State of California
Natural Resources Agency
Department of Fish and Wildlife
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Santa Cruz Island Fox Recovery Program
May 2013-November 2016

by
Christina Boser

Final Report

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ABSTRACT

In 2004, the Santa Cruz Island Fox (*Urocyon littoralis santacruzae)* was placed on the federal endangered species list after devastating predation rates by non-native golden eagles in the 1990's and early 2000's. The island fox has been listed as threatened by the state of California since 1971. In response to this crisis, island managers, government agencies and research institutions implemented a comprehensive restoration program which helped to save the island fox from extinction. A federal Section 6 grant administered by the California Department of Fish and Wildlife (CDFW) supported island fox conservation on Santa Cruz Island in 2013-2016. Using these funds, The Nature Conservancy (TNC) conducted island-wide census trapping, survival monitoring of a radio-collared sub-sample, and disease management for the purpose of monitoring the recovery of the Santa Cruz Island fox.

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INTRODUCTION

The Santa Cruz Island Fox (*Urocyon littoralis santacruzae*) is endemic to Santa Cruz Island and is one of six subspecies of island foxes that are found only on the California Channel Islands and nowhere else in the world. Historically, fox population estimates were as high as 3,000 on Santa Cruz Island (Laughrin 1973), but by 2001 there were less than 100 individuals remaining in the wild. This catastrophic decline occurred when a small population of non-native golden eagles (*Aquila chrysaetos*) established on Santa Cruz Island in the 1990's. The eagles relied on the food resources provided by a robust population of feral pigs. The eagles also preyed upon the foxes, which had speciated without aerial predators, and thus were naïve to attacks by golden eagles. In less than a decade, a population of just a few dozen eagles was sufficient to drive the endemic island fox to near extinction on three northern Channel Islands.

In March 2004, the federal government listed four of the six subspecies as endangered due to the dramatic declines observed on Santa Cruz, Santa Rosa, San Miguel, and Santa Catalina Islands. The island fox has been listed as threatened by the state of California since 1971. Since that time, a number of steps have been taken to slow the decline and promote survival. On Santa Catalina Island, an extensive vaccination program was initiated to address a disease epidemic that dramatically reduced populations on the eastern part of the island. On Santa Cruz Island, The Nature Conservancy (TNC) initiated an on-island captive breeding program and wild fox monitoring program. In addition, the cause of the decline (predation of foxes by non-native golden eagles) was addressed through an ongoing live capture and translocation program funded by TNC, with previous funding received by the National Park Service (NPS) and the U.S. Fish and Wildlife Service (FWS) across the northern Channel Islands. Feral pigs were removed from Santa Cruz Island to reduce the food resources available to golden eagles. TNC continues to promote fox recovery by improving fox habitat on Santa Cruz Island through a habitat enhancement program, which received funding from California's Wildlife Conservation Board, the State Coastal Conservancy, and the National Fish and Wildlife Foundation.

Santa Cruz Island Fox recovery has been a primary goal for land managers and agencies over the last fifteen years, and in that time considerable progress has been made toward recovery. NPS and TNC translocated 32 adult golden eagles from the islands, with the last breeding pair of golden eagles removed in 2006. TNC has invested over $10 million in the Santa Cruz Island fox captive breeding and recovery program, working cooperatively with NPS but financially supporting the program for the entire island. Due to the significant conservation gains made in the last decade, the Santa Cruz Island fox was federally delisted in August 2016 (USFWS 2015, USFWS 2016). The Santa Cruz Island fox has experienced a significant rise in survival rate (88.5%, SE = 0.047) in 2015 and population size (N = 2150, 80% CI: 1889-2447) in 2016, which is likely near approaching carrying capacity for the island, based on previous pre-decline monitoring estimates.

