



Island Fox Recovery Program

Channel Islands National Park Population Trends (2006–2016) and Recovery Report

Natural Resource Report NPS/MEDN/NRR—2022/2372



ON THE COVER

Female island fox 86401, San Miguel Island, 1994

Photo credit: NPS

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Natural Resource Report NPS/MEDN/NRR—2022/2372

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Executive Summary

In 2016, the National Park Service (NPS) continued to implement recovery actions for endangered island fox subspecies on San Miguel Island (*Urocyon littoralis littoralis*), Santa Rosa Island (*U. l. santarosae*), and (in partnership with The Nature Conservancy) Santa Cruz Island (*U. l. santacruzae*). The NPS is the lead for monitoring island foxes on San Miguel and Santa Rosa Islands, which are the focus of this report. Annual monitoring indicates that both populations have generally increased over time yet both populations decreased in 2016.

The three subspecies were the object of intense recovery actions from 1999–2008; primary actions included relocation of predatory golden eagles (*Aquila chrysaetos*), captive breeding, and reintroduction of island foxes. From 1999–2006, 44 golden eagles were trapped on the islands and relocated to northern California, with a resultant increase in island fox survival. A 10-year program of captive breeding and release of all three island fox subspecies was completed in 2008. During that period, in which captive breeding was conducted separately on each island, 225 pups were born in captivity, and 254 foxes were released to the wild. Excellent reproduction in the wild, exceeding the per capita reproduction in captivity, was the primary reason to cease captive breeding. Also, predation by golden eagles had been almost completely mitigated during the 10-year time period, and wild island fox survival rose to 80–90% on all islands.

The NPS island fox program is currently in an intensive monitoring phase designed to ensure that recovery continues, and to document attainment of criteria allowing delisting of the two subspecies from the U.S. Endangered Species Act. Island fox population status is monitored via estimation of island-wide fox abundance using capture-recapture statistics from island-wide grid trapping and estimation of fox mortality using radio-telemetry.

Excellent survival and reproduction in the wild have previously permitted rapid growth of the small, recovering populations, however by the end of the 2016 “fox year” (5/1/2016–4/30/2017) the San Miguel island fox population declined to an estimated 267 adults and 24 pups, resulting in 291 total foxes (Figure 1). The San Miguel subspecies returned to pre-decline population levels in 2011 and may have reached or surpassed carrying capacity. In the 2016 “fox year” (5/1/2016–4/30/2017) the Santa Rosa population estimate was 1025 adults and 598 pups, resulting in 1623 total foxes. Although there was no formal population monitoring on Santa Rosa Island prior to bringing all island foxes into captivity in 2000, if pre-decline densities on Santa Rosa were similar to those on Santa Cruz then the current population on Santa Rosa has reached or possibly exceeded pre-decline numbers. When compared, the adult fox density on San Miguel (7.71 foxes/km²) is over 1.5 times that of Santa Rosa (4.76 foxes/km²).

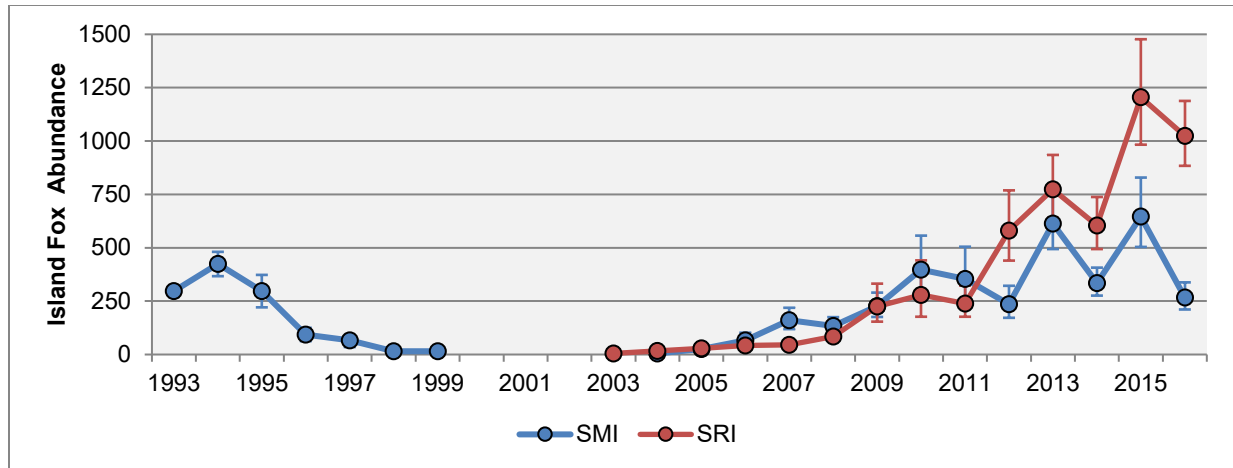


Figure 1. Adult island fox abundance with 80% confidence intervals on San Miguel (SMI) (1993–2016) and Santa Rosa Islands (SRI) (2003–2016). Note: abundance estimates were taken from previous reports (1993–1999), determined via minimum number known alive (2004, 2005) and program secr (2006–2016).

Adult fox survival on San Miguel was 59.1% during the 2016 “fox year”, which represents the 5th straight year of declining adult survival on San Miguel Island (Figure 2). This decrease in survival could be caused by density-dependent effects, continued drought, and the continued prevalence of a novel acanthocephalan parasite. Twenty-one radio-collared foxes died on San Miguel during the 2016 “fox year”. Seven of the 8 foxes that could be necropsied had evidence of infestation by parasites, including acanthocephalas (*Prosthenorchis spp.*) and *Spirocerca spp.*, along with emaciation. No foxes showed signs of eagle predation. Annual adult fox survival on Santa Rosa was 89.2% during the 2016 “fox year”. Six radio-collared foxes died, and one of the two foxes necropsied was infected with *Leptospira*.

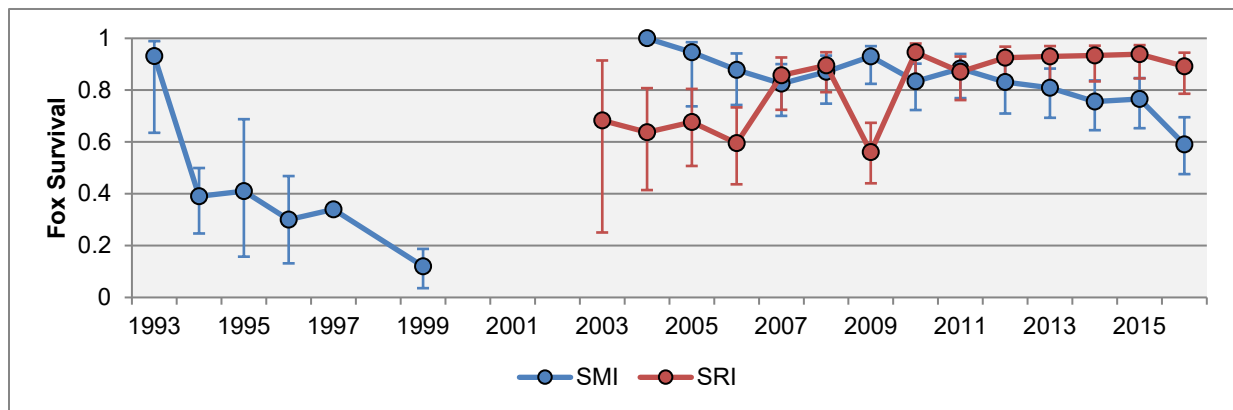


Figure 2. Adult island fox survival with 80% confidence intervals on San Miguel (SMI) (1993–2016) and Santa Rosa Islands (SRI) (2003–2016). Note: survival was taken from previous reports (1993–1999) and determined for the “fox year” (2003–2016).

In 2016, approximately 54% of trapped foxes were vaccinated against rabies, 61% on San Miguel and 52% on Santa Rosa Island. The number of individual foxes vaccinated against rabies was 57 on San Miguel and 148 on Santa Rosa. Approximately 46% of trapped foxes were vaccinated against canine distemper virus (CDV) in 2016, 61% on San Miguel and 42% on Santa Rosa Island. The number of individual foxes vaccinated against canine distemper was 57 on San Miguel and 118 on Santa Rosa.

For the fourth straight year, reproduction was extremely low on San Miguel, where only five pups were caught on the monitoring grids (32 were caught in 2012). A total of 77 pups were caught on Santa Rosa monitoring grids in 2016, up from 69 in 2015. Data on fox weights and body condition reflect the effect of the current drought and high fox densities in the recent past on San Miguel. Adult weights on San Miguel in 2016 declined for the fourth straight year and were the lowest recorded since we began tracking fox weights in 2007. This is not the case on Santa Rosa Island, where fox weights decreased slightly in 2016 but overall have increased in recent years. The highest proportion of foxes on both San Miguel and Santa Rosa islands were in the “thin” body condition category.

The higher mortality, lower reproductive effort, and lower weights are perhaps to be expected as the San Miguel population adjusts to the resource limits of carrying capacity. Plus, food resources are likely lower due to the prolonged drought in southern California. Deer mouse (*Peromyscus maniculatus*) populations on San Miguel have remained low since early 2012 (Coonan 2016). The continued occurrence of the acanthocephalan parasite is also worrisome. At this point, the full impact of the parasite on the fox population is unknown, because post-mortality tissue breakdown has often prevented pathologists from determining effects on individual foxes. We are awaiting identification of the likely intermediate host for the parasite. That information, in turn, will allow the Fox Health Group of the Island Fox Conservation Working Group to formulate a plan for further investigation, and possible intervention, if warranted.

During annual fox trapping island spotted skunks are also captured and this data was used to evaluate skunk demographics, density, and island-wide abundance. In 2016, the average weight of captured skunks was 589 grams (female = 456 g, male = 685 g). Less males were captured than the previous year, which accounted for the decrease in average weight (2015: skunk = 614, female = 445, male = 692) and the increase in the sex ratio (female/male) to 0.92 (2015 = 0.46). This is the highest skunk sex ratio since the fox monitoring program began.

Unlike in previous years, we were not able to estimate island spotted skunk density or abundance on Santa Rosa Island using the 28-model set in program *secr*. The number of skunk captures and recaptures has decreased over time and we were only able to run the constant model to estimate skunk density, resulting in a density of 6.31 skunks/km² and an island-wide abundance of 1374. This is an increase from 2015 but this estimate is not as precise as past years and the number of individual skunks captured was less than in 2015. After reaching high densities during the fox decline, the number of skunk captures and recaptures has dramatically decreased in recent years and the ability of the island fox monitoring protocol to accurately estimate island skunk density

both currently and in the future is questionable, especially as the island fox populations continue to increase.

Acknowledgments

We would like to thank our dedicated island fox crew for gathering the data for this report. Because of their efforts there is excellent information on the status and trend of island fox populations in the Channel Islands National Park (CHIS). Island fox staff in 2016 comprised of Angela Guglielmino, Stacy Baker, Juliann Schamel, Desirae Thomaier, Jackson Vanfleet Brown, Robyn Shea, Andy Abate, and volunteers Melissa Marshall and Ellie Bolas. We would like to thank Tim Coonan for his years of hard work and dedication to island fox recovery and conservation. His guidance and involvement in island fox recovery has been pivotal in the success of the program. The Santa Barbara Zoo continues to support the program by generously offering their staff for volunteer work on the islands. Zoo personnel who volunteered in the fox program for us included Cressa Nursement and Kelly Garner. Thanks to Rich Block and Sheri Horiszny for making this collaboration possible.

CHIS continues to work closely with The Nature Conservancy, on Santa Cruz Island, who serves as a close partner, particularly Christie Boser of their staff. Many thanks to Dave Dewey for conducting aerial radio telemetry of collared foxes.

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Transportation to the islands was smoothly coordinated by NPS dispatcher Renee Denley, and boat transportation was conducted by, Keith Duran, Diane Brooks, and Ed Smith. Rangers Ian Williams and Lulis Cuevas provided on-island support for fox monitoring and management.

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Introduction

Background

The island fox (*Urocyon littoralis*) is a diminutive relative of the gray fox (*U. cinereoargenteus*) that is endemic to the California Channel Islands. The fox is recognized as a distinct subspecies on each of the 6 largest islands where it exists, a distinction upheld by morphological and genetic work (Wayne et al. 1991; Collins 1993). In 2004, the U.S. Fish and Wildlife Service (USFWS) listed four island fox subspecies as endangered, including the three subspecies in CHIS (San Miguel Island fox [*U. littoralis littoralis*], Santa Rosa Island fox [*U. l. santarosae*], and Santa Cruz Island fox [*U. l. santacruzae*]), as well as the subspecies on Santa Catalina Island (*U. l. catalinae*) (USFWS 2004). In the mid- to late-1990s the three NPS subspecies declined severely due to high levels of predation by golden eagles (*Aquila chrysaetos*), whereas the Santa Catalina subspecies declined due to canine distemper virus (CDV; Timm et al. 2009, Coonan et al. 2010).

Dramatic fox population declines on San Miguel and Santa Cruz Islands were detected during the 1990s (Coonan et al. 2010). The fox population on San Miguel declined from an estimated 450 adults in 1994, to 15 in 1999 and the population on Santa Rosa declined from as many as 1,500 in 1994 to 15 animals in 2000 (Roemer et al. 1994; Coonan and Rutz 2001; Coonan et al. 2005b). The Santa Cruz population declined from as many as 2,000 in 1994, to 50–60 in 2000 (Coonan et al. 2010). Prior to implementation of island fox recovery efforts, Roemer (1999) estimated the time to island fox extinction at five years on San Miguel and 12 years for island foxes on Santa Cruz.

Radio telemetry studies revealed that predation by golden eagles was the primary mortality factor for island foxes on the northern Channel Islands and the cause of the massive decline of the three northern subspecies (Roemer et al. 2001). Golden eagle predation was identified as the cause of death for 19 of 21 radio-collared island foxes on Santa Cruz Island from 1993 to 1995 (Roemer et al. 2001). On San Miguel Island in 1998–1999, four of eight radio-collared island foxes were killed by golden eagles in a 4-month period (Coonan et al. 2005b).

Prior to the 1990s, golden eagles had never been recorded breeding on the Channel Islands, but their recent colonization of the islands was due to a new prey base that was not historically present, feral pigs (*Sus scrofa*) and mule deer (*Odocoileus hemionus*) (Latta et al. 2005; Collins and Latta 2006). The absence of bald eagles (*Haliaeetus leucocephalus*), which historically bred on the islands, may have allowed golden eagle colonization (Roemer et al. 2001). Island foxes evolved in the absence of significant diurnal aerial predators such as golden eagles, and therefore may have been more vulnerable to predation than other small carnivores. Moreover, on much of the northern Channel Islands, historic sheep grazing changed the predominant vegetation from shrub to non-native grasslands, which offer much less cover from aerial predators (Van Vuren and Coblentz 1987).

Integrated Island Fox Recovery Team

From 1999–2003, the NPS annually convened a group of experts to help evaluate the status of island foxes on NPS lands, and to make findings regarding appropriate recovery actions. The Island Fox Conservation Working Group (IFCWG) comprised a loose affiliation of public agency representatives, landowners, conservancies, zoological institutions, non-profits, and academics

concerned about conservation efforts for the island fox. The working group served as a forum for information exchange and evaluation of recovery efforts, dividing into subject matter groups to tackle most issues. The group annually reported the status of island foxes on all islands and listed findings in regard to threats to the species and appropriate mitigation actions (see Coonan et al. 2004).

After listing four island fox subspecies as endangered in 2004, the USFWS established an island fox recovery team that retained the characteristics of the IFCWG. Although many recovery teams comprise a small number of individual experts, the Service established an integrated island fox recovery team comprising all 70+ individuals from the former working group. The individuals served as members of specific technical expertise groups, from which individuals were chosen to work on task forces in response to requests from land management agencies (NPS, TNC, Catalina Island Conservancy) regarding management and recovery of island foxes. The task requests were allocated to task groups by the island fox Recovery Coordination Group, which also received the resulting analyses from the task groups and passed on recommendations to the land management agencies, via the USFWS.

The integrated island fox recovery group first met in June 2004 to establish technical expertise groups and task forces, and to begin addressing the task requests formulated by the land management agencies. The team met again in 2005 and 2006 to exchange information on fox conservation and research, review completed work on task requests and recommendations to land managers, continue work on task requests, and provide input to USFWS on development of the draft island fox recovery plan (which had been tasked to the recovery coordination group). The 2007 island fox meeting marked a return to a format similar to the island fox conservation working group meetings. This included exchange of information and small workgroups addressing issues raised by the land management agencies, but not in the formal task analysis request process established by USFWS.

The Recovery Coordination Group was tasked by the USFWS with developing an island fox recovery plan, and the annual island fox meetings in 2005 and 2006 were used to develop recovery actions, criteria and strategies for inclusion in the plan. The process of developing island fox recovery criteria based on demographic modeling was described by Bakker and Doak (2009). Information on the integrated island fox recovery team, and on the island fox recovery plan, is available from the Ventura Field Office of the USFWS.

Recovery Actions

Upon receiving recommendations from a convened panel of experts, NPS began taking emergency recovery actions in 1999, focusing on two measures, capture and relocation of the existing golden eagles on the islands, and captive breeding of the critically low island fox populations. In the summer of 1999, NPS constructed pens on San Miguel and began capture of wild island foxes for captive propagation. By January 2000, 14 island foxes had been captured and placed in the pens, leaving only one in the wild. Four of the captured foxes were males and were paired with four females for breeding. In 2004, after five years of breeding, the San Miguel captive population had increased to 50 animals, exceeding the target captive population size of 40 animals and allowing initial releases back to the wild in fall 2004. The San Miguel captive breeding and reintroduction program ended in 2007,

due to high reproductive success and survival in the wild. During nine years of captive breeding, 53 pups were born in captivity and 62 foxes released to the wild. The recovering wild population has steadily increased since releases began in 2004 (Coonan and Schwemm 2009).

A captive breeding program was initiated for Santa Rosa Island in 2000. The initial captive population on Santa Rosa was 15 animals, which proved to be the island's remaining fox population. Some females were pregnant when captured, and three litters were born in captivity in 2000. With an increase to 56 foxes in 2003, the captive population on Santa Rosa exceeded the target captive population size of 40 foxes, and initial releases began in winter 2003/2004. Annual releases continued through 2008, after which captive breeding was ceased on Santa Rosa. In nine years of captive breeding, 88 pups were born in captivity, and 93 foxes (including some of the foxes originally brought into captivity) were released to the wild (Coonan et al. 2010).

Captive breeding was also conducted on Santa Cruz Island as a joint venture by NPS and The Nature Conservancy, which owns two-thirds of that island. The status of eagles and foxes on Santa Cruz Island was assessed at the 2001 meeting of the Island Fox Conservation Working Group, and consensus was that captive breeding was warranted for that island fox population. In February 2002, a 10-pen captive breeding facility was built on Santa Cruz Island by the NPS and TNC. This facility was stocked with 12 adult island foxes caught as known pairs or individuals from separate areas of the island. A second facility was added in 2004. Initial releases began in 2003 but after five of the nine foxes released were quickly predated on by golden eagles, the 4 remaining foxes were captured and brought back into captivity. No releases occurred in either 2004 or 2005, and the captive population grew to 62 animals in 2005. Releases occurred from 2006–2007, after which the program ceased because of good reproductive success and breeding in the wild (Coonan et al. 2010). In six years of captive breeding, 85 pups were born in captivity and 99 foxes (including some of the foxes originally brought into captivity) were released to the wild (Coonan et al. 2010).

The NPS established a cooperative agreement with the Santa Cruz Predatory Bird Research Group (SCPBRG) in 1999 for the purpose of relocating golden eagles from the northern Channel Islands. Personnel from the SCPBRG began eagle surveys and removal on Santa Cruz Island, the island with the most recent sightings, in late summer 1999. Golden eagles were discovered breeding on both Santa Cruz and Santa Rosa Islands. By the end of 2006, 44 golden eagles had been removed, mostly from Santa Cruz Island, the majority by bownet trapping. Captured birds were released in northeastern California, and satellite telemetry on the first released birds indicates that none attempted to return to the islands (Latta et al. 2005).

