POPULATION DECLINE OF ISLAND FOXES (*UROCYON LITTORALIS LITTORALIS*) ON SAN MIGUEL ISLAND

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ABSTRACT

Annual population monitoring via capture-mark-recapture techniques revealed an abrupt decline in the island fox (*Urocyon littoralis littoralis*) population on San Miguel Island from 1994 to 1998. Adult fox density declined on all three grids monitored during the study period, and the range of decline was between 8.0 and 15.9 foxes/km^2. The estimated population on San Miguel declined from around 450 adults in 1994 to about 40 in 1998. The causes for the decline are unknown. However, the decline was not associated with changes in deer mice (*Peromyscus maniculatus*) density, with winter precipitation, or with seroprevalence to five canine diseases. Predation or other canine diseases or parasites may be factors in the decline. The population may be so low as to make recovery difficult.

Keywords: San Miguel Island, island fox, *Urocyon littoralis littoralis*, population decline.

INTRODUCTION

Since 1993, the National Park Service has conducted annual population monitoring of island foxes (*Urocyon littoralis littoralis*) on San Miguel Island, as part of the long-term ecological monitoring program at Channel Islands National Park. The island fox was a logical choice for monitoring. A diminutive relative of the mainland gray fox (*Urocyon cineroargenteus*), the island fox is found on the six largest of California's eight Channel Islands. Though individuals weigh less than 2.5 kg, the fox is the largest native mammal on the islands. The species has been listed as threatened by the state of California due to its small population size on several islands (California Department of Fish and Game 1987). The island fox was chosen as a key species to monitor at the Park because of its state-listed status, its apparently low population size, the general lack of demographic information about this species, and because of the relatively high amount of public interest in this unique canid. On San Miguel Island, island fox are annually monitored on three grids, using standard mark-recapture techniques.

In this paper we report on a catastrophic decline of island foxes on San Miguel Island, as indicated by the data from the annual population monitoring. We summarize six years of island fox monitoring data and investigate relationships between population parameters and other ecological factors, such as prey availability, weather, and seroprevalence for common canine diseases.

MATERIALS AND METHODS

Study Area

The National Park Service monitors island fox populations on San Miguel Island, the westernmost island of the Northern Channel Islands. At 38.7 km^2, San Miguel is the smallest of the islands on which island foxes occur. The island is a gently sloping plateau with long sandy beaches along the coastline. The island is fully exposed to the prevailing northwesterly wind, and is recovering from a period of severe overgrazing and erosion due to historic sheep ranching (Hochberg et al. 1979).

San Miguel's vegetation is currently dominated by grassland, which covers most of the deeper, stabilized soils on the island terrace (Hochberg et al. 1979). Introduced annuals (*Avena* spp. and *Bromus* spp.) dominate the grasslands. Native bunchgrasses such as *Nasella pulchra* occur more toward the eastern end of the island, but not in large stands. Shrub species, particularly coyote brush (*Baccharis pilularis*), are invading some grassland areas. The second most abundant vegetation type is *Isocoma* scrub, characterized by coast goldenbush (*Isocoma menziesii*), San Miguel Island locoweed (*Astragalus miguelensis*), California saltbush (*Atriplex californica*), and coyote brush. Coastal dune scrub vegetation occurs on the coast and extends well inland in some areas. Some inland sand dune areas are dominated by dense stands of silver lupine (*Lupinus albifrons*). Large bare areas on the island can be characterized as either unstabilized dunes ("sand stripes"), which are generally being colonized by coastal dune scrub species, or as erosion pavement where the soil cover has been removed, leaving a hardpan layer. Sea cliffs are dominated by coastal bluff scrub, including, in some areas, giant coreopsis (*Coreopsis gigantea*) and in others, introduced iceplant (*Mesembryanthemum crystallinum* and *M. nodiflorum*).

Three island fox trapping grids have been established on San Miguel Island (Schwemm 1995). The Dry Lakebed grid comprises primarily grassland cut by gentle ravines on the western end of the island. The western end of the Dry Lakebed grid extends onto a low area that is inundated in years of moderately high precipitation. The eastern end of the grid extends up the west flanks of Green Mountain. The San Miguel Hill grid extends eastward from San Miguel Hill and is the most varied of the three grids, both in topography and vegetation. More than a third of the grid is grassland, a third *Isocoma* scrub, and the remainder is canyon or unstabilized dune. The Willow Canyon grid comprises primarily grassland which is being invaded by *Baccharis*, although portions of the grid comprise *Isocoma* scrub, canyon, coastal bluff scrub, and unstabilized dune.

