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Analysis of the Causes of a Decline in the San Joaquin Kit Fox Population on the Elk Hills, Naval Petroleum Reserve #1, California

National Center for Environmental Assessment
Office of Research and Development, Cincinnati, OH

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NOTICE

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ABSTRACT

This report demonstrates the utility of the Causal Analysis/Diagnosis Decision Information System (CADDIS) for determining the cause of biological impairments on contaminated sites. The case is a decline in the abundance of a population of the endangered San Joaquin kit fox on the Elk Hills Naval Petroleum Reserve, California, between 1981 and 1986. This precipitous decline was a cause for concern at the time because of its magnitude and because it was associated with an increase in oil production on the site. Although multiple potential causes were investigated at the time, the cause of the decline was not determined. This investigation proposed and analyzed six candidate causes: prey abundance, habitat quality, predation, toxicants, accidents and diseases. Evidence for each was analyzed using CADDIS's scoring system and 15 types of evidence. The conclusion is that predation by coyotes was the proximate cause of the decline. Road kills contributed to the high mortality of foxes, but were much less common. The decline in prey probably contributed to mortality by making the foxes more susceptible to predation. As a model for causal analysis at contaminated sites, this study was successful. Contaminants were eliminated as the cause and an alternative was strongly supported by the evidence. In addition, this study demonstrated the great utility of some types of evidence that had not previously been used in CADDIS: mathematical modeling (a kit fox demographic model) and the analysis of tissues (i.e., fur and blood analyses to eliminate toxicants and diseases, respectively).

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Cover Photo:
San Joaquin kit fox, Elk Hills, California, T.P. O'Farrell.

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LIST OF ABBREVIATIONS

As	Arsenic
BOPD	Barrels of oil per day
CADDIS	Causal Analysis/Diagnosis Decision Information System
EG&G	EG&G Energy Measurements Inc.
MER	Maximum efficient rate
NE	No Evidence
NPR	Naval Petroleum Reserve
U.S. DOE	U.S. Department of Energy
U.S. EPA	United States Environmental Protection Agency
U.S. FWS	U.S. Fish and Wildlife Service

PREFACE

The U.S. Environmental Protection Agency's (2000) method for identifying the causes of biological impairments of the Nation's waters was adapted and developed from methods used in epidemiology for human health. Although it is conceptually generic, the examples and guidance published in its web implementation, CADDIS (http://www.epa.gov/caddis/), and elsewhere are aquatic. In addition, all of the case studies have been aquatic. This report presents one of two case studies that demonstrate the application of the method to contaminated terrestrial sites. This case also extends the range of case studies in other ways. It is focused on a single population of an endangered species, the San Joaquin kit fox, on the Elk Hills Naval Petroleum Reserve, California. It focuses on a discrete temporal event, the precipitous decline in the kit fox population between 1980 and 1986. It is relatively rich in the amount of data available, the diverse types of data and the extended period over which it was generated. Finally, the case relies heavily on mathematical modeling.

This is a cold case. The decline was documented by demographic studies performed for the U.S. Department of Energy in the early 1980s, a period of increased oil production. The range of studies and management activities increased in the late 1980s in response to the decline and concerns expressed by the U.S. Fish and Wildlife Service. However, by the time a study of the factors controlling kit fox abundance was performed, the original decline on the developed portions of the Elk Hills was no longer the focus. Because it used large temporal and spatial scales, that study did not explain the anomalous decline. Hence, it is appropriate to go back and investigate the cause of the original event of concern.

Although the study was conducted to comply with the National Environmental Policy Act (NEPA) and the Endangered Species Act, it is a model for studies of valued populations on Superfund sites. As at Superfund sites, contaminants of concern were identified by reviewing operational records and analyzing wastes and soils. Then potential routes of exposure were determined. Finally, exposure was determined by analysis of fox fur from the contaminated site and comparison to fur from four reference areas and the literature.

The study is a success in that contaminants could be eliminated as a cause and the actual proximate cause, predation by coyotes, was identified. It also confirmed that the inferential approach and types of evidence developed for studies of impaired aquatic communities were applicable to a terrestrial population. Finally, it provided some lessons for future causal analyses. They include:

- Obtain data from multiple reference sites.
- Add new types of evidence to the methodology as needed.
- Use body burdens and (potentially) biomarkers when available.
- Determine the mandate for the causal assessment.

- Avoid spatially or temporally diluting causal relationships.
- Be clear about the spatial and temporal extent of the impairment.

In sum, this case study demonstrates that the same causal inference methodology applies to terrestrial wildlife populations as to aquatic communities. This result suggests that CADDIS can be usefully applied to biological impairments observed on contaminated lands and to any documented decline in a population. It also suggests that causal assessments, like other environmental assessments, are most successful when data are abundant and data quality is high.

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EXECUTIVE SUMMARY

The purpose of this report is to test the utility of the Causal Analysis/Diagnosis Decision Information System (CADDIS; http://www.epa.gov/caddis/) to determine the cause of effects on a population inhabiting a contaminated terrestrial site. CADDIS is a web-based tool to implement the U.S. Environmental Protection Agency's (U.S. EPA) *Stressor Identification* process (U.S. EPA, 2000). It was developed for determining the causes of biological impairments in aquatic ecosystems under the Clean Water Act, and the prior case studies have focused on effects on community metrics in streams. However, the principles and methods of causal analysis should be applicable to all environmental effects.

The case is the observed decline in abundance of a population of San Joaquin kit foxes on the Naval Petroleum Reserve Number 1 (NPR-1) during the period 1980-1985. NPR-1 is located on the Elk Hills, on the western edge of the San Joaquin Valley, west of Bakersfield, California. It is an oil field that was held in reserve for the Navy until 1976 when Congress ordered that it be developed to produce at the maximum efficient rate. A transect survey of wildlife was conducted in 1979 and then in 1980 a program of demographic monitoring of the San Joaquin kit foxes began on the site. Because hundreds of radio-collared foxes were monitored, the time and cause of death, emigration rates, and the fecundity and breeding success of individual foxes could be determined.

The San Joaquin kit fox (*Vulpes macrotis mutica*) is an endangered subspecies. The minimum estimate of their abundance in the NPR-1 study area in summer, based on capture-recapture estimates, declined from a high of 153 in 1981 to a low of 10 in 1991 (Harris et al., 1987; U.S. DOE, 1993). The kit fox decline occurred in the 1980-1986 period. It appeared that the population was being negatively affected by petroleum development activities. This 1981-1986 reduction in abundance, which prompted the concerns in the U.S. Fish and Wildlife Service's 1987 biological opinion, will be termed the decline. The population was stable from 1986-1989, but it declined again from 1989-1991. No formal analysis of the cause of the 1980-1986 decline has been conducted until now.

CADDIS is based on the comparison of evidence for alternative candidate causes. The candidate causes for the decline are (1) prey abundance, (2) habitat alteration, (3) predation, (4) toxic chemicals, (5) vehicular activity and (6) disease. In addition, for each of the first two candidate causes, two causal pathways are considered: from disturbance and from climate.

The analytical phase analyzes and scores evidence from the case and from elsewhere for each candidate cause. Co-occurrence of the candidate causes and effects were determined by comparing developed and undeveloped NPR-1 and by comparing NPR-1 to NPR-2, a nearby oil field which apparently did not experience a kit fox decline during the early 1980s. In addition, temporal co-occurrence at the site was determined by considering when kit foxes and the candidate causes were either increasing or decreasing. For causes that co-occurred with the decline or elements of the causal pathways, regression analysis was used to try to develop exposure-response relationships. In addition, the analysis included manipulations of exposures, symptoms of exposure, and evidence of mechanistic sufficiency for some candidate causes.

Prey for kit foxes were primarily lagomorphs (black-tailed jackrabbits and desert cottontails) and secondarily small mammals (kangaroo rats and pocket mice). Lagomorphs declined at the same time as kit foxes and their decline was greatest in developed areas. The abundances of kit foxes and lagomorphs were linearly correlated. Foxes ate fewer lagomorphs and switched to small mammals. They produced fewer pups and the litters were male biased, which is consistent with poor nutrition. Lagomorph abundances were not correlated or were weakly correlated with precipitation in both the current and previous year. Supplemental feeding increased young-of-the-year survival.

The kit fox decline co-occurred with habitat disturbance by oil development, but not with lack of rainfall. However, active oil development declined as the kit fox population declined so there were no exposure-response relationships for habitat alteration. There were good relationships between precipitation, plant production and fox abundance during a later period of drought.

Coyotes increased in abundance on NPR-1 during the kit fox decline, particularly in the developed areas. Increased mortality, particularly of young-of-the-year foxes, was the cause of the decline and approximately 80% of the known mortalities were due to coyotes. After a coyote control program began, coyote abundance declined and the kit fox population stabilized.

Several toxic chemicals and petroleum leaks occurred in developed NPR-1 during the decline. However, elemental analyses of kit fox fur found that foxes from developed NPR-1 were not highly exposed on average, and there was no correlation of longevity with elemental concentrations. However, a few foxes on developed NPR-1 were relatively highly exposed to a few elements that were associated with oil development. Three kit foxes had arsenic levels equivalent to humans with arsenic poisoning, but they appeared to be healthy. Soils outside spills and sumps did not have elevated levels of elements related to petroleum development.

Increased vehicle traffic inevitably accompanied increased development and approximately 15% of identified kit fox mortalities were road kills. This contributed to the increase in mortality that was shown by demographic modeling to be the probable cause of the decline.

Observations of trapped foxes, necropsies and hematological and serological studies showed no signs of an epizootic that would account for the decline.

The synthesis phase of CADDIS determines the probable cause. The proximate cause of the kit fox decline was found to be predation by coyotes. The evidence for coyotes was strong and consistently positive, and evidence for all other candidate causes was inconsistent.

The CADDIS methodology does not address sources, but the source must be identified to inform management actions. However, the cause of the increase in coyote abundance is unclear.

Other analyses have attributed variation in kit fox abundance to climate, but precipitation was not particularly low during the decline. In particular, two very good precipitation years occurred in the midst of the decline without influencing the decline in fox abundance. In addition, climatic differences cannot account for the differences between sites. This analysis focuses on a particular localized decline rather than larger scale and longer term dynamics addressed by other analyses. In causal analysis, spatial and temporal scales are critical.

The CADDIS methodology proved to be applicable to this terrestrial vertebrate on a contaminated site. However, some modifications were made to accommodate the case. The most important are the separate analysis of different causal chains to some candidate causes and consideration of the source of the likely cause. Another is the identification of a new type of evidence for use in causal analyses in CADDIS, mechanistic sufficiency, to accommodate evidence from the demographic model that linked the modes of action of candidate causes to the effect, reduced kit fox abundance. Third, this case includes an additional synthesis step in which the inconsistencies in evidence concerning some candidate causes was explained by their roles as links in the causal pathway rather than as proximate causes. These changes were not made because the case was terrestrial or because it focused on a population. Rather, they relate to the peculiarities of the available evidence, particularly the abundance of data and the opportunity to use demographic modeling.

1. STEP 1. DEFINITION OF THE CASE

1.1. BACKGROUND

The San Joaquin kit fox (*Vulpes macrotis mutica*) was a relatively common carnivore of the semi-arid habitats of California's San Joaquin Valley from San Joaquin and Stanislaus counties south to Kern County (Grinnell et al., 1937). Starting in the early 1900s agricultural, industrial, and urban developments brought about habitat loss that led to population declines. In 1965 the California Fish and Game Commission classified the San Joaquin kit fox as a protected furbearer. Following passage of the Endangered Species Preservation Act of 1966, the Secretary of Interior listed the San Joaquin kit fox as an endangered subspecies. In 1971 the San Joaquin kit fox was classified as a "rare" species under the California Endangered Species Act of 1970. It received Federal protection under the Endangered Species Act of 1973 (Public Law 93-205) as an endangered species.

The Elk Hills, Naval Petroleum Reserve #1 (NPR-1), Kern County, California, was established in 1912. Production is believed to have begun in 1919 and peaked in 1921 at approximately 60,000 barrels of oil per day (BOPD). Production was steadily reduced to an authorized rate of 2500 BOPD. Under the Naval Petroleum Reserves Production Act of 1976 (Public Law 94-258) Congress directed the Secretary of the Navy, and subsequently the Secretary of Energy, to produce petroleum products from NPR-1 at the maximum efficient rate (MER) consistent with sound engineering practices. An increase in development activities began in 1974 with the Total Capacity Development Program, and expanded in 1976 to comply with the law (U.S. DOE, 1979). In 1979 the U.S. Fish and Wildlife Service (U.S. FWS) notified the U.S. Department of Energy (U.S. DOE) that the development activities on Elk Hills threatened the continued existence of the San Joaquin kit fox and that formal consultation was required.

An integrated, multi-phased field program was designed to gather, synthesize, and interpret ecological information necessary to determine whether U.S. DOE activities on Elk Hills were compatible with the continued existence of the subspecies. During July through September, 1979, transects totaling 522 miles were walked through all sections of Elk Hills. San Joaquin kit fox dens were observed at a relative density of approximately 9.2 per square mile. Kit fox dens were widely distributed, even in areas of high relief and intense oil field activity. The prey base, indicated by relative densities of jackrabbits, cottontails, and quail, was judged to be excellent. The Reserve provided good habitat for a large proportion of the known, extant population (O'Farrell, 1980).

In 1980 U.S. DOE initiated a 15-year study to document the population dynamics of the San Joaquin kit fox on Elk Hills conducted by EG&G Energy Measurements Inc. It estimated abundance, reproduction, mortality, dispersal, and prey abundance, in both developed and undeveloped habitats. That study documented a severe decline in kit fox abundance apparently associated with the increase in petroleum development on NPR-1 (O'Farrell et al., 1986). A 1987 Biological Opinion by the U.S. FWS recommended a study of potential toxic exposures and effects on Elk Hills, which was conducted from 1988 to 1992 (Suter et al., 1992).

1.2. DESCRIPTION OF IMPAIRMENT

Following increased petroleum development activities on the Elk Hills, the minimum number of San Joaquin kit foxes in the NPR-1 study area in summer, based on capture-recapture estimates, declined from a high of 153 in 1981 to a low of 10 in 1991 (Harris et al., 1987; U.S. DOE, 1993) (Figure 1). Winter estimates declined from 165 to 19. Most of the decline occurred in the 1981-1986 period. It appeared that the population was being negatively affected by petroleum development activities. This 1981-1986 reduction in abundance, which prompted the concerns in the U.S. FWS's 1987 biological opinion, will be termed the decline. The population was slowly increasing from 1986-1989, but it declined again from 1989-1991 (Figure 1). The period 1987-1991 is of interest primarily in terms of helping to understand the 1981-1986 decline.

1.3. SPECIFIC EFFECTS

Population dynamics of mammalian species are affected by four processes: reproduction, mortality (or survival), emigration, and immigration. The NPR-1 study was designed to study changes in these processes in both developed and undeveloped habitats, and to assess the causes for any changes observed, especially if the causes originated from petroleum development activities. However, the effect of concern was the decline in kit fox abundance and the demographic parameters are explanatory.

From 1980-1986, juvenile kit foxes experienced much higher mortality rates on developed than undeveloped NPR-1 due to predation and accidents (Table 1). Adults experienced higher mortality in undeveloped areas, but the differences were smaller.

Zoellick et al. (1987) identified differences in reproduction between developed and undeveloped areas of NPR-1 during 1980-1985. The proportion of radio-collared adult vixens that successfully raised pups was 51% in developed habitats and 69% in undeveloped habitats. The proportion of yearlings that successfully raised pups was 8% in developed habitats and 25% in undeveloped habitats. There were no trends on the undeveloped area, but on developed NPR-1, the percent of vixens successfully raising pups declined from 100% in 1980 to 33% in 1985, and the number of litters per unit area also declined. Average litter size did not differ significantly between undeveloped (4.1) and developed (4.4) habitats and there were no temporal trends in litter size between 1980 and 1985. As a result, the reproductive success on developed areas declined relative to undeveloped areas on both per female and per unit area bases (Figures 2 and 3). Finally, the sex ratio of pups born on developed, but not undeveloped, NPR-1 was biased toward males (M:F = 1.33).

The proportion of adults that dispersed during 1980-1986 was 18/78 (0.23) in undeveloped habitats, and 23/99 (0.23) in developed habitats (Scrivner et al., 1987).

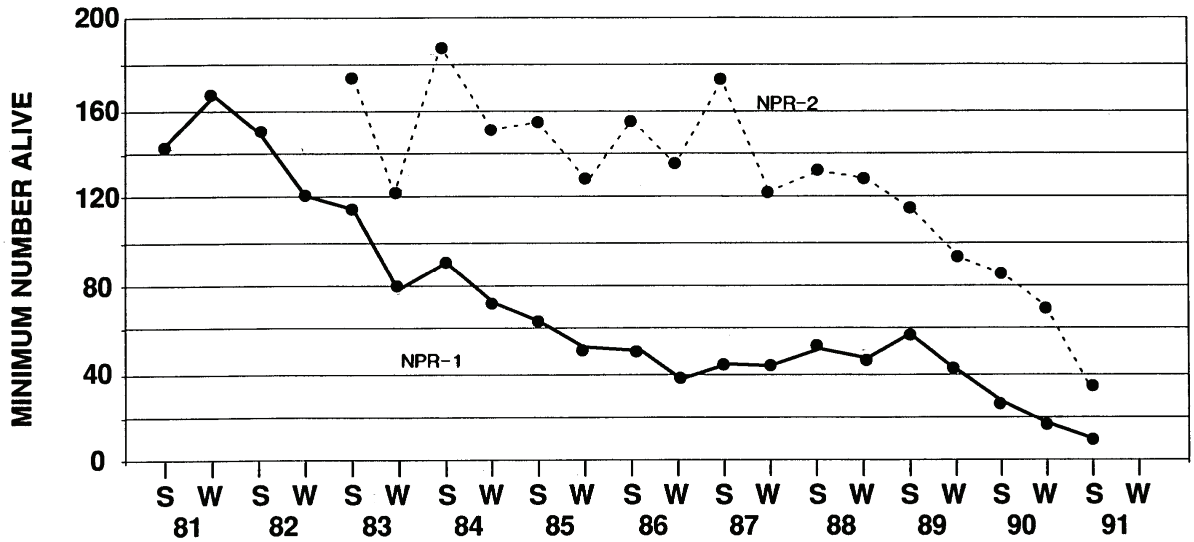

FIGURE 1

Minimum Numbers of Kit Foxes on NPR-1 and NPR-2 (see Section 1.5) from Summer (S) and Winter (W) Surveys (Source: U.S. DOE 1993). The minimum population is the sum of the individuals trapped during each trapping session, plus the number of untrapped foxes that were known to be alive because they were trapped in a previous and a subsequent session.