In the mid-2000s, NPS and its partners implemented larger-scale ecosystem restoration actions that resulted in long-term benefits for island foxes. In 2005–2006, NPS and TNC cooperated to remove feral pigs (>5,000 total) from Santa Cruz Island, thereby eliminating that non-native golden eagle prey source. Elk (*Cervus elaphus*) and mule deer were removed from Santa Rosa Island by 2014. The restoration of bald eagles to the northern Channel Islands, funded by the Montrose Settlements Restoration Program, comprised annual releases of young eagles from 2002–2006. Breeding by released bald eagles began in 2006, and as of 2014 there were >40 bald eagles on the northern

Channel Islands, with breeding occurring on Anacapa, Santa Cruz and Santa Rosa Islands (Coonan et al. 2010).

The decade of recovery actions has resulted in fox populations that are biologically recovered (Coonan and Schwemm 2009, Coonan et al. 2010, Coonan et al. 2014). Island fox populations on the northern Channel Islands have increased from 15 apiece on San Miguel and Santa Rosa and less than 80 on Santa Cruz to adult populations that number in the hundreds on San Miguel and over 1,000 on Santa Rosa and Santa Cruz. This is due to the success of captive breeding, reintroduction, golden eagle removal, and vegetation recovery. Reintroduced foxes and their progeny reproduced readily in the wild, and survival increased to over 90% on all three islands as golden eagle presence and predation decreased. Rapid population growth has moved each population toward levels that indicate recovery and likelihood of persistence over time (Bakker and Doak 2009). The large-scale ecosystem restoration actions of feral pig removal and bald eagle reintroduction have shifted the islands' ecosystem toward a point which favors fox persistence and discourages future golden eagle colonization of the islands. The court-ordered removal of non-native mule deer and elk from Santa Rosa Island has eliminated the last of the nonnative prey base from the northern Channel Islands (Coonan 2012).

The final island fox recovery plan was released to the public in 2015 (USFWS 2015a). The plan recognized the recovery actions that have brought the listed subspecies to the brink of recovery: captive breeding and reintroduction of foxes to the wild, and monitoring and relocation of golden eagles. The plan required that monitoring and mitigation plans be developed for both eagle predation and disease before listed island fox subspecies may be delisted. The plan set demographic goals, combinations of survival and population size, which would guarantee persistence of island foxes into the foreseeable future. The four island fox subspecies had reached these demographic goals, as of 2015. The U.S. Fish and Wildlife Service announced its intention to initiate a status review for the four listed subspecies, to determine if reclassification (delisting or downlisting) is appropriate (USFWS 2015b). The four subspecies were proposed for delisting and delisted in 2016.

Ecological Effects of Changes in Fox Abundance

Island fox decline and recovery has caused changes in the islands' ecosystem structure and function, some of which can be tracked via both annual island fox population monitoring and NPS's long-term ecological monitoring program (see Coonan et al. 2010, Ch. 14 – The Ecological Role of Island Foxes). Recorded changes concurrent with the absence and reappearance of island foxes include those in deer mouse (*Peromyscus maniculatus*) populations. Deer mouse populations on San Miguel generally increased in population until the mid-2000s at which point their populations declined substantially (Coonan 2016). This may be due to multiple factors, including prolonged drought and the concurrent increase in the island fox population. Additionally, island spotted skunks (*Spilogale gracilis amphiala*) are the only other terrestrial carnivores on the Channel Islands and inhabit Santa Cruz and Santa Rosa Islands. Island spotted skunks compete with island foxes and increased when foxes declined on both islands in the mid-1990s (Jones et al. 2008). As foxes recover, island spotted skunks appear to be decreasing, and this interaction is being tracked via island fox population monitoring.

Island Foxes and Long-Term Ecological Monitoring

Island foxes have been monitored at CHIS since 1993, when annual population monitoring of San Miguel Island foxes began as a result of NPS being designated as a Prototype Park for the NPS Inventory and Monitoring (I&M) Program (Davis et al. 1994). CHIS was one of a few parks where such comprehensive ecological monitoring was initiated. Island foxes were chosen to be monitored because the species was the largest native terrestrial vertebrate on the islands, was endemic, and existed at population sizes small enough to render them vulnerable to disease or stochastic demographic declines. The decision to monitor island foxes proved prescient when the monitoring program detected the predation-caused massive decline of San Miguel Island foxes in the mid to late 1990s (Coonan et al. 1998, 2005b).

The early population monitoring, described in what is now considered a legacy monitoring protocol, utilized large (7x7) grids to estimate island fox density (Fellers et al. 1988, Roemer et al. 1994). That monitoring protocol ended in 1999, when the remaining foxes on San Miguel (15 individuals) were brought into captivity. Current island fox monitoring methods on San Miguel, Santa Rosa, and Santa Cruz Island were borne of the island fox recovery effort (Coonan et al. 2010), in addition to the basic monitoring conducted through the I&M Program (Coonan et al. 1998). These methods, which have been used since foxes were first reintroduced to the wild in 2003/2004, utilize smaller grids to estimate density, and couple that with mortality monitoring via radiotelemetry (Coonan et al. 2005a). The latter began in 1998, during the final stages of the decline, and was used to identify golden eagle predation as the cause of the decline. Mortality monitoring and annual density estimation are viewed as appropriate and necessary for tracking island fox recovery and for detecting future threats to island foxes and are currently being implemented on all six islands where foxes exist (Rubin et al. 2007).

This report presents the results of efforts by the NPS to monitor island fox populations from 2006 to 2016 on San Miguel and from 2009 to 2016 on Santa Rosa Islands via trapping, and to track annual survival and mortality causes via radio telemetry (similar monitoring on neighboring Santa Cruz Island, also within CHIS, is conducted by TNC). The recovery actions, which include island fox population and mortality monitoring, were conducted under U.S. Fish and Wildlife Service Recovery Permit TE86267 (Coonan 2015).

The purpose of the monitoring was to:

- 1) estimate density and island-wide adult fox population size
- 2) replace radio collars or affix new radio collars as required
- 3) vaccinate foxes against canine distemper virus and rabies
- 4) establish a “sentinel” group of unvaccinated, radio collared animals
- 5) assess the physical condition of individual foxes

Methods

Fox Trapping

Annual fox trapping was conducted on San Miguel and Santa Rosa Islands from July to January, in order to estimate density, deploy radio collars, establish “sentinel” unvaccinated animals, and administer vaccines. For both grid and transect trapping, box traps (23x23x66 cm, Tomahawk Live Trap Co., Tomahawk, WI) were baited with a mix of dry cat and dog food and a fruit scent (Knob Mountain Raw Fur Co., Berwick, PA). Captured foxes were protected from the elements by careful placement of traps and the use of shade cloth covering each trap. A polyethylene chew bar was wired inside each trap to reduce incidents of tooth damage. Traps were checked every morning.

Upon first capture animals were weighed in the trap then removed and handled without anesthesia. Data collected included sex, age class, reproductive status, and general physical condition (e.g., condition of coat, presence of ectoparasites, injuries). Foxes were assigned to age classes (0–4) via tooth wear as described in Wood (1958) (Figure 3). Age classes do not designate actual age, rather the amount of wear on the first upper molar which is correlated with true age. Younger foxes tend to have less wear than older foxes, though other variables such as diet can impact the amount of wear. Captured foxes were assigned a body score of 1–5 (Table 1) and marked with passive integrated transponder (PIT) tags (Biomark, Boise, ID) inserted subcutaneously between and just anterior to the scapulae. Single-use sterile PIT tag applicators were used in order to minimize transfer of pathogens. Prior to insertion of the PIT tag, the insertion site was cleaned and disinfected with alcohol. Additionally, biological samples were collected and foxes were vaccinated and/or radio-collared as described in detail below.

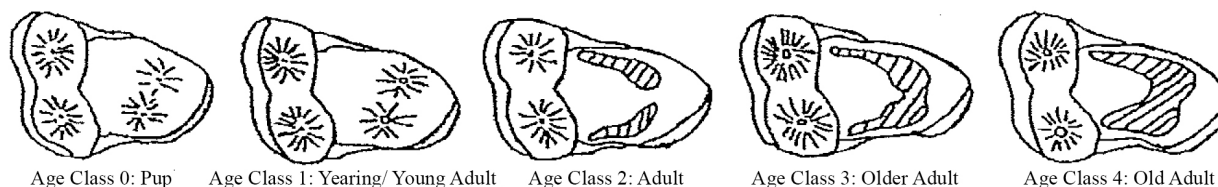


Figure 3. Island fox tooth wear by age class.

Trapping data was collected on paper datasheets and entered into NPS’s Island Fox Access database. The database and datasheets were reviewed for errors shortly after entry and again at the end of the season, as extensive quality assurance and quality control procedures were also employed. Field data sheets are scanned and stored in the NPS resource management office. All electronic data are stored on NPS data servers.

Table 1. Descriptions of body condition scores used to rate captured foxes.

Score	Condition	Description
1	Emaciated	Ribs and lumbar vertebrae easily seen, pelvic bones and all other bony structures obvious and prominent. Tail base prominent and bony. Accentuated concave abdominal tuck. Accentuated, severe hourglass shape to waist. No discernible body fat. Obvious loss of muscle mass.
2	Thin	Ribs and lumbar vertebrae easily seen with no fat cover. Pelvic bones obvious. Tail base bony with little soft tissue. Marked concave abdominal tuck. Marked hourglass shape to waist when viewed from above.
3	Optimal	Ribs, lumbar vertebrae, pelvic bones and other bony structures easily felt with slight fat cover. Tail base smooth with thin, soft tissue cover. Concave abdominal tuck. Smooth hourglass shape to waist.
4	Fat	Ribs, pelvic bones and lumbar vertebrae are difficult to feel. Tail base has fat deposition with moderate soft tissue cover. Concave tuck is decreased to absent. Loss of hourglass shape to waist with back slightly broadened.
5	Obese	Ribs and lumbar vertebrae are very difficult to impossible to feel. Pelvic bones are difficult to palpate with thick tissue cover. Tail base is thickened from fat deposition with thick soft tissue cover. Abdomen is convex with or without a pendulous ventral bulge. Back is markedly broadened.

San Miguel Island

Grids on San Miguel Island were first trapped in 1993–1998, prior to the island fox population decline. Then in 2006, 4 small mini-grids were established, each containing 18 traps in a 3x6 array, however 2 grid locations were altered to create the final grid arrangement used from 2007 to present (Figure 4). Three grids were randomly distributed along the primary east-west cross-island trail and a fourth was placed in the only remaining area without cultural resources, north of the central dunes and south of Hurricane Deck/Harris Point. Although grid distribution across the island does not represent all habitat types and geographic areas, trapping was distributed across the island as much as possible. This sampling approach was required due to sensitive cultural resources on the island. Representation of habitat types by the current grids is similar to that of the larger grids sampled in the 1990's. Although the new grids sample areas with lower slope and ruggedness than the island as a whole, this would be true for any trapping scenario since the rugged cliffs at the island's edge are unsafe to sample (Rubin et al. 2007).

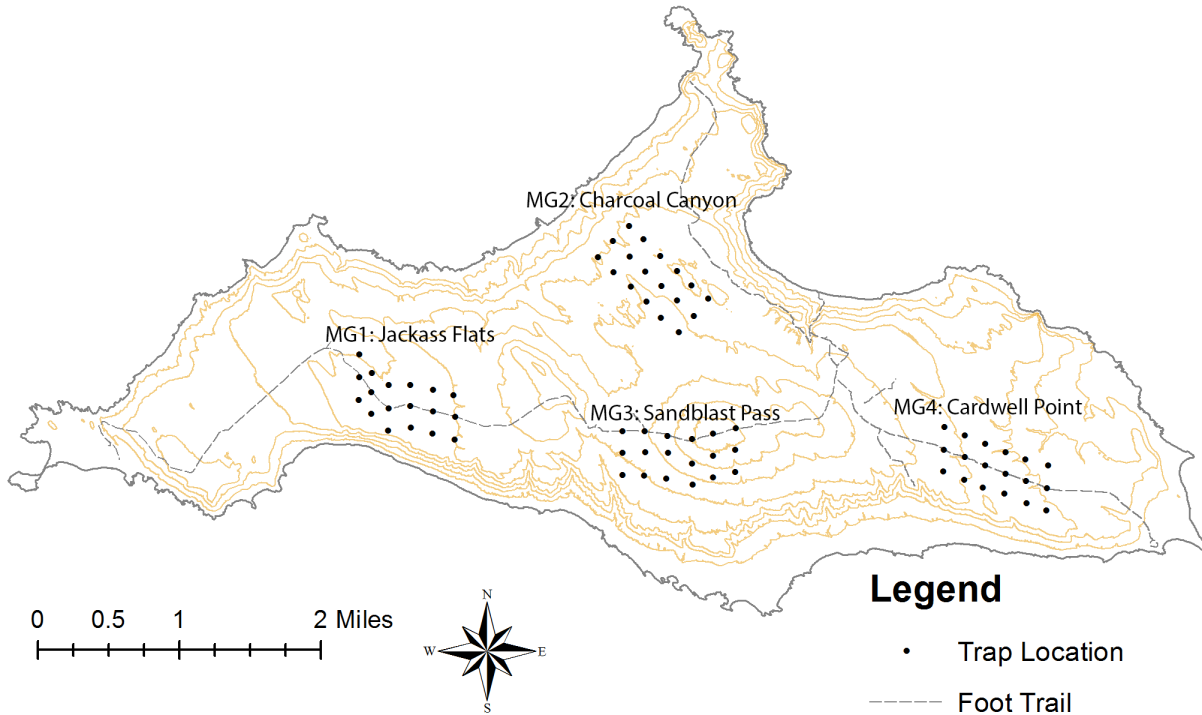


Figure 4. Location of trapping grids on San Miguel Island from 2007 to 2016.

Each grid was placed in close proximity to a trail. On the Jackass Flats (MG1) and Cardwell Point (MG4) grids the middle line of traps was dispersed along the trail at 250 m intervals, with additional lines of traps directly north and south. On the Sandblast Pass grid (MG3) the northern line of traps was dispersed at 250 m intervals with the other two lines spaced at 250 m and 500 m south of the trail. Due to sensitive cultural resources the Charcoal Canyon grid (MG2) does not have a line of traps on the trail, however traps are a close distance to the trail, with all traps spaced 250 m apart. The grids were designed to be relatively easy to set up and trap, so that a 2-person crew could trap one grid per week while still performing other duties (such as monitoring radio collared foxes). Each grid was run for 5 nights. Target trapping was also conducted across the island to complete collaring, vaccination, and biological sample goals for the season.

Santa Rosa Island

Previous population monitoring on Santa Rosa Island utilized line transects, from which it is difficult to estimate density and island-wide population size. Therefore, in 2009, 18 small mini-grids were established on Santa Rosa Island (Figure 5). Each grid contained 12 traps in a 2x6 array with 200 m spacing between traps, as recommended by Rubin et al. (2007). Each grid was run for 6 nights. Target trapping was also conducted across the island to complete collaring, vaccination, and biological sample goals for season.

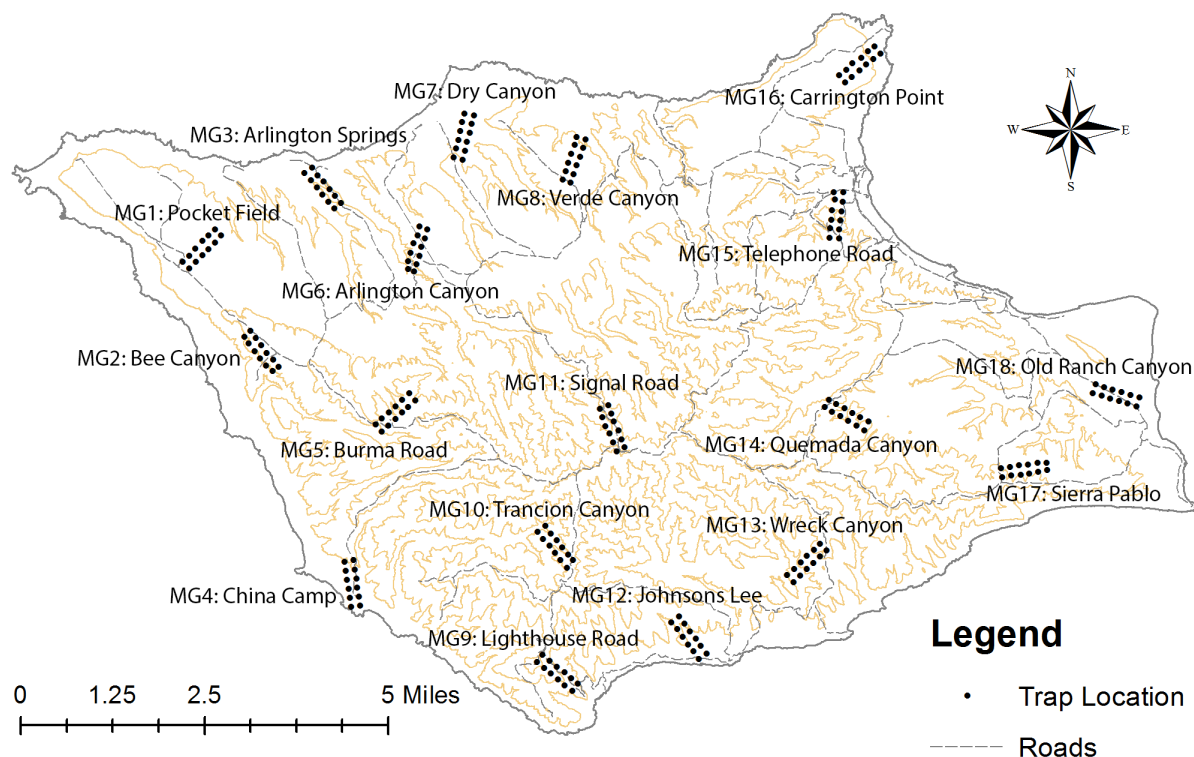


Figure 5. Location of trapping grids on Santa Rosa Island from 2009 to 2016.

Collection of Biological Samples

Blood samples (≤ 10 ml from adults [>1.25 kg] and ≤ 5 ml from pups) were collected from the femoral or jugular vein of captured foxes. The blood was then separated into its component fractions by centrifugation and stored for later genetic and serologic analyses. A portion of the serum from each sample was set aside for archiving in a -80°C freezer at NPS headquarters, Ventura, California. Whiskers were collected for a stable isotope study of fox diet conducted by S. Newsome at the University of New Mexico and scat samples were collected for a St. Louis Zoo hormone study.

In order to investigate whether foxes were shedding *Leptospira* bacteria, a known pathogen on Santa Rosa Island, urine samples were obtained from foxes on Santa Rosa Island with a palpable bladder via cystocentesis (Coonan 2014). The IFCWG recommended further study of *Leptospira* in 2011 to determine if these bacteria are cause for concern.

Vaccination and Sentinel Animals

Although vaccination of wild animals in U.S. National Parks is rare, vaccination is the best strategy for mitigating possible outbreaks of rabies and CDV in island foxes, because a decline would not be detected quickly enough through monitoring of radio collared foxes. Consequently, the IFCWG has recommended that all captured foxes be vaccinated against rabies and a subset of 80–100 foxes be vaccinated against canine distemper virus (CDV) on each island annually (Coonan 2010). Not all foxes are vaccinated against CDV in order to protect the naturally occurring CDV-like morbillivirus that circulates in island fox populations and provides some immunity (Clifford et al. 2006). Selected

animals were vaccinated with Imrab 3 vaccine for rabies and Purevax Ferret Distemper vaccine for CDV (Merial, Inc., Atlanta, GA). The Purevax Ferret Distemper vaccine was previously unavailable in 2014 and 2015, and the Recombitek Canine Distemper vaccine (Merial, Inc., Atlanta, GA) had been approved for use in 2015 by the USFWS and the IFCWG. In 2016, a sample of non-vaccinated, radio collared sentinel animals continued to be established on each island. To facilitate detection of disease outbreaks the IFCWG recommended that each island have up to 20 juvenile (1–2 year old) foxes that are unvaccinated (Coonan 2010).

Fox Demographics

Since grid trapping is standardized on each island, with the equivalent number of traps opened for equivalent days from year to year, only the grid trapping data was used to analyze annual fox demographics. These data were used to calculate a number of metrics that assess the demographic status of the fox population on each island. Age class histograms, combined and separated by sex, were created to examine the age structure of the island fox populations. The average weight of adult male and female foxes, the percent of foxes in each body condition category, and adult sex ratios were determined to examine the overall health of the island fox populations. Finally, reproductive success, as measured by the number of adult females/pups, was calculated for each individual grid and across all trapping grids.