Despite the increase in fox population over the last decade, the proximity to the mainland and very limited history of exposure to mainland diseases puts Santa Cruz Island foxes at risk of

contracting devastating viruses such as rabies and canine distemper virus. Serology data indicate that Santa Cruz Island foxes have no natural resistance to the five most common canine viruses, including canine distemper virus (CDV). Serology results compared across all six subspecies of foxes indicate that Santa Cruz Island foxes have the lowest natural titer levels for CDV, thus without a vaccination program the subspecies would be virtually unprotected from introduced viruses. The island fox recovery program has and will continue to proactively administer rabies and CDV vaccines, and monitor island fox populations to quickly detect mortalities and implement an epidemic response plan if necessary. These management actions are outlined and required by a Conservation Management Agreement signed by TNC and the Fish and Wildlife Service in 2015.

Recovery Plan Tasks

The draft Island Fox Recovery Plan was published by the FWS in Fall 2012 and the requirements in that draft and the subsequent final plan released in February 2015 dictated a number of monitoring actions to verify the status of the island fox. This section 6 grant was written and conducted to enact those monitoring recommendations. These monitoring actions include annual population censuses and frequent radio-collar monitoring checks, as described in the island fox epidemic response and golden eagle monitoring plan.

The Recovery Plan tasks enacted under this grant were described as follows:

a) Implement prophylactic management to avoid extinction or quasi-extinction of wild populations in the event of devastating epidemics. Population viability assessment (PVA) models suggest that the probability of extinction in the face of a rabies or CDV epidemic could be substantially reduced by maintaining a "vaccinated core" of animals. This approach involves maintaining a small number of animals protected from infection by vaccination. These animals act as a "safety net", intended to survive any epidemics that occur and then to form a founder group from which subsequent recovery may occur.

b) Establish and implement monitoring and response strategies to detect and manage infectious disease threats to island fox population persistence. Routinely collect blood samples from a proportion of island foxes on all islands to evaluate ongoing disease risks to island fox populations.

c) Establish island fox monitoring strategies, including recovery criterion. An island fox population must have no more than 5% risk of quasi-extinction over a 50-year period. This risk level must be based upon the following:

- The risk of extinction must be calculated based on the lower 80% confidence interval for a 3-year average of population size estimates, and the upper 80% confidence interval for a 3-year average of mortality rate estimates.

- This risk level must be sustained for at least 5 years, during which time the population trend is not declining.

- Quasi-extinction is defined as a population size of ≤30 individuals.

Grant Objectives

The grant's objectives addressed requirements for delisting the island fox, as detailed in the draft and final Island Fox Recovery Plan. These requirements include: 1) documenting an increasing island fox population by collecting data on survival rates, population trends, and mortality causes; 2) reducing fox mortality by directly managing the primary threat to island foxes, disease; and 3) completing management research by utilizing island-wide datasets, advanced technology, and statistics to anticipate future management needs.

METHODS

Survival Monitoring

In order to monitor the island fox population, gain information on survival rates and detect prominent causes of death, TNC maintained at least 40 collared individuals with active radio-collars year-round. Individuals were collared randomly so as to be statistically representative of the island population to gain the best estimate of island-wide survival and cause of death data. We used captures at grids (already designed to measure the island population size with accuracy) to provide the sample of collared individuals proportionally-distributed across the island. All collars weighed 39.5 grams and had 18-27 month battery life transmitters (167.000 – 169.999 MHz) with mortality switches triggered after 12 hours of no movement (Holohil®, MI-2M).

Aerial survival monitoring of all collared foxes was conducted by TNC and a contractor 1-2 times weekly. When a mortality signal was detected, TNC triangulated the location of the carcass and collected it.

Population Trends

Indices of population abundance and distribution are required to adaptively-manage an ecologically viable population of island foxes. In 2013-2014, TNC implemented an 18-grid trapping design (based on Scenario B, Figure 3 in Rubin et al. 2007) and in 2015-2016 implemented a 12-grid trapping design. Trapping grids were in a "ladder" configuration of 2 x 6 traps, each spaced 200 m apart. Their locations were predetermined by a geographic information system (GIS) analysis, described in detail in Rubin et al. (2007). The grid pattern and placement was designed to provide a statistically robust estimate of island fox density (to be calculated in Program Density and Program R; Efford 2004). The reduction in the number of the grids was undertaken in 2015 due to the increasing fox population, which allowed us to reduce our trapping effort while still maintaining precise density estimates.

