in ArcView 3.3, the kernel density estimator (Silverman 1986; Worton 1987, 1989), fixed smoothing technique (Seaman and Powell 1996), and LSCV for bandwidth selection (Worton 1989, Seaman et al. 1999, Powell 2000). Kernel density estimation is still the most widely acceptable method of home range estimation despite the lack of a general variance expression, assumption of independent locations, influence of point-pattern distribution, and sensitivity to bandwidth choice (Silverman 1986, Kernohan et al. 2001, Hemson et al. 2005, Downs and Horner 2008). I also estimated annual home ranges as 95% minimum convex polygons (MCP) to allow comparison with previous studies of island foxes (Harris et al.1990). To accurately represent the land area covered by a home range, I calculated topographic surface area (Powell and Mitchell 1998, Greenberg and McClintock 2008) from flat, planimetric area using a 10-m digital elevation model (Jenness 2004).

Data Analyses

I estimated site fidelity between seasons for individual foxes by calculating an index of spatial overlap consisting of the intersection of seasonal home ranges or core areas divided by the union of the seasonal home range or core areas (Millspaugh et al. 2004). I used proportion of overlap among all seasons to represent overall site fidelity within the year and proportion of overlap between paired, consecutive seasons to investigate seasonal space use patterns (Phillips et al. 1998). I defined dispersal as 1-way movement of an individual from an area that had been occupied for a period of time (White and Garrott 1990). Dispersal among adult and sub-adult red foxes predominantly occurs during fall and winter (Storm et al. 1976) which corresponds to the Breeding and Pup-dependence seasons in my study. To distinguish dispersal from a shift in seasonal home ranges, I used no overlap between the first (Breeding) and last (Pup-independence) of my 3 seasons as evidence of possible dispersal. I also examined telemetry data collected before and after the home range study for 1-way movements. Evidence of possible dispersal was indicated by locations occurring outside the calculated fixed-kernel and MCP annual home range boundary that were not preceded (for data collected 18 August – 14 October 2006) or followed (for data collected 15 October – 08 December 2007) by locations within the home range boundary.

I used multiple regression analyses (PROC MIXED) to model size and site fidelity (i.e., overlap) of home ranges and core areas using covariates; comparisons across all 3 seasons were treated as repeated measures. I evaluated 5 covariates in single-variable a priori models: Gender (male, female); Age (younger, intermediate adult, older adult); Season (Breeding, Pup-dependence, Pup-independence); Seasons (paired: breeding/pup-dependence, pup-dependence/pup-independence, pup-independence /breeding); and Road (road or non-road sample). I considered interactions in post hoc models based on biological interest and results of analyses from a priori models. Response variables (e.g., home range size, site fidelity) were log-transformed to better meet the assumptions of normality and homogeneity of variances for multiple regression.

I used an information-theoretic approach with Akaike's Information Criterion corrected for small sample sizes (AIC_c) and deviation of AIC_c values (ΔAIC_c) from the lowest value in the model suite to identify models with strong support ($\Delta AIC_c < 2$), weak support ($\Delta AIC_c = 2–10$), and no support ($\Delta AIC_c > 10$) from the data (Burnham and Anderson 2002). Analyses using seasonal data for the road and non-road samples were exploratory. I calculated parameter estimates for variables contained in models with $\Delta AIC_c < 2$ and ascertained if 95% confidence intervals overlapped zero to determine importance of parameters (Anderson 2008, Arnold 2010). For analyses involving the road and non-road samples, parameter estimates and confidence intervals were provided for only the variable of interest (Road), or interactions containing this variable.

RESULTS

From 18 July–30 November 2006, 65 foxes (28 M, 37 F) were captured and radio-collared including 4 replacements for mortalities. Trap success was 51% when obtaining my random sample (62 foxes captured in 122 trap nights) including 2 recaptures and 8 foxes I did not radio-collar due to oversampling or minimum body mass restrictions (i.e., pups). Four foxes in the random sample (2 each in the road and non-road samples) and 5 additional foxes in the road sample died before I collected data for all 3 seasons. Eleven foxes could not be monitored using vehicle-mounted equipment due to study area restrictions. Thirty-seven of the remaining 45 foxes (>82%) met my standards for inclusion in annual and seasonal home range and core area analyses (Tables 1–3). Fourteen males and 23 females were distributed as 13 younger foxes, 16 intermediate foxes, and 8 older foxes across the 3 study samples. Male foxes ($\bar{x}$ = 2.0 kg) weighed more than females ($\bar{x}$ = 1.8 kg; $\beta = 0.18$, 95% CI = 0.03 to 0.33).

From 18 August – 10 December 2007, I recorded approximately 8,900 locations of foxes (>95% triangulations; Figure 7) and excluded <4% for exceeding error thresholds. Twenty-three unique excursions among 8 foxes (3 M, 5 F) were identified and removed from home range calculations. Annual and seasonal home ranges were calculated using an average of 151 locations (SE = 4, range = 113–194) and 50 locations (SE = 1, range = 30–71), respectively. I found evidence that the road sample had smaller error ellipses ($\bar{x}$ = 3,232 m^2, SE = 84) than the non-road sample ($\bar{x}$ = 6,043 m^2, SE = 151; $P < 0.001$) but larger bandwidths ($\bar{x}$ = 94, SE = 6) than the non-road sample ($\bar{x}$ = 68, SE = 4; $P < 0.001$). More locations were obtained on road foxes ($\bar{x}$ = 153, SE = 10) than non-road foxes ($\bar{x}$ = 132, SE = 3; $P = 0.049$). We found some evidence that number of locations was correlated with size of bandwidth ($\rho = -0.29$, $P = 0.067$) but no evidence that number of locations was correlated with size of 95% fixed-kernel UD ($\rho = -0.047$, $P = 0.779$).

Sizes of Home Ranges and Core Areas

Topographic fixed-kernel estimates (Tables 1–2) were on average 2% larger (SE = 0.4) than planimetric fixed-kernel estimates. Ninety-five percent MCP annual home range topographic estimates for my random sample averaged 0.62 km^2 for males (SE = 0.13), 0.86 km^2 for females (SE = 0.13), and 0.76 km^2 overall (SE = 0.09) and were 10% larger, 9% smaller, and 2% smaller, respectively, than my topographic fixed-kernel estimates (Table 1). The inflection point corresponding to annual core area size occurred at the 68% UD isopleth on average (SE = 2, range = 50–85).

Random Sample.– The minimum AIC$_c$ models included Gender as the predictor for annual home range and core areas (Table 2). However, annual home range (β_{gender} =

−0.13, 95% CI = −0.55 to 0.29) and core area (β_{gender} = −0.10, 95% CI = −0.56 to 0.36) sizes did not differ between genders (Table 1). The minimum AIC_c model included Season as the predictor for seasonal home range sizes. Home ranges during Pup-independence were 12% larger compared to Pup-dependence (β_{season} = 0.20, 95% CI = 0.01 to 0.38) and 16% larger compared to Breeding (β_{season} = 0.24, 95% CI = 0.08 to 0.40) whereas home range sizes during Breeding and Pup-dependence did not differ (β_{season} = −0.04, 95% CI = −0.17 to 0.09). The minimum AIC_c model included Season and a closely ranked second model (ΔAIC_c = 0.4) included Gender as predictors for seasonal core areas. Seasonal core area sizes did not differ between genders (β_{gender} = 0.001, 95% CI = −0.39 to 0.40) and seasons (Pup-independence and Pup-dependence, β_{season} = 0.20, 95% CI = −0.02 to 0.41; Pup-independence and Breeding, β_{season} = 0.17, 95% CI = −0.09 to 0.42; Breeding and Pup-dependence, β_{season} = 0.03, 95% CI = −0.19 to 0.25).

Road and Non-road Samples.– The minimum AIC_c model included Road as the predictor for all analyses (Table 3). Annual home ranges were 77% larger (β_{road} = 0.59, 95% CI = 0.25 to 0.93) and annual core areas were 82% larger (β_{road} = 0.57, 95% CI = 0.22 to 0.93) for road foxes compared to non-road foxes (Table 4). Seasonal home ranges were 66% larger (β_{road} = 0.64, 95% CI = 0.35 to 0.93) and seasonal core areas were 59% larger for road foxes than non-road foxes (β_{road} = 0.47, 95% CI = 0.15 to 0.80). A post-hoc model that considered Road + Season + Road x Season as predictors for seasonal home range areas had a lower AIC_c value than a priori models (Table 3). Home ranges for road foxes compared to non-road foxes were 110% larger during Breeding (β_{season} = 0.72, 95% CI = 0.34 to 1.09), 59% larger during Pup-independence (β_{season} =

0.52, CI = 0.21 to 0.82), but not different during Pup-dependence (β_{season} = 0.23, 95% CI = −0.17 to 0.63).

Home Range and Core Area Site Fidelity

Random Sample.– The minimum AIC$_c$ models included Gender as the predictor of site fidelity among all seasonal home ranges and core areas and between paired seasonal home ranges (Table 5). Overlap among all seasonal home ranges was 33% larger for males than females (β_{gender} = 0.09, 95% CI = 0.02 to 0.16), but did not differ by gender among all seasonal core areas (β_{gender} = −0.01, 95% CI = −0.07 to 0.05; Table 6). Overlap between paired seasonal home ranges was 19% greater for males than females (β_{gender} = 0.08, 95% CI = 0.02 to 0.14). The minimum AIC$_c$ model included Season and a closely ranked second model (ΔAIC$_c$ = 0.7) included Gender as predictors for paired seasonal core areas. However, amount of overlap did not differ between genders (β_{gender} = −0.02, 95% CI = −0.08 to 0.04) or paired seasons (Breeding/Pup-dependence and Pup-dependence/Pup-independence, $\beta_{seasons}$ = 0.07, 95% CI = −0.001 to 0.13; Pup-dependence/Pup-independence and Pup-independence/Breeding, $\beta_{seasons}$ = −0.03, 95% CI = −0.09 to 0.04; Breeding/Pup-dependence and Breeding/Pup-independence, $\beta_{seasons}$ = 0.04, 95% CI = −0.04 to 0.12).

Road and Non-road Samples.– Top models (ΔAIC$_c \leq 2$) included Road as a predictor of site fidelity among all seasonal home ranges and core areas (Table 7). However, amount of overlap among all seasons did not differ between road and non-road fox home ranges (β_{road} = −0.04, 95% CI = −0.11 to 0.04) and core areas (β_{road} = −0.05, 95% CI = −0.10 to 0.003). Road was not included in top models for overlap between paired seasonal home ranges but was included for paired seasonal core areas. However, I did not detect a difference in amount of overlap between paired seasonal core areas for road and non-road foxes ($\beta_{road} = -0.05$, 95% CI = −0.11 to 0.004).

Dispersal

I detected no dispersal activity during the home range study (October 15 2006 – October 15 2007) for any foxes in the random sample. Overlap existed between the first and last seasonal home ranges for all foxes, and the amount of overlap between these non-consecutive seasons was similar to the amount of overlap between consecutive seasons (Table 3). Limited radio-telemetry data suggest 1 male and 1 female fox may have started dispersing during September – December 2007 but data are not conclusive. The last 2 locations I obtained on the male fox were 11 days apart and in the same area >1.5 km outside his FK home range boundary. I obtained the last 2 locations on the female fox 25 days apart and in the same area 0.18 km outside her FK home range boundary. Additionally, 1 male fox not in the random sample (i.e., exclusively in the road sample) was located a final 6 times in the same area 2.5 – 2.9 km from his FK home range boundary over the last 8 weeks of monitoring (October – December 2007). For each of these foxes, no previous excursions had been detected during the 16 months they were monitored. Although they may have started dispersing, data are inadequate to determine if dispersal occurred.

DISCUSSION

Island foxes are thought to have one of the smallest home range sizes of any canid (Roemer et al. 2001*b*). Annual home range size estimates for my random sample were 36% and 116% larger, respectively, than previous home range estimates for island foxes that were generalized from studies on the Santa Cruz Island subspecies (Roemer et al.

2001*b*, Crooks and Van Vuren 1996). Nonetheless, my comparable MCP estimate is less than half the size reported for the next-smallest home range (1.56 km^2 80% MCP) belonging to Blanford's fox (*V. cana*; Geffen et al. 1992), and affirms that island foxes have one of the smallest home ranges of any canid. My annual core area estimates were 68% larger than those estimated by Crooks and Van Vuren (1996) although I note these authors defined core areas using a standard 50% isopleth while my core areas were derived from the data with isopleths varying between 50–85 ($\bar{x}$ = 67.5). Recent studies demonstrate that areas of concentrated use (i.e., core areas) are better defined empirically rather than with an arbitrary value (Powell 2000, Burdett et al. 2007).

My result that home range and core area size did not differ between genders agrees with previous studies (Crooks and Van Vuren 1996, Roemer et al. 2001*b*). I found evidence that home range size varies seasonally which agrees with observations from early studies dividing the year into ≥3 seasons (Laughrin 1977, Fausett 1982), but differs from a more recent study dividing the year into only 2 seasons (Crooks and Van Vuren 1996). However, my result that core area size was similar between seasons agrees with Crooks and Van Vuren (1996). Only 15% of female foxes on San Clemente Island whelped pups during 2007 (Resnik and Andelt 2011). I suspect that differences in seasonal home range and core area sizes may be more pronounced during years with greater reproductive success. In particular, they would be smaller during the pup-dependence season when movement is restricted by caregiving. I did not find differences in home range or core area size or overlap among age groups. This may be due to island foxes reaching sexual maturity at 1 year (Laughrin 1977, Clifford et al. 2007) and only 1 fox <12 months old in my study.

