8 A Monitoring Plan for Santa Cruz Island Foxes

With an area of 249 km^2, Santa Cruz Island is the largest of the eight Channel Islands, with an approximate length of 38 km (24 miles) and a width of 3-11 km (1.9-6.9 miles; Table 1-1; Laughrin 1973). Its eastern edge is 30 km (19 miles) from mainland California (Schoenherr et al. 1999; Map 1-1). Historically, the island was owned by two landowners: the Santa Cruz Island Company and another private landowner (Laughrin 1973). In 1978, 90% of the island was effectively purchased by and came under the protection of The Nature Conservancy; the remaining portion came under the ownership and protection of the National Park Service in 1997 (Schoenherr et al. 1999). Today, TNC owns 76% of the island and NPS owns 24%.

A dominant feature of Santa Cruz Island's topography is the east-west running Central Valley, situated along a geological fault and flanked by two mountain ranges (Van Vuren and Coblentz 1987; Map 8-1). To the north of the valley lies a rugged ridge with elevations of 750 meters (2,461 feet), where slopes exceed 30°, and to the south lies a smaller mountain range with elevations of 465 meters (1,526 feet; Laughrin 1973, Van Vuren and Coblentz 1987). Most of the coastline is composed of precipitous cliffs. The Central Valley has a semi-continental climate and may experience freezing temperatures during the winter (Laughrin 1971).

The diversity of terrain and temperature, along with the availability of year-round fresh water in many canyons, support a higher diversity of habitat types and species than any other Channel Island (Schoenherr et al. 1999; Map 8-2). Santa Cruz Island supports at least 45 nesting bird species, 480 native plant species, and 12 native mammalian species, including the island spotted skunk (*Spilogale gracilis amphialus*, Laughrin 1973, Schoenherr et al. 1999). Major vegetation types include grassland (36% of the island), chaparral and coastal sage scrub (48% of the island), and woodland and forest communities (10% of the island; Minnich 1980, cited in Van Vuren and Coblentz 1987). Laughrin (1973) reported that foxes on Santa Cruz Island used all these habitat types (Map 7-2).

8.1 Santa Cruz Island Foxes

Foxes on Santa Cruz Island were first described by C. H. Merriam in 1903 (Laughrin 1971). As on other Channel Islands, fox populations have experienced periods of low density in past years (Laughrin 1971). Numbers were higher prior to 1918, when ranch hands killed foxes to reduce damage to ranch vineyards (Laughrin 1980). During a museum collecting trip in 1948, no foxes were observed during 23 days of field work, and only four individuals were trapped (Bills 1969, cited in Laughrin 1973).

Higher numbers were again observed during field work in 1970, leading Laughrin (1971) to describe the population size as "...unlikely to be greater than 3,000." Based on further trapping in 1973, Laughrin (1973) concluded that densities on Santa Cruz Island were high compared to other islands, which he attributed to the high habitat diversity and food abundance. He also noted that animals captured in 1973 were mostly young, healthy animals. Further trapping conducted during 1973-1977 resulted in density estimates higher than those documented on other islands, and field data suggested a stable population during this time period (Laughrin 1980).

During 1991-1993, Crooks (1994) trapped foxes as part of a comparative ecology study of foxes and island skunks. Although trap success was lower than reported by Laughrin (1980), foxes were observed to be "…abundant and easily captured." The difference in trap success observed in Crooks' (1994) study versus that observed by Laughrin (1980) could have been due to difference in trapping design or due to traps being set in different habitat or at different times of year. Crooks (1994) interpreted a high proportion of young animals to indicate an increasing population.

Based on field work conducted in 1993, Roemer et al. (1994) estimated the population on Santa Cruz Island to be 1,465 foxes. However, by 1998 the population was estimated at only 232 animals (Roemer 1999), and by 1999 at only 133 foxes (Roemer et al. 2001b). Predation by golden eagles was suspected of causing this decline (Roemer 1999). Roemer (1999) reported that between 1995 and 1998 the populations on Santa Cruz and San Miguel dropped by 90% and the estimated time to extinction was 5-17 years. Population modeling and sensitivity analyses showed that survival of pup and adult foxes, and fertility of adult foxes, had the greatest influence on population growth rate compared to other demographic parameters, and field data showed that these parameters had changed the most during the years of decline (Roemer et al. 2002a). On Santa Cruz Island, survival across all age classes decreased during the study period, and adult fertility decreased during 1993-1998. Roemer (1999) suggested that a captive breeding program could increase pup survival, and he recommended removal of golden eagles and reintroduction of bald eagles as restoration actions.

It is believed that golden eagles first colonized the northern Channel Islands in the early 1990s, with the first reported sightings in 1993 (Roemer 1999, Roemer et al. 2001b). Golden eagle sightings and fox predation increased on the northern islands during 1993-1998, with low fox survival rates leading to near extirpation of the wild population (Roemer 1999, Roemer et al. 2001b). During this period, fox captures and density estimates on two capture grids decreased, and it was estimated that predation by golden eagles accounted for 90% of fox mortalities observed during the study, with golden eagles linked to 19 of 21 known fox mortalities on the western end of Santa Cruz Island (Roemer 1999). Eagle predation and associated fox population declines were also documented on San Miguel and Santa Rosa islands (Roemer 1999). Fox populations on the southern Channel Islands (San Nicolas, San Clemente, and Santa Catalina) remained relatively stable during this same time period, although the San Clemente fox population decreased at a slower rate over a 10-year period (Roemer et al 2001b). An ongoing collaborative effort among island managers is underway to remove all resident golden eagles from the islands (S. Morrison, TNC, pers. comm.).

Human activities likely promoted the presence of golden eagles on Santa Cruz Island. Pigs were introduced to the Channel Islands in the 1850s (Junak et al. 1995) and have been on Santa Cruz Island since at least the 1920s (Van Vuren 1984). A simulation model suggested that the fox population alone could probably not have supported the number of eagles observed on Santa Cruz Island over an extended time, leading the authors to conclude that feral pigs were subsidizing the predator's diet, thus contributing to the decline of fox populations on the northern islands (Roemer et al. 2001b). Feral pigs also cause severe damage to fox habitat, particularly streamside vegetation in canyon bottoms, and may impact water sources (Van Vuren 1984). An effort by TNC and NPS to remove pigs on the northern islands is nearing completion (Morrison et al. 2007). The extirpation of bald eagles due to organochlorine contamination by the late 1950s (Kiff 1980) may have removed an effective competitor of or deterrent to golden eagles. Finally, grazing by domestic livestock may have changed vegetation composition and structure, thereby reducing available cover and making foxes more susceptible to eagle predation (Roemer 1999, Roemer et al. 2001b).

Although Santa Cruz Island has had limited human development compared to other Channel Islands, it has nonetheless been heavily impacted by livestock grazing (Laughrin 1973). Domestic sheep were grazed on the island starting in the 1850s (Brumbaugh 1980, cited in Van Vuren and Coblentz 1987), and the island at times supported over 50,000 sheep (Van Vuren and Coblentz 1987). Over time the sheep became increasingly feral until routine annual round-ups became impossible, and shooting and trapping were implemented as control measures in the early 1900s (Van Vuren and Coblentz 1987). During 1979-1980, 20,000 feral sheep were estimated to occupy the island, along with other introduced mammals including feral pigs and domestic cattle (Van Vuren and Coblentz 1987). State wildlife agencies recommended that all exotic mammals on the island, most being grazers, browsers, or up-rooters of native vegetation, should be removed (CDFG 1987). Most sheep were removed in the 1980s, with the remaining 2,000 sheep removed in the late 1990s, but the damage from long-term overgrazing is still evident (Crooks and Van Vuren 1995, Schoenherr et al. 1999). Van Vuren and Coblentz (1987) noted that about half of the island had been moderately to severely impacted as a result of defoliation and trampling. By the early 1990s, cattle grazing was also eliminated (Beatty and Licari 1992, cited in Crooks 1994). The cessation of grazing pressure is thought to have facilitated an invasion of an exotic plant, fennel (*Foeniculum vulgare*), to spread through many of the grassland communities on the island (Crooks 1994).

Although no large-scale disease die-off has been reported for foxes on Santa Cruz Island, disease remains a real threat to all island foxes, as demonstrated by the near extirpation of Santa Catalina Island foxes, because their isolation on islands has minimized or prevented their exposure to diseases. In addition, the low genetic diversity observed among island foxes may increase their susceptibility to novel diseases (Wayne et al. 1991). For this reason, introduction of novel diseases, particularly those introduced by dogs and other animals brought to the island by humans, presents a constant and serious risk.