TABLE 1

Age-Specific Risk of Death for Developed and Undeveloped Habitat Based on Location at the Time of Death

Age at Death (years)	Cause	Developed	Undeveloped
0	Predation	0.58	0.36
	Vehicle	0.25	0.00
	Other	0.03	0.04
	Unknown	0.41	0.36
1	Predation	0.25	0.39
	Vehicle	0.00	0.08
	Other	0.00	0.00
	Unknown	0.16	0.21
2	Predation	0.27	0.36
	Vehicle	0.00	0.04
	Other	0.00	0.00
	Unknown	0.06	0.16
3	Predation	0.22	0.37
	Vehicle	0.15	0.00
	Other	0.15	0.00
	Unknown	0.00	0.11
4	Predation	0.27	0.39
	Vehicle	0.00	0.39
	Other	0.00	0.00
	Unknown	0.27	0.22

Source: Floit and Barnthouse (1991).

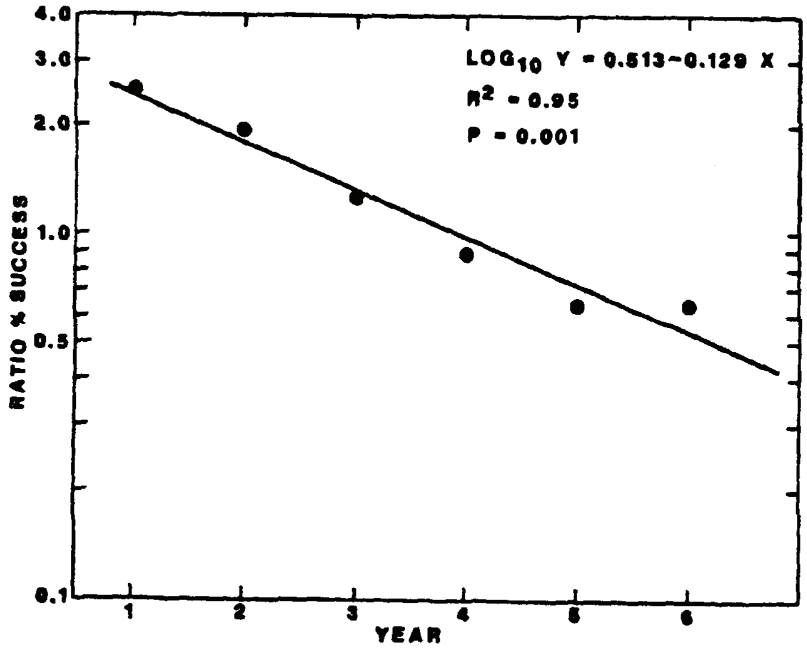

FIGURE 2

The Ratio of the Percentage of Female Kit Foxes Successfully Raising Pups in Developed Habitat to the Percentage of Females Successfully Raising Pups in Undeveloped Habitats as a Function of Time from 1980-1985 on NPR-1 (Source: Zoellick et al., 1987)

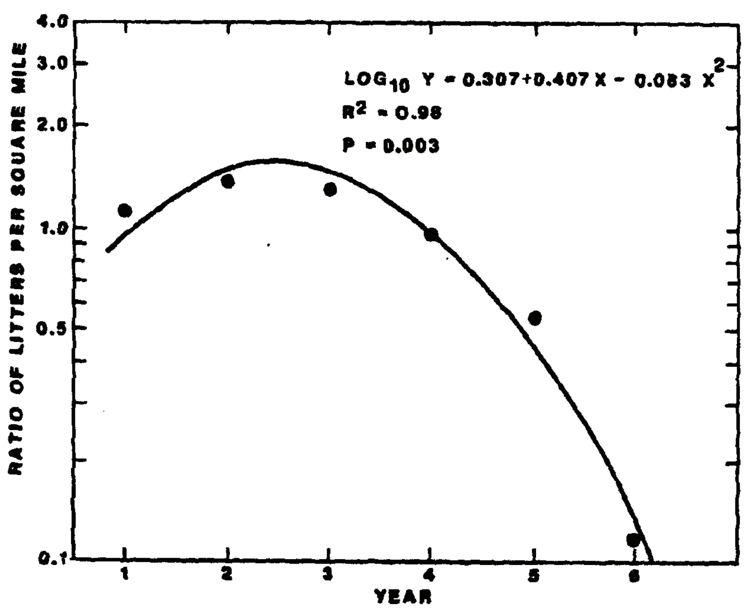

FIGURE 3

The Ratio of the Number of Litters Per Square Mile in Developed Habitat to the Number of Litters Per Square Mile in Undeveloped Habitats as a Function of Time from 1980-1985 on NPR-1 (Source: Zoellick et al., 1987)

Pup dispersal was 16/62 (0.26) from undeveloped habitats, and 32/67 (0.48) from developed habitats (Scrivner et al., 1987). There appears to be net emigration of pups, but not adults, from developed habitats to undeveloped habitats. However, data on immigration were lacking.

In sum, the greater decline in abundance on the developed portion was associated with greater mortality and greater emigration of young-of-the-year foxes as well as lower fecundity of one year old females and lower reproductive success.

1.4. DESCRIPTION OF THE GEOGRAPHIC AREA UNDER INVESTIGATION

NPR-1 is located about 30 miles southwest of Bakersfield, Kern County, California (Figure 4). It encompasses 47,245 acres, including most of the low foothills of the Temblor Range known as the Elk Hills that extend southeastward into the San Joaquin Valley. Elevations range between 290 feet above sea level on the valley floor at the northeastern boundary, to 1551 feet along the main ridge in the western part of the Reserve. The topography consists of gently rounded slopes with narrow divides, an intricate system of highly dissected draws and dry stream channels in the higher elevations, and gently rolling hills and flat valley land along the perimeter. Almost all of the petroleum developments on NPR-1 are located in the central uplands.

Undisturbed surface soils are predominately sandy loams that support relatively good vegetative cover. These deep, well drained, sandy loams belong to either the Elk Hills series or the Cajon and Kimberlina series. Soils over large areas consist of highly variable, undeveloped stratified Torriorthents that have many saline-alkaline areas which support little or no vegetation.

NPR-1 and the San Joaquin Valley have a Mediterranean climate characterized by relatively cool, wet winters and hot, dry summers. About 89% of the mean annual precipitation (5.72 inches) falls during the growing season (November-April). Low rainfall is supplemented by a high incidence of fog and high humidity during the winter. The annual mean maximum temperature is 78°F; the mean minimum temperature is 52°F.

Vegetation on the Reserve is part of a very broad type called Valley Grassland that surrounds the agricultural land of the Central Valley. In its pristine condition much of the Valley Grassland probably consisted of perennial bunchgrasses and an overstory of shrubs, but European plant introductions and livestock grazing converted almost all of it to an annual grassland in the mid to late 19th century. Vegetation patterns were further altered by heavy sheep grazing between the late 1860s and 1965 when the Navy, which operated the Reserve prior to the U.S. DOE, eliminated grazing leases. NPR-1's dominant ground cover is red brome, *Bromus rubens*, an introduced annual grass. The dominant shrub is desert saltbush, *Atriplex polycarpa*, which is especially dense in disturbed areas such as along roadsides and edges of well pads.

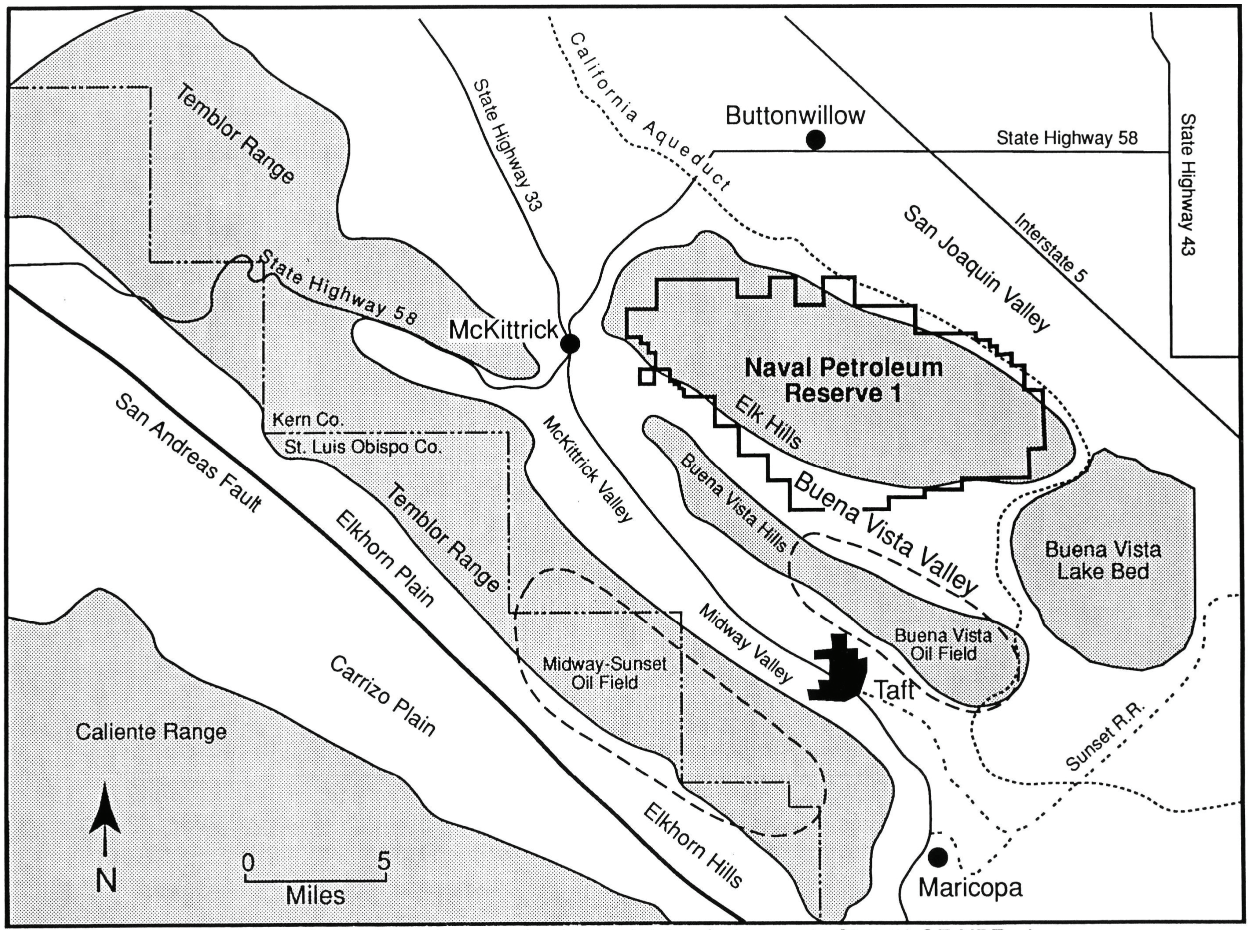

FIGURE 4

A Map Showing the Location of NPR-1 on the Elk Hills and its Context Including the Buena Vista Oil Field (NPR-2), a Developed Reference Area, and the Carrizo Plain, an Undeveloped Reference Area (Source: U.S. DOE, 1993)

The Reserve supports 23 species of mammals, 83 species of birds, 8 species of reptiles, and 2 species of amphibians.

NPR-1 has been operated by the federal government as an oil field since 1912. In 1976 at the beginning of MER there were already 1286 wells onsite (U.S. DOE, 1993). Subsequently an additional 1029 wells were drilled and support facilities were expanded and upgraded.

Analysis of causal relationships on NPR-1 is limited by the confounding of topography (uplands and lowlands) and degree of development (developed and undeveloped). As described above, the majority of petroleum developments were in the uplands, and the majority of the lowlands were undeveloped. There were insufficient areas of either developed lowlands or undeveloped uplands to distinguish those factors. Also, the area was not pristine prior to recent disturbances. Oil development affected the site to some degree since the early 20th century. Measurements of conditions prior to petroleum developments or prior to 1974 were unavailable. The analysis is also limited because kit foxes are highly mobile and can have home ranges that include both developed and undeveloped habitats. Hence, it was necessary to consider spatially disjoined reference sites.

The descriptions in this section of the natural features of NPR-1 were adapted from O'Farrell et al. (1986).

1.5. DESCRIPTION OF THE REFERENCE SITES

This causal analysis uses three reference sites. One is a nearby oil field and the other two have no oil development (Table 2).

Naval Petroleum Reserve No. 2 (NPR-2) occupies the Buena Vista Hills, south of NPR-1 (Buena Vista Oil Field in Figure 4). It has lower elevations but is ecologically similar. However, its oil resources were developed earlier then those on NPR-1, and, although some oil development activities occurred there in the 1980s, there was no increase in production as on NPR-1. Kit fox demographic studies on NPR-2 began in 1983. The population was apparently stable until 1988, but declined thereafter (Figure 1). It is likely that some movement of foxes between the two reserves occurs, but the fact that the decline on NPR-1 in the early-to-mid 1980s was not mirrored on NPR-2 suggests that they are not a single population. NPR-2 was a reference area for the study of chemical exposures and for activities and physical disturbances associated with increased oil production.

The Carrizo Plain (now a National Monument) lies south of NPR-1 and NPR-2, beyond the Temblor Range in San Luis Obispo County (Figure 4). It is primarily grassland, supporting some cattle grazing. It has no oil production.

Camp Roberts is a California Army National Guard training site in San Luis Obispo and Monterey Counties between the Salinas River floodplain and the Santa

TABLE 2

Sites Considered in the Causal Analysis of the Kit Fox Decline

Site	Development	Kit Foxes	Status
Elk Hills/ NPR-1 developed	Oil field with active drilling, facility construction and oil production during the decline	Primary site of the decline	The site of the case
Elk Hills/ NPR-1 undeveloped	Low density of oil development with pipe lines and other support facilities	The decline was later and less intense	Near field negative reference
Buena Vista Hills/ NPR-2	Heavily developed prior to the period of concern. Little oil production and little active development	No apparent decline in the period of concern	Positive reference
Carrizo Plain	No oil development Cattle grazing	No apparent decline in the period of concern	Far field negative reference
Camp Roberts	No oil development Military training activities	No apparent decline in the period of concern	Far field negative reference

Lucia Mountains. It encompasses 172 km^2 of primarily rolling hills with grassland, oak woodland and chaparral. It has no oil production.

1.6. OBJECTIVES OF THE INVESTIGATION

Although data were collected and analyzed to support a determination of the cause of the apparent decline of the San Joaquin kit fox population on Elk Hills in the 1980s, a complete causal analysis was not performed at that time. This investigation applies the Causal Analysis/Diagnosis Decision Information System (CADDIS; http://www.epa.gov/caddis/) to the problem. CADDIS is a web-based tool to implement the U.S. EPA's Stressor Identification process (U.S. EPA, 2000). This investigation reanalyzes the data that were available in the 1980s to determine the cause of a decline in the abundance of San Joaquin kit foxes on NPR-1. Data were available from EG&G's kit fox demographic study which included a research program by Oak Ridge National Laboratory, Tennessee, to determine whether toxic chemicals from oil development were a plausible cause of the decline. The results of those studies satisfied concerns of the California Fish and Game Commission and U.S. FWS, but no formal analysis was conducted at that time to identify the cause of the decline. This reanalysis serves as a test of the applicability of CADDIS to an impairment of a wildlife population on a contaminated terrestrial site. Although CADDIUS was developed primarily to address impairments of aquatic biotic communities, there is no reason that it would not serve to address populations and terrestrial cases as well. The report ends with a consideration of data collected after 1990 and of subsequent studies of the factors controlling kit fox demographics at larger scales as a check of the reasonableness of the CADDIS results.

2. STEP 2. LIST CANDIDATE CAUSES

2.1. INITIAL LIST OF CANDIDATE CAUSES

Six potential candidate causes were identified in the 1980s: altered food supplies, habitat alteration, predators, toxic chemicals, vehicular activity, and disease.

2.2. STAKEHOLDERS

Two types of stakeholders provided the impetus and funding for the studies of kit fox demographics and the causes of decline. The natural resource trustees, the U.S. FWS and the California Department of Fish and Game, were concerned that habitat disturbance and toxic chemicals associated with increased oil production were harmful to kit foxes. The concerns of the U.S. FWS were expressed in biological opinions released in 1980 and 1987. The U.S. DOE and Chevron U.S.A. were also concerned with environmental protection and they funded the studies, but their primary mission was increasing oil production. They emphasized predation and the influence of climate on habitat and prey availability. All causes advocated by stakeholders were considered.

2.3. INFORMATION ON POTENTIAL SOURCES

Petroleum development involved removal of vegetation which potentially altered food supplies (candidate cause 1) and kit fox habitat (candidate cause 2). In addition, metals and other petroleum-associated contaminants (candidate cause 4) would occur in the developed areas. Accidents (candidate cause 5) were primarily road kills; the length of roads and the amount of traffic was believed to be increased by development. It was hypothesized that development might attract coyotes (candidate cause 3) and coyotes or workers might carry diseases (candidate cause 6). Hence, the candidate causes were spatially confounded, because they were all hypothesized to be primarily associated with developed areas.