Island Fox Monitoring Methods

On San Miguel, island foxes are annually monitored with a standardized capture-recapture protocol developed for island foxes and also used on San Clemente, Santa Catalina, and Santa Cruz islands (Roemer et al. 1994). Fieldwork was conducted in mid- to late-summer (July to September) from 1993 to 1998. The Willow Canyon and San Miguel Hill grids each have 49 traps arrayed in a 7 x 7 grid. The Dry Lakebed grid has 48 traps arrayed in a 6 x 8 grid. In 1993, trapping on the Willow Canyon grid was conducted with 42 traps in a 6 x 7 array. Distance between traps is 250 m. Live traps (23 x 23 x 66 cm, Tomahawk Live Trap Co., Tomahawk, WI) were baited with dry cat food and a fruit scent (Knob Mountain Raw Fur Co., Berwick, PA). Traps were covered with burlap and placed to provide protection from sun, wind, and precipitation. A "chew tube" made of refrigerator (polyethylene) tubing was wired to the inside of each trap to provide captured foxes with a soft surface to chew upon. Each grid was trapped annually for six days, except for the Dry Lakebed grid, which was not trapped in 1993. During trapping, traps were checked once during every 24-hr period.

Upon first capture, foxes were weighed (±25 g), and sex, age, reproductive condition, presence of ectoparasites, and injuries were recorded. Foxes were aged according to tooth eruption and wear patterns on the first upper molar (Wood 1958) and were assigned to discrete age classes. Foxes were classified as pups (Age Class 0), young adults (Age Class 1: ca. 7 months to 2 years), adults (Age Class 2: ca. 2 to 3 years), mature adults (Age Class 3: ca. 3 to 4 years old) and old adults (Age Class 4: >4 years old). Foxes were marked with colored ear tags (Nasco-West, Modesto, CA) inserted in the pinna, and/or passive integrated transponder (PIT) tags (Biomark, Boise, ID) inserted subcutaneously between and just anterior to the scapulae. During the course of the study we shifted from use of ear tags to use of PIT tags because the latter have a lower loss rate (Schwemm 1996), result in fewer injuries to foxes, and are inconspicuous. During the study we caught foxes which had been marked during the design phase of the monitoring program (Fellers et al. 1988). These foxes were originally caught from 1985 to 1989 and were marked with collars made from 12 mm wide plastic cable ties. Collars were securely attached around the neck, and an identification number was permanently etched on the collar.

Estimation of Density and other Population Parameters

Island fox adult population sizes were estimated annually for each grid using closed population models from the program CAPTURE (version 2, White et al. 1982) as described by Roemer et al. (1994). Because CAPTURE's models for population size do not work well with very small population sizes, Chapman's modification of the Lincoln-Peterson (LP) estimator was used to estimate population size for the Dry Lakebed grid in 1996. Lack of adult captures prevented us from estimating population size, and thus densities, for the Dry Lakebed grid in 1997 and 1998, and the San Miguel Hill grid in 1998. To avoid counting animals twice, foxes that were captured on more than one grid in a given year were counted only on the grid where they were captured more frequently. This occurred only between the Willow Canyon and San Miguel Hill grids, which are contiguous. The number of adult foxes captured on both grids and subsequently assigned to one grid for 1993-1998 was 5, 2, 3, 4, 1, and 1, respectively.

Density of adult foxes (classes 1, 2, 3 and 4) was estimated for all grids and years, because adult density is a more conservative indicator of population change than total density. Pups were thus excluded from density estimates to reduce the variability introduced by interannual variation in pup survival. Adult density was estimated using the mean maximum distance moved (MMDM) method (Wilson and Anderson 1985). Naïve (or crude) density is calculated according to $D = N/A$, where N is the estimate of population size and A is the area of the trapping grid. Although closed population models assume that populations are closed both demographically and geographically, the naïve density estimator does not account for "edge effect" resulting from incomplete geographic closure. The size of the area trapped is actually larger than the size of the grid, due to the movements of animals residing on or just outside the grid. To account for this, the effective trap area A(W), where W is the boundary strip around the grid, was determined using estimates of MMDM provided by CAPTURE. MMDM is a measure of the maximum distance an animal moves between successive captures. A(W) was estimated by adding ½

MMDM to all sides of a grid. Density was estimated for each grid by dividing N by A(W). Standard errors of density estimates and 95% confidence intervals were estimated using the methods of Wilson and Anderson (1985).

