



Island Fox Recovery Program

Channel Islands National Park 2015 Annual Report

Natural Resource Report NPS/MEDN/NRR—2021/2308



ON THE COVER

Female island fox 86401, San Miguel Island, 1994

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Contents

	Page
Figures.....	v
Tables.....	vii
Executive Summary	viii
Acknowledgements.....	xi
Introduction.....	1
Background	1
Integrated Island Fox Recovery Team	2
Recovery Actions	2
Ecological Effects of Changes in Fox Abundance	4
Island Foxes and Long-Term Ecological Monitoring	5
Methods.....	6
Fox Trapping	6
San Miguel Island.....	7
Santa Rosa Island	8
Collection of Biological Samples	9
Vaccination and Sentinel Animals	9
Fox Demographics.....	10
Fox Survival Monitoring	10
Fox Density/Abundance Estimation.....	11
Island Fox Recovery.....	13
Spotted Skunk Demographics and Density / Abundance Estimation.....	13
Results.....	14
San Miguel Island.....	14
Fox Trapping	14
Vaccination, Sentinel Animals, and Collection of Biological Samples	15
Fox Demographics.....	15

Contents (continued)

	Page
Fox Survival Monitoring	18
Fox Density/Abundance Estimation.....	21
Island Fox Recovery	24
Santa Rosa Island	25
Fox Trapping	25
Vaccination, Sentinel Animals, and Collection of Biological Samples	25
Fox Demographics.....	26
Fox Survival Monitoring	29
Fox Density/Abundance Estimation.....	31
Island Fox Recovery	35
Spotted Skunk Demographics and Density/Abundance Estimation.....	36
Discussion	41
San Miguel Island.....	41
Santa Rosa Island	42
Island Spotted Skunks	43
Literature Cited	44

Figures

	Page
Figure 1. Adult island fox abundance (estimated number of individuals) with 80% confidence intervals on San Miguel (SMI) (1993–2015) and Santa Rosa Islands (SRI) (2003–2015).....	ix
Figure 2. Island fox tooth wear by age class.....	6
Figure 3. Location of trapping grids on San Miguel Island.....	8
Figure 4. Location of trapping grids on Santa Rosa Island.....	9
Figure 5. Number of female (F) and male (M) foxes captured in each age class (0–4) across all trapping grids on San Miguel Island, 2006–2015.....	16
Figure 6. Average fox weight by sex with 80% confidence intervals across all trapping grids on San Miguel Island, 2006–2015.....	16
Figure 7. Percent of foxes in each body condition category (1–5) across all trapping grids on San Miguel Island, 2006–2015.....	17
Figure 8. Adult fox sex ratio (females/males) across all trapping grids on San Miguel (SMI) (2006–2015) and Santa Rosa Islands (SRI) (2009–2015).....	17
Figure 9. Reproductive effort (pups/adult females) of island foxes across all trapping grids, and by individual grid, on San Miguel Island, 2006–2015.....	18
Figure 10. 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 2015.....	18
Figure 11. Sex ratio of adult foxes (including sample size) across all trapping grids and for all radio-collared individuals on San Miguel Island, 2006–2015.....	19
Figure 12. Adult fox survival with 80% confidence intervals and sample sizes on San Miguel Island, 2004–2016.....	20
Figure 13. Adult fox density across all trapping grids and for individual grids on San Miguel Island, 2006–2015.....	22
Figure 14. Adult fox density with 80% confidence intervals across all trapping grids on San Miguel (2004–2015) and Santa Rosa Islands (2003–2015).....	22
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, 2004–2015.....	24
Figure 16. San Miguel Island adult fox extinction risk, 2004–2015.....	25

Figures (continued)

	Page
Figure 17. Number of female (F) and male (M) foxes captured in each age class (0–4) across all trapping grids on Santa Rosa Island, 2009–2015.....	26
Figure 18. Average fox weight by sex, with 80% confidence intervals, across all trapping grids on Santa Rosa Island, 2009–2015.....	27
Figure 19. Percent of island foxes in each body condition category (1–5) across all trapping grids on Santa Rosa Island, 2009–2015.....	27
Figure 20. Reproductive effort (pups/adult females) of island foxes across all trapping grids and by individual grids A) MG1–6, B) MG7–12 and C) MG13–18 on Santa Rosa Island, 2009–2015.....	28
Figure 21. Percent of adult foxes in each age class (1–4) (including sample size) across all grid trapping and for all radio-collared individuals on Santa Rosa Island in 2015.....	29
Figure 22. Sex ratio of adult foxes (including sample size) across all grids and for all radio-collared individuals on Santa Rosa Island, 2009–2015.....	30
Figure 23. Adult fox survival with 80% confidence intervals and sample sizes on Santa Rosa Island, 2003–2015.....	31
Figure 24. Adult fox density across all trapping grids and by individual grids A) MG1–6, B) MG7–12 and C) MG13–18 on Santa Rosa Island, 2009–2015.	32
Figure 25. 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 Santa Rosa Island, 2003–2015.....	34
Figure 26. Santa Rosa Island adult fox extinction risk, 2006–2015.	36
Figure 27. Average adult skunk weight by sex with 80% confidence intervals across all trapping grids on Santa Rosa Island, 2009–2015.....	37
Figure 28. Skunk sex ratio (female/male) across all trapping grids on Santa Rosa Island, 2009–2015.....	37
Figure 29. Spotted skunk density with 80% confidence intervals and number of individual skunks captured across all trapping grids on Santa Rosa Island, 2009–2015.....	38
Figure 30. Adult fox density and island skunk density with 80% confidence intervals across all trapping grids on Santa Rosa Island, 2009–2015.....	40

Tables

	Page
Table 1. Descriptions of body condition scores used to rate captured foxes.	7
Table 2A. Number of foxes captured, by age and sex, across all trapping grids and target trapping on San Miguel, 2015.....	14
Table 2B. Number of foxes captured, by age and sex, across all trapping grids and target trapping on Santa Rosa Islands, 2015.	14
Table 3. Number of vaccinations administered and biological samples collected from individual island foxes across all trapping grids and target trapping on San Miguel and Santa Rosa Islands, 2015.	15
Table 4. Mortalities of radio collared foxes on San Miguel Island from 1/1/2015–4/30/2016.	20
Table 5. Number of individual adult foxes captured (Ind.) and estimates of adult fox density for individual trapping grids (MG).....	23
Table 6. Island-wide adult fox and total (adults and pups) fox abundance across all trapping grids on San Miguel Island, 2004–2015.	23
Table 7. Mortalities of radio collared foxes on Santa Rosa Island from 1/1/2015–4/30/2016.	31
Table 8. Number of individual adult foxes captured (Ind.) and estimates of adult fox density for individual trapping grids (MG).....	33
Table 9. Island-wide adult fox and total (adults and pups) fox abundance across all trapping grids on Santa Rosa Island, 2003–2015.....	34
Table 10. 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, 2015.....	38
Table 11. Island-wide spotted skunk abundance with 80% confidence intervals on Santa Rosa Island 2009–2015.....	39

Executive Summary

In 2015 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 and both populations increased in 2015.

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 allowed rapid growth of the small, recovering populations, and by the end of the 2015 “fox year” (5/1/2015–4/30/2016) the San Miguel Island fox population was estimated to be 646 adults and 31 pups, resulting in 677 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 2015 “fox year” (5/1/2015–4/30/2016) the Santa Rosa population was estimated to be 1205 adults and 496 pups, resulting in 1701 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.

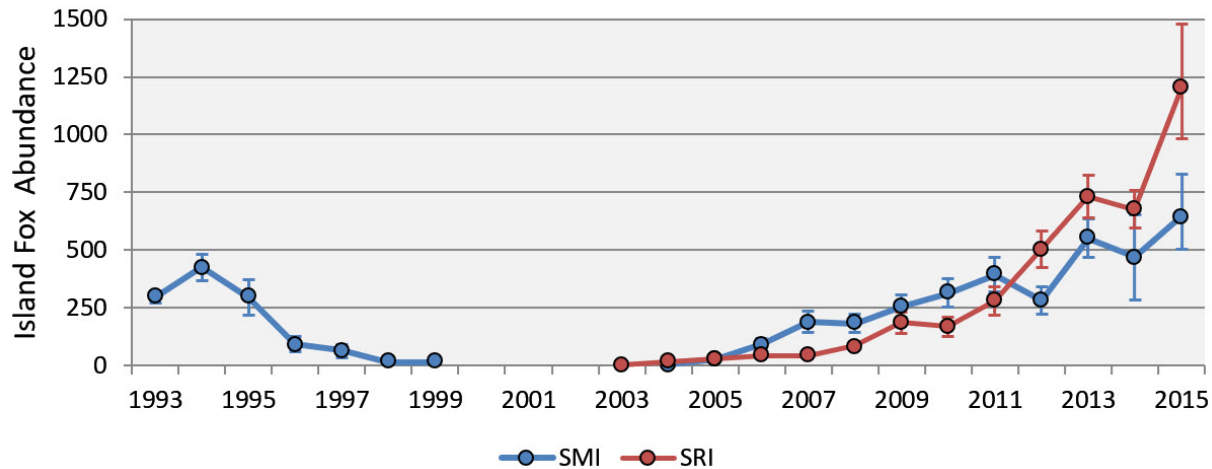


Figure 1. Adult island fox abundance (estimated number of individuals) with 80% confidence intervals on San Miguel (SMI) (1993–2015) and Santa Rosa Islands (SRI) (2003–2015). Note: abundance estimates were taken from previous reports (1993–1999), determined via minimum number known alive (2004, 2005), program *DENSITY* (2006–2014), and program *secr* (2015).

Adult fox survival on San Miguel was 76.6% during the 2015 “fox year”. This lower estimate of survival may potentially be due to density-dependent effects, continued drought, and the continued prevalence of a novel acanthocephalan parasite. Thirteen radio-collared foxes died on San Miguel during the 2015 “fox year.” Eight of the 13 foxes that could be necropsied since January 2015 had evidence of heavy infestation by an acanthocephalan parasite (*Prosthenorchis spp.*) with emaciation and enteritis (inflammation of the small intestine), while 10 of the necropsied foxes had a *Spirocerca* parasite infection in the colon. None of the fox mortalities showed signs of golden eagle predation. Adult fox survival on Santa Rosa was 93.9% during the 2015 “fox year” and only three radio-collared foxes died, all from unknown causes.

In 2015, approximately 59% of trapped foxes were vaccinated against rabies, 75% on San Miguel and 51% on Santa Rosa Island. The number of individual foxes vaccinated against rabies was 96 on San Miguel and 150 on Santa Rosa. Approximately 52% of trapped foxes were vaccinated against canine distemper virus (CDV) in 2015, 74% on San Miguel and 42% on Santa Rosa Island. The number of individual foxes vaccinated against canine distemper was 95 on San Miguel and 122 on Santa Rosa.

For the third straight year, reproduction was extremely low on San Miguel, where only seven pups were caught on the monitoring grids (32 were caught in 2012). A total of 69 pups were caught on Santa Rosa monitoring grids in 2015, up from 25 in 2014. Data on fox weights and body condition reflect the effect of the current drought and high fox density on San Miguel. Adult weights on San Miguel in 2015 declined for the third 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 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 impact of the parasite is unknown, because post-mortality tissue breakdown has 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 island fox trapping island spotted skunks are also captured and this data was used to analyze skunk demographics, density, and island-wide abundance. The average weight of captured skunk was 614 grams (male = 692, female 445), which is the heaviest average weight of skunks since the monitoring program began. Similar to previous years, the sex ratio (female/male) of skunk was heavily male biased (0.46). As in previous years, we were able to estimate island spotted skunk density and abundance on Santa Rosa Island since they were individually marked with passive integrated transponder (PIT) tags. We used program *secr* on skunk capture data from the 18 trapping grids to estimate a mean skunk density of 4.58 skunks/km² and an island-wide abundance of 986. This represents a dramatic decline over the past three years and the first time that skunk abundance has been lower than island fox abundance. After reaching highs 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 is questionable, especially as the island fox populations continue to increase.

Acknowledgements

We would like to thank our dedicated island fox crew for gathering the data for this report. Because of their efforts we have excellent information on the status and trend of island fox populations in the Channel Islands National Park (CHIS). Island fox field staff in 2015 comprised of Angela Guglielmino, Robyn Shea, Andy Abate, Stacy Baker, and a number of volunteers: Juliann Schamel, Desirae Thomaier, Melissa Marshall, and Michael Morales. The Santa Barbara Zoo continues to support our program by generously offering their staff for volunteer work on the islands. Zoo personnel who volunteered in the fox program for us included Cressa Moody and Mark Huelly. Thanks to Rich Block and Sheri Horiszny for making this collaboration possible.

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Introduction

Background

The island fox (*Urocyon littoralis*), a diminutive relative of the gray fox (*U. cinereoargenteus*), is endemic to the California Channel Islands. The fox is recognized as a different subspecies on each of the 6 largest islands, 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 as endangered four island fox subspecies, 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). The three NPS subspecies had declined in the mid- to late-1990s due to high levels of predation by golden eagles (*Aquila chrysaetos*), whereas the Santa Catalina subspecies had 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 island fox population on San Miguel declined from an estimated 450 adults in 1994 to 15 in 1999 (Coonan, Schwemm, et al. 2005). Foxes on Santa Rosa may have numbered more than 1,500 in 1994 (Roemer et al. 1994) but declined to 15 animals by 2000 (Coonan and Rutz 2001). The Santa Cruz population declined from as many as 2,000 adults in 1994 to 50–60 in 2000 (Coonan et al. 2010). Prior to implementation of island fox recovery efforts, Roemer (1999) estimated time to extinction at five years for island foxes on San Miguel and 12 years for island foxes on Santa Cruz.

Evidence from radio telemetry studies showed 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 from 1994 to 2000 (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, Schwemm, et al. 2005).

Until the 1990s, golden eagles had never been recorded breeding on the Channel Islands, and their recent colonization of the islands was due to a prey base, feral pigs (*Sus scrofa*) and mule deer (*Odocoileus hemionus*), that was not present prehistorically (Latta et al. 2005; Collins and Latta 2006). The absence of bald eagles (*Haliaeetus leucocephalus*), which bred historically on the islands and whose presence may have kept golden eagles away, may also have allowed golden eagle colonization of the islands (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; Coonan et al. 2015).

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 (TNC), 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 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.

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 requires 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) was appropriate (USFWS 2015b). The three subspecies on the Northern Islands were 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 amphiata*) 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 was begun 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 at which 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; Coonan, Schwemm, et al. 2005).

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 were borne of the 10-year 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 radio telemetry (Coonan, McCurdy, et al. 2005). 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 our efforts in 2015 to monitor island fox populations on San Miguel and 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 USFWS 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 2015 to January 2016, 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 2). 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, Idaho) 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.

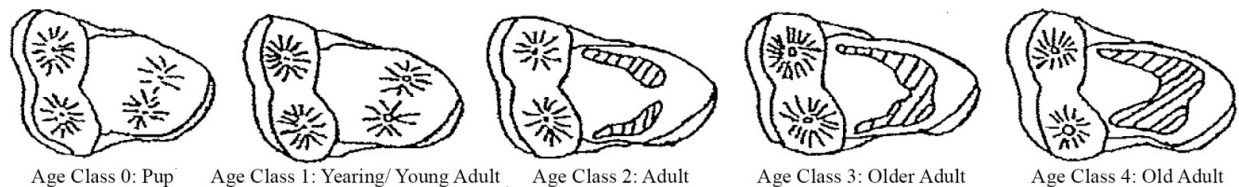


Figure 2. Island fox tooth wear by age class.

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.

Trapping data was collected on paper datasheets and entered into digital Excel tables. The tables were reviewed for errors shortly after entry and again at the end of the season. The Excel tables were then imported into NPS's Island Fox Access database, where 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.