To explore the possibility that the population decline observed in the mid-1990s was caused by disease, foxes were tested for exposure to five potentially lethal diseases and checked for heartworm and parasites, and these samples were compared to disease profiles from 1988 (Roemer et al. 2000, Roemer et al. 2001b). Roemer et al. (2001b) found no concordance between pathogen prevalence and the temporal and geographic pattern of population decline. No canine distemper virus was found in any of the five subpopulations sampled, and parvovirus decreased between the two sampling periods. Canine heartworm (*Dirofilaria immitis*) was suspected to be a potential threat to island foxes, and positive *Dirofilaria* antigen tests were documented in samples from four of the six populations (San Miguel, Santa Rosa, Santa Cruz, and San Nicolas) collected in 1988 and during 1997-1998 (Roemer et al. 2000). Despite the apparently high antigen seroprevalence (58-100% in 1997-98), necropsy of over 400 island foxes from all islands has found no evidence of heartworm nor heartworm disease (L. Munson, UC Davis, unpublished data). Therefore, the antigen test results are now suspected to be false positives, possibly detecting another antigen present in fox serum (Coonan et al. 2005, Bakker et al. 2006). Other evidence also suggests that heartworm infection did not contribute to the observed population declines. The seroprevalence measured on San Nicolas Island, where the fox population was stable and dense, was higher than on Santa Cruz Island, where the population was decreasing at the time of the study (Roemer et al. 2000, Roemer et al. 2001b). In addition, the heartworm test detected antigens in all four populations in or before 1988, pre-dating the population declines. Finally, seroprevalence in the San Miguel Island population was high in 1994, when densities on that island reached the highest levels ever recorded.

The Channel Islands have a depauperate terrestrial mammalian fauna, resulting in few natural competitors and few prey species (Laughrin 1971). On Santa Cruz and Santa Rosa islands, island foxes are sympatric with island spotted skunks, an endemic subspecies of the western spotted skunk (Crooks 1994). Spotted skunks were, however, reported to be relatively rare on Santa Cruz Island in 1970 (Laughrin 1971). Trapping and observational data from 1991-1993 also suggest that spotted skunks were relatively rare compared to island foxes, and that the two species differed in spatial, dietary, and temporal use of resources (Crooks 1994, Crooks and Van Vuren 1995). However, Roemer (1999) reported that an increase in skunk captures was observed on both Santa Cruz and Santa Rosa islands during the decline of the fox population, suggesting that competition does occur between the two species. On Santa Cruz Island, trap success for skunks was 1.3% while the fox population was large, and it increased to 8.8% 5 years after the fox population had declined. However, this higher trap success could have been due to more empty traps being available when fewer foxes were present.

The Santa Cruz Island fox population has been brought back from near extinction, primarily through the establishment of an active program to remove golden eagles and pigs from the island, and a captive breeding program that provides a safety net for the population. There are currently an estimated 264 foxes in the wild (Schmidt et al. 2007), and 33 in captivity (R. Wolstenholme, TNC, pers. comm.).

8.2 Monitoring Objectives

Parameters for tracking recovery

- Annual estimate of island-wide population size, with an 80% confidence interval. The point estimate should ideally have a coefficient of variation (CV) of ≤20%.
- Estimate of total and cause-specific annual mortality rates. Mortality monitoring should be sufficient to detect an annual rate of eagle predation of 2.5% or greater, averaged over 3 years. In addition, these data should provide a means of surveying for disease and facilitate health research.
- Trend in population size estimated either from annual abundance estimates or from population models. This estimate has no targeted precision; rather the precision of the trend estimate will be determined by the precision of the population estimates and possibly by precision of mortality rates.

<u>Parameters for island-specific management decisions</u>

- Cause-specific mortality rates by age and sex, considering all causes of mortality.
- Habitat- and site-specific density.
- Habitat- and site-specific survival.
- Disease and health profiles, as sampled from all dead foxes and from a subset of the living population based on sampling protocols determined by the Fox Health TEG.

8.3 Past and Current Monitoring

8.3.1 Summary of Past and Current Monitoring Protocols

The first known quantitative study of Santa Cruz Island foxes was conducted in 1970 (Laughrin 1971). In that study, 609 trap-nights resulted in 230 captures of 198 individual foxes (Laughrin 1971). This provided preliminary data on sex ratios, age structure, general distribution, weights, and body condition.

In 1973, additional field work was conducted to examine: (a) distribution and relative abundance, (b) food habits and availability, and (c) factors affecting the welfare of the population (Laughrin 1973). Traps were set up in three different lines; the first line of 30 traps set in a 3x5 grid pattern with two traps at each station, and the two lines set out as linear transects, with traps placed 160-320 meters (0.1-0.2 mile) apart (Laughrin 1973). Trapping occurred during March 1973, and each line was trapped for 3-4 days. The three trap lines each traversed multiple habitat types. In addition, all areas visited were searched for signs of fox use, and scat was collected for diet analysis. Data collected from this field effort included sex ratios, age structure, reproductive status (based on number of lactating females), general health and body condition, and distances moved between captures. An index of trap success was recorded, and a density estimate was generated for each line of traps, assuming that each transect sampled an area 800 meters (0.5 mile) wide. This assumption was based on the average distance moved by recaptured individuals on San Clemente Island (Laughrin 1973). An island-wide population estimate was initially generated by multiplying these density estimates by the entire island size, but Laughrin (1973) abandoned this approach due to the “inappropriateness” of applying these possibly unreliable estimates to the entire island. Different fox densities were observed among different habitat types, causing Laughrin (1973) to suggest that future monitoring methods should sample all major habitat types. He further suggested that various parts of the islands be trapped as close in time as possible, that repeat sampling be used, and that a grid trapping design would likely produce a more reliable density estimate than one using transects (Laughrin 1973).

Laughrin (1980) conducted further trapping on Santa Cruz Island during seven trapping sessions in 1973-1977 to assess abundance in different habitats and during different years. Thirty traps were placed in lines along roads or trails, with a spacing of 320 meters (0.2 mile), and trapped for 3 days (Laughrin 1980). Trap lines were placed in the same areas within two habitat types (chaparral and woodland) each year, because sightings and sign indicated that these were high density areas. Data obtained from this field effort included age structure, sex ratio, body condition, and general health. In addition, as in previous years, trap success was recorded, and an estimate of density was generated for each transect (Laughrin 1980).

In 1991-1993, Crooks (1994) conducted a comparative ecology study on the island fox and the sympatric island skunk to examine relative abundance, sex ratios, age structure, and variation in weight by age, sex, and season for both species. The study was conducted at two locations on the island─Rancho del Norte, at the northeastern side of the island, primarily dominated by fennel-invaded grasslands, and Central Valley, dominated by chaparral and grasslands (Crooks 1994). Although the purpose of trapping was to radiocollar animals, demographic data were collected during the trapping effort. Traps were set along movement routes and other activity areas. This effort provided data on sex ratios, age structure, weight, and body condition. Population density estimates were not generated, but trap success rates (overall and by season) were used as an index of relative abundance. In addition, six foxes in each study area (three males and three females) were radiotracked during 11 months in 1992 to collect data on home range, daily activity, and habitat preference (Crooks and Van Vuren 1995, 1996). Locations were estimated 3-5 times per week via triangulation, and home ranges were generated using the adaptive kernel method (Worton 1989). Habitat selection was examined, based on availability of various habitat types in each of the two study areas, and scat samples were collected for diet analysis.

During 1993-1998, Roemer et al. (1994) trapped to assess population size and demographic parameters. Two grids were established, with locations chosen to represent dominant habitat types and to avoid areas heavily impacted by humans and areas of steep and rugged topography. The two grids covered 2.1% of the island (Roemer 1999). The first grid, referred to as the Central Valley or Mixed grid, consisted of 5x10 traps in grassland, chaparral, oak woodland, coastal sage scrub, and riparian habitat. The second grid, referred to as the Fraser Point or Grass grid, was 5x13 traps in grassland and coastal dune scrub habitat. Trap spacing was 250 meters, traps were set for 5-7 consecutive days, and trapping was conducted from late May to early September. The two grids were trapped for 5 years (1993 and 1995-1998; Roemer 1999).

Population size estimates were generated for each of the grids using the program CAPTURE (White et al. 1982) and Chapman's modification of the Lincoln-Petersen method (Seber 1982). The latter method was included as a comparison method because model selection in the program CAPTURE may not be robust with small sample sizes (Roemer et al. 1994). Density was estimated from $D = N/A_W$ where A_W is the effective trapping area obtained by adding a boundary strip of width W to the area of the grid, with W estimated as half the mean maximum distance moved (MMDM) between traps (Dice 1938, Wilson and Anderson 1985, Roemer et al. 1994).

An island-wide population estimate was generated by extrapolating grid-specific density estimates to the entire island. The composition of various vegetation types (referred to as habitat types in Roemer et al. 1994) on each grid was compared to the composition of corresponding vegetation types on the island, and "…fox density from each grid was then multiplied by the appropriate habitat area for each island, yielding an estimate of the number of adults." Developed, barren, and cultivated areas were omitted from the calculations (Roemer et al. 1994).