Oil production is a source of disturbance in the form of devegetated areas. Sections, and in some cases half sections, of the study area were classified as undeveloped or developed based on the area of land disturbed by oil field development (well pads, sumps, roads, pipelines, pipe storage yards, facilities). The areal percent disturbance was calculated by overlaying transparent dot grids (Bryant, 1943; Mosby, 1980) on 1:10,000 scale aerial photographs taken in 1983, and counting the proportion of dots that overlapped disturbances. When the proportions were graphed the distribution of numbers was bimodal. There was a clear demarcation between the two bell curves at about 15%. For purposes of the study, sections or half sections with greater than 15% of the land area disturbed were considered to be developed habitat (Figures 5 and 6).

The study area occupied 44.5 square miles of NPR-1 and a small adjacent buffer: 18.5 square miles were undeveloped and 26 square miles were developed.

FIGURE 5

Undisturbed Habitat on NPR-1. Photo by T.P. O'Farrell, February 1984.

FIGURE 6

Disturbed Habitat on NPR-1 Showing Waste Water Sumps. Photo by T.P. O'Farrell, June 1980.

approximately 3.6 acres disturbed per well, 3334 acres were disturbed for MER through 1983 and 3704 acres through 1988 or approximately 8% of NPR-1.

In addition to this passive measure of disturbance, land area disturbed, active sources of disturbance must be considered. These include active well drilling and associated construction of roads, pipelines and other facilities, which produce noise, dust, chemical spills, vehicle traffic, and human presence as well as removal of vegetation. These development activities may be represented by the drilling rate (Table 3). Between 1974-1983, 93 wells were drilled per year on average, after which the average rate dropped to 26 per year (U.S. DOE, 1993). Operation and maintenance activities may be indicated by rates of oil production which climbed rapidly from 1976-1982 and then declined (Table 3).

Oil development is a source of various potentially toxic materials. Therkelsen (1972) studied wildlife conservation problems in the petroleum fields of Kern County, California, and reported that dissolved solids, salts, and other minerals caused deaths, nervous disorders, diarrhea, and decreased reproduction in livestock and wildlife. Suter (1988) reviewed the literature and records at NPR-1 and determined that potentially toxic materials were used or produced on the site, that livestock and wildlife effects had been documented in the past, and that potential routes of exposure for kit foxes were present on the site. Sources were widely distributed in the developed portions of the site.

2.4. CONCEPTUAL MODELS

Conceptual models represent the relationships among potential sources, routes of transport and exposure, proximate causes and effects. Sources are represented by parallelograms, intermediate steps in the causal process are represented by rounded rectangles, proximate causes are represented by rectangles, mechanisms are represented by hexagrams and the endpoint effect in all cases is “kit fox abundance.”

The first conceptual model (Figure 7) presents the consequences of changes in habitat, prey or predators resulting from either anthropogenic disturbances or reduced precipitation. The second conceptual model (Figure 8) represents the induction of toxic effects due to exposure to chemicals associated with oil production. The third conceptual model (Figure 9) represents acute lethality due to either traffic accidents or accidents during oil development. The last conceptual model (Figure 10) represents disease-induced death or infertility due to a combination of exposure to a pathogen and susceptibility. Potential sources of exposure include coyotes and humans carrying pathogens from their pets.

2.5. FINAL LIST OF CANDIDATE CAUSES

The final candidate causes, including subcauses associated with different sources, are listed in Table 4 and described in the following sections.

TABLE 3

NPR-1 Developmental and Production Statistics, Fiscal Years 1976-1990

Fiscal Year	Crude Oil (10^6 bbl)	Developmental Wells
1974-1976	NA	258
1976	3.8	NA
1977	36.9	168
1978	43.5	120
1979	52.6	82
1980	58.3	64
1981	62.6	46
1982	60.7	101
1983	57.4	87
1984	50.5	30
1985	47.7	22
1986	42.2	22
1987	39.8	29
1988	39.2	NA
1989	35.5	NA
1990	29.5	NA
Total	660.5	1029

Source: U.S. DOE (1993).
NA = Not available

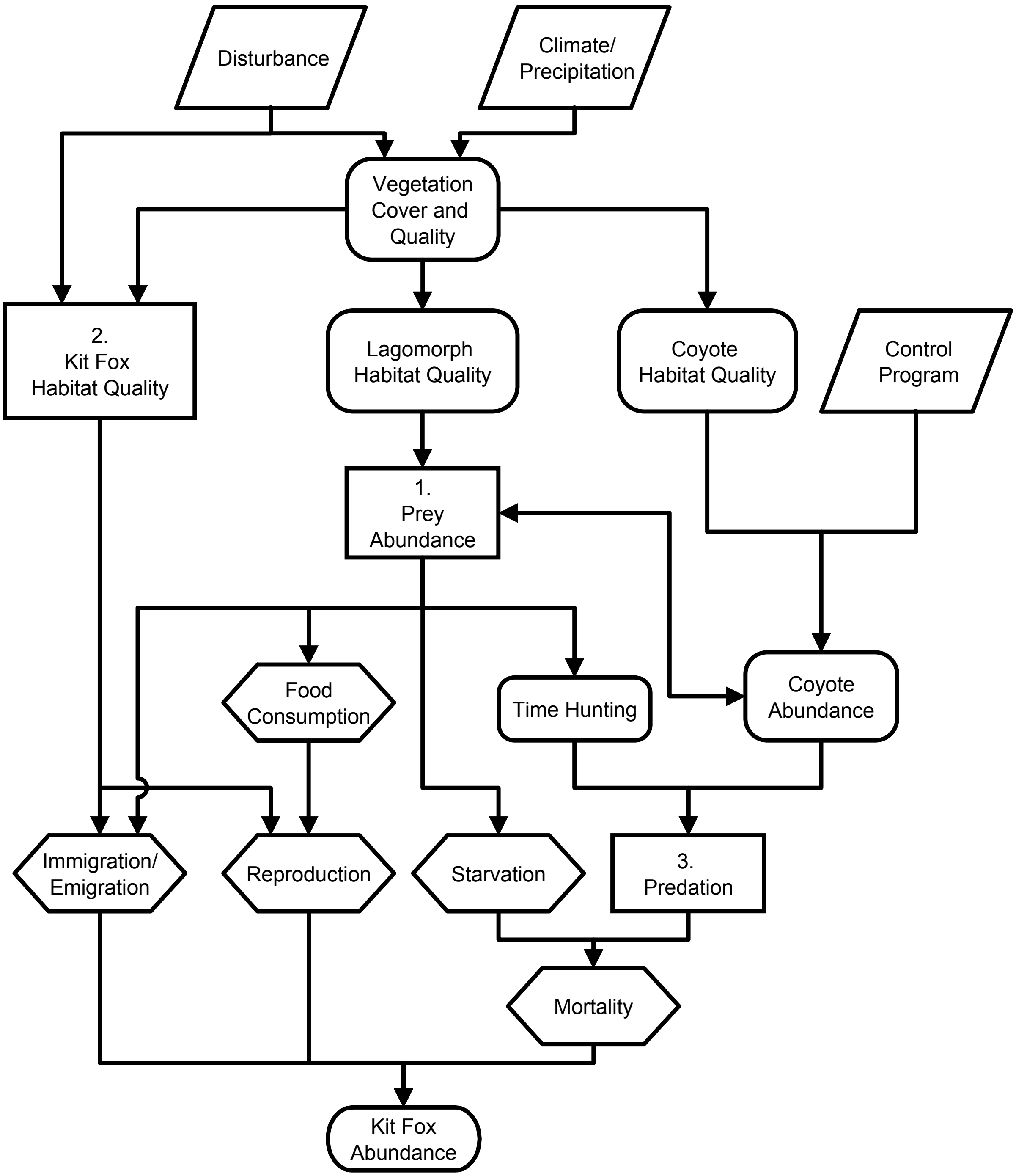

FIGURE 7

A Conceptual Model of Three Potential Causes of the Decline in Kit Fox Abundance That are Related to Natural History: (1) Prey Abundance, (2) Habitat Alteration, and (3) Predation

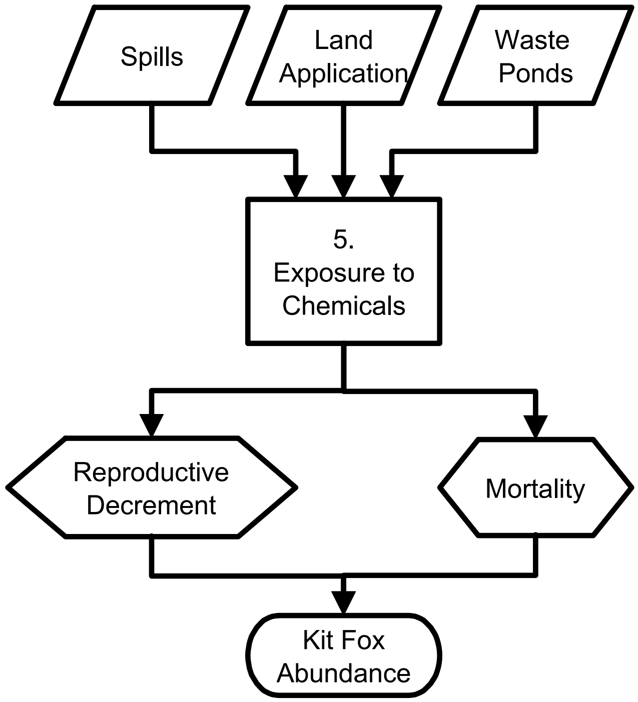

FIGURE 8

A Conceptual Model of Toxic Chemicals as a Cause of the Decline in Kit Fox Abundance

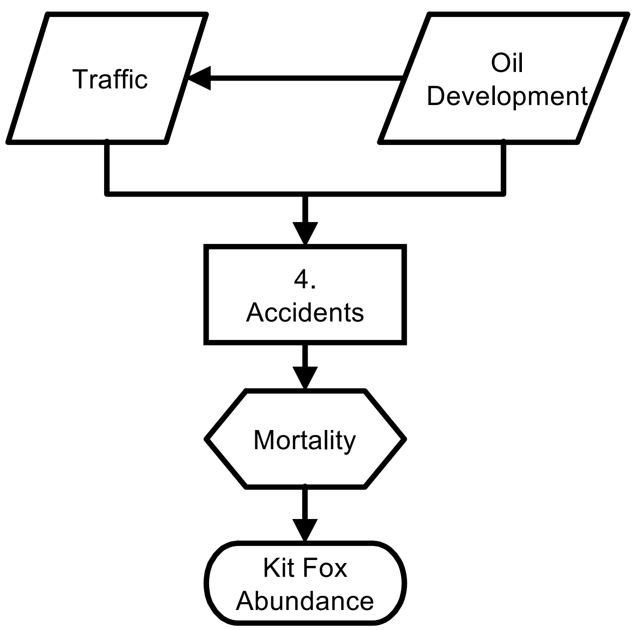

FIGURE 9

A Conceptual Model of Accidents as a Cause of the Decline in Kit Fox Abundance

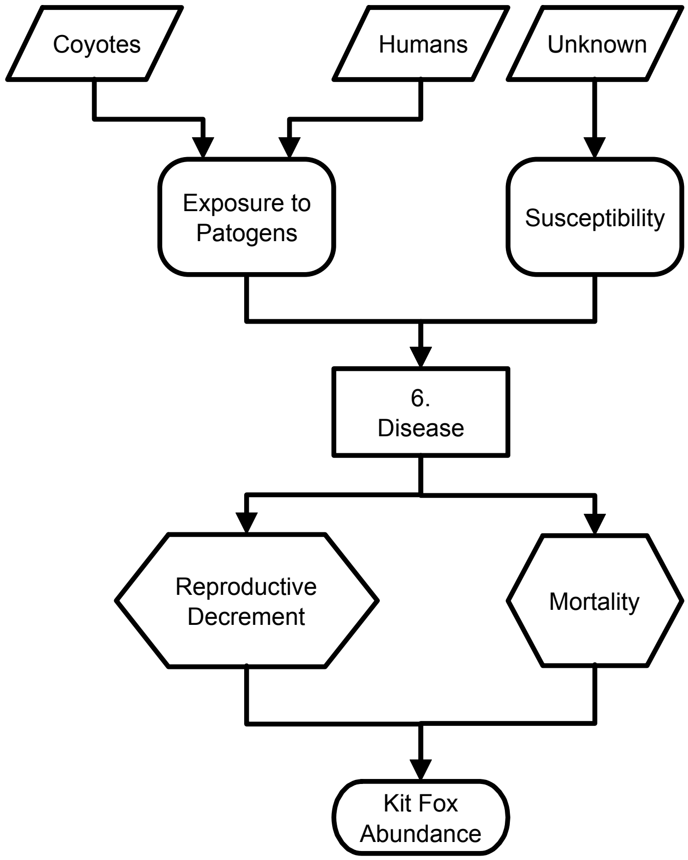

FIGURE 10

A Conceptual Model of Disease as a Cause of Decline in Kit Fox Abundance

TABLE 4

Candidate Causes

Number	Description
1a	Reduced prey abundance due to habitat disturbance
1b	Reduced prey abundance due to climate
1c	Reduced prey abundance due to predation
2a	Kit fox habitat alteration due to disturbance
2b	Kit fox habitat alteration due to climate
3	Predation on kit foxes
4	Toxic effects on kit foxes
5	Accidents involving kit foxes
6	Diseases of kit foxes

2.5.1. Candidate Cause 1. Prey Abundance

This candidate cause refers to a reduction in prey abundance due to reduced vegetation cover or quality which in turn may be due to disturbance during oil development (Cause 1a), to climatic effects, particularly reduced precipitation (Cause 1b), or to coyote competition for kit fox prey species (Cause 1c) (Figure 7). This cause includes changes in the relative abundance of prey species, particularly declines in lagomorphs (black-tailed jackrabbit and desert cottontail) relative to small rodents (primarily kangaroo rats and pocket mice).

2.5.2. Candidate Cause 2. Habitat Alteration

This candidate cause refers to direct effects of habitat quality on kit foxes including the abandonment of the site by foxes seeking more acceptable habitat or to reduced reproductive success due to fewer adequate denning sites. In addition to physical disturbance of the soil and vegetation, human activities may cause stress, disruption of hunting and increased energy expenditure. Activities close to whelping and pupping dens might disturb vixens and cause them to neglect or even abandon their litters. Like Candidate Cause 1, habitat alteration may be ultimately caused by disturbance during oil development (Cause 2a) or to climatic effects, particularly reduced precipitation (Cause 2b) (Figure 7). Also, habitat alteration may be cumulative (e.g., the total area devegetated by development) or immediate (e.g., the effects of active construction and drilling activities on the willingness of foxes to use an area).

2.5.3. Candidate Cause 3. Predators

This candidate cause refers to increased abundance of coyotes resulting in increased competition or mortality of foxes by coyotes (bobcats are also potential predators but were much less abundant). Oil development may make the site more attractive to coyotes by increasing road kills and food waste to be scavenged and, until the control program began, by protecting coyotes from hunters.

2.5.4. Candidate Cause 4. Toxic Chemicals

This candidate cause refers to toxic effects on the foxes due to exposure to chemicals associated with oil development. The two principal sources were spills of oil or chemicals used in production activities or waste ponds that contained produced water (water pumped up with the petroleum) (Figure 8).

2.5.5. Candidate Cause 5. Vehicular activity

This candidate cause refers to kit fox mortality due to being struck by vehicles or injured by equipment during oil production. Increased oil production increased vehicle traffic and construction activities that may bury foxes in their dens (Figure 9).

2.5.6. Candidate Cause 6. Disease

This candidate cause refers to any of various diseases of canids that may have been endemic or may have been brought to the site by coyotes or by humans from their pets (Figure 10).

3. STEP 3. EVALUATE DATA FROM THE CASE

The case consists of the kit fox population on the Elk Hills (NPR-1) in the first half of the 1980s. Three spatial comparisons are possible (Table 2). (1) The NPR-1 site was divided into developed and undeveloped areas, which allows the comparison of areas in which foxes were directly exposed to drilling, construction, and other development activities during the surge in oil production and areas where there was very little development activity. (2) Comparisons could be made between NPR-1 as a whole and a reference site, the Buena Vista Hills (NPR-2). This is a comparison of an actively developing oil field and one that is in production but where little new development was occurring. (3) Comparisons can be made between the developed and undeveloped portions of both oil fields combined (NPR-1 and NPR-2). This comparison incorporates the loss of habitat due to oil development, but not the effects of active development.

Although no baseline period is available to allow comparison of the development period with a pre-development period, temporal comparisons are possible. In the period 1981-1986, the NPR-1 kit fox population declined rather precipitously but the NPR-2 population was relatively stable at a high level (Figure 1). The NPR-2 population decreased precipitously from 1987-1991 while the NPR-1 population increased slightly until 1989 and then resumed its decline until 1991. Hence, we are interested in what happened in the early-to-mid 1980s on NPR-1 that did not occur on NPR-2.

Each line of evidence is given a score, as follows:

+++	convincingly supports
– – –	convincingly weakens
++	strongly supports
– –	strongly weakens
+	somewhat supports
–	somewhat weakens
0	neither supports nor weakens
NE	no evidence

For each of the first two candidate causes, (1) prey abundance and (2) habitat alteration, two sources were considered (a) disturbance and (b) climate. Where evidence permits, the candidate cause was scored, and each causal pathway from a source to a cause was scored. Note that, for a particular piece of evidence, the score is never higher and is usually lower for the full pathways (e.g., 1b. from climate to prey abundance) than for the cause (e.g., 1. prey abundance), because a more complex hypothesis requires stronger evidence to achieve the same degree of belief. The logic is the same as the logic that requires that joint probabilities must be smaller than simple probabilities.

This case uses a type of evidence not found in prior implementations of Stressor Identification or CADDIS, demographic modeling of the affected kit fox population. Floit and Barnthouse (1991) created a projection matrix model of the NPR-1 population for the period 1981-1986, the period of decline. A similar model created by EG&G for the supplemental impact statement extended to 1989, so it included the recovery period (U.S. DOE, 1993). These models gave qualitatively similar results, but some rates were quite different. Because these models show which mechanisms were sufficient to cause the decline, this type of evidence from the site is called mechanistic sufficiency.

