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STERILANTS FOR MANAGING THE POPULATIONS OF RED-WINGED BLACKBIRDS (*Agelaius phoeniceus*)

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COYOTE CONTROL TO PROTECT ENDANGERED SAN JOAQUIN KIT FOXES AT THE NAVAL PETROLEUM RESERVES, CALIFORNIA

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ABSTRACT: We investigated the effectiveness of a coyote (*Canis latrans*) control program implemented to increase numbers of endangered San Joaquin kit foxes (*Vulpes macrotis mutica*) at the Naval Petroleum Reserves in California (NPRC). Between 1980 and 1985, the kit fox population on NPRC declined approximately 66% while coyote abundance apparently increased. Coyote predation was identified as the primary cause of mortality for kit foxes. From 1985 to 1990, the U. S. Department of Energy (DOE) sponsored a program to kill coyotes with the objective being to reduce predation on kit foxes and increase fox numbers. Control methods during the first 4 years were limited to trapping, shooting, and denning. In the last 12 months of the program, aerial gunning was implemented and significantly increased control intensity. This more intensive strategy was not conducted for a sufficient length of time to evaluate its effectiveness. Thus, conclusions regarding coyote control at NPRC are based primarily on the first 4 years of the program. During the 5-year effort, 591 coyotes were killed. Although coyote scent-station indices declined during the period of control, the contribution of the control effort to this decline is unclear. Reproductive rates of female coyotes did not exhibit a compensatory increase as is commonly observed when coyote populations are artificially depressed. After control was initiated, kit fox capture indices and survival rates did not increase, and the proportion of fox deaths due to coyotes did not decrease. The number of coyotes removed annually may not have been sufficient to effectively reduce coyote abundance. Kit fox and coyote population trends both were significantly correlated to lagomorph abundance. Thus, food availability probably was the primary factor influencing the population dynamics of both predators. Control efforts were discontinued pending further consideration of the merits of control and its potential efficacy at NPRC.

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INTRODUCTION

San Joaquin kit foxes are federally listed as endangered. DOE's Naval Petroleum Reserves #1 and #2 (NPR-1 and NPR-2, respectively) in California encompass large tracts of native habitat for kit foxes. Fox numbers on NPRC have been monitored since winter 1980-81. Between 1980 and 1985, the number of kit foxes trapped per 100 trap-nights declined approximately 66% while coyote abundance apparently increased. Almost 80% of kit fox deaths were attributable to predators, primarily coyotes (Berry et al. 1987).

In February 1985, DOE initiated a program to kill coyotes in an attempt to reduce predation on kit foxes. The U. S. Department of Interior, Division of Animal Damage Control was contracted to conduct the coyote control program. From 1985 to 1988, coyote control was conducted on NPR-1. In 1989, control efforts were expanded to include NPR-2 and a 24-km wide buffer area around NPRC. The control program was terminated in May 1990 due to questions regarding efficacy and ethics. We evaluated the success of the control program in reducing coyote numbers and predation on kit foxes on NPR-1. The short duration (10 months) of control on NPR-2 precluded a similar evaluation for this area.

STUDY AREA

NPRC is located 42 km southwest of Bakersfield in western Kern County, California. NPR-1 and NPR-2 comprise 19,120 ha and 12,173 ha, respectively. The reserves consist of gently rounded slopes that are highly dissected by steep draws and dry stream channels. Alluvial plains and flat valley lands occur around the perimeter of the reserves. Elevations range from 88 m to 473 m. The arid climate is hot and dry in summer, and cool and wet in winter with frequent fog. Temperatures in summer often exceed 38°C, and seldom go below 0°C in winter. Annual precipitation averages about 12.5 cm and occurs primarily as rain falling between November and April (O'Farrell et al. 1986, O'Farrell et al. 1987). Vegeta-tion is typical of the San Joaquin Saltbush association (Kuchler 1977). Dominant shrubs include valley saltbush (*Atriplex poly car pa*), cheesebush (*Hymenoclea salsola*), and bladderpod (*Isomeris arborea*). Herbaceous cover is dominated by the introduced annuals red brome (*Bromus rubens*) and red-stemmed filaree (*Erodium cicutarium*).

Petroleum products have been produced at NPRC since about 1920. Disturbances associated with oil field activities include construction of roads, well pads, and other facilities. An endangered species protection program was initiated in 1979. This program included monitoring population trends of kit foxes, coyotes, and prey species (O'Farrell et al. 1986).