Grid trapping generally began on June 30 and was completed by October 30 each year. These dates were selected because pups are out of dens by July and are weaned, but are unlikely to disperse from natal territories prior to October. Trapping during the summer months increases the accuracy of the census by reducing the likelihood of foxes dispersing between grids. Grids were baited with dry cat food and loganberry paste lure and were set open for six consecutive nights. Traps were checked every morning between sunrise and six hours after sunrise. All trapping activities followed the Terms and Conditions outlined in TNC's state and federal permits for island foxes and island spotted skunks.

Island Fox Handling

Foxes captured during grid trapping were scanned to determine if they had been tagged in a previous year. The capture status (new, previously tagged, or recaptured during a grid) was recorded for every capture. Those individuals not previously tagged were tagged beneath the scruff of the neck using a single-use passive integrated transponder (PIT) syringe (Biomark® TX1440). New and previously-tagged foxes were weighed and aged (via tooth wear), and parasite load, body condition, and reproductive condition were assessed. Staff treated minor injuries with first aid, if needed. Some individuals were radio collared, vaccinated against rabies and canine distemper viruses, and had a blood sample collected. Fox handling methods were consistent for grid and roadside captures.

Disease Risk Management

Vaccination of at least 80 foxes against rabies and canine distemper viruses within the core areas (central valley and isthmus) was recommended by the veterinary group associated with island fox recovery efforts. Enacting this requirement required a focused trapping effort and thus we conducted roadside trapping along with grid trapping to maximize captures. Traps were placed from 250 to 350 meters apart in vegetation that shield traps from the sun and wind. All trap site coordinates were recorded using a global positioning system (GPS) unit, entered in the trap locations spreadsheet, and flagged. Vaccination was also conducted opportunistically during grid trapping.

We vaccinated most adult foxes captured within the core areas to increase the concentration of protected animals within those cores. Pups captured within the core areas were not vaccinated until mid-July, as per recommendations made by TAG. The canine distemper vaccine (Merial's Purevax® Ferret Distemper) was administered to foxes by intramuscular injection in the left hip. The rabies vaccine (Merial's Imrab 3®) was administered with a subcutaneous injection in the right hip. Foxes were vaccinated against both viruses and were held for five minutes following the injections to monitor for any adverse reactions to the vaccine.

The collection of biological samples that can be used for disease research allows TNC to monitor for a variety of diseases and further protect foxes from the risk of introduced diseases. We prioritized our blood sample collection from individuals that have never been previously vaccinated.

On average, we collected 5cc of blood from selected individuals, which provided at least two 1-ml serum samples and one vial holding a red blood cell (RBC) clot. We used 20- and 22-gauge 1.5" needles on 10 ml syringes to collect samples from the jugular vein or artery from foxes wearing muzzles that doubled as blindfolds. Samples were stored in a cooler with ice packs while in the field and then refrigerated. On the same day as collection, we processed samples using a centrifuge to separate serum from red blood cells. We used plastic pipettes to transfer each serum or RBC sample into micro vials. Samples were labeled with animal id, collection date, and sample type and frozen.

Data Analysis

Population and survival data was analyzed by Dr. Victoria Bakker and researchers at Colorado State University. Dr. Bakker also used the recent data to improve island fox population and demographic modeling (via PVA) using the long-term dataset collected during our annual monitoring efforts. These tools help us to better understand fox extinction risk, survival rates, and tolerance of predation pressure.

STUDY SITE

Santa Cruz Island, one of eight California Channel Islands, is located 30 km off the coast of California and lies within Santa Barbara County. The island is co-owned by TNC, which owns 76% of the island and NPS, which owns the remaining eastern portion. The 249 km^2 island is the largest of the Northern Channel Islands (Figure 1). It is approximately 34 km long east to west and 3 to 11 km wide from north to south (Schoenherr et al. 1999). The topography is dominated by an east to west running central valley with mountains on each side reaching a maximum elevation of 750 m (Laughrin 1973, Van Vuren and Coblentz 1987).