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 with traps spaced 250 m apart. In 2007, the location of two grids were moved slightly, resulting in consistent trap locations from 2007–2015 (Figure 3). 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).

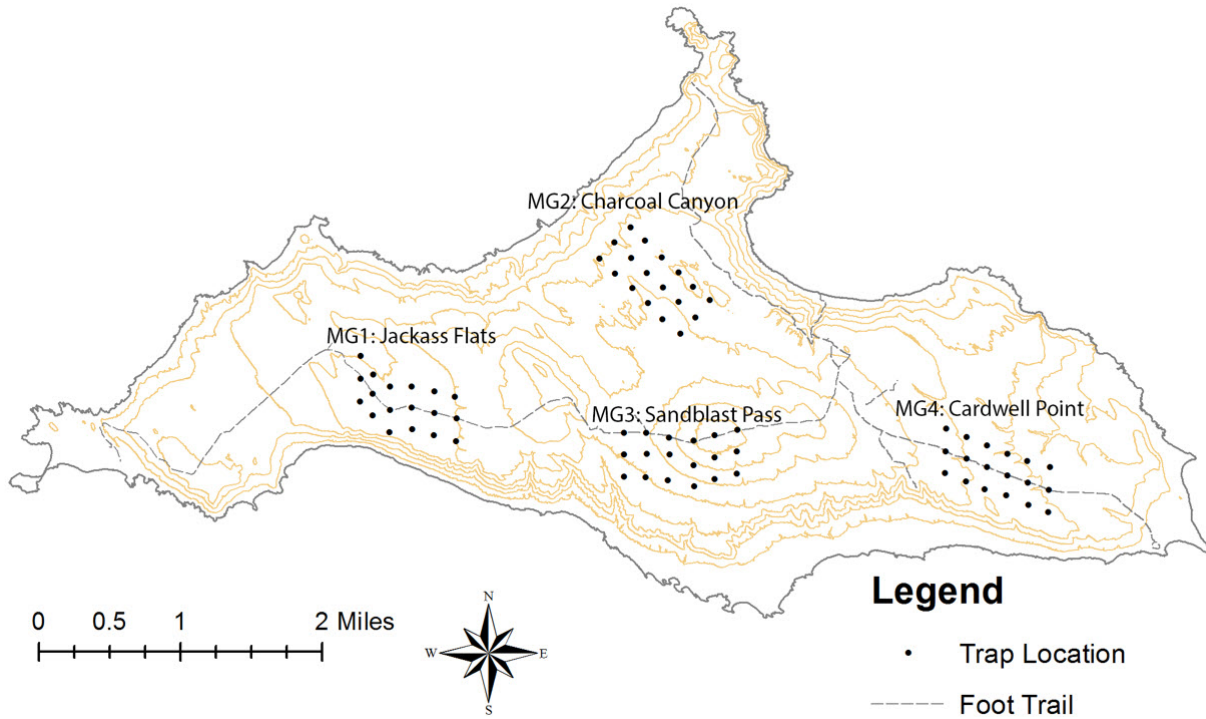


Figure 3. Location of trapping grids on San Miguel Island.

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 4). 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 the season.

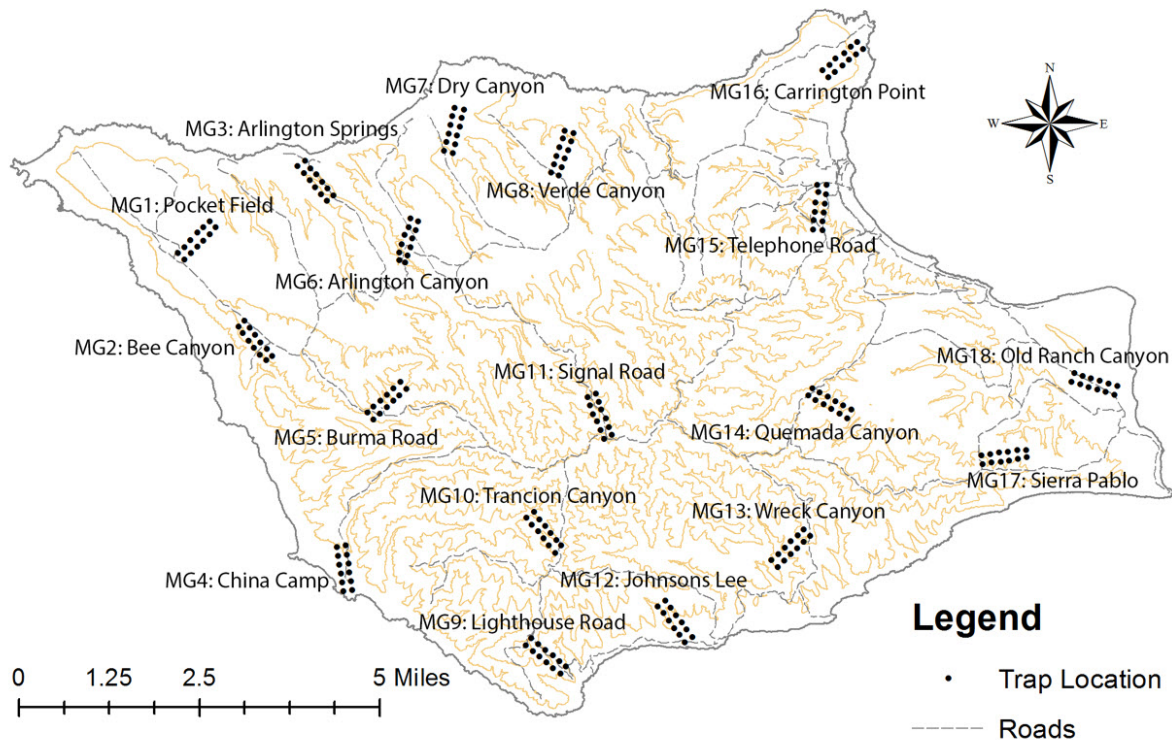


Figure 4. Location of trapping grids on Santa Rosa Island.

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. Additionally, a portion of the blood samples collected were sent to the American Museum of Natural History, under a national agreement between that institution and the NPS for archiving biological specimens of endangered species. 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 for rabies (Merial, Inc., Atlanta, GA). The Purevax Ferret Distemper Vaccine for CDV that had been approved for use in the past was not available in 2014 and 2015. In 2015 we were approved by USFWS and the IFCWG to use a new CDV vaccine, Recombitek Vaccine Canine Distemper (Merial, Inc., Atlanta, GA). Five collared foxes per island were vaccinated originally to test for any side effects, then the vaccine was administered to select foxes. A vaccine trial to examine antibody response to the new vaccine was conducted on 14 island foxes. The trial also tested for response differences in single versus double doses, and foxes receiving a booster. While annual boosters are necessary to maintain protective levels, double doses did not produce a higher immediate response (J. King, unpublished data). In 2015, we continued to establish a sample of non-vaccinated, radio collared sentinel animals on each island. In order to detect 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 the 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 in order 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 in 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 and 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.

In previous years 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 survival and adult fox abundance, we analyzed the adult fox survival in 2015 for the “fox year.” All estimates of adult fox survival prior to 2015 in this report were taken from previous reports and were determined for the calendar year. In the 2016 Island Fox Recovery Program Report all past adult fox survival estimates will be reanalyzed to reflect the “fox year” survival.

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) we used spatially explicit capture-recapture statistics via program *secr* (version 4.2.3, R version 3.02; Efford 2018) 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. We defined a habitat mask as having a buffer of 900 meters around all traps that was clipped to the shoreline of each island. We defined the grid cell spacing 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. Our 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. We determined the buffer and grid size values that corresponded to when changes in density estimates leveled off.

We used the full maximum likelihood estimator for multi-catch data and a half normal detection function for all models. Although the box traps we 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. But 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 we considered models 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 analysis 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).

We considered all possible additive combinations of effects on parameters, 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 population estimates were generated by multiplying island area by the average density across all grids. To estimate the density and abundance of fox pups we analyzed the pup capture data using the same set of 28 models that we used to estimate adult fox density and abundance. To estimate the total number of foxes we added the island-wide adult fox abundance 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 we analyzed the adults and pup data together and allowed density and both g_0 and σ to vary 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 the island. To estimate adult fox density for individual grids, only adult data from that grid were included in the analysis.

In previous years annual fox density and abundance estimates were determined using program *DENSITY* (Efford et al. 2004). Program *secr*, which was used to determine the 2015 estimates, is a newer version of program *DENSITY* and was developed by the same individuals. Additionally, previous annual fox density and abundance estimates were determined without including behavioral components into the models. Behavior can be an important factor in island fox capture patterns and the inclusion of behavior in the models can result in different estimates. All estimates, prior to 2015, of island fox density and abundance presented here were taken from previous annual reports, therefore they were determined via *DENSITY* and did not include behavioral components. In the 2016 Island Fox Recovery Program Report all past island fox density and abundance estimates will be reanalyzed using *secr* and will include behavioral components.

Island Fox Recovery

For both island fox subspecies we determined if 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 $1 - \text{annual survival}$). 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). We plotted 3-year averages of adult abundance and adult mortality to determine if those values resulted in acceptable extinction risk ($<5\%$ over 50 years). We used a spreadsheet tool developed by V. Bakker (Montana State University) to plot current values against isoclines, representing various levels of extinction risk for island foxes on each island (Bakker and Doak 2009).

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 female, male, 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. Similar to the island fox estimates, all estimates of island skunk density and abundance prior to 2015 in this report were taken from previous reports and were determined via *DENSITY*. In the 2016 Island Fox Recovery Program Report all past island skunk density and abundance estimates will be reanalyzed using *secr*.

Results

San Miguel Island

Fox Trapping

Fox grid trapping to estimate population density on San Miguel Island occurred in September 2015, whereas target trapping to manage collars and administer vaccines occurred intermittently from July 2015 through January 2016. A total of 79 individual foxes (7 pups, 72 adults) were captured a total of 158 times on 4 grids, whereas a total of 61 individual foxes (15 pups, 46 adults) were captured a total of 112 times during target trapping (Table 2). Across both trapping methods 128 individual foxes (20 pups, 108 adults) were captured a total of 270 times (Table 3).

Table 2A. Number of foxes captured, by age and sex, across all trapping grids and target trapping on San Miguel, 2015.

Age	Grid Trapping			Target Trapping		
	Female	Male	Total	Female	Male	Total
Pups	4	3	7	9	6	15
Adults	35	37	72	20	26	46
Total	39	40	79	29	32	61

Table 2B. Number of foxes captured, by age and sex, across all trapping grids and target trapping on Santa Rosa Islands, 2015.

Age	Grid Trapping			Target Trapping		
	Female	Male	Total	Female	Male	Total
Pups	29	40	69	14	17	31
Adults	78	71	149	30	22	52
Total	107	111	218	44	39	83

Table 3. Number of vaccinations administered and biological samples collected from individual island foxes across all trapping grids and target trapping on San Miguel and Santa Rosa Islands, 2015.

Vaccine / Sample	San Miguel	Santa Rosa
Total individual foxes	128	291
Total captures	270	725
Rabies vaccines / individuals	97 / 96	150 / 150
CDV vaccines / individuals	115 / 95	129 / 122
Blood samples / individuals	164 / 127	317 / 286
Whisker samples / individuals	153 / 122	314 / 288
Urine samples / individuals	0	198 / 177
Scat samples / individuals	36 / 32	93 / 73

Vaccination, Sentinel Animals, and Collection of Biological Samples

Vaccines were administered to San Miguel Island foxes during both grid and transect trapping, with two foxes vaccinated against rabies only, one vaccinated against canine distemper only, and 94 vaccinated against both rabies and canine distemper (Table 3). Throughout the 2015 “fox year” on San Miguel Island, 14 foxes received new radio collars, six of which replaced old collars. Of these 14 foxes, five of them were sentinels (i.e., never vaccinated against rabies or canine distemper). Eighteen foxes that had active radio collars from previous years were captured again in 2015, of which seven were sentinels. Additionally, 24 foxes with active radio collars, 15 of which were sentinels, were not captured in 2015. During the 2015 trapping season a total of 26 individual foxes acted as sentinel animals, with 20–22 sentinel foxes being monitored at any given time. A total of 164 blood, 153 whisker, and 36 scat samples were also collected from 127, 122 and 32 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 5). Only seven pups (age class 0) were captured in 2015, which was the third consecutive year that pup captures were low and the second 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 total number of adults and total number of foxes captured were similar to the past 2 years.

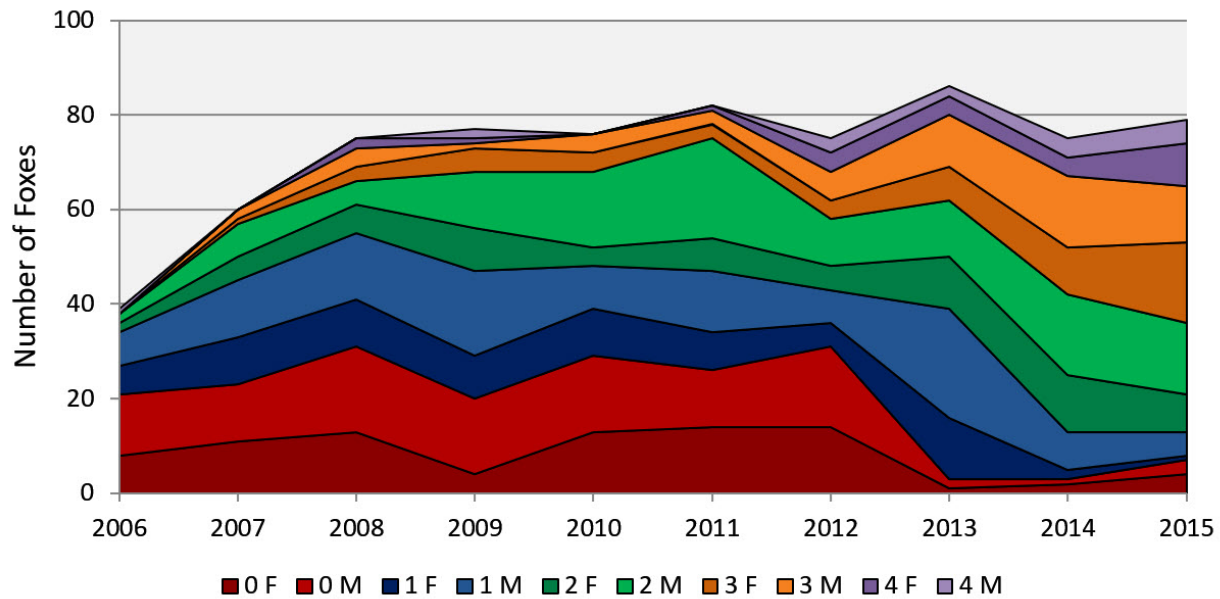


Figure 5. Number of female (F) and male (M) foxes captured in each age class (0–4) across all trapping grids on San Miguel Island, 2006–2015.

The average weight of adult female and male foxes on San Miguel Island in 2015 was the lowest recorded, with females averaging 1.87 kg (80% CI = 1.92–1.83) and males averaging 2.05 kg (80% CI = 2.10–2.00) (Figure 6). Coinciding with low adult fox weights, a higher proportion of foxes were classified as body condition 2 than body condition 3 in 2015 (Figure 7). This was the third consecutive year in which this is the case. Additionally, the proportion of foxes classified as body condition 1 in 2015 was the highest recorded.