METHODS

Effect of Control on Coyotes

From 1985 to 1988, coyotes were killed by trapping, shooting, and denning. Coyotes were trapped using #3 leghold traps with offset jaws, and trapped coyotes were shot. Pan tension devices were used on traps to exclude kit foxes. Coyotes also were shot opportunistically with a rifle. Occasionally, a predator call was used to attract coyotes within shooting range. Pups at known coyote dens were shot or trapped. Beginning in 1989, aerial gunning from a helicopter was used to kill coyotes. Data and samples collected from dead coyotes included locations, weights, standard morphometric measurements, stomachs, blood, lower canine tooth samples, and female reproductive tracts.

Coyote population trends on NPR-1 were monitored annually beginning in 1985 using scent-station surveys conducted in spring (February-March). Spring indices probably best estimate the resident breeding population (G. Connolly, Denver Wildlife Research Center, pers. commun.). Eleven scent-station survey lines were established with each line consisting of 10 scent-stations spaced 0.5 km apart along an unpaved road. Scent-stations were constructed using standard methods (Roughton and Sweeny 1982). Visits by coyotes were recorded and an index of abundance was produced by dividing the number of stations with visits by the number of operable stations and multiplying by 1,000 (Harris 1986).

The proportion of reproductively active females was determined annually by examining reproductive tracts for fetuses or placental scars. Average litter size was estimated annually using counts of fetuses and placental scars. Average litter size was compared among years to determine if coyote reproduction exhibited a compensatory increase in response to coyote removals.

Effect of Control on Kit Foxes

Kit fox population trends were monitored by live-trapping foxes in winter. Winter indices probably best estimate the resident breeding population. Foxes were captured in wire-mesh box traps, ear-tagged, and released. Indices of abundance were obtained by determining the number of individual foxes captured per 100 trap-nights.

Kit fox survival rates and sources of mortality were determined by monitoring foxes wearing radiocollars with mortality sensors. Survival rates of radiocollared foxes were estimated annually by determining the proportion of adults that survived for 180 days and 365 days, and the proportion of juveniles that survived to subadulthood (July 15) and adulthood (December 1). Survival rates before and during coyote control were compared. Dead foxes were necropsied to determine cause of death. Of those foxes for which cause of death could be identified, the proportion of mortalities due to predators was determined for the periods before and during coyote control.

Effects of Lagomorph Abundance on Predator Populations

Lagomorphs (black-tailed jackrabbits [*Lepus californicus*] and desert cottontails [*Sylvilagus audubonii*]) constitute important prey for kit foxes at NPRC (O'Farrcll et al. 1987, Scrivner et al. 1987), and probably for coyotes. Summer (June) lagomorph abundance provides a measure of food availability during pup rearing; food availability during reproduction can influence the population dynamics of both coyotes (Gier 1968) and kit foxes (Egoscue 1975). Summer lagomorph density was estimated beginning in 1984 using data from line-transect surveys (Harris 1986). Forty-two 1.6-km transects were established on NPR-1. Perpendicular distances between transects and flush points were used to estimate lagomorph densities using Program TRANSECT (Laake et al. 1979, Burnham et al. 1980).

Statistical Analyses

Linear regression was used to determine: if number of kit foxes captured per 100 trap-nights was related to coyote scent-station indices, or lagomorph densities; if kit fox survival rates were related to coyote scent-station indices; and if coyote scent-station indices were related to lagomorph densities. Regression analysis also was used to test for significantly increasing or decreasing trends among coyote, kit fox, and lagomorph indices.

A chi-square test with Yate's correction for continuity was used to compare proportions of foxes surviving and proportions of foxes killed by predators before and during coyote control. Finally, average litter size of coyotes was compared among years using one-way analysis of variance and the Tukey multiple comparison test.

Table 1. Number of coyotes killed annually from 1985 to 1990 at the Naval Petroleum Reserves, California.

Year	NPR-1	NPR-2	Buffer [a]	Total
1985	40			40
1986	63			63
1987	16			16
1988	66			66
1989	110	56	44	210
1990	45	31	120	196
Total	340	87	164	591

[a]24-km wide zone around NPRC.

RESULTS

Effects of Control on Coyotes

Between 1985 and 1990, 591 coyotes were killed at NPRC (Table 1). On NPR-1, 340 coyotes were killed with 155 (46%) taken in the last 12 months of the control effort when aerial gunning was used.