Island vegetation is made up of several general types of communities (chaparral, coastal sage scrub, grassland, and oak woodland) but can also be classified into much more detailed habitat categories (AIS 2007). The study area for this project included the entire island without regard to the NPS/TNC property line that crosses the island's isthmus (Figure 2). The diverse island habitat supports 480 native plant species, eight species of reptiles and amphibians, and four land mammals. The Santa Cruz Island harvest mouse (*Reithrodontomys megalotis santacruzae*) and the Santa Cruz Island deer mouse (*Peromyscus maniculatus santacruzae*) are prey of island foxes and possibly the island skunk (*Spilogale gracilis amphiala*). The island skunk is a state species of special concern, and is likely that both endemic species compete for resources with the skunk being the less able competitor. The foxes and skunks also consume a variety of native plants and insects year round (Cypher 2009).
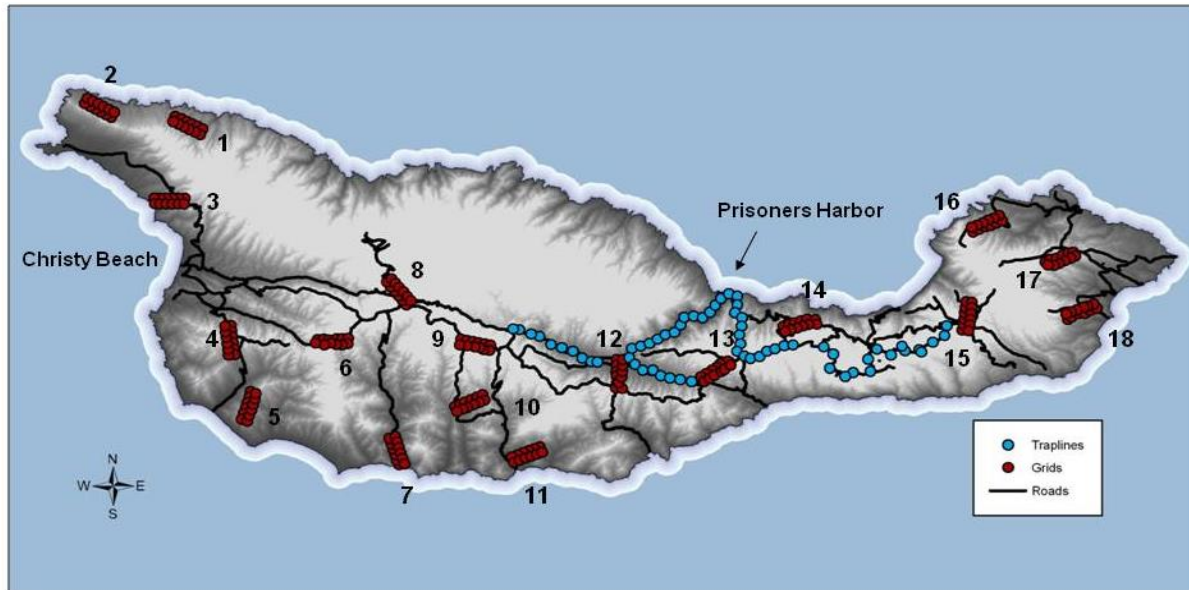
Figure 1. Santa Cruz Island, CA. Legend indicates fox trapping grid layout 2013-2014.

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Figure 2. A map of the twelve trapping grids run in 2015-2016 on Santa Cruz Island, CA.

RESULTS

Interagency Collaboration

For the duration of this grant, TNC maintained close collaboration with research institutions including the UC Davis Wildlife Health Center, California State University-Stanislaus Endangered Species Recovery Program, St. Louis Zoological Society, and CSU. We have shared our management results and analysis techniques with these land managers, FWS, and CDFW in an annual paper we distribute at the Island Fox meetings in Ventura, CA. C. Boser also collaborated on a paper with other island land managers regarding the population status of three island fox subspecies. This paper was published in 2012 in the 8th California Islands Symposium Proceedings (Coonan et al. 2012). In 2010 and in 2015, we entered into cooperative agreements with CSU.

