

THESIS

REPRODUCTION, DENNING, AND SPATIAL ECOLOGY OF JUVENILE, YEARLING  
AND ADULT SAN CLEMENTE ISLAND FOXES (*UROCYON LITTORALIS CLEMENTAE*)

Submitted by

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## ABSTRACT

### REPRODUCTION, DENNING, AND SPATIAL ECOLOGY OF JUVENILE, YEARLING AND ADULT SAN CLEMENTE ISLAND FOXES (*UROCYON LITTORALIS CLEMENTAE*)

The endemic California Channel Island fox (*Urocyon littoralis*) declined substantially on four of the six islands that it occupies between 1994 and 2002. One subspecies, the San Clemente Island fox (SCLI; *Urocyon littoralis clementae*) has maintained a relatively stable population compared to the subspecies that declined. The San Clemente Island fox is listed as threatened by the state of California, thus, increased information on reproductive behavior and success as well as home range area and dispersal is essential for understanding the population dynamics of this species. I used a spatially balanced random sampling design to capture and radio-collar 30 foxes from 31 December 2008 to 10 January 2009. I then captured juvenile island foxes from 20 June to 8 October 2009.

I determined reproductive status of 28 island foxes through observations of collared yearlings and adults with or without juveniles between 25 February and fall 2009. A greater proportion of adults (11/20) than yearlings (1/8), and a greater proportion of females (9/12) than males (3/16) were observed interacting with juveniles. Litter sizes averaged 2.0 juveniles. Only one of 28 collared foxes exhibited either polygamous or “helper” behaviors. Parturition started approximately two months earlier than historically recorded on other islands. I observed four dens located in shrubs and one den in a hole without surrounding vegetation. The average slope of terrain next to dens was 6°, average aspect was 148°, and orientation of the most worn entrance to the den averaged 152°. If monetary resources are limited, I suggest focusing on

females to monitor and estimate reproductive success because males were infrequently found with juveniles. If emergence from dens continues to occur earlier than previously recorded, then the current recommended time period for trapping (20 June–January) may need to exclude January to reduce stress during pregnancy of females. Our results should help inform future population modeling for the San Clemente Island fox population.

Home range sizes varied by age class, whereas sex and type of telemetry (vehicle vs walk-in) did not affect home range size. I did not observe overlap often enough to evaluate differences by age classes, but the largest percentage of overlap occurred between an adult male and yearling male (57.8%) and an adult male with an adult female (47.4%). Five of 17 juveniles, one of nine yearlings, and 0 of 21 adults dispersed. I documented the largest average (3.49 km) and maximum dispersal (10.0 km) of any Channel Island fox study. The presence of dispersal in SCLI foxes suggests that 1) juveniles, and particularly males, should be targeted for vaccination because they are more likely to disperse and possibly transmit diseases than older age classes, and 2) if populations are reduced, island foxes may be able to repopulate areas through dispersal.

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## DEDICATION

*This research is dedicated to my family and friends who continue to amaze me with the depth of their empathy, intelligence, hard work, and humor. Very few people ever realize the true impact their personality, support, and encouragement have on others. Every encouraging smile and sympathetic ear helped me get one step closer to finishing this thesis. I strive to spend as much time, empathy, and encouragement on my family and friends as they have spent on me.*

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# CHAPTER 1: REPRODUCTION AND DENNING BY SAN CLEMENTE ISLAND FOXES: AGE, GENDER, AND POLYGAMY

## INTRODUCTION

The San Clemente Island (SCLI) fox (*Urocyon littoralis clementae*) is listed as threatened by the state of California. Four of the six Channel Island fox subspecies (*U. l. littoralis*, *U. l. santarosae*, *U. l. santacruzae*, and *U. l. catalinae*) have experienced population declines of over 80% between 1994 and 2002, and were listed as endangered by the United States Fish and Wildlife Service in 2004 (Roemer et al. 2001a; Coonan et al. 2005a; Coonan et al. 2005b; Timm et al. 2009). In 2008, the International Union for the Conservation of Nature and Natural Resources listed these subspecies as critically endangered due to their restricted range and previous population declines (Roemer et al. 2008). Although the four subspecies are recovering, all subspecies are still vulnerable due to small population size, potential exposure to diseases, and low genetic variation. The SCLI fox has a comparatively stable population (Roemer 1999; Roemer et al. 2001a), however, for unknown reasons the population declined substantially from 1998–2000 (Garcelon 1999; Schmidt et al. 2004). On SCLI, Gregory et al. (2012) conducted a 5-year analysis of 12 trapping grids and found that production of pups varied among years and number of pups captured per female varied up to 4-fold between least and most productive areas. These grid surveys, conducted for one month every summer are used to inform managers about the SCLI fox population. Collecting more precise data on reproductive success using radio telemetry may be useful in the future for understanding population dynamics.

Channel Island foxes generally are monogamous (Crooks and Van Vuren 1996); however, polygamy and socially monogamous pairs (pairs that occupied the same territory but

have extra-pair fertilization) have been observed (Roemer et al. 2001*b*; Gould and Andelt 2011; Resnik and Andelt 2012). On SCLI, pregnant female foxes have been observed as early as mid-February with juveniles observed above ground by the end of March to mid-April (Gould and Andelt 2011; Resnik and Andelt 2012). However, foxes on the four northern islands are thought to give birth during April–May (Laughrin 1973; Moore and Collins 1995; Roemer et al. 2001*b*; Asa et al. 2007; Clifford et al. 2007). For Channel Island foxes, average litter sizes of two are common, but litters up to five have been observed (Laughrin 1973; Moore and Collins 1995; Clifford et al. 2007; Gould and Andelt 2011; Resnik and Andelt 2012).

Until recently, characteristics of den sites have not been well documented for the island fox (Gould and Andelt 2011; Resnik and Andelt 2012). Dens used by island foxes have primarily been found in rock piles, dense brush and cavities in the ground or under tree trunks (Roemer et al. 2004). On SCLI, the majority of the dens have occurred in rock piles and lemonade sumac (*Rhus integrifolia*; Resnik and Andelt 2012) as well as canyons and drainages, underground holes, and in or near vegetation (Gould and Andelt 2011). In addition 2–3 dens can be used in succession (Resnik and Andelt 2012) and dens tend to have westerly facing aspects and 17–18° slopes, on average (Gould and Andelt 2011).

In at least three subspecies of Channel Island fox, the proportion of yearling foxes reproducing was lower than that for older age classes of foxes (Roemer 1999; Coonan et al. 2005*a*; Clifford et al. 2007). Roemer (1999) also found differences between subspecies in number of pups produced per reproductively successful female, suggesting that reproductive data collected for one subspecies cannot be used as a surrogate for another subspecies. Studies of reproduction by island foxes also tended to focus on female reproductive potential with very

little research evaluating how males are associated with litters (Clifford et al. 2007; Gould and Andelt 2011; Resnik and Andelt 2012).

I expanded on the research of Gould and Andelt (2011) and Resnik and Andelt (2012) who focused on the continuum of female reproductive success from rural to urban SCLI foxes and of a random sample of SCLI foxes, respectively. I assessed evidence of reproductive activity by observing both sexes as associated with juveniles. I hypothesized that a greater proportion of: 1) adults, compared to yearlings, would be observed with juveniles due to more extensive life experiences and the likelihood of being sexually mature, and 2) females, compared to males, would be observed more frequently with juveniles due to their need to nurse their young. Finally, few studies have examined characteristics of den sites chosen by SCLI foxes so I gathered data on den site characteristics to compare to previous years.

## MATERIALS AND METHODS

*Study area*--San Clemente Island lies 102 km west-northwest of San Diego, California (Phillips et al. 2007) and is approximately 34 km long by 6.5 km wide with an area of 146 km<sup>2</sup> (Olmstead 1958; Jorgensen and Ferguson 1984). Elevation ranges from 0–599 m. SCLI contains a plateau that extends the length of the island, a steep eastern escarpment, and west-facing, wave-cut terraces (Jorgensen and Ferguson 1984). The southwestern slope consists of large canyons with steep sides. The island is primarily composed of volcanic rock, but sand dunes exist on the northwest portion of the island (Olmstead 1958). Most vegetation on SCLI is categorized as maritime desert scrub, grassland, and coastal dune (Thorne 1976; Sward and Cohen 1980). In addition, coastal bluff, coastal sage scrub, valley and foothill grasslands, island woodland, southern riparian woodland, and coastal marsh vegetation types occur in smaller quantities (Philbrick and Haller 1977).

San Clemente Island has a combination of Mediterranean and maritime climate (Laughrin 1973; Philbrick and Haller 1977) with the highest mean temperatures occurring in August (~21°C) and the lowest mean temperatures in January–February (~12°C; Yoho et al. 1999). During the summer, an inversion layer can form creating significantly higher temperatures at higher elevations that emerge above the fog (Shoenherr et al. 1999). Annual precipitation ranges from 11.3–49.2 cm per water year (1 July–30 June; Yoho et al. 1999) with most rainfall occurring between December–April with droughts common during the summer. During our study on SCLI, precipitation varied from 9.1–23.3 cm during the 2008–2009 water year to 19.8–51.3 cm during the 2009–2010 water year depending on where the rain was collected (U.S. Department of the Navy, unpublished data).

I studied foxes on the northern 55% of SCLI, excluding two restricted areas on the southern (56.0 km<sup>2</sup>) and northern (2.1 km<sup>2</sup>) portions of SCLI (Fig. 1.1). I did not survey a 7.4 km<sup>2</sup> area on the eastern escarpment with slopes greater than 25°.

*Capturing foxes*--I selected a spatially balanced random sample of sites to place traps using ArcGIS 9.2 and the Reversed Randomized Quadrant-Recursive Raster (RRQRR) algorithm (Theobald et al. 2007) in an attempt to reduce spatial autocorrelation between trap sites. I placed 74 traps throughout the northern 55% of SCLI. I used 23 x 23 x 66 cm cage traps (Tomahawk Live Trap Co., Tomahawk, WI) modified with plexiglas (Fort Collins Plastics, Fort Collins, CO) attached to the inside of the door as well as a chew bar (45.7-cm-long polyethylene tubing) to reduce potential trap injuries (Snow et al. 2008). Traps were baited with approximately 57 g (Gould and Andelt 2011) of Purina Friskies Signature Blend cat food (Nestlé Purina PetCare Company, St. Louis, MO) and Very Berry bait (On Target A.D.C., Cortland, IL). I placed burlap, surrounding vegetation, and rocks on traps to minimize exposure of foxes to



weather. Traps were removed after one trap night and placed in a new location determined by RRQRR.

I trapped from 31 December 2008–10 January 2009. I physically restrained foxes and then recorded sex, weight, and signs of pregnancy such as a swollen abdomen. Age class was determined by tooth wear on the first upper molar (Wood 1958). Based on age class, foxes were separated into yearlings, born during the spring of 2008, and adults, born prior to spring 2008. I drew 3–6 ml of blood from a jugular vein to be used to screen for disease and genetics. A passive integrated transponder (PIT) tag (Biomark Inc., Boise, ID) was inserted subcutaneously between the scapulae. To reduce the possibility of a disease outbreak, in 2009, approximately 25% of all foxes on SCLI had received rabies and distemper vaccinations. In case vaccination affected the reproduction or behavior of foxes, I vaccinated eight of 30 foxes to approximate the proportion of the population on SCLI that were vaccinated. Each fox was fitted with a 44-g collar (M1930, Advanced Telemetry Systems, Isanti, MN) weighing <3% of the body weight of the fox.

*Reproduction and denning*--I used telemetry antennas mounted on a vehicle and methods described by Gould and Andelt (2011) and Resnik and Andelt (2012) to initially determine where most foxes were located. I then used hand-held 3-element Yagi antennas and obtained three bearings separated by 20–160°, within a 20-min time span and taken from 20–50 m away, to locate foxes. Each fox was located twice per week from 25 February–20 June 2009 and was observed for 20 min to determine reproductive status, emergence of litters from dens, litter size, and presence of other adult and yearling foxes. I varied the time of day that each fox was located from 0800–1600. I considered a fox to have reproduced if it was observed at a den site with juveniles (born spring 2009) or traveling inside its home range with juveniles. From 7–20 June

2009, I conducted visual observations twice per week for foxes not previously observed with juveniles to insure that all litters were detected; but foxes previously identified with juveniles were observed only once per week. From 20 June 2009 to 31 December 2009, I located all foxes once per week using vehicle telemetry or hand-held Yagi.

Dens were defined as a site where a collared fox and juveniles entered and exited from the same feature (e.g., shrub, hole, etc.). I recorded the first observed date of occupation by a fox and the minimum duration the den was occupied (number of days between first and last observation at den). Aspect and orientation of den entrances were taken using a compass. I measured slope by recoding the difference in degrees of a compass held at eye level and a pole marked at eye level held ten m from the entrance. I categorized types of vegetation as maritime desert scrub (gentle and rough), grassland fine loamy, grasslands clay, developed/disturbed, sand dunes, or other. I also recorded presence of plant species, scat, food scraps, and type of bedding (fur, feathers, vegetation). I measured the distances from den to anthropogenic (paved roads, two track roads, nearest urban areas, culvert, and supplemental food source) and natural (nearest canyon and drainage) features using a combination of Garmin eTrex Vista GPS units in the field and the measure tool in ArcGIS in the office. I measured den sites 5–6 months after the last observation at the den.

In addition, I opportunistically captured collared females from 20 June to 8 October 2009 to ascertain if adult females lactated by presence of tinted fur, length and color of the fur and nipple, whether or not the nipple was swollen, and if I could express milk (Roemer 1999). Signs of lactation were noted as support for determining reproductive status, but were not used as a definitive indicator due to the presence of pseudo-pregnancy in some canid species (Asa and Valdespino 1998). Our techniques for capturing, handling, and monitoring foxes were approved

by Colorado State University's Institutional Animal Care and Use Committee (protocol 09-051A-01).

## RESULTS

From 31 December 2008–10 January 2009, I captured 32 foxes in 74 trap-nights (Fig. 1.1), but one adult male and female were not collared because I had reached our objective for sampling. I did not attempt to locate dens or determine reproductive success for one yearling male and one adult female, because they were located in restricted areas. Average weights for our subsamples of adult males, adult females, yearling males, and yearling females were  $1.85 \pm 0.05$  kg ( $\beta \pm 1$  SE) (range = 1.65–2.18 kg),  $2.07 \pm 0.12$  kg (range = 1.60–2.90 kg),  $1.77 \pm 0.06$  kg (range = 1.55–1.90 kg), and  $1.70 \pm 0.12$  kg (range = 1.45–1.85 kg), respectively. Weights of adult males and adult females did not differ (Wilcoxon-Rank-Sum Test,  $W = 0.55$ ,  $P = 0.36$ ). Three of four adult females that weighed over 2.0 kg did not show signs of being pregnant, whereas, a fourth female weighed 2.9 kg, and had a large and firm stomach suggesting pregnancy.