The evidence from the site for each candidate cause is presented in this section. Evidence from the site addresses the issue, did the candidate cause, in fact, cause the effect in this case. In the following section (Section 4) the evidence from elsewhere is presented for each candidate cause. That evidence addresses the issue--is the candidate cause capable of causing effects of this type? In Section 5, the evidence for each candidate cause is summarized and compared. As you read the evidence, you may wish to look ahead to the summaries of the evidence in Tables 9-14.

3.1. PREY ABUNDANCE

3.1.1. Spatial/Temporal Co-occurrence

Prey abundance is judged to co-occur with the kit fox decline if prey abundance was low where and when the kit fox decline occurred. Two comparisons were possible.

3.1.1.1. *Developed Versus Undeveloped*

Lagomorphs, initially the primary prey of kit foxes on Elk Hills, declined in both developed and undeveloped habitats (1980-1984 based on road surveys), but the decline was much greater (5.3x) in the developed area where they were more abundant than in the undeveloped area (1.9x) (Figure 11, Table 5). Kangaroo rat abundances did not show a trend, but were much higher in the undeveloped area (Table 5). Hence, a decline in the principal prey co-occurred in space with disturbance and with the most rapidly declining component of the kit fox population, which supports prey abundance as a cause (1 = ++). This evidence supports prey abundance through the disturbance pathway as a cause (1a = +). It does not support the climatic pathway because the climate did not differ between areas of NPR-1. However, that evidence is weak because local weather or soil moisture data were not available (1b = –).

3.1.1.2. *NPR-1 Versus NPR-2*

Transect surveys from 1983-1991 showed a consistent decline in jack rabbits for NPR-1 as a whole (Figure 12). On NPR-2, lagomorph densities did not decline until 1987 but then declined until 1991 (U.S. DOE, 1993) (Figure 13). That is consistent with the delay in onset of kit fox decline on NPR-2 relative to NPR-1 (Figure 1). Hence, the declines in kit foxes on both NPR sites co-occurred with declines in lagomorph prey, which supports prey abundance as a cause (1 = ++), but the declines were not

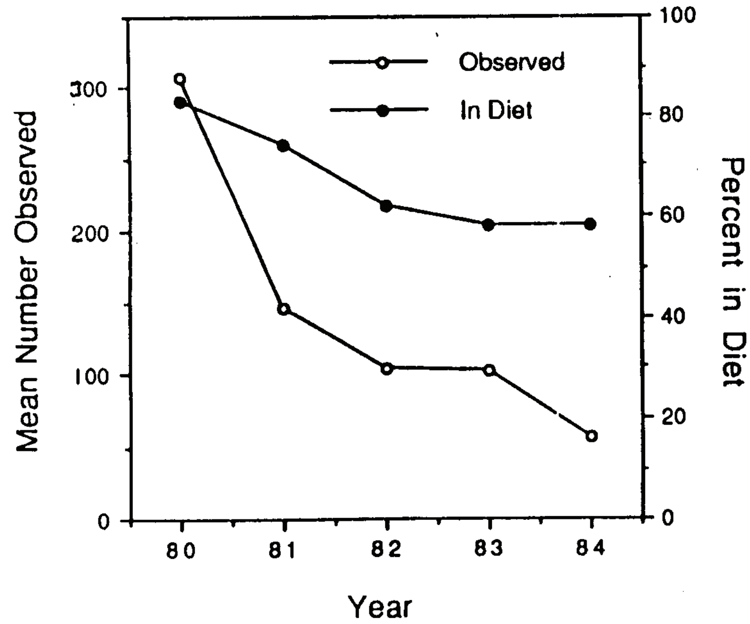

FIGURE 11

Number of Lagomorphs Observed on NPR-1 and Their Percentage in the Diets of San Joaquin Kit Foxes From 1980-1984 (Source: U.S. DOE, 1993)

TABLE 5

Relative Abundance of Lagomorphs (number observed) and Kangaroo Rats (trapping success) in Two Habitats on Elk Hills, California, Between 1980-1984

Months	Year	Undeveloped			Developed		
		Number of Lagomorphs Observed	Kangaroo Rats		Number of Lagomorphs Observed	Kangaroo Rats	
			Trapping Effort (trap-nights)	Trapping Success (%)		Trapping Effort (trap-nights)	Trapping Success (%)
Jun-Nov	1980	139	250	41.6	850	675	5.0
Dec-May	1981	133	900	54.3	286	1425	10.2
Jun-Nov	1981	103	900	41.7	630	1598	2.1
Dec-May	1982	112	900	45.9	182	1700	3.3
Jun-Nov	1982	115	900	34.3	246	1800	2.4
Dec-May	1983	133	900	66.6	142	1800	5.7
Jun-Nov	1983	89	899	38.9	282	2399	2.0
Dec-May	1984	84	450	64.4	224	1350	5.9
Jun-Nov	1984	71	300	57.3	160	900	7.6

Source: Scrivner et al. (1987).

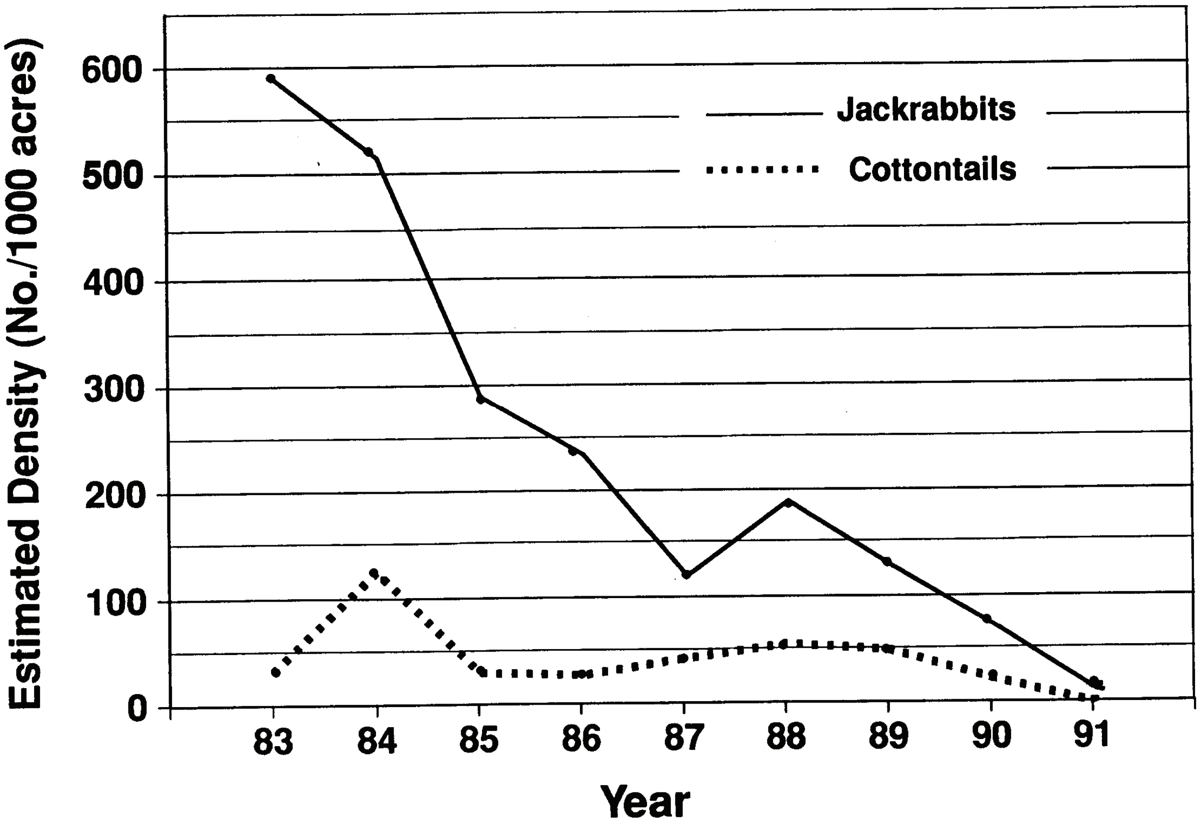

FIGURE 12

Estimated Density of Lagomorphs on NPR-1 from 1983-1991 (Source: U.S. DOE, 1993)

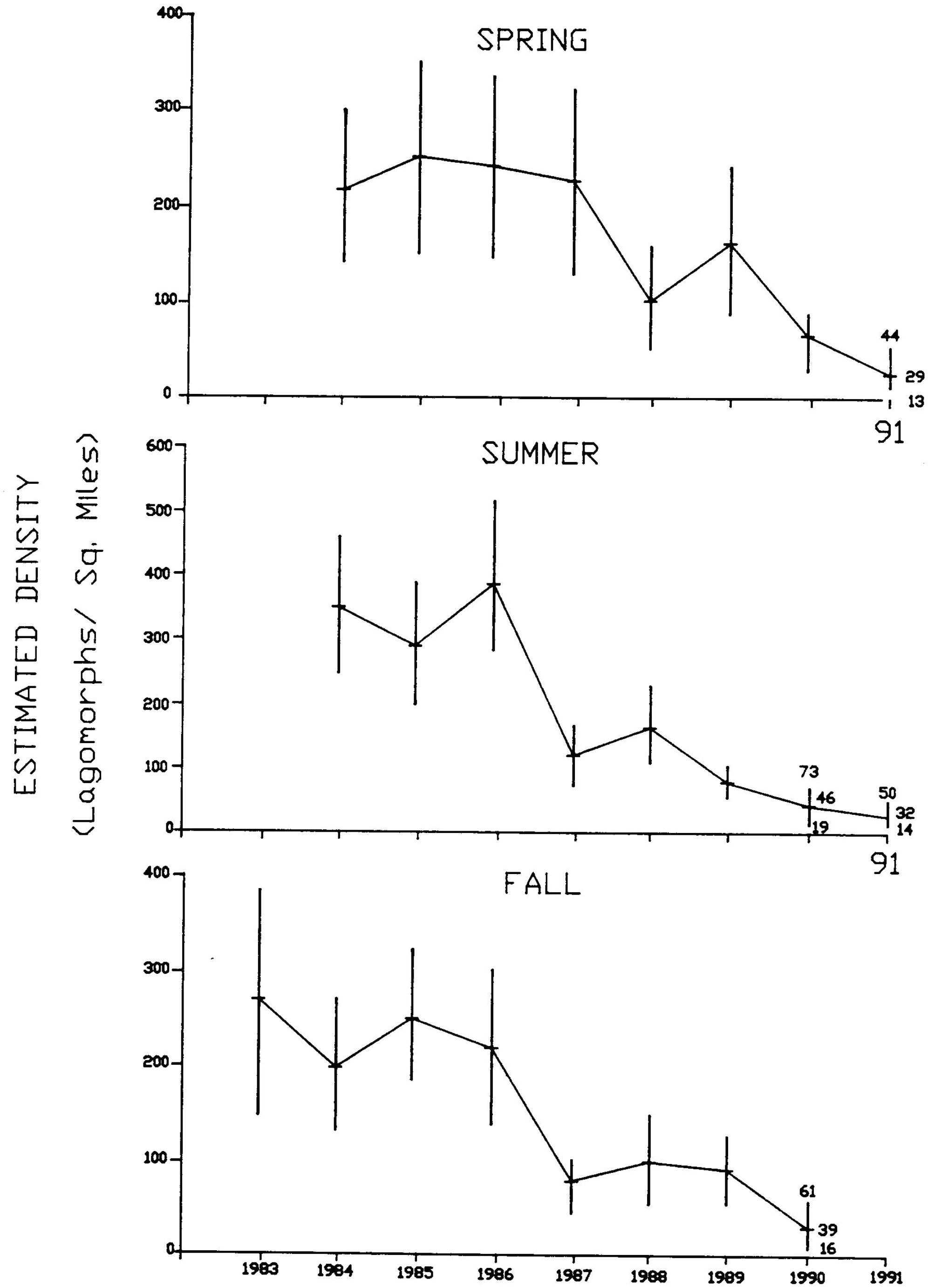

FIGURE 13

Lagomorph Density Estimates on NPR-2 (Source: U.S. DOE, 1993) contemporaneous. This evidence supports prey abundance through the disturbance pathway (1a = +). It does not support the climatic pathway, but without local weather or soil moisture data the evidence is weak (1b = –).

3.1.2. Temporal Sequence

Since the decline in both lagomorphs and foxes appears to have been underway at the beginning of the time series, it is not possible to determine whether a decline in prey began before the decline in foxes. Temporal sequence might also be derived from a time series, if there were a consistent lag between a decline in abundance of prey and a decline in kit foxes. However, the steady decline in both predators and prey during the period of concern precludes the identification of a clear temporal sequence (Figures 1, 11 and 12). As a result, the correlations of lagomorph and fox abundance are not consistently better with a one year time lag than without (see Stressor-Response Relationship in the Field, below). The temporal sequence is undefined (0).

3.1.3. Evidence of Exposure or Biological Mechanism

3.1.3.1. *Prey Utilization*

During the period of decline, the proportion of fecal samples from NPR-1 containing fur of lagomorphs decreased and kangaroo rats, usually the secondary prey, increased in developed and undeveloped areas (Table 6). This indicates changes in prey utilization that are consistent with a decline in preferred prey and switching to secondary prey in all areas. This evidence is clear and consistent with declines in prey abundance as a cause (1 = ++). Since it occurred in developed and undeveloped areas it is consistent with the climate pathway, but not disturbance (1a = – & 1b = +).

3.1.4. Stressor-Response Relationship in the Field

Kit fox abundance was linearly related to lagomorph abundance in the previous year on developed NPR-1 during 1981-1985 based on road surveys ($r^2 = 0.68$ for $y = -230 + 6.0x$) and less well related to lagomorph abundance in the same year ($r^2 = 0.31$). Kit fox abundance was even better related to lagomorph abundance in the same year on undeveloped NPR-1 during 1981-1985 based on road surveys ($r^2 = 0.98$ for $y = 8.2 + 0.69x$) and less well related to lagomorph abundance in the previous year ($r^2 = 0.66$).

Kit fox abundance was highly linearly correlated with jack rabbit abundance in the same year on NPR-1 during 1983-1991, based on transect surveys ($r^2 = 0.89$ for $y = 19 + 0.15x$) and less well correlated with jack rabbit abundance in the previous year ($r^2 = 0.56$). In both cases, the relationship is due to the first and last two years of the series.

In sum, the decline of foxes and of lagomorphs on both developed and undeveloped NPR-1 in the 1980s results in multiple good stressor-response relationships from two different lagomorph surveys, with or without a time lag. This

TABLE 6

Frequency of Occurrence (%) of Lagomorphs and Kangaroo Rats in the Scats of San Joaquin Kit Foxes Collected in Three Habitats and Two Time Periods Between 1980-1984, Elk Hills, California

Habitat	Year	Frequency of Occurrence (%)					
		Dec-May			Jun-Nov		
		Sample Size	Lagomorphs	Kangaroo Rats	Sample Size	Lagomorphs	Kangaroo Rats
Undeveloped Flat	1980	5	100.0	0.0	4	100.0	0.0
	1981	26	84.6	3.8	60	78.3	13.3
	1982	76	77.6	19.7	31	45.2	32.3
	1983	64	39.1	45.3	33	27.3	42.4
	1984	22	36.4	50.0	32	43.8	37.5
Undeveloped Hilly	1980	17	100.0	5.9	5	60.0	0.0
	1981	49	87.8	14.3	21	81.0	0.0
	1982	51	78.4	9.8	15	33.3	20.0
	1983	49	61.2	20.4	13	76.9	15.4
	1984	12	58.3	33.3	29	51.7	20.7
Developed Hilly	1980	5	100.0	0.0	24	91.7	4.2
	1981	122	88.5	4.9	108	85.2	0.9
	1982	176	82.7	2.8	78	67.9	5.1
	1983	69	81.2	7.2	22	40.9	18.2
	1984	17	47.1	29.4	28	57.1	17.9

Source: Scrivner et al. (1987).

result is consistent with loss of prey as a cause (1 = ++) and, because the correlations occurred in both developed and undeveloped areas, with the climate pathway (1b = +) but not disturbance (1a = –).

3.1.5. Causal Pathway—Disturbance

The primary pathway for disturbance is from oil development activities to reduced vegetation, reduced prey and reduced kit foxes (Figure 7). The creation of well pads and other construction activity inevitably destroyed vegetation thereby reducing food and cover for prey organisms. The lagomorph and kit fox declines were greatest in the developed areas of NPR-1. Hence, all steps in the causal pathway were present which qualitatively supports the disturbance pathway (1a = +).

3.1.6. Causal Pathway—Climate

The primary causal pathway for climate is from reduced precipitation to reduced vegetation, reduced prey and reduced kit foxes (Figure 7). During the 1981-1986 period of kit fox decline and the three preceding years, effective precipitation measured in Bakersfield was above average in five years and below average in three (Figure 14). In particular, the good and extremely good precipitation in 1982 and 1983 had no apparent effect on the ongoing kit fox decline (Figure 1). This is contrary to other studies that found a relationship when they included both NPR sites and a longer time period (Cypher et al., 2000). That suggests that something was negating the expected precipitation effects on NPR-1 in the period of concern. This evidence weakens climate (1b = –).

Kit fox abundance on NPR-1 was not correlated with precipitation in the same year, the prior year, two years previously, or three years previously. This was true for both the period of decline (1981-1986) and for the entire study period (1981-1990). (The time lags account for potential causal lags due to the time required for vegetation and prey to respond to precipitation.) This evidence weakens climate (1b = –).

In addition, if precipitation was the source of the kit fox decline, one would expect to see the same pattern of decline on NPR-2. However, kit fox abundance on NPR-2 was stable during 1983-1987 and declined thereafter (Figure 1). (Note that the apparent fluctuations in Figure 1 are seasonal rather than annual.) This evidence weakens climate (1b = –).

