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S. B. Floit
L. W. Barnthouse

Environmental Sciences Division
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DEMOGRAPHIC ANALYSES OF A SAN JOAQUIN KIT FOX POPULATION

Sara B. Floit[1] and Lawrence W. Barnthouse

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[1]School of Public and Environmental Affairs, Indiana University, Bloomington.

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ABSTRACT

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The San Joaquin kit fox, *Vulpes macrotis mutica*, is a federally listed endangered species, and under California law it is considered threatened. A population of the San Joaquin kit fox survives on Naval Petroleum Reserve-1 (NPR-1), an active oil field at Elk Hills in Kern County, California. Between 1980 and 1986 EG&G Energy Measurements conducted intensive studies of the life history and population dynamics of the kit fox population on NPR-1. EG&G found that the population had declined significantly. Possible causes of the decline include increased human activity connected with oil production, increased predation by coyotes, adverse effects of toxic oil field wastes, and natural environmental change.

In May 1987, Oak Ridge National Laboratory began an investigation of the relationship between oil field materials and wildlife on NPR-1. As part of this study, we analyzed data on the dynamics of the NPR-1 kit fox population collected by EG&G from March 1980 through August 1986. We used conventional methods of life table analyses to quantify (1) age-specific birth and death rates and (2) instantaneous and finite rates of population change. We performed separate analyses for subpopulations in undeveloped and developed areas of NPR-1. We used the abundance and mortality data provided by EG&G to estimate annual age-specific risks of mortality due to predation, vehicles and other known causes, and unknown causes. From the life table, we estimated the changes in reproduction and survival that would be required to stabilize the population.

We found that between 1980 and 1986, the kit fox population on NPR-1 declined by about 30% per year in both developed and undeveloped habitats. Coyote predation was the dominant source of mortality for all ages of kit foxes in all habitats, however, positive relationships between risk factors (e.g., where coyote predation was higher, other risks were also higher) suggest the existence of a common cause that increases the exposure of kit foxes to many sources of mortality. A 50% increase in survival for all age groups would stabilize the population and permit approximately a 6% annual growth rate, even if all reproductive parameters remained unchanged.

1. INTRODUCTION

The San Joaquin kit fox, *Vulpes macrotis mutica*, is a subspecies of North America's smallest species of fox (Holing 1987). It is a federally listed endangered species, and under California law it is considered threatened (Holing 1987). A population of the San Joaquin kit fox survives on Naval Petroleum Reserve-1 (NPR-1), an active oil field, at Elk Hills in Kern County, California. In 1980 the U. S. Fish and Wildlife Service (USFWS) was consulted for recommendations on how oil field activity could be continued without causing harm to the kit fox population (Berry et al. 1987a). EG&G Energy Measurements began an intensive study of the kit fox population on NPR-1 in 1980 to comply with one of the USFWS recommendations (Berry et al. 1987a). This study lasted from 1980 to 1986.

In 1986 and 1987, EG&G published various reports describing the kit fox population on the reserve. The many topics covered included: reproductive capability (Zoellick et al. 1987b), rates and causes of mortality (Berry et al. 1987), population estimates (Harris et al. 1987), diet (Scrivner, O'Farrell and Kato 1987a), prey populations (Harris 1986b), instances of disease (McCue and O'Farrell 1986a), serology (McCue and O'Farrell 1986b), den characteristics (Berry et al. 1987b), monitoring techniques (Harris 1987), dispersal (Scrivner, O'Farrell, and Kato 1987b), movement and home range (Zoellick, O'Farrell, and Kato 1987a), coyote control programs (Harris 1986a, Scrivner and Harris 1986, Scrivner 1987), management plan for NPR-1 (O'Farrell and Scrivner 1987), resurvey of endangered species (O'Farrell and Mathews 1987), and a study of endangered species on Naval Petroleum Reserve-2 (NPR-2) (O'Farrell et al. 1987a). These studies determined that the kit fox population at NPR-1 had declined. Possible causes of the decline include increased human activity as a result of oil production, increased predation by coyotes, adverse effects of toxic oil field wastes, and natural environmental change.