Of foxes captured during 1993-1995, a subset of individuals near Fraser Point at the west end of the island was included in a study designed to (a) examine the spatial distribution, relatedness, and mating system of island foxes, and (b) document the impact of eagle predation on survival, population density, and fox behavior (Roemer 1999). Twenty-five foxes belonging to 11 social groups or *families* were tracked intensely (with locations every 2-3 days) for a period of approximately 1 year (November 1993-December 1994), and then less intensely (about twice per month) until the end of the study in September 1995. A larger sample of animals was included in a genetic analysis of relatedness and mating systems. Monthly survival of radiocollared foxes was calculated using the Kaplan-Meier staggered entry design (Pollock et al. 1989, Roemer 1999), and apparent survival was also estimated separately from 1995-1998 grid trapping data using the Cormack-Jolly-Seber model in program MARK (White and Burnham 1999). The study provided information on home ranges, space use overlap among paired and unpaired animals, dispersal and estimates of gene flow, estimates of genetic relatedness, mating system, reproduction (number of pups trapped), survival and cause-specific mortality rates, activity patterns, and disease exposure (Roemer 1999).

In 1998, Roemer (1999) trapped foxes along transects on Santa Cruz Island and the other five islands inhabited by island foxes as part of a cross-island comparison of density (Roemer 1999). Traps were set approximately 200 meters apart, for 6 nights, for a total of 76 trap-nights. Trap results were presented as trap success to compare abundance across islands.

In 2001, the Institute for Wildlife Studies began monitoring population size, distribution, and productivity to examine the effects of golden eagle predation on the population. That year, trapping was distributed as widely as possible across the island, to assess population status following the reported decline caused by golden eagles (Roemer 1999, Schmidt et al. 2007). Starting in 2002, foxes were trapped along transects distributed across the island, primarily along roads, trails, and ridges, excluding steep and rugged terrain, with traps set approximately 300 meters apart. Twelve transects of 35-49 traps were each trapped for 4 consecutive nights during June through November (Schmidt et al. 2007, R. Wolstenholme, TNC, pers. comm.).

That field effort, which has been continued annually since 2002, generates data on sex ratios, age structure, health and body condition, and preliminary data on survival. In addition, trap data are used to generate an estimate of island-wide abundance by using MNKA and extrapolating this number to unsampled portions of the island. The area sampled is determined by assuming an effective trap radius of 500 meters around each trap (minus overlap). Approximately 41% of Santa Cruz Island is sampled by this trapping effort (Schmidt et al. 2007).

In 2006, a 1-km^2 grid was overlaid on the island and, based on the number of individual foxes captured in each grid cell, a mean and standard deviation of fox density was generated (foxes per km^2). This number was used to extrapolate to the unsampled areas. Population size was estimated by adding MNKA to the number estimated as being in the unsampled areas (Schmidt et al. 2007).

A subset of captured foxes and animals released from captivity were radiocollared and monitored for survival, using ground telemetry and a remote tracking station at Diablo Peak (the highest point on the island). The remote station, which uses a cell phone for remote communication to researchers, was designed to pick up signals from foxes on the north side of North Ridge. In 2005 and 2006, a total of 88 and 90 foxes, respectively, were radiocollared and monitored on Santa Cruz Island for survival, with each animal's signal checked at least once per week. Signals on a subset of about 40 animals are checked twice per week (L. Vermeer, TNC, pers. comm.). All animals found dead are sent to US Davis for necropsy.

8.3.2 Representation Analysis of Current Trapping Protocols

To determine how well existing trapping protocols represent habitat variability on the island, we conducted univariate and multivariate representation analyses (Appendices E and J). The univariate analysis suggests that the current trapping protocol does not adequately represent habitat variability on Santa Cruz Island. Trapped areas tend to be less steep, farther from the shoreline and freshwater, and closer to roads and developed areas than the average on the island (Appendix E; Maps 8-3 and 8-4). Some of these differences may not be biologically relevant, as some differences were small relative to fox movements (e.g., distance to freshwater) or are not believed to be relevant given the small absolute difference (e.g., slope; Appendix E). However, the bias toward roads and developed areas, and away from steeper areas near the shoreline, may have relevance if density or survival of foxes differs with these habitat factors.

We also performed a principal components analysis (PCA) for key habitat attributes, comparing mean principal component (PC) scores for trapped areas to those of the entire island. Transect trapping on Santa Cruz Island has greatly under-represented remote shoreline and interior canyons. Once accounting for topography linked to proximity to shoreline and freshwater (i.e., canyons), steep and rugged habitat was sampled in proportion to its availability. Existing transects appear to sample vegetation proportionally to its occurrence on the island. Nonetheless, under-sampling of remote shoreline and interior canyons occurs systematically in all vegetation types.

8.3.3 The Ability of Existing Protocols to Meet Current Objectives

Previous and ongoing studies of Santa Cruz Island foxes have produced a wealth of valuable information, including data on population trends, estimates of density, age structure and sex ratios, animal health, and survival. In this section we discuss the adequacy of existing protocols to address current monitoring objectives (Section 8.2). We recognize that previous protocols may not have been designed to address the same set of objectives. Our summary is intended to indicate where refinements can be made to better address current monitoring objectives, rather than to critique previous study designs.

Population size

Although field data have been used to generate an island-wide population estimate for Santa Cruz Island, several shortcomings limit the accuracy and precision of these estimates:

1. Current trapping is along transects which can provide relative abundance indices. However, transect sampling is typically not used to generate density estimates using traditional mark-recapture analysis methods and, in general, data from transect sampling do not provide estimates of abundance or density as precisely as grid trapping data. A

primary shortcoming of transect trapping is the difficulty of estimating effective trap area around the transect (Spencer et al. 2006, Schmidt and Garcelon 2003). However, we recognize the challenge of trapping grids on steep and rugged terrain, and suggest that transect sampling may be necessary. Fortunately, newly developed methods of spatially explicit capture-recapture analysis (Efford 2004) should allow use of modified transect configuration on large rugged islands (Section 8.4.2).

2. Grids were trapped on the island for 5 years (1993, 1995, 1996, 1997, and 1998; Roemer et al. 1994, Roemer 1999) and resulting data provided robust grid-specific density estimates and abundance estimates. However, the two grids represented a small portion of the island and didn't adequately represent habitat diversity on the island, so data can not be confidently extrapolated to the entire island.
3. Current trapping protocols are biased towards areas near roads and development, and away from steep areas such as the shoreline.
4. The current method of determining the portion of the island sampled (adding a 500-meter radius around each trap) assumes that distances moved in various habitat types, and at various population densities, remain constant, when this is actually not known. In fact, distances moved (and resulting home ranges) can vary by season, habitat, island, sex, density, and age (Moore and Collins 1995). In addition, the method of overlaying a 1-km^2 grid on the entire island and generating a mean and standard deviation of fox density from capture data to be applied to un-sampled portions of the island may be problematic. It is not clear if this approach corrects data for capture effort per grid cell. That is, a cell including several traps might be weighted the same as a cell with only one trap. Furthermore, this method does not appear to consider different densities in different habitats. This approach also does not include a way of estimating sampling error. Finally, this approach appears to assume that all foxes in the cell are captured, rather than accounting for capture probability using mark-recapture methods.
5. The current trapping protocol is labor-intensive and costly, approaching an island census rather than an estimate based on sampling methods.

Survival and cause-specific mortality rates

Although annual capture data on marked animals can be used to estimate apparent survival rates, they do not reveal mortality causes or distinguish between mortality and emigration, and they do not facilitate immediate management response in the event of a disease outbreak or sudden increase in predation. After the population decline in the mid-1990s and subsequent reestablishment of the population, a large number of animals have been radiocollared and monitored for survival. For example, during 2005 and 2006, at least 70 radiocollared foxes were monitored for survival at any one time[6], providing preliminary data on survival and cause-

---

[6] Some models had suggested that the removal of feral pigs from Santa Cruz Island could have the effect of increasing the mortality rate of foxes due to golden eagle predation (Courchamp et al. 2003). The increase in the number of collared foxes during that period was intended to provide enhanced monitoring through that period of hypothesized heightened risk for the foxes.

specific mortality rates. However, several factors may limit the ability to generate robust estimates of survival and cause-specific mortality:

1. Current survival monitoring may not be frequent enough to determine causes of death. Signals on about 40 animals are checked twice weekly, and the remainder are checked once per week (R. Wolstenholme, TNC, pers. comm.). This frequency is likely adequate for monitoring for mortalities due to eagle predation (because carcasses could be investigated soon enough to determine cause of death), but it would not be adequate for disease surveillance during summer months. The Fox Health TEG suggests that animals be checked at least every 2-3 days in the winter and every 1-2 days in the summer, with an ideal scenario of daily checks, to increase the chance of meaningful necropsy results.
2. It is not known if adequate numbers of collared animals are monitored throughout the year. If collar batteries do not last for an entire year, there may be a period when the number of functional collars decreases. Unless additional trapping is conducted between annual trapping surveys, or if pulse rates on collars are reduced to extend battery life to ≥12 months, there may be periods when inadequate numbers of animals are monitored.
3. Currently, radiocollared foxes may not be representative of the entire population. Few animals are captured and monitored on the north side of North Ridge, due to steep and rugged terrain, and poor access. Based on the distribution of known golden eagle nest sites, however, the north side may support more golden eagles than the remainder of the island (S. Morrison, TNC, pers. comm.); thus, foxes in this area may be at higher risk of golden eagle predation. A remote telemetry monitoring station on Mount Diablo was designed to aid in monitoring signals from foxes on the north side of North Ridge (along north beaches and in north facing canyons); however, this monitoring system has worked with limited success (R. Wolstenholme, TNC, pers. comm.). It is possible that future survival monitoring will also under-represent the north side of the island and, in this situation, managers should be aware that island-wide survival could be under-estimated if foxes on the north side do indeed have lower survival; something that could be especially problematic if the north slope functions as a “sink” for the island population overall. We suggest that this be investigated in a focused research project (Section 8.5.3).
4. It is not clear how well the wild population is represented by the monitored sample. Ideally, sampled animals should include males and females, with an age distribution representative of the population. Although pups should be included in this sample, we recognize the current challenges of monitoring pup survival, because their small size precludes use of radiocollars. We suggest that further research be conducted to develop methods of estimating pup survival (Section 8.5.3).

Trends in population abundance or density

The extensive transect trapping that occurs every year on Santa Cruz Island may provide a useful index of changes in density. It is even possible that a less intensive effort could provide such an index, with trap success used to establish indices of relative abundance over time. However, several aspects of the trapping protocols could be improved and standardized to make year-to-year data more comparable and more amenable to standard analysis methods:

1. Trap success alone should not generally be used as an index but instead should be corrected for capture probability.
2. Some inter-annual variation apparently exists in trap locations, and this could cause inter-annual variability in trapping results. Standardized transects should be trapped at the same locations every year, with the same inter-trap distances, because inter-trap spacing can influence capture probabilities. Ideally, reports should show actual trap locations or provide coordinates to help standardize trap locations.
3. The number of traps and areas trapped has changed across years, making trap data less useful for assessing trends. For example, on the northwestern end of Santa Cruz Island, transects were abandoned after several years of low trap success, most likely due to personnel or budget limitations, when it would have been ideal to continue these transects to monitor long-term trends or shifts in distribution. However, the purpose of that protocol may not have been to monitor population trends, and obtaining other data (e.g., minimum number known alive) may have been a priority. Given that abundance trends are now a desired monitoring product, a trapping protocol, once established, should remain consistent across years, so that trends can best be recognized.
4. Some inter-annual variation exists in the timing of trapping, which may also influence trap results. To provide the best data for assessing population trends, standardized transects should be trapped at the same time every year. Transects should be trapped according to a standardized schedule during the annual trapping period, and the trapping period should be standardized among islands.
5. It is not known if other protocols such as the time of day when traps are opened, checked, and closed, types of bait, and types of traps have been kept constant across years. These should be standardized to the extent feasible.
6. Sampling is not distributed across the island to represent all habitat types and geographic areas. We recognize that this will likely be impossible with any feasible trapping protocol, due to Santa Cruz Island's rugged and steep terrain. We therefore suggest that (a) an attempt is made to distribute trapping across the island as much as possible, and (b) habitat use and selection studies be conducted to determine if under- or over-representation of certain habitat types or geographic parts of the island introduces bias into analysis of trends (see Section 8.5.3).

Existing data have provided an estimate of past abundance trends. However, the above improvements could increase accuracy and precision of trend estimates.

Survival and density by habitat type

Current monitoring protocols are unlikely to provide robust density estimates by habitat type. Improved placement of transects in combination with newly developed analytical techniques, such as those implemented in the program DENSITY (Efford 2004), may help stratify density estimates by habitat, as recommended for island fox monitoring on San Clemente Island (Spencer et al. 2006). If strict random placement is chosen and multiple sampling units are used, multivariate analyses could be used to examine the influence of various habitat attributes (Section 8.4.2) Research on habitat selection and home-range size, using locational data from radiocollared animals would also shed light on differences in habitat quality across the island landscape (Section 8.5.3).

Current protocols do not provide a way to monitor survival by habitat type. However, radio-location data would allow analysis of time spent in each habitat type.

8.4 Monitoring Protocols for Santa Cruz Island

8.4.1 Feasibility Considerations for Monitoring Activities

Section 2.2.2 outlined general constraints and considerations related to field protocols that pertain to all islands. In addition to those general constraints of access, timing, weather, animal welfare, and cost, monitoring on Santa Cruz Island must consider the following specific issues:

1. The island is very rugged, which makes fieldwork difficult (Maps 8-3 and 8-4). Approximately 61% of the island has terrain with slopes greater than 30% (16.7°) which, according to NPS management, is the maximum terrain steepness feasible for field work.
2. Although there is a fairly extensive system of roads and trails, the island's large size constrains some monitoring activities, such as daily signal checks from the ground. Approximately 36% of the island is more than 1 km from existing roads accessible by four-wheel-drive vehicles, and off-road vehicle use is prohibited. Effective field work in these areas requires increased field personnel to carry traps and other equipment on foot and to access all set traps within a reasonable time frame.
3. Lack of roads limits access to areas north of North Ridge and limits travel between the east end of the island, owned by NPS, and the remainder of the island. Housing and transportation for field crews is also limited on the easternmost 10% of the island, which must be accessed by boat.

8.4.2 Candidate Trapping Protocols

As described in Section 2.4.1, we had two options for trapping protocols on Santa Cruz Island: transect-based trapping using multiple small units, and island-wide random trapping.

We first evaluated the feasibility of island-wide random trapping. Using a plausible range of fox movement patterns and capture probabilities, we simulated the number of traps and trap-nights required to obtain sufficient recaptures to generate a population estimate with desired precision. In this simulation, traps were placed in random locations across the island each night and then moved to new random locations on each subsequent night. Results indicate that adequate precision (CV[$\hat{N}$] ≤20%) could be obtained only if 80-120 traps were trapped and moved each night for at least 15 nights, or if 200 traps were trapped and moved for 5 nights (data not shown). Due to the logistical challenge of moving ≥80 traps to a new location for every trap occasion (night) on this large and rugged island, this method was deemed impractical by Santa Cruz Island biologists, and we therefore abandoned this option for Santa Cruz Island.

We also explored the use of transects, which could be more practical in rugged and steep terrain than larger grids would be (Appendix M). Simulation results indicate that parallel paired lines (referred to here as units) produce better results than single straight lines with the same number of traps and spacing (Appendix M). Simulations were also used to evaluate the number of traps, trap-spacing, and number of nights trapped that would provide the best precision in relation to effort (Appendix M). Based on these results, we chose to use a standard trapping unit with dimensions of 2x6 traps, spaced at 200 meters and trapped for 6 nights, in further evaluations of trap effort versus resulting precision, with the primary question being how many such units would be required to obtain adequate precision (Appendix M). Given a particular trap layout and duration, resulting precision depends largely on the number of recaptures. Recaptures, in turn, are determined by the fox density and behavior, which influence detection by the sampling system. Program DENSITY models these behaviors using two detection parameters to describe movement patterns and capture probabilities when encountering traps (Efford 2004, Efford et al. 2004, Appendix M). Simulations were run at a range of densities, and detection parameters were set at a range of plausible values as well as a best estimate of detection scenarios, generated by V. Bakker using actual trap data from multiple years and multiple islands, and the program DENSITY. Data archives from the many years of field work on the various islands provided a valuable resource for identifying these best estimates.

Simulation results suggest that 33 recaptures (collectively across all units on the island during the complete annual capture session) are necessary to obtain a mean $\mathrm{CV}(\hat{D}) = 20\%$, and that 40 recaptures would further assure that this precision is obtained in most runs (Appendix M). Based on simulations, Figure M-7 in Appendix M indicates the precision expected at varying densities, when different numbers of units are trapped, with $\mathrm{CV}(\hat{D}) = 20\%$ representing approximately 33 recaptures, while Figure M-4 in the same appendix shows the number of units required to obtain 40 recaptures at varying densities. The latter therefore provides a more conservative goal, which would assure a $\mathrm{CV}(\hat{D}) \leq 20\%$. Our goal was to identify logistically feasible scenarios that would obtain at least 33 recaptures and, based on number of expected recaptures, we estimated expected precision with the equation $\mathrm{CV}(\hat{D}) = 0.894m^{-0.297}-0.116$, where m = the number of recaptures (Appendix M).