Fox Survival Monitoring

On both islands, mortality-sensing radio-telemetry collars (Holohil Systems Ltd., Ontario, Canada) were placed on a subset of captured foxes to assess survival rates and causes of mortality. Collared foxes were selected in an attempt to be representative of the population as a whole, while also maintaining radio collars on approximately 20 sentinel yearling foxes per island to facilitate early detection of a possible disease outbreak, as recommended by the island fox recovery plan (USFWS 2015a). The age structure and sex ratio of collared foxes were compared against those of the grid-trapped foxes. Collared foxes were monitored at least weekly to determine their general location and signal type (normal or mortality). If a mortality signal was detected, the dead fox was located and recovered. Data collected at the site prior to removing the carcass included; 1) information that might indicate cause of mortality, 2) position of the carcass with respect to its surroundings, including digital photographs, and 3) general condition of the animal (e.g., eviscerated, intact, damage by insect scavengers, etc.). The location of the carcass was recorded via GPS, and a general description of the habitat was recorded.

Carcasses were tagged with pertinent identification, date and location information. If carcasses could be brought to the mainland within 48 hours of being located they were refrigerated, otherwise they were frozen. Carcasses were then shipped by overnight carrier to the California Animal Health & Food Safety Laboratory System in Davis, California (Leslie Woods, DVM) for necropsy. Because freezing of tissues increases autolysis, and therefore decreases data that can be extracted from histological examinations, it is advantageous to have the animal necropsied as soon as possible after death and to avoid freezing if possible. If disease was suspected in the death of the animal, tissues were prepared for histological analysis.

Prior to 2015, annual adult fox survival was determined for the calendar year (Jan 1–Dec 31). Since abundance estimates are determined for the “fox year” (May 1–Apr 30) and island recovery is based on estimates of adult fox abundance and survival combined, we analyzed the adult fox survival in 2016 for the “fox year.” Additionally, we re-analyzed all prior years of survival data to estimate annual adult fox survival during the “fox year.”

Annual survival of radio collared foxes was estimated using known-fate models in program MARK (version 9.0; Cooch and White 2010). We calculated an 80% confidence interval about the annual survival rate, as the 95% confidence interval is too conservative and increases the risk of a Type II statistical error (i.e., wrongly accepting a false null hypothesis; V. Bakker, Montana State University, and D. Doak, University of Wyoming, pers. comm, T. Coonan).

Fox Density / Abundance Estimation

Since foxes are individually marked via PIT-Tags (Passive Integrated Transponder), spatially explicit capture-recapture statistics via program *secr* (version 4.2.3, R version 3.02; Efford 2018) was used to estimate island-wide fox density and abundance on San Miguel and Santa Rosa Islands. Program *secr* estimates density explicitly by modeling capture probability as a joint function of two parameters, detection (g_0) and spatial movement (σ) (i.e., the shape of the detection function curve). In *secr* a habitat ‘mask’, representing grid cells of potentially occupied habitat, must be defined. The habitat mask was defined as having a buffer of 900 meters around all traps that was clipped to the shoreline of each island. The grid cell spacing was defined as 50 m for San Miguel Island and 100 m for Santa Rosa Island. If buffer size is too small or grid cell size too large density estimates can be biased, whereas if buffer size is too large or grid cell size too small, estimates are unbiased but require unnecessary computational power and time. The values for buffer size and grid cell size were determined by evaluating the corresponding changes in density estimates when different values for buffer size and grid cell size were used. The buffer and grid size values selected corresponded to when changes in density estimates leveled off.

The full maximum likelihood estimator for multi-catch data and a half normal detection function was used for all models. Although the box traps used can theoretically only catch one animal at a time (i.e., single-catch), there is no known maximum likelihood estimator for single-catch traps. Since density estimates using the multi-catch likelihood for single-catch data are only slightly biased, we analyzed all data using the multi-catch likelihood (Efford et al. 2009).

To estimate adult fox density and abundance models were considered where each parameter (g_0 and σ) remained constant, as well as varied by sex and two types of behavior (b and B). Permanent behavior (b) is modeled by foxes having an initial probability of capture and/or distance value for its first capture and a second probability of capture and/or distance value for all subsequent captures. Temporary behavior (B), otherwise known as Markovian behavior, is also modeled by foxes having two probabilities of capture and/or distance values, one value when the fox had not been captured the previous day and a separate value when the fox had been captured the previous day. When the second probability of capture is higher or the second distance value is lower than the first, foxes are demonstrating “trap happy” behavior, wherein they are more likely to be trapped following their initial capture. When the second probability of capture is lower or the second distance value is higher

than the first, foxes are demonstrating “trap shy” behavior, wherein they are less likely to be trapped following their initial capture. For all analyses, g_0 and σ remained constant across the trapping period time frame (i.e., 5 days for San Miguel and 6 days for Santa Rosa).

All possible additive combinations of effects on parameters were considered, resulting in a 28-model set. Model selection was performed using information theoretic methods with model support quantified based on AICc values (Burnham and Anderson 2002). Final density estimates were based on model averaging according to AICc weights. Island-wide abundance estimates were generated by multiplying island area by the average density across all grids. To estimate the density and abundance of fox pups, the pup capture data was analyzed using the same set of 28 models used to estimate adult fox density and abundance. To estimate the total number of foxes, the island wide adult fox abundance was added to the island-wide fox pup abundance. When pup captures and recaptures are low, estimates of pup density and abundance are unreliable. In this case, the data for adults and pups were analyzed together, with density, g_0 and σ varying by age in our models, resulting in a 112-model set. This estimated pup abundance was added to the island-wide adult fox abundance, determined from the adult fox data alone, to estimate total fox abundance across each island. To estimate adult fox density for individual grids, only adult data from that grid were included in the analysis.

Prior to 2015, annual fox density and abundance estimates were determined using program *Density* (Efford et al. 2004). Program *secr* is a newer version of program *Density* that was developed by the same individuals and includes more functionality. Since previous years’ estimates were determined via *Density* and did not include behavioral components, in this report we re-analyzed all prior years’ fox capture data using program *secr*. Behavior can be an important factor in island fox capture patterns and the inclusion of behavior in the models can result in different estimates. In this report all fox density and abundance estimates across all years were determined using program *secr* and included behavioral components in the models.

Island Fox Recovery

For both island fox subspecies it was evaluated whether their populations met the demographic recovery criteria developed by the U.S Fish and Wildlife Service for its Island Fox Recovery Plan by using annual estimates of island-wide adult fox abundance and adult fox mortality (calculated as 1 – annual survival). Recent demographic modeling incorporated life-history characteristics of the well-studied island foxes with environmental drivers and uncertainty to develop extinction probabilities for combinations of population size and annual mortality (Bakker et al. 2009). Three-year averages of adult abundance and adult mortality were plotted to determine if those values resulted in acceptable extinction risk (<5% over 50 years). A spreadsheet tool developed by V. Bakker (Montana State University) was used to plot current values against isoclines, representing various levels of extinction risk for island foxes on each island (Bakker and Doak 2009). In this report, island fox recovery was reanalyzed for each island using the updated abundance estimates from *secr* and the updated survival estimates from program MARK.

Spotted Skunk Demographics and Density / Abundance Estimation

The island spotted skunk (*Spilogale gracilis amphiala*) is a subspecies of the western spotted skunk (*Spilogale gracilis*) and the only other terrestrial carnivore on the Channel Islands, inhabiting Santa Rosa and Santa Cruz Islands. Skunks were caught in traps set for island fox monitoring and when caught, skunks were restrained, weighed, sexed, and individually marked with a PIT Tag.

To evaluate spotted skunk demographics over time we determined the average weight of females, males, and all spotted skunks captured. We also determined the sex ratio (female/male) of all captured spotted skunks. Using mark-recapture statistics, we estimated island-wide skunk density and abundance via program *secr*. We followed the same method as described above for foxes. Juvenile skunks are not captured often and are not easily distinguished from adults; therefore, age was not considered and all skunk captures were grouped together. Unfortunately, the number of skunk captures and recaptures were too low to successfully estimate skunk density and abundance using program *secr*. Instead we estimated density by dividing the number of skunks captured by the effective trapping area of all 18 grids. Since island spotted skunks are considered habitat generalists and are known to exist in all habitats on the island, we extrapolated skunk density to the entire island to estimate island-wide abundance (Crooks and Van Vuren 1995).

Results

San Miguel Island

Fox Trapping

In 2016, fox grid trapping to estimate population density on San Miguel Island occurred in September and October, whereas target trapping to manage collars and administer vaccines occurred intermittently from September 2016 through January 2017. A total of 56 individual foxes (5 pups, 51 adults) were captured a total of 122 times on 4 grids, whereas a total of 48 individual foxes (3 pups, 45 adults) were captured a total of 75 times during target trapping (Tables 2 & 3). Across both trapping methods 94 individual foxes (8 pups, 86 adults) were captured a total of 197 times (Table 4).

Table 2. Number of foxes captured, by age and sex, across all trapping grids and target trapping on San Miguel Island, 2016.

Age	Grid Trapping			Target Trapping		
	Female	Male	Total	Female	Male	Total
Pups	3	2	5	2	1	3
Adults	25	26	51	20	25	45
Total	28	28	56	22	26	48

Table 3. Number of foxes captured, by age and sex, across all trapping grids and target trapping on Santa Rosa Island, 2016.

Age	Grid Trapping			Target Trapping		
	Female	Male	Total	Female	Male	Total
Pups	36	41	77	8	5	13
Adults	80	81	161	16	22	38
Total	116	122	238	24	27	51

Table 4. Vaccinations administered and biological samples collected from island foxes across all trapping grids and target trapping on San Miguel and Santa Rosa Islands, 2016.

Vaccine / Sample	San Miguel	Santa Rosa
Total individual foxes	94	284
Total captures	197	724
Rabies vaccines (individuals)	59 (57)	149 (148)
CDV vaccines (individuals)	59 (57)	119 (118)
Blood samples (individuals)	82 (79)	268 (266)
Whisker samples (individuals)	81 (79)	220 (219)
Urine samples (individuals)	NA	53 (53)
Scat samples (individuals)	16 (16)	52 (49)

Vaccination, Sentinel Animals, and Collection of Biological Samples

During the 2016 “fox year,” vaccines were administered to San Miguel Island foxes during both grid and transect trapping, with 57 foxes vaccinated against both rabies and canine distemper (Table 4). Additionally, 32 foxes received new radio collars, 11 of which replaced old collars. Of these 32 foxes, 18 were sentinels (i.e., never vaccinated against rabies or canine distemper). Nine foxes that had active radio collars from previous years were captured again in 2016, four of which were sentinels. However, 26 foxes with active radio collars, of which 13 were sentinels, were not captured in 2016. During the 2016 trapping season a total of 35 individual foxes acted as sentinel animals, with 18–27 monitored at any given time. A total of 82 blood, 81 whisker, and 16 scat samples were collected from 79, 79 and 16 individual foxes respectively.

Fox Demographics

When foxes captured via trapping grids were stratified by age class, age class 2 and 3 individuals comprised the majority of the current fox population on San Miguel Island (Figure 6). Only five pups (age class 0) were captured in 2016, which was the fourth consecutive year that pup captures were low and the third consecutive year that age class 2 and 3 individuals comprised the majority of the population. Previously age class 0 and 1 individuals comprised the majority of the population. The number of adults and number of total foxes captured were a decline from previous years.

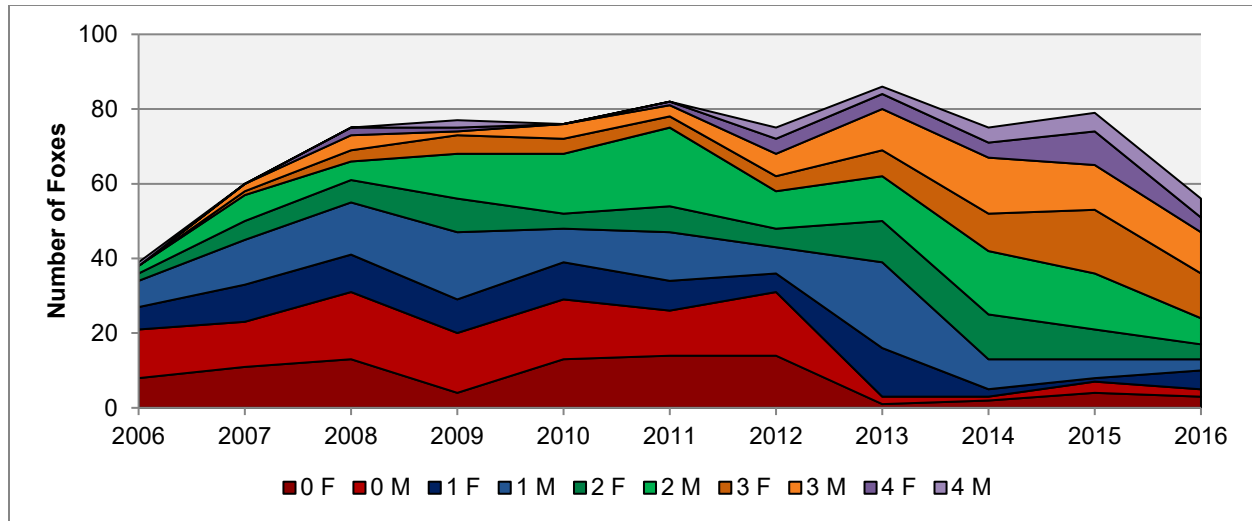


Figure 6. Number of female (F) and male (M) foxes captured in each age class (0–4) across all trapping grids on San Miguel Island, 2006–2016.

The average weight of adult female and male foxes trapped on grids on San Miguel Island in 2016 was similar to 2015 and lower than previous years, with females averaging 1.85 kg (80% CI = 1.90–1.80) and males averaging 1.95 kg (80% CI = 2.01–1.88) (Figure 7). Coinciding with low adult fox weights, a higher proportion of foxes were classified as body condition 2 than body condition 3 in 2016 (Figure 8). This was the fourth consecutive year in which this is the case. Additionally, the proportion of foxes classified as body condition 1 in 2016 was the highest recorded.

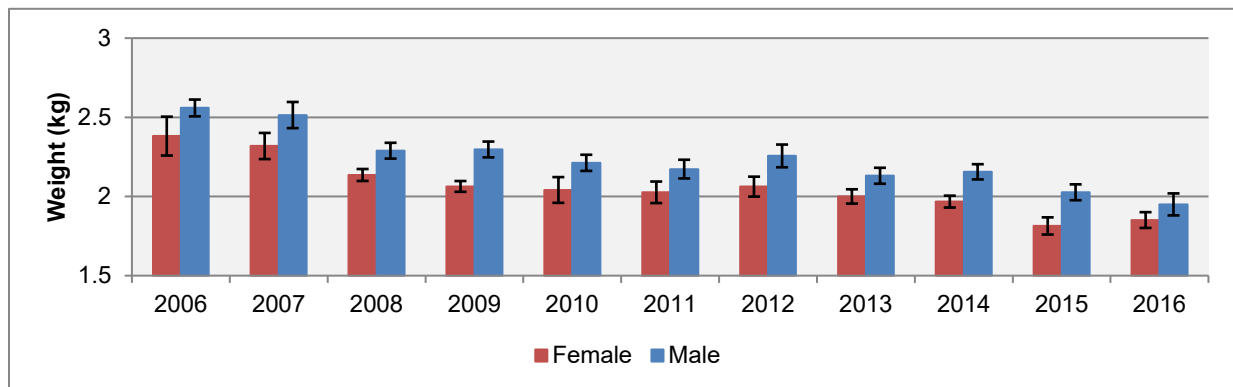


Figure 7. Average fox weight by sex, with 80% confidence intervals, across all trapping grids on San Miguel Island, 2006–2016.

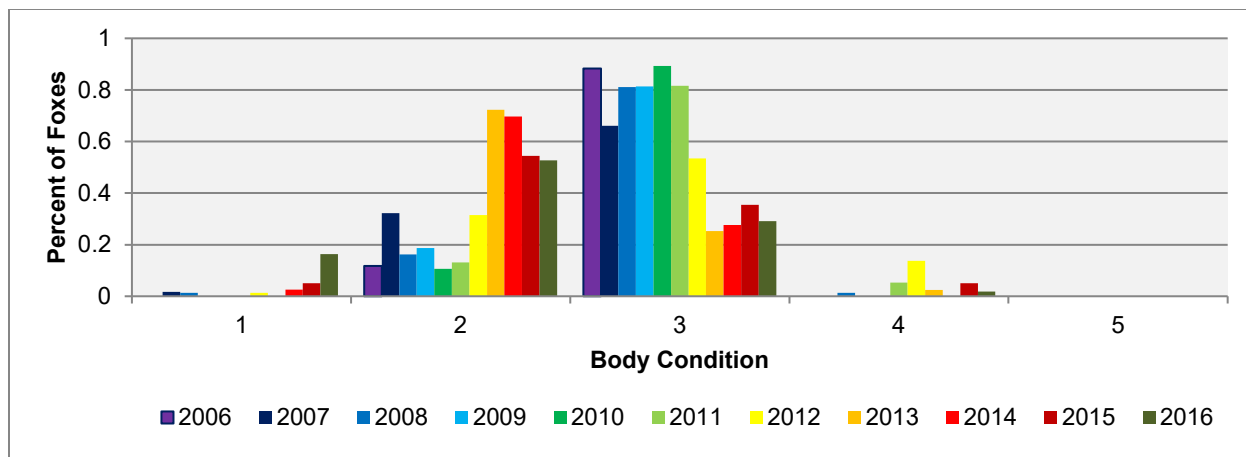


Figure 8. Percent of foxes in each body condition category (1–5) across all trapping grids on San Miguel Island, 2006–2016.

In 2016, the ratio of adult female to adult male foxes on trapping grids on San Miguel Island was 0.96 (Figure 9). This ratio has been steadily increasing since 2011 when it was the lowest ever recorded. Although the 2016 value is still below 1, it is the highest recorded ratio on San Miguel Island.

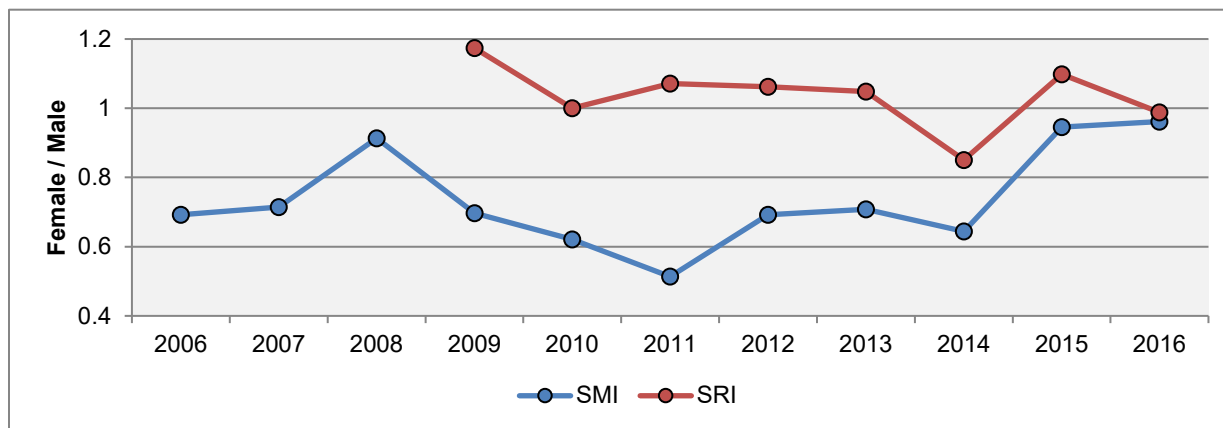


Figure 9. Adult fox sex ratio (female/male) across all trapping grids on San Miguel (SMI) (2006–2016) and Santa Rosa Islands (SRI) (2009–2016).

The ratio of pups to adult females across all grids, an index of reproductive effort, was 0.20 in 2016 on San Miguel Island (Figure 10). This is the fourth consecutive year where reproductive effort was low (< 0.30). When separated by individual grids, all four grids showed low reproductive effort (< 0.30).