*Reproduction and denning*--I walked toward and obtained 25–36 locations for each of 28 foxes for a total of 850 locations between 1 January and 20 June 2009 (Appendix Table A.1.1). I obtained visual observations on 6–25 occasions per fox, and each fox was observed with juveniles on 0–5 occasions (Appendix Table A.1.1). I observed 12 of the 28 foxes interacting with 24 juveniles for a minimum average litter size of  $2.0 \pm 0.28$  juveniles/female. A greater proportion of adults (11/20) than yearlings (1/8) (One-Sided Fisher's Exact Test,  $P = 0.048$ ), and a greater proportion of females (9/12) than males (3/16) (One-Sided Fisher's Exact Test,  $P = 0.004$ ) were observed with juveniles (Table 1.1). The earliest date I observed litters above ground was on 18 March 2009 (Appendix Table A.1.2).

Six females that were observed with juveniles showed signs of recent lactation (Appendix Table A.1.2). In addition, two of three females that were not observed with juveniles showed signs of lactation, and one of these females was located under a rock where the sounds of suckling juveniles were heard.

I observed one collared male that may have exhibited polygamous behavior by associating with two adult females and four juveniles at a den. Each female nursed at least two juveniles, but I was unable to determine if any juveniles suckled from both females. In another observation, an adult female and juvenile female that were collared in early October 2009, but were not part of our random sample, continued to use similar areas and were observed on two separate occasions with at least two of the same juveniles during the next spring.

*Characteristics of den sites*--I located five dens that were used a minimum of  $26 \pm 7.6$  days on average (range = 8–49 days). The earliest date a den was observed being used was 13 March 2009. The dens were located on slopes that averaged  $6 \pm 1.7^\circ$ , and aspects averaged  $148 \pm 52^\circ$  (Appendix Table A.1.3). Orientation of the most worn den hole varied considerably around an average of  $151 \pm 56^\circ$  (Appendix Table A.1.3). Dens averaged  $2.6 \pm 0.4$  entrances and four of five dens contained three entrances. Two dens were located in boxthorn (*Lycium californicum*), one in morning glory (*Calystegia macrostegia*) and prickly pear cactus (*Opuntia littoralis*), one in a lemonade sumac bush, and the fifth was an unsheltered hole in a grassy field. One den contained shredded sticks for bedding and two dens contained bones of prey items.

Distances from anthropogenic features varied; dens were located an average of  $649 \pm 357$  m (range = 2–1,550 m) from the nearest paved road,  $239 \pm 154$  m (range = 5–833 m) from the nearest two-track road,  $486 \pm 258$  m (range = 2–1,370 m) from the nearest culvert,  $5,262 \pm 2,639$  m (range = 0–15,006 m) from the nearest urban area, and  $5,562 \pm 2,651$  m (range = 52–15,282

m) from the nearest anthropogenically provisioned food source. Distances of dens to natural features included  $764 \pm 502$  m (range = 24–2,722 m) from the nearest canyon,  $131 \pm 83$  m (range = 0–404 m) from the nearest drainage, and  $665 \pm 212$  m (range = 442–1,511 m) from the nearest capture site of the parents.

## DISCUSSION

Our findings that adult females produced more pups than yearling females agrees with previous research on SCLI (Roemer 1999), on other subspecies of island fox (Roemer 1999; Coonan et al. 2005a; Clifford et al. 2007), on the Mednyi Island Arctic fox (*Alopex lagopus semenovi*; Goltsman et al. 2005), and on the red fox (*Vulpes vulpes*; Harris 1979). Notably, in 2009, I observed 33% of yearling and 89% of adult female foxes associated with juveniles, whereas Roemer (1999) reported only 16% of yearling (6.2–79.2%) and 29% of adult (56.5–98.0%) females produced juveniles (95% Wilson score CI; Wilson 1927; Newcombe 1998). This difference in reproductive rates may be due to yearly variation or the monitoring method used (VHF telemetry versus grid surveys used by Roemer). If reproductive success was underestimated using yearly grid surveys, the importance of juveniles to the population models may be inaccurate. By documenting a larger proportion of adults than yearlings that reproduce, I have added more specific fertility information that can be used for future demographic modeling.

My data suggests that females may contribute more to parental care than males because I only observed three males with litters (Table 1.1). The even sex ratio of island foxes (Garcia and Associates 2011) suggests that if both sexes visit dens at the same frequency I would expect to observe similar proportions of males and females with juveniles. Male Mednyi Island Arctic foxes exhibited a similar pattern and spent little time in the breeding dens (Kruchenkova et al. 2009). If male Channel Island foxes also demonstrate this behavior, and if males are used to

calculate rate of reproduction, then I would be underestimating the number of juveniles born during the year.

I estimate that the juveniles I observed outside two dens on 18 March 2009 were conceived as early as the beginning of January (Moore and Collins 1995). Early observations of juveniles outside of dens may indicate that some females on SCLI are breeding approximately two months earlier than historically recorded for other subspecies of island foxes (Laughlin 1973; Moore and Collins 1995; Roemer et al. 2001*b*; Asa et al. 2007; Clifford et al. 2007). In spring 2007 and 2008, parturition was estimated to first occur in late January to mid-February (Gould and Andelt 2011; Resnik and Andelt 2012). In contrast, on Santa Cruz Island and Santa Catalina Island, parturition occurred in April (Roemer et al. 2001*b*; Clifford et al. 2007). These observations on SCLI may reflect an earlier emergence from dens or merely an increase in observational efforts.

The heavier weights of some females captured in early January also supports the conclusion that some SCLI females are breeding earlier. In previous years, weights of male island foxes were similar ( $P > 0.05$ ; Gregory et al. 2012) or males were significantly heavier than female island foxes ( $P < 0.05$ ; Collins 1993; Crooks 1994; Schmidt et al. 2004; Schmidt and Garcelon 2005; Resnik 2012). Without an abdominal ultrasound, I was uncertain if the four heavy females caught in January 2009 were in the early stages of pregnancy or were just larger than average. Comparisons of the reproductive periods of foxes on each of the Channel Islands may yield yet another distinction between subspecies.

Rainfall may also impact female productivity. I found that nine of 12 females reproduced when SCLI received 9.1 to 23.3 cm of rainfall in 2008–2009 water year, whereas six of 12 females reproduced during 2007–2008 (Gould and Andelt 2011) and four of 13 females

reproduced during 2006–2007 (Resnik and Andelt 2012) when SCLI received 11.5–45.3 cm and 4.3–9.8 cm of rainfall, respectively. Gregory et al. (2012) suggested a precipitation threshold might exist under which reproduction could be suppressed instead of a linear increase between precipitation and female productivity.

Parturition and litter size may be underestimated in our study if perinatal mortality occurred before juveniles were old enough to be observed outside the den. Free-ranging foxes on Santa Catalina Island exhibited perinatal mortalities of 43.2% and most mortalities of pups occurred at or soon after birth (Clifford et al. 2007). In addition, if researchers are unable to detect all juveniles, or if there is variability when island foxes reproduce, I could underestimate litter size. In one case, an adult female was observed entering and exiting the same bush throughout the spring, but was not observed with a juvenile until 3 October 2009, 90 days after the last litter was found. If mortalities occurred in other litters before this date, then I may not have detected all juveniles. However, observed litter sizes in this study were similar to the average litter size of 2.0 for females on SCLI during 2007 and 2008 (Gould and Andelt 2011; Resnik and Andelt 2012) and other Channel Island fox subspecies (Laughrin 1973; Moore and Collins 1995; Clifford et al. 2007) suggesting that I observed most kits in a litter.

Our observations on SCLI of two adult females associated with one litter of juveniles suggest that I was observing polygamous behavior, helping behavior, or possibly more than one pair of foxes using the same den. Considering that research on SCLI has not been designed specifically to detect polygamy, it may be more prevalent than I have documented. Increased polygamy or helping behaviors may be associated with island conditions, such as higher density, which may force foxes into closer proximity and increase the chances for extra pair copulations (Roemer et al. 2001*b*; Kamler et al. 2004; Goltsman et al. 2005; Iossa et al. 2009). Documenting

prevalence of polygamy may be important for determining disease transmission and population size.

Due to our limited 20-min observation periods of reproductive activity by collared foxes, I was unable to obtain many visuals of juveniles entering and exiting dens, and thus I have a small sample size of dens. During 2008, collared female foxes on SCLI were observed for longer periods of time (up to 30 min per visit and one 8 h observation) until visuals of juveniles were obtained (N. P. Gould, pers. comm.) and more dens were observed. Consequently, dens found in 2008 may be a more accurate representation of the population than those measured in 2009. It is possible that in 2009, foxes chose structures that were difficult to observe as dens. For instance, lemonade sumac or boxthorn shrubs were large enough to obstruct views of juveniles and dens. In multiple cases, foxes were suspected of denning, but were only observed with juveniles away from the suspected den site. In 2008, a majority of the dens were found in canyons, drainages, and underground caverns, but also in rock outcrops, rock piles, lemonade sumac, and rip-rap (Gould and Andelt 2011). Distances from dens to supplemental food sources and urban areas should not be considered independent variables because all supplemental food sources were located within the boundaries of urban areas as defined by Gould and Andelt (2011).

While I suggest continued research into the specifics and variation of female reproduction, it may be unnecessary to follow males because less information on reproduction apparently can be gathered. If trapping continues in January I suggest using ultrasound imaging to determine parturition of females and litter size (Clifford et al. 2007), collecting genetic data for determining parentage (Roemer et al. 2001*b*), and increasing observations by one of the following methods: longer observations preferably at dawn and dusk due to inactivity during



daytime (Laughrin 1973; Garcelon 1999), more frequent observations, or use of remote cameras (Clifford et al. 2007). Clifford et al. (2007) suggest a combination of ultrasound, remote cameras, and observations to determine presence and size of litters. For example, Clifford et al. (2007) reported ultrasound indicated that of 30 females known to be pregnant, 15 cases had fetal counts that were higher than the number of weaned pups observed.

Currently, trapping on SCLI can occur between 20 June–January (U.S. Department of the Navy, pers. comm.) which may overlap with when females are still pregnant or nursing. If emergence continues to be observed earlier than historically recorded then the time period for trapping may need to be adjusted to exclude January, if it is documented to increase stress to pregnant female. Most importantly, multiple years of reproductive data are needed to obtain unbiased estimates of reproductive parameters. This should include collecting covariate data such as population size and rainfall that may illuminate factors affecting reproduction in females. As with many threatened and endangered species, continued monitoring of reproduction is crucial for future population modeling and ensuring the successful conservation of the San Clemente Island fox.

Table 1.1. Collared foxes monitored for interactions with juveniles on San Clemente Island, California, USA during the reproductive season of 2009.

	Adult male	Adult female	Yearling male	Yearling female
Number of collared foxes monitored <sup>a</sup>	11	9	5	3
Number of collared foxes observed with a juvenile	3	8 <sup>b</sup>	0	1 <sup>b</sup>
Number of juveniles observed with collared foxes	7	15	0	2

<sup>a</sup>One yearling male and one adult female were excluded because they used restricted areas and I was unable to adequately observe them.

<sup>b</sup>One adult female trapped on 13 July 2009 and one yearling female trapped on 21 July 2009 were lactating, but they were not observed with juveniles.

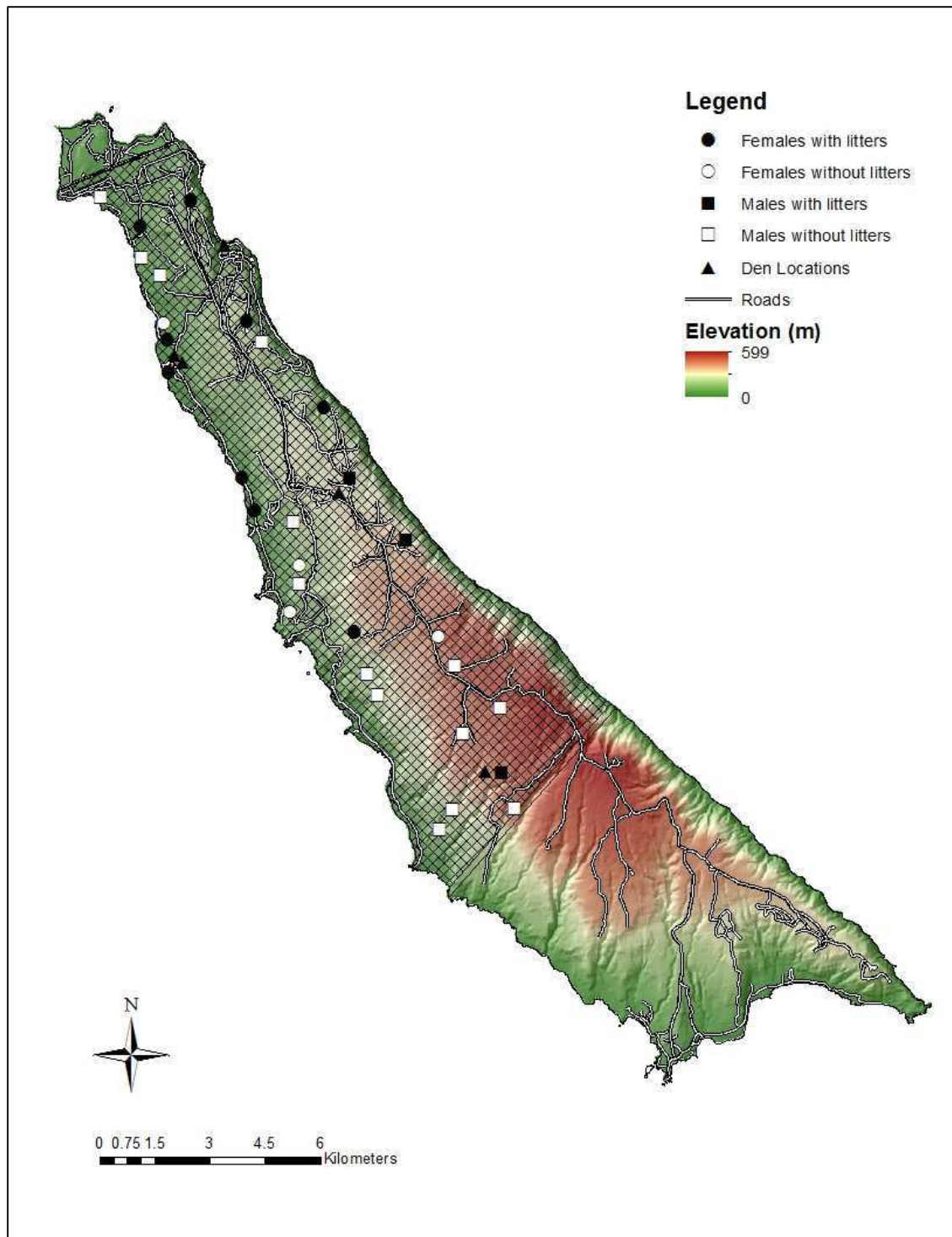


Figure 1.1. Locations of 30 San Clemente Island foxes (*Urocyon littoralis clementae*) trapped and collared from 31 December 2008–10 January 2009, and five dens subsequently found on San Clemente Island, California, USA.