At current fox densities on Santa Cruz Island (estimated to be 1.02 fox/km^2), simulation results suggest that a protocol with 24 trapping units would provide a density estimate with the targeted precision, with $\mathrm{CV}(\hat{D})$ simulated to be 20-21% (Appendix M). We propose this scenario as Santa Cruz Island Trapping Scenario A. We developed a map of this scenario by placing (and orienting) 24 units randomly on the island, using the following rules: (a) units must originate on or near a road, (b) units must be ≥1,500 meters apart to reduce the chance of an individual fox moving between grids, (c) trap locations should avoid steep slopes with ≥30% (16.7°) slope to reduce risks to field personnel (Map 8-5). Although it is possible to place units closer to each other, maintaining at least 1,500 between units eliminates the need to account for inter-unit movements, and the nearly "regular" spacing of units that results from this spacing rule approaches a systematic sample which should have reduced sampling variance.

If this level of effort is infeasible, a smaller number of units could be trapped, but at the expense of precision. For example, if 18 units were trapped, resulting $\mathrm{CV}(\hat{D})$ would be 22-23% at the current population size, and would improve to the targeted precision if density increased to 1.7 foxes/km^2. We propose this scenario as Santa Cruz Island Trapping Scenario B, and produced a map with units located in the same manner as for Scenario A (Map 8-6).

There is no *correct* answer on scenario choice, and variations of the two scenarios defined above are possible. The final choice will depend on the trade-off between effort expended and desired precision, which will depend in part on population density and recapture rates. At current densities, Scenario A, with 1,728 total trap-nights, will provide good precision and the best habitat representation. If this level of effort is deemed impractical, units could be eliminated randomly to make the protocol more feasible. We provide Scenario B, with a total of 1,296 trap-nights, as a more feasible but less precise and representative approach.

The expected precision of either of these two scenarios could likely be increased by increasing the number of nights trapped (because this would increase the expected number of overall recaptures); however, this may be detrimental to foxes that are caught repeatedly. Trap-happy behavior may create a challenge with any trapping regime for this species and could bias estimates to an unknown degree and possibly reduce precision slightly. Use of maximum likelihood methods, currently being incorporated into program DENSITY, will make it possible to include a learned response in the model; however, further analyses would be necessary to properly model this behavior in island foxes (M. Efford, pers. comm.).

8.4.3 Representation Analyses of Selected Candidate Trapping Protocols

To determine how well selected candidate trapping protocols represent habitat variability on Santa Cruz Island, we conducted representation analyses using both univariate and multivariate techniques and compared habitat representation resulting from the two candidate protocols (Scenarios A and B) to habitat variability of island-wide areas as well as those sampled by the existing protocol (Appendices E and J).

Univariate analyses (Appendix E) indicate that areas sampled by all three trapping scenarios have lower slope than island-wide areas, and Scenario B additionally samples areas with lower ruggedness. This is not surprising, as logistic and safety constraints require that traps are not placed in steep and rugged terrain. These differences may not have an influence on trap results, however, because absolute differences were small (Appendix E). The existing trapping protocol and Scenario A both sample areas that differ from island-wide areas in distance to shore, but the absolute differences are small relative to fox movement patterns and may, therefore, not have biological relevance. Although all three trapping scenarios sampled areas closer to roads (as was expected, as traps were placed in proximity to roads for logistic reasons) and to developed areas, compared to island-wide areas, this difference was most extreme in the existing protocol. It is possible that this may bias trap results, if foxes select or avoid areas close to roads and developed areas. Although all three trap scenarios did not sample vegetation categories in proportion to their availability on the island, Scenario A sampled these most adequately.

Multivariate analyses (Appendix J) indicate that existing transects and proposed Scenario A under-represent roadless, remote shoreline characteristic of areas on the north, west, and the south sides of the island, while Scenario B represents this feature consistent with its overall presence on the island. Existing transects and both proposed scenarios under-sample remote steep and rugged interior areas to a similar degree. Proposed scenarios over-sample rugged terrain on flatter ground. Overall, Scenario B appears to represent the habitat characteristics of the island best, despite fewer trapping units overall. This efficiency is achieved because most of the additional trapping units comprising Scenario A occur in areas closer to roads and development, which tend to be over-sampled. Biases in multivariate habitat sampled by proposed scenarios likely result from logistical constraints placed on trap unit location to ensure feasibility of the trapping effort.

We suggest that habitat use and selection be examined in radiocollared foxes to determine which, if any, of the above habitat differences might bias trap results. In addition, density and demographic rates in disproportionately-sampled habitat types should be compared to overall island-wide patterns to ensure that these biases do not bias monitoring results.

8.4.4 Survival and Cause-Specific Mortality Monitoring

Due to the large size and rugged terrain of Santa Cruz Island, frequent ground monitoring of radio signals will be difficult without a large investment of personnel hours and vehicles. Even if a full-time person and vehicle were dedicated to the task of monitoring 40 foxes distributed across the island, this task may not be feasible, especially as a large portion of the island (e.g., north of North Ridge) is not accessible by road. Currently, signals on approximately 40 foxes are checked from the ground about twice per week, and signals on the remaining 33 collared foxes are checked once per week.

The use of remote telemetry receivers could be considered as an alternative or an addition to ground monitoring (see Section 2.4.2). However, assuming a detection range of 5 km, many tall towers would likely be necessary to detect foxes across Santa Cruz Island. Remote telemetry technology has been used on the island in the form of a tower on Diablo Peak (the highest point on the island). This tower, which transfers signal information via cell phone, is currently limited in its effectiveness because it cannot detect foxes in several north-facing canyons north of North Ridge and several steep drainages on the south side of the island. A preliminary viewshed analysis suggested that nine 45-meter high towers with a 5 km detection range would not adequately monitor San Clemente Island, which is smaller and has less rugged terrain than Santa Cruz Island (B. Cohen, TNC, pers. comm.). A viewshed analysis could determine the necessary number and most effective placement of towers, based on their height, and portions of the island that would be monitored effectively by the remote system. Prior to the viewshed analysis, the detection range of collars should be confirmed in the field.

We suggest that a promising monitoring option for Santa Cruz Island may be aerial monitoring from an airplane. As described in Section 2.4.2, aerial monitoring may provide a cost-effective strategy on the three largest islands (Santa Catalina, Santa Rosa, and Santa Cruz) and an option that should be explored is the idea of the three islands (SCIC, NPS, and TNC) jointly contracting a pilot and airplane to monitor the three islands on a regular basis. This may reduce the collective cost of monitoring foxes on the three islands and would provide a time-efficient and thorough method for monitoring foxes on Santa Cruz Island.

If aerial monitoring is found to be infeasible, a combination of ground monitoring and remote telemetry monitoring should be considered as a second choice. Personnel hours would need to be dedicated for regular monitoring of areas accessible by existing roads and trails, and remote monitoring towers could be placed strategically to detect signals in areas difficult to access from the ground. For example, a viewshed analysis could be conducted to identify all areas that could be monitored from existing roads and trails on a regular basis. Placement of remote towers could then be evaluated to detect signals from the remaining parts of the islands. For example, towers could be placed on high points along the North Ridge to detect signals on the north side of this ridge. Alternatively, if field personnel are unable to check the entire island frequently enough, monitoring efforts could be split geographically so that the east half of the island is checked one day and the west half of the island is checked on alternating days, a strategy that is similar to what is currently used on Santa Cruz Island. An additional alternative is that the north shore of the island could be left void of radiocollared animals (i.e., no animals collared in that portion of the island), thereby relying on animals in the remainder of the island acting as sentinels. However, annual mortality rates may then not be representative of the island as a whole.

Finally, as described in Section 2.4.2, the use of GPS collars for monitoring survival of 40 animals may provide a cost-efficient option, depending on prices of collars. We suggest that island managers collaboratively evaluate and compare the cost efficiency of the above survival monitoring approaches, to find the most cost effective options for each island.

Estimates of habitat- and site-specific survival rate can be generated if survival data obtained by the above methods are combined with locational data on radiocollared animals. We suggest this joint approach as a research module in Section 8.5.3. We suggest that survival estimation be performed with the known fate model in MARK, rather than the simple Kaplan-Meier estimator.

8.5 A Tiered Approach for Population Monitoring

8.5.1 Recommended Long-Term Trapping Protocols

We recommend that trapping be conducted according to one of the following two scenarios, based on an evaluation of trade-offs such as expected precision, logistical feasibility, and representation of habitat variability on the island:

- Scenario A: 24 units of 2x6 traps, for a total of 1,728 trap-nights annually (Map 8-5)
- Scenario B: 18 units of 2x6 traps, for a total of 1,296 trap-nights annually (Map 8-6)

Trapping should be conducted at the same time each year, and be synchronized with timing on other islands, to facilitate the most accurate comparisons across years and islands. We suggest that July represents the most optimum trap period (Section 2.2.2). Furthermore, to reduce the probability of fox moves between sampling units, all units should be trapped in as short a time period as possible.