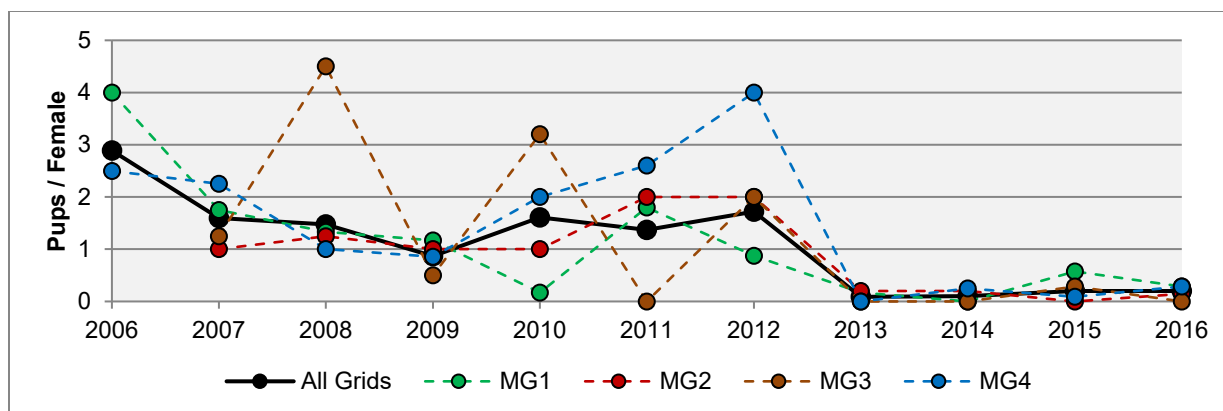


Figure 10. Reproductive effort (pups/adult females) of island foxes across all trapping grids, and by individual grid, on San Miguel Island, 2006–2016. (MG1: Jackass Flat, MG2: Charcoal Canyon, MG3: Sandblast Pass, MG4: Cardwell Point). Grids MG2 and MG3 were not trapped in 2006, as two alternate grid locations were trapped that year but never trapped again. The reproductive effort of these alternate grids are not displayed in this figure .

Fox Survival Monitoring

Throughout the 2016 “fox year,” a total of 67 foxes (2 pups, 65 adults) were monitored via radio collars on San Miguel Island, with 37–49 foxes being monitored at any given time. To determine how closely collared foxes represented the overall fox population, the percent of adult foxes in each age class (Figure 11) and their sex ratio (Figure 12) were compared to foxes captured across all 4 trapping grids. In general, collared foxes seemed to represent the overall fox population with similar proportions of each age class. However, the sex ratio of collared foxes was male biased in age class 1 and female biased in age class 2.

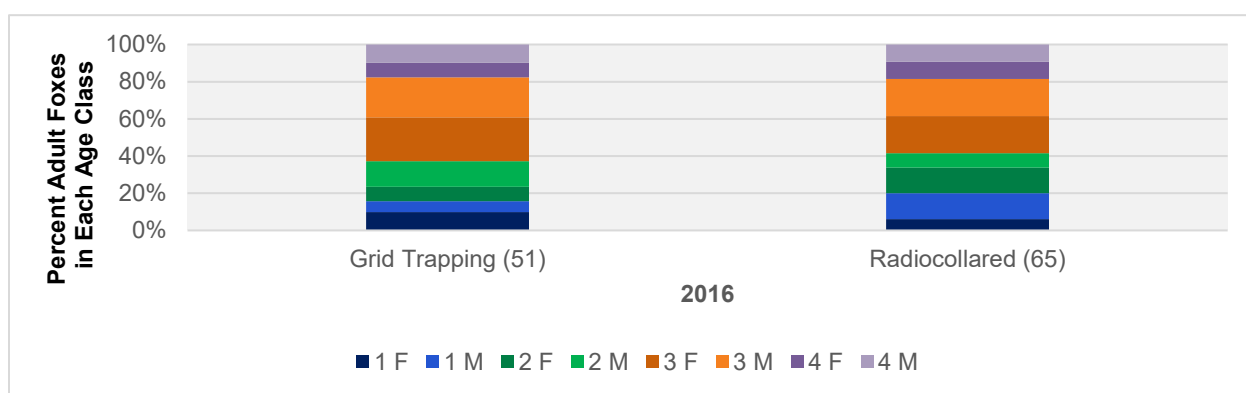


Figure 11. Percent of adult foxes in each age class (1–4) (including sample size) across all trapping grids and for all radio-collared individuals on San Miguel Island in 2016.

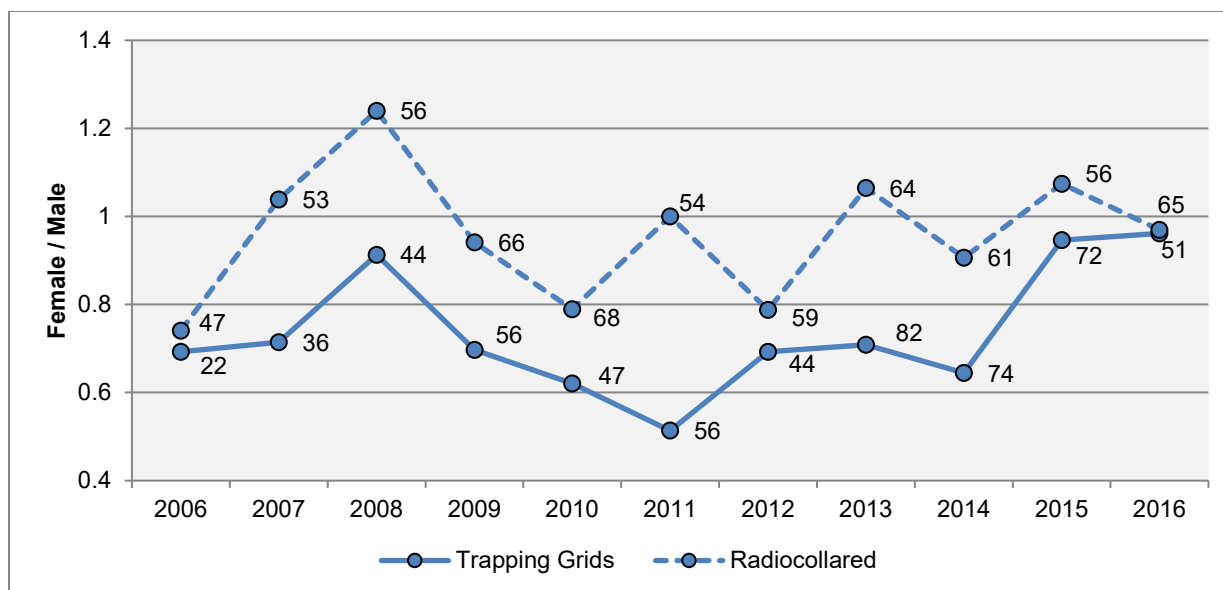


Figure 12. Sex ratio of adult foxes (including sample size) across all trapping grids and for all radio-collared individuals on San Miguel Island, 2006–2016.

Annual known-fate survival for adult island foxes in the 2016 “fox year” was 59.1% ($n=65$; 80% CI = 47.6–69.5%), which is the lowest survival rate of adult foxes since the monitoring program began (Figure 13). Annual adult survival on San Miguel was extremely low in 2016 and was the fourth consecutive year of low survival (<80%). An annual adult survival rate of 80% or more is optimal for a stable or increasing fox population (Roemer et al. 2001). Twenty-one radio-collared foxes died (12 female, 9 male) within the 2016 “fox year,” none from eagle predation but signs of disease or parasites were detected in eight carcasses (Table 5). Additionally, 13 of the foxes were recovered too late to conduct a necropsy. With adult fox survival decreasing to worrisome levels, the quick retrieval of fox carcasses should be a priority.

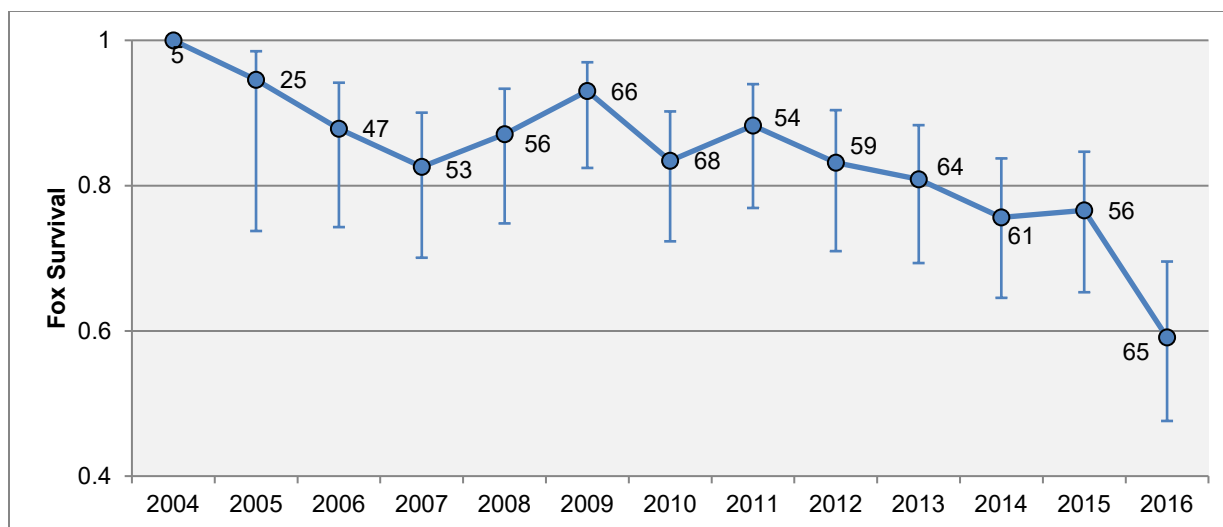


Figure 13. Adult fox survival with 80% confidence intervals and sample sizes on San Miguel Island, 2004–2016. Note: survival was determined for each “fox year” (May to April).

Table 5. Mortalities of radio collared foxes on San Miguel Island for the 2016 “fox year” (5/1/2016–4/30/2017).

ID	PIT Tag	Sex	Age	Born	Date	Mortality Cause
M279	D0522	M	6	Wild	6/14/16	Necropsy Cancelled due to severe postmortem autolysis
F384	B281A	F	8	Wild	8/22/16	No necropsy due to extreme decay
M306	56367	M	6	Wild	8/22/16	No necropsy due to extreme decay
M294	47343	M	8	Wild	8/22/16	Emaciation, enteritis, diffuse w/ acanthocephala, colitis w/ spirocerca
F369	04869	F	5	Wild	8/31/16	No necropsy due to extreme decay
F349	E4D11	F	8	Wild	9/1/16	Emaciation, enteritis/acanthocephala, spirocerca
M251	73B52	M	9	Wild	9/6/16	No necropsy due to poor condition
F375	07084	F	4	Wild	9/14/16	No necropsy due to poor condition
F373	4514E	F	10	Wild	10/17/16	No necropsy due to poor condition
M299	D2E53	M	6	Wild	10/24/16	No necropsy due to poor condition
F385	38980	F	3	Wild	11/20/16	No necropsy due to extreme decay
F389	15754	F	4	Wild	12/1/16	No necropsy due to extreme decay
F348	C7602	F	8	Wild	12/31/16	Necropsy cancelled due to autolysis

Table 5 (continued). Mortalities of radio collared foxes on San Miguel Island for the 2016 “fox year” (5/1/2016–4/30/2017).

ID	PIT Tag	Sex	Age	Born	Date	Mortality Cause
M288	85823	M	6	Wild	1/12/17	No necropsy due to poor condition
F355	00C50	F	9	Wild	1/26/17	Emaciation, nematodes/hookworm (massive #), cestodes, acanthocephalon (rare), spirocerca, pulmonary nematodes
F372	72803	F	11	Wild	1/27/17	Hepatitis, pulmonary arteropathy
M326	18229	M	6	Wild	2/13/17	Emaciation, enteritis/acanthocephala, colitis/spirocerca, intussusception, E. coli isolated in kidney
F400	15768	F	U	Wild	2/24/17	valvular endocarditis (cause of death), emaciation with intestinal/pulmonary parasitism (acanthocephala, hookworms, cestodes, spirocerca, lungworms)
M325	72219	M	6	Wild	2/25/17	Emaciation, enteritis w/ numerous hookworms, acanthocephala, and cestodes; colitis/spirocerca; pulmonary nematodes (heavy infection)
M315	26252	M	3	Wild	2/27/17	Emaciation, small intestine with acanthocephala, cestodes, and presumptive hookworms; colitis/spirocerca; pulmonary nematodes
F374	63C2F	F	9	Wild	2/27/17	Necropsy cancelled due to autolysis

Fox Density / Abundance Estimation

The estimated island-wide density of adult island foxes on San Miguel Island in 2016 was 7.1 foxes/km² (80% CI = 5.60–8.99) (Figure 14, Figure 16, Table 6). Adult density ranged from a high of 9.42 foxes/km² on the MG1: Jackass Flats grid to a low of 4.62 foxes/km² on the MG3: Sandblast Pass grid. Due to the lack of data for individual grid analysis, models including behavioral components (b and B) were not included and all individual grid estimates were determined using the constant model. Multiplying the island-wide density by the area of the island (37.66 km²) yielded a population estimate of 267 adult foxes (80% CI = 211–338) (Figure 15, Table 7). This represents an approximately 59% decrease from the 2015 estimate of 646 foxes. Since only five pups were captured five times there was not enough pup captures to accurately estimate pup density and abundance using pup captures alone. Instead we estimated island-wide pup density using the capture data from all foxes (adults and pups), resulting in 0.64 pups/km² (80% CI = 0.36–1.15) with a corresponding island-wide abundance of 24 pups (80% CI = 13–43). The estimated island-wide abundance of all foxes (adults and pups) was 291 total foxes (80% CI = 224–381).

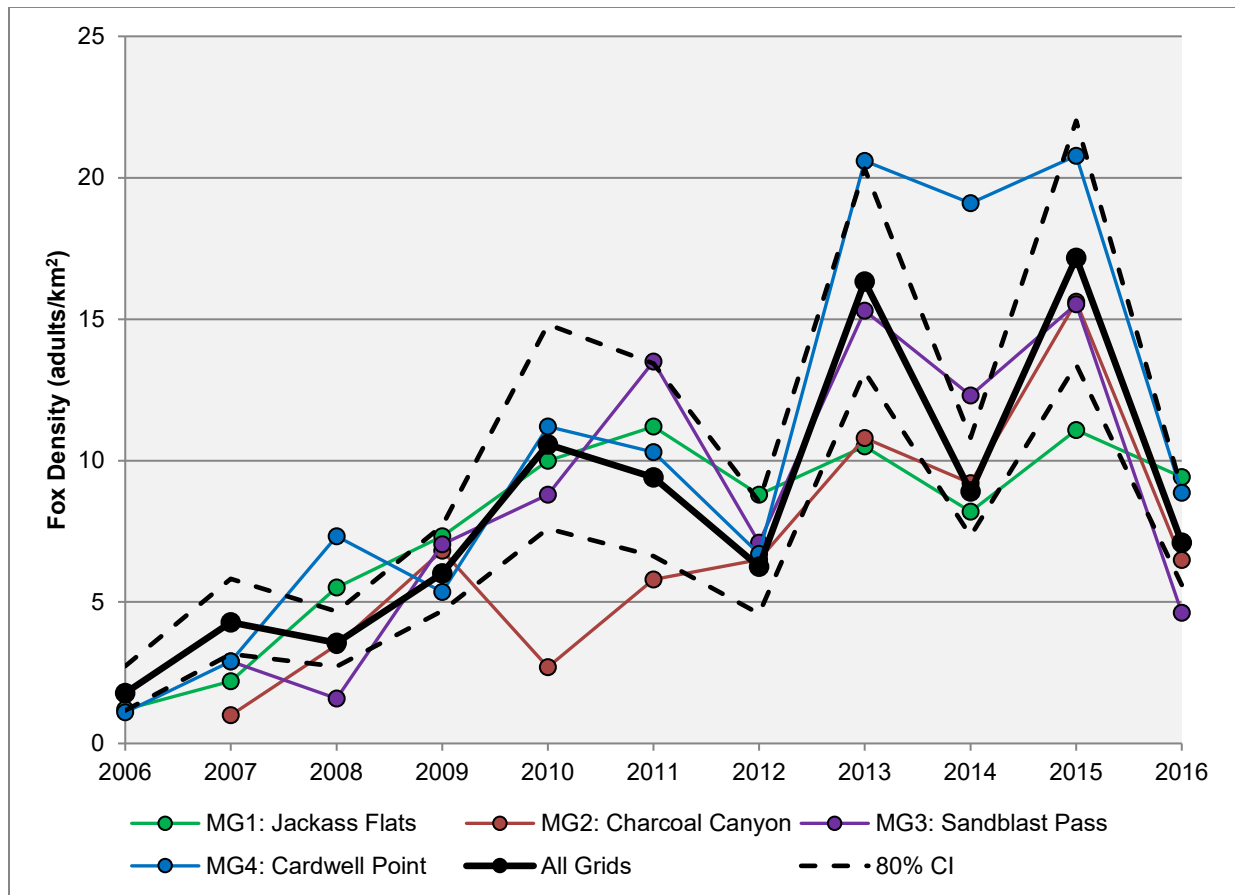


Figure 14. Adult fox density across all trapping grids and for individual grids on San Miguel Island, 2006–2016. Density estimates were determined via program *secr*.

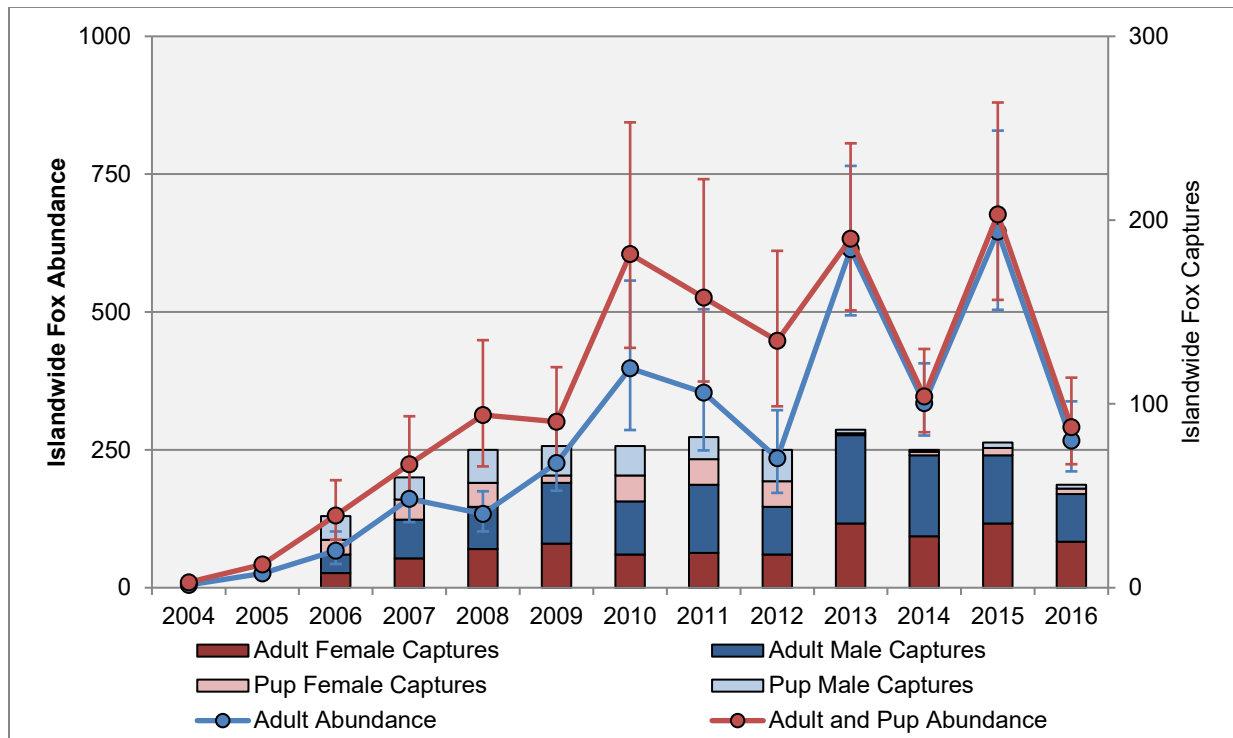


Figure 15. Island-wide fox abundance (adults and total) with 80% confidence intervals and the number of individual foxes captured, by age and sex, across all trapping grids on San Miguel Island, 2004–2016. Note: abundance estimates were determined via minimum number known alive (2004–2005) and program *secr* (2006–2016).