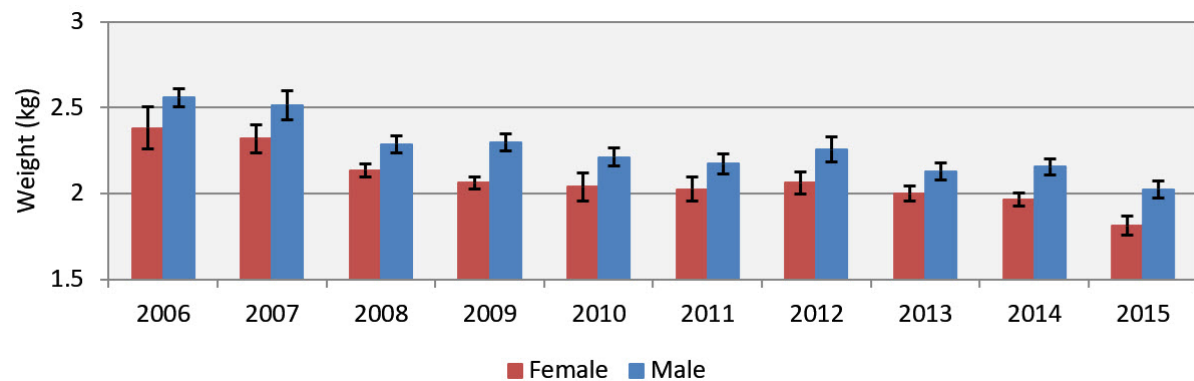


Figure 6. Average fox weight by sex with 80% confidence intervals across all trapping grids on San Miguel Island, 2006–2015.

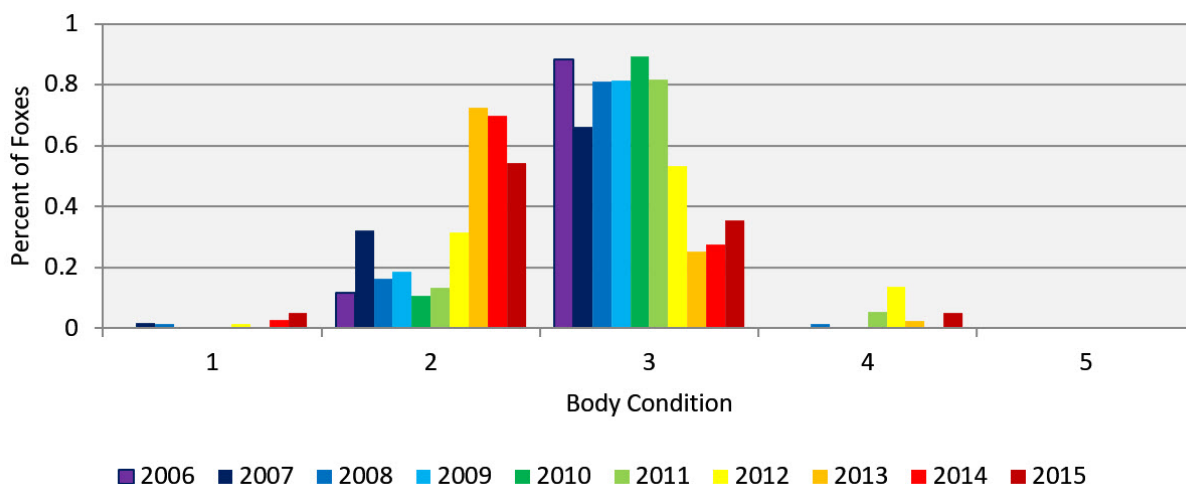


Figure 7. Percent of foxes in each body condition category (1–5) across all trapping grids on San Miguel Island, 2006–2015.

In 2015, the ratio of adult female to adult male foxes on trapping grids on San Miguel Island was 0.95 (Figure 8). This ratio has been steadily increasing since 2011 when it was the lowest ever recorded. Although the 2015 value is still below 1, it is the highest recorded ratio on San Miguel Island.

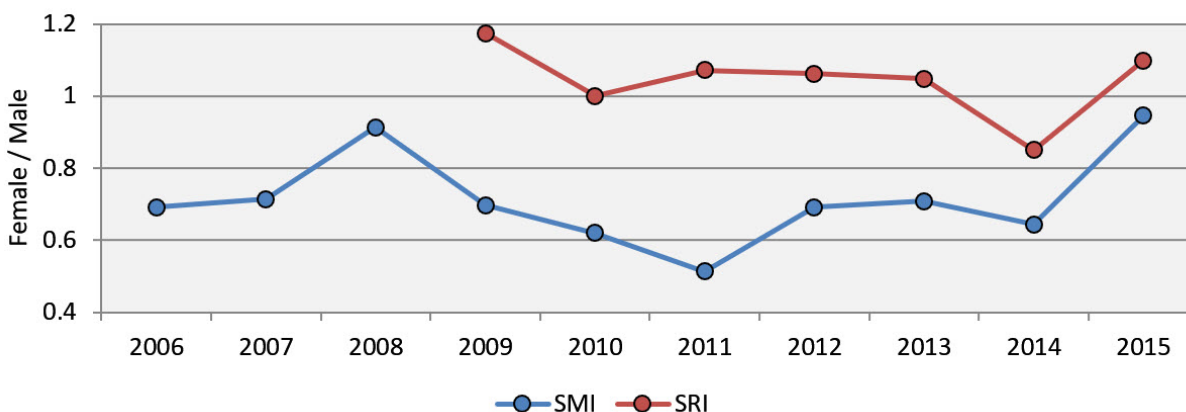


Figure 8. Adult fox sex ratio (females/males) across all trapping grids on San Miguel (SMI) (2006–2015) and Santa Rosa Islands (SRI) (2009–2015).

The ratio of pups to adult females across all grids, an index of reproductive effort, was 0.20 in 2015 on San Miguel Island (Figure 9). This is the third consecutive year where reproductive effort was low (< 0.30), although it was a slight increase over the last two years. When separated by individual grids, three grids showed low reproductive effort (< 0.30) but the Jackass Flats (MG1) grid had a reproductive effort of 0.57, an increase from the last two years.

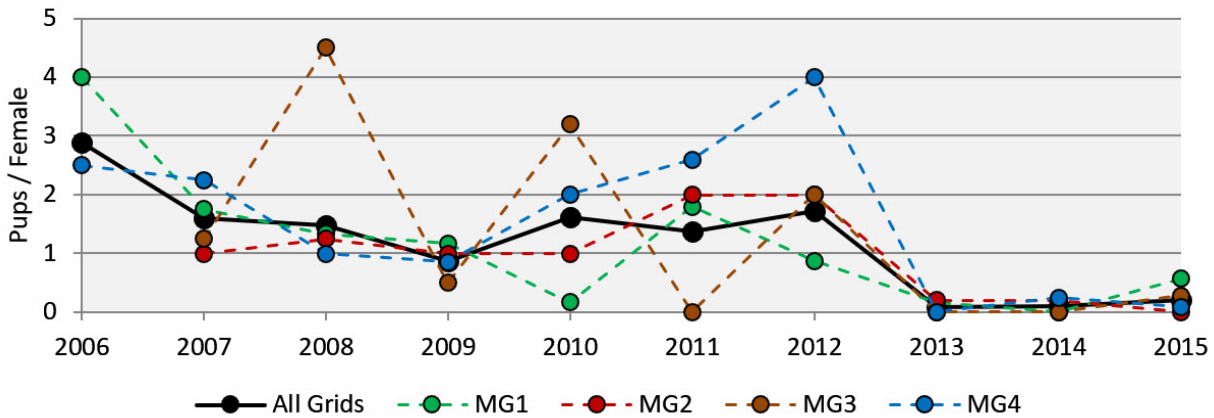


Figure 9. Reproductive effort (pups/adult females) of island foxes across all trapping grids, and by individual grid, on San Miguel Island, 2006–2015. (MG1: Jackass Flat, MG2: Charcoal Canyon, MG3: Sandblast Pass, MG4: Cardwell Point).

Fox Survival Monitoring

Throughout the 2015 “fox year,” a total of 57 foxes (1 pup, 56 adults) were monitored via radio collars on San Miguel Island, with 43–48 foxes being monitored at any given time. To determine how closely collared foxes represented the fox population as a whole we compared the percent of adult foxes in each age class (Figure 10) and their sex ratio (Figure 11) to foxes captured across all 4 trapping grids. In general, collared foxes seemed to fairly represent the fox population as a whole, however collared foxes had a higher proportion of both female foxes and age class 1 individuals compared to trapped foxes. Yearling foxes are targeted for disease monitoring as thus may not accurately represent the proportion of yearlings in the overall island population.

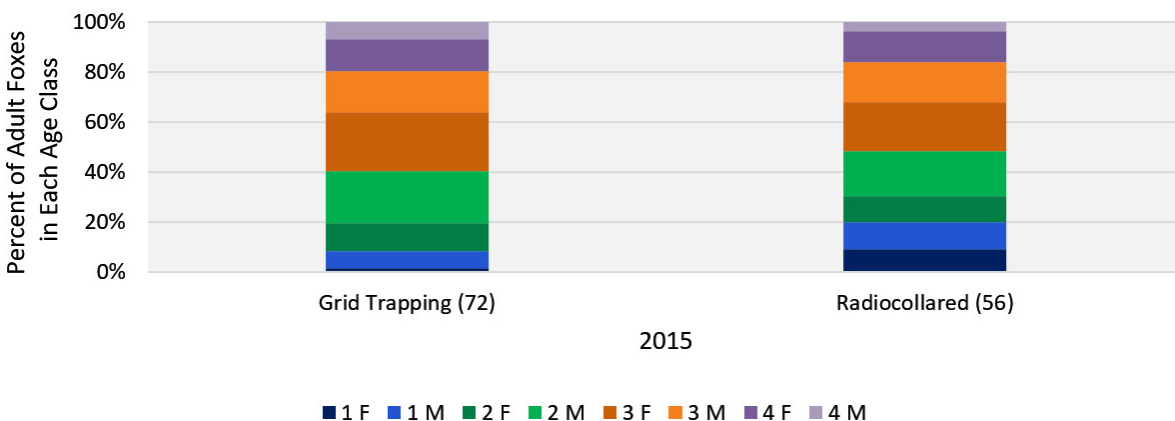


Figure 10. Percent of adult foxes in each age class (1–4) (including sample size) across all trapping grids and for all radio-collared individuals on San Miguel Island in 2015.

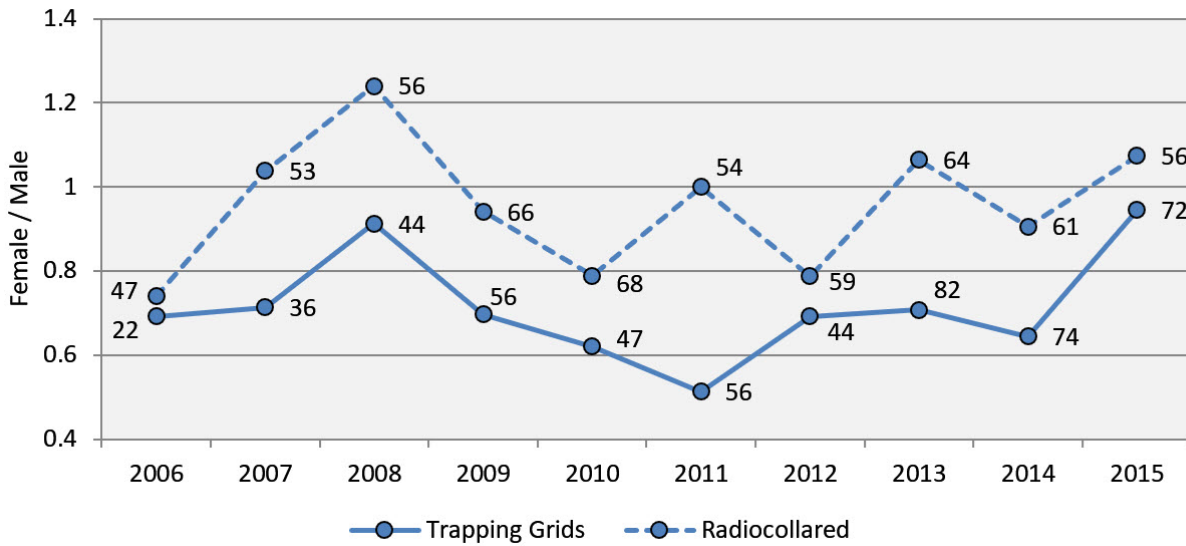


Figure 11. Sex ratio of adult foxes (including sample size) across all trapping grids and for all radio-collared individuals on San Miguel Island, 2006–2015.

Annual known-fate survival for adult island foxes in the 2015 “fox year” was 76.6% ($n=56$; 80% CI = 65.3–84.7%) (Figure 12). To align with annual adult fox abundance estimates, the adult island fox survival in 2015 was determined for the “fox year”, whereas all previous fox survival estimates were determined for the calendar year. Annual adult survival was relatively low for the third straight year on San Miguel. An annual adult survival rate of 80% or more is optimal for a stable or increasing fox population (Roemer et al 2001). Thirteen radio collared foxes died (7 female, 6 male) within the 2015 “fox year,” with none from eagle predation but signs of disease or parasites were detected in 10 of the 13 carcasses. Five additional radio collared foxes died (1 female, 4 male) in 2015, prior to the start of the 2015 “fox year,” none from eagle predation but three of the five had signs of disease or parasites (Table 4).

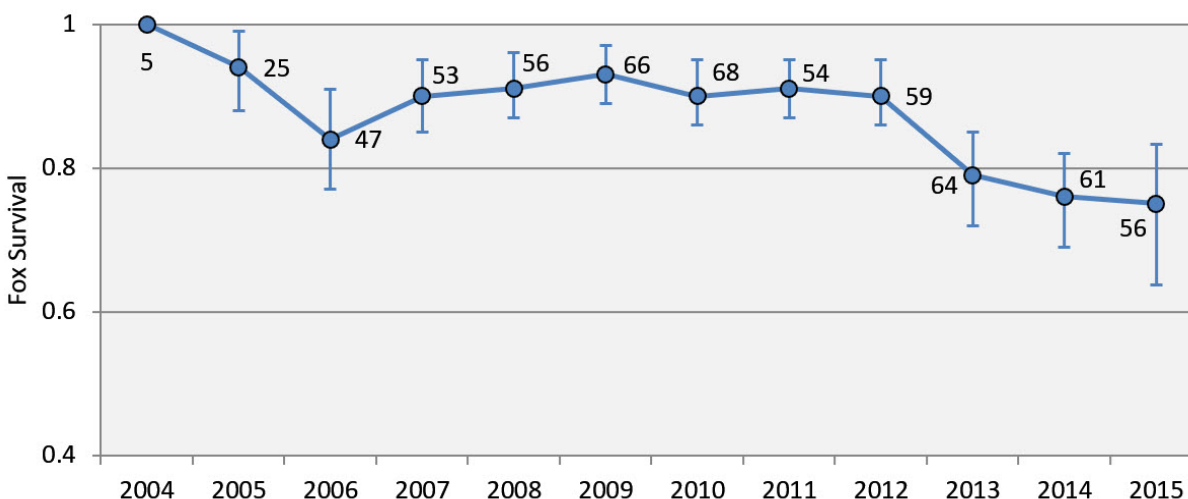


Figure 12. Adult fox survival with 80% confidence intervals and sample sizes on San Miguel Island, 2004–2016. Note: survival was determined for the calendar year (2006–2014) and the “fox year” (2015).

Table 4. Mortalities of radio collared foxes on San Miguel Island from 1/1/2015–4/30/2016.