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## CHAPTER 2: SPATIAL ECOLOGY OF JUVENILE, YEARLING, AND ADULT SAN CLEMENTE ISLAND FOXES

### INTRODUCTION

Data on size and location of home ranges and dispersal behavior can be used to better understand disease transmission (Sanchez 2012), maintenance of genetic variability (Gompper et al. 1998), intraspecific relationships (Chamberlain and Leopold 2000), and spatial requirements necessary for persistence and management of many species. The San Clemente Island fox (SCLI; *Urocyon littoralis clementae*) is an endemic subspecies of the Channel Island fox (*Urocyon littoralis*) that often maintains similar sizes and locations of home ranges among years (Gould and Andelt 2013). Home range size of the Channel Island fox vary by subspecies, type of habitat (Sanchez 2012; Drake 2013), season, and methodology used to estimate home range size (Powers 2009; Resnik 2012). In addition, at least one subspecies of island fox on Santa Cruz Island has exhibited excursions and short dispersals (August 1993–September 1995; Roemer et al. 2001). Due in part to the fox’s small body size (~1.8–2.0 kg; Resnik 2012) and insular nature, the average size of island fox home ranges is smaller than almost all canid species (Roemer et al. 2001).

On SCLI, home range sizes were largest during pup-independence season (15 June–14 October; Resnik 2012), when population densities were low (Sanchez 2012), and for foxes that spent a smaller proportion of time in urban areas (where food resources are more stable and abundant; Gould and Andelt 2013). On SCLI, the fox population appeared to be relatively stable when most home range studies occurred (Roemer 1999; Roemer et al. 2001; Garcia and Associates 2011; Sanchez 2012) compared to studies that were conducted on other islands during

(Roemer et al. 2001) and after (Drake 2013) large declines in island fox populations. Because of this, home range estimates on SCLI (Resnik 2012; Gould and Andelt 2013) may be more representative of Channel Island fox home range sizes in the absence of large fluctuations in density.

Overlap of home ranges in Channel Island foxes is greater for male-female pairs (Crooks and Van Vuren 1996; Roemer et al. 2001), when population densities are high (Drake 2013), and when adults are providing for yearling and related offspring (Roemer et al. 2001; Ralls et al. 2013). Quantifying the amount of home range overlap between juveniles, yearlings, and adults should help us better understand the potential for disease transmission (Sanchez 2012) and relationships among neighbors (Powers 2009).

Although not usually included in home range analyses (Burt 1943), excursions (temporary movements outside of a home range) and dispersal (movement from a home range to establish a new home range) can provide insights to gene flow, disease transmission, and colonization processes (Bohonak 1999; Clobert et al. 2009; Sanchez 2012). Although numerous adult, and some yearling foxes have been monitored, dispersal has not been observed on SCLI (Garcelon 1999; Resnik 2012; Gould and Andelt 2013). Only a few cases of dispersal have been observed for Channel Island foxes, primarily on Santa Cruz Island (Roemer et al. 2001), and the subject warrants further investigation (Drake 2013). Because of the small area of the Channel Islands, long range dispersals are not possible (Roemer 1999). If juveniles compete with adults and are forced into suboptimal habitats, they may disperse more frequently and farther away than older, more experienced individuals.

For my research, I sought to determine if age class and sex had an effect on home range size and dispersal behavior. I predicted that: 1) juveniles (<1 year old) will have smaller home

ranges than yearlings (1–2 years old) and adults (>2 year old), and 2) a larger proportion of juveniles will disperse than yearlings and adults. To the best of my knowledge, my study was the first attempt to place radio-telemetry collars on juvenile foxes. I also investigated differences in home range overlap and excursions among age classes of SCLI foxes. Understanding whether there are age-related differences in home range sizes, the extent of home range overlap and when dispersals occur, will help inform future management efforts.

## MATERIALS AND METHODS

*Study area*--San Clemente Island is the most southern and 4th largest of the seven California Channel Islands at 34 km long by 6.5 km wide with an area of 146 km<sup>2</sup> (Olmstead 1958; Jorgensen and Ferguson 1984). San Clemente Island is primarily comprised of maritime desert scrub, grassland, and coastal dune habitats (Thorne 1976; Philbrick and Haller 1977; Sward and Cohen 1980). SCLI is owned and operated by the U.S. Navy and contains three urban areas where island foxes often obtain food from humans (Gould and Andelt 2013). The island contains a wide variety of food sources for this generalist species including rodents, lizards, arthropods, and plants (Phillips et al. 2007). The elevation on the island ranges from 0–599 m and topography varies from flat sloped areas on the NW side of the island to increasingly large canyons and terraces in the southwest part of the island. A steep escarpment spans approximately 22 km on the southeastern coast and is mostly inaccessible to researchers. The climate is a combination of Mediterranean and maritime (Laughrin 1973; Philbrick and Haller 1977). Temperatures vary monthly between averages of ~12°C in January to 21°C in August (Yoho et al. 1999). Annual precipitation ranged from 11.3–49.2 cm per water year (1 July–30 June; Yoho et al. 1999) with most rainfall occurring between December–April, and droughts were common during the summer.

*Capturing foxes*--I used a combination of ARCGIS (v9.2; Environmental Systems Research Institute, Inc., Redlands, California) and the reversed randomized quadrant-recursive algorithm (RRQRR; Theobald et al. 2007) to select random, spatially-balanced trapping locations throughout the study area. Adult (born prior to spring 2008) and yearling (born spring 2008) foxes were captured from 31 December 2008–10 January 2009 and will hereafter be called the random sample (Appendix Figure A.2.1). All foxes were captured using 23 x 23 x 66 cm cage traps (Tomahawk Live Trap Co., Tomahawk, WI) modified with plexiglass (Fort Collins Plastics, Fort Collins, CO) attached to the inside of the door as well as a chew bar (45.7-cm-long polyethylene tubing) to reduce potential trap injuries (Snow et al. 2012). I baited traps with approximately 57 g (Gould and Andelt 2011) of Purina Friskies Signature Blend cat food (Nestlé Purina PetCare Company, St. Louis, MO) and On Target Very Berry paste bait (On Target A.D.C., Cortland, IL). I reduced exposure of foxes to the elements by covering traps with burlap and surrounding vegetation. Traps were set in the afternoon after the peak heat of the day and checked early in the morning to prevent overheating. Captured foxes were physically restrained and blindfolded to reduce stress. I recorded sex, weight, signs of pregnancy such as a swollen abdomen, and estimated age class using tooth wear (Wood 1958; Collins 1993). I drew 3–6 ml of blood from a jugular vein to screen for disease and genetics. A passive integrated transponder (PIT) tag (Biomark Inc., Boise, ID) was inserted subcutaneously between the scapulae. I vaccinated eight of 30 foxes to approximate the proportion of the population on SCLI that were vaccinated against rabies and distemper. Each fox was fitted with a 44-g collar (M1930, Advanced Telemetry Systems, Isanti, MN) weighing <3% of the body weight of the fox.

I captured juvenile foxes for radio collaring (born spring 2009) from 20 June–8 October 2009. To increase capture success for juveniles, I employed one of three strategies: 1) I targeted

juveniles associated with at least one of the collared random sample of foxes, 2) I collared juveniles that were captured on trapping grids used for population surveys (Garcia and Associates 2011), and 3) I used RRQRR to select random locations to trap juveniles within areas I did not have collared adults and yearlings, and where trapping grids were not present (Appendix A.2.1). At each trapping location, I placed eight traps for two consecutive nights (Appendix Figure A.2.2).

Because island fox home ranges show little overlap with neighboring foxes (Roemer et al. 2001), and had a mean home range diameter of 0.96 km (N.P. Gould, W.F. Andelt, and E.E. Hamblen, unpublished 2010 report), I used a one km diameter buffer around each random trap location for juveniles as a proxy for trapping in each home range. This ensured that there was at least one trap within one km of any location in the study area (Appendix Figure. A.2.3). I collared a maximum of two juvenile foxes per trap location to limit the possibility of collaring related juveniles that may have similar home range sizes.

I processed juveniles caught during the summer following methods described for the random sample of captures. In addition, presence of milk teeth, indentations on incisors, appearance of coat, and body mass were used to determine if a fox was a juvenile (Wood 1958; Collins 1993). Foxes were organized into: adult males (AM), adult females (AF), yearling males (YM), yearling females (YF), juvenile males (JM), and juvenile females (JF). All foxes were assumed to transition to the next age class on 17 February, the average date of parturition (Resnik and Andelt 2012).

*Radio-telemetry*--I used a vehicle mounted antenna to locate foxes (hereafter called vehicle foxes). I acquired locations for each fox spaced at least one week apart to reduce temporal autocorrelation. I systematically rotated when each vehicle fox was located during a 24

h day to reduce bias associated with repeatedly sampling an individual during the same part of the day. I collected fewer locations during the last six months of my study period for adults and yearlings captured during January 2009 (~3/month; January–July 2010). Decreased location sampling was justified because I had already obtained one year of locations for these foxes, they had not dispersed and home range sizes and boundaries were assumed to be relatively constant. Locations of juveniles caught during summer 2009 were collected from date of collar attachment (20 June–8 October 2009) until July 2010 in an attempt to obtain approximately one year of locations. The inter-bearing angles for radio locations were 20–160 degrees apart and within an interval of 20 min to increase accuracy of estimated locations (Swihart and Slade 1985). Antennae on vehicles were tested at least once per month to ensure the accuracy of signal direction was within two degrees of the true bearing.

For foxes that were too far from roads to use a vehicle antenna, I attempted to collect 1–4 locations/month on foot (hereafter called walk-in foxes). I obtained all locations for walk-in foxes from 0800–1600 due to U.S. Navy safety restrictions. My techniques for capturing, handling, and monitoring foxes were approved by Colorado State University’s Institutional Animal Care and Use Committee (protocol 09-051A-01).

*Data analyses*--I estimated error associated with each telemetry location using location of a signal software (LOAS, 4.0.3.8; Ecological Software Solutions LCC, Urnäsch, Switzerland) similar to Resnik (2012), Snow et al. (2012), and Gould and Andelt (2013). I adjusted bearings using declination estimates from the National Geophysical Data Center (2009). I used the Andrews M-estimator (bearings >3), and Maximum Likelihood Estimator (bearings = 3) to calculate error ellipses, and used error polygons for biangulations (bearings = 2). I censored locations with error ellipses and polygons greater than 52 000 m<sup>2</sup> and 22 710 m<sup>2</sup>, respectively,

from the data analyses (Resnik 2012; Snow et al. 2012; Gould and Andelt 2013). These areas represented 4% and 2% of the average home range size calculated by Resnik (2012). I only included foxes in my home range analyses that had >80% successful location attempts.

I used 95% minimum convex polygons (MCP) for home range size estimates because home ranges created with the commonly used fixed kernel estimates and least-squares cross-validation bandwidth tends to overestimate home range size when <50 locations are used (Seaman et al. 1999). These planimetric home ranges were calculated and then clipped to the coastline of SCLI (Resnik 2012) using Program R packages *adehabitatHR* and *PBSmapping* (v2.15.1; R Development Core Team 2008).

*Variation in home range size by age class, sex, and type of telemetry.*

I modeled variation in home range sizes among foxes using a general linear models approach with age class (juvenile, yearling (2009 and 2010), or adult), sex (male and female), and type of telemetry (vehicle and walk-in) as predictor variables. I estimated home range size for each fox using all locations pre- (17 February 2009–16 February 2010) or post-transition (17 February 2010–31 July 2010) to the next age class. I then chose the time period (pre- or post-transition) that had the most locations to estimate one home range size per individual. For each fox, I generated an area-observation curve by plotting the 95% MCP home range estimates (y-axis) against the number of locations used to generate the home range estimates (x-axis), then visually estimated the number of locations necessary to reach an asymptotic home range size (Stickel 1954; Odum and Kuenzler 1955; Harris et al. 1990). I used only home range estimates from foxes that appeared to reach an asymptote on the area-observation curve to produce as reliable and unbiased home range estimates as possible (Harris et al. 1990). In order to account for any additional bias due to number of locations used, I weighted each observation by the



number of locations used to construct the home range estimate by using the weight expression within the glm function in Program R. By doing this, home range areas created using a larger number of locations would be weighted as more important than those created using fewer locations. Type of telemetry was used as a covariate because the time period (24 h/day vs 8 h/day) and telemetry error (vehicle antenna vs Yagi antenna) potentially differed between vehicle and walk-in locations. I used the Box-Cox normality plot to determine that the log transformation was most likely the best transformation for the data (Box and Cox 1964), and evaluated normality and homogeneity of residuals using the Shapiro-Wilk statistic (Shapiro and Wilk 1965), probability-probability plot, quantile-quantile plot, and Studentized residual plots. I used Tukey's Honest Significant Difference (Tukey 1949) for multiple comparisons.

*Home range sizes for individual foxes that transitioned to the next age class, one year after transition, and transitioned after dispersal.*

To better understand how age class affected home range size, I examined the difference in home range estimates before and after three types of transition using: 1) locations collected prior to [e.g. June 2009 to 16 February 2010] and after [e.g. 17 February to July 2010] the age class transition on 16 February 2010, 2) locations collected one year apart (approximately February to August for each year to remove the seasonal effect), and 3) locations separated by a dispersal event. The first two methods examined the effects of the age class transition, while the third examined if foxes transition to larger or smaller home range after dispersal. In each case, I used individuals as their own control by creating two 95% MCP home ranges for each fox (using the same number of locations for each home range) and subtracting the pre-transition home range size from the post-transition home range size. For example, to compare juvenile and yearling

home range sizes, I calculated the difference of the home range size while a yearling minus the home range size of the same individual before they transitioned (as a juvenile).