To estimate annual island-wide population of adult foxes, average annual density from the three grids was multiplied by the island area (38.7 km^2) except for 1998, when low number of adult captures prevented us from estimating density for two of the three grids. Some adults may have avoided traps in 1998, perhaps because the abundance of deer mice (*Peromyscus maniculatus*) was high enough to deter adults from investigating the traps as food sources. Pups, on the other hand, were readily caught in 1998. For example, we caught five pups on the Dry Lakebed grid in 1998, but no adults. Therefore, to estimate the island-wide population of adults in 1998, we reconstructed the adult population according to the number of pups that were caught (15). Assuming that adult fox pairs had two to three pups per litter, which is the approximate range of litter sizes from the previous five years on San Miguel Island (Coonan et al. 1998), then the adult population on the three grids was 10 to 14 foxes in 1998. Multiplying by the area of the island produces a range of 28 to 39 adult foxes, with an average of 33. This does not account for non-breeding adults.

Pup productivity was calculated as the number of pups recorded annually on each grid. Adult and pup survival rates were estimated with program MARK (White and Burnham 1997), which uses individual encounter histories to provide estimates of apparent survival for populations of marked animals. Apparent survival is the probability of recapturing an animal between encounter sessions. Apparent survival does not account for emigration, and thus may underestimate true survival, which is the probability of surviving between encounter sessions. For survival analysis, we pooled data for the Willow Canyon and San Miguel Hill grids, since there was considerable movement of individual foxes between those grids. During the study period, 23 foxes moved between the San Miguel Hill and Willow Canyon grids, as indicated by recaptures. In contrast, only one fox moved between the Dry Lakebed grid and any other grid during the study period.

Prey Availability

Data from the Park's long-term ecological monitoring program (Coonan 1995, 1996; Schwemm 1995, 1996; Austin 1996, 1998) were used as indices of population trend for vertebrate prey and vegetation food items. Collins and Laughrin (1979) report that island foxes on San Miguel Island are opportunistic omnivores, consuming a wide variety of plants and animals. Summer and fall diets comprised insects and the fruits and leaves of sea-fig, or iceplant (*Carpobrotus chilensis*), whereas winter diets were characterized by deer mice (*Peromyscus maniculatus*), birds, insects, and iceplant.

Spring and fall densities of deer mice were estimated with capture-recapture data from four permanent grids. Each grid comprised 100 Sherman traps in a 10 x 10 configuration, with 7 m spacing between traps. Mouse grids were monitored in both the spring and fall seasons, except when funding or personnel constraints prevented it. Deer mouse density was estimated using the program CAPTURE. To estimate relative abundance of ground-nesting birds, landbirds were monitored in spring and fall along permanent line transects that utilize the island's trail system (van Riper et al.1988). All birds within 100 m of the transect midline were recorded. For an index of annual abundance we used spring counts for horned larks (*Eremophila alpestris*) and western meadowlarks (*Sturnella neglecta*) from each line transect.

Relative cover of sea-fig was used as an index of availability for sea-fig fruits and leaves, though we do not know if sea-fig fruit and leaf availability is correlated with sea-fig relative cover. Data from the Park's vegetation monitoring program (Halvorson et al. 1988) were used to calculate relative cover of sea-fig. Vegetation was monitored annually on 16 permanent transects on San Miguel Island. Each 30 m transect comprises 100 points at which vegetation cover of all species is recorded. Relative cover of sea-fig was calculated as the number of sea-fig hits on each transect. Relative cover was averaged for habitat types with multiple transects. We did not collect data on abundance of insects and other arthropods.

Weather

Daily precipitation data were obtained from the daily weather log maintained at the Nidever Canyon Ranger Station, San Miguel Island.

Exposure to Canine Diseases

Fox blood samples were collected and tested for presence of antibodies to five lethal canine diseases. Three to 10 ml of blood were drawn from the femoral vein of unanesthetized captured foxes. Sera was obtained from 22 foxes in 1994, 15 foxes in 1995, and 18 foxes in 1997. Serum was separated from the cellular fraction by centrifugation, removed, and then frozen. Sera were tested for antibodies against canine adenovirus, canine distemper, canine parvovirus, *Leptospira canicola*, and *Leptospira ictero*. Serologic tests were conducted at the Washington Animal Disease Diagnostic Laboratory, Washington State University, Pullman, WA. Antibody titers of ≥1:5 were considered evidence of previous exposure to canine adenovirus and canine distemper virus. Antibody titers of ≥1:25 were considered evidence of previous exposure to canine parvovirus. Antibody titers of ≥1:100 were considered evidence of previous exposure to *Leptospira canicola* and *Leptospira ictero*. Seroprevalence for each disease was calculated as the percentage of the total number of samples that tested positive.