The relationship of total lagomorph counts (mostly jack rabbits) from road surveys on NPR-1 in 1980-1984 to precipitation in the same year and the previous year was analyzed by linear regression. With one exception, correlations were extremely low for both developed and undeveloped areas. In undeveloped areas, lagomorph abundance was negatively correlated with precipitation in the previous year, which is contrary to expectations. Jack rabbit abundance by transect survey was weakly positively correlated with precipitation in the same year ($r^2 = 0.30$) or in the previous year ($r^2 = 0.32$) during 1983-1990. This evidence weakens climate (1b = –).

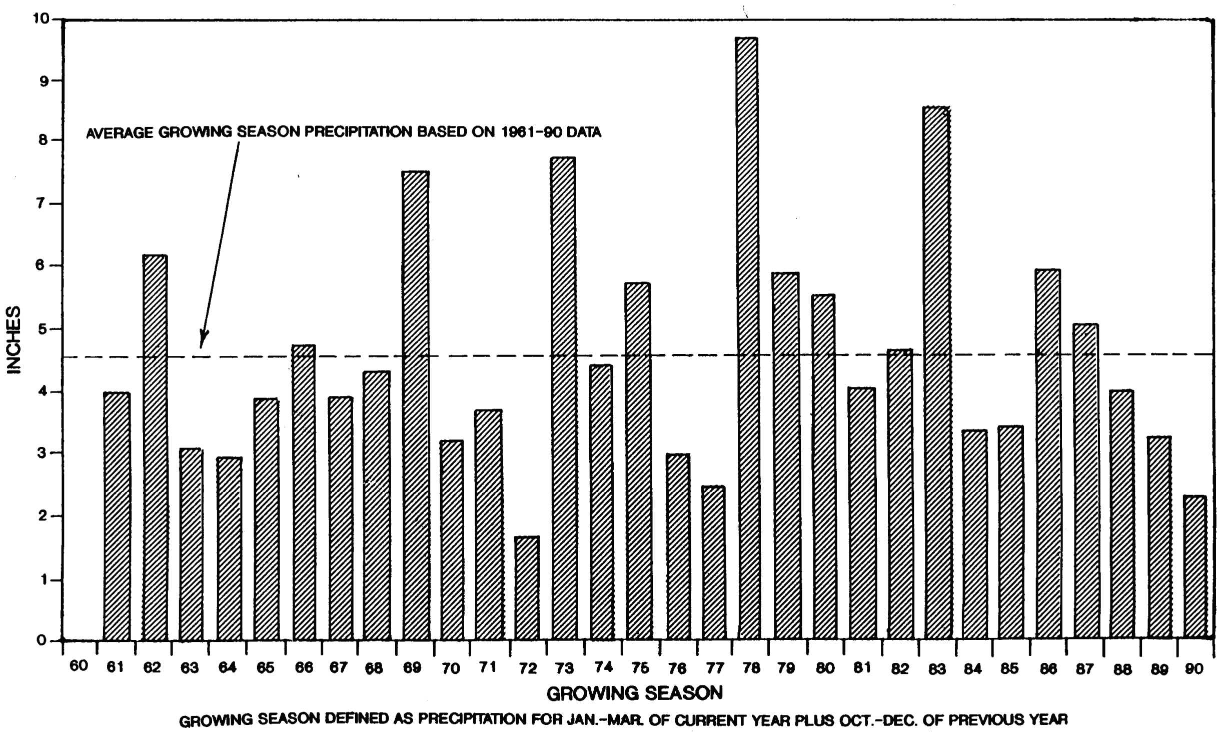

FIGURE 14

Average Growing Season Precipitation for Bakersfield, California (Source: U.S. DOE, 1993)

Based on visual inspection, vegetation production on NPR-1 declined between 1988 and 1991 (U.S. DOE, 1993). Also, at an undisturbed 32 acre site on NPR-1, annual production declined from 1596 pounds/acre in 1988, to 644 pounds/acre in 1989 and to 85 pounds/acre in 1990. This corresponds to a period of steady decline in precipitation (Figure 14). This evidence is consistent with precipitation as a cause of reduced plant production, but it does not relate to the principal period of kit fox decline when precipitation was higher (1981-1986). This evidence is ambiguous (1b = 0).

In sum, the evidence for the causal pathway from climate to vegetation, lagomorph prey, and kit fox is negative (overall 1b = –).

3.1.7. Causal Pathway—Competition

Coyotes are primarily predators of lagomorphs and, to a much lesser extent, small rodents (Cypher and Spencer, 1998). Their increase between 1979 and 1984 coincided with declines in lagomorphs and kit foxes. However, regular quantitative monitoring of coyote abundance and analysis of coyote diets did not begin until 1985 and after that time coyote abundance declined. By then the principal decline of foxes and lagomorphs was complete and kit foxes had switched primarily to kangaroo rats. Hence Cypher and Spencer's (1998) conclusion that there was little competition for food may not be relevant to the period of concern. The evidence is consistent with coyote competition during the period of kit fox decline, but the evidence for the following period is not (1c = 0).

3.1.8. Manipulation of Exposure

To determine the influence of food availability of kit foxes, a supplemental feeding study was conducted in 1988 and 1989. Supplemental feeding at individual occupied dens in 1988 increased survival of pups relative to controls from 10-50% and increased survival of adults from 30-70% (U.S. DOE, 1993). Results were positive in 1989 as well, but the differences were smaller due to increased survival of unfed foxes. That may be due to heavier coyote control activities in 1989 (U.S. DOE, 1993). This evidence supports prey abundance, but is not strong because the studies occurred after the decline and the manipulation was not of the prey (1 = +).

3.1.9. Symptoms

3.1.9.1. *Starvation*

Starvation was not reported to be a cause of death in kit fox necropsies. That is negative evidence for a shortage of prey as a cause of mortality (–).

3.1.9.2. *Reproductive*

Male-biased sex ratios of pups, as observed on developed NPR-1, are characteristic of female canids that are in poor condition due to poor nutrition (Zoellick et al., 1987). This symptom supports prey abundance but may occur with other causes (1 = +). Because this symptom occurred on developed NPR-1, it supports prey abundance through the disturbance pathway (1a = +). It does not support the climatic pathway because the climate did not differ between areas of NPR-1 (1b = –).

3.1.10. Mechanistic Sufficiency

The most likely demographic mechanism of low prey abundance is poor nutrition and reduced fecundity, but the observed reduction in fecundity was only a minor contributor to the decline (Floit and Barnthouse, 1991). This evidence weakens the case for prey abundance (1 = –).

3.2. HABITAT ALTERATION

On NPR-1, habitat alteration has been thought to result from disturbance associated with oil development (2a - Disturbance) or climatic effects (2b - Climate). The climatic effects are assumed to be reduced plant biomass and production, resulting in reduced habitat quality. In contrast, oil development may act through loss of vegetation, noise, human presence, or other disturbances. Although habitat preferences in terms of vegetation types are known, no detailed habitat model is available for kit foxes that would allow quantification of the effects of disturbance on habitat quality. The area developed, number of wells drilled and volume of oil produced are used as surrogates for habitat disturbance. Growing season precipitation and plant production were used as surrogates for habitat alteration due to climate.

3.2.1. Spatial/Temporal Co-occurrence—Disturbance

3.2.1.1. *Disturbed Versus Undisturbed*

The NPR-1 kit fox decline was most severe in the disturbed areas. By 1990, very few foxes in the NPR-1 study area occurred in the developed upland areas; the remaining foxes were found primarily in the flatter undeveloped areas (U.S. DOE, 1993). Hence, the decline spatially co-occurred with cumulative habitat disturbance. This evidence supports disturbance of habitat (2a = +).

3.2.1.2. *Temporal Co-occurrence—Disturbance*

During the period of decline (1981-1986), oil development continued with a peak in 1982-1983 followed by a relatively low level of drilling (Table 3). Given the possibility of time lags and cumulative effects, temporal co-occurrence is ambiguous (2a = 0).

3.2.2. Spatial/Temporal Co-occurrence—Climate

Precipitation was believed to be similar on both developed and undeveloped areas of NPR-1 and on NPR-2, so the differences in the rates and timing of kit fox declines is not accounted for by climatic effects on habitat (2b = –).

3.2.3. Temporal Sequence

The period of increased development began in 1974 and drilling appeared to peak in 1976-1978 (Table 3). The beginning of the kit fox decline is uncertain, but it began no later than the first monitored interval (1981-1982). Hence, the temporal sequence is ambiguous (2 = 0).

3.2.4. Stressor-Response Relationships in the Field—Disturbance

The 1981-1986 period of kit fox decline and the full 1981-1990 study period were also periods of decline in well drilling and oil production (except for a blip in 1982-1983, Table 3). Hence, stressor-response models for active disturbance (i.e., number of wells completed) and kit fox abundance have the wrong sign for the causal hypothesis. Another approach is to relate the proportional change in kit fox abundance to the number of wells completed in the same year or the previous year, but that yielded no apparent relationships. Hence, the stressor-response relationships weaken the causal hypothesis (2a = – –).

3.2.5. Stressor-Response Relationships in the Field—Climate

Few data quantify changes in habitat quality or quantity that might result from climate and that could be related to fox abundances. However, plant production may be a surrogate for climate-mediated habitat quality. At an undisturbed 32 acre site on NPR-1, annual production declined from 1596 pounds/acre in 1988, to 644 pounds/acre in 1989 to 85 pounds/acre in 1990 (U.S. DOE, 1993). These data do not correlate well with kit fox abundance in the same year, but they do correlate perfectly ($r^2 = 0.999$) with kit fox abundance in the following year ($y = 7.4 + 0.032X$). Although suggestive, models based on three points inspire little confidence, and the time series is outside the period of concern, so the evidence is ambiguous with respect to the decline (2b = 0).

3.2.6. Evidence of Exposure or Biological Mechanism

No evidence.

3.2.7. Causal Pathway—Disturbance

Oil development involves the destruction of vegetation, which diminishes habitat. Noise and human activity also diminish habitat during the period of construction and drilling activity. All steps in this causal pathway were present (2a = ++).

3.2.8. Causal Pathway—Climate

The climate was not consistently poor and vegetation data are lacking in the period of decline. In particular, while kit foxes steadily declined in the period of concern, precipitation was above average, then below, then above again and below again (Figure

14, Section 2.1.6). This lack of a relation between precipitation and kit fox abundance weakens the case for climate-induced habitat alteration as a cause (2 = – –).

Vegetation data were available for a later period. Based on visual inspection, vegetation production on NPR-1 declined in undisturbed areas between 1988 and 1991 (U.S. DOE, 1993). At an undisturbed 32 acre site on NPR-1, annual production declined from 1596 pounds/acre in 1988, to 644 pounds/acre in 1989 to 85 pounds/acre in 1990. This corresponds to a period of steady decline in precipitation (Figure 14). These data are well correlated with precipitation in the same year ($r^2 = 0.987$) ($y = 1011x – 2395$). However, models based on three points inspire little confidence, the time series is outside the period of concern, and the precipitation was lower than in the period of concern, so the evidence is ambiguous (2 = 0).

The combined score for the climate to habitat pathway is weakly negative (2 = –).

3.2.9. Mechanistic Sufficiency

Because habitat could affect mortality, fecundity and emigration, the demographic models cannot be used to determine the mechanistic sufficiency of habitat modification as a cause (2 = 0).

3.3. PREDATORS

3.3.1. Spatial/Temporal Co-occurrence—Developed versus Undeveloped

Coyotes were more abundant on developed than undeveloped NPR-1 in the period of decline and the decline was greater on developed NPR-1 (U.S. DOE, 1993). That spatial co-occurrence supports predation (+).

3.3.2. Spatial/Temporal Co-occurrence—Temporal on NPR-1

Coyote numbers were lowest when the first survey was conducted on NPR-1 in 1979 (8 observed on 522 miles of transect), but 5 years later 108 were observed over those transects (U.S. DOE, 1993). Hence, an increase in coyote numbers occurred within the same time interval as the observed decline in kit fox abundance, but the pattern of abundance between those dates in unknown. Hence, the decline co-occurred with the candidate cause (+).

3.3.3. Spatial/Temporal Co-occurrence—NPR-1 versus NPR-2

Coyote abundance on NPR-2 was not known for the period of concern (i.e., prior to 1985) (Figure 15). After that, it was irregular and did not correspond to kit fox abundance patterns except that both dropped in the late 1980s, after the kit fox decline (0).

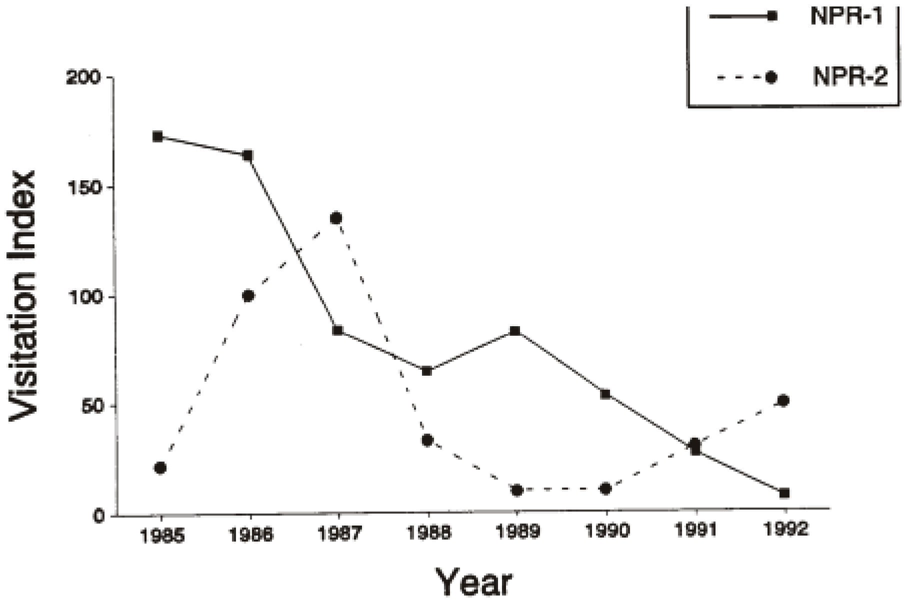

FIGURE 15

Winter Visitation Indices for Coyotes on the Elk Hills (NPR-1) and Adjacent Buena Vista Hills (NPR-2), California, 1985-1992 (Source: EG&G/EM, 1992)

3.3.4. Temporal Sequence

The low abundance of coyotes in 1979 suggests that an increase in coyote abundance did not precede the decline in kit foxes, but the timing of the coyote increase and the beginning of the kit fox decline are unclear. This evidence is ambiguous (0).

3.3.5. Stressor-Response in the Field

Between 1979 and 1985, the coyote population on NPR-1 greatly increased and the kit fox population greatly declined. Then the coyote population declined from 1985 (when coyote control and regular monitoring, using scent stations, began) until 1991 (Figure 15) (U.S. DOE, 1993). For three years following the onset of coyote control (1986-1989) the kit fox population stopped declining. Then from 1989-1991, both declined. Because of the switch from transect surveys to scent stations, correlations with kit fox abundance cannot be calculated for the period of decline or the entire period of interest. However, the stressor-response relationship is qualitatively correct until 1989. When coyotes increased, kit foxes declined, and when coyotes declined, kit foxes stopped declining. Hence, the stressor-response relationship could not be quantified (NE) and the qualitative association is scored as spatial/temporal co-occurrence, above.

3.3.6. Causal Pathway

Multiple causal pathways that may associate coyote abundance with oil development were not documented (Figure 7). It is speculated that the absence of shooting and trapping prior to the control program may have allowed the increase coyote abundance, but it does not explain the initially low numbers. Coyotes may have also benefited from increased road kills to be scavenged or from food discarded by workers (Cypher and Spencer, 1998). Those resources inevitably increased with increased oil production activities in the late 1970s and would have been associated with developed areas.

There is some evidence for the causes of the coyote decline. Coyote abundance declined during the period of the control program beginning in 1985. The decline also corresponded to the decline in lagomorph prey and, after 1988, to below average precipitation.

Evidence exists for complete causal pathways to coyote abundance and predation on kit foxes (+).

3.3.7. Evidence of Exposure or Biological Mechanism

Because coyotes do not consume the foxes that they kill, predation by coyotes was well documented by necropsy of foxes from NPR-1. Coyote-killed foxes were identified by characteristic puncture wounds and associated muscle and bone injuries

(Cypher and Spencer, 1998). This evidence for the predation mechanism is clear and consistent (++).

3.3.8. Manipulation of Exposure

A coyote control program was conducted for 6 years on and around NPR-1 beginning in 1985. The decline of the kit fox population ended in the second year of this period. Overall, 591 coyotes were killed. This evidence supports predation as the cause, but is ambiguous because there is no reference and other factors may confound the effects of coyote control (+).

3.3.9. Mechanistic Sufficiency

A demographic model of kit foxes on NPR-1 for the period 1980-1986 found that the decline was caused by high mortality, particularly of young-of-the-year foxes (Floit and Barnthouse, 1991). The mortality due to predation alone was more than sufficient to cause a decline. Although fecundity was depressed in developed areas relative to undeveloped areas, the population abundance was insensitive to variance in fecundity. Net emigration from the developed areas did not significantly contribute to the decline. A less detailed analysis of an equivalent model for the U.S. DOE (1993) that extended to 1989 gave qualitatively similar results, but different rates because of inclusion of a period after the decline (1986-1989). In sum, mortality was the mechanism of the decline and predation was the overwhelming cause of mortality (80%; Table 7). This line of evidence strongly supports predation as the proximate cause (+++).

3.4. TOXIC CHEMICALS

The data concerning kit fox exposures and data analyses used for this candidate cause are presented in Suter et al. (1992). That report presents more results in more detail.

3.4.1. Spatial/Temporal Co-occurrence

Chemicals related to oil production occurred on the developed areas at much greater concentrations than on undeveloped areas during the period of population decline. Sources included produced water sumps, oil spills, drilling fluids in sumps or deposited on land, and spills of chemicals used in oil production (Suter, 1988; U.S. DOE, 1993). The arsenical anti-corrosion compound W-41 and the hexavalent chromium added to drilling fluids were particular concerns. Arsenic-contaminated water was deposited in six unlined sumps and arsenic-contaminated wastes were deposited in unlined trenches. Hexavalent chromium was spilled on at least 65 sites. The less toxic trivalent chromium in drilling fluids is widely distributed on the site. This evidence supports toxicants (+).