Coyote scent-station indices on NPR-1 declined significantly between 1985 and 1991 ($r = -0.92$, $n = 7$, $P < 0.01$) (Figure 1). Scent-station surveys and coyote control both were initiated in 1985, therefore, abundance indices are not available for the period prior to coyote control. However, during biological surveys conducted on NPR-1 in 1979 and 1984, 8 and 108 observations of coyotes were recorded, respectively, suggesting that coyote numbers may have been increasing in the early 1980's (O'Farrell 1980, O'Farrell and Mathews 1987).

The proportions of female coyotes that were reproductively active ranged from 35% to 63% (Table 2). In 1990, most coyotes were killed too early in the breeding season to

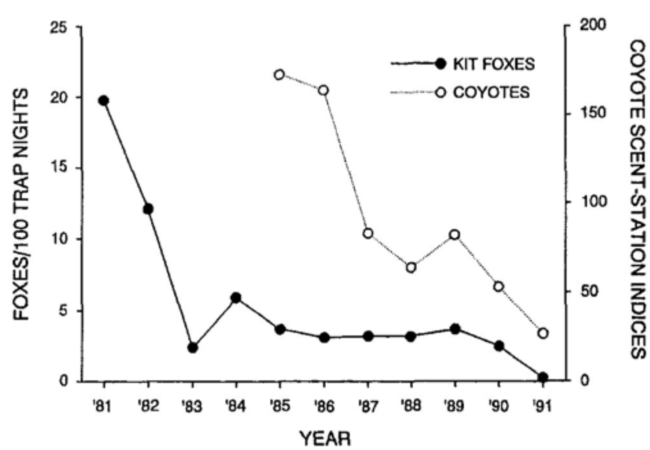

Figure 1. Spring scent-station indices for coyotes from 1985 to 1991 and number of individual kit foxes trapped per 100 trap-nights in winter from 1981 to 1991, Naval Petroleum Reserve #1, California.

assess reproductive status. Average litter size for all years was 6.8 (SE = 0.28), and did not differ significantly between years ($F = 0.22$; 4,53 df; $P = 0.93$) (Table 2).

Effects of Control on Kit Foxes

The number of foxes captured per 100 trap-nights on NPR-1 significantly declined from 1981 to 1990 ($r = -0.73$, $n = 11$, $P = 0.02$) (Figure 1). The decline was most pronounced between 1981 and 1983. Fox population indices did not increase after coyote control was initiated. Number of foxes captured per 100 trap-nights and coyote scent-station indices were not correlated ($r = 0.46$, $n = 6$, $P = 0.36$). A significant inverse relationship was expected if coyote control had been effective in reducing coyote numbers and if coyote predation was suppressing the kit fox population.

No increase in kit fox survival was detected after coyote control was initiated (Table 3). The proportion of radiocollared adult foxes surviving for 180 days and 365 days did not differ between pre-control (1980-1984) and control (1985-1990) periods (180 days: $X^2 = 0.01$, 1 df, $P=0.93$; 365 days: $X^2 = 2.41$, 1 df, $P = 0.12$). The proportion of radiocollared juvenile foxes surviving to adulthood (December 1) also did not differ between periods ($X^2 = 0.73$, 1 df, $P = 0.39$) while the proportion surviving to subadulthood (July 15) was significantly higher prior to the initiation of coyote control ($X^2 = 10.41$, 1 df, $P < 0.01$) (Table 3). Furthermore, there was no correlation between coyote scent-station indices and proportions of adults surviving to 180 days ($r = 0.29$, $n = 6$, $P = 0.57$) or 365 days ($r = -0.15$, $n = 6$, $P = 0.78$) or between scent-station indices and proportions of juveniles surviving to subadulthood ($r = 0.31$, $n = 6$, $P = 0.56$) or adulthood ($r = 0.56$, $n = 6$, $P = 0.24$). A significant inverse relationship was expected if lower coyote abundance resulted in higher fox survival.

Table 2. Annual proportion of reproductively active adult female coyotes from 1985 to 1990, Naval Petroleum Reserve #1, California.