Survival Monitoring

Between May 2013 and October 2016, we monitored foxes 194 times from the air and on average, located 94% of the foxes with functioning radio-collars. We located 22 collared fox mortalities. Only one of these was killed by a golden eagle. This occurred in February of 2016 when an adult golden eagle was known to be located around the Fraser Point eagle nest for a period of nearly 4 months. This is good evidence that the fox population can sustain a very low level of periodic golden eagle predation without population-level impacts. Cause of death was not always able to be determined by staff at UC Davis necropsying the carcasses (Table 1). Fox survival rates were calculated annually between May 1 and April 30 of a given year using radio monitoring data (Table 2).

Table 1. Collared fox mortalities on Santa Cruz Island, CA May 2013-October 2016.

Fox ID	Cause of death	UTM E	UTM N	Date	Location Description
M434	Unknown	263697	3766819	6/18/2013	Yellowbanks
F529	Complications due to cactus fruit ingestion	245734	3761628	8/1/2013	Justiano
M489	Unknown	260493	3766591	8/1/2013	Loma Peloma
M732	Unknown	235828	3766075	11/25/2013	Pozo
F124	Unknown	252220	3765894	1/19/2014	Valley Peak
M178	Unknown	235828	3763930	1/28/2014	Pozo
F552	Unknown	264380	3766914	3/16/2014	Yellowbanks
F206	Unknown	243509	3761480	4/8/2014	Alamos
M232	Unknown	237972	3762146	7/23/2014	Fraser
M746	No carcass found	263935	3768511	8/7/2014	Montonon
M642	Unknown	263569	3768955	8/7/2014	Montonon

M409	Unknown	230938	3773122	3/14/2015	Fraser
F70	Old age	241691	3762499	3/29/2015	Laguna
F295	Unknown	244479	3765401	7/11/2015	Horquetta
M835	Eagle	237930	3762340	2/15/2016	Fraser
M826	Unknown	243946	3766125	3/7/2016	Ridge road
M692	Unknown	248777	3765140	3/7/2016	Field station
M829	Unknown	251249	3764747	3/18/2016	Valley peak
M846	Unknown	248757	3762277	3/31/2016	Portezuelo
M627	Foot stuck through collar	248757	3765004	4/8/2016	Main ranch
F211	Broken neck	236188	3765669	4/13/2016	Pozo
F213	Old age	254270	3766334	9/19/2016	Del Norte

Table 2. Annual fox survival rate from 2013-2016.

Monitoring Period	Survival Rate	Standard error
May 2013-April 2014	91.35%	0.002
May 2014-April 2015	88.90%	0.05
May 2015-April 2016	88.50%	0.047

Population trends

Fox capture success per grid generally increased between 2013-2016 (Table 3). Young-of-the-year capture success averaged approximately 20% of total trap population over the three trapping years. Total number of individual skunks incidentally-captured ranged from 37 in 2013, to 23 in 2014, 8 in 2015, and 14 in 2016.

Table 3. Number of individual foxes captured on trapping grids. Note that in 2015 and 2016 we ran only 12 grids while in 2013-14 we ran 18 trapping grids.

Year	Pups	Nonpups	Total	Percent pups
2013	61	154	215	28
2014	25	217	242	10
2015*	41	100	141	29
2016*	20	173	193	10

Disease risk management

A total of 150 foxes were vaccinated for rabies and CDV in 2013-2016, with the exception of 2015 when only 87 foxes were vaccinated. This reduced number of vaccinations was the result of poor trapping success during roadside trapping. Previous research has indicated that a CDV outbreak could be the most severe threat to the island fox population. Our trapping and vaccine strategy already maximizes opportunities to booster foxes, but an increasing fox population

makes it more difficult to recapture the same foxes for an annual booster, without increasing the number of vaccines given. With a dedicated trapping effort, many previously-vaccinated animals received boosters. Most vaccinated animals were captured within the core vaccination areas of the central valley isthmus.