TABLE 7

Percentage of Radiocollared San Joaquin Kit Foxes Dying from Various Causes on NPR-1 from 1980-1988

Class	Number	Cause of Death (as % of deaths of identified cause)		
		Predation	Vehicle	Other
Sex				
Male	91	78.0	16.5	5.5
Female	106	83.0	13.2	3.8
Age				
Pup	82	80.5	14.6	4.9
Adult	103	81.6	14.6	3.9
Year				
1980-82	45	80.0	20.0	0.0
1983-85	113	79.6	12.4	8.0
1986-88	39	84.6	15.4	0.0
Total	197	80.7	14.7	4.6

Source: U.S. DOE (1993).

3.4.2. Temporal Sequence

It is hypothesized that increased development after 1976 increased exposures, but there are no data to support that assumption. Until 1986, all wastes were deposited on site, and waste waters and drilling fluids continued to be deposited in sumps and on land, respectively (U.S. DOE, 1993).

3.4.2.1. Arsenic

The arsenical water treatment chemical W-41 was used on NPR-1 from 1922-1970. Although arsenic residues persisted at the site, arsenic use did not increase immediately before the decline (–).

3.4.2.2. Barium

Barium was used throughout the period of concern and the years before. Increased drilling before the decline inevitably meant increased use of barite and presumably an accumulation of barite on developed NPR-1 (+).

3.4.2.3. Chromium

Lignochromates and hexavalent chromium salts were used in drilling fluids from 1954-1983. Hence, it is plausible that chromium exposures increased as drilling increased in the mid 1970s to early 1980s and chromium contamination increased on developed NPR-1 (+).

Overall, this evidence is ambiguous because there are no data from the late 1970s and no good temporal data (0).

3.4.3. Stressor-Response Relationships in the Field

There were no large or statistically significant correlations of longevity with fur concentrations of any element among the 21 foxes for which both time of death and fur concentration data were available. This evidence weakens toxicants (–).

3.4.4. Evidence of Exposure or Biological Mechanism

Chemical exposures were investigated by analyzing the elemental composition of kit fox fur samples. Elements that were not detected by neutron activation analysis in at least half of the samples were excluded, leaving 35 elements. Fox pups were excluded because of relatively low concentrations and the sexes were combined because they did not differ. Samples came from NPR-1 (49), NPR-2 (12), Camp Roberts (20) and Carrizo Plain (6). Data analysis focused on typical (median concentration) foxes at each site and level of development and on foxes with exceptionally high (top decile) concentrations for each element.

Analysis of data for all 35 elements served to indicate the degree of systematic variance among sites in exposure to metals and metalloids. Statistically significant differences among sites were found for all but three elements (chlorine, cobalt, and vanadium (Table 8). However, most elemental concentrations were not highest on oil fields. Of the 35 elements, Camp Roberts fur had the highest concentrations for 21 and second highest for 6, Elkhorn Plain fur was highest for 7 and second highest for 17, developed NPR-1 fur was highest for 1 and second highest for 6, NPR-2 fur was highest for 4 and second highest for 4 (all NPR-2 foxes were from developed areas), and undeveloped NPR-1 was not highest or second highest for any element, but was lowest for 23 and second lowest for 8. In sum, fur from the undeveloped remote reference sites had the highest concentrations of most detected elements, fur from undeveloped areas on NPR-1 had low concentrations and sites with extensive oil development had intermediate levels. Hence, although there was a statistically significant positive correlation of fur concentration and percent disturbance of the fox's home range on NPR-1 and NPR-2 combined for 23 elements, it was attributable to the exceptionally low concentrations for undeveloped NPR-1, not high concentrations in developed locations.

Some elements in fur were associated with oil development and identified as particular hazards.

3.4.4.1. *Arsenic*

Median arsenic levels were higher in fur from developed NPR-1 and NPR-2 than from other sites. Arsenic in fur was significantly positively correlated with percent disturbance, total wells, and new wells in the fox's home ranges. Arsenic concentrations were highly variable among individuals (>2600x) but only moderately variable among site medians (4.3x).

3.4.4.2. *Barium*

Barite is a major constituent of drilling fluids. The median barium concentration in fur from developed NPR-1 was higher than from any other site. The highest individual concentration and seven of the top ten concentrations were from foxes from developed NPR-1, but the second and fourth highest were from Camp Roberts. Barium concentrations in fur from both oil fields were significantly positively correlated with percent disturbance and the number of wells.

3.4.4.3. *Chromium*

The median chromium concentration in fur from developed NPR-1 was lower than for any other site. Although the median fur concentration and soil concentrations were low, the highest fur concentration was from developed NPR-2 and four of the top ten concentrations were from developed areas. This suggests that some individual foxes had been exposed to chromium-containing wastes. Chromium concentrations in fur were significantly positively correlated with the number of wells in the home range but not the percent disturbance.

TABLE 8

Ranges of Metal Concentrations (ppm) in Hair of Individual San Joaquin Kit Foxes Sampled on the Elk Hills (NPR-1), Adjacent Buena Vista Hills (NPR-2), Carizo Plain and Camp Roberts (Other Sites), California, Compared with Concentrations in Hair from Other Mammals

Metal	NPR-1 Kit Foxes	NPR-2 Kit Foxes	Other Site Kit Foxes	Wildlife	Teton Coyotes (Huckabee, 1972)	High Exposure Areas	Human Normal	Human Toxic
Aluminum	66.8-1710	110.0-881	68.6-2830				5[a]	
Antimony	0.008-1.4	0.017-0.44	<0.005-0.60	<0.2-12[b]	0.09-1.8		0.03-24[c]	
Arsenic	0.03-4.7	0.15-5.4	<0.01-2.6			0.3-8.9[d,e,f]	0.0-2.0[c]	3[c]
Bromine	3.6-66	8.4-23	1.9-26				30[a]	
Calcium	<67-1000	<67-400	<67-2800				497[g]	
Cerium	<0.3-2.3	0.4-1.5	<0.3-3.0	<1-20[b]	1.9-2.6			
Chromium	<0.1-3.9	0.7-7.7	<0.1-5.8	<0.3-640[b]	0.7-5.8	3.9-4.8[h,i]	0.0-40[c]	
Cobalt	0.15-2.40	0.21-1.15	0.14-1.10				0.1[a]	
Copper	0.015-54	11-23	12-48			6.9-8.3[c,j]	7.8-120[c]	
Iron	151-1430	282-4150	270-5500	<21-6400[b]	23-160		26.7[g]	
Magnesium	<40-640	<40-360	<40-660				56.7[g]	

TABLE 8 cont.								
Metal	NPR-1 Kit Foxes	NPR-2 Kit Foxes	Other Site Kit Foxes	Wildlife	Teton Coyotes (Huckabee, 1972)	High Exposure Areas	Human Normal	Human Toxic
Manganese	0.95-31.70	2.13-27.70	1.74-50.60				0.3[a]	
Mercury	0.21-1.2	0.28-3.9	0.25-10	<0.008-10.7[b]	<0.008-2.8	9.8-117.5[k,l]	0.01-30[c]	50-200[c]
Nickel	<1-7	<1-10	<1-8	0.18-1.7[c]			0.0-11[c]	
Gold	0.0007-0.065	0.0015-0.011	0.0013-0.135	<0.04-0.6[b]	0.002-0.04			
Potassium	<28-360	41-250	<28-1300				67.6[g]	
Rubidium	<0.3-2.9	<0.3-1.5	<0.3-3.7	5.8-8.3[b,m]				
Scandium	0.04-0.46	0.06-0.21	0.05-0.54	<0.05-2[b]	0.005-0.009			
Selenium	0.60-1.8	0.90-3.0	0.50-4.2 0.71-27[n]	0.08-17[b]	0.8-7.83	3.8-12[o,p] 0.89-13[q] 0.97-18[r]	0.3-13[c]	8-30[c]
Silver	<0.1-0.2	<0.1	<0.1-0.3	<0.4-110[b]	0.06-12			
Sodium	4.1-212.0	6.6-98.0	14.0-208.0				309[g]	
Titanium	<14-120.0	<14-58.0	<14-114.0				4[a]	

TABLE 8 cont.								
Metal	NPR-1 Kit Foxes	NPR-2 Kit Foxes	Other Site Kit Foxes	Wildlife	Teton Coyotes (Huckabee, 1972)	High Exposure Areas	Human Normal	Human Toxic
Vanadium	0.3-11.5	0.6-3.2	<0.1-4.4				0.006-2.7[c]	
Zinc	93-220	118-178	87-180	13-6300[b]	91-620		65-200[s]	

[a]Lenihan (1978).
[b]Huckabee et al. (1972).
[c]Jenkins (1979).
[d]Lewis (1972).
[e]Orheim et al. (1974).
[f]Livestock grazing near smelters; reference animals had 0-0.46 ppm.
[g]Barker et al. (1976).
[h]Taylor et al. (1975).
[i]Cotton rats from near cooling towers using chromate corrosion inhibitors; reference rats had 0.39 ppm.
[j]Livestock grazing near smelters; reference animals had 6.8-7.8 ppm.
[k]Doi (1973).
[l]Cats from the vicinity of Minamata, Japan.
[m]Rodents from areas of heavily mineralized soils in Idaho.
[n]Kit foxes from Bakersfield.
[o]Schroeder et al. (1970).
[p]Rats fed nominally toxic levels of Se; control rats had 0.6 ppm.
[q]Kit foxes from the Kesterson Reservoir.
[r]Coyotes from the Kesterson Reservoir.
[s]Petering et al. (1971).

Source: Suter et al. (1992).

3.4.4.4. *Sodium*

Sodium was used as a marker for produced water which is primarily a sodium chloride solution. However, neither median nor extreme fur concentrations of sodium were high for developed NPR-1 relative to other sites.

3.4.4.5. *Vanadium*

Vanadium occurs in relatively high concentrations in petroleum and is used as a marker for petroleum in the environment. The median fur concentration was highest for the Carizo Plain, but six of the top ten individuals were from developed NPR-1 and the other four of the top ten were from undeveloped NPR-1 even though undeveloped NPR-1 had the lowest median concentration. Vanadium concentrations were significantly positively correlated with percent development on both NPR-1 and NPR-2. This suggests that some foxes were exposed to petroleum.

To summarize, the median concentrations of arsenic and barium were higher on developed NPR-1 than on other sites and some foxes appeared to be relatively highly exposed. However, there was considerable overlap of the distribution of concentrations with the other sites. Median chromium and vanadium concentrations from NPR-1 were not higher than other sites, but some foxes were relatively highly exposed. This evidence is taken as positive in that it showed that some foxes were exposed to petroleum or metals in the area where the decline occurred (++).

3.4.5. Causal Pathway

Individual pathways of exposure and lines of evidence are scored separately.

3.4.5.1. *Soil Concentrations*

Soil may be a pathway of exposure through direct ingestion or through the food web. Direct ingestion includes grooming and soil ingested incidentally with prey. However, there were no large or statistically significant correlations between elemental concentrations in random soil samples and percent disturbance in the quarter section from which the sample was taken. Similarly, the differences in fur concentrations among sites were not attributable to those soil concentrations. There were no large or statistically significant positive correlations of soil and fur concentrations at NPR-1 or Camp Roberts. Differences in soil concentrations among sites were small relative to differences in fur concentrations. Hence neither soil contamination nor natural soil concentrations account for differences in exposure among foxes. However, this conclusion addresses only soil contamination that is sufficiently wide-spread to be detected by random soil sampling (–).

3.4.5.2. *Soil Intake*

Differences in exposure to metals in soils may be due to differences in rates of intake rather than differences in concentration. Differences in disturbance between developed and undeveloped NPR-1 may result in increased exposure to soil due to dust, but cannot account for differences among other sites. Differences in prey composition may explain the differences among sites (Suter et al., 1992), but that explanation does not account for the decline of foxes on NPR-1 (–).

3.4.5.3. *Local Soil Contamination (Wastes)*

Local spills and deposits of contaminants were abundant on developed NPR-1. Hence, the evidence for soil as a pathway is positive on the basis of local soil contamination (+).

3.4.5.4. *Waste Water*

Produced waters in open sumps may have been a route of exposure to toxicants due to drinking. Kit foxes are desert animals that do not require drinking water and do not normally drink, but they may consume water from produced water sumps. There is no evidence for waste waters as a route of exposure (0).

3.4.5.5. *Petroleum*

Foxes were potentially exposed to petroleum in spills and oil recovery sumps. One kit fox died in spilled oil during the period of study. The evidence for contact with oil as an exposure route is weakly positive (+).

3.4.6. Mechanistic Sufficiency

The demographic model indicated that the decline was caused by mortality, primarily due to predation. There was no evidence that toxicity caused mortality of foxes so it was not the proximate cause (–).

3.5. VEHICULAR ACTIVITIES

3.5.1. Spatial/Temporal Co-occurrence

The increase in development inevitably increased vehicle traffic, and it seems likely that traffic was greatest in developed areas. Most vehicle deaths involved young-of-the-year foxes and occurred in developed areas (Table 7). This evidence supports vehicular activity as a cause (+).

Other types of accidents were minor. Among all known kit fox mortalities on NPR-1 (1980-1990), 1 was buried during construction, 1 was trapped in a pipe, and

4 died in live traps during the demographic studies (U.S. DOE, 1993). Hence, other accidents are not considered.

3.5.2. Temporal Sequence

No data are available to determine the sequential relationship between vehicular activity and kit fox mortality (NE).

3.5.3. Evidence of Exposure or Biological Mechanism

Fifteen percent of identified mortalities of radio-collared kit fox on NPR-1 during 1980-1988 were due to vehicle collisions based on location and necropsy results (U.S. DOE, 1993). This evidence supports vehicular activity as a cause (++).

3.5.4. Causal Pathway

Vehicular activity was not quantified, but it inevitably increased on the site due to increased oil development activities. The 15% of total mortality on NPR-1 due to vehicle strikes was higher than in most other studies where vehicular strikes rarely exceed 10% of mortalities (Bjurlin and Cypher, 2003). This suggests that oil development was responsible for elevated kit fox mortality and supports the causal pathway (+).

3.5.5. Mechanistic Sufficiency

A demographic model of kit foxes on NPR-1, between 1981 and 1986, found that the decline was caused by high mortality, particularly of young-of-the-year foxes (Floit and Barnthouse, 1991). A less detailed analysis of an equivalent model, but for the period 1981-1989, gave qualitatively similar results (U.S. DOE, 1993). Hence, mortality was the cause of the decline and vehicular strikes were responsible for approximately 15% of identified mortality (Table 7). This line of evidence supports accidents as a contributing proximate cause (+).

3.6. DISEASE

3.6.1. Spatial Co-occurrence

Necropsies provided little evidence of possible disease-induced mortality on either NPR-1 or NPR-2 between 1980 and 1995 (Cypher et al., 2000). However, it is possible that an increased frequency of nonlethal disease may have weakened foxes and thereby caused increased predation on developed areas. The absence of evidence of co-occurrence weakens disease as a cause (–).

3.6.2. Temporal Sequence

There is no evidence concerning changes in disease rates (NE).

3.6.3. Causal Pathway

The elements of the hypothesized causal pathway (humans with pets and coyotes) were present, but transport of pathogens onto NPR-1 was not documented so the pathways remain hypothetical (0).

3.6.4. Evidence of Exposure or Biological Mechanism

A serological survey for pathogens was conducted in 1981-1982 and 1984 (McCue and O’Farrell, 1986, 1988), and serum chemistry was analyzed (McCue and O’Farrell, 1992). Canine parvovirus antibodies were found in nearly all foxes, regardless of development. Antibodies for other pathogens were rare and data were insufficient to make comparisons between levels of development. The investigators presumed that if foxes were highly exposed to pathogens it would be reflected in changes in hematological parameters. Sufficient data on hematology were gathered in 1981-1982 to make comparisons between levels of development, but no differences in either mean or extreme values were found (McCue and O’Farrell, 1987). This evidence greatly weakens disease as a cause (– –).

4. STEP 4. EVALUATE DATA FROM ELSEWHERE

All candidate causes are mechanistically plausible (+). That type of evidence is not discussed, because it would not influence the relative strength of evidence for the candidate causes.

4.1. PREY ABUNDANCE

4.1.1. Stressor-Response from Other Field Studies

Numerous studies have demonstrated a positive correlation between the abundances of mammalian predators and their prey. In particular, Egoscue (1975) showed that the abundance of kit foxes (*V. m. nevadensis*) in Utah followed the abundances of black-tailed jack rabbits. That population also showed an elevated male:female ratio of pups. This relationship agrees qualitatively with the relationship at the site (+).

4.2. HABITAT ALTERATION

No evidence from elsewhere (NE).

4.3. PREDATORS

4.3.1. Stressor-Response from Other Field Studies

Coyotes were the cause of 65% of kit fox mortalities on the nearby Carrizo Plain (Ralls and White, 1995). Coyotes may also be a significant cause of mortality in populations of swift foxes (Scott-Brown et al., 1987) and gray foxes (Cypher, 1993). Field studies have documented decreases in red fox abundance in apparent response to increased coyote abundance (Harrison et al., 1989; Major and Sherburne, 1987; Sargent et al., 1987). This evidence qualitatively supports predation (+).

4.4. TOXIC CHEMICALS

4.4.1. Stressor-Response from Other Field Studies

Livestock have died from drinking produced waters at other oil fields, primarily due to osmotic burden (McCoy and Edwards, 1980). Sump waters on NPR-1 were highly saline; samples contained 1720-14,400 mg/L of sodium and four other metals were found at >1000 mg/L, which is consistent with the McCoy and Edwards (1980) study. However, kit foxes do not require drinking water, and, as desert animals, they may not be as sensitive as livestock to osmotic stress. This evidence is ambiguous (0).