My study provides the first rigorous annual and seasonal home range and core area estimates for San Clemente Island foxes. I exercise caution when making comparisons to other studies due to variability in study periods, protocols of data collection, and methods of estimating home ranges and core areas. Rigorous home range estimates are recommended for better estimating the sampling area of mark-recapture grids (Dice 1938, White et al. 1982, Parmenter et al. 2003). Population monitoring of San Clemente Island foxes has been ongoing with few interruptions (1998, 2005–2006) since 1988, and annual efforts typically occur June–August (Institute for Wildlife Studies, unpublished data; Garcia and Associates, unpublished data). I found home range size can fluctuate between seasons, and thus population size and density estimates may be improved by utilizing home range estimates for the appropriate season.

Use of space by foxes with home ranges including and excluding roads is of particular interest given the high rate of vehicle-related mortalities on San Clemente Island. I originally suspected that home ranges encompassing a road were larger because foxes might use them as movement corridors, but Snow et al. (2011) did not locate foxes on roads more than expected at random. My exploratory analysis of seasonal differences revealed that home ranges were larger for road foxes compared to non-road foxes (regardless of gender) during seasons without parenting requirements. I speculate that home range size during the pup-dependence season is more biologically driven than during other seasons for both genders; both male and female foxes are known to exhibit parental care (Garcelon et al. 1999). Starting in the fall, adults spend less time with their pups and range more widely (Fausett 1982).

Excluded from my home range analyses were 19 non-road foxes, 11 due to study area restrictions and 8 with excessive error ellipses and/or low probabilities of being located. These foxes resided in areas with the highest topographic relief in my study area. My inability to include these foxes in analyses may explain the small difference (range = 0-7%) I found between my topographic and planimetric home range estimates. I would expect more substantial differences if those foxes were included. Topography varies considerably among the Channel Islands; several of the islands hosting fox populations have steep cliffs and deep canyons with maximum elevation ranging from 253 m (San Miguel Island) to 753 m (Santa Cruz Island; Schoenherr et al. 1999). Previous home range studies on island foxes used planimetric home range estimates. It is probable that the surface areas represented by those planimetric estimates would yield larger home range and core area estimates; how similar those estimates would be to those I calculated for San Clemente Island foxes is unknown. Accounting for topography in areas of high relief is important for accurately estimating land area utilized and resources available.

My results suggest there is seasonality in home range distribution on San Clemente Island. I found less home range and core area overlap among all seasons than I expected based on previous findings on Santa Cruz Island that foxes were territorial (Roemer et al. 2001*b)* and maintained the same home range year-round (Crooks and Van Vuren 1996). However, site fidelity in the latter study appears to have been assessed by comparing home range size and not spatial orientation; it is unclear if seasonal home ranges were as spatially stable as those authors indicated. My finding that males have similar core area fidelity to females but more home range fidelity than females supports the idea that male island foxes “patrol” their home range and are involved in territory formation and maintenance (Roemer et al. 2001*b*) despite the higher costs associated with insular territorial vertebrates defending a territory (Stamps and Buechner 1985). I speculate that low reproductive success, as observed in 2007 (Resnik and Andelt 2011), could also produce less seasonal site fidelity than during years of higher reproductive success.

It is possible that I observed seasonal differences in home range configuration because I calculated seasonal home ranges using as few as 30 locations. Seasonal home ranges may have not yet reached an asymptote and could be somewhat underestimated. Partial home range overlap between seasons could also be explained as either seasonal shift in space use, as home range “drift” across a landscape which has been observed in red foxes (Storm et al. 1976, Doncaster and Macdonald 1991), or use of inadequate data. Home range studies spanning >1 year would help ascertain if home range drift occurs in island foxes. Seasonal shifts in home range size and configuration have also been seen as a direct consequence of changes in distribution of foxes due to deaths of one fox in a mated pair (Roemer 1999).

I found no evidence of dispersal among the random sample during my home range study. Limited data at the end of and 2 months after the home range study suggested possible dispersal for ≤ 7% of the random sample. My finding of minimal dispersal is consistent with findings on Santa Cruz Island where only 8% of adult foxes dispersed (Roemer et al. 2001*b*). Golden eagle predation was suggested as a possible cause of low dispersal rates and distances (0.16 km, 3.24 km) on Santa Cruz Island (Roemer et al. 2001*b*) but my findings were similar despite the absence of golden eagles on San Clemente Island. Low dispersal among adult foxes is not surprising. The tendency for red foxes to disperse is less pronounced among adults; and when it occurs, it is predominantly during fall and winter for both adults and sub-adults (Storm et al. 1976). In contrast, Roemer et al. (2001*b*) observed ≥1/3 of juvenile foxes (i.e. <12 months old) dispersed on Santa Cruz Island. I was unable to radio-collar juveniles in my study and this remains an area for further research on San Clemente Island.

It is unknown how drought conditions present during my study affected my estimates of home range size and site fidelity. In light of projections for increased drought in the western U.S. (Bates et al. 2008), home range estimates obtained during years of drought and non-drought would help inform managers of the effect of climatic stress on San Clemente Island foxes.

MANAGEMENT IMPLICATIONS

I found considerable disparity between my home range and core area estimates and those from previous island fox studies on Santa Cruz Island. While this may be partly due to different methodologies, it may also indicate that differences exist in spatial ecology between the other island fox subspecies. Given the endangered status of 4 of 6 subspecies as well as differences in climate, habitat, food sources, causes of mortality, and population pressures among the Channel Islands, population monitoring and management strategies could be improved with island-specific home range studies for their respective island fox populations. In light of ongoing population monitoring of foxes on all 6 islands, the most immediate application would be better estimates for the size of buffers around grids used for estimating population size and density.

Table 1. Topographic fixed-kernel annual and seasonal home ranges (km^2; 95% isopleth) and core areas (km^2; variable isopleths) by gender for a random sample of San Clemente Island foxes, California, USA, 2006–2007.

		Seasonal		
Random sample	Annual	Breeding	Pup-dependence	Pup-independence
Home range				
Total (*n* = 29)				
$\bar{x}$	0.75	0.66	0.68	0.76
SE	0.09	0.10	0.11	0.07
Range	0.19–2.69	0.17–2.85	0.15–3.14	0.21–1.66
Male (*n* = 12)				
$\bar{x}$	0.69	0.57	0.63	0.71
SE	0.13	0.11	0.10	0.15
Female (*n* = 17)				
$\bar{x}$	0.79	0.72	0.71	0.79
SE	0.14	0.15	0.17	0.07
Core area				
Total (*n* = 29)				
$\bar{x}$	0.19	0.15	0.14	0.16
SE	0.03	0.02	0.02	0.02
Range	0.05–0.64	0.04–0.65	0.03–0.39	0.04–0.39
Male (*n* = 12)				
$\bar{x}$	0.19	0.15	0.14	0.16
SE	0.05	0.03	0.02	0.04
Female (*n* = 17)				
$\bar{x}$	0.19	0.16	0.13	0.16
SE	0.03	0.04	0.02	0.02

Table 2. Model selection results for multiple regression models predicting annual and seasonal[a] home range and core area sizes for a random sample of San Clemente Island foxes, California, USA, 2006–2007.

Models	K	AIC_c	ΔAIC_c	w_i
Annual home range				
Gender	3	56.4	0.0	0.81
Age	4	59.3	2.9	0.19
Annual core area				
Gender	3	61.6	0.0	0.80
Age	4	64.4	2.8	0.20
Seasonal home range				
Season	4	119.7	0.0	0.87
Gender	3	123.9	4.2	0.11
Age	4	127.0	7.3	0.02
Seasonal core area				
Season	4	167.7	0.0	0.46
Gender	3	168.1	0.4	0.38
Age	4	169.9	2.2	0.15

[a] I divided the year into 3 seasons: Breeding, Pup-dependence, and Pup-independence.

Table 3. Model selection results for multiple regression models predicting annual and seasonal[a] home range and core area sizes for road and non-road samples[b] of San Clemente Island foxes, California, USA, 2006–2007.

Models	K	AIC_c	ΔAIC_c	w_i
Annual home range				
Road	3	63.8	0.0	0.99
Gender	3	74.0	10.2	0.01
Age	4	75.5	11.7	0.00
Annual core area				
Road	3	68.4	0.0	0.98
Gender	3	77.0	8.6	0.01
Age	4	78.7	10.3	0.01
Seasonal home range[c]				
Road	3	157.8	0.0	0.99
Season	4	167.5	9.7	0.01
Gender	3	168.5	10.7	0.00
Age	3	170.7	12.9	0.00
Seasonal core area				
Road	3	214.1	0.0	0.94
Gender	3	221.3	7.2	0.03
Age	4	222.2	8.1	0.02
Season	4	222.5	8.4	0.01

[a] I divided the year into 3 seasons: Breeding, Pup-dependence, and Pup-independence.

[b] Foxes had a home range either overlapping (Road sample) or not overlapping (Non-road) a study road.

[c] Post-hoc models: Road + Season + Road×Season ($AIC_c = 149.6$), Road + Season ($AIC_c = 158.9$).

Table 4. Topographic fixed-kernel annual and seasonal[a] home ranges (km^2; 95% isopleths) and core areas (km^2; variable isopleths) for road and non-road samples[b] of San Clemente Island foxes, California, USA, 2006–2007.

		Seasonal		
Road and non-road samples	Annual	Breeding	Pup-dependence	Pup-independence
Home range				
Road (*n* = 18)				
$\bar{x}$	1.07	1.07	0.82	0.95
SE	0.15	0.17	0.16	0.09
Range	0.55–2.69	0.44–2.85	0.19–3.14	0.42–1.65
Non-road (*n* = 19)				
$\bar{x}$	0.60	0.51	0.60	0.60
SE	0.09	0.07	0.08	0.08
Range	0.19–1.67	0.17–1.27	0.15–1.58	0.21–1.66
Core area				
Road (*n* = 18)				
$\bar{x}$	0.26	0.24	0.16	0.20
SE	0.02	0.04	0.03	0.02
Range	0.11–0.64	0.04–0.65	0.04–0.38	0.03–0.38
Non-road (*n* = 19)				
$\bar{x}$	0.15	0.12	0.13	0.13
SE	0.04	0.02	0.02	0.02
Range	0.05–0.46	0.04–0.34	0.03–0.39	0.04–0.39

[a] I divided the year into 3 seasons: Breeding, Pup-dependence, and Pup-independence.

. [b] Foxes had a home range either overlapping (Road sample) or not overlapping (Non-road) a study road.

Table 5. Model selection results for multiple regression models predicting site fidelity among all and between paired[a] seasonal home ranges or core areas for a random sample of San Clemente Island foxes, California, USA, 2006–2007.

Models	K	AIC_c	ΔAIC_c	w_i
All seasonal home ranges				
Gender	3	−47.5	0.0	0.98
Age	4	−39.7	7.8	0.02
All seasonal core areas				
Gender	3	−56.9	0.0	0.76
Age	4	−54.6	2.3	0.24
Paired seasonal home ranges				
Gender	3	−119.9	0.0	0.75
Seasons	4	−117.5	2.4	0.23
Age	4	−113.2	6.7	0.03
Paired seasonal core areas				
Seasons	4	−77.1	0.0	0.52
Gender	3	−76.4	0.7	0.37
Age	4	−73.9	3.2	0.11

[a] Pairs consist of consecutive seasons (Breeding and Pup-dependence, Pup-dependence and Pup-independence) or non-consecutive seasons (Pup-independence and Breeding).

Table 6. Site fidelity (i.e., proportion of overlap) among all and between paired seasonal fixed-kernel home ranges (km^2; 95% isopleth) and core areas (km^2; variable isopleths) for a random sample of San Clemente Island foxes, California, USA, 2006–2007.

Random sample	All seasons	Paired seasons: Breeding and Pup-dependence[a]	Paired seasons: Pup-dependence and Pup-independence[a]	Paired seasons: Pup-independence and Breeding[b]
Home range				
Total (n = 29)				
$\bar{x}$	0.32	0.52	0.47	0.45
SE	0.02	0.02	0.02	0.02
Range	0.18–0.50	0.30–0.72	0.22–0.69	0.20–0.67
Male (n = 12)				
$\bar{x}$	0.38	0.56	0.52	0.50
SE	0.03	0.04	0.03	0.04
Female (n = 17)				
$\bar{x}$	0.28	0.49	0.43	0.41
SE	0.02	0.03	0.03	0.02
Core area				
Total (n = 29)				
$\bar{x}$	0.12	0.31	0.24	0.27
SE	0.02	0.03	0.03	0.03
Range	0.00–0.34	0.05–0.54	0.00–0.46	0.04–0.77
Male (n = 12)				
$\bar{x}$	0.11	0.29	0.25	0.24
SE	0.01	0.03	0.03	0.03
Female (n = 17)				
$\bar{x}$	0.12	0.31	0.23	0.29
SE	0.03	0.04	0.04	0.04

[a] Consecutive seasons.

[b] Non-consecutive seasons.

Table 7. Model selection results for multiple regression models predicting site fidelity among all and between paired[a] seasonal home ranges or core areas for road and non-road samples[b] of San Clemente Island foxes, California, USA, 2006–2007.

Models	K	AIC_c	ΔAIC_c	w_i
All seasonal home ranges				
Gender	3	−51.1	0.0	0.62
Road	3	−49.7	1.4	0.31
Age	4	−46.9	4.2	0.08
All seasonal core areas				
Road	3	−78.4	0.0	0.74
Gender	3	−75.8	2.6	0.20
Age	4	−73.4	5.0	0.06
Paired seasonal home ranges				
Seasons	4	−146.6	0.0	0.49
Gender	3	−145.5	1.1	0.28
Road	3	−144.4	2.2	0.16
Age	4	−142.8	3.8	0.07
Paired seasonal core areas				
Road	3	−108.0	0.0	0.45
Seasons	4	−107.1	0.9	0.29
Gender	3	−106.3	1.7	0.19
Age	4	−104.2	3.8	0.07

[a] Pairs consist of consecutive seasons (Breeding and Pup-dependence, Pup-dependence and Pup-independence) or non-consecutive seasons (Pup-independence and Breeding).