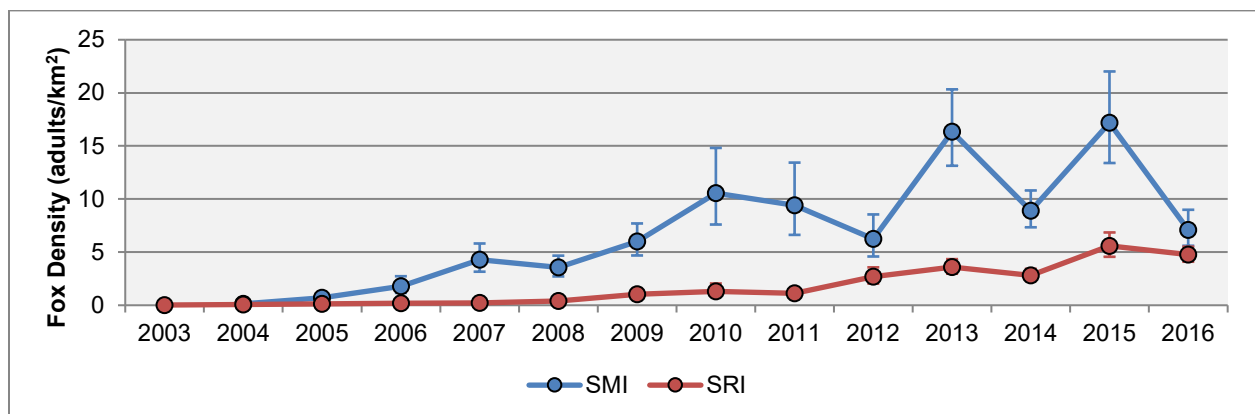


Figure 16. Adult fox density with 80% confidence intervals across all trapping grids on San Miguel (2004–2016) and Santa Rosa Islands (2003–2016). Note: density estimates for San Miguel Island were determined via minimum number known alive (2004–2005) and program *secr* (2006–2016), while density estimates for Santa Rosa Island were determined via minimum number known alive (2003–2008) and program *secr* (2009–2016).

Table 6. Number of individual adult foxes captured (Ind.) and estimates of adult fox density for individual trapping grids (MG). Island-wide density via average of individual grids and island-wide density via all trapping grids combined on San Miguel Island, 2016.

Monitoring Grid	Dates	Ind.	Density (foxes/km ²)	SE	CV ¹
MG1: Jackass Flats	9/16–9/20	13	9.42	3.51	0.371
MG2: Charcoal Canyon	9/16–9/20	11	6.49	2.43	0.374
MG3: Sandblast Pass	10/12–10/16	10	4.62	2.89	0.626
MG4: Cardwell Point	9/21–9/25	17	8.86	2.68	0.303
Average Density	–	–	7.35	–	–
All Grids Combined	9/16–25, 10/12–16	51	7.10	1.32	0.186

¹ Coefficient of variation (CV) is a standardized measure of dispersion of a probability distribution or frequency distribution and a value of 0.20 or lower is desirable. CV= SE/density

Table 7. Island-wide adult fox and total (adults and pups) fox abundance across all trapping grids on San Miguel Island, 2004–2016.

Year	Adults					Total (adults plus pups)				
	n	N	SE	80% CI	λ	n	N	SE	80% CI	λ
2004 ¹	5	5	–	–	–	10	10	–	–	–
2005	26	26	–	–	–	42	42	–	–	–
2006 ²	18	67	23.01	43–102	2.58	39	131	41.76	88–195	3.12
2007	37	161	38.97	119–219	2.40	60	225	58.11	162–331	1.72
2008	44	134	28.71	102–175	0.83	75	314	89.55	220–450	1.40
2009	57	226	44.25	176–290	1.69	77	302	66.78	228–400	.96
2010	47	398	105.82	286–557	1.76	77	605	159.70	435–845	2.00
2011	56	354	99.81	249–505	.89	82	527	143.12	375–742	0.87
2012	44	235	58.11	172–322	.66	75	528	109.59	333–899	1.00
2013	83	614	105.61	494–765	2.61	86	634	117.99	503–806	1.20

n = number of trapped animals; N=estimated population size, SE= standard error, λ =annual rate of increase.

¹ 2004–2005 estimates determined using minimum number known alive (MNKA).

² 2006–2016 estimates determined using program secr.

Table 7 (continued). Island-wide adult fox and total (adults and pups) fox abundance across all trapping grids on San Miguel Island, 2004–2016.

Year	Adults					Total (adults plus pups)				
	n	N	SE	80% CI	λ	n	N	SE	80% CI	λ
2014	72	335	50.95	276–407	.55	75	348	59.06	282–434	0.55
2015	72	646	126.54	504–829	1.93	79	677	139.11	523–880	1.95
2016	51	267	49.73	211–338	.41	56	291	61.30	224–381	0.43

n = number of trapped animals; N=estimated population size, SE= standard error, λ =annual rate of increase.

¹ 2004–2005 estimates determined using minimum number known alive (MNKA).

² 2006–2016 estimates determined using program secr.

Island Fox Recovery

To determine whether the San Miguel Island fox population was approaching biological recovery, three-year averages of adult abundance and adult mortality rate were plotted against fox extinction isoclines developed by Vickie Bakker (et al. 2009). The plots of 3-year averages for 2014–2016 show that the 80% confidence limits for both abundance and mortality fall below the 5% isocline, which is the acceptable level of risk identified in the USFWS island fox recovery plan (Figure 17) (USFWS 2015a). Although the San Miguel fox subspecies has returned to pre-decline population levels and now has six consecutive “boxes” below the 5% extinction isocline (Figure 17A) and can be considered biologically recovered, the recent decline in island-wide abundance and adult survival is worrisome.

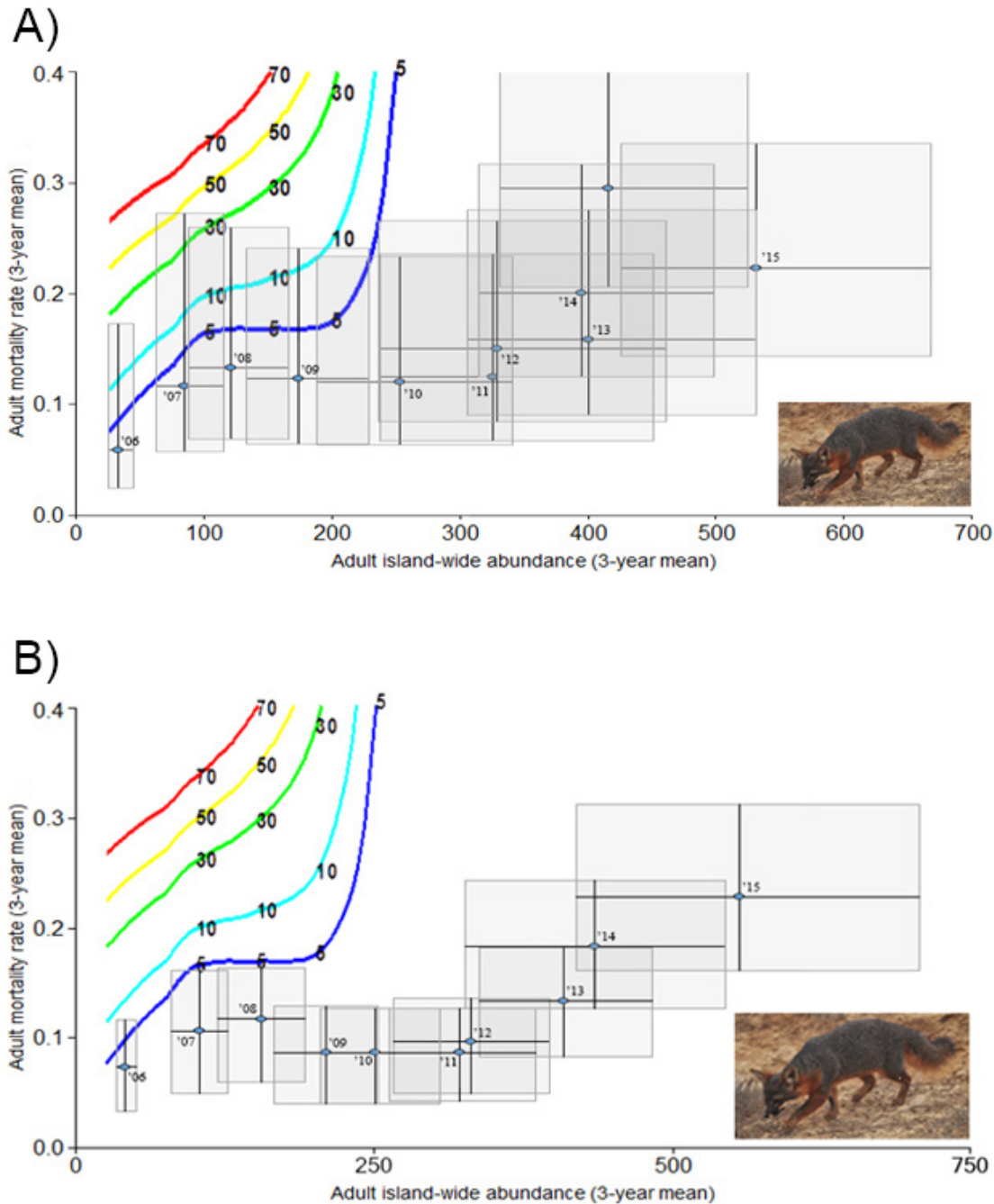


Figure 17. San Miguel Island adult fox extinction risk, 2004–2016. Colored isoclines represent the percent risk of fox extinction (5, 10, 30, 50, 70) over the next 50 years, grey boxes represent the outer extent of 80% confidence intervals for each parameter individually (3-year average abundance and 3-year average mortality rate), and data labels represent the last year of the 3-year averages. A) Extinction risk (2004–2016) with abundance determined over the “fox year” (2004–2016) via minimum number known alive (2004, 2005) and program *secur* (2006–2016) and mortality rate determined over the “fox year” (2004–2016) via known-fate models and B) Extinction risk from the 2015 Island Fox Recovery Program Report (2004–2015) with abundance determined over the “fox year” (2004–2015) via minimum number known alive (2004, 2005), program *Density* (2006–2014), and program *secur* (2015) and mortality rate determined over the calendar year (2004–2014) and “fox year” (2015) via known-fate models.

Santa Rosa Island

Fox Trapping

In 2016, fox grid trapping to estimate population density on Santa Rosa Island occurred in July through November, whereas target trapping to manage collars and administer vaccines occurred in July and December of 2016, and January 2017. A total of 238 individual foxes (77 pups, 161 adults) were captured a total of 666 times on 18 mini-grids in 2016. Additionally, in 2016, a total of 51 individual foxes (13 pups, 38 adults) were captured a total of 58 times during target trapping (Tables 2 & 3). Across both trapping methods 284 individual foxes (87 pups, 197 adults) were captured a total of 724 times in 2016 (Table 4).

Vaccination, Sentinel Animals, and Collection of Biological Samples

During the 2016 “fox year,” vaccines were administered to Santa Rosa Island foxes during both grid and transect trapping, with 30 foxes vaccinated against rabies only and 118 vaccinated against both rabies and canine distemper (Table 4). Additionally, 22 foxes received new radio collars, 8 of which replaced old collars. Of these 22 foxes, 21 were sentinels. Seven foxes that had active radio collars from previous years were captured again in 2016, five of which were sentinels. However, 42 foxes with active radio collars, of which 29 were sentinels, were not captured in 2016. During the 2016 trapping season a total of 55 individual foxes acted as sentinel animals, with 32–46 monitored at any given time. A total of 268 blood, 220 whisker, 53 urine, and 52 scat samples were also collected from 266, 219, 53, and 49 individual foxes respectively.

Fox Demographics

When foxes captured via trapping grids were stratified by age class on Santa Rosa Island, all age classes were represented, with a larger proportion of younger foxes than older foxes (Figure 18). The number of pups captured in 2016 was the highest recorded and along with 2015 was a steep increase from 2013 and 2014. The total number of adults and total number of foxes captured were also the highest recorded.

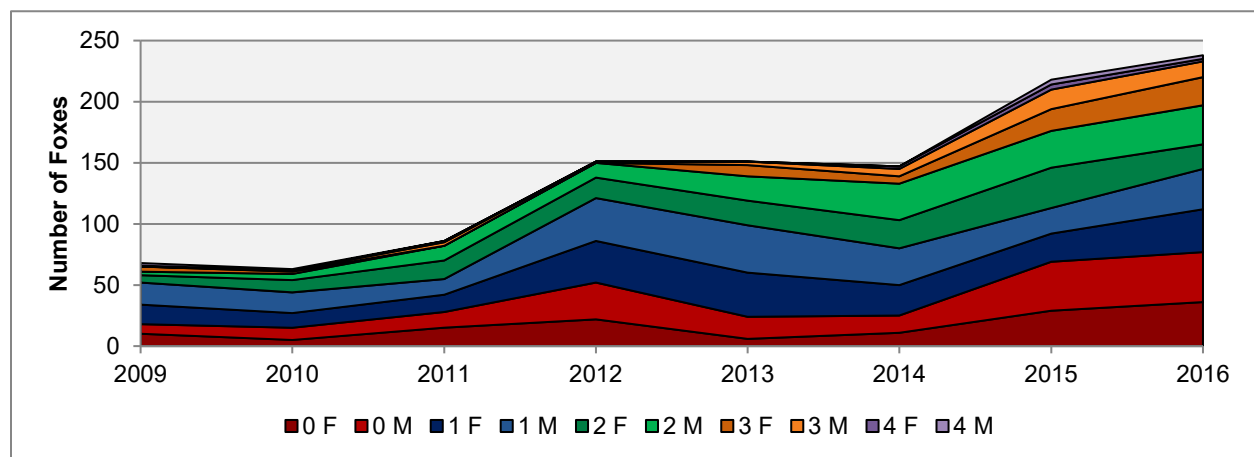


Figure 18. Number of female (F) and male (M) foxes captured in each age class (0–4) across all trapping grids on Santa Rosa Island, 2009–2016.

The average weight of adult female and male foxes trapped on grids on Santa Rosa Island in 2016 were a slight decline from the past three years, with females averaging 2.07 kg (80% CI = 2.02–2.11) and males averaging 2.21 kg (80% CI = 2.17–2.25) (Figure 19). In 2016, more foxes were classified as body condition 2 than body condition 3, and although the proportion of foxes classified as body condition 4 was the highest recorded so was the proportion of foxes in body condition 1 (Figure 20).

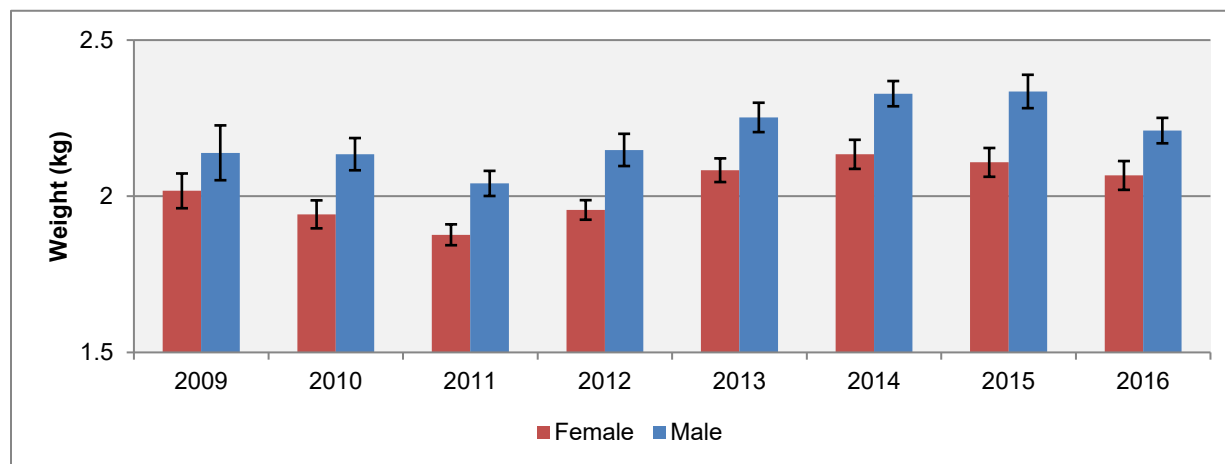


Figure 19. Average fox weight by sex, with 80% confidence intervals, across all trapping grids on Santa Rosa Island, 2009–2016.

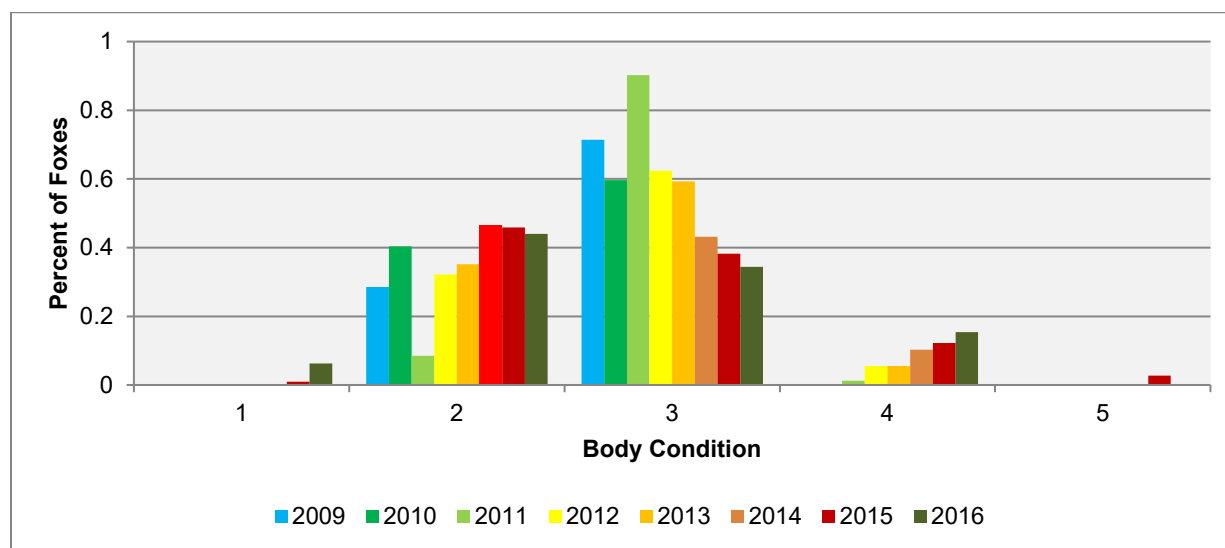


Figure 20. Percent of foxes in each body condition category (1–5) across all trapping grids on Santa Rosa Island, 2009–2016.

The proportion of adult females to adult males trapped on grids on Santa Rosa Island in 2016 was 0.99 (Figure 9). This was a slight decrease from last year when it was 1.10. The ratio of pups to adult females across all grids, an index of reproductive effort, was 0.96 in 2016 (Figure 21). Although this is a slight increase from 2015, it is a significant increase over the last three years and is approaching

a ratio of 1:1. When evaluating individual grids, 9 grids showed an increase in fox reproductive effort from last year, 8 showed a decrease and 1 remained the same.