4.4.2. Stressor-Response from Laboratory Studies

Four metals (cadmium, copper, molybdenum, and strontium) were found in produced waters from open sumps at concentrations above drinking water criteria, so they are potentially toxic in chronic exposures. However, there is no evidence of exposure. This evidence is ambiguous (0).

Although soils concentrations were available for the site, it was not possible to estimate exposures to these materials for comparison to toxic doses. Soil consumption is inevitable, but unquantifiable. This evidence is ambiguous (0).

4.4.3. Stressor-Response from Other Studies—Fur

Elemental concentrations in fur that are related to toxic effects are rare. Concentrations in the fur of wildlife from undeveloped areas were taken to be no-effect levels and concentrations in coyotes from the Grand Tetons National Park, Wyoming, were considered particularly relevant. These no-effect concentrations were available for 12 elements, and none of them were exceeded by NPR-1 kit foxes. Concentrations in fur from various contaminated sites were considered to represent potentially toxic levels. Finally, concentrations associated with toxic effects were available for a few elements. Comparisons are presented here for the three elements of concern for which effects or no-effects data were found (Table 8).

4.4.3.1. *Arsenic*

One fox associated with NPR-1 had 26 ppm arsenic (As) in its fur. This is much higher than concentrations in the hair of humans who died of As poisoning (3 ppm; Table 8). However, that fox lived north of NPR-1 along the California aqueduct and may have been exposed to residues of arsenical agrochemicals. That fox was alive and apparently healthy at the time that fur was collected and lived for more than a year after capture. One fox from developed NPR-1 and one from developed NPR-2 also exceeded the 3 ppm level. This suggests that human hair concentrations are not good indicators of toxic exposures to arsenic in kit foxes. No data were found for other wildlife.

4.4.3.2. *Chromium*

Chromium concentrations in NPR-1 kit foxes were within the range of concentrations in Teton coyotes and other wildlife from uncontaminated areas, so they are assumed to be nontoxic.

4.4.3.3. *Selenium*

Selenium concentrations in NPR-1 kit foxes were low relative to concentrations in rats fed toxic doses of Se, relative to humans experiencing Se toxicity, and relative to kit foxes and coyotes at Kesterson reservoir where birds experienced severe Se toxicity. They were also lower than concentrations in Teton coyotes and other wildlife.

This evidence weakens toxic chemicals as a cause, because there was no indication that the observed concentrations were related to toxicity (–).

4.5. VEHICULAR ACTIVITIES

4.5.1. Stressor-Response from Other Field Studies

The mortality rate from this cause during the period of concern (~15%) is somewhat higher than of kit fox mortalities from vehicles observed in other studies (~10%), as summarized by Cypher et al. (2000). This evidence strengthens vehicles as a cause of the decline (+).

4.6. INCREASED DISEASE

4.6.1. Stressor-Response from Other Field Studies

Mortality due to disease is hard to detect, and Cypher et al. (2000) found no documentation of epizootics in kit foxes. However, field studies have documented decreases in the abundance of other fox species associated with diseases (Nicholson and Hill, 1984). This evidence qualitatively supports disease (+).

5. STEP 5. IDENTIFY THE PROBABLE CAUSE

5.1. PROXIMATE CAUSES

Having analyzed the evidence for each candidate cause in the prior two sections, the next step is to summarize the results, determine the consistency of the evidence for each cause and determine whether there is a reasonable explanation for any inconsistencies. The individual types of evidence and the analysis across types of evidence for each cause are summarized in Tables 9-14. The consistency of the evidence is evaluated across types of evidence for each candidate cause. That is, is the evidence all positive, all negative or mixed? All candidate causes except predation had inconsistent data. The second criterion is the existence of an explanation for the inconsistencies. Explanations were developed for the inconsistencies in three candidate causes (habitat modification, prey abundance and vehicular activity) that involved converting them from candidate causes to contributors to the most likely cause.

After the evidence for each candidate cause is summarized, the evidence is compared across candidate causes to determine which one is best supported (Table 15). First, the candidate causes that can be eliminated are identified, then the most probable cause from among those that remain is identified, and finally the other candidate causes are discussed.

Although the evidence was inconsistent, disease (Candidate Cause 6) can be clearly eliminated, because the evidence from the site was negative. Very few of the trapped foxes were observed to be diseased, little evidence of disease was found during necropsies, and neither serological nor hematological analyses showed evidence of an epizootic that would account for the decline. Disease has caused population declines in other places, but this supporting evidence would be relevant only if there is some positive evidence from the site.

In contrast, evidence for predation (Candidate Cause 3) as the principal proximate cause is consistent and strong. Predation by coyotes is the major cause of death in kit foxes, and a demographic analysis showed that the decline was due to high mortality, with little influence from low fecundity or high emigration (Floit and Barnthouse, 1991).

Evidence for vehicular accidents (Candidate Cause 5) is also positive, but the mortality rate due to accidents is much lower than for predation and not sufficient to account for the decline. Hence, it was a contributing cause.

The evidence for environmental contaminants (Candidate Cause 4) was inconsistent and complex. Contaminants from oil development were present and potential routes of exposure were identified, but only two chemicals, arsenic and barium were elevated in fur from most foxes from developed NPR-1 relative to reference sites. Arsenic levels in three foxes reached levels that indicate acute toxicity in humans, but

TABLE 9

Evidence for Prey Abundance (Candidate Cause 1) Caused by Disturbance 1a, Climate 1b, or Competition (1c)

Type of Evidence	Finding	Score
Types of Evidence that Use Data from the Case		
Spatial/Temporal Co-occurrence: Developed vs. Undeveloped	1. Prey declined where foxes declined.	++
	1a. Prey decline was greatest in developed NPR-1.	+
	1b. The difference between developed and undeveloped areas is unlikely to be climatic.	–
Spatial/Temporal Co-occurrence: NPR-1 vs. NPR-2	1. Declines in foxes at both sites correspond to declines in prey.	++
	1a. Prey decline on NPR-1 in the early 1980s coincided with development.	+
	1b. The difference in timing is unlikely to be climatic.	–
Temporal Sequence	The beginning of the decline is undocumented and the data do not permit analysis of a time lag.	0
Stressor-Response Relationship in the Field	1. Kit fox abundance is highly linearly correlated with lagomorph abundance on NPR-1.	++
	1a. The correlation occurred in developed and undeveloped areas.	–
	1b. The correlation may be related to climate.	+
Causal Pathway: Prey utilization	1a. All steps in this causal pathway are present, but the relationships are qualitative.	+
	1b. Multiple lines of evidence for the climate pathway are negative or ambiguous.	–
	1c. Coyote abundance increased during the NPR-1kit fox decline, but the evidence for competition is weak to ambiguous.	0

TABLE 9 cont.		
Type of Evidence	Finding	Score
Evidence of Exposure or Biological Mechanism	1. The frequency of lagomorph remains in feces declined during the kit fox decline.	++
	1a. The decline occurred in developed and undeveloped areas.	–
	1b. The decline could have been related to climate.	+
Manipulation of Exposure	Feeding studies weakly support food limitations as a cause of kit fox mortality.	+
Laboratory Tests of Site Media	None.	NE
Verified Predictions	None.	NE
Symptoms, Starvation	Necropsies did not report starvation in kit foxes.	–
Symptoms, Reproductive	A male-biased sex ratio of pups is characteristic of malnourished females, but other stressors may also cause it.	+
	1a. The bias occurred in developed areas only.	+
	1b. The decline is unlikely to have been related to climate.	–
Mechanistic sufficiency	Reduced fecundity, the likely first effect of reduced food, was not sufficient to cause or significantly contribute to the decline.	–
Types of Evidence that Use Data from Elsewhere		
Mechanistically Plausible	Low prey abundance, by either the disturbance or climatic pathway, is mechanistically plausible.	+
Stressor-Response from Laboratory Studies	None.	NE
Stressor-Response from Other Field Studies	A study of kit foxes in Nevada showed that their abundance tracked jack rabbit abundance.	+

TABLE 9 cont.		
Type of Evidence	Finding	Score
Manipulation of Exposure at Other Sites	None.	NE
Analogous Stressors	None.	NE
Evaluating Multiple Types of Evidence as a Form of Evidence		
Consistency of Evidence	1a. The evidence is mixed.	–
	1b. The evidence is mixed.	–
Reasonable Explanation of the Evidence	The loss of lagomorph prey may have resulted in increased hunting effort and reduced the nutritional status of females which reduced fecundity but not mortality due to starvation. Hence, it may have been detrimental but not the cause of the decline.	C

C = the explanation makes the candidate cause a contributing factor for another cause.

TABLE 10

Evidence for Habitat Degradation (Candidate Cause 2) Caused by Disturbance 1a or Climate 1b

Type of Evidence	Finding	Score
Types of Evidence that Use Data from the Case		
Spatial/Temporal Co-occurrence	2a. Spatial—Disturbance and the kit fox decline were greatest in developed NPR-1.	+
	2a. Temporal—The temporal pattern of production does not match fox numbers, but time lags are unclear.	0
	2b. Climatic differences are unlikely to account for differences in kit fox declines between disturbed and undisturbed or between NPR-1 and NPR-2.	–
Temporal Sequence	Data from the beginning of the production surge is lacking and the relationship at the end is ambiguous.	0
Stressor-Response Relationship in the Field	2a. Models relating disturbance to kit fox abundance had the wrong sign or no relationship.	– –
	2b. Kit fox abundance is related to plant production, but the data are for a different time period.	0
Causal Pathway	2a. All steps in the causal pathway are present, but unquantified.	++
	2b. Kit fox numbers were not related to precipitation during the period of decline. Evidence for the full causal pathway is limited to a drought after the period of concern.	–
Evidence of Exposure or Biological Mechanism	No evidence.	NE
Manipulation of Exposure	No evidence.	NE
Laboratory Tests of Site Media	No evidence.	NE
Verified Predictions	No evidence.	NE

TABLE 10 cont.		
Type of Evidence	Finding	Score
Symptoms	No evidence.	NE
Mechanistic sufficiency	Because habitat could affect mortality, fecundity and emigration, the demographic models cannot be used to determine the mechanistic sufficiency of habitat modification.	0
Types of Evidence that Use Data from Elsewhere		
Mechanistically Plausible	The mechanism is plausible.	+
Stressor-Response from Laboratory Studies	No evidence.	NE
Stressor-Response from Other Field Studies	No evidence.	NE
Manipulation of Exposure at Other Sites	No evidence.	NE
Analogous Stressors	No evidence.	NE
Evaluating Multiple Types of Evidence as a Form of Evidence		
Consistency of Evidence	1a. The evidence is inconsistent.	–
	1b. The evidence is negative or ambiguous.	– –
Reasonable Explanation of the Evidence	The difference in habitat between developed and undeveloped NPR-1 may have an indirect effect through prey or predator abundance.	C

C = the explanation makes the candidate cause a contributing factor for another cause.

TABLE 11

Evidence for Predators (Candidate Cause 3)

Type of Evidence	Finding	Score
Types of Evidence that Use Data from the Case		
Spatial/Temporal Co-occurrence: Developed vs. Undeveloped	Coyote abundance was greater on developed NPR-1 where the decline was greatest.	+
Spatial/Temporal Co-occurrence: NPR-1 vs. NPR-2	Coyote abundance on NPR-2 was irregular and did not correspond to kit fox abundance patterns except that both dropped in the late 1980s, after the period of concern.	0
Spatial/Temporal Co-occurrence: Temporal co-occurrence on NPR-1	Coyote abundance increased between 1979 and 1984, the period of kit fox decline, but the pattern of abundance between those dates in unknown. From 1985 to 1991 coyotes declined and kit foxes were stable.	+
Temporal Sequence	The low abundance of coyotes in 1979 suggests that an increase in coyote abundance did not precede the decline in kit foxes, but the timing of the coyote increase and the beginning of the kit fox decline are unclear.	NE
Stressor-Response Relationship in the Field	Relationships could not be developed until after the period of decline.	NE
Causal Pathway	The elements of a causal pathway from oil development to coyote predation on kit foxes were observed.	+
Evidence of Exposure or Biological Mechanism	Necropsies demonstrated that most mortalities were caused by coyotes.	++
Manipulation of Exposure	Killing coyotes was associated with decreased kit fox mortality.	+

TABLE 11 cont.		
Type of Evidence	Finding	Score
Laboratory Tests of Site Media	No evidence.	NE
Verified Predictions	No evidence.	NE
Symptoms	No evidence.	NE
Mechanistic sufficiency	The decline was due to mortality and 80% of mortality was due to predation.	+++
Types of Evidence that Use Data from Elsewhere		
Mechanistically Plausible	This mechanism is plausible.	+
Stressor-Response from Laboratory Studies	No evidence.	NE
Stressor-Response from Other Field Studies	Other studies of coyote predation on foxes show high rates and reduced fox abundances.	+
Manipulation of Exposure at Other Sites	No evidence.	NE
Analogous Stressors	No evidence.	NE
Evaluating Multiple Types of Evidence as a Form of Evidence		
Consistency of Evidence	All evidence is positive.	+++
Reasonable Explanation of the Evidence	None needed.	NA

TABLE 12

Evidence for Toxic Chemicals (Candidate Cause 4)

Type of Evidence	Finding	Score
Types of Evidence that Use Data from the Case		
Spatial/Temporal Co-occurrence	Toxic chemicals were found on the site during the period of kit fox decline.	+
Temporal Sequence	Increased drilling activity may have increased exposure to toxicants but the temporal sequence is uncertain.	0
Stressor-Response Relationship in the Field	Kit fox longevity was not negatively correlated with contaminant concentrations in fur.	–
Causal Pathway	Soil—routes of exposure to soil exist, but contaminant concentrations were not elevated in random soil samples from developed NPR-1.	–
	Wastes—spills and deposits of waste were present and available for direct or indirect exposure.	+
	Water—waste waters were highly contaminated, but there was no evidence of drinking by kit foxes.	0
	Petroleum—spills and sumps were available to foxes and at least one died.	+
Evidence of Exposure or Biological Mechanism	Some foxes showed elevated exposure to contaminants in the developed area of NPR-1 or on NPR-1 as a whole.	++
Manipulation of Exposure	None.	NE
Laboratory Tests of Site Media	None.	NE
Verified Predictions	None.	NE

TABLE 12 cont.		
Type of Evidence	Finding	Score
Symptoms	None.	NE
Mechanistic sufficiency	The toxic effects, if any, could not account for the elevated mortality rate that induced the decline.	–
Types of Evidence that Use Data from Elsewhere		
Mechanistically Plausible	Both lethalities and sublethal debilitation due to chemicals occurring on the site are mechanistically plausible.	+
Stressor-Response from Laboratory Studies	Except for arsenic in three foxes, concentrations in fur were not at known toxic levels.	0
Stressor-Response from Other Field Studies—Water	Livestock have died from drinking produced waters, but kit foxes do not require drinking water.	0
Stressor-Response from Other Field Studies—Fur	There is no evidence that observed concentrations were toxic.	–
Manipulation of Exposure at Other Sites	No evidence.	NE
Analogous Stressors	No evidence.	NE
Evaluating Multiple Types of Evidence as a Form of Evidence		
Consistency of Evidence	The evidence was inconsistent.	–
Reasonable Explanation of the Evidence	Although contaminants were available, few foxes were exposed.	–

TABLE 13 Evidence for Vehicular Accidents (Candidate Cause 5)		
Type of Evidence	Finding	Score
Types of Evidence that Use Data from the Case		
Spatial/Temporal Co-occurrence	Most vehicle deaths occurred in developed areas.	+
Temporal Sequence	No evidence.	NE
Stressor-Response Relationship in the Field	No evidence.	NE
Causal Pathway	Vehicular activity increased on the site due to increased oil development activities.	+
Evidence of Exposure or Biological Mechanism	Necropsy of kit foxes established that vehicle collisions were the cause of death.	++
Manipulation of Exposure	No evidence.	NE
Laboratory Tests of Site Media	No evidence.	NE
Verified Predictions	No evidence.	NE
Symptoms	No evidence.	NE
Mechanistic sufficiency	This source of mortality is not sufficient to cause the decline, but it does contribute to the demographic mode of action.	+
Types of Evidence that Use Data from Elsewhere		
Mechanistically Plausible	This mechanism is plausible.	+

TABLE 13 cont.		
Type of Evidence	Finding	Score
Stressor-Response from Laboratory Studies	No evidence.	NE
Stressor-Response from Other Field Studies	The proportion of mortalities due to vehicles is a little higher than most other fox populations.	+
Manipulation of Exposure at Other Sites	No evidence.	NE
Analogous Stressors	No evidence.	NE
Evaluating Multiple Types of Evidence as a Form of Evidence		
Consistency of Evidence	The evidence was inconsistent.	–
Reasonable Explanation of the Evidence	The evidence is consistent with vehicular accidents as a contributory cause, but it would not have been sufficient alone.	C

C = the explanation makes the candidate cause a contributing factor for another cause.

TABLE 14

Evidence for Disease (Candidate Cause 6)

Type of Evidence	Finding	Score
Types of Evidence that Use Data from the Case		
Spatial/Temporal Co-occurrence	Necropsies found few disease-induced mortalities.	–
Temporal Sequence	No evidence.	NE
Stressor-Response Relationship in the Field	No evidence.	NE
Causal Pathway	Elements of the hypothesized causal pathways were present but no evidence supported their operation.	0
Evidence of Exposure or Biological Mechanism	No differences were found in serological or hematological parameters that would support disease as a cause.	– –
Manipulation of Exposure	No evidence.	NE
Laboratory Tests of Site Media	No evidence.	NE
Verified Predictions	No evidence.	NE
Symptoms	Symptoms of nonlethal disease were not recorded.	NE
Mechanistic sufficiency	Disease was not sufficient to cause or significantly contribute to the mortality that induced the decline.	– –
Types of Evidence that Use Data from Elsewhere		
Mechanistically Plausible	The mechanism is plausible.	+

TABLE 14 cont.		
Type of Evidence	Finding	Score
Stressor-Response from Laboratory Studies	No evidence.	NE
Stressor-Response from Other Field Studies	Epizootics causing decreased abundance have been observed in other fox species.	+
Manipulation of Exposure at Other Sites	No evidence.	NE
Analogous Stressors	No evidence.	NE
Evaluating Multiple Types of Evidence as a Form of Evidence		
Consistency of Evidence	The evidence was inconsistent.	–
Reasonable Explanation of the Evidence	The evidence from elsewhere was weakly positive, but the evidence from the site, which was consistently negative, was much more relevant.	–

TABLE 15

Comparison of the Strength of Evidence for the Candidate Causes. Types of evidence with no evidence for any candidate cause were excluded.