Although I created area-observation curves, I was unable to use asymptotes as a method for including individuals in the analysis listed in the aforementioned paragraph, due to the low number of locations obtained per home range. Instead I used the number of locations in each fox's home range estimate/total number of locations per age class to calculate the weighted mean home range size difference and 95% confidence interval (CI) of these differences. The critical value from a t-distribution was used to construct the CI to determine if the 95% CI covered zero for each transition: juvenile-yearling, yearling-adult, and adult-adult. Normality and homogeneity of differences were evaluated using the Shapiro-Wilk statistic (Shapiro and Wilk 1965), probability-probability plots, and quantile-quantile plots. When differences in home range sizes for age classes did not fit the assumption of normality I computed the difference of the natural logs: difference =  $\log(\text{post-transition home range estimate}) - \log(\text{pre-transition home range estimate})$ .

#### *Overlap of home ranges.*

I estimated spatial overlap of home ranges of all foxes that appeared to reach an asymptote on the area-observation curve. I restricted the analysis to 17 February 2009–16 February 2010 to ensure all individuals were in a consistent age class for the entire analysis. I calculated the area of overlap for two foxes and then the percentage of overlap by dividing the area of intersection by the area of union in ARCGIS 10.1 (Millsbaugh et al. 2004; Resnik 2012; Gould and Andelt 2013).

### *Dispersals and excursions.*

I defined dispersal as a movement from an area that had been occupied for at least one month from the date the fox was first collared to another area (White and Garrott 1990). Distances >1 km between the pre- and post- home ranges were considered dispersal events (Resnik 2012). I estimated the proportion of foxes from each age class that dispersed and used the Wilson Score Interval (Wilson 1927; Newcombe 1998) to construct 95% CIs around proportions (for small sample sizes this method performs better than the normal approximation). I estimated dispersal distance by calculating the distance between the arithmetic center of the pre- and post- dispersal home ranges. I compared the 95% CI for the dispersal distance for the juvenile age class to the one yearling that dispersed. I estimated the length of time that it took the fox to disperse by subtracting the last date observed in the pre-dispersal home range from the first date of permanent residence in the post-dispersal home range (i.e., once trips to the pre-dispersal home range ceased). I counted the number of days spent dispersing for each fox and compared the 95% CI for the number of days juveniles dispersed to the yearling that dispersed. I also documented whether dispersals included 1-way movements or if there were repeated visits to the pre-dispersal home range. I documented start and end dates of dispersal to determine if dispersal occurred during a specific season for each age class. I estimated the average age of the fox that dispersed by subtracting the average date of parturition (Resnik and Andelt 2012) from the date the fox was first observed dispersing. I defined excursions as a movement  $\geq 1$  km from the nearest location within the 95% MCP calculated with all locations included followed by a return to the original home range (Adams et al. 2008; Skuldt et al. 2008; Resnik 2012; Gould and Andelt 2013). To determine the number of excursions, I only used foxes that appeared to reach an asymptote on the area-observation curve.

## RESULTS

### *Variation in home range size by age class, sex, and type of telemetry.*

I collared 47 foxes (AM = 11, AF = 10, YM = 6, YF = 3, JM = 11, and JF = 6). Of these, five juveniles (JM = 4 and JF = 1) had more locations after transitioning to yearlings on 17 February 2010 than while they were juveniles, thus I reclassified them as yearling (2010) home ranges in the analyses. Of the 47 foxes, 43 were used in this analysis (3 foxes did not reach asymptotes on the area-observation curves and one fox had a home range two times larger than the next home range and appeared to be an outlier) (Appendix Figure A.2.1; Appendix Table A.2.1).

Area-observation curves appeared to indicate an average of 37, 41, 19 and 18 locations per adult, yearling (2009), yearling (2010), and juvenile, respectively, were necessary to reduce the probability of biased home range estimates. Once log-transformed, the residual distribution no longer deviated from a normal distribution (Shapiro-Wilk test:  $W = 0.97$ ,  $P = 0.305$ ). Home range sizes varied by age class, whereas sex and type of telemetry did not affect home range size (Table 2.1; Table 2.2a). Home range size differences between juvenile-adult, juvenile-yearling (2009), yearling (2010)-adult, and yearling (2009)-yearling (2010) age classes were statistically significant (Table 2.2b). I completed the same analyses with the censored fox included and reached the same conclusion; however I was no longer able to meet the assumption of normality even with a data transformation.

### *Home range sizes for individual foxes that transitioned to the next age class.*

I estimated pre- and post- age class transition home range sizes for 37 foxes (AM to AM = 9, AF to AF = 8, YM to AM = 3, YF to AF = 3, JM to YM = 9, and JF to YF = 5) with an average of  $16.4 \pm 1.4$  ( $\beta \pm 1$  SE),  $16.7 \pm 1.8$ , and  $18.8 \pm 1.4$  locations per adult, yearling, and

juvenile, respectively (Appendix Table A.2.2). The distribution of differences in home range size for yearlings transitioning to adults (Shapiro-Wilk test:  $W = 0.95$ ,  $P = 0.768$ ) and juveniles transitioning to yearlings (Shapiro-Wilk test:  $W = 0.96$ ,  $P = 0.696$ ) fit a normal distribution. The distribution of differences in home range sizes for adults transitioning to the next year of adulthood were not normally distributed, and I found no transformation that allowed the assumption of normality to be met (Shapiro-Wilk test:  $W = 0.81$ ,  $P = 0.003$ ). The mean difference between home range estimates for yearlings that transitioned to adults decreased by  $0.16 \text{ km}^2$  (95% CI:  $-0.08 - -0.24 \text{ km}^2$ ) and the 95% CI did not overlap zero, whereas differences in home ranges of juveniles that transitioned to yearlings ( $\beta$ :  $-0.05 \text{ km}^2$ ; 95% CI:  $-0.11-0.01 \text{ km}^2$ ) and adults that transitioned to the next year of adulthood ( $\beta$ :  $-0.07 \text{ km}^2$ ; 95% CI:  $-0.15-0.02 \text{ km}^2$ ) did not vary significantly from zero (Table 2.3).

*Home range sizes for individual foxes one year after transition.*

I estimated pre- and post- age class transition home range sizes with locations separated by approximately one year for 22 foxes (AM to AM = 9, AF to AF = 7, YM to AM = 3, YF to AF = 3) with an average of  $16.0 \pm 1.5$  ( $\beta \pm 1 \text{ SE}$ ) and  $16.7 \pm 1.8$  locations per adult and yearling (Appendix Table A.2.3). I censored one adult female fox (Fox ID: 013) with a home range size estimate 1.7 times larger than the next largest estimate. Adults that transitioned to the next year had home range estimates that fit the assumption of normality (Shapiro-Wilk test:  $W = 0.98$ ,  $P = 0.967$ ) but the yearling to adult home range estimates fit the assumption of normality only after a log transformation (Shapiro-Wilk test:  $W = 0.86$ ,  $P = 0.184$ ). The mean difference in home range size after one year did not vary for adults that transitioned to the next year of adulthood ( $\beta$ :  $-0.01 \text{ km}^2$ ; 95% CI:  $-0.08-0.07 \text{ km}^2$ ) and for yearlings that transitioned to adults (log-transformed;  $\beta$ :  $-0.89 \text{ km}^2$ ; 95% CI:  $-2.52-0.74 \text{ km}^2$ ; Table 2.3).

*Home range sizes for individual foxes that transitioned after dispersal.*

I estimated pre- and post- dispersal home range sizes for six foxes (YM = 1, JM = 4, JF = 1) with an average of  $15.4 \pm 3.0$  ( $\beta \pm 1$  SE) locations for each juvenile for each home range and 25 locations for the yearling for each home range (Appendix Table A.2.4). The distribution of post-dispersal minus pre-dispersal juvenile home ranges fit the assumption of normality after a log transformation (Shapiro-Wilk test:  $W = 0.96$ ,  $P = 0.787$ ). The mean difference in home range size did not vary for these juveniles (log-transformed mean:  $\beta$ : -0.74; 95% CI: -2.24–0.76; Table 2.3). The one yearling home range size decreased by  $0.33 \text{ km}^2$  (log-transformed: -1.11).

*Overlap of home ranges.*

I observed considerable overlap of the home ranges of some foxes (Table 2.4; Appendix Table A.2.5). I did not observe overlap often enough to evaluate differences by age classes. The largest percentage of overlap occurred between an adult male and yearling male (57.8%) and an adult male with an adult female (47.4%).

*Dispersals and excursions.*

Five of 17 juveniles (proportion ( $p$ ): 0.30; 95% CI: 0.13–0.53), one of nine yearlings ( $p$ : 0.11; 95% CI: 0.02–0.44), and 0 of 21 adults dispersed. Four of 11 juvenile males and one of six juvenile females dispersed. The average dispersal distance for juveniles was 3.83 km (range: 1.24–10.00 km) whereas the yearling dispersed 1.79 km (Appendix Table A.2.4; Appendix Figure A.2.4). Juvenile island foxes completed dispersals within an average of 51 days (range: 14–124 days) and the yearling completed dispersal in 33 days. Dispersals included 1-way movements as well as repeated visits to the pre-dispersal home range before settling in the post-dispersal home range. The juveniles and the yearling completed dispersal within the same time period (24 September 2009–26 January 2010 and 28 October 2009–30 November 2009,

respectively; Appendix Table A.2.4). The average age of dispersal for juveniles was 268 days (95% CI: 221–314 days) whereas the yearling dispersed after 619 days. No foxes completed excursions.

## DISCUSSION

Prior to my study, there was almost no information on how age affects home range size of island foxes (Gould and Andelt 2013). The multiple significant differences between age classes in the first analysis may reflect differences due to the number of locations used to create home ranges rather than meaningful biological differences. For instance, home range sizes of yearlings in 2009 were significantly larger than for yearlings in 2010. This may be due to yearly variation between the two cohorts, but yearlings in 2009 also had almost twice as many locations collected compared to the 2010 yearlings. In addition, yearlings (2009) had home range sizes more similar to adults (both age classes had home range sizes created using similar number of locations) while yearlings (2010) had home range sizes more similar to juveniles (who also had a lower number of locations collected). Although I tried to take into account the effect of number of locations by weighing each home range by the number of locations, I may still be unable to differentiate home range size due to age class and number of locations.

I assumed that yearlings would have an average home range size intermediate between that of juveniles and adults, but my estimates did not show consistent significant differences. I may not have observed significant differences between yearling and juvenile and yearling and adult home range sizes because yearlings can display traits of either juveniles or adult island foxes. For instance, similar to juveniles, yearlings have been observed to share space with their parents (Ralls et al. 2013) whereas other yearlings dispersed (Roemer et al. 2001). During this

study, I observed one yearling male that appeared to form a pair bond with a female similar to that of adults.

The unexpected decrease in home range size for yearlings that transitioned to adults may be due to a small sample size ( $n = 6$ ), an insufficient number of locations, or sampling over too short of a time interval. Minimum convex polygon home range calculations have been found to be sensitive to number of locations (Bekoff and Mech 1984; Börger et al. 2006; Laver and Kelly 2008), and can be sensitive to type I error if the sampling duration is too short (Bekoff and Mech 1984; Fieberg and Börger 2012) and type II error may occur if the utilization distribution of the fox is not convex (White and Garrott 1990; Fieberg and Börger 2012). The decrease in home range size for yearlings that transitioned to adults could also reflect a seasonal effect. The breeding season (15 October–14 February), which coincided with my pre-transition home range estimates, may have larger home ranges than the parturition and pup-dependence season (15 February–14 June) if females stay closer to dens during this time interval. However, differences observed for yearlings may warrant further investigation considering that yearlings that transitioned to adults, with locations separated by one year, did not show a significant change in home range size. In addition, Resnik (2012) did not find a difference in home range size between the breeding and pup-dependence season.

I was surprised that home ranges of juveniles did not change significantly after dispersal and were comparable to the size of home ranges of juveniles that did not disperse. However, considering the small sample size ( $n = 6$ ), an average of 15 locations per 95% MCP, and area-observation curves that did not reach an asymptote, these home range sizes likely were underestimated. The significantly larger home ranges of adults compared to juveniles as well as significantly different home range sizes for yearlings from 2009 and 2010, suggests that home



range size changed with time, but I did not collect enough locations over a long enough period of time to determine when that change occurred.

Similar to previous studies on SCLI (Resnik 2012; Gould and Andelt 2013) and other Channel Islands (Crooks and Van Vuren 1996; Roemer et al. 2001; Powers 2009), I did not observe a difference in home range size between male and female adult foxes. Powers (2009) suggested that because island foxes appeared to exhibit monogamous, biparental care, both sexes may have similar metabolic requirements resulting in similar home range sizes. Other foxes that had similar home range sizes for males and females include the Darwin's fox (*Pseudalopex fulvipes*; Jiménez 2007), an island fox, Blanford's fox (*Vulpes cana*; Geffen et al. 1992), a similar weight to the SCLI fox, and the gray fox (*Urocyon cinereoargenteus*; Chamberlain and Leopold 2000; Temple et al. 2010), the closest related species to the island fox.

The overlap of home ranges that I observed for foxes on SCLI may facilitate contact and subsequent disease transmission between individuals (Sanchez 2012). I could not accurately compare the overlap of adjacent home ranges that I observed to previous studies because I was unable to distinguish mated pairs from neighbors (Crooks and Van Vuren 1996; Roemer et al. 2001). I observed yearling offspring with extensive home range overlap with their presumed parents as did Roemer et al. (2001). Similar to research on gray foxes (Tucker et al. 1993), I documented home range overlap of juveniles with adults of the opposite sex as well as overlap of mother-daughter dyads similar to Ralls et al. (2013). I opportunistically observed a yearling and adult female together and in another case two females associated with the same litter, suggesting that yearling helpers or polygamy may exist to help raise the next year's litter. However, due to the small number of locations used to create the home ranges, no overlap was evident for any of the dyads I observed.