ID	PIT Tag	Sex	Age	Born	Date	Mortality Causes
F379	61981	F	U	Wild	1/10/15	Emaciation, acanthocephalans, spirocerca, lung worms
M302	59264	M	2	Wild	1/21/15	Emaciated, acanthocephalans, spirocerca, lung worms, fused leg
M293	24908	M	7	Wild	2/18/15	No necropsy due to poor condition
M292	75086	M	3	Wild	3/1/15	Not definitive, Pulmonary hyperplasia, spirocerca
M290	07202	M	U	Wild	3/17/15	No necropsy due to extreme decay
F356	15255	F	5	Wild	6/4/15	Emaciation, acanthocephalans, lung worms
M301	21153	M	3	Wild	6/25/15	Unknown
F339	72850	F	8	Wild	7/22/15	Unknown
F352	87160	F	9	Wild	8/29/15	Emaciation, acanthocephala, spirocerca, lung worms
M269	C6125	M	6	Wild	9/4/15	Unknown (desiccated)
M276	07B05	M	7	Wild	9/4/15	Emaciation, Colitis, spirocerca, hyperplasia
F350	44227	F	8	Wild	10/13/15	Emaciation, acanthocephala, spirocerca
F378	61796	F	3	Wild	11/26/15	Emaciation, acanthocephala, severe spirocerca, lung worms
M245	3061E	M	8	Wild	11/27/15	Emaciation, enteritis, colitis, pneumonia, acanthocephala, spirocerca, lung worms
F336	F6C14	F	8	Wild	12/8/15	Emaciation, severe spirocerca, few acanthocephala, Thyroiditis, lymphocytic

Table 4 (continued). Mortalities of radio collared foxes on San Miguel Island from 1/1/2015–4/30/2016.

ID	PIT Tag	Sex	Age	Born	Date	Mortality Causes
M309	26205	M	4	Wild	2/3/16	Emaciation, enteritis, acanthocephala
F391	24063	F	1	Wild	4/6/16	Hemoabdomen and pneumonia w/ intralesional nematodes, colitis w/ spirocerca
M280	52B7A	M	6	Wild	4/20/16	Necropsy cancelled. Acanthocephala found in abdominal cavity

Fox Density/Abundance Estimation

The estimated island-wide density of adult island foxes on San Miguel Island in 2015 was 17.17 foxes/km² (80% CI = 13.39–22.01) (Figure 13, Figure 14, Table 5). Adult density ranged from a high of 20.78 foxes/km² on the MG4: Cardwell Point grid to a low of 11.08 foxes/km² on the MG1: Jackass Flats grid. Due to the lack of data for individual grid analysis, models including permanent behavioral (b) components were not included, resulting in a 16 model set. Multiplying the island-wide density by the area of the island (37.66 km²) yielded a population estimate of 646 adult foxes (80% CI = 504–829) (Figure 15, Table 6). Since only seven pups were captured 11 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 0.83 pups/km² (80% CI = 0.50–1.36) with a corresponding island-wide abundance of 31 pups (80% CI = 18–51). The estimated island-wide abundance of all foxes (adults and pups) was 677 total foxes (80% CI = 522–880).

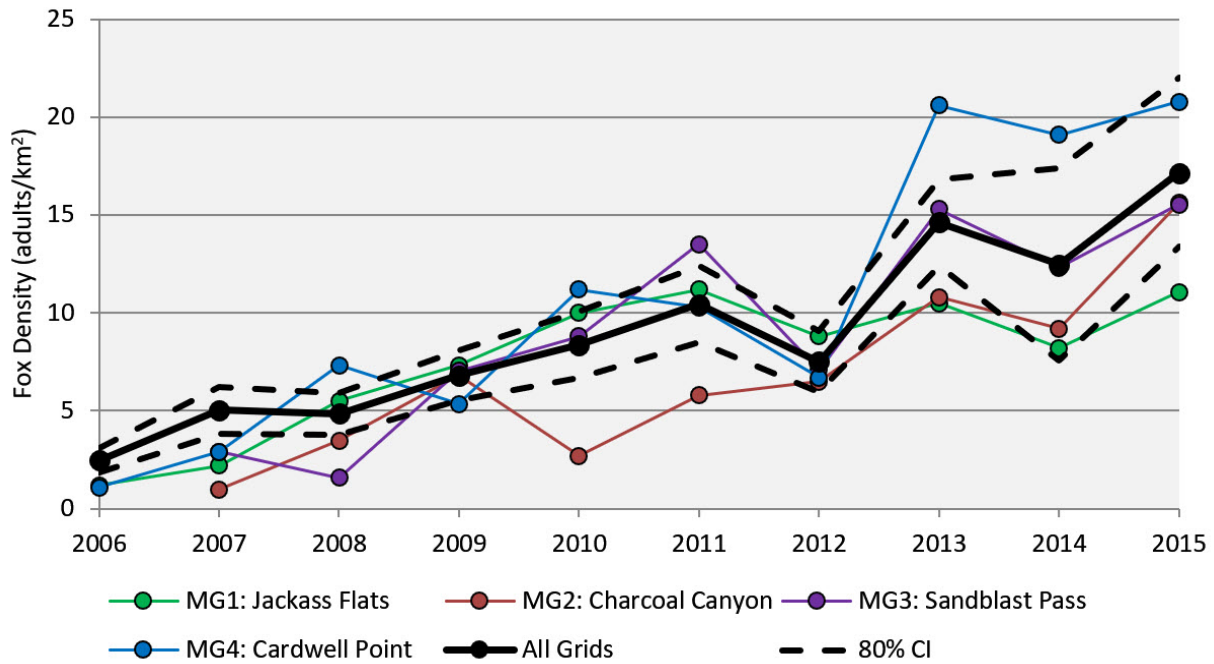


Figure 13. Adult fox density across all trapping grids and for individual grids on San Miguel Island, 2006–2015. Note: density estimates were determined via program *DENSITY* (2006–2014) and program *secr* (2015).

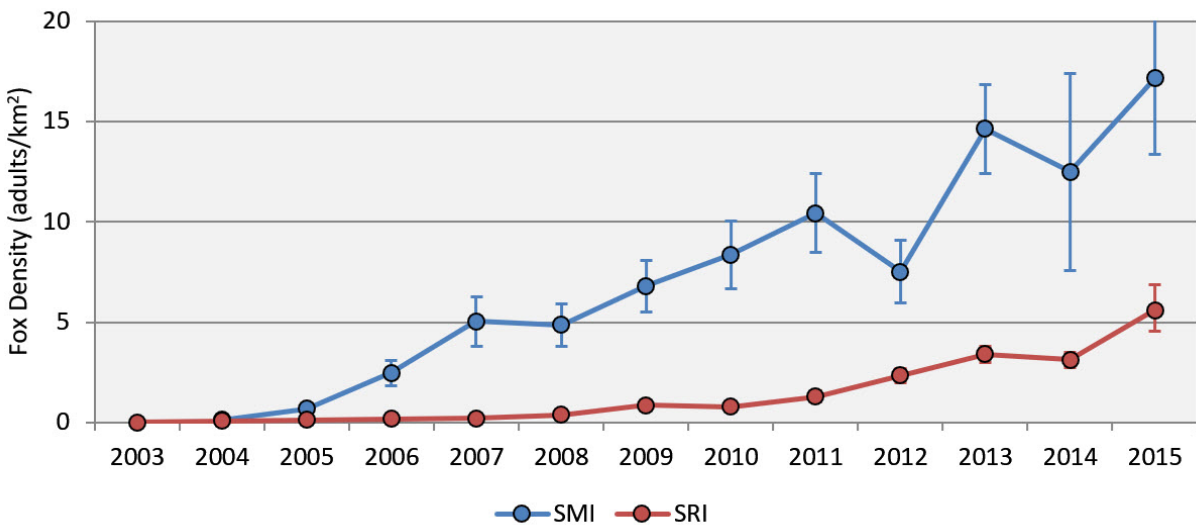


Figure 14. Adult fox density with 80% confidence intervals across all trapping grids on San Miguel (2004–2015) and Santa Rosa Islands (2003–2015). Note: density estimates for San Miguel Island were determined via minimum number known alive (2004–2005), program *DENSITY* (2006–2014), and program *secr* (2015), while density estimates for Santa Rosa Island were determined via minimum number known alive (2003–2008), program *DENSITY* (2009–2014), and program *secr* (2015).

Table 5. 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, 2015.

Monitoring Grid	Dates	Ind.	Density (foxes/km ²)	SE	CV ¹
MG1: Jackass Flats	9/2–9/6	12	11.08	7.71	0.696
MG2: Charcoal Canyon	9/2–9/6	15	15.62	7.04	0.451
MG3: Sandblast Pass	9/2–9/6	18	15.53	7.70	0.496
MG4: Cardwell Point	9/7–9/11	27	20.78	5.59	0.269
Average Density	–	–	15.75	–	–
All Grids Combined	9/2–9/11	72	17.17	3.36	0.196

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 6. Island-wide adult fox and total (adults and pups) fox abundance across all trapping grids on San Miguel Island, 2004–2015.

Year	Adults					Total Adults Plus Pups				
	n	N	SE	80% CI	λ	n	N	SE	80% CI	λ
2004 ¹	–	5	–	–	–	–	10	–	–	–
2005	–	26	–	–	5.20	–	42	–	–	4.20
2006 ²	19	93	18.58	70–117	3.58	39	201	32.32	160–243	4.79
2007	37	190	35.85	144–235	2.04	60	297	43.93	241–354	1.48
2008	44	183	31.51	143–223	0.96	75	282	51.83	215–348	0.95
2009	58	256	37.80	208–305	1.39	79	318	39.66	267–369	1.13
2010	47	315	49.77	252–379	1.23	79	516	62.08	437–595	1.62
2011	56	393	57.52	320–467	1.24	82	581	69.10	493–670	1.12
2012	44	283	46.38	224–342	0.72	76	538	65.79	454–622	0.93
2013	84	551	64.89	468–634	1.95	87	577	66.84	491–662	1.07
2014	74	470	185.00	285–654	0.85	77	515	196.00	318–711	0.89
2015 ³	72	646	126.54	504–829	1.37	79	677	139.11	522–880	1.31

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 2006–2014 estimates determined using program *DENSITY*

³ determined using program *secr*

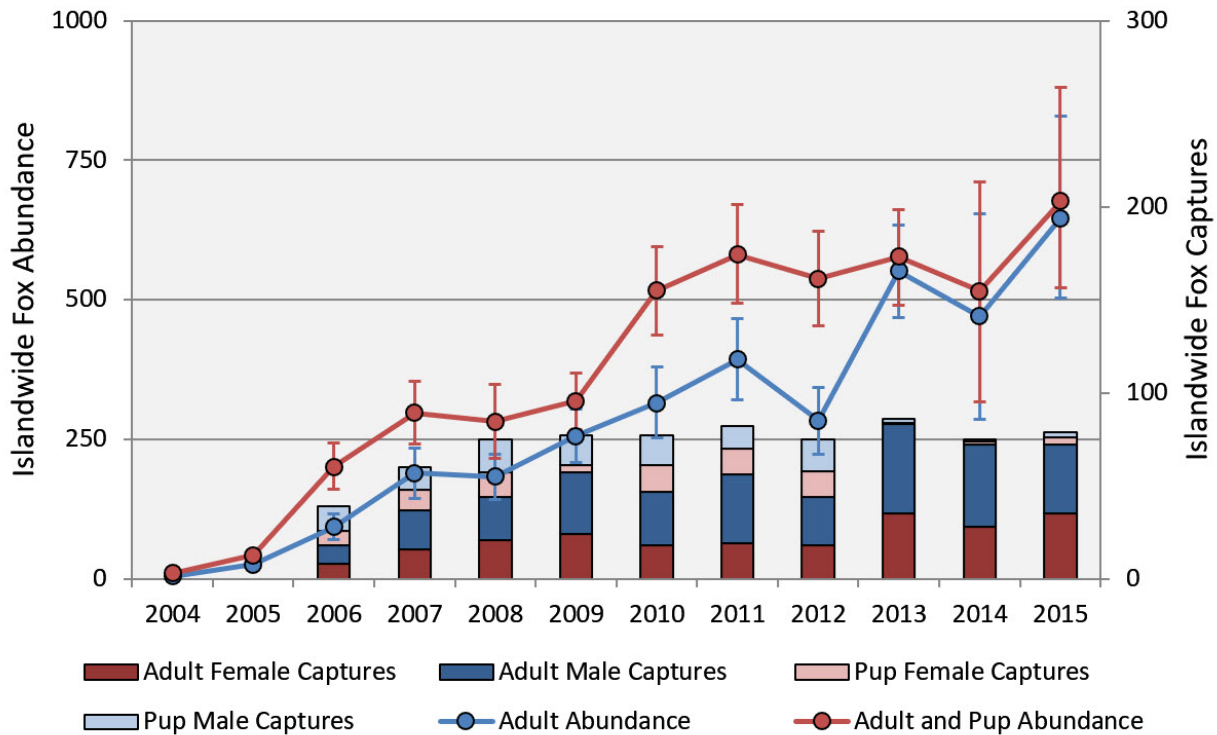


Figure 15. Island-wide fox abundance (adults and total) with 80% confidence intervals and the number of individual foxes captured, by age and sex, across all trapping grids on San Miguel Island, 2004–2015. Note: abundance estimates were determined via minimum number known alive (2004, 2005), program *DENSITY* (2006–2014), and program *secr* (2015).

Island Fox Recovery

To determine whether the San Miguel Island fox population was approaching biological recovery, we plotted 3-year averages of adult abundance and adult mortality rate against fox extinction isoclines developed by Vickie Bakker (Bakker et al. 2009). The plots of 3-year averages for 2013–2015 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 island fox recovery plan (Figure 16) (USFWS 2015a). The San Miguel subspecies has returned to pre-decline population levels and now has seven “boxes” below the 5% extinction isocline, and therefore can be considered biologically recovered.

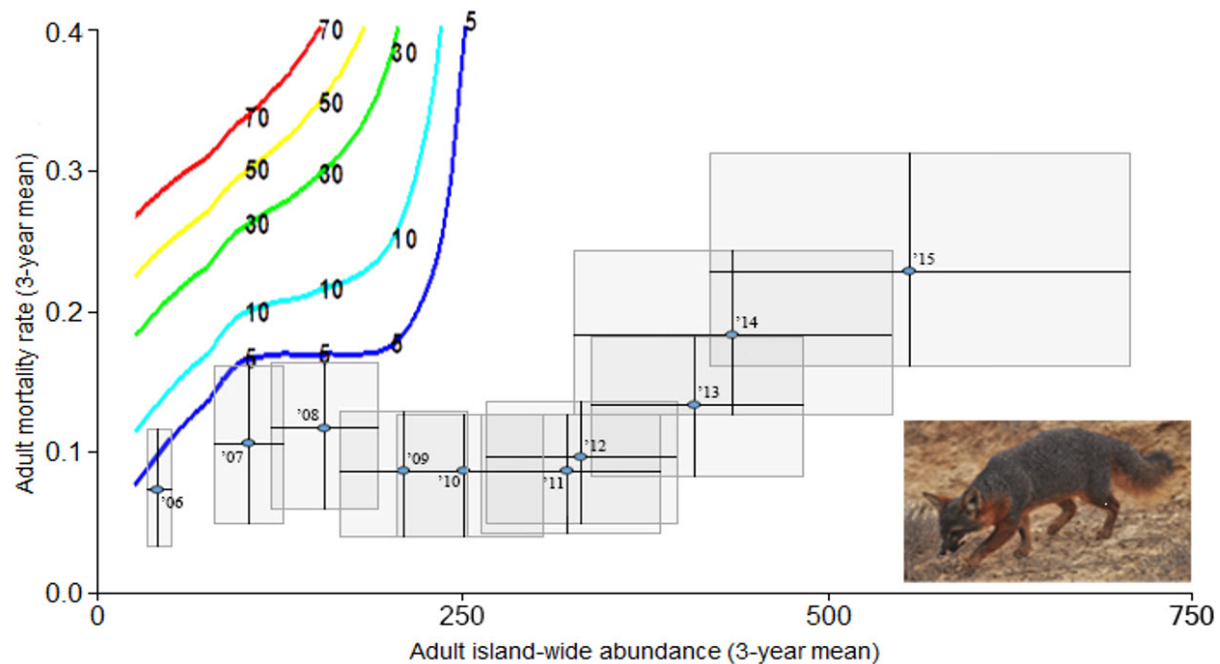


Figure 16. San Miguel Island adult fox extinction risk, 2004–2015. Colored isoclines represent the percent risk of fox extinction (5, 10, 30, 50, 70) over the next 50 years, grey boxes represent the outer extent of 80% confidence intervals for each parameter individually (3-year average abundance and 3-year average mortality rate), and data labels represent the last year of the 3-year averages. Note: abundance estimates were determined via minimum number known alive (2004, 2005), program *DENSITY* (2006–2014), and program *secr* (2015) and mortality rates were determined for the calendar year (2004–2014) and the “fox year” (2015).