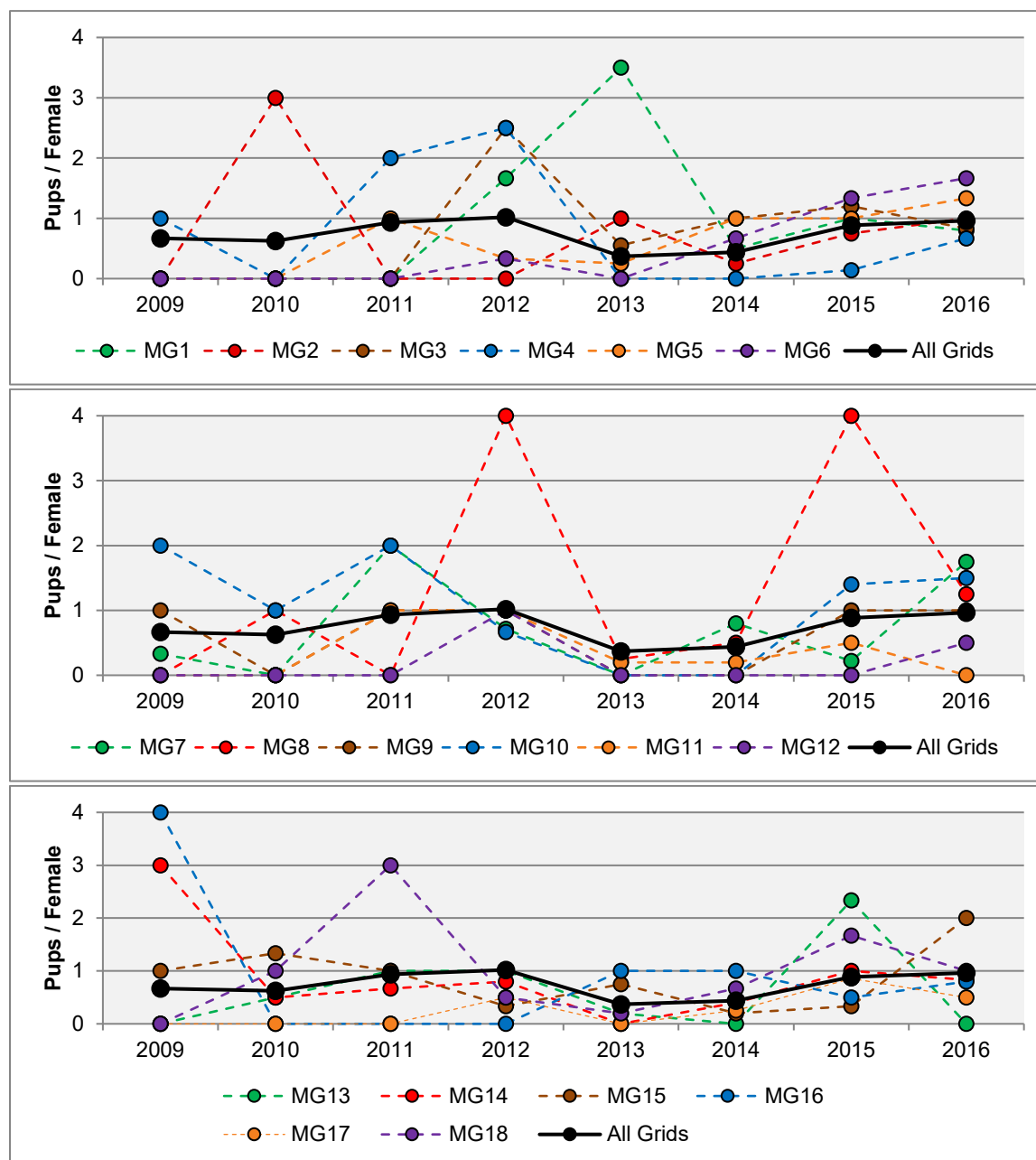


Figure 21. Reproductive effort (pups/adult females) of island foxes across all trapping grids and by individual grids MG1–6 (top), MG7–12 (middle) and MG13–18 (bottom) on Santa Rosa Island, 2009–2016. (MG1: Pocket Field, MG2: Bee Canyon, MG3: Arlington Springs, MG4: China Camp, MG5: Burma Road, MG6: Arlington Canyon, MG7: Dry Canyon, MG8: Verde Canyon, MG9: Lighthouse Road, MG10: Trancion Canyon, MG11: Signal Road, MG12: Johnsons Lee, MG13: Wreck Canyon, MG14: Quemada Canyon, MG15: Telephone Road, MG16: Carrington Point, MG17: Sierra Pablo, MG18: Old Ranch Canyon).

Fox Survival Monitoring

Throughout the 2016 “fox year” a total of 71 foxes (8 pups, 63 adults) were monitored via radio collars on Santa Rosa Island, with 38–54 foxes being monitored at any given time. To determine how closely collared foxes represented the fox population as a whole, the percent of adult foxes in each age class (Figure 22) and their sex ratio (Figure 23) were compared to foxes captured across all 18 trapping grids. In general, collared foxes seemed to represent the fox population as a whole, however collared foxes had a higher proportion of age class 2 and 4 individuals while fewer age class 1 individuals were collared compared to the proportion of age class 1 individuals trapped. Yearling foxes were targeted for disease monitoring, and thus collared foxes may not accurately represent the proportion of yearlings in the overall island population. Collaring decisions were driven by the capture success of foxes that could serve as disease sentinels.

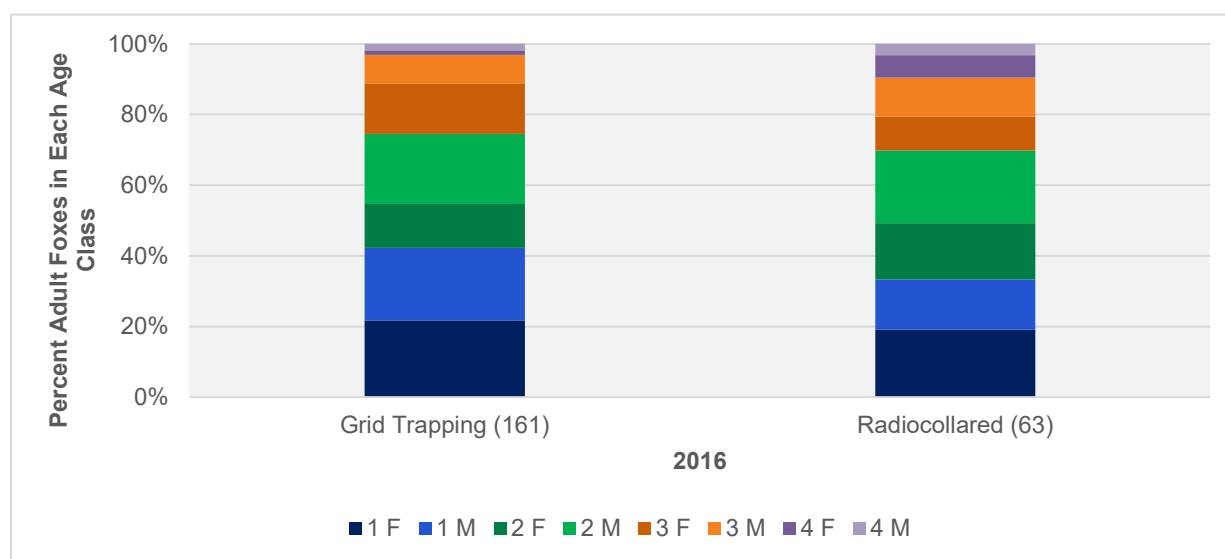


Figure 22. Percent of adult foxes in each age class (1–4) (including sample size) across all trapping grids and for all radio-collared individuals on Santa Rosa Island in 2016.

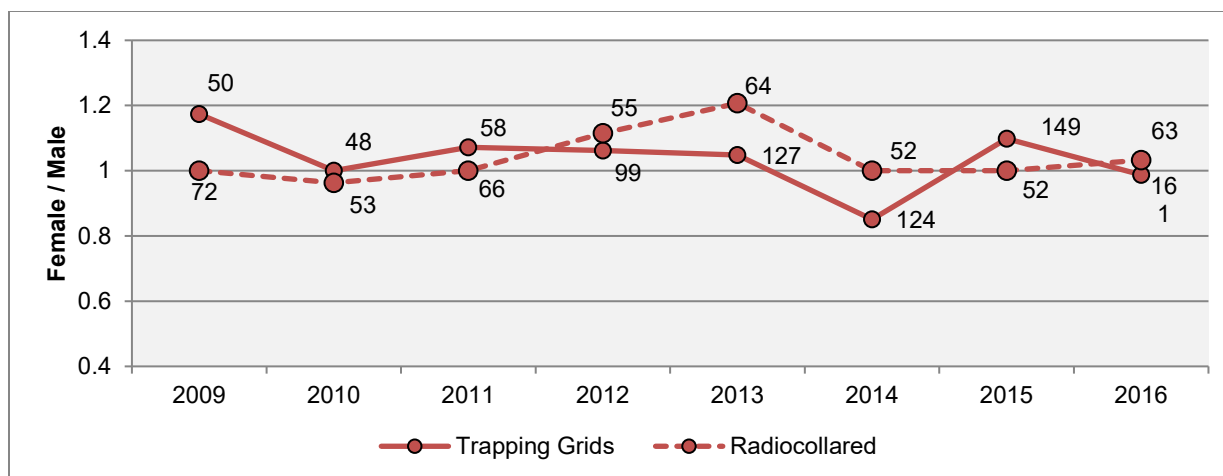


Figure 23. Sex ratio of adult foxes (including sample size) across all trapping grids and for all radio-collared individuals on Santa Rosa Island, 2009–2016.

Annual known-fate survival for adult island foxes in 2016 was 89.2% (n=63; 80% CI = 78.6–94.5%), which is the lowest fox survival since 2011, yet still relatively high (Figure 24). An annual survival rate of 80% or more is optimal for a stable or increasing fox population (Roemer et al. 2001). Six radio collared foxes died within the 2016 “fox year,” none from predation (Table 8).

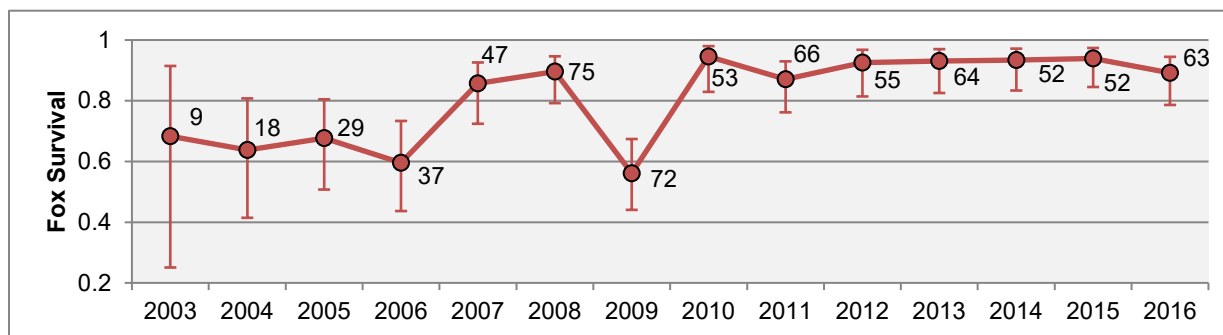


Figure 24. Adult fox survival with 80% confidence intervals and sample sizes on Santa Rosa Island, 2003–2016. Note: survival was determined for each “fox year” (May to April).

Table 8. Mortalities of radio collared foxes on Santa Rosa Island for the 2016 “fox year” (5/1/2016–4/30/2017).

ID	PIT Tag	Sex	Age	Born	Date	Mortality Cause
M123	16420	M	1	Wild	5/11/2016	Probable vehicle strike (Necropsy cancelled due to autolysis)
M114	26203	M	4	Wild	6/7/2016	No necropsy
F132	50E01	F	10	Wild	10/12/2016	No necropsy due to extreme decay
M113	39033	M	4	Wild	1/13/2017	Hemothorax, hemoabdomen (cause undetermined), no anticoagulant rodenticides detected
M136	55511	M	1	Wild	3/25/2017	No necropsy due to poor condition
M127	23830	M	2	Wild	4/20/2017	Leptospirosis, emaciation, colitis/spirocerca, renal mass, otitis externa, enlarged prostate

Fox Density / Abundance Estimation

The estimated island-wide density of adult island foxes on Santa Rosa Island in 2016 was 4.76 foxes/km² (80% CI = 4.10–5.51) (Figure 25, Figure 16, Table 9). Adult density ranged from a high of 15.31 foxes/km² on the MG5: Burma Road grid to a low of 1.69 foxes/km² on the MG9: Lighthouse Road grid. Due to the lack of data for individual grid analysis, models including behavioral components (b and B) were not included and all individual grid estimates were determined using the constant model. One grid (MG9: Lighthouse Road) did not have enough fox captures to estimate density using program *secr* so we divided the number of adult foxes captured by the average effective trapping area of the other 17 grids. Multiplying the island-wide density by the area of the island (215.53 km²) yielded a population estimate of 1,025 adult foxes (80% CI = 884–1188) (Figure 26, Table 10). Fox pups had an estimated density of 2.78 pups/km² (80% CI = 2.24–3.44) with a corresponding island-wide abundance of 598 pups (80% CI = 482–741). The estimated island-wide abundance of all foxes (adults and pups) was 1623 (80% CI = 1366–1929). When comparing both islands, the adult fox density on San Miguel (7.71 foxes/km²) is over 1.5 times more than the adult fox density on Santa Rosa (4.76 foxes/km²) (Figure 16).

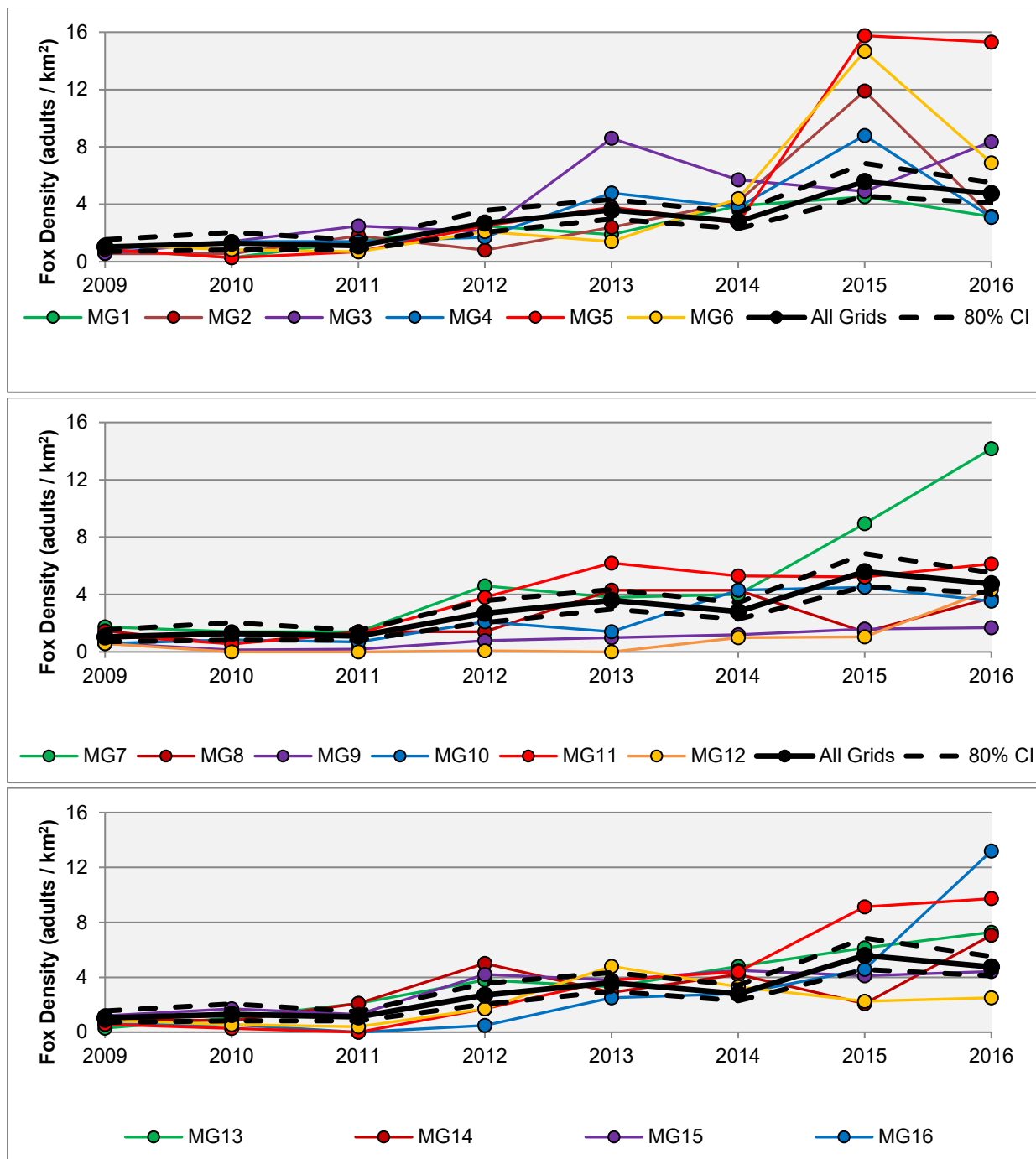


Figure 25. Adult fox density across all trapping grids and for individual grids MG1–6 (top), MG7–12 (middle) and MG13–18 (bottom) on Santa Rosa Island, 2009–2016. (MG1: Pocket Field, MG2: Bee Canyon, MG3: Arlington Springs, MG4: China Camp, MG5: Burma Road, MG6: Arlington Canyon, MG7: Dry Canyon, MG8: Verde Canyon, MG9: Lighthouse Road, MG10: Trancion Canyon, MG11: Signal Road, MG12: Johnsons Lee, MG13: Wreck Canyon, MG14: Quemada Canyon, MG15: Telephone Road, MG16: Carrington Point, MG17: Sierra Pablo, MG18: Old Ranch Canyon).

Table 9. Number of individual adult foxes captured (Ind.) and estimates of adult fox density for individual trapping grids (MG). Island-wide density via average of individual grids and island-wide density via all trapping grids combined on Santa Rosa Island, 2016.

Monitoring Grid	Dates	Ind.	Density (foxes/km ²)	SE	CV ¹
MG1: Pocket Field	8/31–9/5	8	3.15	1.87	.594
MG2: Bee Canyon	8/31–9/5	8	3.16	1.94	.614
MG3: Arlington Springs	10/12–10/18	10	8.36	3.45	.413
MG4: China Camp	11/9–11/14	6	3.09	1.51	.489
MG5: Burma Road	8/31–9/5	13	15.31	5.68	.371
MG6: Arlington Canyon	11/3–11/8	6	6.88	4.25	.618
MG7: Dry Canyon	11/16–11/23	11	14.16	8.49	.600
MG8: Verde Canyon	11/16–11/23	11	3.76	1.50	.399
MG9: Lighthouse Road	8/17–8/22	3	1.69	–	–
MG10: Trancion Canyon	8/17–8/22	10	3.54	2.55	.720
MG11: Signal Road	8/17–8/22	9	6.13	2.69	.439
MG12: Johnson's Lee	8/17–8/22	8	4.34	2.14	.493
MG13: Wreck Canyon	8/3–8/8	10	7.28	3.25	.446
MG14: Quemada Canyon	8/3–8/8	13	7.06	3.23	.457
MG15: Telephone Road	11/24–11/30	5	4.43	3.09	.698
MG16: Carrington Point	7/6–7/11	10	13.20	7.17	.543
MG17: Sierra Pablo	8/3–8/8	11	9.73	3.77	.387
MG18: Old Ranch	8/3–8/8	9	2.50	0.93	.372
Average Density	–	–	6.54	–	–
All Grids Combined	7/6–11/30	161	4.76	.55	.116

¹ Coefficient of variation (CV) is a standardized measure of dispersion of a probability distribution or frequency distribution and a value of 0.20 or lower is desirable. CV= SE/density.

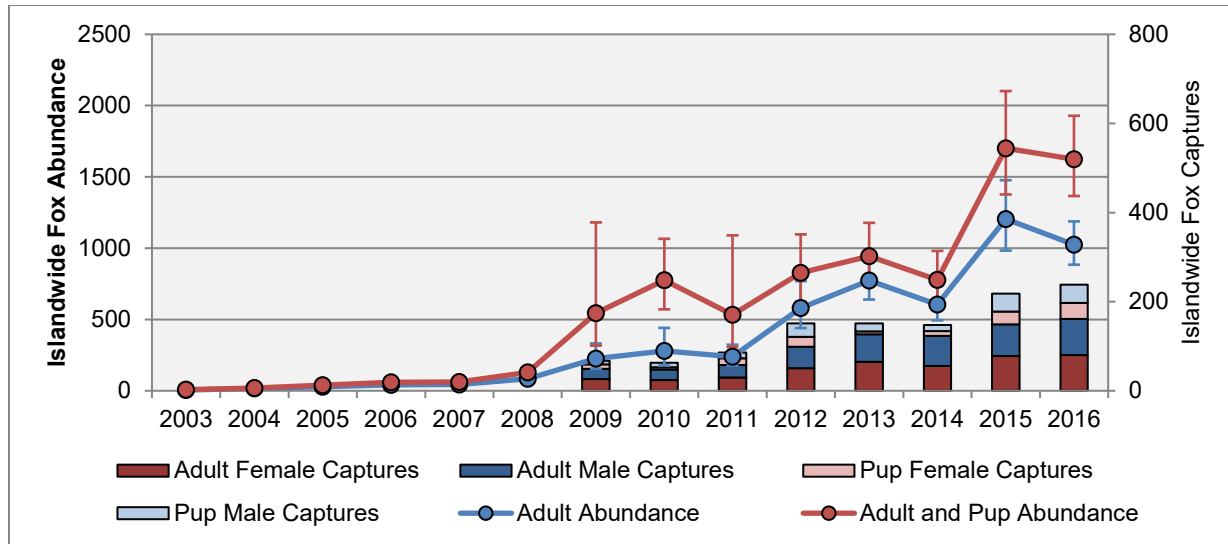


Figure 26. Island-wide fox abundance (adult and total) with 80% confidence intervals and the number of individual foxes captured, by age and sex, across all trapping grids on Santa Rosa Island, 2003–2016. Note: abundance estimates were determined via minimum number known alive (2003–2008) and program secr (2009–2016).