We collected blood samples from individuals during grid and roadside trapping to test for disease titers. In 2013, we collected blood samples from 79 foxes, in 2014, we collected blood samples from 41 foxes, in 2015, we collected blood samples from 41 foxes, and in 2016, we collected blood samples from 48 foxes. At least 1 mL of serum was collected from each of these individuals. We prioritized foxes for blood sample collection based on TAG recommendations, thus the majority of the samples were collected from foxes not previously-vaccinated. Since most roadside traps were located within the core vaccination areas (where there are a greater proportion of previously-vaccinated foxes), we collected more samples from grids located outside of the core vaccination areas. Results of blood tests reviewed by Cornel Veterinary labs indicate that of the 20 samples sent in from 2015, none had protective titers for any of the virus tested, (canine adenovirus, canine coronavirus, canine distemper virus, canine herpesvirus, and canine parvovirus). These results mirror the results of the samples sent in 2010.

Data analysis

During the grant period, peer-reviewed population and demographic publications have been advanced by our radio-collaring effort, the island-wide population census, and the marking of captured individuals with PIT tags. These efforts have allowed us to mark the recovery of the island fox on the quasi extinction graph and provide evidence that the population is recovered and could be de-listed (Figure 3). V. Bakker used the demographic data collected in 2013-2016 to update the PVA for the island fox. It was important to update the PVA with recent data, given the increases in the island fox populations. The older PVA was modeled using data on much smaller island fox populations and thus, was no longer relevant to current population demographics.

Additionally, statistical research into island fox and island spotted skunk population trends on Santa Cruz and the neighboring Santa Rosa Island was conducted by Adam Dillon, PhD candidate at Colorado State University, under the supervision of Dr. Kevin Crooks (Department of Fish, Wildlife, and Conservation Biology).

They used the trapping data, described above to populate their statistical models. Spatially explicit capture-recapture statistics and Program SECR (Efford 2015) were used to estimate annual adult fox density. SECR models animal captures as a joint function of three parameters; density (D), detection ($g0$), and movement (σ). They considered models in which D, $g0$, and σ remained constant or varied across years, sex, and behavior (trap happy/shy). Model selection was performed using information theoretic methods based on AICc (Burnham and Anderson 2002). An insufficient number of skunks were recaptured to allow for calculating a density

estimate; therefore, a cumulative number of skunks captured across all mini-grids was reported annually.

Preliminary results indicate that the most parsimonious SECR model for adult fox captures was density as a function of year, detection as an additive function of year, sex and behavior, and movement as an additive function of year and behavior. The estimated density of adult foxes varied from 1.99 foxes/km^2 in 2008 to 5.75 foxes/km^2 in 2014, which when multiplied by the 250 km^2 of Santa Cruz Island results in a recovering island-wide population of adult foxes from 497 in 2008 to 1,437 in 2014. Across all 18 mini-grids, the annual number of island spotted skunks captured declined from 142 in 2008 to 24 in 2014.

These results to date indicate that the adult island fox population on Santa Cruz Island, following the removal of golden eagles and non-native vertebrates, has increased from 2008 to 2014. In that same time period the number of island spotted skunks captured has declined by > 80%, possibly from increased competition from the recovering island fox.