[b] Foxes had a home range either overlapping (Road sample) or not overlapping (Non-road) a study road.

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PART II

REPRODUCTIVE ECOLOGY AND DEN SITE CHARACTERISTICS OF THE SAN CLEMENTE ISLAND FOX

REPRODUCTIVE ECOLOGY AND DEN SITE CHARACTERISTICS OF THE SAN CLEMENTE ISLAND FOX

The island fox is endemic to six of California's eight Channel Islands and is red-listed by the International Union for the Conservation of Nature as critically-endangered throughout its range. Little is known about reproduction and denning of the San Clemente Island fox (*Urocyon littoralis clementae*), and island foxes in general. I monitored the movements of 27 radio-collared females during 2007 to determine the proportion producing litters, number of kits in weaned litters, chronology of reproduction, and den site characteristics of this subspecies. Only 3 or 4 of 23 females produced a total of 6 pups. Of 13 recaptured and examined for reproductive status, most had lactated in previous years (*n* = 7), or had some evidence of lactating but not weaning pups (*n* = 4); two females had never lactated. Breeding and parturition occurred two months earlier than reported for other island fox subspecies in wild-born or captive breeding populations since the 1970s. Females used two or three dens in succession and dens were almost exclusively found in rock crevices. Five of 23 foxes had home ranges that included supplemental food sources and human habitation, including all four females observed with pups, suggesting this could be a factor in reproductive success.

RESUMEN

El zorro isleño es endemico a seis de las ocho Channel Islands de California y esta en la lista-roja de la Union Internacional para la Conservación de la Naturaleza y se consideran en gran peligro o en vías de extinción a traves de su ambito. Se conoce poco acerca de los hábitos de reproducción y crianza de los zorros de la isla de San Clemente (*Urocyon littoralis clementae*) y de los zorros isleños en general. En 2007 se observó y se le hizo seguimiento a los movimientos de 27 hembras adecuadas con un radio-transmisor en sus cuellos para determinar la proporción que tenían camada, el tamaño de las camadas destetadas, cronología de la reproducción, y las características de las guaridas de esta sub-especie. Solamente 3 o 4 de las 23 hembras produjeron un total de 6 cria. De las 13 que se recapturaron y examinadas para su estado reproductor, la mayoría habían lactado en años previos (*n* = 7) o mostraban evidencia de lactancia pero no de cria destetadas (*n* = 4); dos hembras no habían lactado. Apareamiento y partos ocurrieron dos meses antes que los reportados para otras poblaciones de sub-especies de zorros isleños, nacidos salvajes o en cautiverio despues de 1970. Las hembras usaron dos o tres guaridas en sucesión y las guaridas se encontraron casi exclusivamente en grietas rocosas. Cinco de las 23 zorras tenían territorios que incluian fuentes de alimento suplementarios y territorios con habitación humana, incluyendo las cuatro hembras con crias, sugiriendo que esto pudiera ser un factor en los exitos reproductores.

INTRODUCTION

Island foxes (*Urocyon littoralis*), diminutive relatives of the mainland gray fox (*U. cinereoargenteus*), occur as distinct subspecies on six of California's eight Channel Islands. Subspecies on four islands were listed in 2004 as federally endangered due to predation by golden eagles (*Aquila chrysaetos*) and canine distemper virus (Roemer et al., 2001*a*, 2001*b*; Kohlmann et al., 2005; Timm et al., 2009). The subspecies on San Nicolas (*U. l. dickeyi*) and San Clemente (*U. l. clementae*) islands were listed as Species of Concern by the U.S. Fish and Wildlife Service in 2004. In 2008, the International Union for the Conservation of Nature red-listed the entire species as critically endangered throughout its range. The United States Navy has been actively engaged in conservation efforts to monitor and manage the San Clemente Island fox since the late 1980s.

Little is known about the reproductive ecology of the San Clemente Island fox. Although the population of foxes on San Clemente Island is thought to be relatively stable, concern for the San Clemente subspecies stems from a possible population decline during 1988 to 2002 (Roemer et al., 2001*a*, 2001*b*; Coonan 2003), lack of resistance to disease (Garcelon et al., 1992; Rubin et al., 2007), and the possibility of golden eagle immigration. A vaccination program for the two most potentially dangerous pathogens, canine distemper virus and rabies (Clifford et al., 2006), was begun on San Clemente Island in 2007. Low number of pups produced per female (Roemer, 1999) coupled with high adult survival rates (Snow et al., 2011) and a population structure skewed towards older individuals suggest turnover rates in island fox populations may be low (Laughrin, 1977). Population growth rates are one of the most important factors affecting a population's risk of extinction (Foley, 1994). A better understanding of the reproductive ecology for San Clemente Island foxes is necessary to assess the potential consequences of internal and external pressures on the population.

Free-ranging foxes in all four federally endangered populations have been thoroughly documented as breeding from February-March and whelping from April-May (Laughrin, 1977; Moore and Collins, 1995; Roemer et al., 2001*b*; Asa et al., 2007; Clifford et al., 2007). These dates have been used to infer the chronology of reproduction on San Clemente Island where trapping to cull feral cats (*Felis catus*) is avoided during the fox whelping and pup-dependency seasons to reduce impacts on the fox population. However, the Channel Islands vary greatly in primary productivity, species diversity, and microclimate (Schoenherr et al., 1999; Yoho et al., 1999). The chronology of fox reproduction on San Clemente Island has not been investigated.

Island foxes are generally described as denning in small caves, rock crevices, human-made structures, and hollows under dense brush (Laughrin, 1977) but den sites have not been further characterized. Number of dens used during a reproductive season is unknown for San Clemente Island foxes, and island foxes in general. My objectives were to determine the proportion of females producing litters, number of kits in weaned litters, chronology of reproduction, and den site characteristics of the San Clemente Island fox.

MATERIALS AND METHODS

Study Area

San Clemente Island is the southernmost Channel Island, located approximately 109 km west-northwest of San Diego, California. San Clemente Island is 34 km long, varies from 2.4-6.4 km wide and is characterized by steep cliffs on the eastern slope, a gentler western slope with marine terraces, and steep canyons running from the upper plateau to the shore on both sides of the island (Olmstead, 1958; Schoenherr et al., 1999). The island is owned and operated by the U.S. Navy and has approximately 500 military and civilian residents (U.S. Department of the Navy, in litt.). My study area was on the northern two-thirds of the island, bounded by the eastern and western shorelines (excluding portions on the eastern shore >25° slope), a boundary 300 m north of the airport runway, and a southern boundary designated by a U.S. Navy training area.

Maritime desert scrub (55%) and grassland (33%) comprise the majority of plant communities on San Clemente, and 7% of the island is disturbed (U.S. Department of the Navy, in litt.). This oceanic island is volcanic in origin and is characterized by a Mediterranean Dry Summer Subtropical climate with hot, dry summers and mild winters. Mean summer and winter temperatures are 18 and 13˚C, respectively, with average annual rainfall varying between 15 and 30 cm depending on the location on the island (Schoenherr et al., 1999). Weather station data from San Clemente Island indicate drought conditions were present during my study period; mean temperature was 16 ˚C with total rainfall of 80 mm from August 2006 to December 2007 (California State University Northridge, 2011).

Fox Capture

I used the Reverse Randomized Quadrant-Recursive Raster technique (Theobald et al., 2007) in ArcGIS 9.2 to identify random, spatially-balanced trap locations. I used 66 x 23 x 23-cm cage traps (Tomahawk Live Trap, Tomahawk, Wisconsin) with either 2.54 x 2.54 cm-mesh or 1.27 x 2.54-cm mesh, a scented lure, and dry cat food for bait to capture foxes. During July-November 2006 and February 2007, 34 females and 29 males were captured in 124 trap nights (27% trap success for females; 51% overall) including five females I did not radio-collar due to oversampling (n = 3) or minimum body mass restrictions (i.e., n = 2 pups). Two radio-collared females died before November 2006 and were not included in the study.

Foxes were sexed, weighed, and checked for reproductive status and general physical condition. I assigned foxes to one of five age classes according to amount of wear on the first upper molar (Wood, 1958; Collins, 1987): 0-12 months (age class 0, n =

0); 13-24 months (age class 1, *n* = 9); 25-36 months (age class 2, *n* = 6); 37-48 months (age class 3, *n* = 4); and ≥49 months (age class 4, *n* = 8). I adjusted age estimates using trap records from previous years (Institute for Wildlife Studies, in litt.) when possible or cementum annulation (Matson's Laboratory, Milltown, Montana) if foxes died during or after my study. I fitted foxes with 45-g radio-telemetry collars (Advanced Telemetry Systems, Isanti, Minnesota), comprising 2.4% of average body weight of foxes, and inserted a Passive Integrated Transponder tag (Biomark, Boise, Idaho) subcutaneously between the scapulae. Island foxes are able to reproduce at the end of their first year (Laughrin, 1977; Clifford et al. 2007); thus, I included all radio-collared females in my study (Figure 11). Colorado State University's Institutional Animal Care and Use Committee (protocol 06-098A-01) and California Department of Fish and Game approved animal capture, handling, and monitoring protocols.

Radio-telemetry and Home Range Estimation

I initiated radio-telemetry data collection during mid-August 2006. I primarily used a receiver (Advanced Telemetry Systems, Isanti, Minnesota) connected to a vehicle-mounted, stacked-array of two six-element antennae or a hand-held three-element collapsible antenna to locate foxes. I radio-located foxes every 2 hours during one 8-hour period (0000-0759, 0800-1559, 1600-2359) that rotated every 1-1.5 weeks. I obtained ≥3 bearings <5 minutes apart with inter-bearing angles ≥20˚ (Chu et al., 1989; White and Garrott, 1990). I consistently radio-tracked 20 of 27 foxes to determine denning status; 6 foxes were not consistently accessible due to study area restrictions such as off-limits areas and steep cliffs and canyons, and one fox died during the study.

I used LOAS 3.2 (Ecological Solutions Software, Urnäsch, Switzerland) to convert telemetry data into location estimates and the Animal Movement SA Extension version 2.04 beta (Hooge and Eichenlaub, 2000) in ArcView version 3.3 (Environmental Systems Research Institute, Redlands, California) to estimate 95% fixed kernel home range boundaries (Seaman and Powell, 1996).

Reproductive Chronology and Den Use

I utilized approximately 4,010 radio-telemetry locations obtained from January-June 2007 to investigate denning behavior. I suspected denning behavior when a female repeatedly returned to or remained in one location. Starting in April, one to three times weekly I observed foxes exhibiting this behavior; foxes were observed one to two hours each visit. To avoid disturbing denning foxes or influencing behavior, I observed foxes and suspected dens from ≥ 20-30 m (Roemer et al., 2001*b*; Clifford et al., 2007) until I determined denning status. I considered a den confirmed when I observed pups. Pups are reported to venture from dens between three to four weeks (Laughrin, 1977) and four to six weeks of age (D. L. Clifford, DVM pers. comm.; T. W. Vickers, DVM, pers. comm.). By eight weeks, young spend most of the day outside of the den (Laughrin, 1977). I did not revisit dens until radio-telemetry data on the collared female indicated it was abandoned. I used the above procedure to monitor denning status every 10-14 days of the six foxes not consistently accessible from a vehicle.

I determined the date of den abandonment to be the mid-point between the last date the female was located at the den and the first time she was located away from the den and did not return to it. I considered a trio consisting of two females and one male concurrently sharing a den to be a single denning social group for analyses (Kitchen et al., 1999) rather than two separate denning females. I determined the date of parturition to be the mid-point between the first day I observed the female repeatedly returning to or remaining in one location and the date of the previous location obtained on the female. I then reconciled these dates with age estimates of pups when they emerged from dens. I used descriptions provided by D. L. Clifford, DVM and T. W. Vickers, DVM (pers. comm.) regarding pelage color and texture, facial morphology, behavior, and overall size to estimate age of pups.

Reproductive Condition

During March 2007, I examined the reproductive condition of one of my study females that died, and during June-July 2007 I examined 12 study females that were captured on trapping grids (Garcia and Associates, in litt.). During physical examinations, I recorded weight, nipple size and length, number of pigmented nipples, and degree of pigmentation. I examined abdomens for mammary lactation or swelling, hair loss, and fur discoloration. I took photographs of the abdomen dry (to record characteristics of the fur) and wet (to record characteristics of the mammaries) and sent them for independent assessment by two wildlife veterinarians active in island fox research. The veterinarians rated their level of confidence in each assessment as “low”, “medium”, or “high”. Overall, I determined data were adequate to make inferences about reproductive activity for 23 of my 27 females.

Den Site Characteristics

Building on studies from other fox species (Uresk and Sharps, 1986; Kitchen et al., 2006), I characterized den sites by collecting data on habitat type; aspect; slope; and proximity to paved roads, human habitation, and supplemental food sources. I defined human habitation as the edge of conspicuous human development where people lived, worked, or ate (e.g., edge of a parking lot). I defined supplemental food source as the closest human food preparation facility where foxes were observed scavenging human food waste or observed being fed by humans. I classified aspect as north (0° ± 45), east (90° ± 45), south (180° ± 45), or west (270° ± 45) and calculated average direction per Batschelet (1981). I used a hand-held clinometer (Hays et al., 1981) to determine slope of the den feature (approximately 5 m^2). I measured proximities as straight-line distance from the den entrance.

I used the point-intercept method on six transects radiating from each den to assess vegetative cover and type of substrate surrounding dens. I selected the azimuth of the first transect at random between 0-359° and spaced the remaining transects 60° apart. I collected data every 1 m along a 10-m transect, resulting in 60 data points from which to characterize vegetative cover and substrate surrounding a den. I identified plants by species and later categorized them into functional groups; I pooled data among transects at each den for statistical analyses. I recorded substrates as bare ground, non-persistent litter, persistent litter, rock, or sand; I distinguished rock as occurring naturally or human-made (e.g., riprap). I assessed data by characterizing the percent composition of substrate types and vegetative cover. I considered each den the unit of replication.