Statistical Analysis

Differences among years were evaluated with analysis of variance (ANOVA) (SYSTAT 7.0, SPSS Inc., 1997). Repeated measures analysis of variance (rmANOVA) was used to evaluate trends in landbird and sea-fig abundance. Because island deer mouse density estimates for each grid and year were not replicated, analysis of variance could not be conducted to test for differences among years and grids. Instead, contrasts (Steel et al. 1997) were used to test for differences in deer mouse densities among years. Simple linear regression was used to test relationships between variables.

Percent or proportion data were transformed with the arcsine function prior to analysis. Significance levels were set at 0.05 for all tests except contrasts for comparison of abundance or density estimates, for which significance levels were set at 0.10, in order to minimize the chance of a type 2 error (failing to detect a decrease in abundance or density). In a long-term ecological monitoring program, failing to detect a problem (type 2 error) is at least as serious as a false report (type 1 error) (Steidl et al. 1997).

RESULTS

During the study period we captured 297 individual foxes a total of 904 times. Overall, density on each grid declined over time (Table 1, Figure 1). The rate of decline was similar on the three grids from 1995 to 1996 (approximately 5-6 foxes/km^2). The islandwide population estimate for adults fell from near 450 in 1994 to approximately 40 in 1998 (Figure 2). Apparent annual survival of adults declined

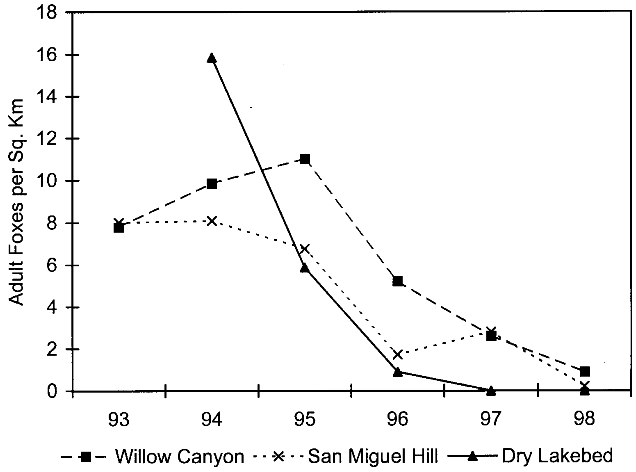

Figure 1. Adult island fox density estimates (number per km^2) for three monitoring grids on San Miguel Island, 1993 to 1998.

Table 1. Total number of adults captured, population estimate (SE), model used, effective trap area [A(W)], density estimate, standard error, and 95% confidence interval for island fox trapping grids on San Miguel Island.

Grid/Year	Number of Adults	Population Estimate (SE)	Model[a]	A(W) km^2	Density (foxes/km^2)	SE	95% CI
Dry Lakebed							
1994	53	54 (1.6)	M(bh)	3.41	15.9	0.47	14.9-16.8
1995	14	21 (4.9)	M(h)	3.58	5.9	1.37	3.2-8.6
1996	2	2	n/a	n/a	0.9	n/a	n/a
1997	0	--					
1998	0	--					
San Miguel Hill							
1993	27	27 (0.1)	M(bh)	3.38	8	0.04	7.9-8.1
1994	27	27 (0.5)	M(bh)	3.34	8.1	0.15	7.8-8.4
1995	21	23 (3.2)	M(h)	3.4	6.8	0.93	4.9-8.6
1996	6	8 (1.8)	M(h)	4.67	1.7	0.39	1.0-2.5
1997	8	16(5.3)	M(h)	5.7	2.8	0.92	1.0-4.6
1998	1	--					
Willow Canyon							
1993	26	28 (2.9)	M(bh)	3.59	7.8	0.8	6.2-9.4
1994	27	34 (7.3)	M(bh)	3.45	9.9	2.1	5.7-14.0
1995	28	34 (4.2)	M(h)	3.09	11	1.36	8.4-13.7
1996	13	17 (3.6)	M(h)	3.26	5.2	1.12	3.0-7.4
1997	10	12 (3.2)	M(h)	4.61	2.6	0.69	1.3-3.0
1998	4	5 (1.7)	M(o)	5.7	0.9	[b]	

[a] Refers to model used by program CAPTURE (White et al. 1982) to estimate population. M(h) = heterogeneous capture probability model; M(bh) = combination of behavior model and heterogeneous capture probability model.