Since only one yearling was observed to disperse, I was unable to estimate differences in timing, distance, or length of time required to disperse between juvenile and yearling age classes. However, a total of 46 foxes <2 years of age were collared from 2006–2009 (Gould 2010; Resnik 2012; Gould and Andelt 2013) and only two unconfirmed dispersals were observed. With a larger sample size, differences in dispersal behavior between age classes may be more apparent. The average and maximum dispersal distances were larger on SCLI than previously reported for any Channel Island fox subspecies (Roemer et al. 2001). San Clemente Island appears to have a stable or slightly increasing fox population (Garcia and Associates 2011; Sanchez 2012) so there may not be as many open territories, thus forcing juveniles to range farther to find available space. My observation of one long distance dispersal and five shorter dispersal distances is similar to the pattern observed in red foxes (*Vulpes vulpes*; Trehwella et al. 1988). It is important to note that my observations of 1-way dispersals are based on locating foxes once per week, thus some repeated visits to pre-dispersal home ranges may not have been detected.

Dispersals of SCLI foxes were observed between pup-independence and breeding, but did not occur during the parturition and pup-dependence season (Resnik 2012). The dates of dispersal that I observed extended the previously documented dispersal period (September–December; Laughrin 1973; Moore and Collins 1995) approximately one month. Hansson (1991) suggested timing of dispersal is not as important in long-lived species which may account for the wider range of dates for dispersal that I observed. Understanding if there are periods of increased dispersal is important because foxes may have higher mortality while crossing unfamiliar roads or areas during dispersal (Markolt et al. 2012).

Dispersal of juveniles on SCLI may not be necessary if there are sufficient resources or if adults receive assistance, such as gathering food, from younger generations to rear young. However, foxes likely should avoid inbreeding. Channel Island foxes have remained in their parents' home ranges into their second year (Roemer et al. 2001). My study followed juveniles until approximately 1.5 years of age; thus I may have underestimated dispersal of the 2009 cohort of juveniles by not tracking movements through their second winter as yearlings. Of the nine yearlings that transitioned to adults, only one dispersed. The lack of dispersal observed by Resnik (2012) and Gould and Andelt (2013) suggest I may not have missed many dispersal events by stopping the study after 1.5 years. At high densities, frequency of dispersal of island foxes may depend on availability of space (Roemer et al. 2001). The density of foxes on SCLI in 2010 (4.7–9.2 foxes/km<sup>2</sup>; Garcia and Associates 2011) suggests the population may have been nearing carrying capacity and the rates of dispersal I observed may be typical for this island under these demographic conditions. Evidence that dispersal may occur more frequently on SCLI than previously observed suggests that this subspecies has the ability to recolonize in the event of a large decline in population.

I recorded dispersal primarily by juvenile males and my results are similar to the male-biased dispersal observed in the San Joaquin kit fox (Koopman et al. 2000), Blanford's fox (Geffen and Macdonald 1992), Mednyi Island Arctic fox (*Vulpes lagopus*; Goltsman et al. 2005), gray fox (Nicholson et al. 1985), and red fox (Harris and Trewhella 1988). Male-biased dispersal may limit inbreeding (Cockburn et al. 1985; Wolff 1993; Koopman et al. 2000; Roemer et al. 2001). If male-biased dispersal is occurring in the SCLI fox population, I suggest vaccinations should focus on juvenile males over other age and sex classes.

I am uncertain if the lack of excursions I observed was due to anomalies in the data, the subjective nature of the definition of excursion, or the method I used to estimate home range size. For one juvenile male fox, I did not collect enough locations to estimate a home range. This fox was first observed up to 3.4 km away from previous locations, returned to what I assumed was the natal home range, and then died approximately 3.3 km away from previous locations suggesting it died while in the process of exploring or dispersing. In another instance, I obtained two locations from a yearling male who then moved 4.29 km. Because these locations were observed directly after the fox was captured, I was uncertain if these represented excursions and subsequent return to a natal home range or a dispersal event. Either way, this suggests my estimates of attempted excursions or dispersals may be underestimated. Previously, Resnik (2012) found 23 separate excursions during her study of SCLI foxes using 95% fixed kernel home ranges. Movement and interactions of island foxes are important to estimate gene flow, the potential for inbreeding, and probability of disease transmission (Sanchez 2012). Sanchez (2012) modeled best immunization options for SCLI foxes, but her estimates for the transmission of diseases may have been underestimated because she did not include dispersal in her models.

I suggest that future studies use a larger sample of island foxes and obtain >1 location per week over multiple years to determine if patterns of space-use by juveniles differs by habitat type, the presence of roads, or is impacted by urban areas. A more extensive and detailed understanding of habitat use and selection may be aided by fine-scale location data. Advances in GPS collar technology may provide the necessary spatial resolution to assess areas of importance for island foxes (Cypher et al. 2014). Determining when and what environmental factors experienced by juveniles and yearling eventually affect adult home range sizes is necessary to better understand space requirements for young foxes. Better information on which foxes

disperse, under what circumstances, and the effects of dispersal on population dynamics are needed to inform future management decisions such as which age class to vaccinate. A more concentrated effort to understand how frequently dispersals occur and if it takes place more frequently at higher population densities is needed to better understand road-kill rates, disease transmission, and genetic variability among island foxes.

Table 2.1. Home range size (km<sup>2</sup>) for San Clemente Island foxes (*Urocyon littoralis clementae*) using 95% minimum convex polygons (km<sup>2</sup>) for all foxes that appeared to reach an asymptote on the area-observation curve. All locations were collected from 17 February 2009–July 2010.

	Number of foxes	Number of locations		Home range size (km <sup>2</sup> )	
		$\bar{x}$	Standard error	$\bar{x}$	Standard error
Adults	18	47	2	0.51	0.06
Males	10	48	3	0.53	0.10
Females	8	46	3	0.48	0.06
Vehicle	11	50	3	0.53	0.10
Walk-in	7	43	4	0.47	0.06
Yearlings (2009)	9	42	4	0.79	0.26
Males	6	38	4	0.97	0.38
Females	3	51	4	0.44	0.12
Vehicle	7	43	5	0.92	0.32
Walk-in	2	40	4	0.34	0.13
Yearlings (2010)	5	23	1	0.14	0.04
Males	4	23	1	0.13	0.05

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Females	1	23	NA	0.2	NA
Vehicle	5	23	1	0.14	0.04
Walk-in	0	NA	NA	NA	NA
Juveniles	11	25	1	0.20	0.04
Males	6	26	2	0.26	0.05
Females	5	24	2	0.13	0.04
Vehicle	10	26	1	0.21	0.04
Walk-in	1	19	NA	0.04	NA

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Table 2.2. Analysis of variance summary table (a) and Tukey multiple comparison of means (b) using 95% family-wise confidence levels (home range sizes were log-transformed) for San Clemente Island fox (*Urocyon littoralis clementae*) home range estimates. Predictor variables include sex (male or female), age (juvenile, yearling (2009), yearling (2010), or adult), and type of telemetry (vehicle or walk-in).

(a)

Variable	d.f.	Sum of squares	F value	P-value
Sex	1	19.8	1.588	0.216
Age	3	449.7	11.999	<0.001 <sup>a</sup>
Telemetry	1	39.2	3.135	0.085
Residuals	37	462.2		

<sup>a</sup>Significant P-value at  $\alpha = 0.05$ .



(b)

Predictor variable	Average difference between groups	95% Confidence interval for log-transformed means		<i>P</i> -value <sup>a</sup>
		Lower	Upper	
Sex				
Male-Female	0.225	-0.149	0.599	0.230
Age				
Juvenile-Adult	-1.016	-1.625	-0.407	<0.001 <sup>b</sup>
Yearling (2009)-Adult	0.224	-0.425	0.873	0.790
Yearling (2010)-Adult	-1.392	-2.197	-0.588	<0.001 <sup>b</sup>
Juvenile-Yearling (2009)	-1.240	-0.525	-1.955	<0.001 <sup>b</sup>
Juvenile-Yearling (2010)	0.377	1.234	-0.481	0.643
Yearling (2009)-Yearling (2010)	1.616	2.504	0.729	<0.001 <sup>b</sup>
Telemetry				
Vehicle-Walk in	0.331	0.764	-0.101	0.129

<sup>a</sup>Adjusted.

<sup>b</sup>Significant *P*-value at  $\alpha = 0.05$ .

Table 2.3. Differences<sup>a</sup> in home range size using individual San Clemente Island foxes (*Urocyon littoralis clementae*) as their own control. I determined if home range size changes for individuals after: age transition on 17 February (difference by age class), one year had passed (difference of one year), and dispersal (difference by dispersal) for locations collected from January 2009–July 2010. All data are presented on the original scale (i.e., the data below are not log-transformed).

	Difference by age class (km <sup>2</sup> )	Difference of one year (km <sup>2</sup> )	Difference by dispersal (km <sup>2</sup> )	
Adults	-0.07 ± 0.04 (17)	-0.01 ± 0.03 (16)		
Males	-0.12 ± 0.05 (9)	0.04 ± 0.03 (9)		
Females	-0.02 ± 0.01 (8)	-0.05 ± 0.04 (7)		
Yearlings	-0.16 ± 0.03 (6)	-0.58 ± 0.52 (6)	-0.33	(1)
Males	-0.18 ± 0.04 (3)	-1.10 ± 0.72 (3)	-0.33	(1)
Females	-0.14 ± 0.02 (3)	-0.03 ± 0.03 (3)		
Juveniles	-0.05 ± 0.03 (14)		-0.08 ± 0.08	(5)
Males	-0.08 ± 0.02 (9)		-0.04 ± 0.08	(4)
Females	-0.00 ± 0.03 (5)		-0.21	(1)

<sup>a</sup>Differences were calculated as post-transition home range size minus the pre-transition home range size (weighted averages ± standard errors and number of individuals in parenthesis).

Table 2.4. Mean percent overlap of home ranges for juvenile, yearling (2009), and adult San Clemente Island foxes (*Urocyon littoralis clementae*) using 95% minimum convex polygons created with locations from 17 February 2009–16 February 2010.

Dyad	Number of			
	Dyads	Mean (%)	Standard error	Range (%)
Adult male-Adult female	1	47.4		
Adult male-Yearling male	3	35.2	12.0	16.9–57.8
Adult male-Juvenile male	4	11.5	6.8	0.2–28.4
Adult male-Juvenile female	1	19.4		
Adult female-Adult female	1	3.1		
Adult female-Yearling male	3	13.6	9.4	0.2–31.8
Adult female-Yearling female	1	0.0		
Adult female-Juvenile male	3	1.9	1.3	0.1–4.4
Adult female-Juvenile female	1	30.7		
Yearling male-Juvenile male	3	2.3	1.6	0.2–5.4
Yearling female-Juvenile male	1	28.9		
Juvenile male-Juvenile male	1	0.1		

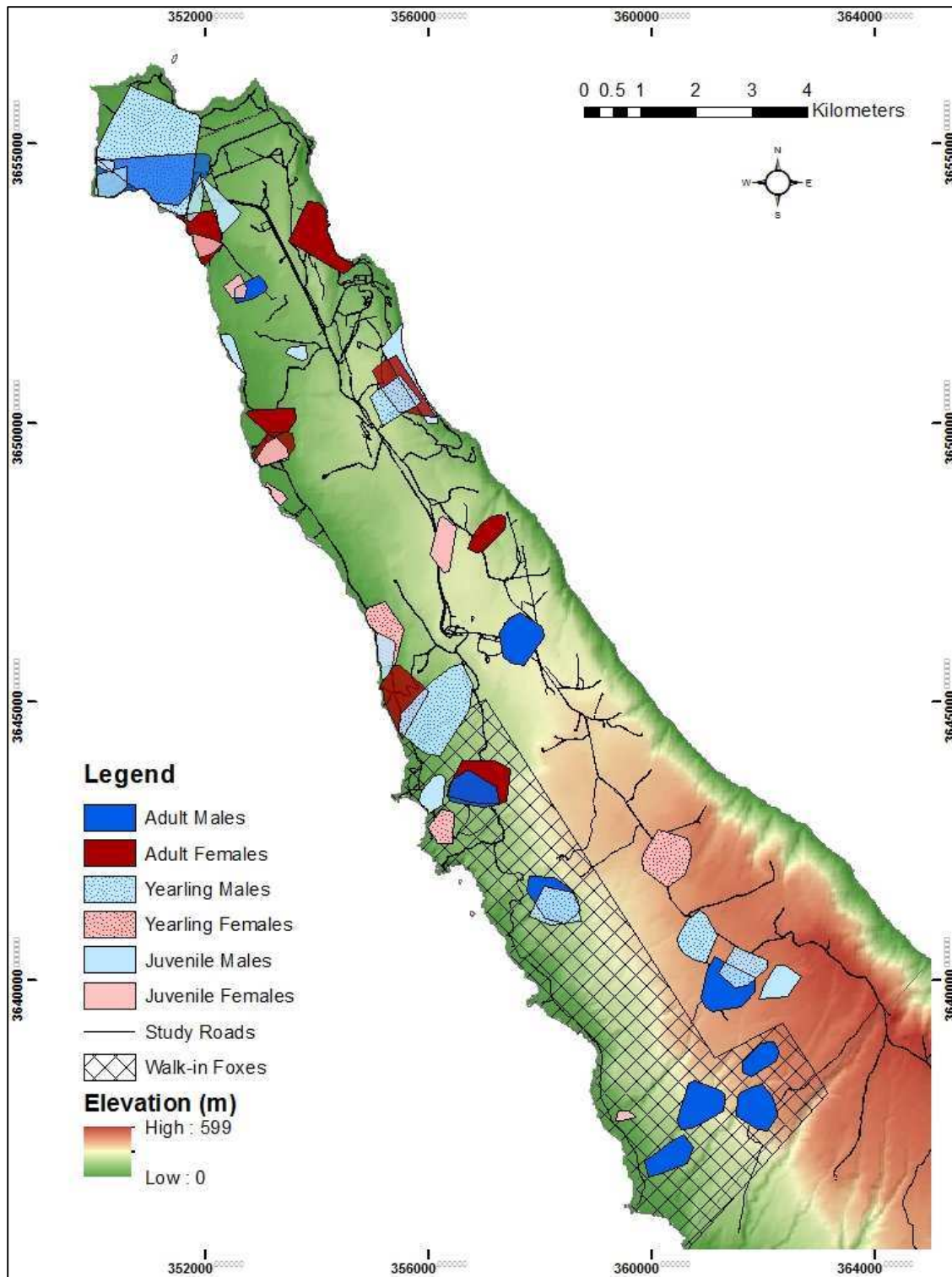


Figure 2.1. Home ranges of San Clemente Island foxes (*Urocyon littoralis clementae*) that appeared to reach asymptotes on area-observation curves obtained with vehicle and walk-in telemetry using 95% minimum convex polygons and locations collected from January 2009–July 2010.