In May 1987, Oak Ridge National Laboratory began an investigation into the relationship between oil field materials and wildlife on NPR-1 (Suter et al. 1988). The initial objective of this study was to determine the quantities of oil field-related materials/chemicals present at NPR-1. Water, soil, vegetation, fox hair, and tissue samples were analyzed for levels of metals and other compounds such as volatile organics. Another objective was to determine whether the observed decline of the kit fox population on NPR-1 could be related to exposure to oil field wastes. In connection with this objective, we analyzed data on the population dynamics of the NPR-1 kit fox population collected by EG&G from March 1980 through August 1986. This demographic analysis had five objectives: (1) to determine the parameters of the kit fox population, (2) to test for differences between rates of reproduction and mortality for foxes present in developed and undeveloped habitats, (3) to determine whether the radiocollared population is a representative sample of the entire kit fox population, (4) to calculate the probability of death, by age, for the major sources of mortality, and (5) to determinate the changes in reproduction and mortality necessary to stabilize the population.

2. METHODS

All of the published studies on the NPR-1 kit fox population were provided to us by EG&G. In addition, we obtained two magnetic tapes containing data on the characteristics of each kit fox trapped or recovered by EG&G. The first, or "trapping" data tape contained information on live-trapped kit foxes. These data included, for each trapped fox, the ear-tag number, sex, possible age and birth year, radiofrequency (if radiocollared), date of capture, reproductive condition, length of body parts, and location of trapping. The second, or "terminal" data tape contained information about dead foxes recovered by EG&G. These data included ear-tag number (if previously captured), condition of the carcass, tissues sampled, and cause of death. A complete list of the information on both tapes is given in Appendix A.

2.1 ASSIGNMENT OF TRAPPING LOCATIONS TO HABITATS

Trapping locations were designated by both a township code and a quarter section code. For example, Township G is divided into sections 1G, 2G, 3G, and 4G. These sections are further subdivided into quarter sections and the quarter sections are subdivided into quarters. For example, the northwest quarter section of township section 1G has four quarters indicated as 1-1 (NWNW), 2-1 (NENW), 1-2 (SWNW), and 2-2 (SENW). These numerical designations were used to describe the trapping location. For the disturbance classification the entire quadrant (i.e. the northwest quadrant) is designated as either developed or undeveloped, depending on the percentage disturbance of the site. A section is designated as developed when more than 15% of the land is disturbed by oil-field activities (Zoellick et. al. 1987b). There are a few exceptions where, for example, one quarter section was undeveloped (<12.0% disturbance), but the entire township section was designated as developed because of extensive disturbance in the other quarter sections.

In the demographic analyses, population parameters were determined both for all foxes within the study area and by habitat. It was necessary to assign each fox to a habitat type, either disturbed or undisturbed. This can be done in two ways: by the location at which the fox is first captured (the "first radiocollar" location) or by the location at which either the body of the fox or the radiocollar was recovered (the "terminal" location).

Because many foxes were captured and recovered in different habitats, we performed parallel analyses using both methods of assigning foxes to habitats.

2.2 CALCULATION OF LIFE TABLE PARAMETERS

We used conventional methods of life table analyses (Krebs 1985) to quantify (1) age-specific birth and death rates and (2) instantaneous and finite rates of change for the radiocollared subpopulation of kit foxes on NPR-1.

Two hundred and seventy foxes were radiocollared during the span of the study, 136 in undeveloped and 134 in developed habitat (Berry et al. 1987a). We used data only for foxes that could be assigned specific ages at collaring and at death. To determine an age at collaring, we examined the trapping data to determine the date on which the first radiocollar frequency was recorded. This date was then compared with either the possible birth year of the fox (trapping data set) or to the year of death (terminal data set) to determine the specific age at which it was first radiocollared. Recovered foxes were assigned specific ages at death from analyses of teeth.