[b] With only 1 recapture, SE and CI could not be estimated.

n/a = number of captures too low to use CAPTURE; Chapman's modifier of the Lincoln-Peterson estimator used instead.

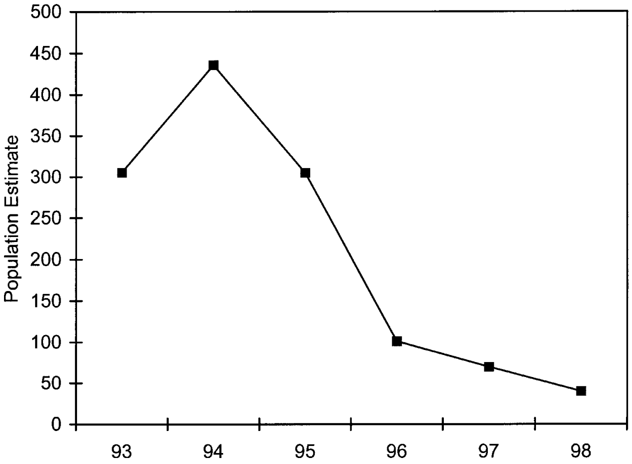

Figure 2. Island-wide adult island fox population estimate, San Miguel Island, 1993 to 1998.

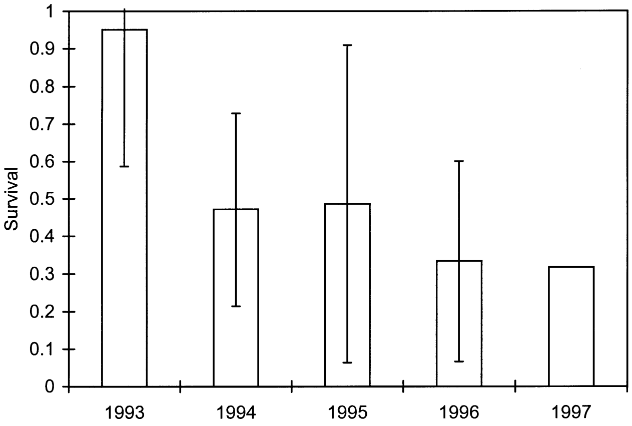

Figure 3. Annual estimates of apparent survival, with 95% confidence interval, for adult island foxes on the Willow Canyon and San Miguel Hills grids, San Miguel Island, 1993 to 1997. Survival estimates generated from program MARK (White and Burnham 1997).

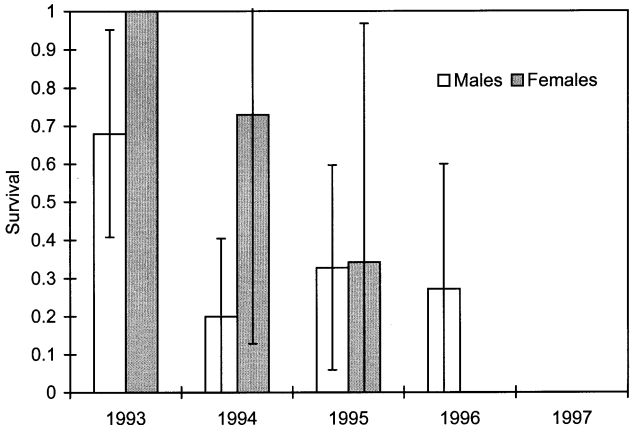

Figure 4. Annual estimates of apparent survival, with 95% confidence intervals, for island fox pups on the Willow Canyon and San Miguel Hill grids, San Miguel Island, 1993 to 1997. Survival estimates generated from program MARK (White and Burnham 1997).