Year	Total	Pregnant or post-partum	% Reproducing	Avg. litter size[a]	SE
1985	16	9	56	6.9	0.61
1986	22	12	55	6.8	0.50
1987	8	5	63	7.6	1.25
1988	20	7	35	6.7	0.78
1989	38	21	55	6.6	0.51
1990	17	1	—[b]	4.0	—

[a]Based on counts of fetuses and placental scars from pregnant and post-partum females, respectively.
[b]In 1990, 16 coyotes were killed too early in the breeding season to determine reproductive status.

Table 3. Survival rates of radiocollared adult and juvenile kit foxes on Naval Petroleum Reserve #1, California.

	Adults				Juveniles			
	Survived 180 days		Survived 365 days		Survived to July 15[a]		Survived to Dec. 1[b]	
Year	n	%	n	%	n	%	n	%
1980	29	75.9	27	70.4	20	90.0	15	33.3
1981	8	87.5	7	85.7	16	87.5	15	33.3
1982	22	68.2	20	45.0	22	90.9	22	36.4
1983	17	41.2	15	20.0	28	78.6	26	23.1
1984	23	39.1	23	26.1	18	55.6	18	16.7
1985	3	66.7	2	0.0	3	66.7	3	33.3
1986	9	66.7	8	50.0	8	62.5	8	37.5
1987	20	55.0	20	20.0	9	22.2	9	0.0
1988	8	62.5	7	28.6	17	52.9	17	11.8
1989	1	0.0	1	0.0	10	90.0	10	50.0
1990	19	63.2	15	46.7	9	44.4	7	0.0
1980-84 (before coyote control)	99	60.6	92	46.7	104	80.8	96	28.1
1985-90 (during coyote control)	60	60.0	53	32.1	56	55.4	54	20.4

[a]Date at which juveniles are considered subadults.
[b]Date at which subadults are considered adults.

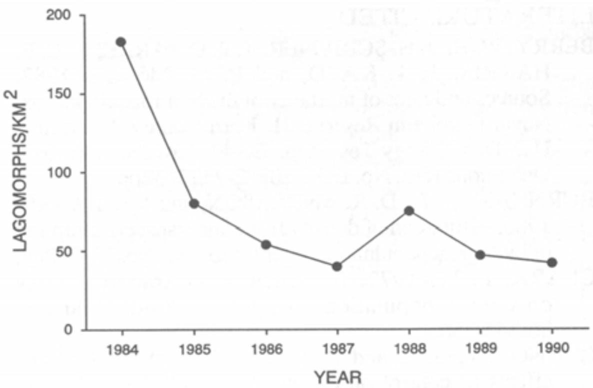

Figure 2. Summer lagomorph density estimates from 1984 to 1990, Naval Petroleum Reserve #1, California.

Table 4. Radiocollared kit fox mortalities due to predators before and during coyote control, Naval Petroleum Reserve #1, California.

	Adults		Juveniles	
Period	n[a]	Percent mortality due to predators	n [a]	mortality due to predators
Before Control	70	75.7	56	76.8
During Control	45	86.7	28	89.3

[a]Number of fox mortalities occurring that year for which cause of death could be determined.

Among kit fox mortalities for which cause of death could be determined, the proportion of mortalities due to predators (Table 4) did not differ between pre-control and control periods for either adults (X^2 = 1.43, 1 df, P = 0.23) or juveniles (X^2 = 1.17, 1 df, P = 0.28).

Effects of Lagomorph Abundance on Predator Populations

Lagomorph density estimates for NPR-1 (Figure 2) declined significantly at the 0.1 alpha level (r = -0.72, n = 7, P = 0.07) between 1984 and 1991. Number of kit foxes captured per 100 trap-nights and lagomorph density estimates were positively related (r = 0.94, n = 7, P < 0.01). Coyote scent-station indices and lagomorph density estimates also were positively related (r = 0.80, n = 7, P = 0.03).

DISCUSSION

Effects of Control on Coyotes

The coyote control program apparently did not have a significant impact on the NPR-1 coyote population. Coyote abundance indices did decline during the period of control, but the contribution of the program to this decline is unclear. Coyote indices also declined on adjacent NPR-2, but this decline began prior to coyote control on that area (Scrivner and Cypher, EG&G Energy Measurements, unpubl. data).

Coyote populations possess a high biological capacity to rapidly recover from losses. This recovery can be achieved through increased reproduction and immigration. When coyote numbers are reduced, competition for food resources decreases and the proportion of adult females reproducing can increase to 94% (Nellis and Keith 1976, Knowlton and Stoddart 1983). Reproductive rates of yearling females can increase to 70% (Gier 1968). Average litter size and juvenile survival rates also can increase (Knowlton 1972). Finally, reduced coyote numbers may result in an increased immigration rate. Coyotes are highly mobile and tend to disperse into low density areas (Knowlton and Stoddart 1983).