Table 10. Island-wide adult fox and total (adults and pups) fox abundance across all trapping grids on Santa Rosa Island, 2003–2016.

Year	Adults					Total (adults plus pups)				
	n	N	SE	80% CI	λ	n	N	SE	80% CI	λ
2003 ¹	–	5	–	–	–	–	8	–	–	–
2004	–	17	–	–	3.40	–	20	–	–	2.50
2005	–	29	–	–	1.71	–	40	–	–	2.00
2006	–	42	–	–	1.45	–	60	–	–	1.50
2007	–	45	–	–	1.07	–	62	–	–	1.03
2008	–	85	–	–	1.89	–	129	–	–	2.08
2009 ²	49	228	72.06	155–340	2.68	67	410	136.59	272–623	3.36
2010	48	279	102.67	177–441	1.22	63	392	133.32	258–600	0.96
2011	58	239	56.96	177–324	0.86	86	448	132.37	311–652	1.14
2012	99	581	128.29	440–769	2.43	151	859	170.88	667–1106	1.92

n = number of trapped animals; N=estimated population size, SE= standard error, λ =annual rate of increase.

¹ 2003–2008 estimates determined using minimum number known alive (MNKA).

² 2009–2016 estimates determined using program secr.

Table 10 (continued). Island-wide adult fox and total (adults and pups) fox abundance across all trapping grids on Santa Rosa Island, 2003–2016.

Year	Adults					Total (adults plus pups)				
	n	N	SE	80% CI	λ	n	N	SE	80% CI	λ
2013	127	774	115.09	640–935	1.33	151	963	155.78	786–1186	1.12
2014	123	605	95.97	494–740	0.78	148	778	135.00	625–971	0.81
2015	149	1205	192.58	983–1477	1.78	218	1701	282.85	1377–2102	2.19
2016	161	1025	118.82	883–1188	0.85	238	1623	220.07	1366–1929	0.95

n = number of trapped animals; N=estimated population size, SE= standard error, λ =annual rate of increase.

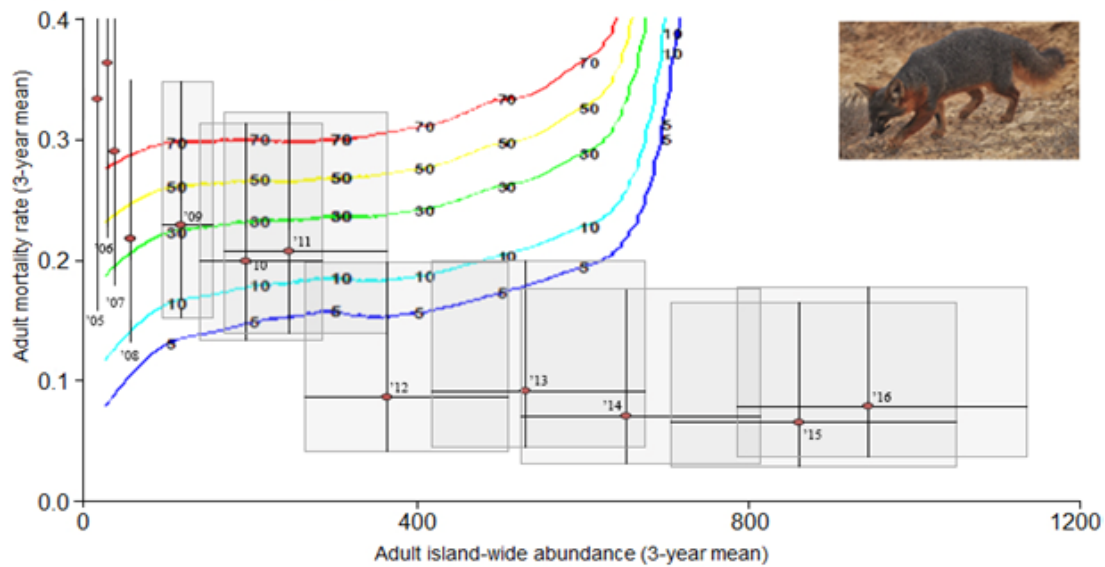
¹ 2003–2008 estimates determined using minimum number known alive (MNKA).

² 2009–2016 estimates determined using program secr.

Island Fox Recovery

To determine whether the Santa Rosa Island fox population was approaching biological recovery, 3-year averages of adult abundance and adult mortality rate were plotted against fox extinction isoclines developed by Vickie Bakker (et al. 2009). The plots of 3-year averages for 2014–2016 show that the 80% confidence limits for both abundance and mortality fall below the 5% isocline, which is the acceptable level of risk identified in the USFWS island fox recovery plan (Figure 27) (USFWS 2015a). The Santa Rosa Island fox population currently has three consecutive “boxes” below the 5% extinction isocline, and although five such consecutive values were previously identified for delisting, the USFWS moved forward to delist the island fox from the Endangered Species List in 2016 due to observed recovery trends.

A)



B)

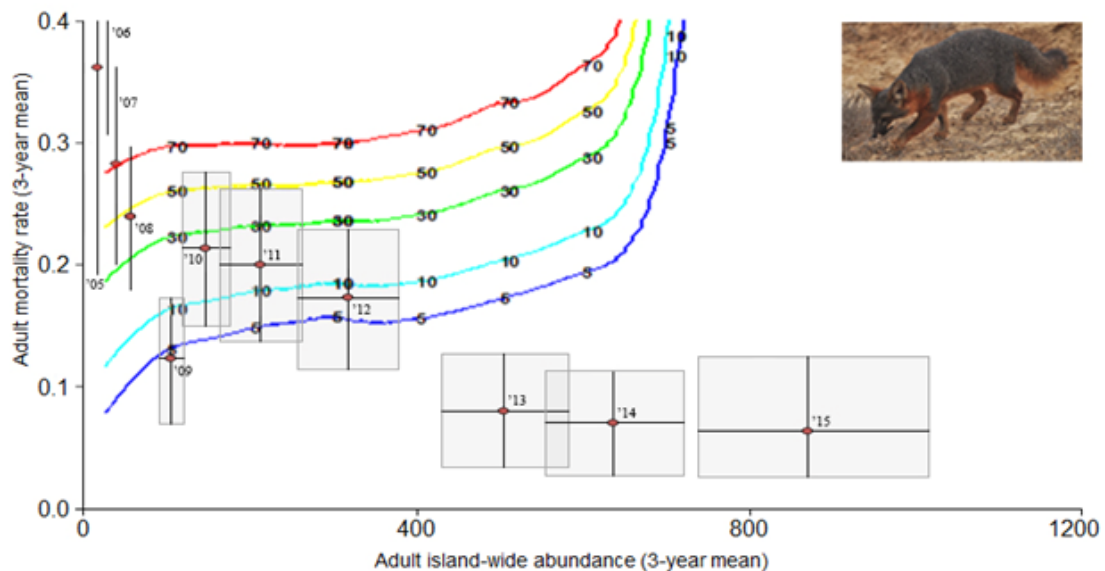


Figure 27. Santa Rosa Island adult fox extinction risk, 2003–2016. Colored isoclines represent the percent risk of fox extinction (5, 10, 30, 50, 70) over the next 50 years, grey boxes represent the outer extent of 80% confidence intervals for each parameter individually (3-year average abundance and 3-year average mortality rate), and data labels represent the last year of the 3-year averages. A) Extinction risk (2003–2016) with abundance determined via minimum number known alive (2004, 2005) and program *secr* (2006–2016) and mortality rate determined over the “fox year” (2003–2016) via known-fate models and B) Extinction risk from the 2015 Island Fox Recovery Program Report (2006–2015) with abundance determined via minimum number known alive (2006–2008), program *Density* (2009–2014), and program *secr* (2015) and mortality rate determined over the calendar year (2006–2014) and “fox year” (2015) via known-fate models.

Spotted Skunk Demographics and Density / Abundance Estimation

To evaluate the island spotted skunk population on Santa Rosa, skunk weights and sex ratio were analyzed across all 18 trapping grids. Over time the average weight of spotted skunks captured on the grids has generally increased. In 2016, the weight of an average skunk was 589 grams (female = 456 g, male = 685 g), which was a slight decrease from 2015 (Figure 28). The ratio of female to male skunks captured on the grids has gradually decreased over time, until this year where it increased substantially. This may be largely due to the smaller sample size of skunks in 2016 (n=23). In 2016 the ratio of female to male skunks was 0.92 (Figure 29).

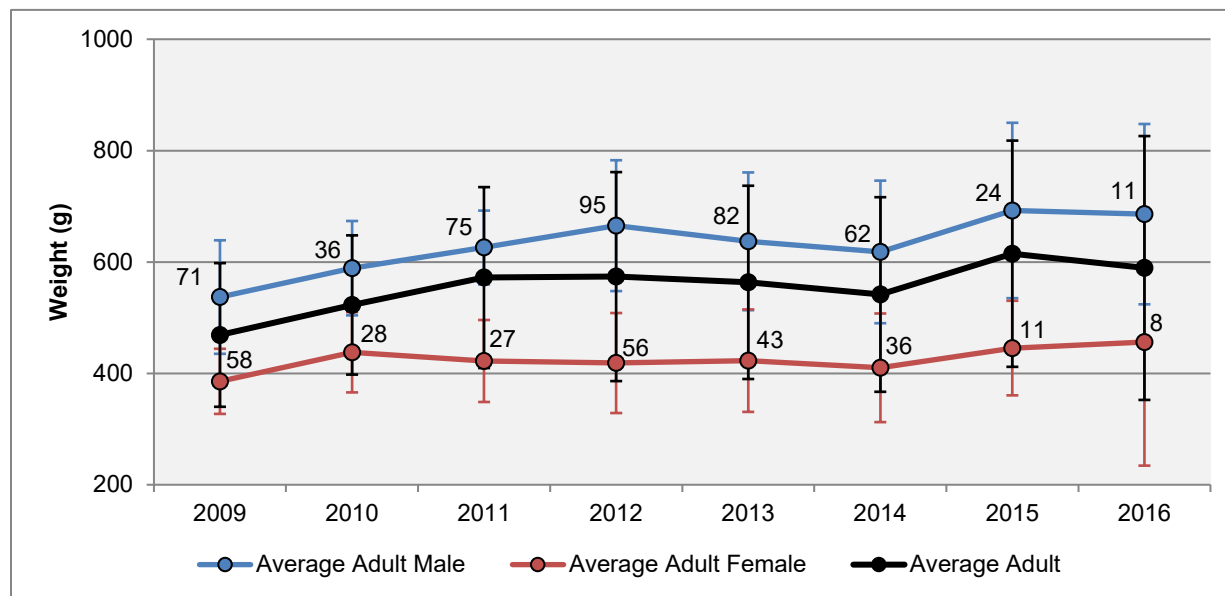


Figure 28. Average adult skunk weight by sex with 80% confidence intervals and sample size across all trapping grids on Santa Rosa Island, 2009–2016.

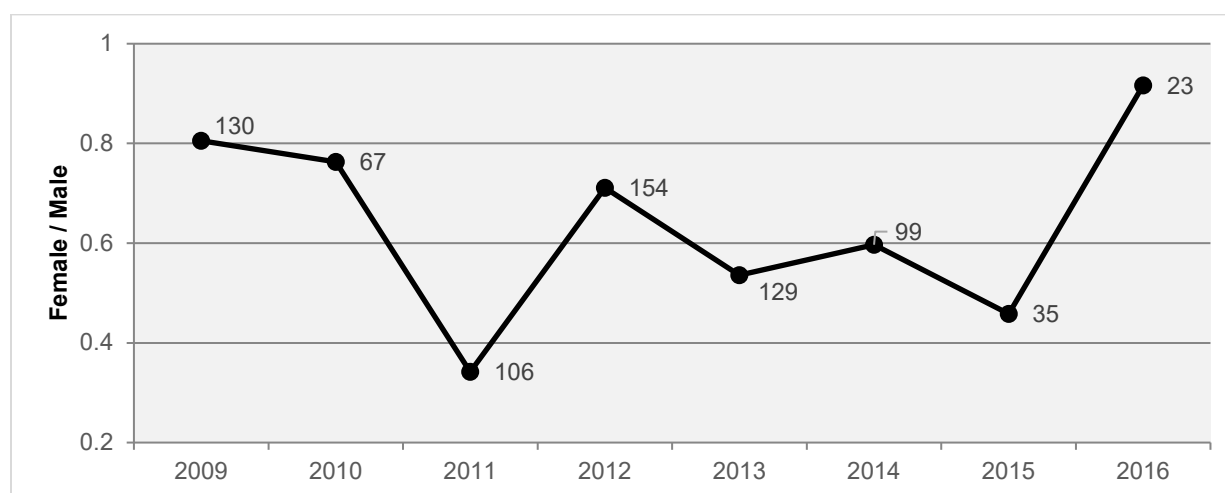


Figure 29. Skunk sex ratio (female/male) and sample size across all trapping grids on Santa Rosa Island, 2009–2016.

The estimated island-wide density of island spotted skunks on Santa Rosa in 2016 was 6.38 skunks/km² (80% CI = 3.37–12.07) (Figure 30, Table 11). In re-analyzing the skunk data from prior years with program *secr*, a number of years (2013, 2015–2016) had problems converging and models containing permanent behavior (b) had to be removed, resulting in a 16-model set. To stay consistent across years we removed the models containing permanent behavior (b) from each year’s analysis. For those years that contained enough captures to include permanent behavior (b) in the models (2009–2012, 2014), the removal of the models either did not alter the estimate at all (2014) or altered it minimally (2009–2012). Due to the lack of skunk captures (n=23) and recaptures (n=4) in 2016, we were only able to estimate skunk density across all grids using the constant model. Additionally, we were not able to estimate individual grid densities for skunks and instead reported the number of individual skunks captured on each grid. Captures on individual grids ranged from 6 skunks on MG9: Lighthouse Road grid to a low of 0 skunks on 9 of the grids. Multiplying the island-wide density by the area of the island (215.53 km²) yields a population estimate of 1374 (80% CI = 726–2601) (Table 12). Although this represents an almost 40% increase from the 2015 estimate(986), the 2016 estimate has a higher standard error and wider confidence intervals suggesting less confidence in the 2016 estimate. When we compare the density of spotted skunks to adult foxes on Santa Rosa Island over time, there is evidence that skunk density has decreased as the adult fox population has recovered and fox density increased (Figure 31).

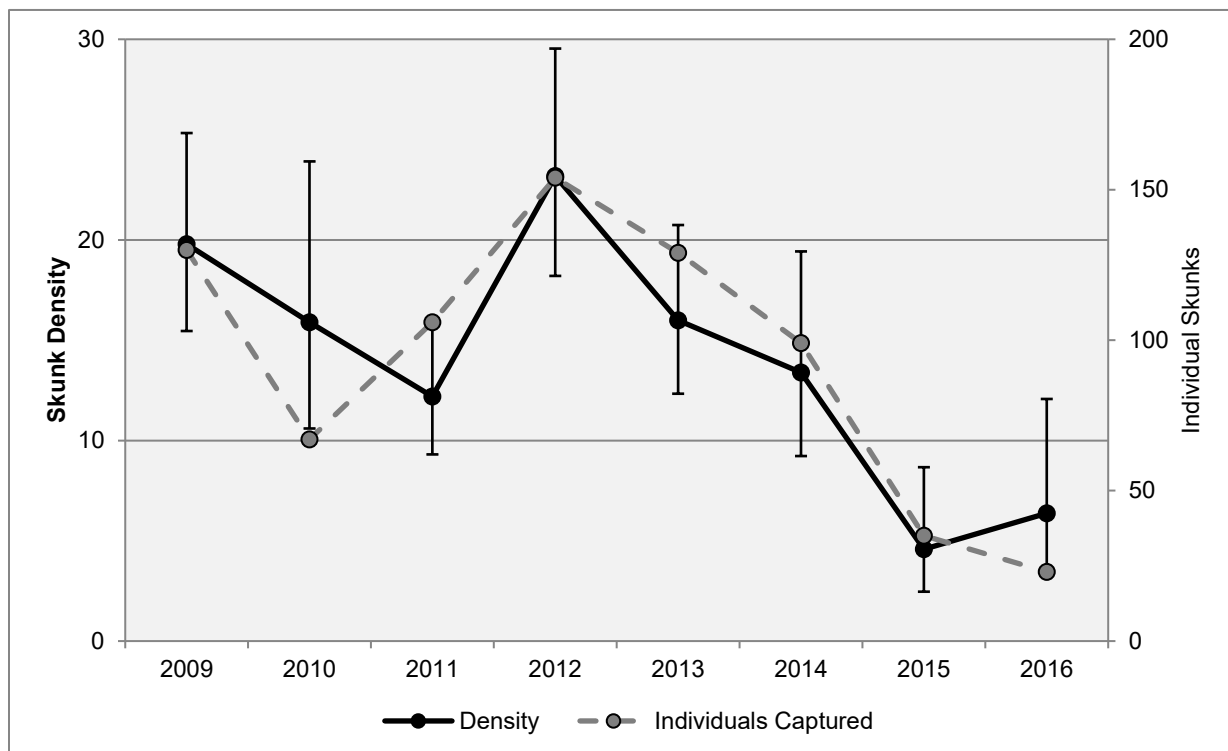


Figure 30. Spotted skunk density with 80% confidence intervals and number of individual skunks captured across all trapping grids on Santa Rosa Island, 2009–2016. Note: density estimates were determined via program *secr*.

Table 11. Number of individual island spotted skunks captured (Ind.) on each grid and the density and number of skunks captured across all trapping grids on Santa Rosa Island, 2016.

Monitoring Grid	Dates	Ind.
MG1: Pocket Field	8/31–9/5	0
MG2: Bee Canyon	8/31–9/5	0
MG3: Arlington Springs	10/12–10/18	0
MG4: China Camp	11/9–11/14	0
MG5: Burma Road	8/31–9/5	1
MG6: Arlington Canyon	11/3–11/8	2
MG7: Dry Canyon	11/16–11/23	1
MG8: Verde Canyon	11/16–11/23	0
MG9: Lighthouse Road	8/17–8/22	6
MG10: Trancion Canyon	8/17–8/22	0
MG11: Signal Road	8/17–8/22	0
MG12: Johnson's Lee	8/17–8/22	5
MG13: Wreck Canyon	8/3–8/8	2
MG14: Quemada Canyon	8/3–8/8	2
MG15: Telephone Road	11/24–11/30	3
MG16: Carrington Point	7/6–7/11	1
MG17: Sierra Pablo	8/3–8/8	0
MG18: Old Ranch	8/3–8/8	0
All Grids Combined	7/6–11/30	23
Density	–	6.38

Table 12. Island-wide spotted skunk abundance with 80% confidence intervals on Santa Rosa Island 2009–2016.

Year	n	N	80% CI	λ
2009	130	4263	3331–5458	–
2010	67	3427	2284–5153	.80
2011	106	2629	2005–3451	.77
2012	154	4997	3923–6366	1.9
2013	129	3446	2657–4470	.69
2014	99	2884	1988–4186	.84
2015	35	986	530–1868	.34
2016	23	1374	726–2601	1.39

n = number of trapped animals; N=estimated population size, CI= confidence interval, λ =annual rate of increase.
All estimates determined using program *secr*.