Santa Rosa Island

Fox Trapping

Fox grid trapping to estimate population density on Santa Rosa Island occurred in July and August 2015, whereas target trapping to manage collars and administer vaccines occurred intermittently from July 2015 through January 2016. A total of 218 individual foxes (69 pups, 149 adults) were captured a total of 587 times on 18 mini-grids, whereas a total of 83 individual foxes (31 pups, 52 adults) were captured a total of 138 times during target trapping (Table 2). Across both trapping methods 291 individual foxes (97 pups, 194 adults) were captured a total of 725 times (Table 3).

Vaccination, Sentinel Animals, and Collection of Biological Samples

Vaccines were administered to Santa Rosa Island foxes during both grid and transect trapping, with 59 foxes vaccinated against rabies only, 31 vaccinated against canine distemper only, and 91 vaccinated against both rabies and canine distemper (Table 3). Throughout the 2015 “fox year” on Santa Rosa Island, 11 foxes received new radio collars, 10 of which were sentinels. Fourteen foxes that had active radio collars from previous years were captured again in 2015, five of which were sentinels. Additionally, 36 foxes with active radio collars, 27 of which were sentinels, were not captured in 2015. During the 2015 trapping season, a total of 42 different individual foxes acted as sentinel animals with 30–40 sentinel foxes monitored concurrently. A total of 317 blood, 314

whisker, 198 urine, and 93 scat samples were also collected from 286, 288, 177, and 73 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 17). The number of pups captured was the highest recorded and a steep increase from the past 2 years. The total number of adults and total number of foxes captured were also the highest recorded.

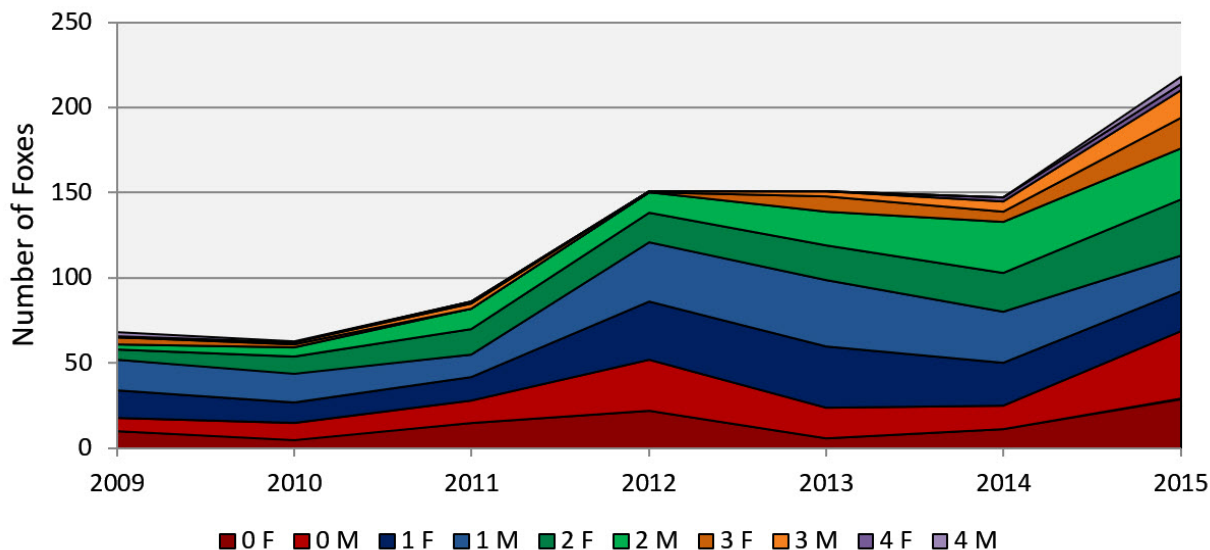


Figure 17. Number of female (F) and male (M) foxes captured in each age class (0–4) across all trapping grids on Santa Rosa Island, 2009–2015.

The average weight of adult female and male foxes trapped on grids on Santa Rosa Island in 2015 were similar to the past two years, with females averaging 2.11 kg (80% CI = 2.15–2.06) and males averaging 2.34 kg (80% CI = 2.39–2.28) (Figure 18). An almost equal proportion of foxes were classified as body condition 2 as body condition 3, similar to last year (Figure 19). Additionally, the proportion of foxes classified as body condition 4 was the highest recorded and for the first time, foxes were classified as body condition 5.

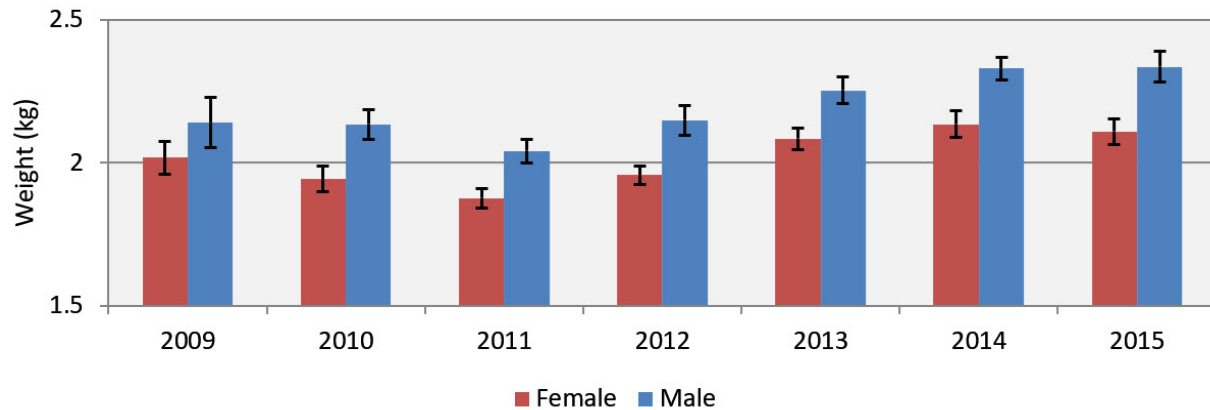


Figure 18. Average fox weight by sex, with 80% confidence intervals, across all trapping grids on Santa Rosa Island, 2009–2015.

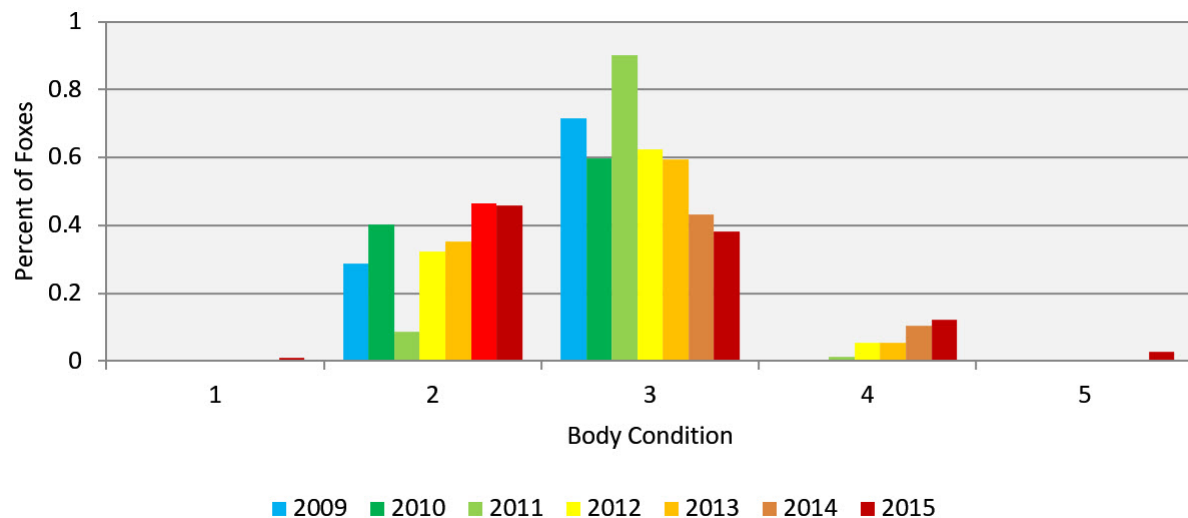


Figure 19. Percent of island foxes in each body condition category (1–5) across all trapping grids on Santa Rosa Island, 2009–2015.

The proportion of adult females to adult males trapped on grids on Santa Rosa Island in 2015 was 1.10 (Figure 8). This was a steep increase from last year when it was 0.85, the only time it has been below 1. The ratio of pups to adult females across all grids, an index of reproductive effort, was 0.88 in 2015 (Figure 20). This is an increase from the last two years and is approaching a ratio of 1. When evaluating individual grids, most showed a slight increase from last year, but MG8: Verde Canyon and MG13: Wreck Canyon grids showed a much steeper increase than the overall trend.

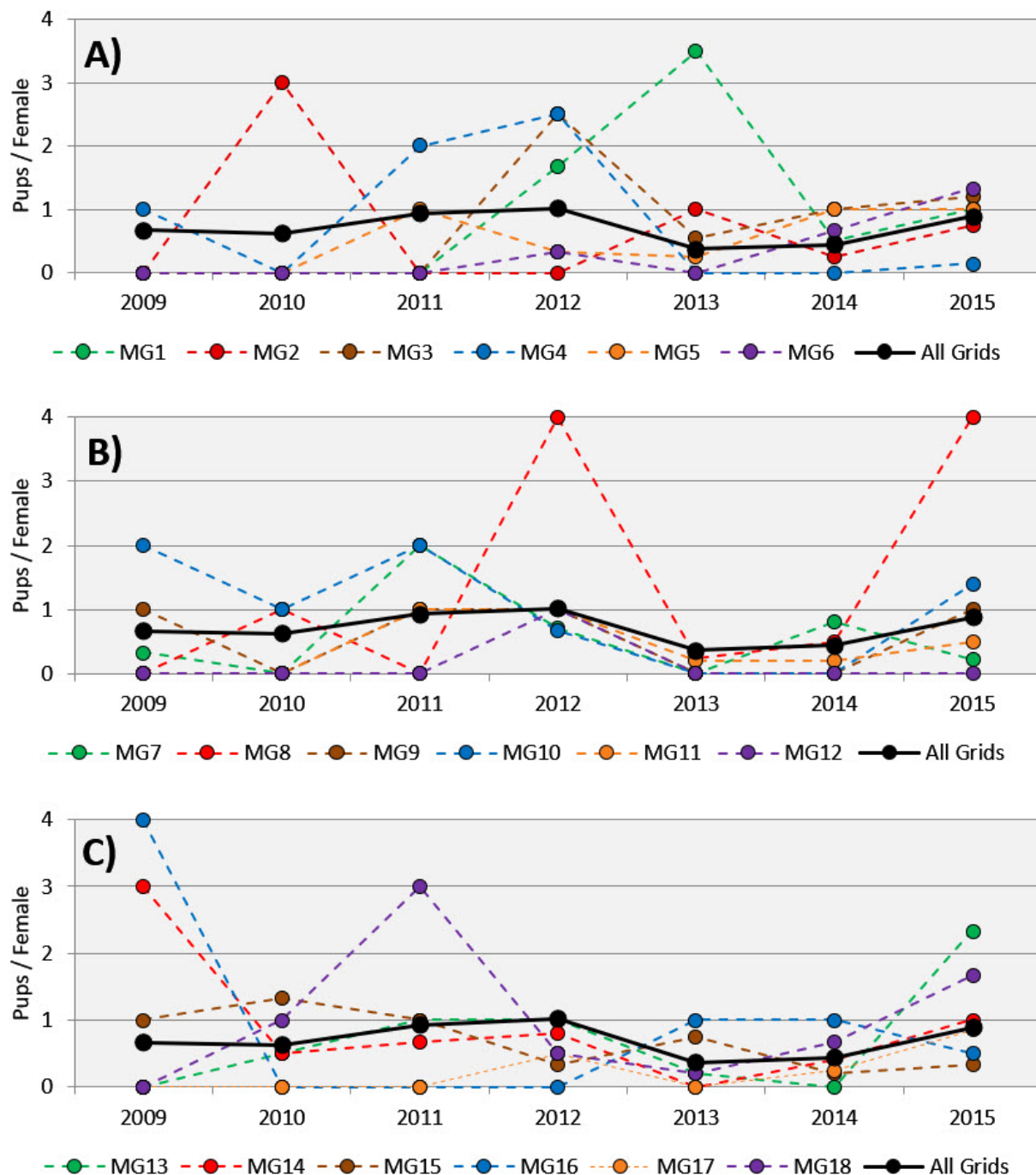


Figure 20. Reproductive effort (pups/adult females) of island foxes across all trapping grids and by individual grids A) MG1–6, B) MG7–12 and C) MG13–18 on Santa Rosa Island, 2009–2015. (MG1: Pocket Field, MG2: Bee Canyon, MG3: Arlington Springs, MG4: China Camp, MG5: Burma Road, MG6: Arlington Canyon, 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 2015 “fox year” a total of 62 foxes (10 pups, 52 adults) were monitored via radio collars on Santa Rosa Island, with 48–56 foxes being monitored at any given time. To determine how closely collared foxes represented the fox population as a whole we compared the percent of adult foxes in each age class (Figure 21) and their sex ratio (Figure 22) 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 1 individuals, while age class 2 individuals were under represented. Yearling foxes are targeted for disease monitoring as thus may not accurately represent the proportion of yearlings in the overall island population.

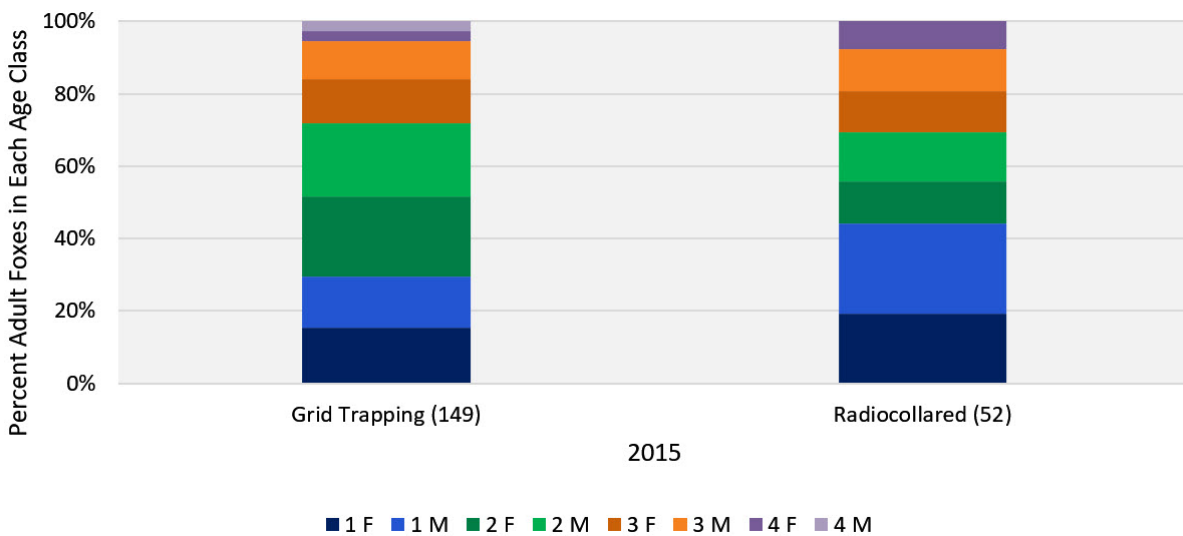


Figure 21. Percent of adult foxes in each age class (1–4) (including sample size) across all grid trapping and for all radio-collared individuals on Santa Rosa Island in 2015.