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## APPENDIX

APPENDIX A.2.1 (APPENDIX A). METHODS FOR CAPTURING JUVENILE SAN CLEMENTE ISLAND FOXES (*UROCYON LITTORALIS CLEMENTAE*) DURING SUMMER 2009.

In order to assess differences in home range size and dispersal between adults, yearlings, and juveniles I captured juveniles born during the spring of 2009 between 20 June and 8 October 2009. To increase capture success for juveniles I employed three different trapping strategies: 1) I targeted for trapping juveniles associated with at least one of the collared random sample of foxes, 2) I collared juveniles that had been captured on the trapping grids used for population surveys, and 3) I used RRQRR to randomly select locations to trap juveniles, within areas I did not have collared adults or yearlings, or trapping grids. Under all three strategies I placed three traps in each of two locations and two traps at a third location to ensure each home range was sampled for 16 trap nights. Strategy two took advantage of grids set by GANDA to trap over larger areas to reduce the trapping effort necessary for CSU personnel.

Trapping locations (home ranges of collared foxes, trapping grids, and points generated by RRQRR) were placed <1 km from other trapping locations and served as a proxy for placing traps within every home range. A buffer of one km diameter was used because the average home range from the 2006–2007 study was 0.72 km<sup>2</sup> and 0.96 km in diameter under the assumption that home ranges were circular (N.P. Gould, W.F. Andelt, and E.E. Hamblen, unpublished 2010 report). Juveniles <1 kg and with a neck diameter <11 cm were recaptured at least two weeks later to allow for neck growth and weight gain. I collared a maximum of two juveniles per trap location.

The minimum circumference (14.1 cm) of collars used on juveniles was determined by the average neck size of nine adults collared during January 2009. Twelve juveniles that weighed 1–1.3 kg were fitted with collars weighing an average of 30.8 g. Five juveniles >1.3 kg

received collars that weighed an average of 41.8 g. I attempted to observe the first five captured juveniles every other day for six days to assure that there were no complications with the collar.

*Capturing Juveniles of Collared Adults*--The first strategy included efforts to capture juveniles from known collared adults and yearlings. For collared adults I placed two traps near the adult fox location and two sets of three traps at suspected dens. CSU personnel did not attempt to trap juveniles of collared foxes with more than half of their home range within a GANDA trapping grid (see next paragraph) to reduce over sampling.

*Capturing Juveniles from Grid Surveys Conducted by Garcia and Associates (GANDA)*--To complete the second strategy of capturing juveniles, I collaborated with GANDA personnel who trapped island foxes from 27 June–22 July 2009 to estimate population size (hereafter referred to as trapping grids). These one km by 1.75 km grids were comprised of 40 traps that were set at 250-m intervals in a 5 x 8 pattern and operated for four nights. Some juveniles caught by GANDA were released initially due to being too small to collar or being processed too late in the day (after 1100). CSU personnel retrapped these juveniles that were initially released by placing two traps at the initial trap location and two sets of three traps approximately 228 m away (the average distance between traps set at dens and location of a collared adult or yearling from strategy 1) in opposite directions from each other and perpendicular to the direction of the wind. Traps were placed within 20 m of the initial GPS coordinates in suitable habitat, such as near trails or flattened vegetation, to increase the chance of capturing a juvenile fox.

If during the original trap grids two juveniles were captured on a single grid that were both <1 kg and within one km of each other, I randomly chose which juvenile to trap again. If the first juvenile was not caught after two nights, I did not attempt to recapture the second juvenile on the grid.

*Capturing Juveniles at Points Determined by RRQRR Program*--A third strategy of juvenile trapping covered all parts of the study area that were >1 km from traps set near collared adults (traps set in strategy 1) or >1 km from a trapping grid (traps set in strategy 2). I used a spatially balanced random design (RRQRR) to select a location within these unsampled areas to set traps. Traps were placed in the same manner as used during recaptures at trapping grids, with two traps placed at the point determined by RRQRR and two sets of three traps approximately 228 m in each direction perpendicular to the wind.



TABLE A.1.1. (APPENDIX A). LOCATIONS AND VISUALS OF 28<sup>a</sup> YEARLING AND ADULT SAN CLEMENTE ISLAND FOXES (*UROCYON LITTORALIS CLEMENTAE*) WITH JUVENILES ON SAN CLEMENTE ISLAND, CALIFORNIA, USA FROM 25 FEBRUARY–20 JUNE 2009.

Fox ID	Sex	Age	Locations per fox	Visuals per fox	Visuals of juveniles per fox	Visuals of juveniles per visuals of fox
013	F	A	32	25	0	0.00
025	F	A	25	16	3	0.19
035	M	Y	31	9	0	0.00
045	M	A	29	9	0	0.00
053	M	Y	32	18	0	0.00
073	M	A	28	17	1	0.06
083	F	Y	32	23	0	0.00
094	F	Y	33	6	0	0.00
105	M	A	32	18	0	0.00
115	M	Y	32	25	0	0.00
124	M	A	30	18	0	0.00
133	F	A	36	20	0 <sup>b</sup>	0.00

146	M	A	31	18	0	0.00
154	M	A	29	17	1	0.06
165	F	A	27	24	3	0.13
175	F	A	28	15	1	0.07
185	F	A	29	19	2	0.11
195	F	Y	29	11	3	0.27
205	F	A	30	23	1	0.04
214	M	A	31	15	0	0.00
224	F	A	28	19	2	0.11
234	M	A	30	15	0	0.00
243	M	A	31	17	0	0.00
264	M	Y	34	13	0	0.00
274	M	A	32	23	0	0.00
286	M	Y	30	25	0	0.00
295	M	A	29	16	5	0.31
306	F	A	29	17	1	0.06

<sup>a</sup>Twenty-eight of 30 foxes are presented here due to insufficient observations on two foxes that used restricted areas.

<sup>b</sup>Fox 133 was not observed with a juvenile until 3 October 2009 and thus was not included in this table.

TABLE A.1.2. (APPENDIX A). EVIDENCE OF REPRODUCTION FOR A RANDOM SAMPLE OF 30<sup>a</sup> FOXES CAPTURED ON SAN CLEMENTE ISLAND, CALIFORNIA, USA DURING SUMMER 2009.

Fox ID	Sex	Age	Date litter was first discovered	Number of juveniles observed with yearling or adult	Number of juveniles trapped in home ranges of collared foxes	Lactation status during summer 2009 <sup>b</sup>
013	F	A	---	0	2	NC
025	F	A	18 Mar 09	1	1	SL
065 <sup>c</sup>	F	A	---	---	1	SL
133	F	A	03 Oct 09	1	0	E
165	F	A	30 Mar 09	1	0	SL
175	F	A	17 May 09	2	4	SL
185	F	A	23 Mar 09	3	1	SL
205	F	A	22 Apr 09	2	2	NC
224	F	A	14 Apr 09	3	0	SL
306	F	A	08 Jun 09	2	0	NC
083	F	Y	---	0	0	E

094	F	Y	---	0	0	NA
195	F	Y	25 Apr 09	2	--- <sup>d</sup>	NC
045	M	A	---	0	1	---
073	M	A	15 Apr 09	1	--- <sup>d</sup>	---
105	M	A	---	0	1	---
124	M	A	---	0	--- <sup>d</sup>	---
146	M	A	---	0	0	---
154	M	A	18 Mar 09	2	0	---
214	M	A	---	0	0	---
234	M	A	---	0	0	---
243	M	A	---	0	0	---
274	M	A	---	0	0	---
295	M	A	31 Mar 09	4	0	---
035	M	Y	---	0	0	---
053	M	Y	---	0	0	---
115	M	Y	---	0	0	---
255 <sup>c</sup>	M	Y	---	---	--- <sup>d</sup>	---

264	M	Y	---	0	--- <sup>d</sup>	---
286	M	Y	---	0	0	---

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<sup>a</sup>Twenty-eight of 30 foxes are presented here due to insufficient observations on two foxes that used restricted areas.

<sup>b</sup>Signs of lactation status were: E (expressed milk), SL (signs of lactation), NA (no signs of lactation) and NC (not caught).

<sup>c</sup>Fox used restricted area and was not observed often.

<sup>d</sup>Fox was not trapped and examined during summer 2009 by Colorado State University employees.

TABLE A.1.3. (APPENDIX A). MEASUREMENTS OF FIVE DENS OF FOXES COLLARED IN JANUARY 2009 AND USED DURING THE REPRODUCTIVE SEASON OF 2009 ON SAN CLEMENTE ISLAND, CALIFORNIA, USA.

Fox ID	Slope (°)	Aspect (°)	Orientation (°) <sup>a</sup>	Entrances <sup>b</sup>
025	10	10	36	3
073	9	157	141	3
154	6	50	29	1
185	2	271	308	3
306	2	250	244	3

<sup>a</sup>Orientation of the most worn entrance to den.

<sup>b</sup>Number of entrances to den.

TABLE A.2.1. (APPENDIX A). HOME RANGE ESTIMATES (KM<sup>2</sup>) FROM 95% MINIMUM CONVEX POLYGONS FOR SAN CLEMENTE ISLAND FOXES (*UROCYON LITTORALIS CLEMENTAE*) THAT APPEARED TO REACH AN ASYMPTOTE ON THE AREA-OBSERVATION CURVE. ALL LOCATIONS WERE COLLECTED FROM JANUARY 2009–JULY 2010.

Fox ID	Sex	Age Class	Telemetry	Number of locations <sup>a</sup>	Start date <sup>b</sup>	End date <sup>b</sup>	Home range size (km <sup>2</sup> )
025	F	Adult	VT	51	22 Jan 09	27 Jan 10	0.64
035	M	Yearling (2009)	WI	36	01 Feb 09	28 Oct 09	0.47
045	M	Adult	VT	56	21 Jan 09	15 Feb 10	1.37
053	M	Yearling (2009)	VT	54	22 Jan 09	03 Feb 10	0.44
065	F	Adult	WI	40	09 Mar 09	13 Feb 10	0.72
073	M	Adult	WI	23	13 Feb 09	04 Aug 09	0.25
083	F	Yearling (2009)	VT	57	22 Jan 09	15 Feb 10	0.63
094	F	Yearling (2009)	WI	44	24 Feb 09	13 Feb 10	0.21
105	M	Adult	VT	53	21 Jan 09	02 Feb 10	0.17



115	M	Yearling (2009)	VT	33	23 Jan 09	10 Sep 09	0.43
124	M	Adult	WI	48	08 Feb 09	12 Feb 10	0.44
133	F	Adult	VT	53	20 Jan 09	03 Feb 10	0.61
146	M	Adult	WI	49	07 Feb 09	16 Feb 10	0.51
154	M	Adult	VT	54	22 Jan 09	03 Feb 10	0.53
165	F	Adult	VT	46	23 Jan 09	03 Feb 10	0.26
175	F	Adult	VT	49	21 Jan 09	02 Feb 10	0.43
185	F	Adult	VT	51	22 Jan 09	12 Jan 10	0.33
195	F	Yearling (2009)	VT	53	20 Jan 09	03 Feb 10	0.48
205	F	Adult	VT	26	22 Jan 09	31 Jul 09	0.58
214	M	Adult	WI	47	14 Feb 09	12 Feb 10	0.55
234	M	Adult	WI	50	07 Feb 09	16 Feb 10	0.36

243	M	Adult	WI	43	24 Feb 09	13 Feb 10	0.43
255	M	Yearling (2009)	VT	41	02 Feb 09	15 Feb 10	2.72
264	M	Yearling (2009)	VT	34	20 Jan 09	16 Oct 09	1.33
274	M	Adult	VT	55	24 Jan 09	15 Feb 10	0.66
286	M	Yearling (2009)	VT	27	23 Jan 09	23 Jul 09	0.40
306	F	Adult	VT	54	22 Jan 09	02 Feb 10	0.30
325	M	Juvenile	VT	29	16 Jul 09	15 Feb 10	0.19
334	F	Juvenile	VT	19	23 Jul 09	23 Nov 09	0.29
345	M	Yearling (2010)	VT	23	17 Feb 10	28 Jul 10	0.07
356	F	Juvenile	VT	25	16 Jul 09	02 Feb 10	0.13
366	F	Juvenile	VT	29	06 Jul 09	02 Feb 10	0.11
385	M	Juvenile	VT	27	06 Jul 09	12 Jan 10	0.27

396	F	Juvenile	VT	26	31 Jul 09	12 Jan 10	0.06
425	M	Juvenile	VT	29	03 Aug 09	15 Feb 10	0.25
435	M	Juvenile	VT	25	24 Aug 09	15 Feb 10	0.21
476	F	Yearling (2010)	VT	23	17 Feb 10	28 Jul 10	0.20
485	M	Yearling (2010)	VT	27	24 Feb 10	28 Jul 10	0.11
504	F	Juvenile	WI	19	03 Oct 09	16 Feb 10	0.04
555	M	Juvenile	VT	31	29 Jun 09	27 Jan 10	0.47
563	M	Yearling (2010)	VT	22	17 Feb 10	30 Jul 10	0.28
576	M	Juvenile	VT	17	21 Aug 09	07 Dec 09	0.14
625	M	Yearling (2010)	VT	21	24 Feb 10	28 Jul 10	0.06

<sup>a</sup>Number of locations used to create home ranges and used to weight home range estimates.

<sup>b</sup>First (Start date) and last date (End date) that locations were collected.

Note: Variables include sex (M = male or F = female), age (J = juvenile, Y = yearling (2009 or 2010), or A = adult), and type of telemetry (VT = vehicle or WI = walk-in).

TABLE A.2.2. (APPENDIX A). HOME RANGE SIZES (KM<sup>2</sup>) ESTIMATED IMMEDIATELY BEFORE (PRE) AND AFTER (POST) 17 FEBRUARY 2010 FROM 95% MINIMUM CONVEX POLYGONS FOR SAN CLEMENTE ISLAND FOXES (*UROCYON LITTORALIS CLEMENTAE*).