RESULTS

Reproductive Chronology and Reproductive Condition

Data indicate 3 or 4 of 23 females (13 or 17%; Figure 12) whelped a total of six pups that survived until weaning. One female was age class one, one was age class three, and two were age class four. Two of the females (age classes one and four) observed with pups concurrently shared a den; it is unknown which female, or if both, whelped the pups (*n* = 3) in that litter. The other two litters consisted of one and two pups. Litters were last observed in August 2007.

I observed each litter for the first time April 13-16 and estimated that parturition occurred February 17-23. Of the 13 females I examined for reproductive condition, most had either lactated in previous years but not during 2007 (*n* = 7; 54%), or had some evidence of lactating during 2007 but did not wean pups (*n* = 4; 31%); two foxes (15%) had never lactated. Independent assessments from the wildlife veterinarians reported that none of the 13 females had the amount of hair loss or discoloration typical of foxes that nurse pups to weaning; they had medium-high to high levels of confidence in their assessments. Foxes were in overall good physical condition and weighed an average of 1.8 kg (*SE* = 0.2). None of the 13 females I examined had been observed with pups.

Prior to being captured on grids, radio-telemetry data indicated denning behavior for 5 of the 12 females. Lactation exams suggested four of these five had recently lactated but their mammaries did not resemble those of a female with weaned pups; they were also never observed with pups. Three females not trapped on grids but monitored with radio-telemetry exhibited behavior suggesting denning but were also not observed with pups.

Den Site Characteristics

Seven dens were located during my study (Figure 13). Denning groups used an average of 2.3 (*SE* = 0.3) dens, with successive rather than concurrent use. Natal dens were used for an average of 39 days (*SE* = 6.8) after which litters were moved to a second den for an average of 61 days (*SE* = 15.9). One litter utilized a third den for 31 days.

On average and for each denning group, successive dens were located closer to human habitation and supplemental food sources. Paved roads, however, were only closer to successive dens when averaged across denning group (Table 8). Only 5 of 27 females in my study, and all 4 of the females confirmed denning, had home ranges that included supplemental food sources and human habitation.

Table 8. Distance (m) of San Clemente Island fox (*Urocyon littoralis clementae*) dens from selected parameters on San Clemente Island, California, USA, during 2007.

	Distance (m)					
	Natal den (*n* = 3)		Second den (*n* = 3)		Third den (*n* = 3)	
Parameters	Mean	*SE*	Mean	*SE*	Mean	*SE*
Paved road	105	46	91	27	35	---
Previous den (2007)	---	---	182	5	442	---
Human habitation	238	153	202	130	108	---
Supplemental food source	359	136	302	147	148	---

Three den entrances were oriented to the north (316°, 334°, and 350°), two to the east (58° and 102°), and one each to the south (149°) and west (294°) ($\bar{\theta}$ = 2.8°; north). Mean slope was 32° (*SE* = 3.4). Six of seven dens were located in rock structures and one den was located in dense shrubs. Five of seven dens were located in maritime desert scrub habitat and the remaining two were located in developed/disturbed habitats. Substrates surrounding dens were composed of rock (64.5%), bare ground (26.9%), and sand (9%). Vegetative cover surrounding the seven dens were shrubs (23.1%), vines (15.7%), forbs (5.7%), sub-shrubs (2.1%), grasses (1.4%), and no vegetative cover (51.7%). Species composition reflected a dominance of *Rhus integrifolia* shrubs (46%), *Calystegia macrostegia* vines (33%), and *Salsola tragus* forbs (11%). Rock substrates were comprised of approximately 57% in-situ rock, 40% rip-rap, and 3% concrete.

DISCUSSION

The number of females observed with pups during 2007 was very low. I suspect this could be due to drought conditions on San Clemente Island during 2006 and 2007. Reduced rates of reproduction have occurred in red foxes (*Vulpes vulpes*; Lindstrom, 1989) and swift foxes (Angerbjörn et al., 1991) during years of reduced food availability. Food availability affects ovulation but has the strongest effects on lactating females (Bronson, 1989) and can influence litter size at weaning (Tannerfeldt and Angerbjörn, 1998). Although population size naturally fluctuates in response to a host of intrinsic and extrinsic factors including climate conditions, drought and corresponding reductions in wild foods offer an incomplete explanation for the poor reproductive success I observed in 2007. Data from weather stations on San Clemente Island are available since 1996 and indicate rainfall was highly variable during 1996-2007. Ninety-five percent of annual precipitation occurred from November through April (Yoho et al. 1999) which coincides with breeding, parturition, and early pup-dependency for the San Clemente Island fox. During 1996-2007, annual grid-trapping to monitor the population occurred during all but 3 years. Using precipitation from the previous August through July as an index of resource availability and the potential for population recruitment in a given year, the number of pups captured on trapping grids during the summer (Institute for Wildlife Studies, in litt.) did not correspond well with the amount of precipitation during years of abundant rainfall (≥245 mm), years with drought (≤44 mm), and years approaching the eight-year mean (128 mm, range = 100-157 mm; Kaiser et al., in litt.; California State University, http://www.csun.edu/csbs/departments/geography/SanClementeProject).

Fluctuations in island fox populations corresponding to climate shifts have not been documented and it is unclear whether climate was a factor in the possible decline of the San Clemente fox population observed in the 1990s (Coonan, 2003). Annual grid-trapping provides important information about population trends but does not add information about pup and juvenile mortality. Roemer (1999) suggested that greater primary productivity on the northern Channel Islands during 1994-1995 was responsible for larger litter sizes observed on the northern islands compared to San Clemente Island. Weaned litter sizes in my study were similar to estimates for Santa Catalina Island foxes (1.8; Clifford et al., 2007), Santa Cruz Island foxes (1.25; Roemer, 1999) and is within the range reported by Moore and Collins (1995) and Coonan et al. (2005). No data exist for litter sizes of other wild-born island fox populations during 2007. The social group I observed consisting of a male and more than 1 female, suggesting polygynous mating, has also been observed in Santa Cruz Island foxes (Roemer et al., 2001*b*).

Reproductive Chronology

In contrast to the reproductive chronologies previously reported for island foxes, I found parturition occurring in mid-February on San Clemente Island. Based on estimates of a 50-53 day gestation period (Laughrin, 1973; Moore and Collins, 1995), mating occurred as early as December. Breeding in December and whelping in February has not been documented for litters born in the wild or in captivity for any island fox subspecies. From 2001-2007, the earliest island fox litter born in a zoo or breeding facility was March 29; the majority of births occurred April-June, similar to what has been reported for wild populations of the four endangered subspecies.

Sample size was not adequate to assess the prevalence of parturitions occurring in February on San Clemente Island, or the range of parturition dates within a given year. Although I also do not know whether 2007 was an unusual year or part of a biological pattern, there is anecdotal evidence that fox pups were heard inside a den in February 2002 on San Clemente Island (D. Garcelon, pers. comm.). My results indicating parturition occurs as early as February should be incorporated into measures for minimizing impacts on the San Clemente Island fox. Unfortunately, no data exist for comparing parturition dates to other free-ranging island fox subspecies during 2007.

Den Site Characteristics

My results indicate dens were almost exclusively located in rock crevices, contrary to the variety of den locations previously documented for island foxes (Laughrin, 1977). Although this suggests a proclivity to select rock crevices, poor reproduction during 2007 resulted in few dens to study. All foxes in my study moved litters a short distance from the natal den four to seven weeks after parturition. This agrees with findings for Santa Catalina Island foxes (Clifford et al., 2007) and is similar to red foxes that move their offspring one to three times (Storm et al., 1976). The close proximity of dens to supplemental food sources suggests they could be an important resource for foxes that have these sites within their home range.

Like other insular endemic species, island foxes are especially vulnerable to stochastic events. In 2004, four subspecies of island fox were listed as federally endangered. Monitoring, research and conservation efforts for the San Clemente Island fox subsequently increased to help management decisions prevent a similar population decline. This study provides an initial assessment of the reproductive ecology and den site characteristics for the San Clemente Island fox. In light of increasing internal and external pressures on this population, further research on reproduction, recruitment, and den site selection is indicated. Longer-term studies should compare reproductive success and pup survival in free-ranging island foxes across subspecies (i.e., island) and under different climate conditions. This will help establish whether reproduction is shifted earlier on San Clemente Island relative to fox populations on other Channel Islands. Perinatal mortality has been studied in island foxes (Clifford et al., 2007), but pup mortality between the perinatal period and weaning, and from weaning to reproductive maturity is also unknown. Future research might also investigate the impacts of food stress on recruitment rates and reproductive chronology between free-ranging foxes with and without access to supplemental food. Finally, characteristics at den sites should be compared to random sites within the home ranges of foxes to ascertain site selection versus availability.

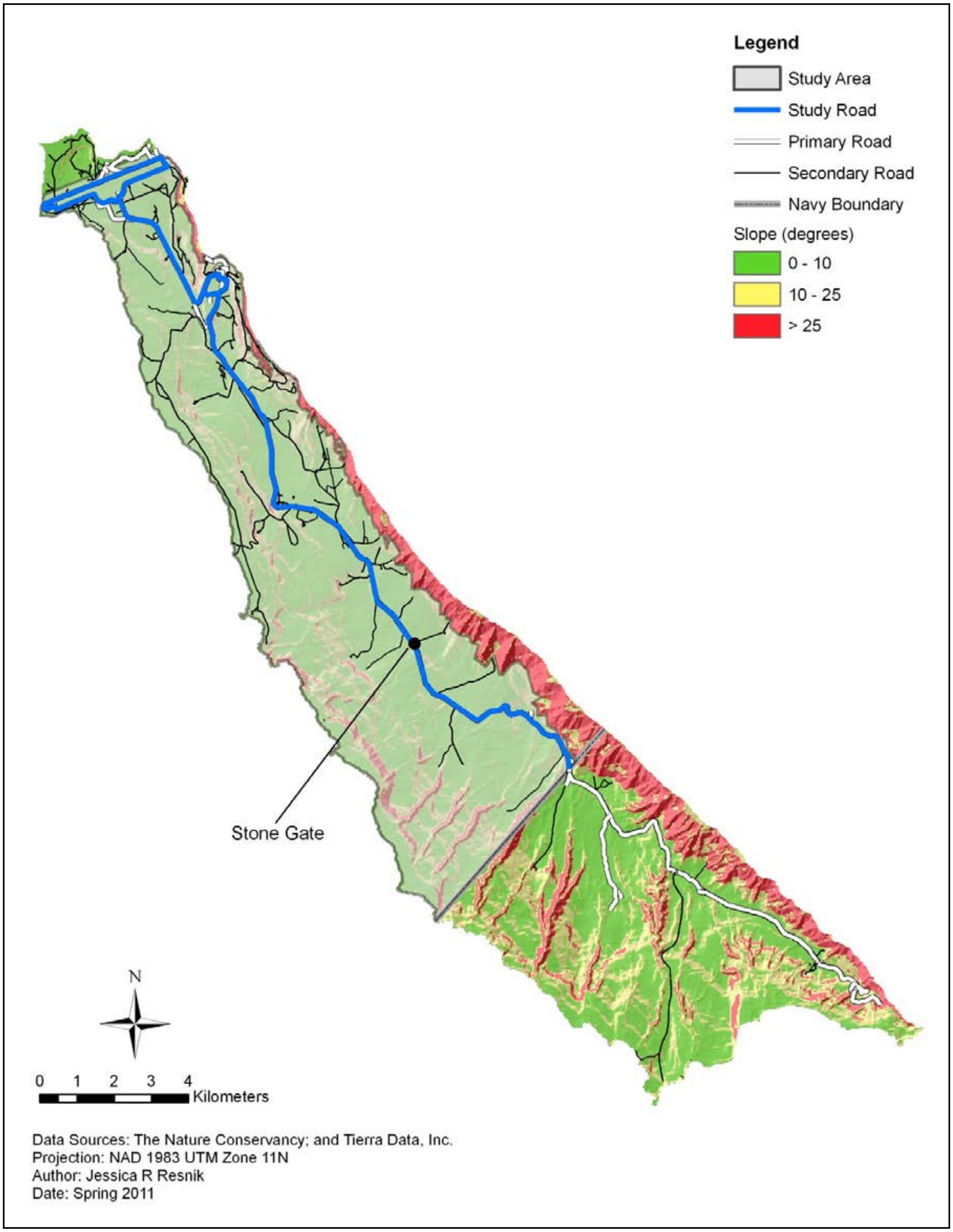
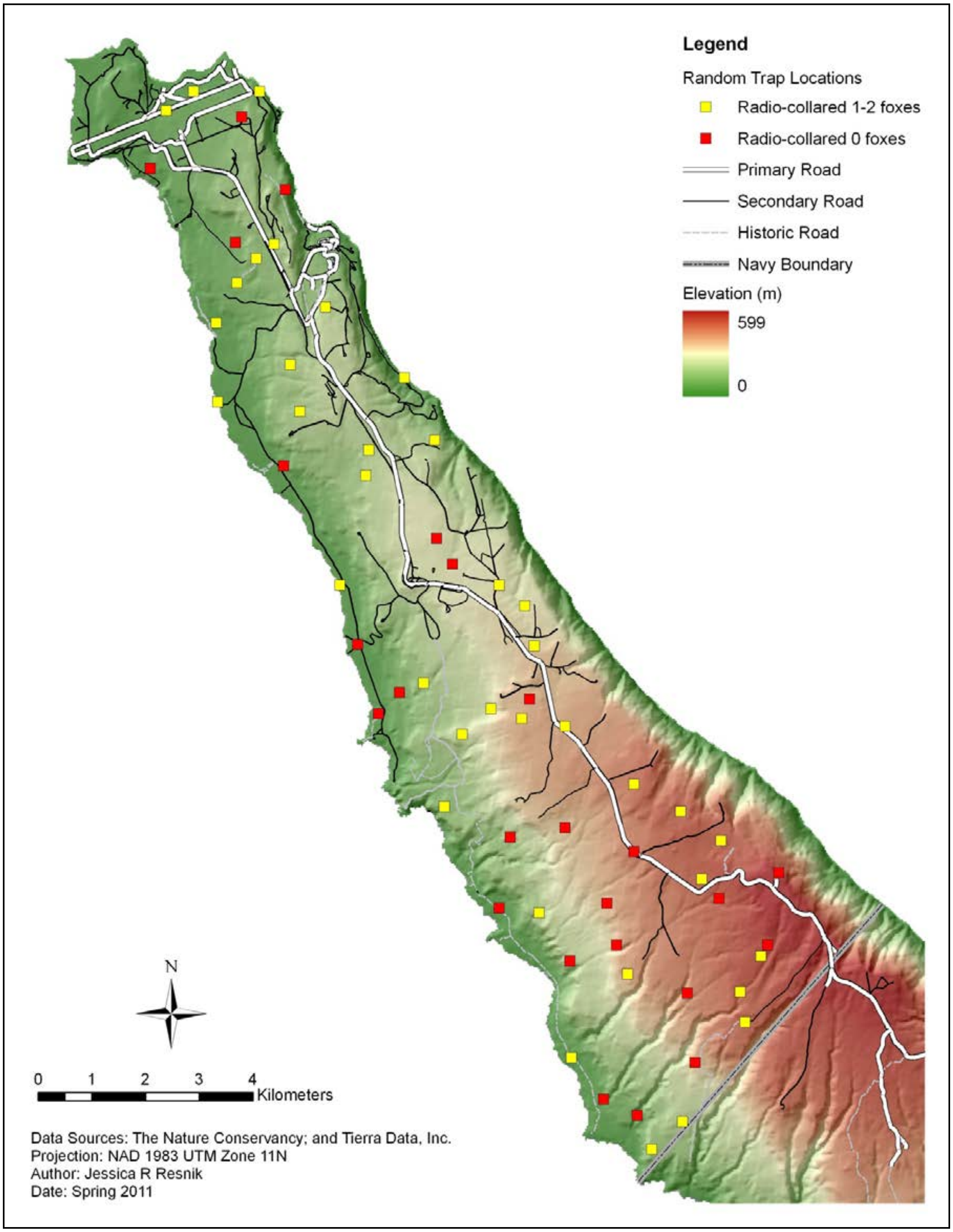