Survival rates were calculated using mortality data from Berry et al. (1987a) and EG&G data tapes (Appendix A). It was necessary to estimate the total number of live foxes at each age, including both those radiocollared at that age and those radiocollared at previous ages. The number of age 0 (juvenile) kit foxes radiocollared on NPR-1, and the number of these that died before age 1 year were available directly from Berry et al. (1987a). Because births occur from mid to late February, February 16 was considered the birth date for all foxes. To obtain the number of live 1-year old radiocollared foxes, we added the number of foxes first collared at age 1 year to the number of collared juveniles that survived to age 1 year,i.e., to (February 16 of the year following their birth). To estimate the number of 2-year olds, we subtracted the number of recovered 1-year-old kit foxes from the number of live 1-year olds and then added the number of kit foxes first collared at age 2 years. We repeated this procedure for all ages of kit foxes recovered on NPR-1. Age-specific survival rates were then estimated by dividing the number of foxes reaching each age by the number that died before reaching the next age.

We also calculated survival rates for groups of foxes collared at a particular age. The purpose of this analysis was to determine whether there was a relationship between age at collaring and subsequent survival. The purpose of this analysis was to determine whether radiocollaring could be deleterious to the kit foxes' survival. Because juvenile survival rates for foxes collared as adults could not be determined, our analyses compared survival at 1-year of age and older for foxes collared during their first year and foxes collared as yearlings or older.

We calculated fecundity for the radiocollared subpopulation as a whole and by habitat type using data from Zoellick et al. (1987b). Percentage ovulation and percentage success at raising pups were determined for foxes in each habitat type for yearling and adult age classes. Litter size was determined for yearlings and adults in combined habitats only. Because data on litter size for foxes in developed and undeveloped habitats were not available, it was necessary to assume that litter size was the same in both habitats. We assumed the sex ratio in each litter to be the same for each age class but calculated separate sex ratios for litters in developed and undeveloped habitats. Age-specific fecundity (m_x) values were calculated as the product of (1) the fraction of females ovulating at each age x, (2) the average litter size for females of age x, (3) the fraction of females of age x successfully rearing litters, and (4) the fraction of the pups that were females.

We used the age-specific survival and fecundity estimates described to calculate the following life table statistics (Krebs 1985): (1) net reproductive rate (NRR), defined as the expected number of female pups successfully reared by a female during her lifetime, (2) generation time (GT), defined as the average time interval between the birth of parents and the birth of their offspring, and (3) the intrinsic (r) and finite (R) rates of population change, which quantify the annual rate of increase or decline in population size.

We independently estimated the rate of change of the entire NPR-1 kit fox population (including foxes that were not radiocollared) from the capture-recapture population estimates published by Harris et al. (1987). We assembled a 6-year time series of population sizes by averaging primary sampling periods for each year. One count (winter of 1980) was excluded from the analysis because trapping effort and area were not comparable with the other counts. We regressed the logarithms of the population estimates against time using the equation

$$\ln N_t = \ln N_o + rt. \qquad (1)$$

where

N_1 = population size at time t and

N_o = population size at time O.

The slope of the regression (r) is an estimator of the intrinsic rate of population change, provided that the population is near a stable age distribution.

2.3 PARTITIONING OF MORTALITY INTO SOURCE-SPECIFIC RISK FACTORS

The four sources of kit fox mortality on NPR-1 during the period 1980-86 were defined by EG&G: predation, vehicles, other, and unknown. Predation consisted mostly of coyote kills, with one known bobcat kill and a suspected golden eagle kill. Vehicular deaths were caused by trucks and other vehicles on the roads built across NPR-1. The "other" category included foxes that were killed by known causes such as shooting or disease, and the term "unknown" was used to classify deaths that had no known cause. We used the abundance and mortality data provided by EG&G to estimate mortality risk factors. These factors indicate the annual risk that a fox of a given age in a given habitat type will die from each of the above sources of mortality, independent of all of the others.

We used the same estimates of the initial number of kit foxes in each age group used to calculate age-specific survival rates (Sect. 2.2). We included in the initial population sizes foxes that were considered still alive at the end of the study in 1986. For each animal that died during the study period, the age at death and cause of death were determined from the EG&G terminal data set (Appendix A).