Fox ID	Sex	Age	Telemetry	Number of locations <sup>a</sup>	<u>Pre 17 February</u>		<u>Post 17 February</u>		<u>Home range size (km<sup>2</sup>)</u>	
					Start date <sup>b</sup>	End date <sup>b</sup>	Start date <sup>b</sup>	End date <sup>b</sup>	Pre	Post
013	F	A-A	VT	22	11 Sep 09	15 Feb 10	25 Feb 10	28 Jul 10	0.144	0.099
025	F	A-A	VT	21	14 Sep 09	27 Jan 10	17 Feb 10	28 Jul 10	0.313	0.367
035	M	Y-A	WI	16	15 Jul 09	28 Oct 09	18 Mar 10	28 Jul 10	0.354	0.072
045	M	A-A	VT	22	17 Sep 09	15 Feb 10	24 Feb 10	28 Jul 10	0.751	0.241
053	M	Y-A	VT	18	05 Oct 09	03 Feb 10	17 Feb 10	30 Jul 10	0.356	0.275
065	F	A-A	WI	9	18 Jun 09	13 Feb 10	26 Feb 10	29 Jul 10	0.055	0.076
083	F	Y-A	VT	17	23 Oct 09	15 Feb 10	24 Feb 10	30 Jul 10	0.447	0.313

094	F	Y-A	WI	9	19 Sep 09	13 Feb 10	26 Feb 10	29 Jul 10	0.171	0.104
105	M	A-A	VT	24	11 Aug 09	02 Feb 10	17 Feb 10	31 Jul 10	0.105	0.237
124	M	A-A	WI	10	22 Sep 09	12 Feb 10	18 Feb 10	05 Jul 10	0.368	0.011
133	F	A-A	VT	18	11 Oct 09	03 Feb 10	17 Feb 10	30 Jul 10	0.523	0.429
146	M	A-A	WI	8	07 Sep 09	16 Feb 10	11 Mar 10	24 Jul 10	0.076	0.082
154	M	A-A	VT	18	28 Sep 09	03 Feb 10	17 Feb 10	30 Jul 10	0.394	0.378
165	F	A-A	VT	18	27 Aug 09	03 Feb 10	18 Feb 10	30 Jul 10	0.183	0.182
175	F	A-A	VT	22	24 Aug 09	02 Feb 10	17 Feb 10	28 Jul 10	0.305	0.277
185	F	A-A	VT	23	12 Aug 09	12 Jan 10	17 Feb 10	28 Jul 10	0.143	0.172
195	F	Y-A	VT	23	11 Aug 09	03 Feb 10	17 Feb 10	30 Jul 10	0.334	0.167
214	M	A-A	WI	10	09 Sep 09	12 Feb 10	18 Mar 10	29 Jul 10	0.273	0.200
234	M	A-A	WI	9	01 Sep 09	16 Feb 10	11 Mar 10	24 Jul 10	0.161	0.137

243	M	A-A	WI	9	19 Sep 09	13 Feb 10	26 Feb 10	29 Jul 10	0.334	0.138
255	M	Y-A	VT	17	19 Oct 09	15 Feb 10	24 Feb 10	28 Jul 10	0.286	0.086
274	M	A-A	VT	17	23 Oct 09	15 Feb 10	24 Feb 10	30 Jul 10	0.571	0.499
306	F	A-A	VT	18	21 Sep 09	02 Feb 10	17 Feb 10	28 Jul 10	0.240	0.163
325	M	J-Y	VT	22	10 Sep 09	15 Feb 10	25 Feb 10	31 Jul 10	0.172	0.118
334	F	J-Y	VT	15	17 Aug 09	23 Nov 09	24 Feb 10	09 Jun 10	0.278	0.054
345	M	J-Y	VT	18	06 Jul 09	05 Nov 09	17 Feb 10	22 Jun 10	0.263	0.083
356	F	J-Y	VT	23	28 Jul 09	02 Feb 10	18 Feb 10	31 Jul 10	0.133	0.086
366	F	J-Y	VT	22	24 Aug 09	02 Feb 10	17 Feb 10	18 Jul 10	0.083	0.180
385	M	J-Y	VT	20	03 Sep 09	12 Jan 10	17 Feb 10	13 Jul 10	0.268	0.134
425	M	J-Y	VT	22	24 Sep 09	15 Feb 10	24 Feb 10	28 Jul 10	0.204	0.178
435	M	J-Y	VT	21	21 Sep 09	15 Feb 10	02 Mar 10	30 Jul 10	0.326	0.247

476	F	J-Y	VT	17	28 Sep 09	12 Jan 10	17 Feb 10	15 Jun 10	0.117	0.200
485	M	J-Y	VT	25	27 Aug 09	15 Feb 10	24 Feb 10	13 Jul 10	0.115	0.110
504	F	J-Y	WI	16	21 Oct 09	16 Feb 10	11 Mar 10	24 Jul 10	0.027	0.092
555	M	J-Y	VT	24	27 Aug 09	27 Jan 10	17 Feb 10	30 Jul 10	0.350	0.179
563	M	J-Y	VT	13	23 Jul 09	26 Oct 09	17 Feb 10	25 May 10	0.103	0.148
625	M	J-Y	VT	5	27 Aug 09	24 Sep 09	24 Feb 10	23 Mar 10	0.093	0.016

<sup>a</sup>Number of locations used to create each home range and used to weight home range estimates.

<sup>b</sup>First (Start date) and last date (End date) that locations were collected.

Note: Variables include sex (M = male or F = female), age transition (J-Y = juvenile to yearling, Y-A = yearling to adult, or A-A = adult to next year of adulthood), and type of telemetry (VT = vehicle or WI = walk-in).

TABLE A.2.3. (APPENDIX A). HOME RANGE SIZES (KM<sup>2</sup>) ESTIMATED FOR INDIVIDUAL SAN CLEMENTE ISLAND FOXES (*UROCYON LITTORALIS CLEMENTAE*) SEPARATED BY ONE YEAR FROM 95% MINIMUM CONVEX POLYGONS.

Fox ID	Sex	Age transition	Telemetry	Number of locations <sup>a</sup>	<u>2009</u>		<u>2010</u>		<u>Home range size (km<sup>2</sup>)</u>	
					Start date <sup>b</sup>	End date <sup>b</sup>	Start date <sup>b</sup>	End date <sup>b</sup>	Pre	Post
025	F	A-A	VT	21	10 Feb	31 Jul	17 Feb	28 Jul	0.627	0.367
035	M	Y-A	WI	16	23 Mar	21 Jul	18 Mar	28 Jul	0.416	0.072
045	M	A-A	VT	22	26 Feb	20 Jul	24 Feb	28 Jul	0.147	0.241
053	M	Y-A	VT	18	25 Feb	23 Jul	17 Feb	30 Jul	0.166	0.275
065	F	A-A	WI	9	09 Mar	29 Jul	26 Feb	29 Jul	0.237	0.076
083	F	Y-A	VT	17	05 Mar	28 Jul	24 Feb	30 Jul	0.275	0.313
094	F	Y-A	WI	9	06 Mar	29 Jul	26 Feb	29 Jul	0.114	0.104



105	M	A-A	VT	24	19 Feb	28 Jul	17 Feb	31 Jul	0.111	0.237
124	M	A-A	WI	10	21 Feb	27 Jun	18 Feb	05 Jul	0.082	0.011
133	F	A-A	VT	18	21 Feb	28 Jul	17 Feb	30 Jul	0.275	0.429
146	M	A-A	WI	8	20 Mar	19 Jul	11 Mar	24 Jul	0.242	0.082
154	M	A-A	VT	18	20 Feb	28 Jul	17 Feb	30 Jul	0.369	0.378
165	F	A-A	VT	18	20 Feb	20 Jul	18 Feb	30 Jul	0.207	0.182
175	F	A-A	VT	22	19 Feb	03 Aug	17 Feb	28 Jul	0.349	0.277
185	F	A-A	VT	23	21 Feb	31 Jul	17 Feb	28 Jul	0.210	0.172
195	F	Y-A	VT	23	21 Feb	28 Jul	17 Feb	30 Jul	0.260	0.167
214	M	A-A	WI	10	23 Mar	29 Jul	18 Mar	29 Jul	0.318	0.200
234	M	A-A	WI	9	17 Mar	19 Jul	11 Mar	24 Jul	0.041	0.137
243	M	A-A	WI	9	24 Feb	08 Jul	26 Feb	29 Jul	0.330	0.138

255	M	Y-A	VT	17	19 Mar	12 Aug	24 Feb	28 Jul	3.191	0.086
274	M	A-A	VT	17	05 Mar	28 Jul	24 Feb	30 Jul	0.264	0.499
306	F	A-A	VT	18	14 Feb	28 Jul	17 Feb	28 Jul	0.152	0.163

<sup>a</sup>Number of locations used to create each home range and used to weight home range estimates.

<sup>b</sup>First (Start date) and last date (End date) locations were collected.

Note: Variables include sex (M = male or F = female), age transition (Y-A = yearling to adult or A-A = adult to next year of adulthood), and type of telemetry (VT = vehicle or WI = walk-in).

TABLE A.2.4. (APPENDIX A). HOME RANGE ESTIMATES FROM 95% MINIMUM CONVEX POLYGONS FOR SAN CLEMENTE ISLAND FOXES (*UROCYON LITTORALIS CLEMENTAE*) PRE- AND POST- DISPERSAL INCLUDING AGE (J = JUVENILE OR Y = YEARLING) AND SEX (M = MALE OR F = FEMALE).

Fox ID	Age/ Sex	Number of locations <sup>a</sup>	<u>Pre-dispersal</u>		<u>Post-dispersal</u>		<u>Home range size</u> (km <sup>2</sup> )		Days to complete dispersal <sup>c</sup>	Age at dispersal <sup>d</sup>	Dispersal distance (km) <sup>e</sup>
			Start date <sup>b</sup>	End date <sup>b</sup>	Start date <sup>b</sup>	End date <sup>b</sup>	Pre	Post			
035	YM	25	05 May 09	28 Oct 09	30 Nov 09	28 Jul 10	0.407	0.082	33	619	1.79
334	JF	19	23 Jul 09	23 Nov 09	18 Dec 09	07 May 10	0.291	0.082	25	279	1.87
345	JM	18	06 Jul 09	05 Nov 09	09 Jan 10	25 May 10	0.263	0.084	65	261	1.8
385	JM	22	11 Aug 09	12 Jan 10	26 Jan 10	13 Jul 10	0.208	0.113	14	329	1.24
563	JM	13	23 Jul 09	26 Oct 09	23 Nov 09	24 Feb 10	0.103	0.369	28	251	10.00
625	JM	5	27 Aug 09	24 Sep 09	26 Jan 10	03 Mar 10	0.093	0.004	124	219	4.22

<sup>a</sup>Number of locations used to create each home range and used to weight home range estimates.

<sup>b</sup>First (Start date) and last date (End date) of location collection.

<sup>c</sup>Days between the last date observed in the pre-dispersal home range and the first date of permanent residence in the post-dispersal home range (i.e. once trips to the pre-dispersal home range ceased).

<sup>d</sup>Days between estimated date of parturition of 17 February and last date observed in pre-dispersal home range.

<sup>e</sup>Distance from midpoint of pre- and post- dispersal 95% MCP home ranges.

TABLE A.2.5. (APPENDIX A). OVERLAP OF HOME RANGES OF SAN CLEMENTE ISLAND FOXES (*UROCYON LITTORALIS CLEMENTAE*) FROM 95% MINIMUM CONVEX POLYGONS USING LOCATIONS COLLECTED FROM 17 FEBRUARY 2009–16 FEBRUARY 2010. FOX ID, AGE (J = JUVENILE, Y = YEARLING, OR A = ADULT) AND SEX (M = MALE OR F = FEMALE) ARE INCLUDED.

Fox ID		035	045	053	065	105	133	175	185	195	205	214	243	255	264	274	286	306	325	356	366	385	425	555	576
	Age/Sex	YM	AM	YM	AF	AM	AF	AF	AF	YF	AF	AM	AM	YM	YM	AM	YM	AF	JM	JF	JF	JM	JM	JM	JM
035	YM											0.37													
045	AM													0.97								0.00	0.23		0.01
053	YM										0.25													0.05	
065	AF												0.37												
105	AM																				0.05				
133	AF									0.00					0.16				0.00						
175	AF													0.01						0.13		0.01			0.02
185	AF																	0.02							
195	YF						0.0													0.15					
205	AF			31.8																				0.23	
214	AM	57.8																							
243	AM				47.4																				
255	YM		31.0					0.2															0.04		0.01
264	YM						8.9																		
274	AM																								
286	YM																								
306	AF								3.1																
325	JM						0.1			28.9															
356	JF							30.7																	
366	JF					19.4																			
385	JM		0.2					1.1																	0.00
425	JM		16.6											1.3											
555	JM			5.4							28.4														
576	JM		0.7					4.4						0.2									0.1		

Note: Values above and right of grey squares are the area (km<sup>2</sup>) of overlap. Values below and to the left of grey squares are the percentage of overlapped area (overlap/union of the two home ranges).