Figure 1. San Clemente Island fox (*Urocyon littoralis clementae*) research, 2006–2007,was conducted on the northern 2/3 of San Clemente Island, California, USA.



Data Sources: The Nature Conservancy; and Tierra Data, Inc.
Projection: NAD 1983 UTM Zone 11N
Author: Jessica R Resnik
Date: Spring 2011

Figure 2. Spatially-balanced random sample of San Clemente Island foxes (*Urocyon littoralis clementae*), California, USA, 2006–2007.

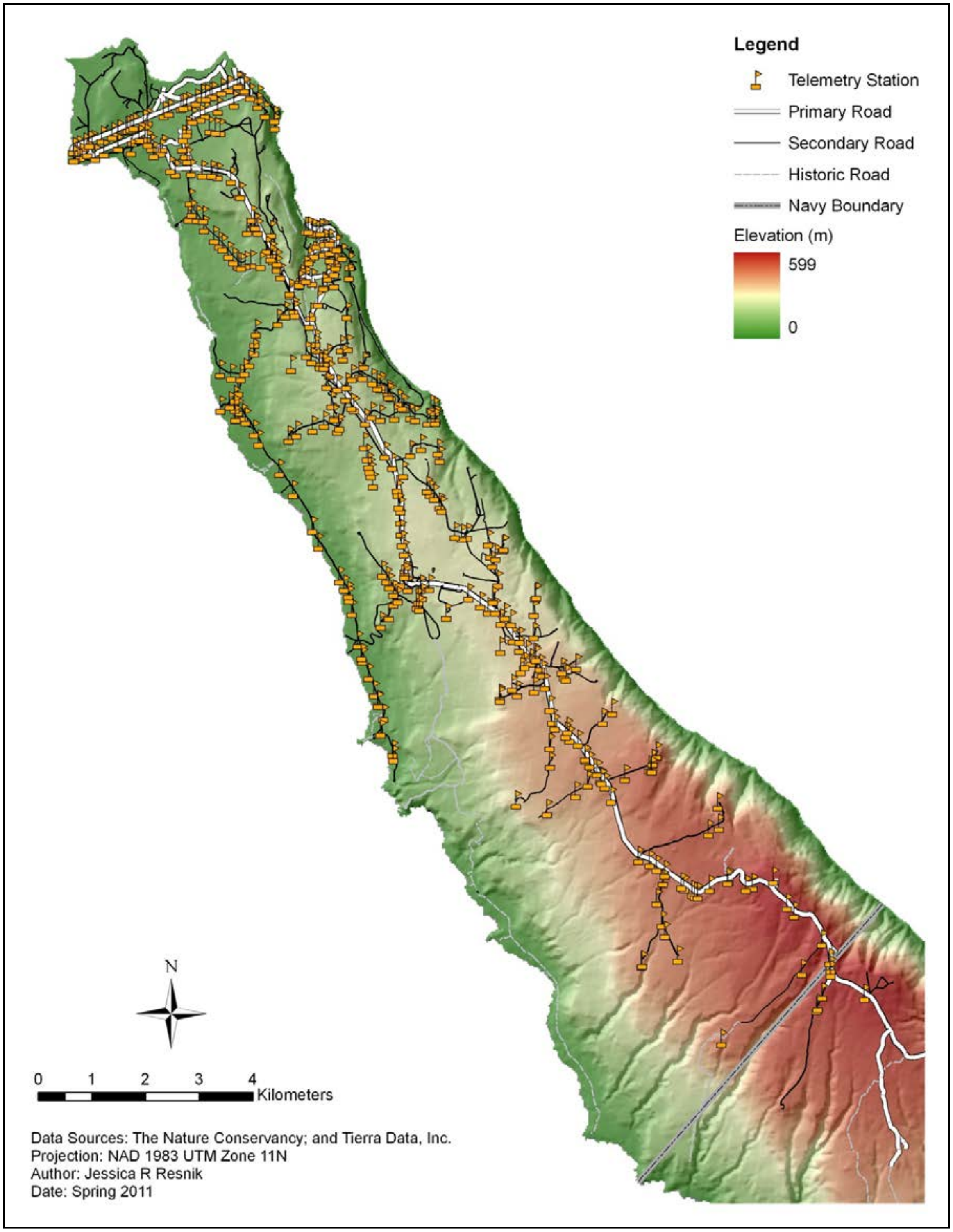


Figure 3. Telemetry stations (n = 354) of known UTM coordinates established for monitoring San Clemente Island foxes (*Urocyon littoralis clementae*), California, USA, 2006–2007.

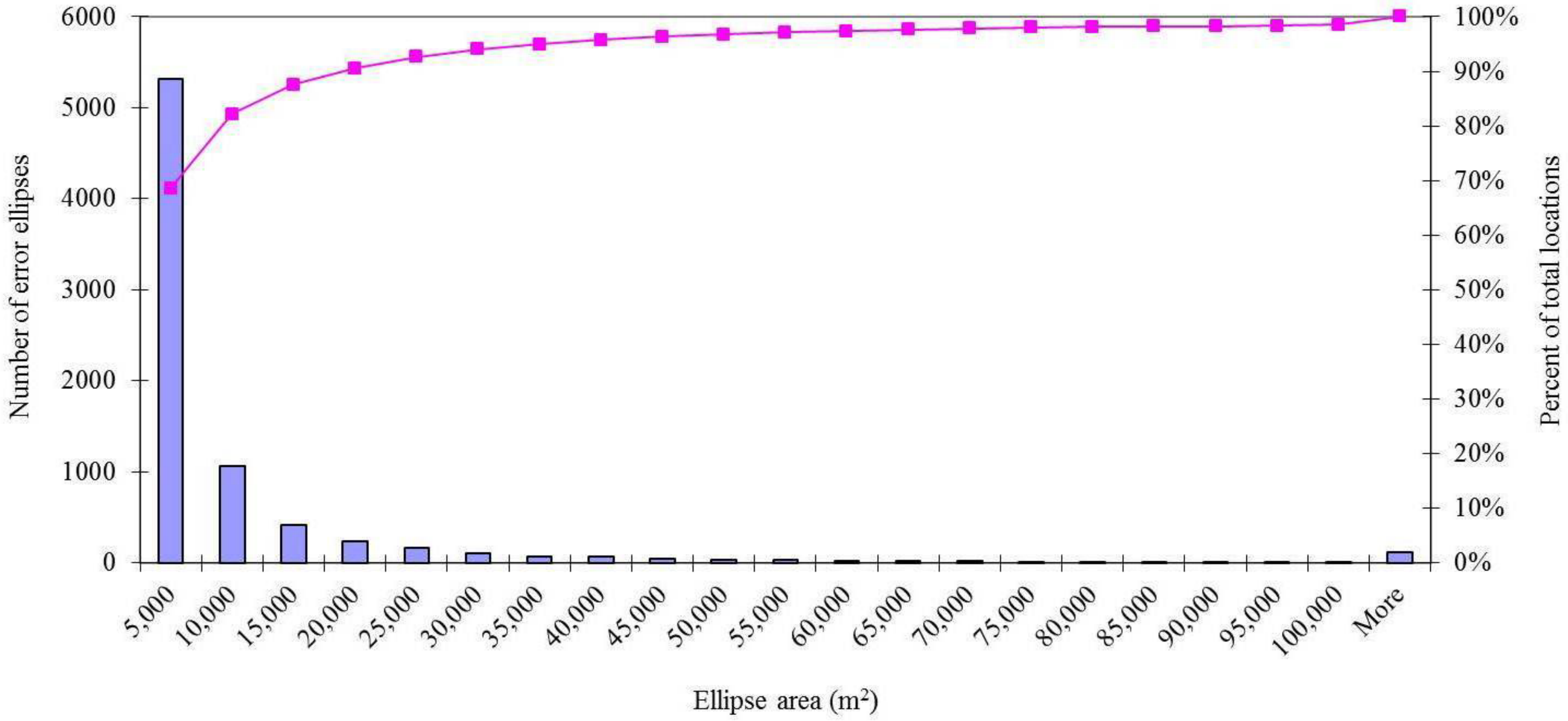


Figure 4. Cumulative distribution of error ellipses for radio-telemetry locations obtained on San Clemente Island foxes (*Urocyon littoralis clementae*), California, USA, 2006–2007.

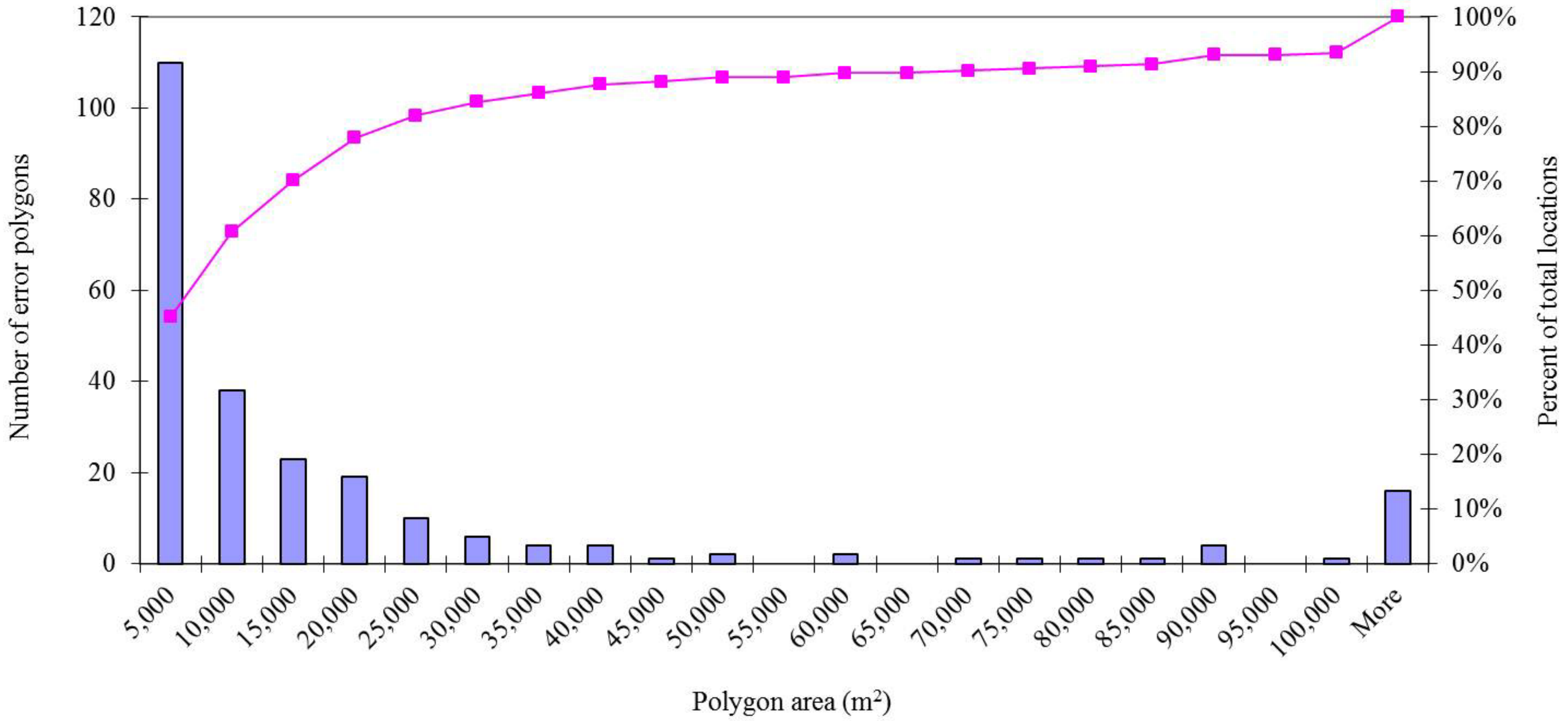


Figure 5. Cumulative distribution of error polygons for radio-telemetry locations obtained on San Clemente Island foxes (*Urocyon littoralis clementae*), California, USA, 2006–2007.