The equation used for the determination of the mortality risk factors (m) originated in the fisheries management literature and is commonly known as Ricker's "Type II" fishery model (Ricker 1975; Barnthouse et al. 1981). We assume that the various sources of mortality are independent (i.e., that the risk of a particular fox being killed by a vehicle is independent of its risk of being killed by a coyote). The proportion of foxes alive at the beginning of the study that died from cause i during the year is defined as the exploitation rate u_i. The sum of the exploitation rates (i.e., the sum of all u_i) is equal to the total fraction of the group dying during the year (A). When the different sources of mortality are independent, exploitation rates are not equivalent to probabilities of death. Some of the animals killed by coyotes would have been hit by vehicle if they had survived predation. Probabilities or risks of death from any one cause of mortality (m_i) can be calculated from u_i and A using the equation

$$m_{(i)} = 1 - (1 - A)^{u(i)/A} \quad . \tag{2}$$

The probability of any animal surviving through the year **s** is equal to $(1 - A)$ and also equal to the product of the probabilities of surviving each of the individual sources of mortality.

The data provided by EG&G were sufficient to calculate mortality risk factors by age and habitat for each of the four categories of mortality.

3. RESULTS

Tables 1 through 3 summarize the data on age-at-collaring and age-at-death for radiocollared kit foxes on NPR-1. Table 1 presents the data for all habitats combined. It lists the number of foxes dying at each age, broken down by age-at-collaring. Tables 2 and 3 contain similar compilations but tabulated separately for each habitat type. In Table 2 the habitat designations are made based on first radiocollar location; in Table 3 they are made by terminal location. We used the data presented in these tables to calculate age-specific mortality rates (1) for NPR-1 as a whole and (2) separately for disturbed and undisturbed habitats. The age-specific survival rates are presented in Tables 4 and 5. The relationship between survival and age at collaring, as presented in Table 6, appears to indicate that juveniles do have a different pattern of survival than adults.

Because inspection of Table 1 suggested that the age at which a kit fox was collared might affect its subsequent probability of survival, we grouped the mortality data by age-at-collaring and calculated age-specific survival rates for each group (Table 6). Table 6 suggests that foxes collared at age 0 (<1 year) had lower subsequent survival rates than foxes collared at age 1 year or older. A contingency table analysis (Table 7) shows that the differences in survival are statistically significant. We performed the same analysis with the data broken down by habitat and found that the difference in survival rates between kit foxes collared in their first year of life and kit foxes collared at older ages persists regardless of the habitat designation of the animals and the method of assigning animals to habitats.

The data used to calculate age-specific fecundity are summarized in Table 8. As noted in Sect. 2, the components of fecundity, as defined for life table analysis, include the probability of ovulation, mean litter size, sex ratio, and probability of litter success. We found these parameters to vary substantially between ages and habitat types. The age-specific fecundity values (Table 9) show that average fecundity is much lower at age 1 year than at older ages, and that 1-year-old females have a much higher net fecundity in undeveloped than in developed habitat.

Table 10 presents the life table we developed for the NPR-1 kit fix population, and Table 11 presents the life table statistics net reproductive rate (NRR), generation time (GT), instaneous rate of population change (r), and finite rate of population change (R).

Table 1. Mortality data for all foxes in EG&G study

Age collared (years)	Total number collared	Number dying within age class 0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
0	145	106	25	10	2	1	1			
1	31		12	7	5	4	3			
2	14			4	4	4	2			
3	11				6	3	2			
4	4				3			1		
5	5					3		1		1
6	0									
7	1								1	

Table 2. Mortality data broken down by habitat—terminal location

Age collared (years)	Habitat[a]	Total number collared	Number dying within age class 0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
0	D	66	55	5	3	2		1			
	U	67	42	18	6		1				
1	D	9		3	1	2	1	2			
	U	22		9	6	3	3	1			
2	D	5			1	1	2	1			
	U	9			3	3	2	1			
3	D	3				1	1	1			
	U	7				4	2	1			
4	D	3					2		1		
	U	1					1				
5	D	1									1
	U	3						2	1		
6	D	0									
	U	0									
7	D	1							1		
	U	0									

[a]D = developed; U = undeveloped.