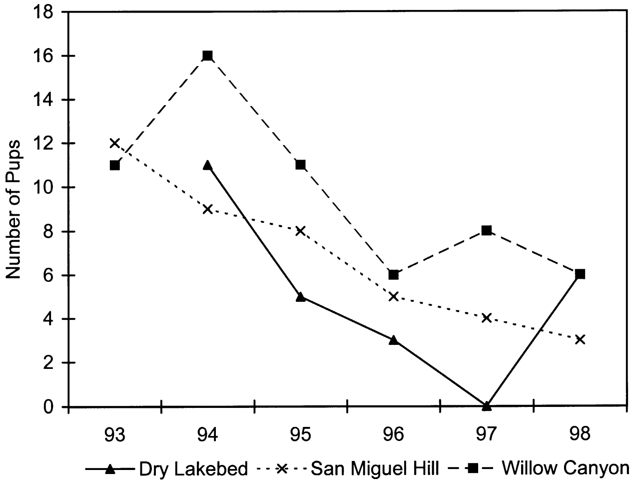

Figure 5. Total number of island fox pups captured on each of three trapping grids, San Miguel Island, 1993 to 1998.

over the study period (Figure 3). On the Dry Lakebed grid, no previously captured foxes were recaptured during monitoring in 1996, 1997, or 1998. Apparent survival of pups differed between sexes for the Willow Canyon/ San Miguel Hill grids (Figure 4). Female pup survival on those grids declined over time, and was apparently zero in 1997. Pup production generally decreased over the study period (Figure 5), except for an increase from 1997 to 1998 on the Dry Lakebed grid.

The fox population decline was not apparently associated with changes in prey availability. Linear contrasts showed that spring and fall mouse densities did not decrease or increase on the 4 mouse grids. Spring abundance of ground nesting birds did not decline over time (rmANOVA, F = 2.275, p = 0.121), although spring abundance of horned larks did decline (rmANOVA, F = 2.822, p = 0.099). Relative cover of sea-fig, or iceplant, generally increased on San Miguel Island between 1984 and 1996. On 6 permanent vegetation transects, sea-fig cover increased from 1984 to 1996 (rmANOVA, F = 5.572, $p < 0.001$). The increase after 1990 may reflect the higher precipitation during this period, in contrast to the drought years preceding this. During the study period, sea-fig cover did not change over time (rmANOVA, F = 1.187, p = 0.334).

Although annual precipitation varied over the six-year study period (Figure 6), adult density was not associated with previous winter's precipitation on either the Willow Canyon grid (f = 0.440, p = 0.544) or the San Miguel Hill grid (f = 0.023, p = 0.886), and adult survival was not correlated with winter precipitation (F = 0.066, p = 0.814).

The island fox population decline was not associated with changes in seroprevalence to canine diseases. Of the five diseases tested, antibodies were detected only for parvovirus and canine adenovirus (Table 2). Seroprevalence to canine adenovirus was high in all years tested, and was similar to seroprevalence in 1988 (Garcelon et al. 1992). Antibodies to canine parvovirus were detected in 2 of 22

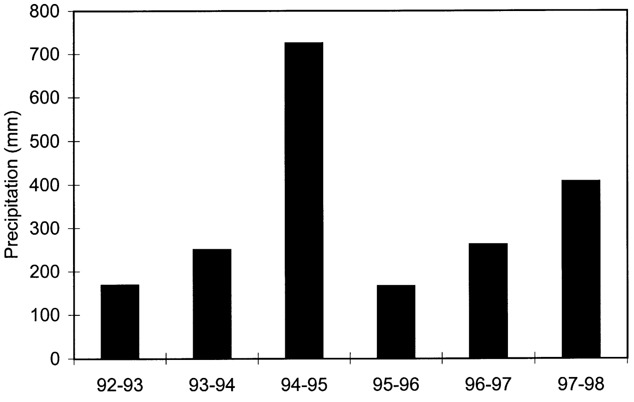

Figure 6. Winter (October - April) precipitation, San Miguel Island, 1992 to 1998.

Table 2. Prevalence of serum antibodies to canine diseases in island foxes, San Miguel Island.

	1988[a]	1994	1995	1997
n	23	22	15	18
Canine adenovirus	96[b]	95	100	89
Canine distemper	0	0	0	0
Canine parvovirus	30	9	0	0
Leptospira canicola	0	0	0	0
Leptospira ictero	0	0	0	0

[a] Data from Garcelon et al. (1992).

[b] Prevalence = (Number of positive samples/total number of samples tested) x 100.

samples from 1994, but not in any samples from 1995 or 1997. Seroprevalence to canine parvovirus was 30% (7/23) in 1988.