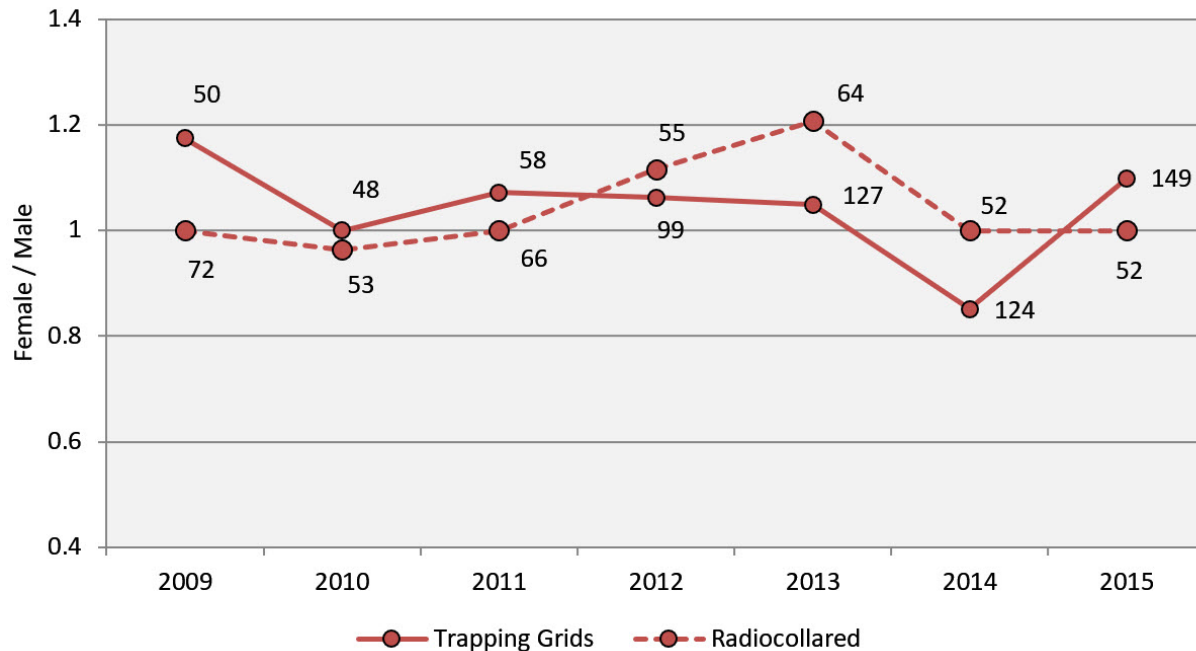


Figure 22. Sex ratio of adult foxes (including sample size) across all grids and for all radio-collared individuals on Santa Rosa Island, 2009–2015.

Annual known-fate survival for adult island foxes in the 2015 “fox year” was 93.9% ($n=52$; 80% CI = 84.5–97.4%) (Figure 23). To align with annual adult fox abundance estimates, the adult island fox survival in 2015 was determined for the “fox year,” whereas all previous fox survival estimates were determined for the calendar year. Annual adult survival was high for the fifth straight year on Santa Rosa. An annual survival rate of 80% or more is optimal for a stable or increasing fox population (Roemer et al. 2001). Three radio collared male foxes died within the 2015 “fox year,” all from unknown causes. One additional radio collared male fox died in January 2015 with signs of parasites and mild trauma (Table 7).

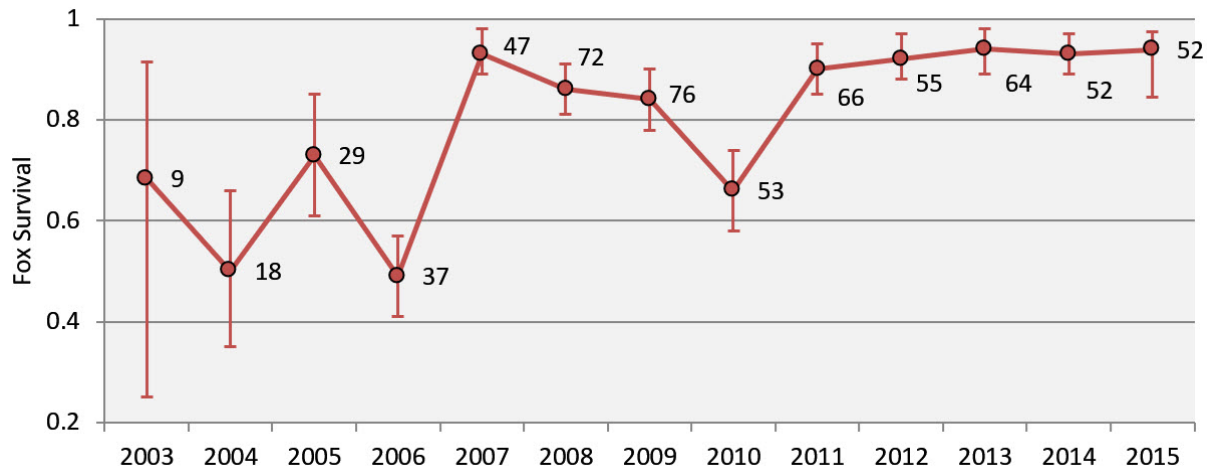


Figure 23. Adult fox survival with 80% confidence intervals and sample sizes on Santa Rosa Island, 2003–2015. Note: survival was determined for the calendar year (2003–2014) and the “fox year” (2015).

Table 7. Mortalities of radio collared foxes on Santa Rosa Island from 1/1/2015–4/30/2016.

ID	PIT Tag	Sex	Age	Born	Date	Mortality Causes
M116	03614	M	6	Wild	1/16/15	Mild trauma (mild bruising to soft tissue along left thorax), spirocerca
M93	41B20	M	8	Wild	10/13/15	Unknown, (desiccated)
M118	18118	M	2	Wild	3/3/16	Unknown
M119	15669	M	2	Wild	3/4/16	Unknown

Fox Density/Abundance Estimation

The estimated island-wide density of adult island foxes on Santa Rosa Island in 2015 was 5.59 foxes/km² (80% CI = 4.56–6.86) (Figure 24, Figure 15, Table 8). Adult density ranged from a high of 15.75 foxes/km² on the MG5: Burma Road grid to a low of 1.06 fox/km² on the MG12: Johnson’s Lee 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. Two grids (MG9: Lighthouse Road and MG12: Johnson’s Lee) did not have enough fox captures to estimate density using program *secr* so we divided the number of adult foxes captured on each by grid by the average effective trapping area of the other 16 grids. Multiplying the island-wide density by the area of the island (215.53 km²) yielded a population estimate of 1,205 adult foxes (80% CI = 983–1477) (Figure 25, Table 9). Fox pups had an estimated density of 2.30 pups/km² (80% CI = 1.83–2.90) with a corresponding island-wide abundance of 496 pups (80% CI = 394–625). The estimated island-wide abundance of all foxes (adults and pups) was 1701 (80% CI = 1377–2102). When comparing both islands, the adult fox density on San Miguel (17.17 foxes/km²) is over three times more than that on Santa Rosa (5.59 foxes/km²) (Figure 15).

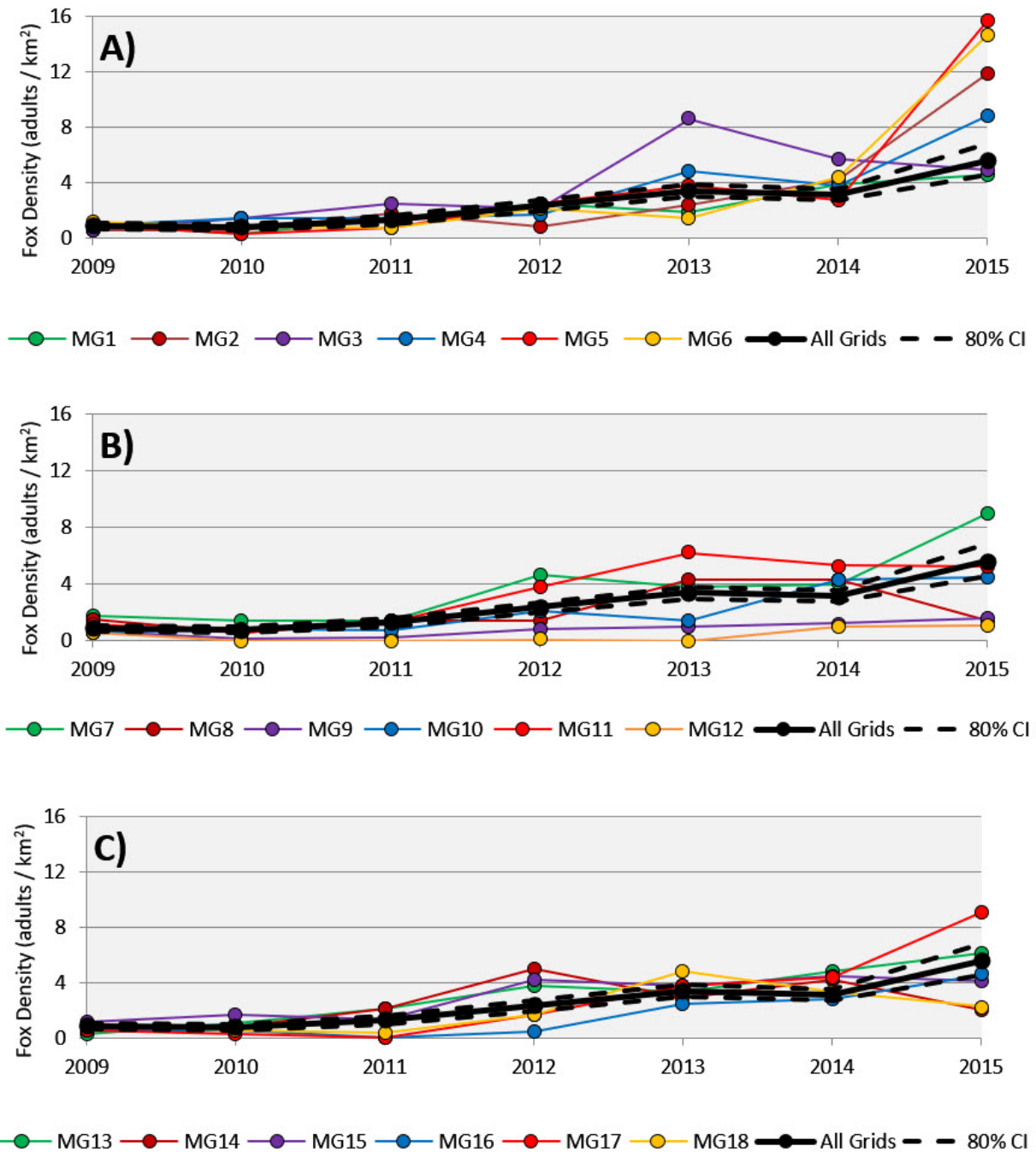


Figure 24. Adult fox density across all trapping grids and by individual grids A) MG1–6, B) MG7–12 and C) MG13–18 on Santa Rosa Island, 2009–2015. (MG1: Pocket Field, MG2: Bee Canyon, MG3: Arlington Springs, MG4: China Camp, MG5: Burma Road, MG6: Arlington Canyon, MG7: Dry Canyon, MG8: Verde Canyon, 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). Note: density estimates were determined via program *DENSITY* (2009–2014) and program *secr* (2015).

Table 8. 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, 2015. Note: individual grid and all grid combined estimates were determined using program *secr*.

Monitoring Grid	Dates	Ind.	Density (foxes/km ²)	SE	CV ¹
MG1: Pocket Field	7/22–7/27	7	4.53	2.23	.492
MG2: Bee Canyon	7/22–7/27	8	11.89	5.46	.459
MG3: Arlington Springs	7/22–7/27	11	4.91	2.27	.462
MG4: China Camp	7/22–7/27	11	8.80	3.61	.410
MG5: Burma Road	7/22–7/27	10	15.75	6.01	.382
MG6: Arlington Canyon	8/8–8/13	6	14.66	9.72	.663
MG7: Dry Canyon	7/29–8/3	15	8.95	3.19	.356
MG8: Verde Canyon	7/29–8/3	6	1.39	.62	.446
MG9: Lighthouse Road	8/5–8/10	3	1.59	–	–
MG10: Trancion Canyon	8/5–8/10	9	4.51	2.39	.530
MG11: Signal Road	8/8–8/13	9	5.22	2.39	.458
MG12: Johnson's Lee	8/5–8/10	2	1.06	–	–
MG13: Wreck Canyon	8/19–8/24	7	6.15	3.06	.498
MG14: Quemada Canyon	8/19–8/24	8	2.07	1.06	.512
MG15: Telephone Road	8/19–8/24	12	4.10	1.56	.380
MG16: Carrington Point	8/19–8/24	9	4.58	2.50	.546
MG17: Sierra Pablo	8/19–8/24	10	9.13	4.24	.464
MG18: Old Ranch	8/19–8/24	6	2.25	1.38	.613
Average Density	–	–	6.20	–	–
All Grids Combined	7/22–8/24	149	5.59	.89	.160

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. $CV = SE/density$.

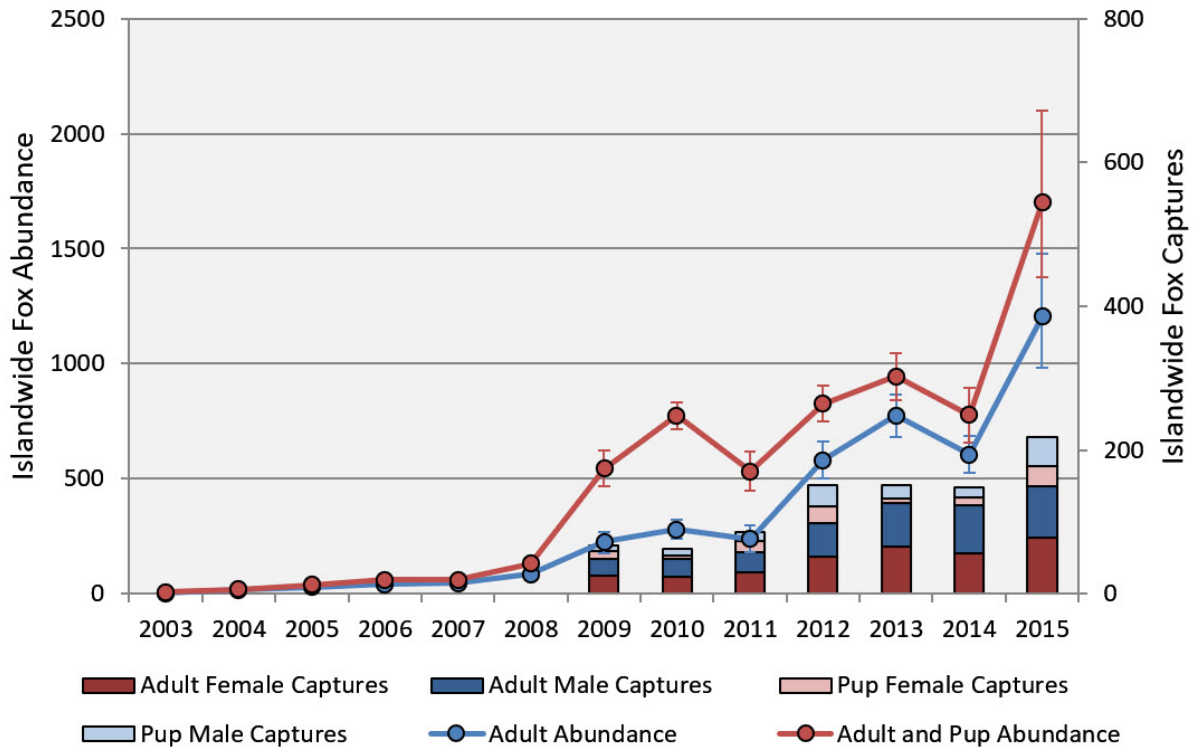


Figure 25. Island-wide fox abundance (adults and total) with 80% confidence intervals and the number of individual foxes captured, by age and sex, across all trapping grids on Santa Rosa Island, 2003–2015. Note: abundance estimates were determined via minimum number known alive (2003–2008), program *DENSITY* (2009–2014), and program *seccr* (2015).