Table 3. Mortality data broken down by habitat—radiocollar location

Age collared (years)	Habitat[a]	Total number collared	Number dying within age class 0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	9-9
0	D	80	61	10	5	2	1	1			
	U	63	45	13	5						
1	D	13		2	2	3	3	3			
	U	18		10	5	2	1				
2	D	5			2		2	1			
	U	9			2	4	2	1			
3	D	3				1	1	1			
	U	8				5	2	1			
4	D	2					1		1		
	U	2					2				
5	D	1									1
	U	4						3	1		
6	D	0									
	U	0									
7	D	1								1	
	U	0									

[a]D = developed; U = undeveloped.

Table 4. Age-specific survival rates for all habitats combined

Age (years)	Probability of survival
0	0.27
1	0.47
2	0.55
3	0.54
4	0.38
5	0.21
6	0.33
7	0.50
8	0

Table 5. Age-specific survival rates by habitat type

Age (years)	1st Radio-collar location[a,b] U	1st Radio-collar location[a,b] D	Terminal location[b,c] U	Terminal location[b,c] D
0	0.29	0.24	0.37	0.17
1	0.36	0.63	0.43	0.60
2	0.45	0.64	0.48	0.71
3	0.39	0.68	0.52	0.60
4	0.22	0.47	0.25	0.50
5	0.17	0.25	0.17	0.29
6	0	0.50	0	0.50
7			0.50	0.50
8		0		0

[a]Habitat designation based on first radiocollar location.
[b]U = undeveloped, D = developed.
[c]Habitat designation based on terminal recovery location.

Table 6. Relationship between survival rate and age-at-collaring

Age (years)	Age when collared (years) 0	1	2	3	4	5
0	0.2690					
1	0.3590	0.6129				
2	0.2857	0.6316	0.7143			
3	0.5000	0.5833	0.6000	0.4545		
4	0.5000	0.4286	0.3333	0.4000	0.2500	
5	0.0000	0.0000	0.0000	0.0000	1.0000	0.4000
6					0.0000	0.5000
7						1.0000
8						0.0000

Table 7. Contingency table for chi-square analysis[a] of the age at death with respect to the age when collared

Collared age		Age at death (years) 1	2	3 or >	Totals
0	(ob)	25.00	9.00	4.00	38.00
	(exp)	13.39	7.60	17.01	
1 or >	(ob)	12.00	12.00	43.00	67.00
	(exp)	23.61	13.40	29.99	
Totals:		37.00	21.00	47.00	105.00

[a]Chi-square value: 31.77, Degrees of freedom = 2, and $P < 0.005$.

Table 8. Reproductive statistics used in the calculation of fecundity

Age of mother (years)	Success raising pups (%)	Ovulation (%)	Litter size[a]	Fraction of female pups
Yearling	16	94.67	4.5	0.5000
Yearling (U[b])	25	100.00	4.5	0.5635
Yearling (D)	8	92.00	4.5	0.4286
Adult	59	100.00	4.2	0.5000
Adult (U)	51	100.00	4.2	0.5635
Adult (D)	69	100.00	4.2	0.4286

[a]Litter size for 2 year old adult was 4.1.
[b]Habitat type (U = undeveloped; D = developed).

Table 9. Fecundity for entire study area and by habitat

Age (years)	Overall fecundity	Developed habitat	Undeveloped habitat
0	0.0000	0.0000	0.0000
1	0.3408	0.1419	0.6339
2	1.2095	1.2124	1.1783
3	1.2390	1.2420	1.2070
4 or >	1.2390	1.2420	1.2070

Table 10. Life table for the NPR-1 kit fox population

Age (years)	1(x)[a]	m(x)[b]
0	1.00	0.0
1	0.26	0.34
2	0.12	1.21
3	0.069	1.24
4	0.035	1.24
5	0.014	1.24
6	0.003	1.24
7	0.001	1.24
8	0.0005	1.24
9	0.0	0.0

[a]Probability of surviving from birth to age x.
[b]Expected number of female pups reared by a female alive at age x.