DISCUSSION

Anecdotal information (Laughrin 1980) indicates that island fox populations have fluctuated widely in historic times, for unknown reasons. In this study we documented an abrupt decline in the island fox population on San Miguel Island from 1994 to 1998. Although other island fox populations have been shown to fluctuate, the range of the decline on San Miguel Island was greater than that reported for other island fox populations. Fox populations on San Clemente and Santa Catalina islands have fluctuated over time (Roemer et al. 1994). On those islands, within-grid density varied approximately 2 to 3 foxes/km^2 on four grids and approximately 6 foxes/km^2 on one grid. In contrast, the range of adult density on San Miguel Island during the recorded decline was 10.1 foxes/km^2 on the Willow Canyon grid, approximately 8.0 foxes/km^2 on the San Miguel Hill grid, and 15.9 foxes/km^2 on the Dry Lakebed grid.

On the eastern half of the island (Willow Canyon and San Miguel Hill grids), adult survival was initially high, but declined over the study period. The highest density was recorded on the Dry Lakebed grid in 1994, but survival was low from 1994 to 1995, and apparently no foxes survived from 1995 to 1996 on the Dry Lakebed grid, or from 1996 to 1997. We did not document actual mortality of foxes in our study, and it is possible that foxes not seen in subsequent years may have dispersed from the grids. On the Willow Canyon and San Miguel Hill grids in 1997 we recaptured five individuals which had not been captured for two to four years previously. However, it is unlikely that a significant number of foxes not recaptured had dispersed away from the grids, because the proportion of the island sampled by the three grids was high, approximately 30% (see effective trap area estimates in Table 1).

We expected to observe declines in food availability, because such changes drive population dynamics of other fox populations, to varying degrees. Changes in food availability drive fox population dynamics primarily through effects on reproduction and nutritional status. Decline in prey availability can result in fewer females breeding, smaller litters, fewer pups, or lower pup survival to yearling stage. Such effects on reproduction have been observed for fox populations closely linked to single food sources (kit fox, *Vulpes macrotus*: Egoscue 1975, White and Ralls 1993; mainland arctic fox, *Alopex lagopus*: MacPherson 1969; insular red fox, *Vulpes vulpes*: Zabel and Taggart 1989; mainland red fox: Goszczynski 1989), as well as the generalist gray fox (Root and Payne 1985). Although we expected the decline in the fox population to be accompanied by declines in food, the prey items that we monitored did not decline over the study period. Like the mainland gray fox, the island fox is a generalist omnivore which does not rely on a single prey species (Moore and Collins 1995). Island fox diet changes seasonally according to availability of food items. The most important food items for island foxes on San Miguel Island are deer mice and the fruits of sea-fig. Deer mice, which were reported to be present in 11 to 76% of San Miguel Island fox scats (Collins and Laughrin 1979), did not decline over the study period.

Sea-fig has been reported to account for 30 to 90% volume of fox scats in all seasons (Collins and Laughrin 1979) and was most important in summer. Relative cover of sea-fig did not decline during the study period, although measurement of sea-fig cover may not accurately reflect fruit availability. Additionally, there is a scale-induced die-off of sea-fig occurring near Simonton Cove which the Park's vegetation monitoring program did not detect in its transects (K. McEachern, pers. comm. 1998).

We did not monitor invertebrate populations, and thus may have missed seasonal and annual fluctuation in invertebrates. Insects are seasonally important in San Miguel Island fox diets, occurring in 70 to 80 % of spring and fall scats, and accounting for 35% and 23% of the total volume of scats in those seasons, respectively (Collins and Laughrin 1979). It is possible that insect availability may have changed over the study period due to weather, and could have affected fox populations.

The only prey item that declined over the study period was horned larks. Birds are somewhat seasonally important in the diet of San Miguel Island foxes, occurring in 22% of spring scats, and accounting for an average of 13% of scat volume during spring (Collins and Laughrin 1979). Although horned larks declined over time, it is unlikely that this adversely affected nutrients available to foxes, since their diet is sufficiently diverse in the spring to allow them to switch to other food items, including seasonally abundant orthopterans.