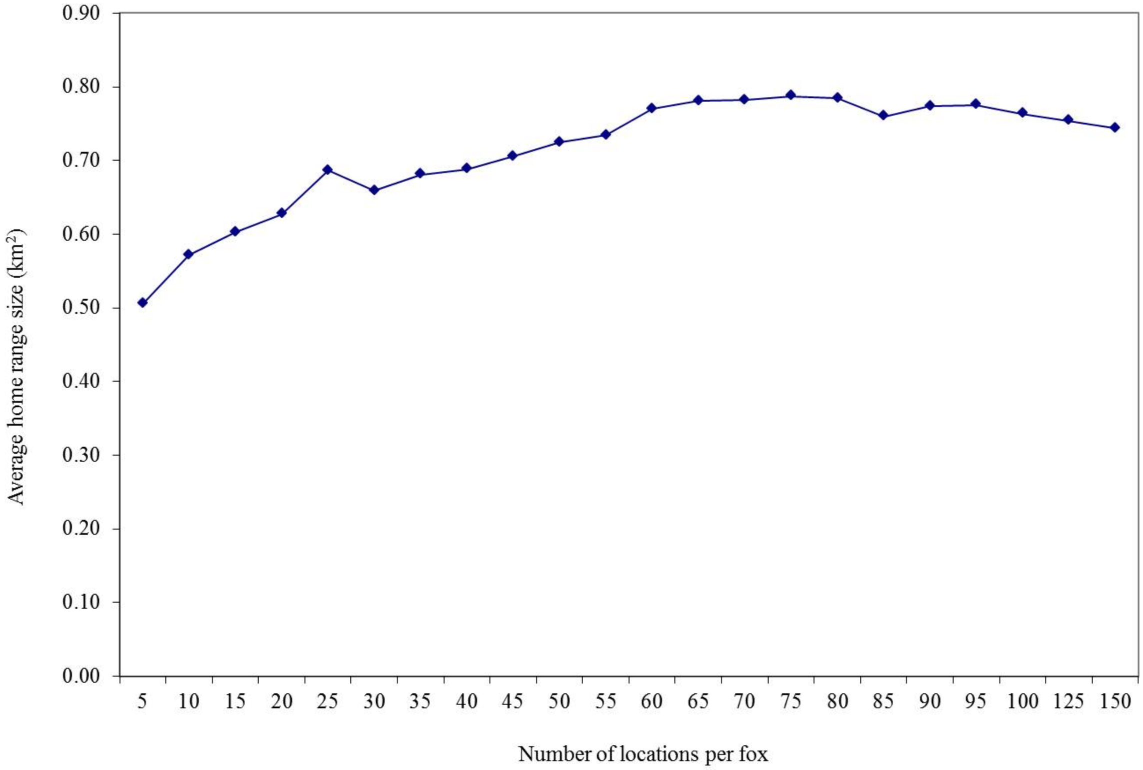


Figure 6. Cumulative observation-area curve for fixed-kernel home ranges (95% isopleth) of San Clemente Island foxes, California, USA, 2006–2007.

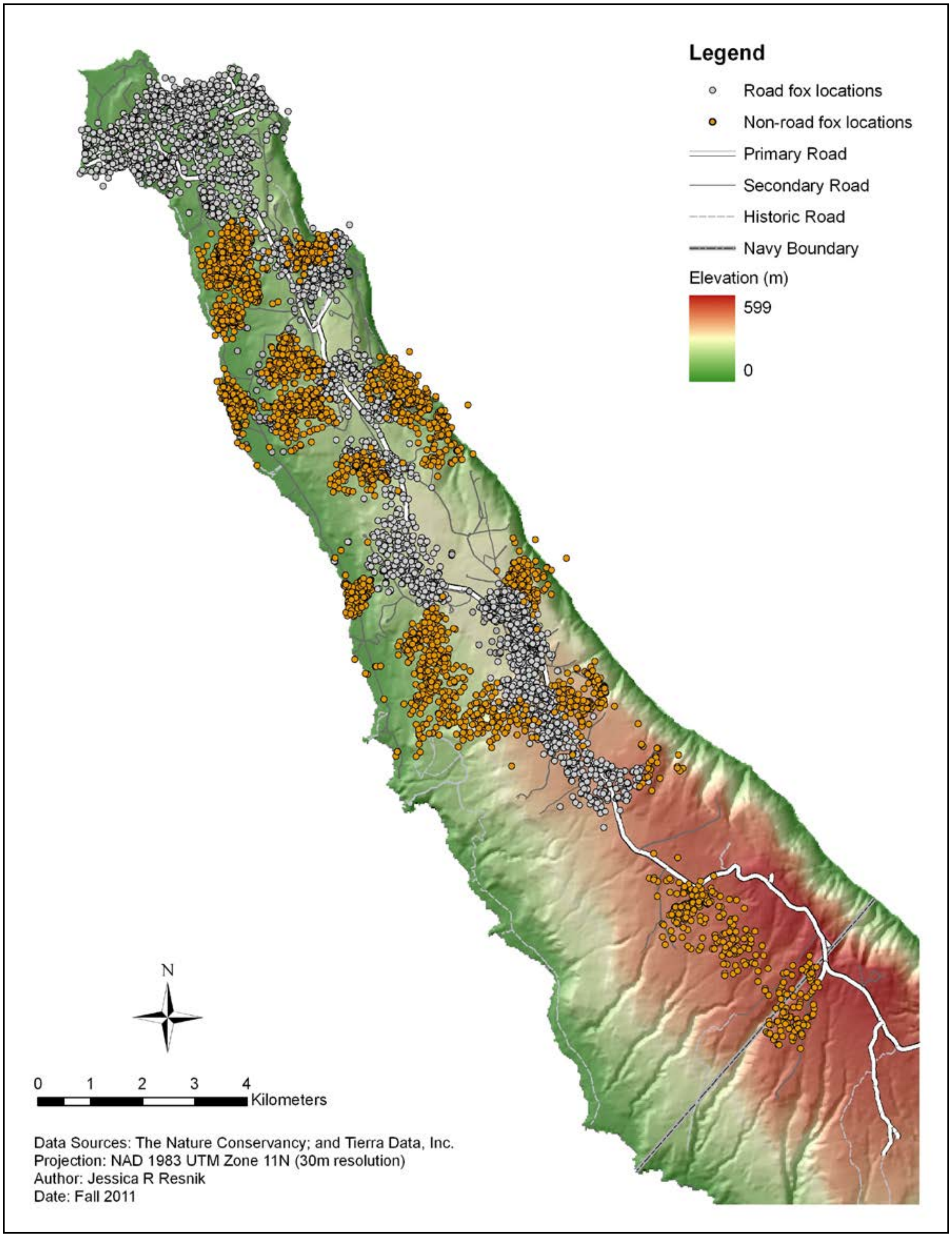
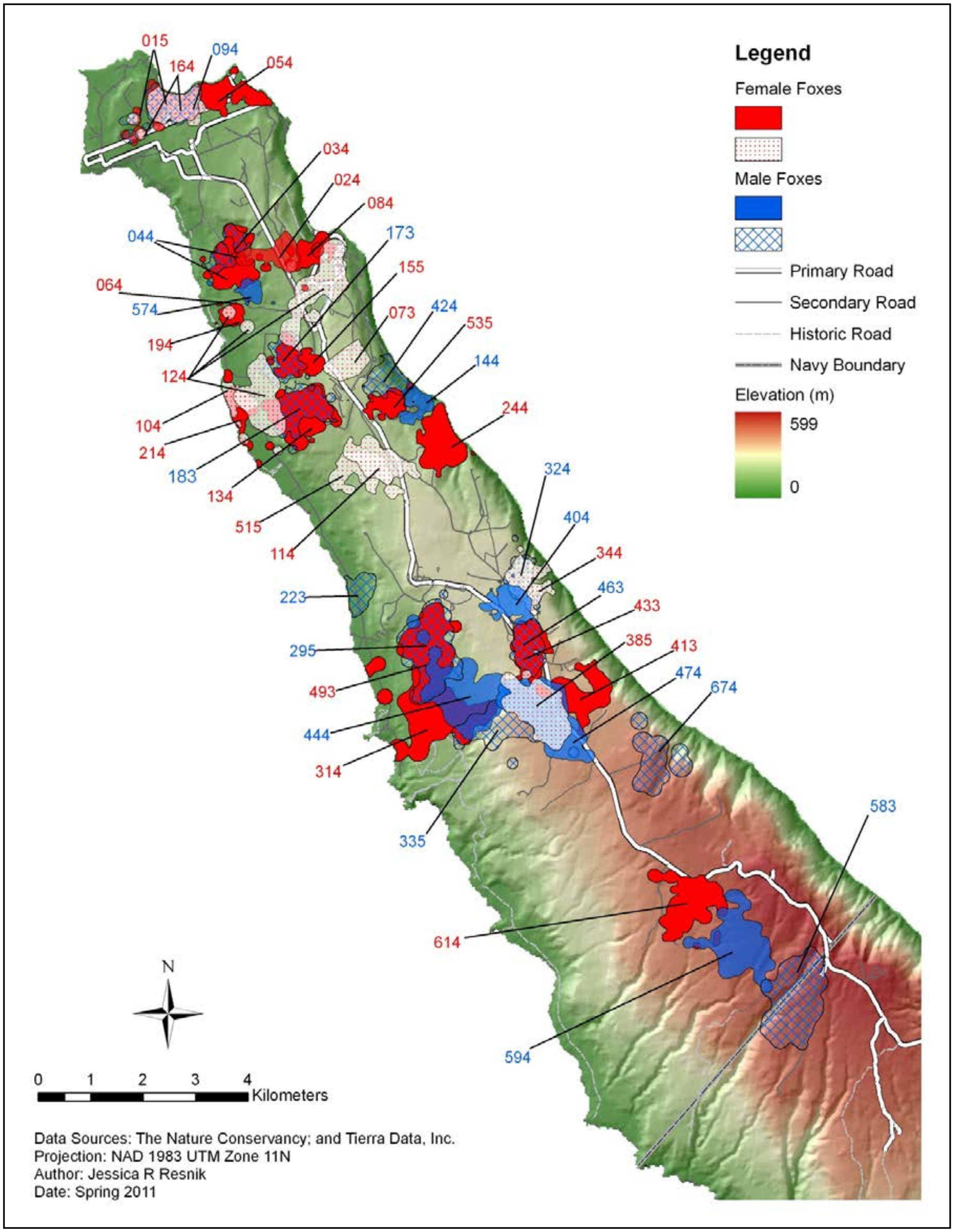


Figure 7. Radio-telemetry locations obtained on San Clemente Island foxes (*Urocyon littoralis clementae*), California, USA, 2006–2007.



Data Sources: The Nature Conservancy; and Tierra Data, Inc.
Projection: NAD 1983 UTM Zone 11N
Author: Jessica R Resnik
Date: Spring 2011

Figure 8. Fixed-kernel home ranges (95% isopleth) for the random sample of San Clemente Island foxes (*Urocyon littoralis clementae*), California, USA, 2006–2007.