Table 11. Life table statistics for all foxes

Statistic	All habitats	Terminal[a] D	Terminal[a] U	1st Radiocollar[a] D	1st Radiocollar[a] U
NRR[b]	0.4022	0.3246	0.5787	0.4665	0.3870
GT[c]	2.4158	2.9496	1.9954	2.9305	1.8384
r[d]	-0.3389	-0.3424	-0.2539	-0.2423	-0.4530
R[e]	0.7126	0.7101	0.7758	0.7848	0.6357

[a]D = developed; U = undeveloped.
[b]Net reproductive rate.
[c]Generation time (y)
[d]Intrinsic rate of change.
[e]Finite rate of change.

These results confirm the known fact that the kit fox population on NPR-1 has been declining. The life table statistics for all habitats combined (Table 11) suggest that the population declined at a rate of about 30% per year from 1980 to 1986. The between-habitat comparisons (Table 11) show that the decline has occurred in both developed and undeveloped habitats. Interestingly, comparisons of population statistics between habitat types are extremely sensitive to the method used to assign animals to habitats: if assignments are made based on first radiocollar location, the calculated rate of decline is much greater in undeveloped than in developed habitat. If assignments are made based on terminal location, exactly the opposite pattern is observed.

As an independent check on the validity of the life table statistics presented in Table 11, we used Eq. 1 to estimate the rate of decline of the kit fox population on NPR-1 from the capture-recapture population estimates of Harris et al. (1987). This estimate (Table 12) applies to the entire population, including both collared and uncollared subpopulations and both developed and undeveloped habitats. The slope calculated from the regression in Table 12 is directly comparable to the instantaneous rate of population change (r) for both habitats combined in Table 11. The good agreement between these values indicates that the radiocollared subpopulation has been declining at approximately the same rate as the total population on NPR-1.

Table 13 tabulates the data used to calculate age-specific mortality risk factors. Predation by coyotes and "unknown" causes account for most of the mortality to both

Table 12. Regression analysis of 6 year time series of population estimates

Year	Population size	ln
1	155.00	5.04
2	139.00	4.93
3	96.50	4.57
4	83.00	4.42
5	48.50	3.88
6	33.00	3.50

[a]Slope: -0.3155, Finite rate of change: 0.7294, Standard error: 0.0318, 95% confidence interval: 0.6677 to 0.7968

Table 13. Kit fox mortality data arranged by age class and cause of death

Age (years)	Initial population	Cause of death				Total deaths
		Predation	Vehicle	Other	Unknown	
0	152	53	9	4	41	107
1	79	24	4	0	11	39
2	54	18	1	0	5	24
3	42	12	2	2	2	18
4	28	7	4	0	5	16

juvenile and adult kit foxes. Risks of mortality calculated using equation 2 are presented in Table 14. For NPR-1 as a whole, juvenile kit foxes experience a 45% risk of predation mortality during their first year of life (Table 14). For the remainder of their lives, the animals surviving their first year experience a 31-36% annual risk of predation. Annual risks of death due to vehicles are only about 10% for age 0 animals and between 2-19% for ages 1-4.

Table 15 presents separate mortality risk factors for developed and undeveloped habitat, using both methods of assigning foxes to habitats. Regardless of which method is used, juvenile mortality risks for predation and vehicles are higher in developed than in undeveloped habitat.

We adjusted the fecundity and mortality estimates in Tables 4 and 9 to identify the decreases in mortality or increases in reproduction needed to stabilize the population. We examined four possible changes. First, we increased the net fecundity [$m(x)$] of yearling foxes to 1.2, approximating the values calculated for older foxes. Because most of the reproductive parameters vary relatively little with age, this change is effectively equivalent to increasing the litter success of yearlings to the value observed in older foxes. Second, we increased the litter size for all ages to 6 years, leaving all other components of net fecundity unchanged. Third, we raised the survival rate of juveniles to 0.5 (approximately the value observed in older animals), while leaving all reproductive parameters unchanged from their base values. Finally, we raised the age-specific survival rates [$s(x)$] for all ages by 50% of their base values.