The high capacity of coyotes to recover from population reductions inhibits efforts to achieve effective coyote control. Sterling et al. (1983) determined that a coyote population would have to be reduced by 50% annually to produce a population decrease. Connolly and Longhurst (1975) developed a model to simulate coyote population dynamics and found that with an annual population reduction of 75% and no immigration, a coyote population could be exterminated in slightly over 50 years. Furthermore, they determined that coyote populations reduced by intensive control could recover to pre-control densities in three to five years.

Although the proportion of the coyote population removed annually at NPR-1 is unknown, the number of coyotes removed apparently was insufficient to produce a significant decrease in coyote abundance. Consistent coyote pregnancy rates and litter sizes suggests that no compensatory reproduction was occurring further indicating that control efforts apparently were not effective. Aerial gunning increased the number of coyotes removed, but probably was not conducted for a sufficient length of time to determine the effectiveness of this strategy in reducing coyote abundance.

Effect of Control on Kit Foxes

The goal of the coyote control program was to reduce predation on kit foxes. This presumably would result in an increase in fox numbers. However, fox abundance indices did not increase after coyote control was initiated. Furthermore, survival rates did not increase, and the proportion of fox mortalities due to predators did not decrease. Thus, the control program did not produce the desired benefit to the kit fox population. The relative stability of fox indices during coyote control might suggest that coyote removals prevented a further fox population decline. However, such a situation should have been accompanied by an increase in fox survival if coyote predation was suppressing fox numbers and if coyote control was effective.

An important assumption inherent in the control effort at NPRC is that fox mortality due to coyotes is additive and not compensatory. However, the significance of predation on kit foxes is unknown. The failure of fox abundance indices to increase after initiation of coyote control could indicate that predation is compensatory. Likewise, survival rates did not increase further suggesting that predation is compensatory and not additive. However, a reduction in coyote abundance should have reduced the proportion of fox mortality attributable to predators regardless of whether predation was additive or compensatory. The absence of a decline in fox mortality due to predators again indicates that the control effort was not effective in reducing coyote abundance.

Effects of Prey Availability on Predator Populations

Prey availability, particularly lagomorph abundance, probably exerts a strong influence on the population dynamics of both kit foxes and coyotes. Abundance indices for both predators were significantly correlated with lagomorph density estimates. Coyote and fox indices also were correlated to lagomorph density on NPR-2 (Scrivner and Cypher, EG&G Energy Measurements, unpubl. data) Thus, declining lagomorph abundance may have precipitated a population decline among both kit foxes and coyotes. The reason for the lagomorph decline is unknown. Lagomorph populations can be cyclic and periodically peak and crash (Wagner and Stoddart 1972). The decline also could have resulted from prolonged drought conditions in the San Joaquin Valley. The availability of alternate prey (e.g., kangaroo rats [*Dipodomys* spp.]) was not assessed.

Low prey availability may have reduced the reproductive success of both coyotes and kit foxes. From 1980 to 1985 when lagomorphs were abundant at NPRC (Harris 1986), 59% (n = 69) of radiocollared adult female foxes were observed with pups (Zoellick et al. 1987). However, only 6% (n = 17) were observed with pups in 1991 when lagomorph abundance was low (EG&G Energy Measurements, unpubl. data). In western Utah, the proportion of breeding female foxes and average litter size both declined in response to reduced lagomorph availability (Egoscue 1975). Similarly, proportion of females breeding and litter size among coyotes in Kansas declined in response to depressed jackrabbit densities (Gier 1968). Furthermore, coyote population indices in northern Utah varied in response to jackrabbit density, and coyote reproductive rates were positively correlated with rabbit density (Clark 1972). Thus, prey availability can strongly influence the population dynamics of both coyotes and kit foxes.

CONCLUSIONS

Evaluating the success of the coyote control program at NPRC was difficult due to the many ecological factors influencing the kit fox population. Control efforts prior to 1989 did not appear to benefit kit foxes. The revised program implemented in 1989 that included aerial gunning was not conducted for a sufficient length of time to evaluate its effectiveness. Coyote control efforts at NPRC have been discontinued pending further consideration of the merits and potential efficacy of control.

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