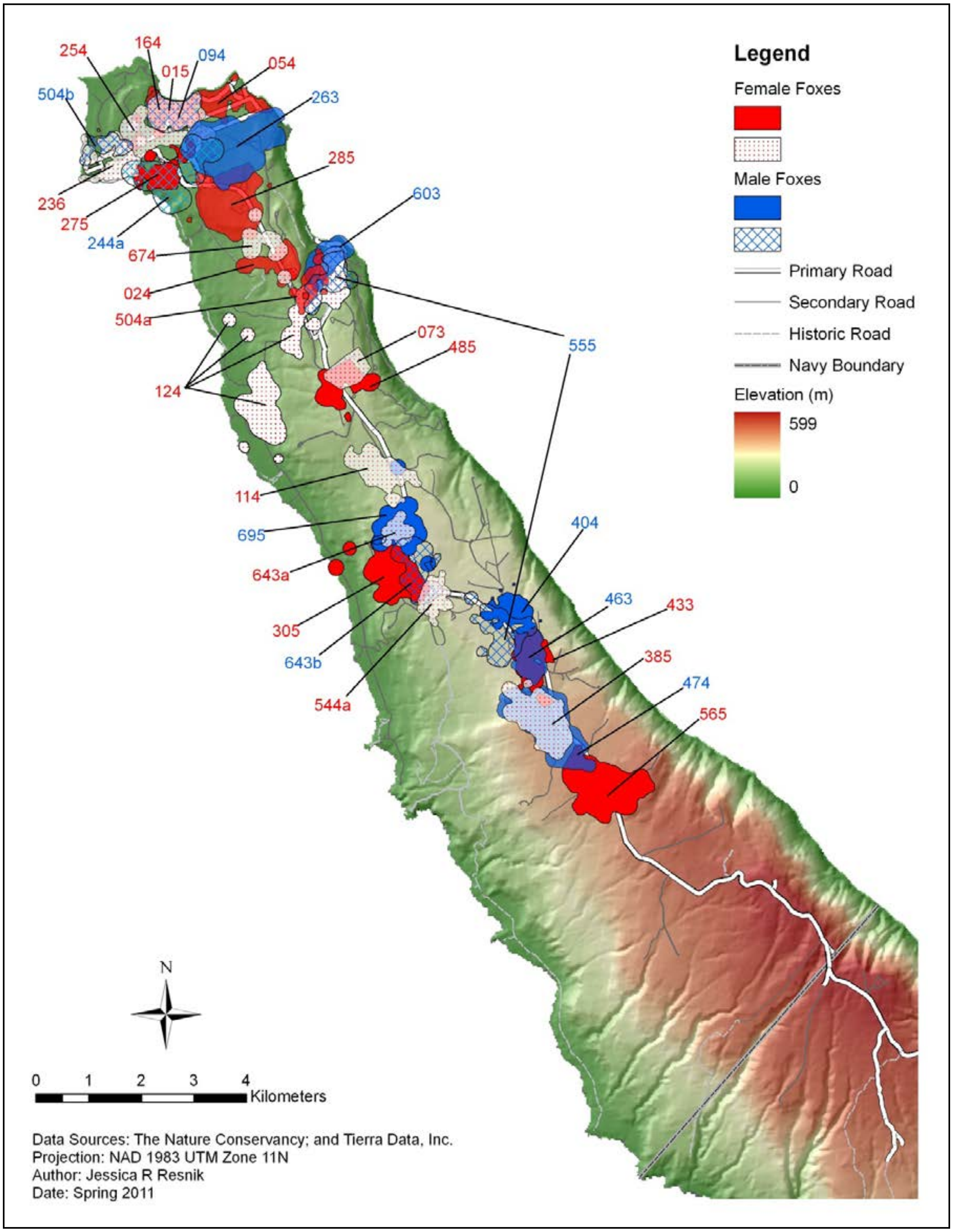
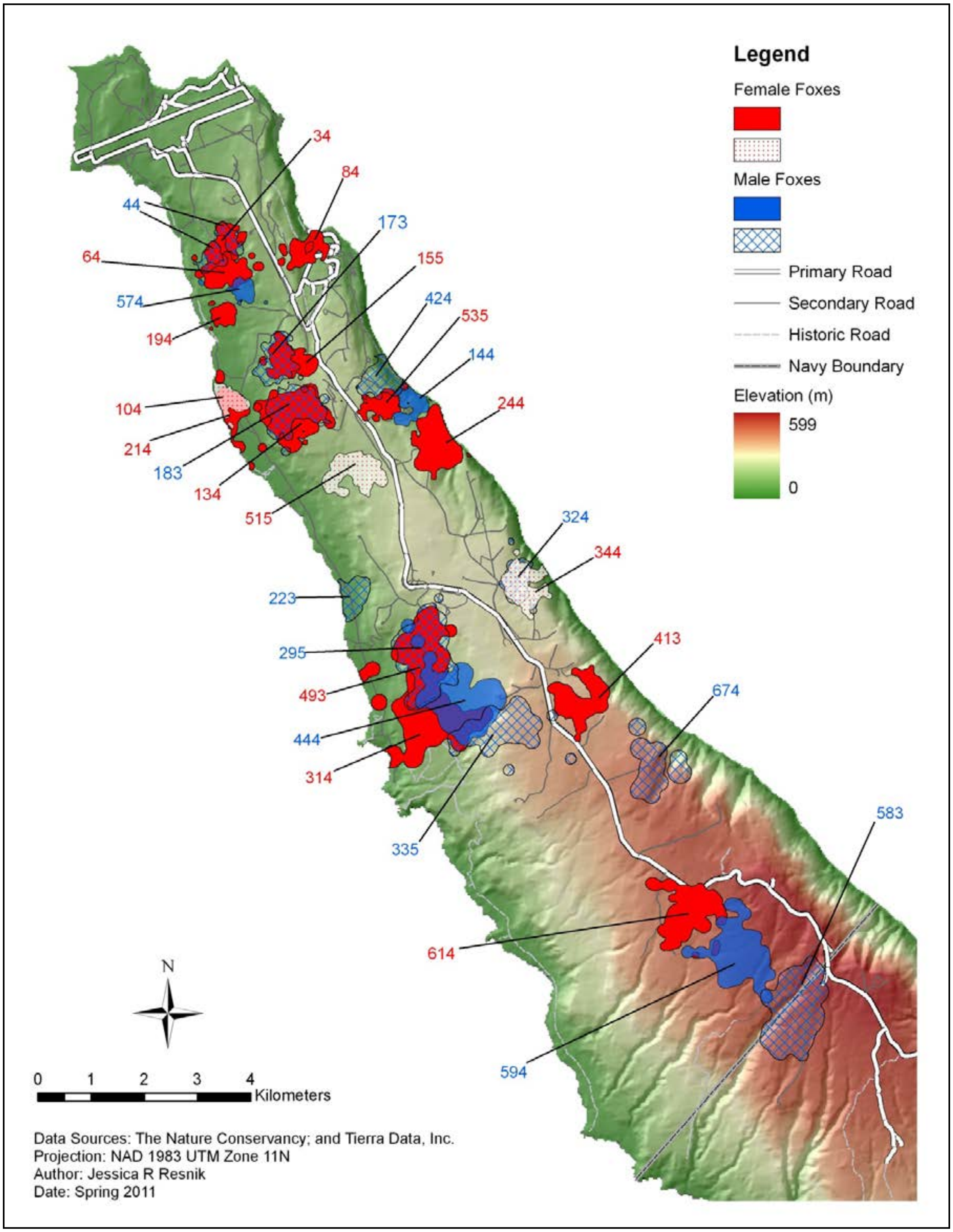


Figure 9. Fixed-kernel home ranges (95% isopleth) for the road sample of San Clemente Island foxes (*Urocyon littoralis clementae*), California, USA, 2006–2007.



Data Sources: The Nature Conservancy; and Tierra Data, Inc.
Projection: NAD 1983 UTM Zone 11N
Author: Jessica R Resnik
Date: Spring 2011

Figure 10. Fixed-kernel home ranges (95% isopleth) for the non-road sample of San Clemente Island foxes (*Urocyon littoralis clementae*), California, USA, 2006–2007.

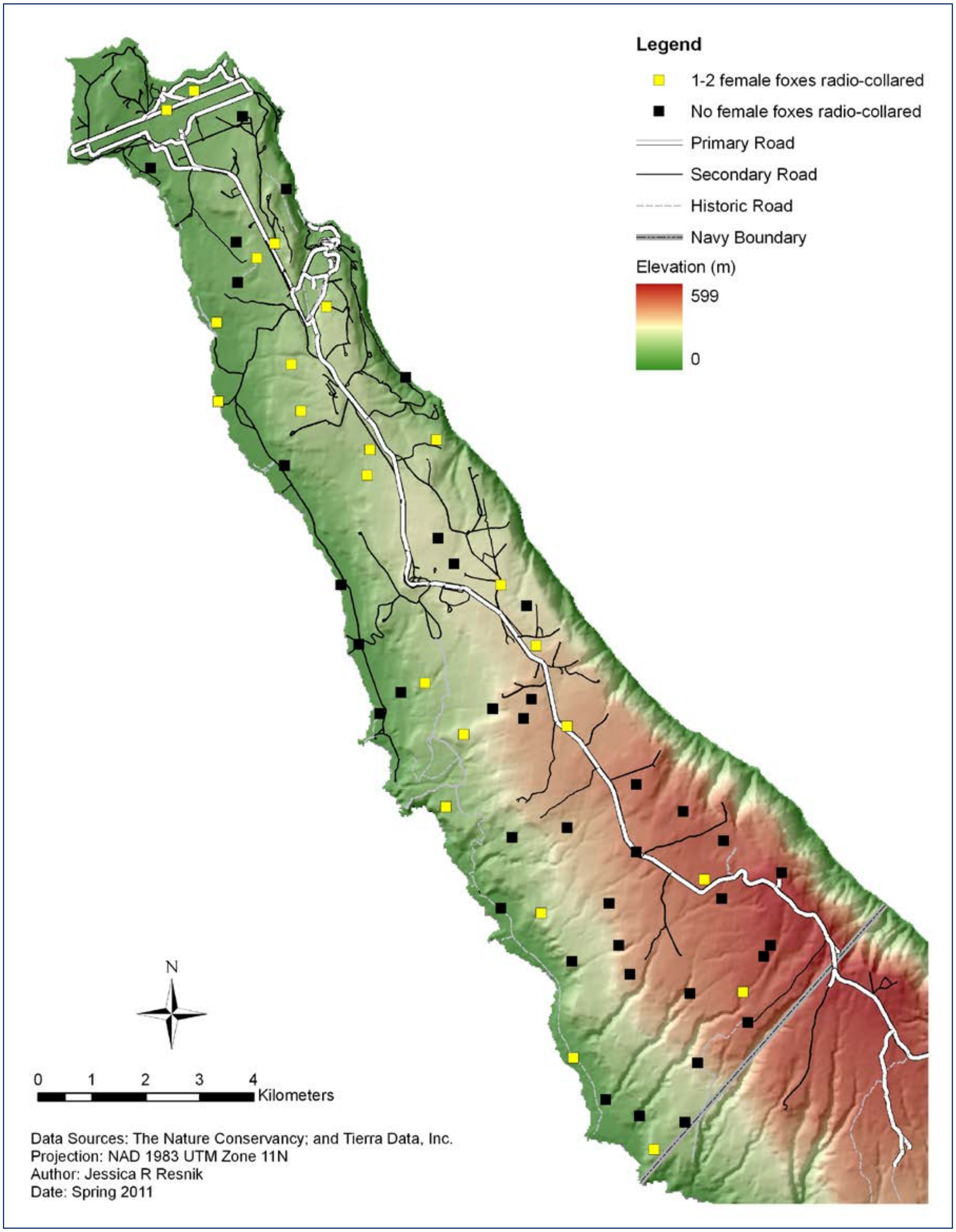


Figure 11. Capture locations of females radio-collared in the random sample of San Clemente Island foxes (*Urocyon littoralis clementae*), California, USA, 2006–2007.

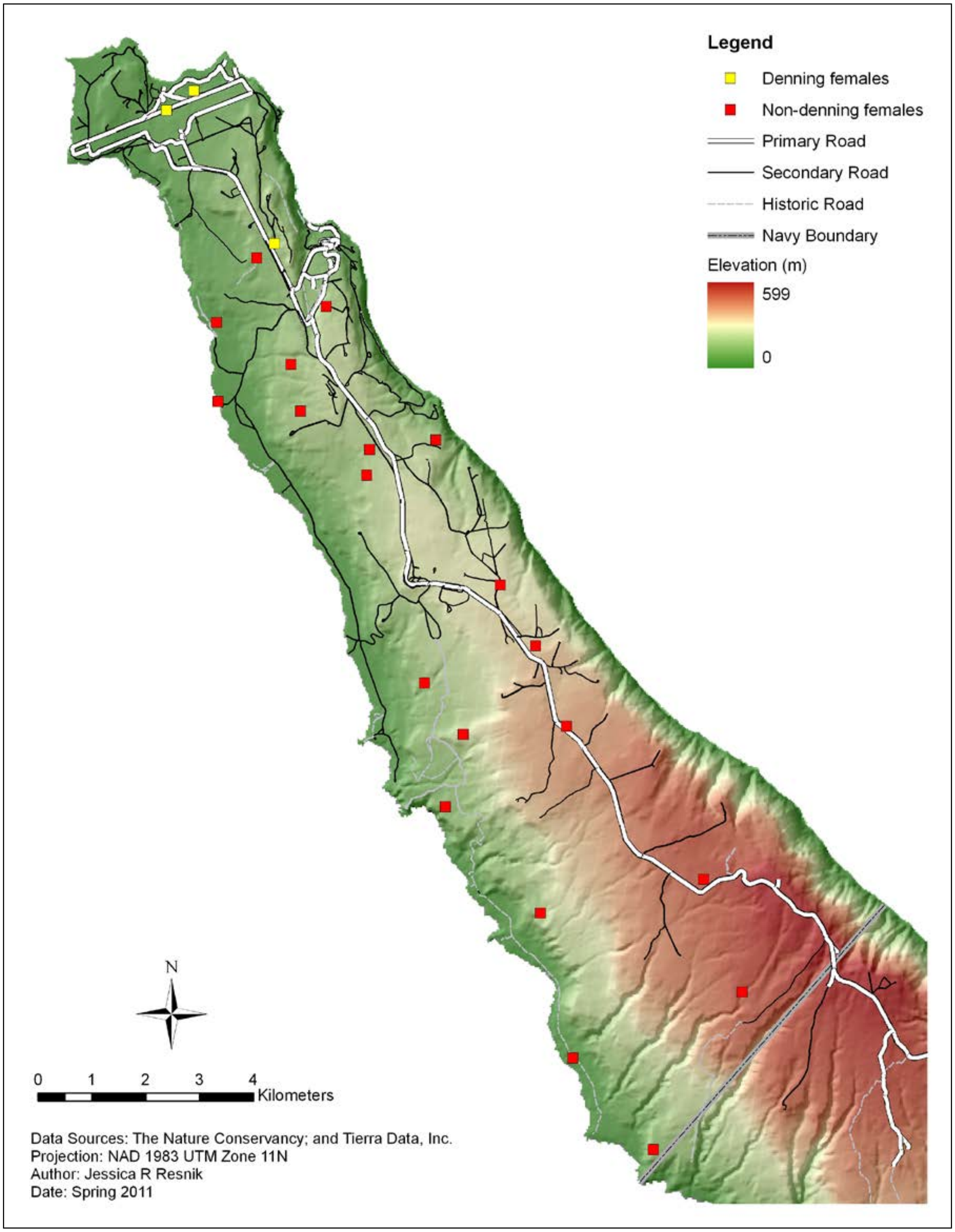


Figure 12. Capture locations of radio-collared denning and non-denning female San Clemente Island foxes (*Urocyon littoralis clementae*), California, USA, 2006–2007.