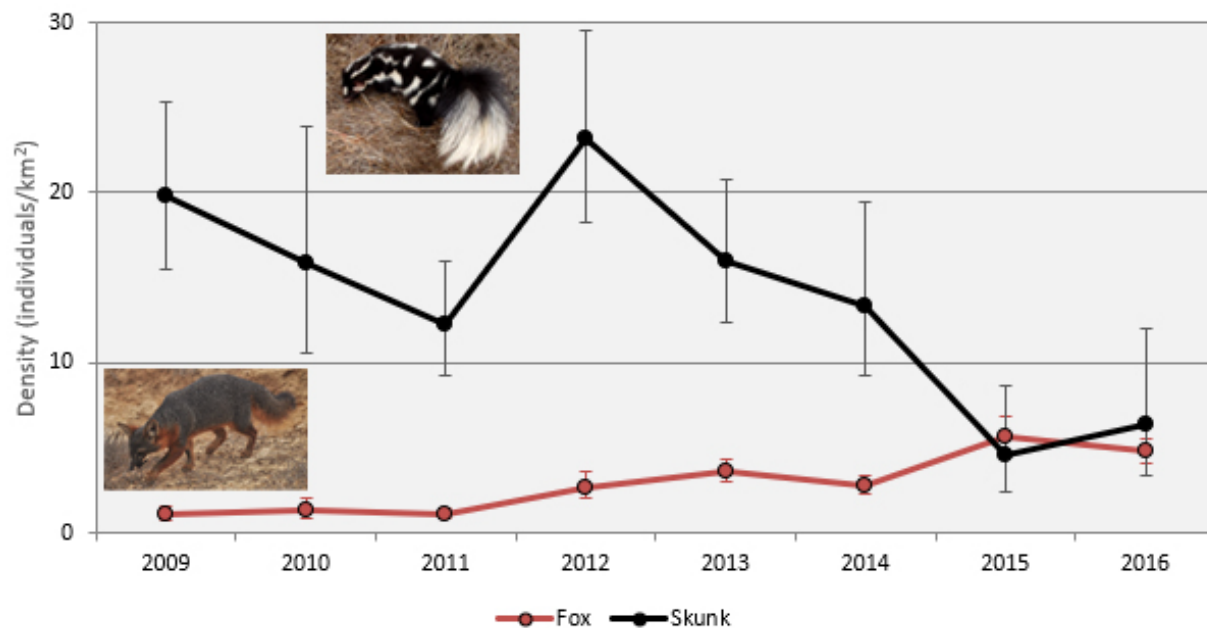


Figure 31. Adult fox density and island skunk density with 80% confidence intervals across all trapping grids on Santa Rosa Island, 2009–2016. Note: all density estimates determined via program *secr*.

Discussion

San Miguel Island

Following the dramatic decline of island foxes in the late 1990's and the release of captive foxes in the mid 2000's, the fox population on San Miguel began to steadily increase. In 2011 and 2012 the fox population decreased slightly, followed by years of dramatic population fluctuations, oscillating between densities of approximately 6 to 16 foxes/km². During this time, 2011–2016, the California Channel Islands were experiencing a prolonged drought which may have impacted food resources, pup production and population abundance across the islands. From 2013–2016 the pup production on San Miguel has been extremely low and the weight of an average adult fox has declined over the same time period. In 2016, the adult and total fox densities were 7.10 and 7.74 foxes/km² respectively, corresponding to an adult and total fox abundance of 267 and 291 respectively. The adult fox density and abundance in 2016 was a 58.6% decrease from 2015, when the highest recorded densities were observed on San Miguel Island. When estimating fox density on individual grids, the western and eastern most grids had higher density than the two central grids.

For this 2016 report we reanalyzed all past years' trapping data (SMI:2006–2016) using program *secr*. In this reanalysis we incorporated models that allowed for changes in behavior (i.e., trap happy or trap shy) and in every year except 2009, the most parsimonious model included a behavioral component, either permanent (b) or temporary (B), in either the probability of detection (g_0) or in the animal's movement parameter (sigma). When animals exhibit trap happy behavior they are more likely to be captured after their initial capture and/or have a smaller movement parameter following their initial capture (i.e., attracted to the trap). In this situation the same animals are continuing to get into the traps. If behavior is not included in the models the program inaccurately assumes that most, if not all, of the animals in the area have been captured and the density estimates will be biased low. If behavioral components are included in the model then the program assumes there are more animals on the landscape that are not being captured due to their trap happy behavior. In this situation the confidence intervals may be large because it is difficult to estimate how many animals are in the area that are not being caught. Conversely when animals exhibit trap shy behavior they are less likely to be captured after their initial capture and/or have a larger movement parameter following their initial capture (i.e., avoiding the trap). In this situation animals that are initially captured avoid the traps. If behavior is not included in the models the program inaccurately assumes that there are more animals in the area than there truly are because animals are avoiding the traps and not being recaptured resulting in density estimates that are biased high. If behavioral components are included in the model then the program assumes these captured animals are still in the area and just avoiding the traps due to trap shy behavior. Of the 10 years when the top model included a behavioral component, in all but three years (2007, 2010, 2015), foxes demonstrated trap happy behavior.

Since the estimates of adult fox densities on San Miguel fluctuated dramatically from 2012 to 2016, with only smaller changes in the number of adults captured between 2013 and 2015 (72–83), we explored potential explanations. We initially determined the overall “top” model across all years on San Miguel by averaging the AIC weight of each of the 28 models across all years (2006–2016). The top model (D.1.g.B.s.B) allowed for variation in the probability of capture (g_0) and in the movement

parameter (sigma) via temporary behavior (B) and accounted for an average AIC weight of 8.36%. We then used this single model to estimate adult fox density for each year. We repeated this with the constant model (D.1.g.1.s.1) which did not allow for variation in behavior or sex for either parameter. We then graphed these single model estimates against the model averaged estimates (Figure 32).

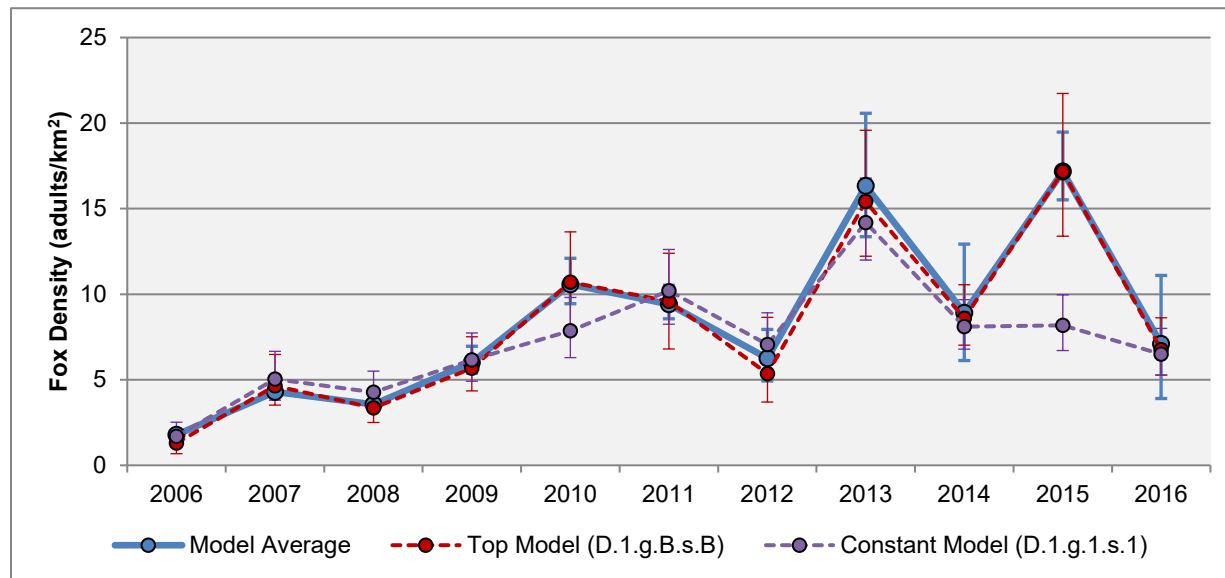


Figure 32. Model averaged and single model estimates of adult fox density across all trapping grids on San Miguel Island, 2006–2016. Note: density estimates were determined via program *secr*.

As expected, the annual density estimates of the top model tracked the model averaged estimates very closely. When the constant model estimates are compared against the model averaged estimates, most years track very closely, with the exception of 2015 and to a lesser degree year 2010. In 2010, the constant model contained 0% of the AIC weight, indicating there is no confidence in that model in accurately estimating fox density; whereas 8 of the total 28 models combined contained 100% of the AIC weight and all 8 of them included temporary behavioral components in one or both of the modeled parameters (g_0 and σ).

We then evaluated the annual estimates of the probability of capture (g_0) and movement (σ) over time on San Miguel. The probability of capture remained relatively constant over time and mostly ranging between 0.2 and 0.3 (Figure 33); whereas σ showed a relatively steady decline over time (Figure 34). As the fox population increases over time it's expected that their territories would get smaller and hence the movement parameter would decrease. However, it is interesting is that the exact same number of adult foxes were captured in 2014 and 2015 yet their movement parameters were quite different, indicating that the low density estimate in 2014 and the high density estimate in 2015 were mainly driven by the amount the foxes moved.

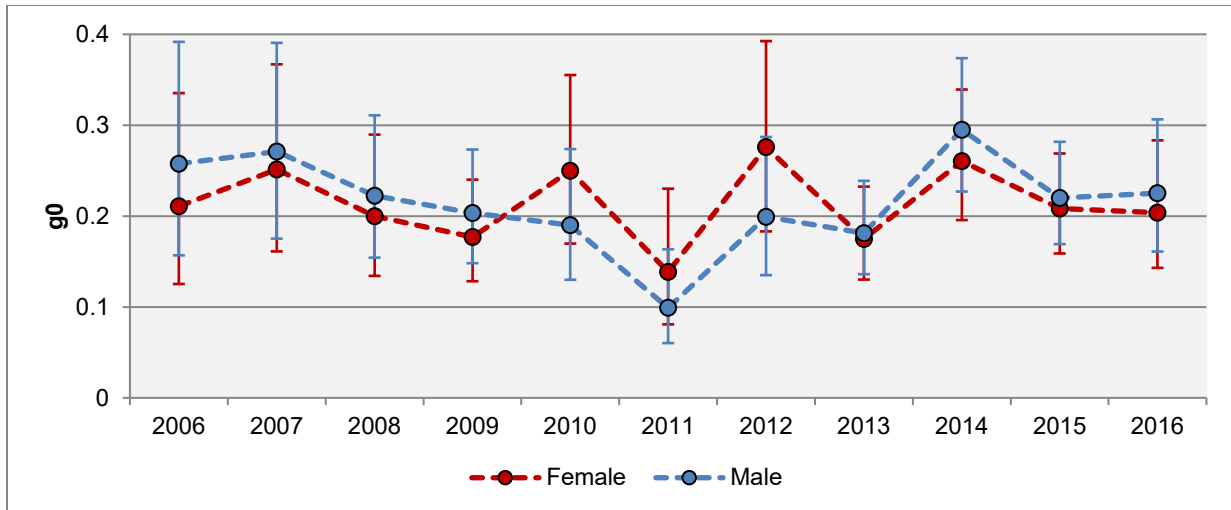


Figure 33. Annual estimates of the probability of capture (g_0) for female and male adult foxes on San Miguel Island. Note: estimates were determined via program *secr*.

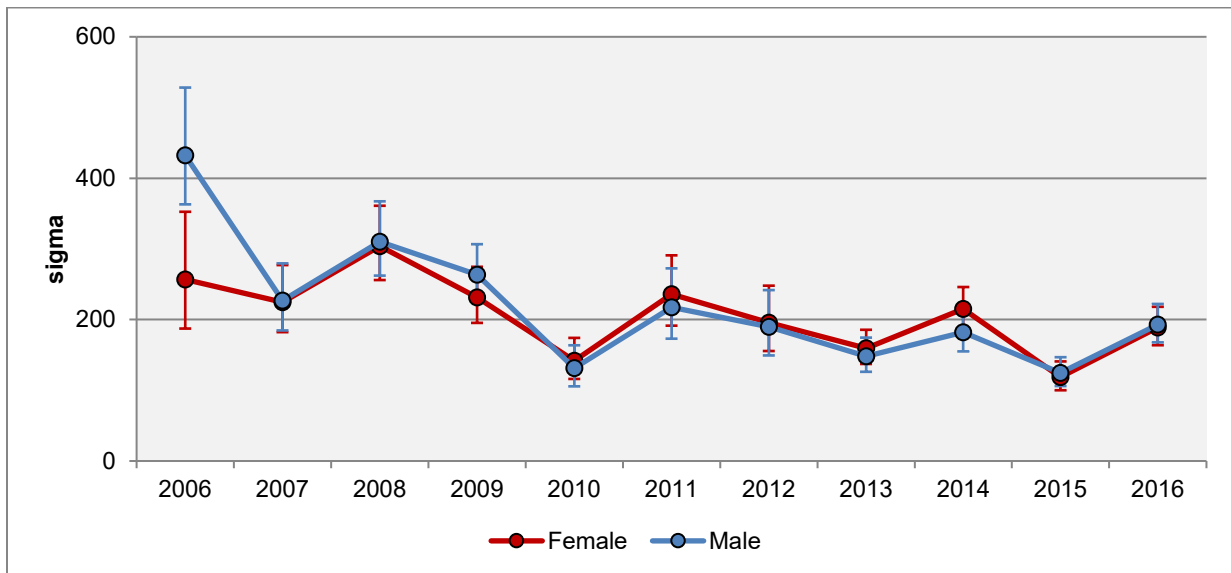


Figure 34. Annual estimates of the movement parameter (σ) for female and male adult foxes on San Miguel Island. Note: estimates were determined via program *secr*.

When the 2016 estimates of adult fox abundance and mortality were plotted against the extinction isoclines, the results indicated that the San Miguel fox population has returned to pre-decline levels and now has six consecutive “boxes” below the 5% extinction isocline, meeting the requirements for biological recovery. When past years’ fox data was reanalyzed foxes often demonstrated “trap happy” behavior and density estimates were higher and with more uncertainty to account for this. The higher density estimates with larger variation resulted in large recovery “boxes” but most of the “boxes” still remained outside the 5% extinction isocline. Following these results the San Miguel island fox subspecies was removed from the endangered species act in 2016 (USFWS 2015a, USFWS 2015b).

Although the recovery of the San Miguel Island fox subspecies is a success, further investigation of the 2016 fox data reveals some concerning trends in the population. The majority of the San Miguel fox population is made up of older adult foxes (age class 2 and 3), with very few pups captured. This is the fourth straight year that pup captures have been low and the third consecutive year that older age classes have comprised the majority of the population. The average weight of males and females has been declining in recent years with the 2016 values being some of the lowest recorded. Corresponding with low pup captures, reproductive effort was low for the fourth consecutive year. Additionally, the survival rate of San Miguel foxes has been steadily declining. Although the island-wide abundance and density of foxes on San Miguel is still relatively high, data indicates that the population is a thinner, lighter, and older population than in the past.

Some of the higher mortality and thinner, aging population may be due to the effects of extended drought and density-dependent regulation. Precipitation records from nearby Santa Rosa Island indicate that an extended regional drought has occurred for the past 5 years. Island fox density on San Miguel has been extremely high in past years and currently is over 1.5 times higher than on Santa Rosa. With a smaller island area, San Miguel is expected to have higher fox density than Santa Rosa, but smaller island area may also correlate with more dramatic fluctuations in fox abundance as their population responds quickly to the availability, or lack thereof, of food and/or territorial resources. These high fox densities most likely cause increased competition for limited food resources. The NPS's deer mouse (*Peromyscus maniculatus*) monitoring program has detected low numbers during the drought period and seven of the eight fox carcasses that were necropsied showed signs of emaciation. With high fox densities, it's possible that the fox population on San Miguel has reached, or possibly exceeded, carrying capacity.

Another factor in fox mortality on San Miguel is the recent appearance of an acanthocephalan parasite (*Prosthenorchis* spp.) that has not been recorded in island foxes before. Also called spiny-headed worms, acanthocephalans are endoparasites that require two hosts. Juvenile acanthocephalans are parasitic within insects or crustaceans, while the adults are parasitic in vertebrates, where they encyst in the intestinal wall and can cause intestinal perforation, lesions and peritonitis. Acanthocephalans (*Profilicolis* spp.) are known to cause mortalities in sea otters (*Enhydra lutris*) (Kreuder et al. 2003). Acanthocephalans were first identified in one San Miguel island fox carcass in January 2012, in which large acanthocephalans were found in the small intestine, and the fox was characterized as "severely parasitized" (L. Woods, California Animal Health and Food Safety Laboratory System, unpubl. data). From 2013 to 2015, acanthocephalans were found in 20 of 25 San Miguel island fox carcasses that were intact enough for necropsy (Coonan et al. 2014, Coonan et al. 2015, Dillon et al. 2015). Acanthocephalans were found in seven of eight carcasses analyzed between May 2016 and April 2017, sometimes with heavy loads. Most foxes with acanthocephalans also had significant infestation with another parasite, *Spirocerca*. It is unclear whether acanthocephalans are a cause of mortality for island foxes because the nature and the severity of the lesions are lost quickly through autolysis and by freezing the carcass; field necropsies may be necessary to reveal the true severity of lesions caused by acanthocephalans (L. Woods, California Animal Health and Food Safety Laboratory System, personal comm.).

The Island Fox Health Group, a subset of the IFCWG, considered the acanthocephalan cases on San Miguel at the 2013 and 2014 working group meetings, and recommended further investigation (Coonan 2013). Recent research has identified it as a possible new species of *Prosthenorchis* however surveys are needed to determine if the parasite occurs in either of the two lizard species (alligator lizard *Elgaria multicarinata* and western fence lizard *Sceloporus occidentalis*) or in invertebrate prey items on San Miguel. Island fox fecal samples have been collected for fecal floatation tests to determine if foxes are actively shedding eggs of the parasite, and specimens of potential hosts have been collected and sent to the California Animal Health and Food Safety Laboratory for testing. The Health Group did not think the current impact on foxes warranted treatment with anthelmintics, though that may be a possibility if a significant number of additional mortalities occurs.

Santa Rosa Island

The Santa Rosa Island fox population has increased dramatically since their past decline. Although population growth slowed over the past several years, possibly due to five years of extended drought, it has generally increased and is likely above its estimated pre-decline levels (Roemer et al. 1994). Despite this year's analysis resulting in a slightly decreased density and abundance estimate, overall the Santa Rosa fox population appears healthy. All age classes are represented in the population including a large number of young foxes. The population has a healthy average weight and body condition, a both a female to male ratio and reproductive effort of close to 1. More adults and pups were captured in 2016 than any prior year besides 2015, and overall the population appears to not yet be limited by resources. Four of the 18 individual trapping grids had an estimated density of 9–15 foxes/km², whereas 7 of the 18 grids had an estimated density of less than 4 foxes/km².

When the 2016 estimates of adult fox abundance and mortality were plotted against the extinction isoclines, the results indicated that the Santa Rosa fox population has returned to pre-decline levels and now has three consecutive “boxes” below the 5% extinction isocline. When past years' fox data was reanalyzed foxes often demonstrated “trap happy” behavior and density estimates were higher and contained more uncertainty to account for this. The higher density estimates and larger variation resulted in larger recovery “boxes” but most of the “boxes” still remained outside the 5% extinction isocline. Five consecutive years below this extinction risk were previously identified for delisting, however since this trend continued in 2016, the Santa Rosa Island subspecies was removed from the endangered species act in 2016 (USFWS 2015a, USFWS 2015b).

Island Spotted Skunks

Island foxes and island spotted skunks are thought to be competitors, most likely through interference competition, with island foxes being dominant (Roemer et al. 2002, Jones et al. 2008). Following the island fox declines in the late 1990s, the island spotted skunk populations on both Santa Rosa and Santa Cruz Islands increased. As the fox population on Rosa began to recover the skunk population remained high. However, since peak populations in 2012, the skunk population has decreased dramatically and their density and abundance are now similar than those of the island foxes. Although the decline in skunk captures, density and abundance strongly suggests a decline in the island spotted skunk population, there is also evidence that foxes may be out-competing skunks for

traps, thus limiting the number of skunks captured. In 2012, 153 individual skunks were captured across the trapping grids, whereas in 2016 only 23 individual skunks were captured, which corresponded to an increase in fox trapping success from 31.1% in 2012 to 67.0% in 2016. With fewer skunk captures each year, and low recapture rates, the current island fox monitoring protocol is not adequate to sample and monitor island spotted skunks populations in the future.

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The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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National Park Service
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