Analyses are ongoing, with expected completion of resulting scientific manuscripts in 2017. Ongoing work includes: 1) refinement of annual island-wide population trend estimates for island foxes and island spotted skunks on Santa Cruz and Santa Rosa Islands from 2008-2014 using spatially explicit capture-recapture statistics, incorporating covariates such as habitat type, annual precipitation, and interspecific competition intensity; 2) development of habitat suitability models for the island fox on Santa Cruz and Santa Rosa Island, resulting in spatial models of fox density by habitat types on both islands; and 3) evaluation of density-dependent regulation in island fox populations, evaluating survival and reproductive rates as a function of fox density over time.
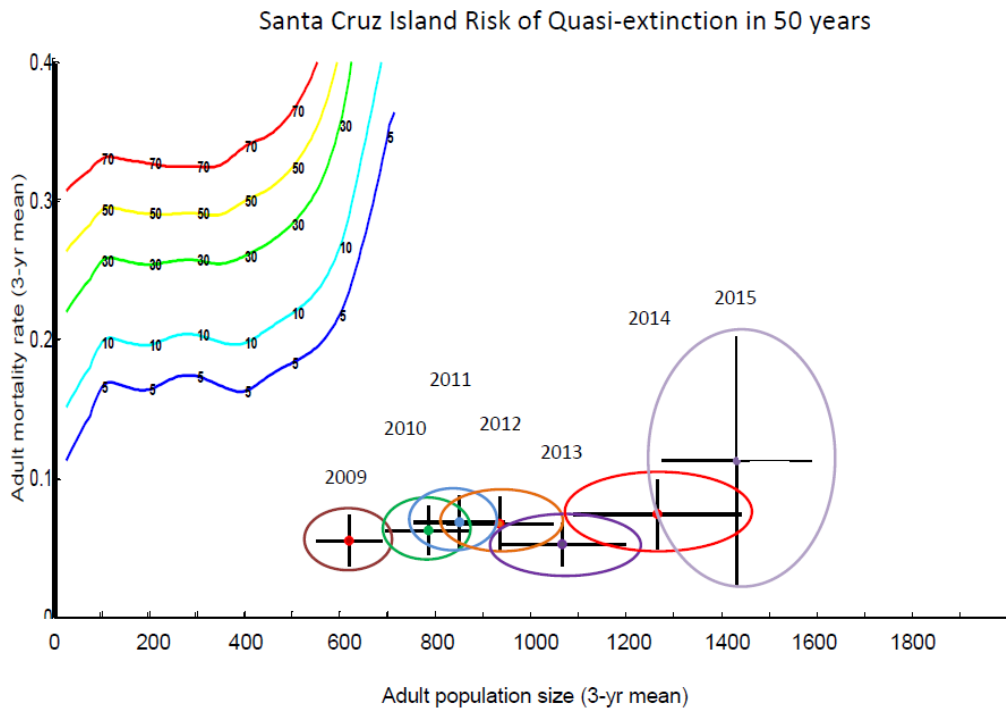
Figure 3. Recovery status of island foxes on Santa Cruz Island, 2009 – 2015. The figure depicts the risk of quasi-extinction in 50 years. Datapoints are 3-year averages of each labeled year and the 2 preceding years with 80% joint confidence ellipses. The 2009 datapoint includes the 2007 population size estimate from transect data, not the current ladder grid data (Bakker 2012).

DISCUSSION

Critical to island fox recovery on Santa Cruz Island is a robust monitoring program that can quickly detect emerging threats. Although the threat of golden eagle predation has largely been mitigated, the threat of disease introduction still remains. The fox program is currently structured to detect and manage a disease threat should it emerge. Additionally, further research into island fox behavior and management techniques is currently in progress at CSU. PhD student Adam Dillon expects to finish his dissertation on island fox and skunk interaction and population drivers in June 2017 and this research will enhance our understanding of the fox as a keystone island species.

Mark-recapture data was used to choose the best population models that explained the relative influences of factors such as habitat and interspecific interactions on population density (V. Bakker). These models indicate that the fox population on Santa Cruz Island increased at a steady rate of approximately $\lambda = 1.1$ from 2008 to 2015. Capture data from 2009 to 2015 detected a dynamic between skunk and fox densities such that skunk and fox captures were inversely related. Average skunk capture success on trapping grids was lower than average fox

capture success in all years, and is decreasing. Skunk trapping success has declined from a high in 2005 and is now similar to the low success that reported in the late 1960's and early 1970's and 1990's, prior to the fox extinction crisis (0.5%; Laughlin 1973, personal communication K. Crooks 2011).

We accomplished four trapping sessions during the course of the grant (2013-2016) and the results of these sessions were presented in the preceding section. These sessions and the subsequent radio monitoring data collected on a weekly basis allowed us to analyze and present the survival rates, population trends, and mortality data described in the Results Section above. Although no collared foxes on Santa Cruz Island died of diseases, disease risk management remains a high priority because modeling research and data on island fox titers show that island foxes are very susceptible to mainland diseases such as CDV.