8.5.2 Recommended Monitoring for Survival and Cause-Specific Monitoring

To address a primary monitoring objective outlined in Section 2.4.2, and to track survival and cause-specific mortality for Santa Cruz Island foxes, we recommend the following actions:

1. Annually radio-collar at least 40 foxes with mortality-sensing collars (Section 2.4.2). These foxes should be widely distributed across the island. We expect that most, if not all, of the 40 foxes may be captured and radiocollared during trapping designed for collection of demographic data, while a small amount of targeted follow-up trapping may be necessary if inadequate numbers or composition of animals are captured, or if previously collared animals need to be captured to remove old collars. Some level of collar failure and/or mortality is expected to occur every year; therefore, the initial number of animals collared should ideally be increased to at least 45. Additional follow-up trapping may be necessary if the number of radiocollared animals falls below 40.
2. Explore the option of aerial signal monitoring, ideally in collaboration with monitoring efforts on Santa Catalina and Santa Rosa (and possibly San Miguel) islands. If feasible, contract pilot and airplane to conduct routine (ideally daily, but at least every other day during summer) monitoring of all radiocollared foxes.
3. If aerial monitoring is not feasible, explore the option of a remote monitoring system to augment ground monitoring.
    - Conduct pilot studies to determine actual, in field, detection ranges for telemetry signals as a function of terrain, location, tower heights, etc.
    - Conduct a viewshed analysis to identify areas that can be monitored via telemetry from established roads and trails.
    - Conduct a viewshed analysis to determine number and locations of towers necessary to monitor animals in areas where ground-monitoring is not feasible. This would also help determine zones (e.g., the bottom of some canyons) from which a collar signal will not be detected by a tower).
    - Dedicate personnel hours needed to assure that signals are checked in all the ground-monitoring areas at a minimum of every 2 days during the summer and every 3 days during the winter, with a preferred schedule of a signal check on every animal each day.
    - If the above investigations warrant the use of remote telemetry on towers, construct towers and install and test the automatic recording system.
4. Explore the use of GPS collars for survival monitoring (Section 2.4.2).
5. Have personnel on call on the island to immediately locate and investigate mortalities, and develop a protocol for transporting carcasses to UC Davis for necropsy.

8.5.3 Recommended Research Modules

Monitoring protocols outlined in this report will produce a standardized long-term flow of demographic data on island foxes. In addition to providing information for management and conservation decisions, this dataset will provide a context for additional research studies on island fox biology, environmental factors affecting the viability and dynamics of fox populations, and management intervention. Information gained from research projects may, in turn, be used to refine future monitoring protocols or analyses of monitoring data. Monitoring and research modules are therefore complementary, although research modules may only occur for short time periods, while monitoring is designed to be an ongoing effort.

Recommended research modules for Santa Cruz Island include:

1. Habitat and space use**.** Habitat selection and space use studies should examine specific behavioral and demographic patterns relative to roads, specific vegetation types, water sources, and shoreline areas. These data will be useful, for example, in interpreting annual trap data (e.g., to determine if over- or under-representation of certain habitats or portions of the island are likely to bias population estimates). Studies on home range size, movement patterns, and dispersal relative to density will increase our understanding of habitat quality differences and potential source-sink dynamics. In addition, further information is needed on fox-skunk relationships, including population dynamics and habitat-use relationships. The presence of radiocollared animals (for survival monitoring) will greatly facilitate such studies.
2. Factors influencing survival. One of the monitoring objectives for Santa Cruz Island is to monitor survival in relation to habitat use. Long-term survival monitoring data (Section 8.5.2) should help identify factors that influence survival rates using covariates within known fate models in program MARK or Cox proportional hazards modeling (Cox 1972). For example, such an analysis could be used in combination with locational data on radiocollared animals to test whether foxes using open habitats such as grasslands experience higher risk of eagle predation than foxes in areas of greater vegetation cover, as hypothesized by Roemer (1999). Results of this type of analysis could inform future sample selection for collared foxes based on vulnerability to mortality.
3. Disease and health**.** Although standardized disease and health monitoring will be conducted every year, as per recommendations of the Fox Health TEG, some tests or the intensity of testing may vary from year to year, as determined by veterinarians and epidemiologists, and some focused short-term research projects may be warranted.
4. Reproduction and early pup survival. Although annual trap data may provide some information on reproduction (e.g., indexed by the proportion of captured females exhibiting signs of reproduction), further research is needed on reproduction, early pup survival, and factors influencing these measures. The presence of radiocollared foxes will facilitate such research, but other methods such as use of remote cameras or genetic techniques (via scat or hair sampling) may be necessary.
5. Vegetation. The island-wide vegetation map should be updated every 5-10 years. As part of this effort, field studies should measure vegetation height, structure, and composition at pre-determined sites to track changes due to habitat recovery, climate change, and human activity. These data will be useful for understanding temporal and spatial patterns of fox habitat use.
6. Effectiveness of remote telemetry stations. If aerial monitoring of fox survival is not feasible for the long-term, a study should explore the use of remote monitoring systems to augment survival monitoring efforts on the ground. This should include determining

actual, in field, detection ranges for telemetry signals as a function of terrain, location, tower heights, etc., and number and locations of towers needed to monitor the island adequately (see Section 8.5.2).

7. Indices of trend. We recommend further research on the use of sign (e.g., scat, tracks, camera "observations") as an index of population trend. This should include statistical comparison to more formal estimates of population trend.
8. Trap protocols and analysis of trap data. In our analysis of potential trap protocols, trap detection parameters were refined with the use of existing data from multiple islands; however, increased understanding of the behavior of foxes in relation to trapping could improve the choice of trapping protocols and the analysis of trap data. For example, it may be possible to more adequately model trap-happy behavior and incorporate this into density estimation models.

   Similarly, fox movement behaviors may influence the appropriate methods of data analysis. For example, further research should be conducted to evaluate whether home range shape (e.g., elongated home ranges due to movement along roads, trails, and ridges) influences or biases density estimates, and how trap protocols and analyses may account for such potential influences.

   Further research is also needed to evaluate a potential approach for estimating density by combining telemetry and trapping data (Section 2.3.2). Generally, this approach calls for delineating the area associated with a trapping unit, determining the proportion of locations within the trapping area for radio-collared animals, and estimating density for each unit based on the relationship between the proportion of locations within the trapping unit and probability of capture. This method requires further development for optimal design to assess how precision would vary with different grid sizes, trapping durations, numbers of radiocollared foxes, telemetry location frequencies, and telemetry location precision.

   On Santa Cruz Island, the presence of skunks creates an additional challenge related to trapping protocols, because capture of skunks reduces the number of traps available to foxes. Further research and analysis on how to best account for this issue, and how the prior capture of a skunk influences subsequent capture of a fox in the same trap, can help refine future trap protocols.