Results of this analysis are presented in Table 16. Surprisingly, most of the changes had little effect on the instantaneous rate of population change (r). Neither of the changes in fecundity had more than a negligible effect on r. Presumably at the prevailing mortality rates too few foxes are surviving to reproductive ages for increases in litter production or rearing success have much effect. Increasing juvenile survival to the survival rate observed in older foxes increased r, but not nearly enough to stabilize the population. Only the last change, increasing the survival rate for all ages, had the desired effect of raising r above 0, thus permitting stabilization of the population. This result implies that if the annual rate of survival for all foxes were increased by 50% over its current level, the population would grow by approximately 6% per year.

Table 14. Age-specific risk of death for four sources of mortality

Age (years)	Predation	Vehicles	Other	Unknown	Total
0	0.45	0.10	0.04	0.37	0.70
1	0.34	0.07	0.00	0.17	0.49
2	0.36	0.02	0.00	0.12	0.44
3	0.31	0.06	0.06	0.06	0.43
4	0.31	0.19	0.00	0.23	0.57

Table 15. Age-specific risk of death for developed and undeveloped habitat

Age at death (years)	Cause	Terminal[a]		1st radiocollar[a]	
		D	U	D	U
0	Predation	0.58	0.36	0.51	0.43
	Vehicle	0.25	0.00	0.14	0.05
	Other	0.03	0.04	0.02	0.08
	Unknown	0.41	0.36	0.39	0.40
1	Predation	0.25	0.39	0.16	0.47
	Vehicle	0.00	0.08	0.03	0.11
	Other	0.00	0.00	0.00	0.00
	Unknown	0.16	0.21	0.19	0.17
2	Predation	0.27	0.36	0.26	0.49
	Vehicle	0.00	0.04	0.00	0.06
	Other	0.00	0.00	0.00	0.00
	Unknown	0.06	0.16	0.08	0.17
3	Predation	0.22	0.37	0.15	0.54
	Vehicle	0.15	0.00	0.10	0.00
	Other	0.15	0.00	0.10	0.00
	Unknown	0.00	0.11	0.00	0.16
4	Predation	0.27	0.39	0.33	0.35
	Vehicle	0.00	0.39	0.08	0.48
	Other	0.00	0.00	0.00	0.00
	Unknown	0.27	0.22	0.15	0.35

[a]D = developed, U = undeveloped.

Table 16. Influence of life table changes on rate of population change

Life table change	r
1-year-old fecundity[a]	-0.23
litter size[b]	-0.23
juvenile survival[c]	-0.12
all age survival[d]	+0.06

[a]Increase net fecundity of 1-year-olds (Table 9) from 0.34 to 1.2.
[b]Increase average litter size (Table 8) for all ages from 4.5 to 6.
[c]Increase age-specific survival (Table 4) of juvenile foxes from 0.27 to 0.5.
[d]Increase age-specific survival (Table 4) for all ages by 50%.

4. DISCUSSION

Habitat-specific differences in survival and reproduction of San Joaquin kit foxes on NPR-1 have already been thoroughly documented, so no further discussion of these differences is needed here. The differences in age-specific survival rates between foxes radio-collared during their first year of life and at age 1 year or older is noteworthy but cannot be explained solely on the basis of data analyzed in this report.

The results of principal interest here are the life table statistics and the mortality risk factors. The life table statistics (Table 11) show that between 1980 and 1986 the kit fox population on NPR-1 declined at a rate of about 30% per year. The rate of change calculated from life table analysis is consistent with the rate calculated from capture-recapture population estimates (Table 12), suggesting that the demographic characteristics of the radiocollared subpopulation are representative of the kit fox population as a whole. We were unable to determine whether the developed and undeveloped habitats differ with respect to overall life table statistics because the two methods of assigning animals to habitats produced inconsistent results.