We expected that annual precipitation could affect fox populations either positively, by increasing productivity and prey populations, or negatively, by affecting fox survival. San Miguel Island is subject to periodic drought caused by El Niño - Southern Oscillation events, but it is unknown whether this results in prey scarcity. We began monitoring foxes after a six-year drought had ceased, and thus cannot quantify the effects of drought on San Miguel Island foxes and their food base. However, record precipitation in 1995 did not result in higher mouse densities and higher fox densities. In fact, fox densities declined in the three years following the record precipitation. On the other hand, the high precipitation of winter 1994-1995 and winter 1997-1998 may have adversely affected fox survival on San Miguel Island. Precipitation was almost twice as high in winter 1994-1995 than in any other year, even the El Niño year of 1997-1998. Adult survival was lower in 1994-1995 than in 1993-1994, but, over the study period, adult survival was not correlated with winter precipitation. Unless changes in insect availability occurred, factors other than food availability and weather may have caused the observed island fox population decline.

The observed decline in the San Miguel fox population may be due to a disease agent. The pattern of population decline on the island (from west to east) suggests a disease spreading within the fox population in that same direction. Results from this and previous studies (Garcelon et al. 1992) indicate that island foxes on San Miguel Island have antibodies for canine parvovirus and canine adenovirus. Although exposure to canine adenovirus was high for all years, it is unknown whether this has impacted fox populations. Other free-ranging canids have also shown high seroprevalence to canine adenovirus, and the disease can cause high mortality rates in juveniles, according to Garcelon et al. (1992). Those authors documented high seroprevalence rates (72 to 97%) for four of the six island fox populations; Santa Cruz and Santa Catalina showed no antibodies to canine adenovirus. Garcelon et al. (1992) concluded that the high seroprevalence indicated that canine adenovirus may be enzootic in the island fox. In this study, female pup survival rates declined over time, and perhaps were influenced by canine adenovirus.

No antibodies to canine distemper have been found in any of the fox populations on the Channel Islands, suggesting either that distemper has never been introduced to island fox populations, or that island foxes are extremely susceptible to distemper and none survived exposure (Garcelon et al. 1992). Canine distemper has been identified as a factor in periodic local population declines of gray foxes on the California mainland (P. Swift, pers. comm. 1996) and has been identified as a significant mortality factor for some gray fox populations in the southeastern United States (Nicholson and Hill 1984, Davidson et al. 1992). On San Miguel Island, occasional visits by domestic dogs could expose island foxes to various diseases. Although domestic dogs are not allowed on the island, boaters have been observed bringing their pets ashore on San Miguel Island (I. Williams, pers. comm. 1996) and on nearby Santa Cruz Island (G. Roemer, pers. comm. 1994). During the decline, fox carcasses were not collected and necropsied, or examined for clinical evidence of disease. Without such evidence, it is difficult to rule out disease as a factor. Other diseases or parasites may have played a role in the observed population decline. We are currently investigating the occurrence in island foxes of a common canine parasite, heartworm (*Dirofilaria immitis*), and exposure to a calicivirus, San Miguel sea lion virus.

The extremely small adult population size estimated for San Miguel island foxes (40 adults) decreases the probability of this population persisting over time. Although a population viability analysis (PVA) has not been conducted for the San Miguel Island subspecies of island fox, the population's decrease to approximately 40 adults is alarming. Although such a small population size may compromise the maintenance of adequate genetic variation in the population (Franklin 1980; Lande and Barrowclough 1987), the demographic consequences for population persistence are more important in the short-term (Lande 1988). A population as low as 40 individuals may be subject to random demographic variation, as variation in individual birth and death rates causes the population to fluctuate, perhaps to extinction (Gilpin and Soule 1986).

Recent information indicates that island fox populations are declining on Santa Rosa and Santa Cruz Islands, as well as on San Miguel (G. Roemer and D. Garcelon, pers. comm. 1996). As on San Miguel, the reasons for the declines on Santa Rosa and Santa Cruz are not immediately apparent. The observed population decline of island fox on San Miguel Island comprises a "red flag" situation detected by a long-term ecological monitoring program. It also underscores the need for a monitoring program to marshal the fiscal and scientific support required to investigate cause and effect, after a red flag situation is discovered. Although the current island fox monitoring program provides a more complete dataset than any other terrestrial protocol at Channel Islands National Park, it is still insufficient to tease out the factors responsible for the observed population decline. Active and in-depth research is required to determine the roles that parasites and disease play in island fox population dynamics, and to directly determine mortality factors. Until factors for the decline can be established, and, if possible, mitigated, the data thus far raise the specter of a local extirpation of island fox on San Miguel Island, and perhaps on the other two islands where the fox occurs in the Park.

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