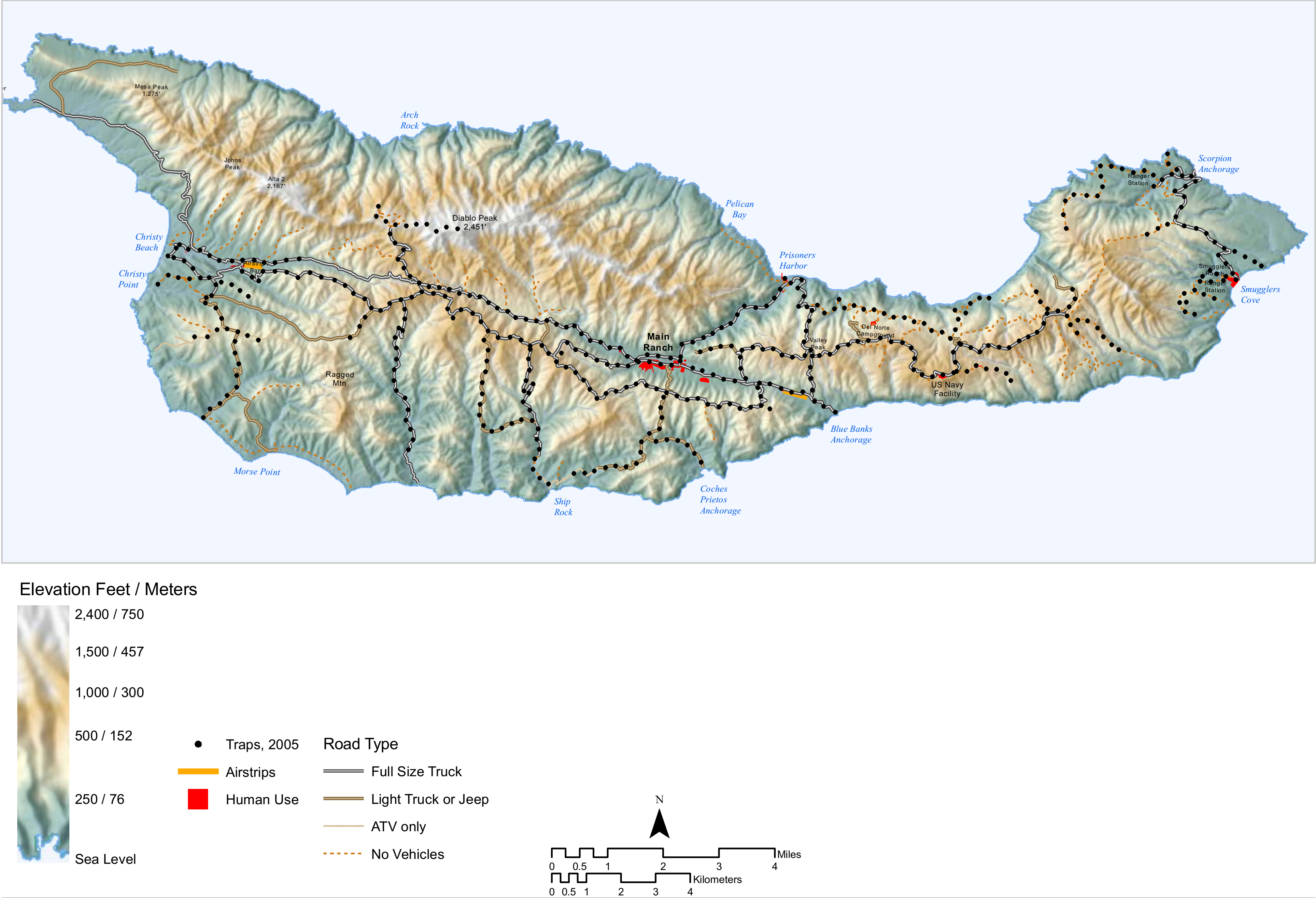
   Due to some inaccessible areas, trapping scenarios proposed for Santa Cruz Island fail to sample 12-15% of the island (Section 2.4.1), primarily areas north of North Ridge. To assess potential bias caused by lack of trapping in this stratum of the island, we recommend that methods such as genetic sampling, sign surveys, or camera traps be used to compare relative density in sampled and unsampled areas, ideally every 3-5 years.

Section 3.2 outlines additional non-fox data that should be routinely monitored and integrated with fox data.

CONSERVATION BIOLOGY INSTITUTE
The Nature Conservancy
SAVING THE LAST GREAT PLACES ON EARTH

Santa Cruz Island

Map 8-1 Existing Traps

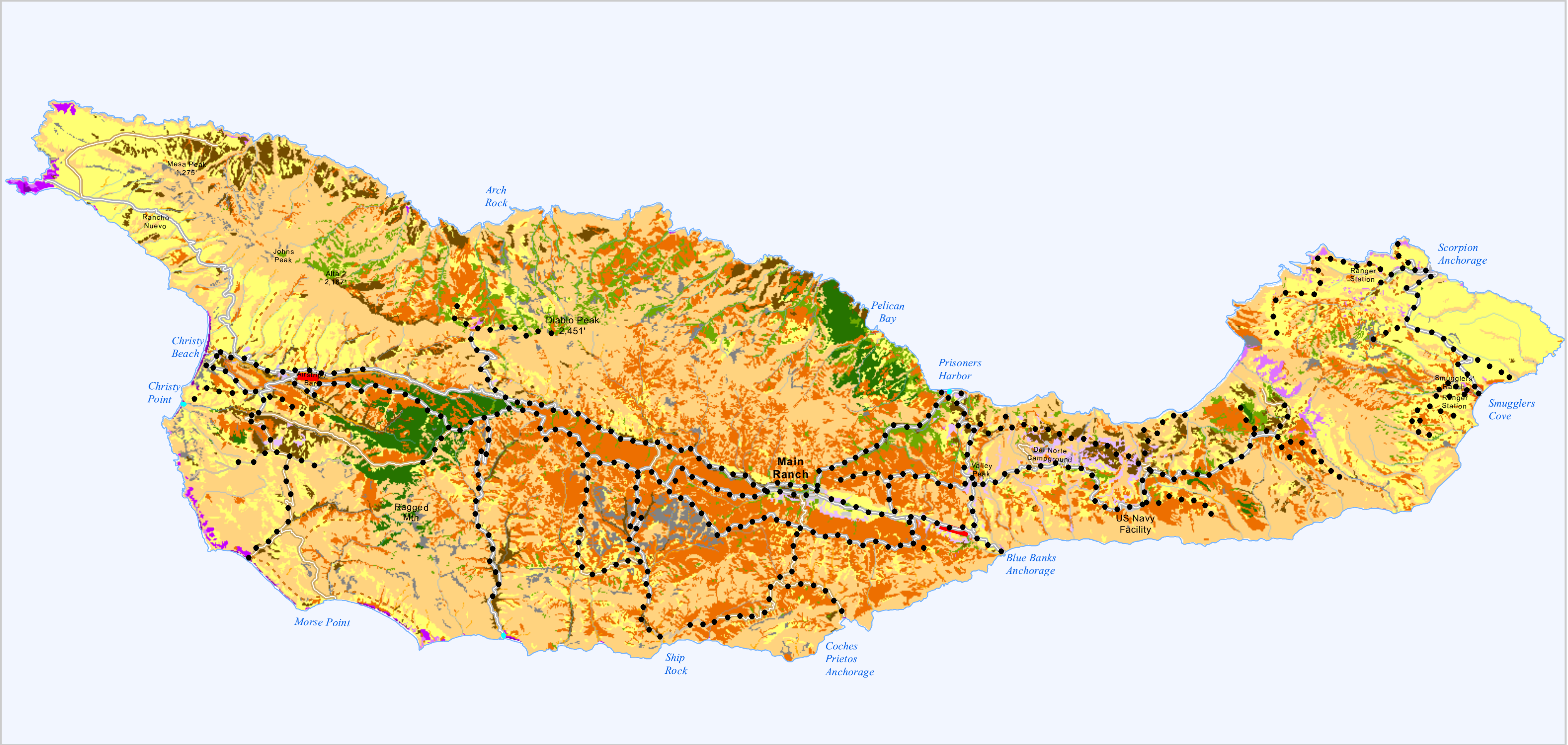


CONSERVATION BIOLOGY INSTITUTE

The Nature Conservancy
SAVING THE LAST GREAT PLACES ON EARTH

Santa Cruz Island

Map 8-2 Existing Traps in Relation to Vegetation



Forest/Woodland: Coniferous
- 🟩 Temperate Needleleaf Evergreen Forests

Forest/Woodland: Non-Coniferous
- 🟩 Xeric Sclerophyll Evergreen Woodlands
- 🟩 Temporarily Flooded Cold Season Deciduous Forests
- 🟩 Temperate Broadleaf Sclerophyll Evergreen Forests

Shrublands
- 🟫 Temperate Microphyllous Evergreen Shrublands
- 🟧 Temperate Broadleaf Sclerophyll Evergreen Shrublands (Chaparral)
- 🟧 Temporarily Flooded Cold Season Deciduous Shrublands
- 🟧 Temperate Xeric Mixed Drought-Deciduous Shrublands

Grasslands
- 🟫 Saturated Temperate Perennial Graminoids
- 🟨 Seasonally or Temporarily Flooded Graminoids
- 🟨 Tall Temperate Annual Graminoids, Non-Fennel
- 🟪 Tall Temperate Perennial Graminoids
- 🟪 Tidally Flooded Grasslands
- 🟪 Tall Temperate Forblands
- 🟪 Tall Temperate Annual Graminoids, Fennel

Other
- ⬜ Developed
- ⬛ Sparsely Vegetated / Barren
- 🟥 Planted

- ● Traps, 2005
- 🟥 Airstrips

Road Type
- ═ Full Size Truck
- ═ Light Truck or Jeep
- ─ ATV only
- - - No Vehicles