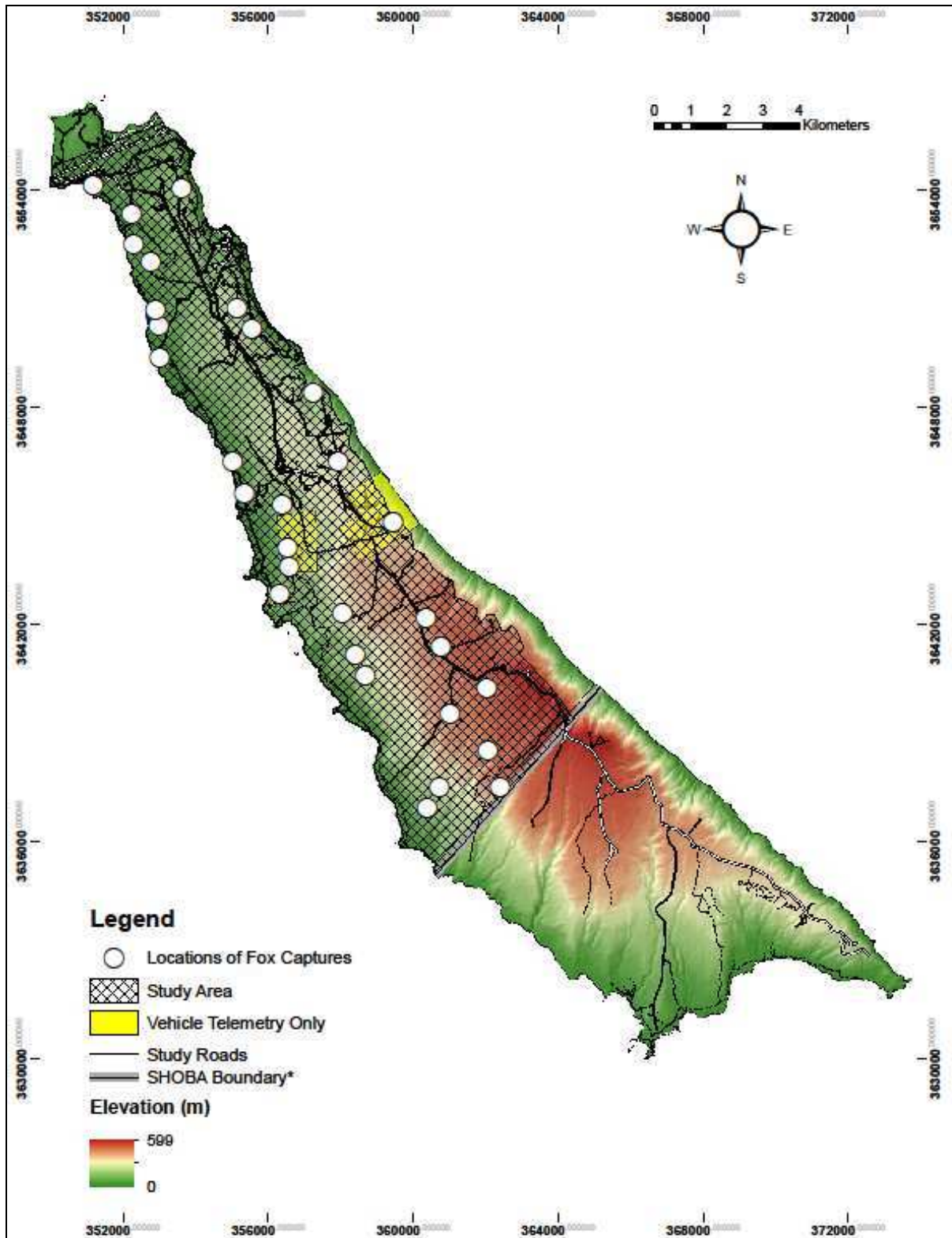
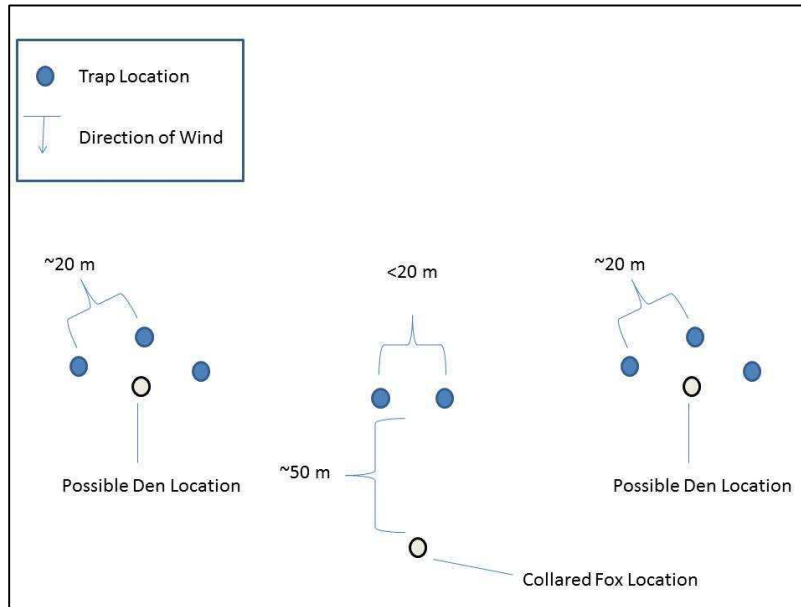


FIGURE A.2.1. (APPENDIX A). STUDY AREA AND LOCATIONS WHERE 30 ADULT AND YEARLING FOXES WERE CAPTURED ON SAN CLEMENTE ISLAND FROM 31 DECEMBER 2008–10 JANUARY 2009.

(a)



(b)

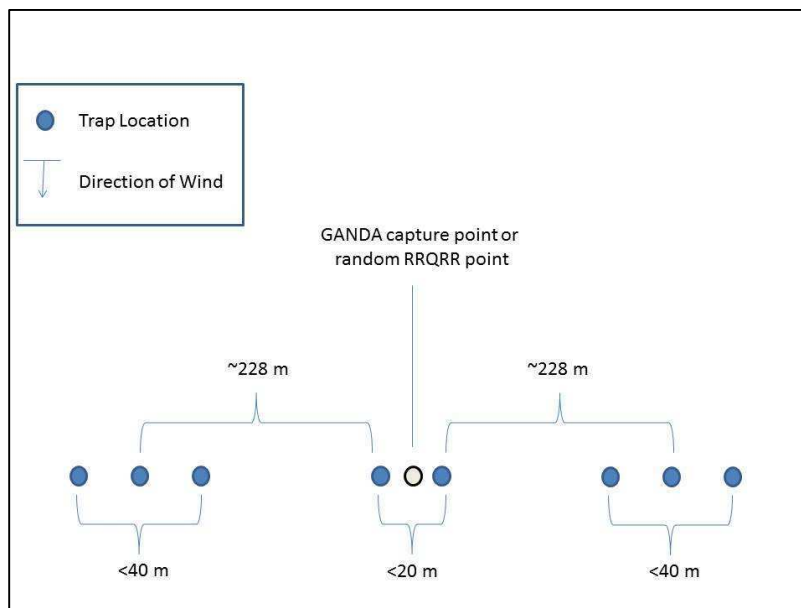


FIGURE A.2.2. (APPENDIX A). PLACEMENT OF TRAPS USED TO CAPTURE JUVENILES OF COLLARED SAN CLEMENTE ISLAND FOXES (*UROCYON LITTORALIS CLEMENTAE*) (A) AND RECAPTURE JUVENILES CAUGHT BY GANDA (B) OR PLACED AT POINTS DETERMINED BY THE REVERSED RANDOMIZED QUADRANT-RECURSIVE ALGORITHM (B) FROM 20 JUNE–8 OCTOBER 2009.

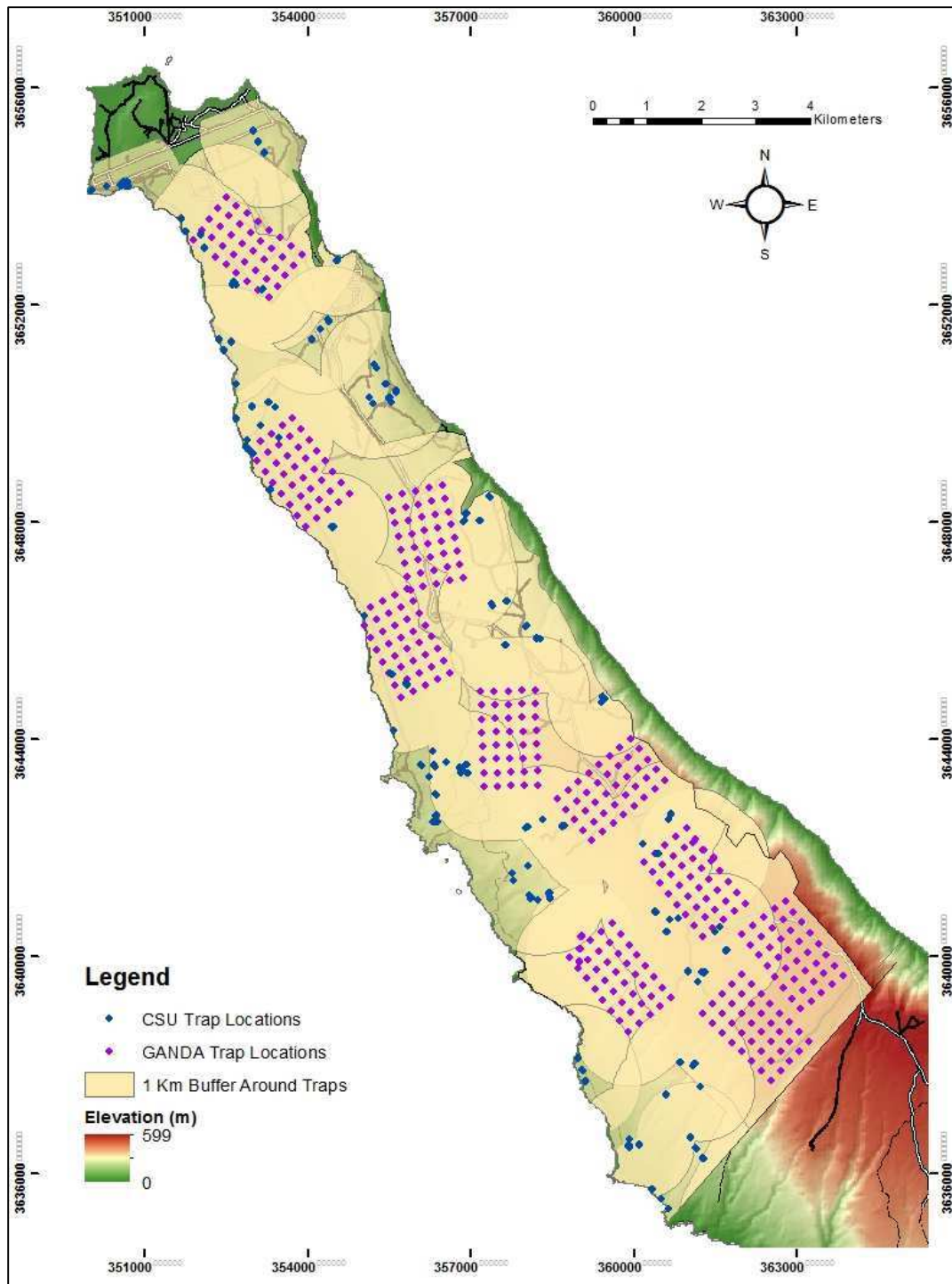


FIGURE A.2.3. (APPENDIX A). ONE KM SHADED BUFFER AROUND EACH TRAP LOCATION, WHICH ENSURED THAT AT LEAST ONE TRAPPING LOCATION WAS WITHIN ONE KM OF ANY POINT ON THE SAN CLEMENTE ISLAND STUDY AREA FROM 20 JUNE–8 OCTOBER 2009.

Note: Foxes were trapped by Colorado State University employees (CSU trap locations) or Garcia and Associates (GANDA trap locations).



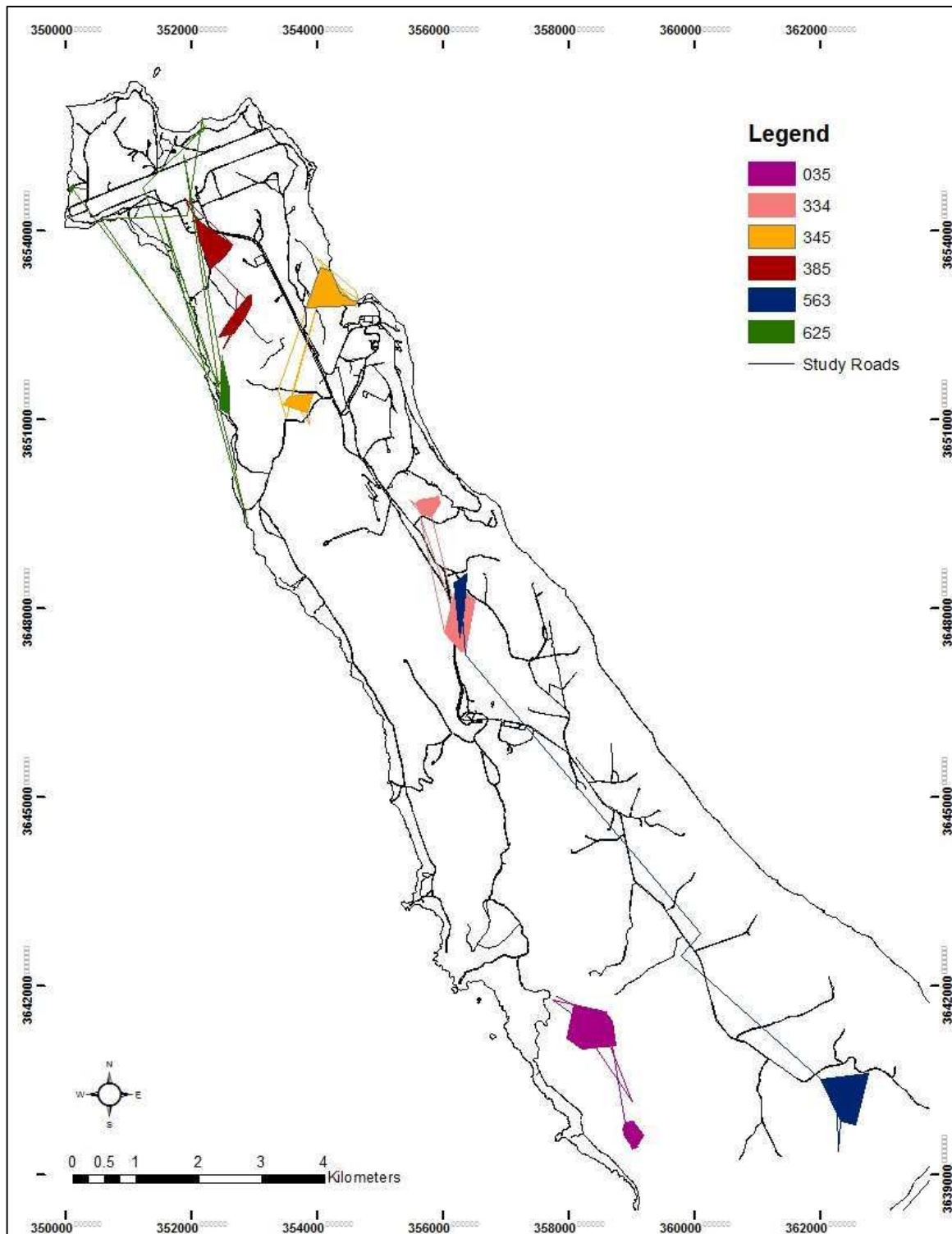


FIGURE A.2.4. (APPENDIX A). DISPERSAL OF SIX SAN CLEMENTE ISLAND FOXES (*UROCYON LITTORALIS CLEMENTAE*) SHOWING SEQUENTIAL LOCATIONS (LINES) FROM TIME OF CAPTURE TO ARRIVAL IN POST-DISPERSAL HOME RANGES (MINIMUM CONVEX POLYGONS) FROM JANUARY 2009–JULY 2010.