Table 9. Island-wide adult fox and total (adults and pups) fox abundance across all trapping grids on Santa Rosa Island, 2003–2015.

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

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 2009–2014 estimates determined using program *DENSITY*

³ 2015 estimates determined using program *seccr*

Table 9 (continued). Island-wide adult fox and total (adults and pups) fox abundance across all trapping grids on Santa Rosa Island, 2003–2015.

Year	Adults					Total (adults plus pups)				
	n	N	SE	80% CI	λ	n	N	SE	80% CI	λ
2009 ²	59	187	36.34	140–233	2.20	85	389	59.88	313–466	3.02
2010	49	169	32.29	128–210	0.90	64	292	46.08	233–351	0.75
2011	57	280	46.89	220–340	1.66	84	449	64.78	366–532	1.54
2012	99	505	61.47	426–584	1.80	152	637	59.65	561–713	1.42
2013	127	732	71.44	641–824	1.45	152	894	78.85	793–995	1.40
2014	123	676	63.14	596–757	0.92	148	877	92.56	759–996	0.98
2015 ³	149	1205	192.58	983–1477	1.78	218	1701	282.85	1377– 2102	1.94

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 2009–2014 estimates determined using program *DENSITY*

³ 2015 estimates determined using program *secr*

Island Fox Recovery

To determine whether the Santa Rosa Island fox population was approaching biological recovery, we plotted 3-year averages of adult abundance and adult mortality rate against fox extinction isoclines developed by Vickie Bakker (Bakker et al. 2009). The plots of 3-year averages for 2013–2015 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 island fox recovery plan (Figure 26) (USFWS 2015a). The Santa Rosa Island fox population currently has three consecutive “boxes” below the 5% extinction isocline but requires five such consecutive values in order to be considered biologically recovered and to support delisting.

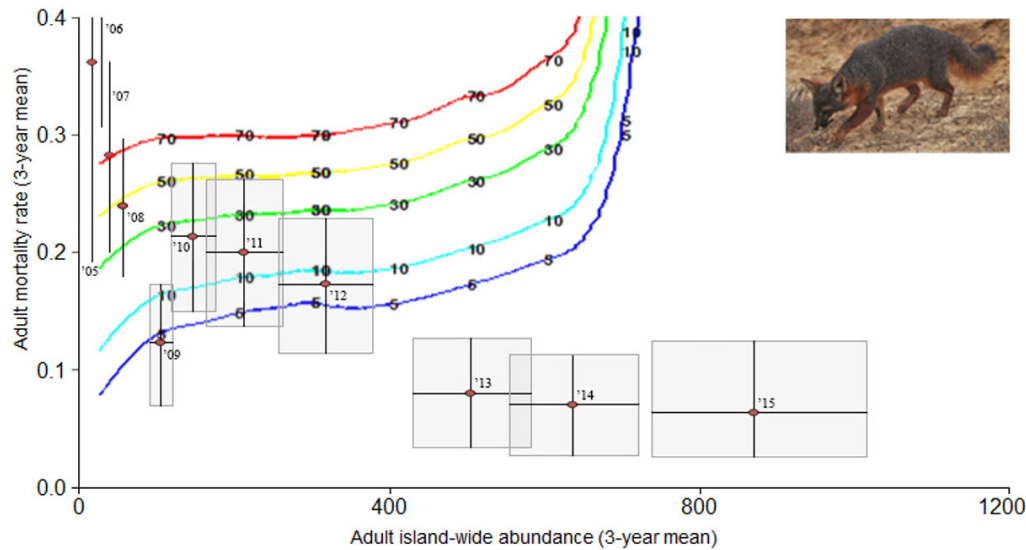


Figure 26. Santa Rosa Island adult fox extinction risk, 2006–2015. Colored isoclines represent the percent risk of fox extinction (5, 10, 30, 50, 70) over the next 50 years, grey boxes represent the outer extent of 80% confidence intervals for each parameter individually (3-year average abundance and 3-year average mortality rate), and data labels represent the last year of the 3-year averages. Note: abundance estimates were determined via program *DENSITY* (2006–2014) and program *secr* (2015) and mortality rates were determined for the calendar year (2006–2014) and the “fox year” (2015).

Spotted Skunk Demographics and Density/Abundance Estimation

To evaluate the island spotted skunk population on Santa Rosa we analyzed the weights and sex ratio of all skunks captured across all 18 trapping grids. Over time the average weight of spotted skunks captured on the grids has increased, with an average male and female in 2015 weighing 692 and 445 grams respectively (Figure 27). The ratio of female to male skunks captured on the grids has gradually decreased over time. In 2015, the skunk sex ratio was 0.46, meaning for every female skunk captured over two male skunks were captured (Figure 28).

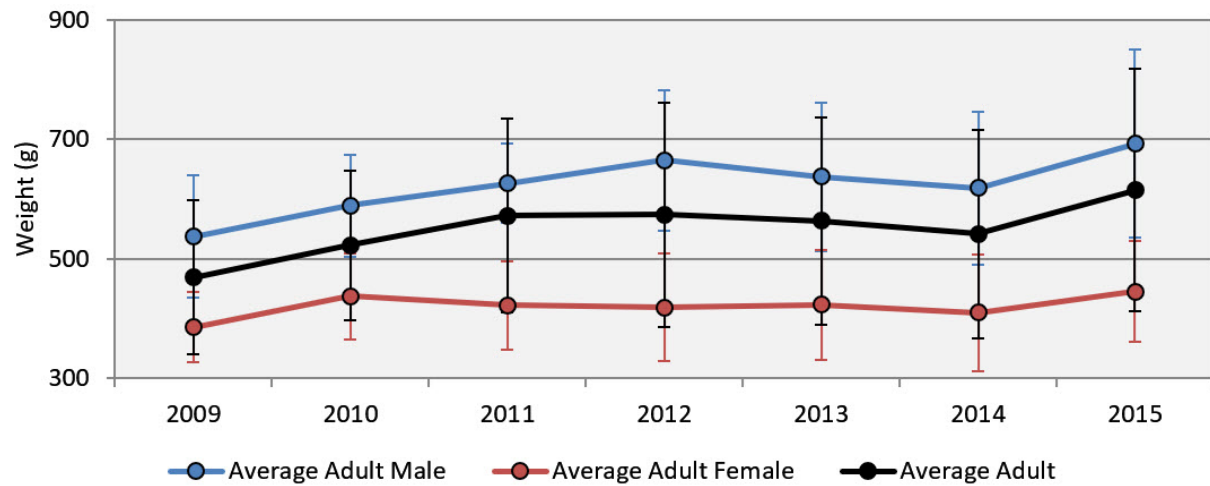


Figure 27. Average adult skunk weight by sex with 80% confidence intervals across all trapping grids on Santa Rosa Island, 2009–2015.

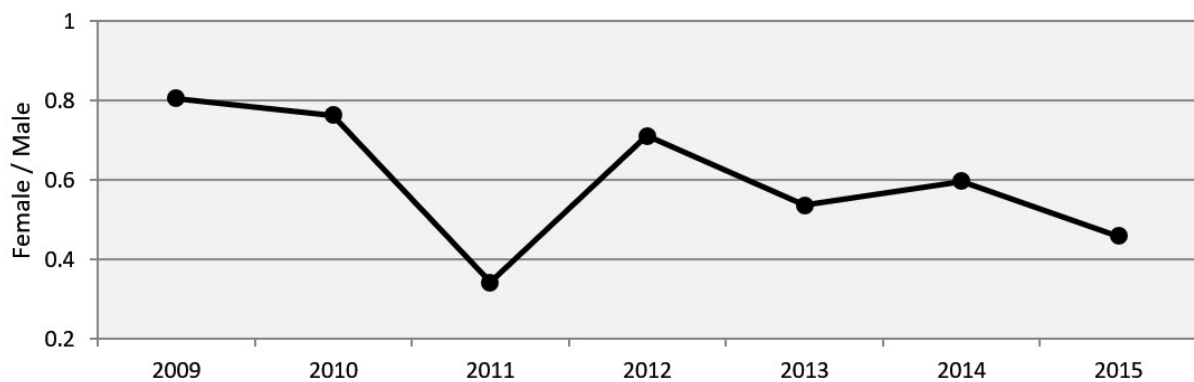


Figure 28. Skunk sex ratio (female/male) across all trapping grids on Santa Rosa Island, 2009–2015.

The estimated island-wide density of island spotted skunks on Santa Rosa in 2015 was 4.58 skunks/km² (80% CI = 2.46–8.67) (Figure 29, Table 10). Density ranged from a high of almost 22 skunks/km² on MG16:Carrington Point and MG17:Sierra Pablo to a low of 0 skunks/km² on MG1:Pocket Field, MG3:Arlington Springs, MG4:China Camp, MG9:Lighthouse Road, and MG15:Telephone Road. Due to the lack of skunk captures (n=35) and recaptures (n=8) in 2015, we were unable to include models that contained permanent behavior components (b) in our grid analysis, resulting in a 16-model set. Additionally, for individual grid analysis we could not include either behavioral components (b and B) and all individual grid estimates were determined using the constant model. Multiplying the island-wide density by the area of the island (215.53 km²) yielded a population estimate of 986 skunks (80% CI = 530–1868) (Table 11).

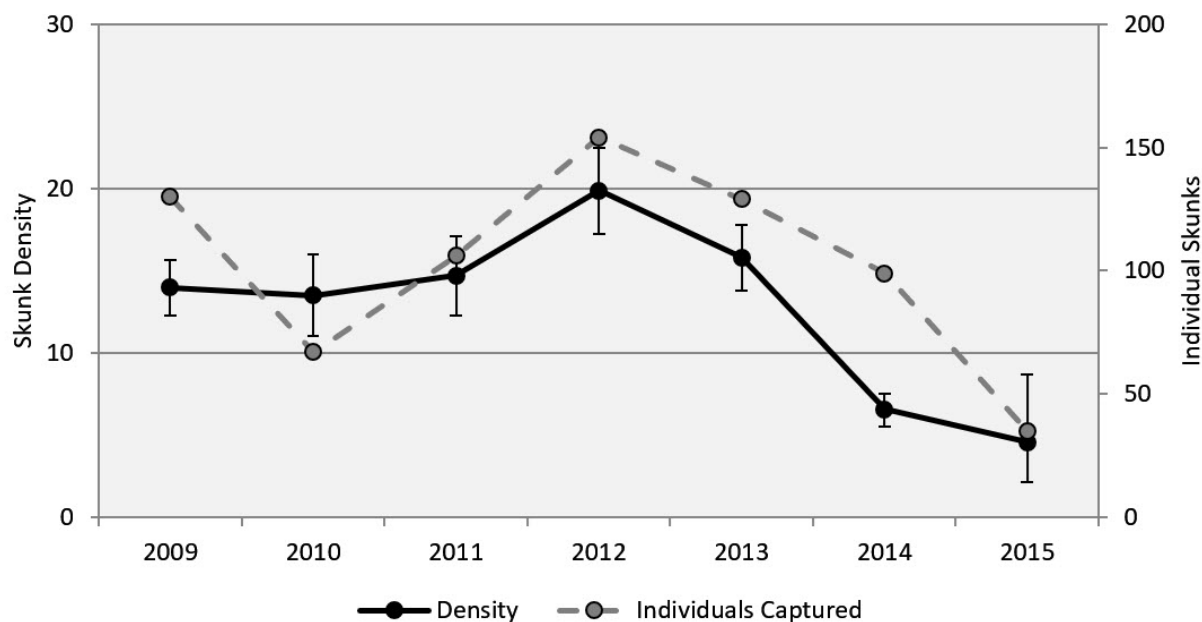


Figure 29. Spotted skunk density with 80% confidence intervals and number of individual skunks captured across all trapping grids on Santa Rosa Island, 2009–2015. Note: density estimates were determined via program *DENSITY* (2009–2014) and program *secr* (2015).

Table 10. 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, 2015. Note: individual grid and all grid combined estimates were determined using program *secr*.

Monitoring Grid	Dates	Ind.	Density (foxes/km ²)	SE	CV ¹
MG1: Pocket Field	7/22–7/27	0	0	–	–
MG2: Bee Canyon	7/22–7/27	2	3.48	–	–
MG3: Arlington Springs	7/22–7/27	0	0	–	–
MG4: China Camp	7/22–7/27	0	0	–	–
MG5: Burma Road	7/22–7/27	2	3.48	–	–
MG6: Arlington Canyon	8/8–8/13	1	1.74	–	–
MG7: Dry Canyon	7/29–8/3	1	1.74	–	–
MG8: Verde Canyon	7/29–8/3	1	1.74	–	–
MG9: Lighthouse Road	8/5–8/10	0	0	–	–
MG10: Trancion Canyon	8/5–8/10	1	1.74	–	–
MG11: Signal Road	8/8–8/13	2	3.48	–	–

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 10 (continued). 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, 2015. Note: individual grid and all grid combined estimates were determined using program *secr*.

Monitoring Grid	Dates	Ind.	Density (foxes/km ²)	SE	CV ¹
MG12: Johnson's Lee	8/5–8/10	5	4.29	3.26	.76
MG13: Wreck Canyon	8/19–8/24	5	8.71	–	–
MG14: Quemada Canyon	8/19–8/24	2	3.48	–	–
MG15: Telephone Road	8/19–8/24	0	0	–	–
MG16: Carrington Point	8/19–8/24	6	21.82	29.77	1.36
MG17: Sierra Pablo	8/19–8/24	6	21.42	30.42	1.42
MG18: Old Ranch	8/19–8/24	1	1.74	–	–
Average Density	–	–	4.38	–	–
All Grids Combined	7/22–8/24	35	4.58	2.41	.53

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 11. Island-wide spotted skunk abundance with 80% confidence intervals on Santa Rosa Island 2009–2015.

Year	n	N	80% CI	λ
2009 ¹	130	3014	2652–3376	–
2010	71	2911	2373–3448	.97
2011	104	3166	2653–3678	1.09
2012	155	4282	3718–4846	1.35
2013	129	3404	2979–3406	.79
2014	99	1415	1188–1614	.42
2015 ²	35	986	530–1868	.70

n = number of trapped animals; N = estimated population size; CI = confidence interval; λ = annual rate of increase

¹ 2009–2014 estimates determined using program *DENSITY*

² Determined using program *secr*

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 30). In 2015, the density of skunks on Santa Rosa was lower than the density of adult foxes, which is the first time this occurred since the monitoring program began.