N

Vegetation data from The Nature Conservancy, 2007

0 0.5 1 2 3 4 Miles

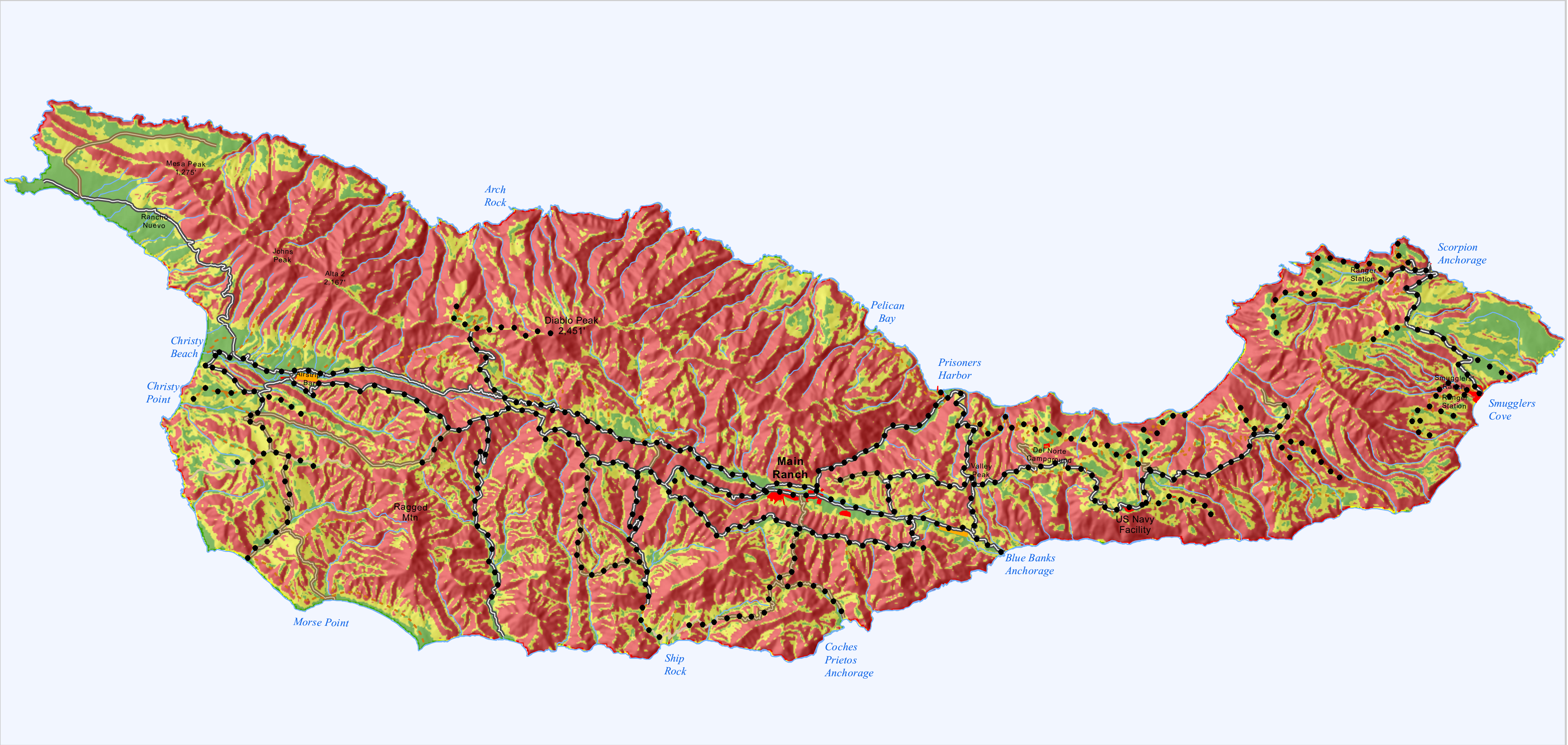
0 0.5 1 2 3 4 Kilometers

CONSERVATION BIOLOGY INSTITUTE

The Nature Conservancy
SAVING THE LAST GREAT PLACES ON EARTH

Santa Cruz Island

Map 8-3 Existing Traps in Relation to Slope



Slope, degrees

🟩	< 9
🟨	9 - 17
🟥	> 17

●	Traps, 2005
▬	Airstrips
🟥	Human Use

Road Type

═	Full Size Truck
═	Light Truck or Jeep
—	ATV only
- - - - -	No Vehicles

N

Slope derived from 30m DEM

0 0.5 1 2 3 4 Miles

0 0.5 1 2 3 4 Kilometers

The Nature Conservancy
SAVING THE LAST GREAT PLACES ON EARTH

CONSERVATION BIOLOGY INSTITUTE

Santa Cruz Island

Map 8-4 Existing Traps in Relation to Ruggedness

Ruggedness

Natural Breaks (Jenks)
Based on the distribution of Ruggedness across all five islands

- 🟩 0.000 - 0.005
- 🟩 0.006 - 0.016
- 🟨 0.017 - 0.031
- 🟧 0.032 - 0.054
- 🟥 0.055 - 0.179

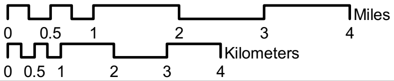
● Traps, 2005
Airstrips
🟥 Human Use

Road Type
Full Size Truck
Light Truck or Jeep
ATV only
No Vehicles

Avenue script created and provided by M. Sappington [National Park Service] and K. Longshore [U.S. Geological Survey]

N

Ruggedness derived from 30m DEM



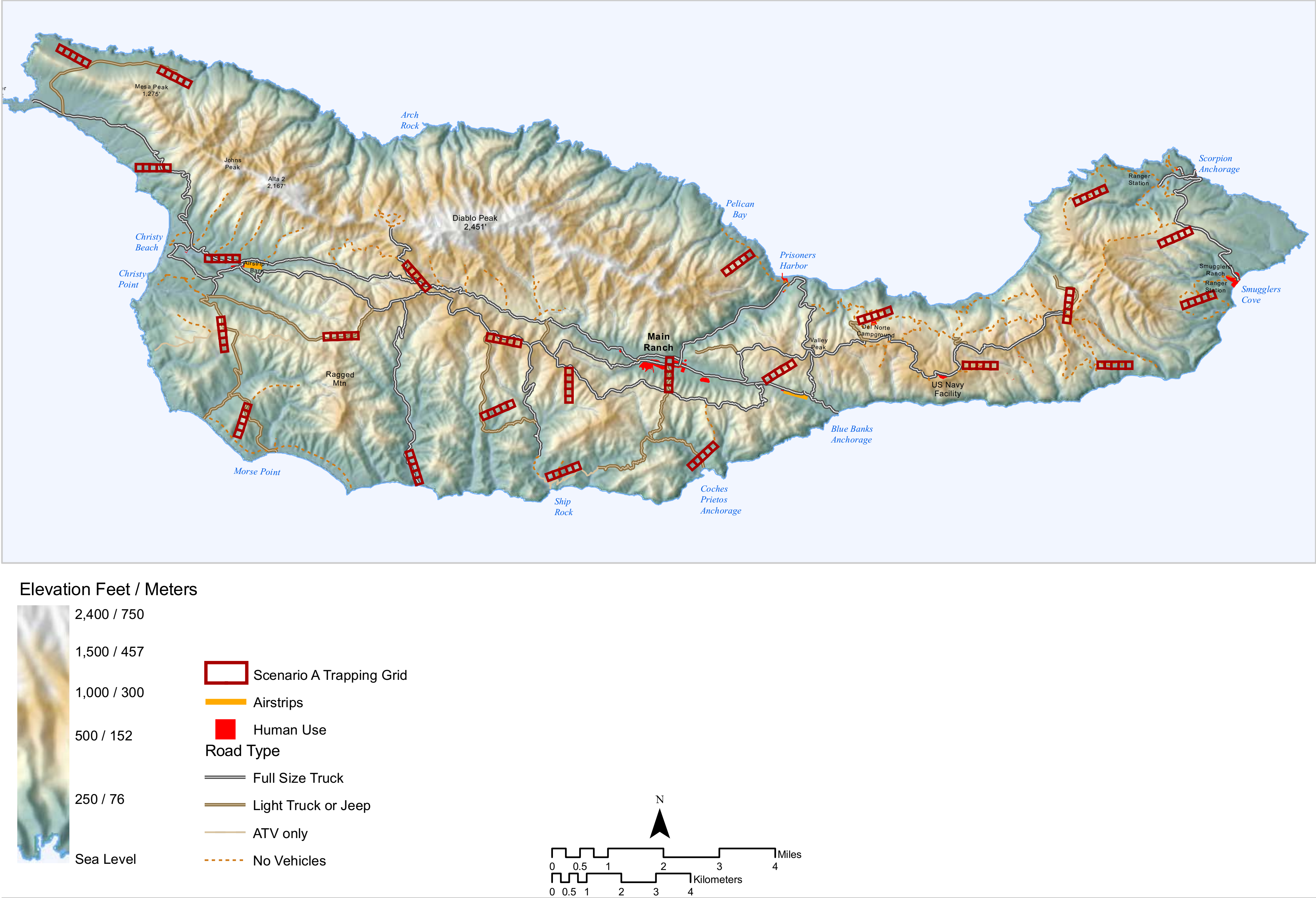
CONSERVATION BIOLOGY INSTITUTE

The Nature Conservancy

SAVING THE LAST GREAT PLACES ON EARTH

Santa Cruz Island

Map 8-5 Trapping Scenario A



The Nature Conservancy
SAVING THE LAST GREAT PLACES ON EARTH

Santa Cruz Island

Map 8-6 Trapping Scenario B