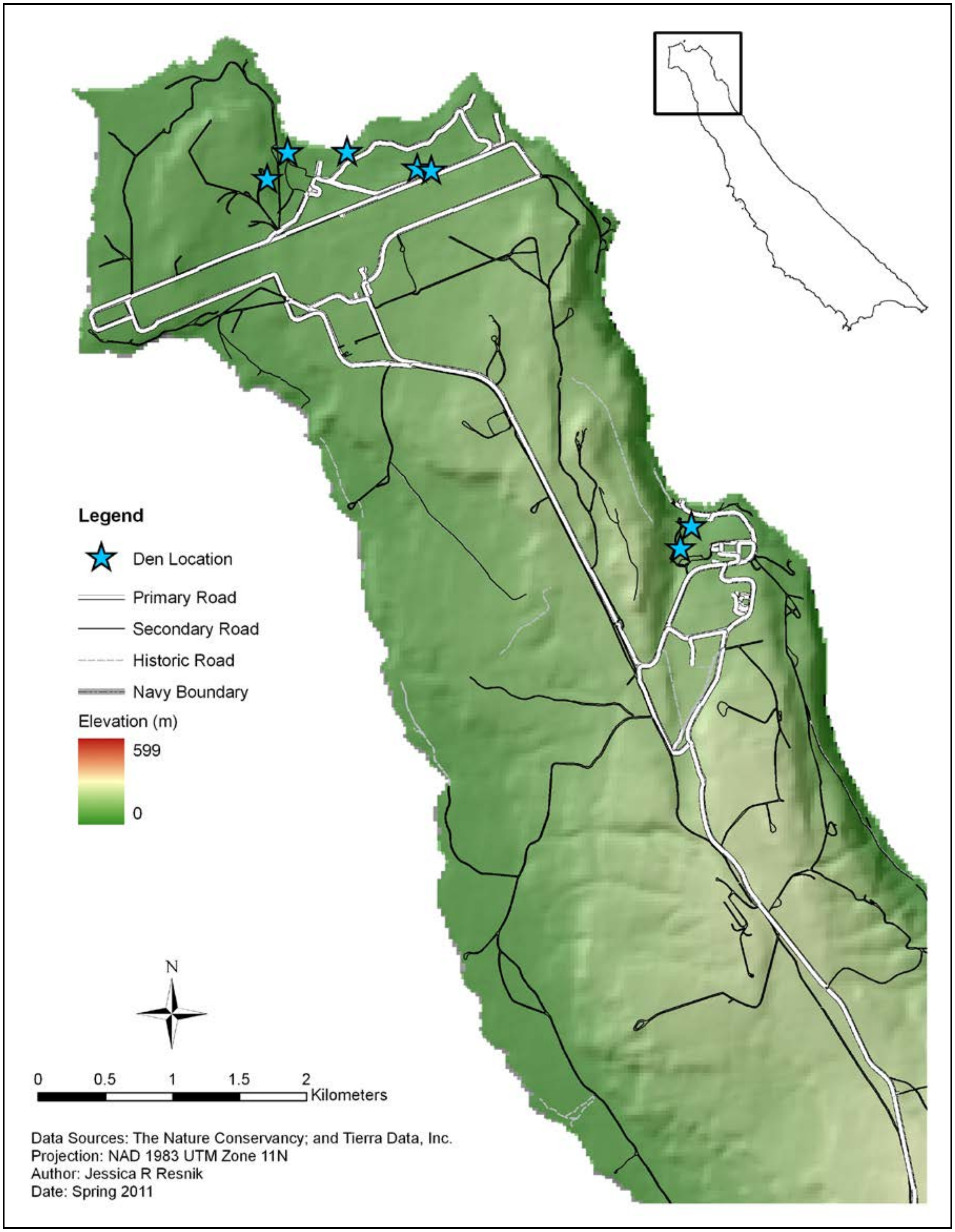


Figure 13. Locations of dens for radio-collared denning female San Clemente Island foxes (*Urocyon littoralis clementae*), California, USA, 2006–2007.

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APPENDIX

SUPPLEMENTARY INFORMATION

Summary of data used for calculating annual home ranges of San Clemente Island foxes, California, USA, 2006–2007. Home ranges were estimated for foxes meeting threshold criteria.

Fox[a]	Sex	Age Group	Random sample	Road or Non-road sample	Period monitored	Number of successful radio-locations[b]	Probability of locating[b]	FK LSCV bandwidth	FK estimate (km^2)	MCP estimate (km^2)
15	F	Young	Random	Road	7/18/2006 to 10/6/2007	156	0.92	85	0.81	0.87
24	F	Young	Random	Road	7/18/2006 to 7/4/2007	177	0.96	N/A	N/A	N/A
34	F	Adult	Random	Non-road	7/18/2006 to 10/6/2007	157	0.98	65	0.49	0.54
44	M	Adult	Random	Non-road	7/19/2006 to 10/6/2007	155	0.98	64	0.36	0.48
54	F	Old	Random	Road	7/18/2006 to 10/4/2007	220	0.99	91	0.61	0.81
64	F	Old	Random	Non-road	7/19/2006 to 10/6/2007	154	0.97	61	0.48	0.58
73	F	Adult	Random	Road	7/18/2006 to 9/27/2006	22	0.88	N/A	N/A	N/A
84	F	Adult	Random	Non-road	7/19/2006 to 10/4/2007	167	0.97	53	0.38	0.48
94	M	Young	Random	Road	7/19/2006 to 10/6/2007	138	0.82	90	0.77	0.88
104	F	Young	Random	Non-road	7/18/2006 to 10/4/2007	154	0.98	58	0.28	0.32
114	F	Adult	Random	Road	7/18/2006 to 10/2/2007	208	0.95	76	0.71	0.95
124	F	Old	Random	Road	7/18/2006 to 10/2/2007	190	0.95	132	2.69	2.61
134	F	Young	Random	Non-road	7/18/2006 to 10/4/2007	141	0.85	85	1.18	0.95
144	M	Young	Random	Non-road	7/18/2006 to 9/24/2007	138	0.87	57	0.44	0.35
155	F	Young	Random	Non-road	7/18/2006 to 10/4/2007	151	0.91	63	0.61	0.55
164	F	Old	Random	Road	7/19/2006 to 10/4/2007	212	0.97	78	0.70	0.93
173	M	Old	Random	Non-road	7/19/2006 to 10/4/2007	144	0.94	59	0.56	0.42
183	M	Young	Random	Non-road	7/19/2006 to 9/24/2007	156	0.95	77	0.75	0.71
194	F	Old	Random	Non-road	8/19/2006 to 10/4/2007	148	0.99	43	0.21	0.27
214	F	Old	Random	Non-road	7/19/2006 to 3/4/2007	66	0.97	N/A	N/A	N/A
223	M	Adult	Random	Non-road	8/19/2006 to 10/3/2007	141	0.96	66	0.40	0.28

Fox[a]	Sex	Age Group	Random sample	Road or Non-road sample	Period monitored	Number of successful radio-locations[b]	Probability of locating[b]	FK LSCV bandwidth	FK estimate (km^2)	MCP estimate (km^2)
236	F	Young	No	Road	9/9/2006 to 10/4/2007	204	0.95	71	0.55	0.68
244a	M	Old	No	Road	9/9/2006 to 10/25/2006	28	1.00	N/A	N/A	N/A
244b	F	Adult	Random	Non-road	2/21/2007 to 9/24/2007	95	0.81	N/A	N/A	N/A
254	F	Young	No	Road	9/10/2006 to 6/12/2007	150	0.97	N/A	N/A	N/A
263	M	Adult	No	Road	9/10/2006 to 10/4/2007	199	0.93	114	1.71	1.49
275	F	Adult	No	Road	9/9/2006 to 10/4/2007	213	0.97	69	0.63	0.87
285	F	Adult	No	Road	9/13/2006 to 9/5/2007	199	0.97	92	1.46	1.01
295	M	Young	Random	Non-road	8/10/2006 to 10/3/2007	134	0.83	106	0.17	1.21
305	F	Young	No	Road	2/10/2007 to 9/11/2007	116	0.96	N/A	N/A	N/A
314	F	Young	Random	Non-road	8/10/2006 to 10/3/2007	68	0.40	N/A	N/A	N/A
324	M	Adult	Random	Non-road	8/9/2006 to 9/25/2007	109	0.69	N/A	N/A	N/A
335	M	Adult	Random	Non-road	8/9/2006 to 9/25/2007	77	0.48	N/A	N/A	N/A
344	F	Old	Random	Non-road	8/10/2006 to 9/25/2007	80	0.51	N/A	N/A	N/A
354	M	Adult	Random	Non-road[c]	8/10/2006 to 9/29/2007	23	0.86	N/A	N/A	N/A
364	F	Adult	Random	Non-road[c]	8/3/2006 to 11/24/2007	28	0.90	N/A	N/A	N/A
375	M	Adult	Random	Non-road[c]	7/29/2006 to 9/29/2007	22	0.81	N/A	N/A	N/A
385	F	Adult	Random	Road	7/30/2006 to 8/16/2007	191	0.96	92	1.04	0.86
393	F	Old	Random	Non-road[c]	7/30/2006 to 9/22/2006	1	1.00	N/A	N/A	N/A
404	M	Adult	Random	Road	8/6/2006 to 9/25/2007	162	0.93	54	0.60	0.44
413	F	Adult	Random	Non-road	7/29/2006 to 10/2/2007	154	0.90	79	0.81	0.87
424	M	Young	Random	Non-road	8/2/2006 to 9/24/2007	125	0.86	66	0.48	0.42
433	F	Young	Random	Road	8/6/2006 to 8/16/2007	201	0.99	75	0.61	0.84
444	M	Adult	Random	Non-road	8/6/2006 to 9/18/2007	72	0.45	N/A	N/A	N/A

Fox[a]	Sex	Age Group	Random sample	Road or Non-road sample	Period monitored	Number of successful radio-locations[b]	Probability of locating[b]	FK LSCV bandwidth	FK estimate (km^2)	MCP estimate (km^2)
463	M	Young	Random	Road	8/7/2006 to 9/18/2007	204	0.94	61	0.55	0.47
474	M	Adult	Random	Road	8/7/2006 to 10/3/2007	218	0.96	113	1.53	1.67
485	F	Young	No	Road	11/11/2006 to 10/2/2007	174	0.99	81	0.64	0.70
493	F	Young	Random	Non-road	8/9/2006 to 10/3/2007	121	0.75	N/A	N/A	N/A
504a	F	Old	No	Road	9/12/2006 to 12/21/2006	55	0.98	N/A	N/A	N/A
504b	M	Old	No	Road	6/25/2007 to 10/4/2007	56	1.00	N/A	N/A	N/A
515	F	Old	Random	Non-road	8/24/2006 to 9/24/2007	149	0.94	71	0.70	0.67
535	F	Old	No	Non-road	9/12/2006 to 10/2/2007	194	0.94	52	0.36	0.52
544	F	Young	No	Road	9/14/2006 to 1/31/2007	72	1.00	N/A	N/A	N/A
555	M	Adult	No	Road	9/14/2006 to 10/2/2007	178	0.84	114	2.05	1.76
565	F	Adult	No	Road	9/14/2006 to 10/3/2007	210	0.99	99	1.52	1.20
574	M	Adult	Random	Non-road	11/18/2006 to 8/23/2007	114	0.99	41	0.19	0.13
583	M	Adult	Random	Non-road	11/19/2006 to 10/2/2007	102	0.77	N/A	N/A	N/A
594	M	Adult	Random	Non-road	8/23/2006 to 10/2/2007	74	0.47	N/A	N/A	N/A
603	M	Adult	No	Road	1/9/2007 to 9/25/2007	132	0.87	N/A	N/A	N/A
614	F	Adult	Random	Non-road	8/15/2006 to 10/2/2007	137	0.81	93	1.10	1.47
624	F	Adult	Random	Non-road[c]	7/26/2006 to 11/24/2007	30	0.94	N/A	N/A	N/A
634	M	Adult	Random	Non-road[c]	8/15/2006 to 11/24/2007	29	0.78	N/A	N/A	N/A
643a	F	Young	No	Road	1/27/2007 to 2/14/2007	13	1.00	N/A	N/A	N/A
643b	M	Old	No	Road	3/5/2007 to 10/3/2007	119	0.98	N/A	N/A	N/A
654	M	Adult	Random	Non-road[c]	7/21/2006 to 10/13/2007	17	0.55	N/A	N/A	N/A
665	M	Old	Random	Non-road[c]	7/27/2006 to 7/8/2007	21	1.00	N/A	N/A	N/A
674a	M	Young	Random	Non-road	8/15/2006 to 2/15/2007	27	0.47	N/A	N/A	N/A

Fox[a]	Sex	Age Group	Random sample	Road or Non-road sample	Period monitored	Number of successful radio-locations[b]	Probability of locating[b]	FK LSCV bandwidth	FK estimate (km^2)	MCP estimate (km^2)
674b	F	Old	No	Road	7/21/2007 to 8/13/2007	16	1.00	N/A	N/A	N/A
682	M	Old	Random	Non-road[c]	7/26/2006 to 6/3/2007	19	0.95	N/A	N/A	N/A
695	M	Old	No	Road	11/7/2006 to 1/18/2007	28	0.88	N/A	N/A	N/A
704	F	Young	Random	Non-road[c]	8/15/2006 to 11/8/2007	30	0.97	N/A	N/A	N/A
715	F	Adult	Random	Non-road[c]	7/21/2006 to 12/5/2007	34	0.87	N/A	N/A	N/A

[a] Numbers represent the VHF frequency of individual radio-collars; numbers followed by a letter indicate a radio-collar that was re-used on a different fox.

[b] Representative of data collected between 10/15/2006 and 10/14/2007.

[c] Fox was not consistently accessible for radio-telemetry by vehicle.