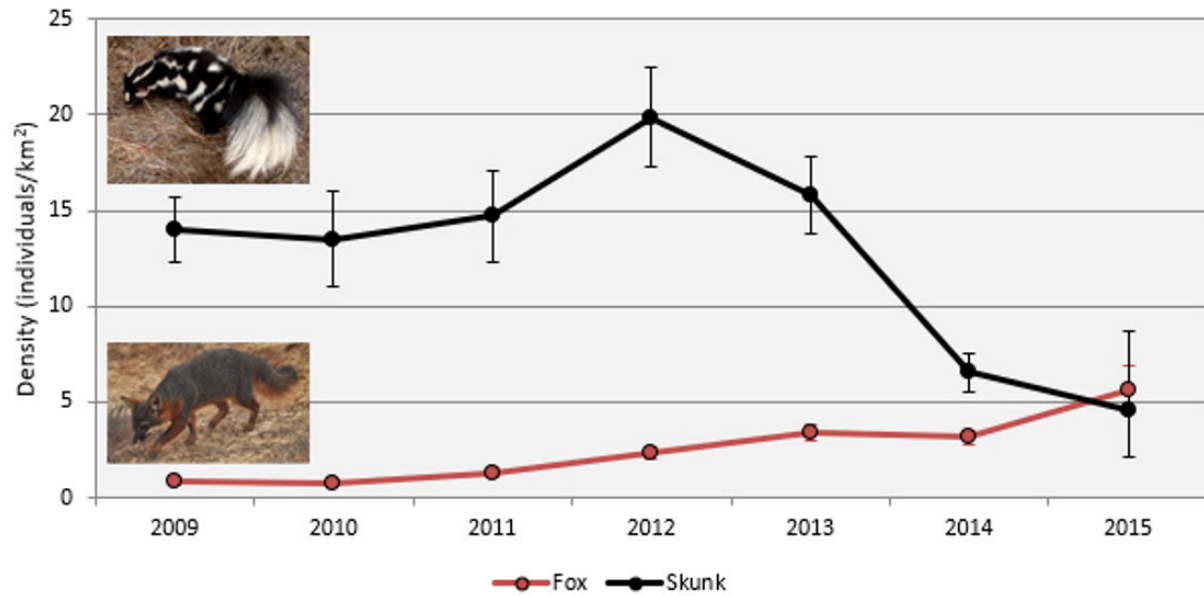


Figure 30. Adult fox density and island skunk density with 80% confidence intervals across all trapping grids on Santa Rosa Island, 2009–2015. Note: density estimates were determined via program *DENSITY* (2009–2014) and program *secr* (2015).

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 has steadily increased. By 2011, the density of adult foxes exceeded 10 foxes/km², and over the next few years, the estimated size of the total fox population (adults and pups) remained relatively stable, between 500 and 600 foxes. In 2015, the adult and total fox densities were 17.17 and 18.00 foxes/km² respectively, corresponding to an adult and total fox abundance of 646 and 677 respectively. The adult fox density and abundance in 2015 were the highest recorded on San Miguel. When estimating fox density on individual grids, the western most grid had the lowest density, the two central grids had higher density, and the eastern most grid had the highest density.

The methods employed to estimate fox density in 2015 were different than those in previous years, which may explain some of the differences in estimated population size between 2015 and previous years. When we plotted the 2015 estimates of adult fox abundance and mortality against the extinction isoclines, the results indicated that the San Miguel fox population has returned to pre-decline levels and had eight consecutive "boxes" below the 5% extinction isocline by 2015, meeting the requirements for biological recovery. Following these results the San Miguel island fox subspecies was proposed for removal from the endangered species list (USFWS 2015a; USFWS 2015b) and was delisted in 2016.

Although the recovery of the San Miguel Island fox subspecies is a success, further investigation of the 2015 fox data does reveal 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 third straight year that pup captures have been low and the second 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 2015 values being the lowest recorded. Corresponding with low pup captures, reproductive effort was low for the third consecutive year. Additionally, the survival rate of San Miguel foxes has declined for the last three years. Although the island-wide abundance of foxes on San Miguel is 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 4 years. Although 2015 was a dry year, it did have slightly more precipitation than previous years which may be responsible for the increase in pup production. Island fox densities on San Miguel are among the highest recorded and are over three times higher than that 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 10 of the 12 fox carcasses that were necropsied showed signs of emaciation. Additionally, the island-wide abundance on San Miguel has remained high and relatively constant since 2010, suggesting that the carrying capacity of foxes on the island has been reached or possibly surpassed.

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 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). In 2013 and 2014, acanthocephalans were found in 10 of 12 San Miguel island fox carcasses that were intact enough for necropsy (Coonan et al. 2014, Coonan et al. 2015). Acanthocephalans were found in 10 of 13 carcasses analyzed between January 2015 and April 2016, typically in heavy loads. Some 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 three years of extended drought, it has continued to increase in 2015 and is likely above its estimated pre-decline levels (Roemer et al. 1994). 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 female to male ratio over 1, and an increased reproductive effort.

Our analysis of the 2015 Santa Rosa Island fox trapping data estimated an increase in island-wide fox density and abundance from previous years. The methods employed to estimate fox density in 2015 were different than those in previous years, which may explain some of the differences in estimated population size between 2015 and those previous. More adults and pups were captured in 2015 than ever before and overall the population appears to not yet be limited by resources. The increase in island-wide density and abundance seemed to be largely driven by the increases in density and abundance at specific grids. Six of the 18 grids had an estimated density of approximately 9–16 foxes/km², which was a substantial increase from the overall density in previous years. Of these 6 grids, 5 (MG2:Bee Canyon, MG4:China Camp, MG5:Burma Road, MG6:Arlington Canyon, and MG7:Dry Canyon) were located on the western side of the island, possibly receiving more rain and fog resulting in more available resources, however 1 of the grids (MG17:Sierra Pablo) was located on the eastern end of the island.

The overall increase in island-wide fox density and abundance, coupled with high survival, resulted in a low extinction risk, indicating the Santa Rosa subspecies has recovered. The Santa Rosa population has returned to pre-decline levels and had 3 “boxes” below the 5% extinction isocline by 2015. Although five consecutive years below this extinction risk were initially required for delisting, the Santa Rosa Island subspecies was proposed for removal the endangered species list (USFWS 2015a, USFWS 2015b) and was delisted in 2016.

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 lower 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 2015 only 35 individual skunks were captured. 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 skunk populations in the future.

Literature Cited

- Bakker, V. J., and D. F. Doak. 2009. Population viability management: Ecological standards to guide adaptive management for rare species. *Frontiers in Ecology and the Environment* 7:158–165.
- Bakker, V. J., D. F. Doak, G. W. Roemer, D. K. Garcelon, T. J. Coonan, S. A. Morrison, C. Lynch, K. Ralls, and R. Shaw. 2009. Incorporating ecological drivers and uncertainty into a demographic viability analysis for the island fox. *Ecological Monographs* 79(1):77–108.
- Burnham, K. P., and D. Anderson. 2002. *Model selection and multi-model inference*, second edition. Springer-Verlag, New York.
- Clifford, D. L., J. A. K. Mazet, E. J. Dubovi, D. K. Garcelon, T. J. Coonan, P. A. Conrad, and L. Munson. 2006. Pathogen exposure in endangered island fox (*Urocyon littoralis*) populations: Implications for conservation management. *Biological Conservation* 131:230–243.
- Collins, P. W. 1993. Taxonomic and biogeographic relationships of the island fox (*Urocyon littoralis*) and gray fox (*U. cinereoargenteus*) from western North America. Pages 351–390 in F. G. Hochberg, editor. *Third California Islands Symposium: Recent Advances in Research on the California Islands*. Santa Barbara Museum of Natural History, Santa Barbara, California. *Proceedings of the Third California Islands Symposium*.
- Collins, P. W., and B. C. Latta. 2006. Nesting season diet of golden eagles on Santa Cruz and Santa Rosa Islands, Santa Barbara County, California. Santa Barbara Museum of Natural History Technical Reports – No. 3.
- Cooch, E., and G. White, editors. 2010. *Program MARK: Analysis of data from marked individuals, a gentle introduction*. 9th edition. Online: <http://www.phidot.org/software/mark/>
- Coonan, T. J. 2010. Twelfth annual meeting, island fox working group, summary report. unpublished report on file at headquarters, Channel Islands National Park.
- Coonan, T. J. 2013. Fifteenth annual meeting, island fox working group, summary report. unpublished report on file at headquarters, Channel Islands National Park.
- Coonan, T. J. 2014. Sixteenth annual meeting, island fox working group, summary report. unpublished report on file at headquarters, Channel Islands National Park.
- Coonan, T. J. 2015. Annual report for island fox recovery actions conducted under Permit TE10857-2. Report submitted to Ventura Fish and Wildlife Office. On file at headquarters, Channel Islands National Park.
- Coonan, T. J. 2016. 2013–2015 deer mouse monitoring annual report: Channel Islands National Park. Natural Resource Data Series NPS/MEDN/NRDS—2016/1070. National Park Service, Fort Collins, Colorado.

- Coonan, T. J., G. Austin, and C. Schwemm. 1998. Status and trend of island fox, San Miguel Island, Channel Islands National Park. NPS D-122. National Park Service, California.
- Coonan, T. J., A. Guglielmino, and R. Shea. 2014. Island fox recovery program: Channel Islands National Park 2013 annual report. Natural Resource Report NPS/MEDN/NRR—2014/845. 32 National Park Service, Fort Collins, Colorado.
- Coonan, T. J., A. Guglielmino, and R. Shea. 2015. Island fox recovery program: Channel Islands National Park 2014 annual report. Natural Resource Report NPS/MEDN/NRR—2015/1047. National Park Service, Fort Collins, Colorado.
- Coonan, T. J., K. McCurdy, K. A. Rutz, M. Dennis, S. Provinsky, and S. Coppelli. 2005. Island fox recovery program 2004 annual report. Technical Report 05-07. National Park Service, Ventura, California.
- Coonan, T.J. and K. Rutz. 2001. Island fox captive breeding program: 1999–2000 annual report. Technical Report 01-00. National Park Service, Ventura, California.
- Coonan, T. J., K. A. Rutz, K. McCurdy, D. K. Garcelon, B. C. Latta, and L. Munson. 2004. Island fox recovery program, 2003 annual report. Technical Report 04-02. National Park Service, Ventura, California.
- Coonan, T. J., and C. A. Schwemm. 2009. Factors contributing to success of island fox reintroductions on San Miguel and Santa Rosa Islands, California. Pages 363–376 in C. C. Damiani and D.K. Garcelon, editors. Proceedings of the Seventh California Islands Symposium, Oxnard, California, February 5–8, 2008. Institute for Wildlife Studies, Arcata, California.
- Coonan, T. J., C. A. Schwemm, and D. K. Garcelon. 2010. Decline and recovery of the island fox: A case history for population recovery. Cambridge University Press, UK.
- Coonan, T. J., C. A. Schwemm, G. W. Roemer, D. K. Garcelon, and L. Munson. 2005. Decline of an island fox subspecies to near extinction. *Southwestern Naturalist* 50(1):32–41.
- Davis, G. E., K. R. Faulkner, and W. L. Halvorson. 1994. Ecological monitoring in Channel Islands National Park, California. The Fourth California Islands Symposium: Update on the Status of Resources. W. L. Halvorson and G. J. Maender, editors. Santa Barbara Museum of Natural History, Santa Barbara, California.
- Efford, M. G. 2018. *secr*: Spatially explicit capture-recapture models. R package version 3.1.5. <https://CRAN.R-project.org/package=secr>.
- Efford, M. G., D. L. Borchers, and A. E. Byrom. 2009. Density estimation by spatially explicit capture-recapture: Likelihood-based methods. Pages 255–269 in D. L. Thomson, E. G. Cooch, and M. J. Conroy editors. *Modeling Demographic Processes in Marked Populations*. Springer.

- Efford, M. G., D. K. Dawson, and C. S. Robbins. 2004. *DENSITY*: software for analyzing capture-recapture data from passive detector arrays. *Animal Biodiversity and Conservation* 27 (1):217–228.
- Fellers, G. M., C. A. Drost, and B. W. Arnold. 1988. Terrestrial vertebrates monitoring handbook. Unpublished report on file at park headquarters, Channel Islands National Park, Ventura, California.
- Jones, K. L., D. H. Van Vuren, and K. R. Crooks. 2008. Sudden increase in a rare endemic carnivore: Ecology of the island spotted skunk. *Journal of Mammalogy* 89:75–86.
- Kreuder, C., M. A. Miller, D. A. Jessup, L. J. Lowenstine, M. D. Harris, J. A. Ames, T. E. Carpenter, P. A. Conrad, and J. A. Maezt. 2003. Patterns of mortality in southern sea otters (*Enhydra lutris nereis*) from 1998–2001. *Journal of Wildlife Disease* 39:495–509.
- Latta, B. C., D. D. Driscoll, J. L. Linthicum, R. E. Jackman, and G. Doney. 2005. Capture and translocation of golden eagles from the California Channel Islands to mitigate depredation of endemic island foxes. Pages 341–350 in D. K. Garcelon, and C. A. Schwemm, editors. *Proceedings of the Sixth California Islands Symposium*. National Park Service Technical Publication CHIS-05-01, Institute for Wildlife Studies, Arcata, California.
- Roemer, G. W. 1999. The ecology and conservation of the island fox (*Urocyon littoralis*). Ph.D. dissertation, University of California, Los Angeles, California. 229 pp.
- Roemer, G. W., T. J. Coonan, D. K. Garcelon, J. Bascompte, and L. Laughrin. 2001. Feral pigs facilitate hyperpredation by golden eagles and indirectly cause the decline of the island fox. *Animal Conservation* 4:307–318.
- Roemer, G. W., C. J. Donlan, and F. Courchamp. 2002. Golden eagles, feral pigs, and insular carnivores: How exotic species turn native predators into prey. *Proceedings of the National Academy of Sciences* 99:791–796.
- Roemer, G. W., D. K. Garcelon, T. J. Coonan, and C. Schwemm. 1994. The use of capture-recapture methods for estimating, monitoring, and conserving island fox populations. Pages 387–400 in W. L. Halvorson, and G. J. Maender, editors *The Fourth California Channel Islands Symposium: Update on the Status of Resources*. Santa Barbara Museum of Natural History, Santa Barbara, California.
- Rubin, E. S., V. J. Bakker, M. G. Efford, B. S. Cohen, J. A. Stallcup, W. D. Spencer, and S. A. Morrison. 2007. A population monitoring framework for five subspecies of island fox (*Urocyon littoralis*). Prepared by the Conservation Biology Institute and The Nature Conservancy for the Recovery Coordination Group of the Island Fox Integrated Recovery Team. U.S. Fish and Wildlife Service, Ventura, California.

- Timm, S. F., L. Munson, B. A. Summers, K. A. Terio, E. J. Dubovi, C. E. Rupprecht, S. Kapil, and D. K. Garcelon. 2009. A suspected canine distemper epidemic as the cause of a catastrophic decline in Santa Catalina Island foxes (*Urocyon littoralis catalinae*). *Journal of Wildlife Diseases* 45:333–343.
- U.S. Fish and Wildlife Service. 2004. Listing of the San Miguel island fox, Santa Rosa island fox, Santa Cruz island fox, and Santa Catalina island fox as endangered; final rule. *Federal Register* 69(44):10335–10353.
- U.S. Fish and Wildlife Service. 2015a. Recovery plan for four subspecies of island fox (*Urocyon littoralis*). U.S. Fish and Wildlife Service, Sacramento, California.
- U.S. Fish and Wildlife Service. 2015b. Endangered and threatened wildlife and plant; recovery plan and initiation of status review for four subspecies of island fox (*Urocyon littoralis*). *Federal Register* 80(45):12521–12522.
- Van Vuren, D. and B. E. Coblentz. 1987. Some ecological effects of feral sheep on Santa Cruz Island, California, USA. *Biological Conservation* 41:253–268.
- Wayne, R. K., S. B. George, D. Gilbert, P. W. Collins, S. D. Girman, and N. Lehman. 1991. A morphologic and genetic study of the island fox, *Urocyon littoralis*. *Evolution* 45:1849–1868.
- Wood, J. E. 1958. Age structure and productivity of a gray fox population. *Journal of Mammalogy* 39(1):74–86.

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