This fox recovery project, created by a collaborative effort among TNC, university researchers, and agencies such as FWS and CDFW, may be used as a model endangered species recovery strategy. The program is structured as a long-term recovery project, which addresses critical data requirements meant to guide management actions and addresses emerging threats, while remaining functionally efficient and scalable as the conservation needs of the islands' endemic species change.

Recommendations

We highly-recommend continuing the population censuses and survival monitoring strategies that were enacted as part of this Section 6 grant. The quality of data collected from the trapping grids provides us with accurate estimates, which are extremely important in guiding management decisions. Grid trapping is an excellent means of collecting mark-recapture data while simultaneously radio-collaring, vaccinating, and collecting biological samples from foxes (Rubin et al. 2008). The work conduced in 2015-2016 shows that we can reduce the effort of trapping but still achieve useful population estimates that allow us to keep a pulse on the population. Additionally, given the decreasing number of the non-target species (island spotted skunks) captured in traps, which we observed during the course of the grant, more effort should be spent to study the spotted skunks and determine if the observed decline through their entire range (both Santa Cruz and Santa Rosa) should be managed for the population viability of the species.

Assessing the effects of climate change on endangered species is of paramount concern and importance to island managers. It is critical that baseline data on island fox activity patterns and space-use are collected now, when we are just beginning to experience the effects of climate change. We recommend in future years we collect data on island fox and island skunk movements using GPS collars. These GPS data can be interfaced with weather stations, climate change models, and our updated 2015 vegetation map to predict alternations in space-use with changes in vegetation structure, precipitation, and temperature. These models will assist managers in anticipating the effects of climate change on island fox carrying capacity and distribution. As distribution is limited to the island, the species' range cannot shift with changes

in climate (as has been recorded in other species). Thus, land managers may be required to increase management of the island fox during those extreme weather events that might catastrophically limit critical resources. GPS collars would provide analysts with the data necessary to anticipate extreme reactions to climate change so that they may suggest options for mitigation, especially in light of apparent competition between the two species.

We must also continue to increase the resiliency of the ecosystems of Santa Cruz Island by restoring the native plants and removing habitat-modifying weeds. TNC is committed to improving the habitat for island foxes by managing a strong and innovative weed removal program. We have received funding from the Wildlife Conservation Board, as well as from private donors to eradicate 30 weeds species from Santa Cruz Island. We are committed to restoring native island vegetation, which will strengthen our island ecosystems against the uncertainties of climate change.

We suggest that TNC, CDFW, and FWS implement the following recommendations to achieve successful island fox recovery and threat management:

- Continue the comprehensive management program of interagency collaboration, island-wide trapping, island fox radio monitoring, golden eagle threat response, island fox vaccination, and island fox biological sample collection. This program allows TNC to adaptively-manage island fox recovery, quickly respond to emerging threats, and reduce the likelihood of a second extinction crisis on Santa Cruz Island.
- Continue the proactive prophylactic program by vaccinating 150 foxes each year for the next five years. The introduction of a virulent mainland disease will always be possible as visitation to the Channel Islands increases.
- Purchase and deploy GPS collars to track fox and skunk movements, resource use, and competition.
- Analyze GPS data in conjunction with climate change models to re-calibrate the island fox PVA, assess the impact of climate change on island fox recovery, and dictate management actions for the next 10-50 years.
- Increase the resiliency of island ecosystems and improve habitat for the island fox by searching out and removing habitat-modifying weeds that are unintentionally introduced to Santa Cruz Island.
- Strengthen our research collaborative by continuing to support graduate students interested in conducting management research on island foxes and island spotted skunks.

ACKNOWLEDGEMENTS

Thanks to Vickie Bakker who has played an integral role in the Island Fox Recovery team by producing comprehensive publications, such as the PVA, and continues to provide excellent statistical advice, analyses, and leadership.

Our partners at the National Park Service remain crucial collaborators in the island fox recovery effort, as in every other conservation project on Santa Cruz Island. Much thanks to Kate Faulkner, Tim Coonan, and Angela Guglielmino.

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