The mortality risk factors (Tables 14 and 15) produced both expected and unexpected results. As expected, coyote predation is the dominant source of mortality for all ages of kit foxes. Each juvenile kit fox has a 45% risk of being killed by a coyote before its first birthday; older animals have a 30 to 35% annual risk of coyote predation. The rank order of mortality risks is the same for both habitat types (Table 15), but the magnitudes of the risks differ substantially between habitats. For juvenile kit foxes, coyote predation is greater in developed than in undeveloped habitat. Most of the other mortality risk factors are also higher in developed than in undeveloped habitat. For adult kit foxes, this pattern is exactly reversed: coyote predation is substantially greater in undeveloped habitat, and most of the other mortality risks are also greater. These patterns are the same regardless of which method is used to assign animals to habitats. We cannot explain them based on the data available to us. The correlations observed between risk factors (i.e., wherever coyote predation is high vehicular mortality is also high) suggest the existence of a common cause that increases the exposure of kit foxes to many sources of mortality. For example, the risks of mortality from both coyote predation and vehicle collision are probably directly related to the amount of time an animal spends foraging and to the distance it travels away from its den. Our results, although not conclusive, suggest that the explanation for the high rate of mortality of kit foxes may not be simply that there are too many coyotes and vehicles.

Regardless of the cause, it is clear that reducing the total mortality rate for all age groups is the key to stabilizing the kit fox population on NPR-1. Our life table sensitivity analysis (Table 16) shows that changes in reproduction (expressed as either litter size of all females or net reproductive success of females reproducing as juveniles) and juvenile survival have negligible effects on the rate of population decline. However, a 50% increase in survival for all age groups would stabilize the population and permit approximately a 6% annual growth rate, even if all reproductive parameters remained unchanged.

We suggest two avenues for further investigation based on these results. Obviously, comparisons between NPR-1 and healthy kit fox populations such as the population on NPR-2 would be quite valuable. Comparisons between age-specific mortality rates would be particularly interesting. However, population-level characteristics such as reproduction and mortality rates are ultimately functions of the survival and reproduction of individual animals. Detailed observations of individual animals and dens might provide valuable insights into the definition of good and bad habitat and the relationship between habitat quality (e.g., presence of cover, abundance of lagomorphs, and degree of disturbance by man) and the probability that an animal will survive and reproduce. Such information would be valuable both for interpreting the causes of the decline of the population and designing an effective recovery program.

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Appendix A

EG&G DATA TAPE INFORMATION

Kit Fox Trapping Data Format

1. Capture date
2. Eartag
3. Observer
4. Birthyear
5. Radio collar frequency
6. Sex
7. Capture No.
8. Quarter section (1-1, 2-1, 3-1, etc.)
9. Section (18G, 3S, etc.)
10. Weight, gross
11. Bag weight
12. Collar weight
13. Net weight
14. Age
15. Serial number
16. Length of ear from notch (EFN)
17. Length of ear from base (EFB)
18. Length of hind foot
19. Fleas (if noted, observed, or collected)
20. Scat (collected or not)
21. Card Num-A
22. Vaginal condition
23. Pregnancy information
24. Condition of mammae
25. Penis information
26. Testes information
27. Cauda epididymides (present or not)
28. Eye condition
29. Trapping type
30. Area (NPR-1, NPR-2, etc.)
31. Physiography of trap location
32. Written remarks
33. Type of teeth
34. Condition of teeth
35. Tooth chart (present or absent)
36. Card Num-B

Terminal Data Sheet Data Format

1. Ear tag No.
2. Date
3. Sex
4. Age
5. Birth year
6. Section code
7. Quarter section
8. Net weight
9. Ear from notch (EFN)
10. Ear from base (EFB)
11. Hind foot in mm
12. Tail length in mm
13. Radiocollar frequency
14. Fleas (noted, collected or not)
15. Type of teeth
16. Condition of teeth
17. Tooth chart (present or not)
18. EG&G number
19. Observer
20. Card No.
21. Study area
22. Condition of remains
23. Surface wounds
24. Broken bones
25. Haematomas
26. Thoracic cavity (wounds, etc.)
27. Other wounds
28. Stomach gross weight in grams
29. Contents net weight in grams
30. Contents of stomach (identification)
31. Endoparasites
32. Fresh tissue samples
33. Preserved tissue samples
34. Reproductive organs (collected or not)
35. Saved material
36. Probable cause of death
37. Written remarks
38. Card No.

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