Types of Evidence	Prey		Habitat		Predation	Toxics	Accidents	Disease
	Disturbance	Climate	Disturbance	Climate				
Evidence that Uses Data from the Case								
Spatial/Temporal Co-occurrence	++		+	–	+	+	+	–
	+	–						
Temporal Sequence	0		0		0	0	NE	NE
Evidence of Exposure or Biological Mechanism (Pathway independent)	++		NE	NE	+ +	+ +	+ +	– –
Evidence of Exposure or Biological Mechanism (By pathway)	–	+						
Causal Pathway[a]	+	–	+ +	–	+	+	+	0
Stressor-Response Relationships from the Field (pathway independent)	+ + +		– –	0	NE	NE	NE	NE
Stressor-Response Relationships from the Field (by pathway)	–	+						
Manipulation of Exposure	+		NE	NE	+	NE	NE	NE
Symptoms, Starvation[b]	–		NE	NE	NE	NE	NE	NE
Symptoms, Reproductive[b] (pathway independent)	+							
Symptoms, Reproductive[b] (by pathway)	+	–						

TABLE 15 cont.

Types of Evidence	Prey		Habitat		Predation	Toxics	Accidents	Disease
	Disturbance	Climate	Disturbance	Climate				
Mechanistic Sufficiency	–		0		+++	–	+	– –
Evidence that Uses Data from Elsewhere								
Mechanistically Plausible Cause	+	+	+	+	+	+	+	+
Stressor-Response Relationships from Other Field Studies	+		NE	NE	0	0	+	+
Stressor-Response Relationships from Laboratory Studies	NE	NE	NE	NE	–	0	NE	NE
Evaluating Multiple Lines of Evidence								
Consistency of Evidence	–	–	–	– –	+++	–	–	–
Explanation of the Evidence	C[c]		C[c]		NA	–	C[c]	–

[a]An additional causal pathway for prey abundance, competition for prey by coyotes, was ambiguous.
[b]The categories of symptoms apply only to prey abundance.
[c]The explanation of the evidence makes the candidate cause a contributor to another cause.

those foxes appeared healthy when captured and their longevity was not apparently reduced. Barium is much less toxic and, although fur levels on NPR-1 were high, they significantly overlapped with fur from reference sites. One fox died after becoming coated in oil. In sum, there was no evidence that toxic exposures could account for the high mortality rates that caused the decline.

The availability and utilization of lagomorph prey (Candidate Cause 1) were strongly related to kit fox abundance, but clinical symptoms of poor condition or starvation were not observed in trapped animals or during necropsies. Prey availability can affect fecundity and females on developed areas produced fewer pups, but the demographic analysis indicated that variance in kit fox fecundity did not significantly contribute to variance in kit fox abundance. Hence, prey availability does not appear to be a significant proximate cause. However, it may be a contributing factor in other sources of mortality. That is, fewer large prey and greater use of small prey implies more time spent hunting and greater exposure to coyotes and vehicles.

The evidence for habitat alteration (Candidate Cause 2) is ambiguous. The area devegetated is known, but the quality of habitat provided by the vegetated and devegetated areas and the affects of human activities on habitat utility for kit foxes are unknown. The fact that emigration from the developed areas exceeded emigration from the undeveloped areas suggests that habitat quality was lower in developed areas.

6. SOURCES

Although causal analysis must begin by identifying the proximate cause, the source of that cause must be identified in order to plan management actions. Hence, we must ask why coyote abundance and associated mortality increased in the early 1980s.

Climate is a potential source of habitat alteration and reduced abundance of lagomorph prey. This region is semi-arid and a few drier than average years can reduce the fecundity and survival of lagomorph prey. However, the period of concern was not especially or consistently dry. The year with the second highest precipitation in the 30 year record occurred during the decline (Figure 14). In addition, climate would be the same for developed and undeveloped areas and for both NPR-1 and NPR-2. Hence, just as climate can be eliminated as the cause of kit fox decline via the habitat or prey causal pathways (1b and 2b), it cannot be the cause of increased coyote numbers or predation in the early 1980s. The later dry period of 1988-1990 shows that low precipitation can produce a clear signal: production of plants and abundance of lagomorphs, coyotes and kit foxes all declined. Therefore, climate can be eliminated as the source of the decline.

Disturbance due to oil development and production is a source of habitat alteration and reduced prey abundance. Evidence for the effects of disturbance comes primarily from comparisons of developed and undeveloped areas of NPR-1. The decline in both kit foxes and lagomorphs was greater on developed than undeveloped NPR-1. Although the mechanism is unclear, it seems likely that some aspect of active oil development contributed to the decline. However, it is possible that the differences in the demographics of kit foxes and lagomorphs between developed and undeveloped areas were due to natural differences.

Counterintuitively, disturbance may also be a source of increased coyote abundance. Coyotes were more abundant on developed than undeveloped NPR-1 during the decline. Prior to the coyote control program, site development may have improved coyote habitat by keeping hunters off the site and by providing sources of fresh water, discarded food and road kills to be scavenged. Cypher and Spencer (1998) suggested that the availability of anthropogenic food resources may have increased coyote abundance and predation of kit foxes on the Elk Hills.

Diseases in coyotes may also be sources of changes in coyote abundance. The low observed abundance of coyotes in 1979 may have been due to disease. Between 1972 and 1983 the prevalence of antibodies against canine parvovirus in wild coyotes captured in three western states coincided with the epizootic of the disease in domestic dogs (Thomas et al., 1984). It is a significant potential pathogen for wild canids, and it was believed to be linked with declines in coyote numbers (Cypher et al., 2000). There is no known evidence of a parvovirus epizootic in coyotes in the San Joaquin Valley, but kit foxes tested on NPR-1 carried parvovirus antibodies. It is possible that the increase in coyotes was a rebound from parvovirus and that kit foxes are resistant. However, that hypothesis suggests that the high abundance of coyotes in 1985 reflected the peak of a population that oscillates over long time periods. That would suggest in turn that kit foxes are normally rare or absent in the developed areas of NPR-1.

The final conceptual model for the cause of the kit fox decline is presented in Figure 16. The proximate cause is predation. The mechanism is mortality which is shared with vehicular accidents, so accidents are a contributor but are not sufficient. The source of the increased predation is much less clear. However, the availability of prey and other food are likely contributors. The coyote control program is a likely source of the decline in coyote abundance that ended the kit fox decline, but reduced prey abundance may have also contributed.

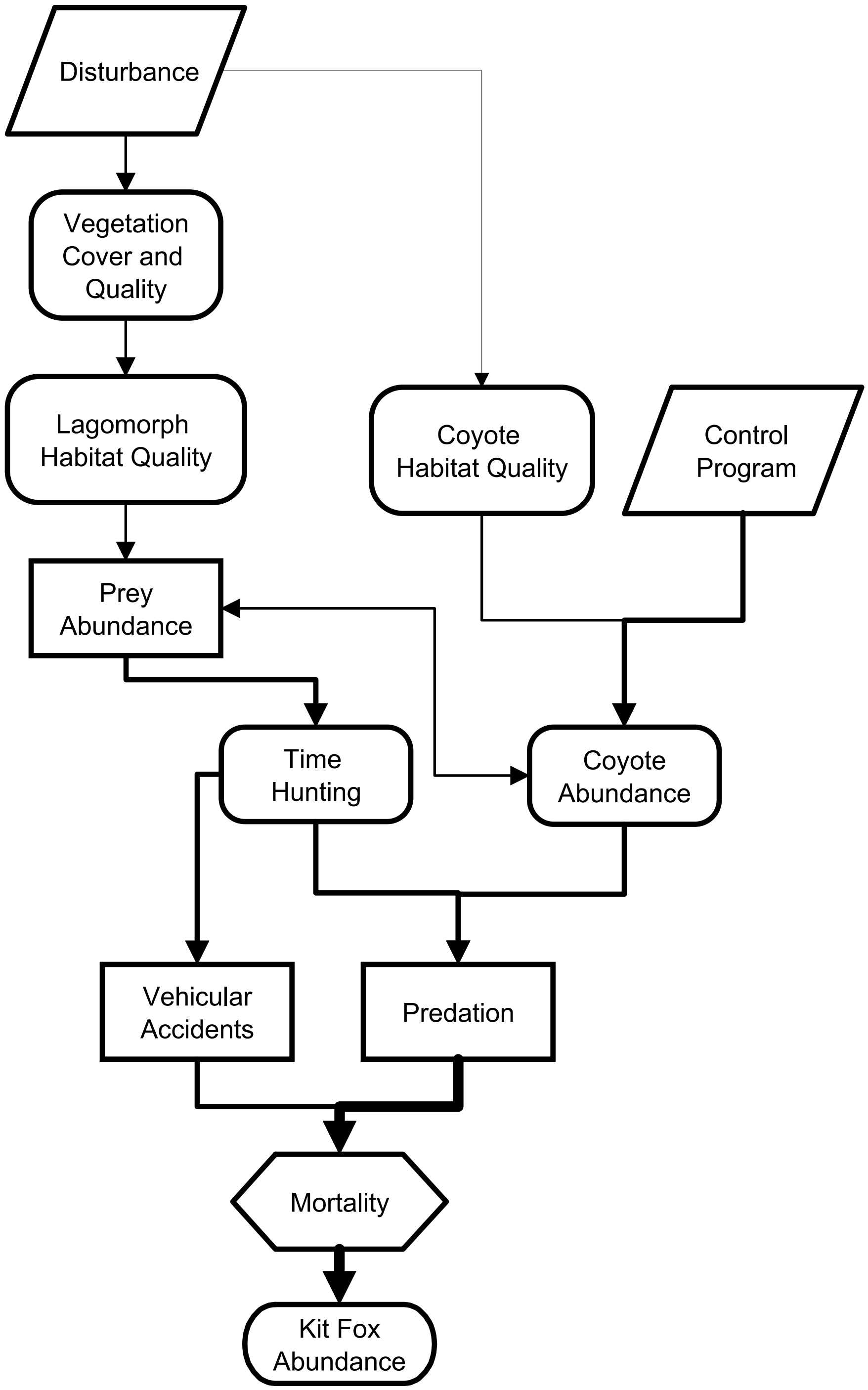

FIGURE 16

The Final Conceptual Model for the Cause of the Kit Fox Decline. The thickness of the arrow lines indicates the degree of confidence in the causal connection.

7. LATER STUDIES AND OTHER ATTRIBUTIONS OF CAUSE

The kit fox demographic studies continued on the NPR sites until 1995 (Cypher et al., 2000). Kit fox numbers rose from 1991-1994, reaching nearly the same level as in 1981. They then dropped in 1995 to the same levels as in the mid 1980s. Prey abundances followed a similar pattern. Kit fox numbers were very low in 1991 due to a preceding period of consistently dry years with very low vegetation production, and the recovery was associated with higher precipitation.

Spotlight survey of kit foxes on the Elkhorn Plain (on the northeastern side of the Carizo Plain; Figure 4) by the California Department of Fish and Game found a decline of approximately 50% between 1980 and1994 (Ralls and Eberhardt, 1997). In contrast, 1994 was a year of extremely high kit fox abundance on the Naval Petroleum Reserves (Cypher et al., 2000). This is weak evidence, but it supports the idea that local forces can override a regional source such as climate.

The U.S. DOE’s (1993) supplemental EIS attributed the decline to precipitation, based on a comparison of the 3 and 5 years before 1981 to those after and to unspecified effects of development. They confused the nearly constant proportion of mortality that was due to predation with a nearly constant predation rate. This error created the mistaken impression that there was not sufficient variation in predation to cause the variation in kit fox mortality or abundance.

Cypher et al. (2000) thoroughly reviewed available information concerning the cause of variance in kit fox abundance. They concluded that kit fox abundance was driven by precipitation in the previous year. However, they lumped data from kit foxes on both NPRs and some adjoining areas and they included data out to 1995. The differences between their results and the results of this analysis of the decline on NPR-1 in the early 1980s illustrate the importance of scale in causal analysis.

8. CONCLUSIONS

The available evidence indicates that the cause of the kit fox decline in the early-to-mid 1980s was increased predation by coyotes. The cause of the increased predation appears to have been increased coyote abundance and, when prey declined, increased kit fox susceptibility due to increased time out of the dens, hunting. The cause of the increased coyote abundance is unclear. The kit fox decline ended after a coyote control program was instituted and coyote numbers declined.

The elimination of toxicants and diseases as causes has practical management implications. No additional measures need be taken to eliminate exposures to toxicants or to reduce the introduction of pathogens. The prior assessment of contaminant risks to kit foxes was sufficient to allay the concerns of stakeholders (Suter et al., 1992). However, this assessment is superior in two respects. First, the use of a formal causal analysis method provides greater assurance of the quality of the results. Second, identification of the likely proximate cause provides increased confidence that the negative results for contaminants were not a result of inadequate data or analysis.

The implications of coyote predation for management are less clear, because the cause of the increase in coyotes is unclear. However, the finding that precipitation is not absolutely or invariably determinate of kit fox abundance should encourage management actions. These might include revegetation to increase prey abundance, preservation of kit fox dens which provide cover from predators, coyote control, and, in extreme situations, supplemental feeding. All of these were practiced on NPR-1 for some time and to some degree, but it is not clear how successful any of them were. However, the endangered status of kit foxes could justify adaptive management studies to determine the most efficacious practices.

9. LESSONS LEARNED

Be clear about the difference that defines the impairment. In prior Stressor Identification and CADDIS case studies, the impairments have been defined as a condition that was considered impaired by comparison to a reference site or a regional reference. In this case, the impairment was defined as a decline in abundance over a defined temporal interval.

Obtain a baseline. When, as in this case, an impairment is defined by a time series, it is particularly desirable to include a time period prior to the onset of the impairment. In this case, that would have meant beginning the monitoring activities on NPR-1 prior to the increased development in 1974, or at least before implementing the legal mandate for production at the maximum efficient rate in 1976. A semi-quantitative survey of kit foxes was performed in 1979 and the kit fox demographic surveys began in 1981 (eight years after development increased).

Monitor the potential causes and sources. Lagomorph monitoring began along with kit fox monitoring, but full prey monitoring began two years later. Vegetation production was monitored only in a small plot seven years later, and precipitation and soil moisture were not monitored on site. Regular coyote surveys began in 1985. Site contamination was measured erratically, but contamination studies aimed at kit fox exposures did not begin until nine years later. Ideally, a problem formulation should precede any monitoring program including the development of conceptual models of the hypothesized causal relationships.

Allow for time lags when analyzing evidence of temporal co-occurrence. Although this advice occurs in CADDIS, lags have not been demonstrated in prior case studies. In the long-term multi-site study, prey abundance lagged one year and kit fox abundance lagged two years behind precipitation (Cypher et al., 2000). Time lags in this study were less clear, but also ranged from 0-2 years.

Avoid spatially or temporally diluting causal relationships. The impetus for assessing kit fox abundance on NPR-1 was to determine the effects of the increase in production as required by NEPA and then to determine the cause of the observed decline in the early 1980s in response to the U.S. FWS's 1987 Biological Opinion. However, the final causal analysis commissioned by the U.S. DOE lumped NPR-1 with NPR-2 and modeled combined data from 1983-1995 (Cypher et al., 2000). Because the analysis was spatially and temporally extensive, it identified a spatially and temporally extensive cause, precipitation. However, precipitation does not explain the biological trends in the early 1980s.

Consider the mandate for the causal assessment. If the mandate is to assess contaminants as a cause, as in a Superfund assessment, this causal assessment is complete. Contaminants were not supported as a cause by the evidence, and other causes were. However, if the mandate were to manage the kit fox population, the assessment narrows the range of concerns and is suggestive of management options but is not conclusive.

Consider alternative causes. Although the evidence for contaminants was weak to negative, they might still have been suspect if alternative causes had not been supported by evidence.

Use internal measures of exposure (i.e., body burdens, biomarkers, and immunological markers) when possible. If sufficient reference data are available for comparison, concentrations of contaminants in biological samples can be used to determine whether exposures are occurring. Specific contaminants that are not elevated can be eliminated. Biomarkers that are specific to a chemical or class of chemicals could be used equivalently. However, body burdens and biomarkers of exposure are, at best, weak positive evidence unless they can be linked to effects in an exposure-response relationship. Immunological markers can be used equivalently to determine whether organisms have been infected by specific pathogens.

Obtain data from multiple reference sites. Comparisons of elemental concentrations in fox fur from developed and undeveloped locations were misleading. That was not apparent until data were obtained from other reference sites.

Source identification may need to be integrated. Stressor Identification and CADDIS were designed to determine the most likely proximate cause in impaired water bodies. Under the Clean Water Act, sources are identified and the pollution load is apportioned among them in a separate step after the cause is identified. However, in some contexts of causal analysis, it is expected that the source will be identified along with the cause. In addition, sources must be distinguished in some cases to identify the proximate cause. The separation of causal pathways from climate and petroleum development was important because some evidence clearly supports one causal pathway and not the other. Finally, source identification suggests which management actions are likely to be successful. This case study shows how that integration can be accommodated within the CADDIS methodology, but the approach depends on the nature of the cause. If the cause had been a chemical contaminant or pathogen, a separate step would have been required for source identification with a different inferential approach. However, if the cause is a change in a species such as an increase in a predator or a decrease in prey, then the same inferential approach may be used. In addition, source assessment is constrained by the definition of the cause. If the proximate cause can be clearly defined, as with prey abundance, the integration is easy, because there are few sources and only the causal pathways are different. However, habitat quality for kit foxes cannot be clearly defined or quantified, so the entire analysis is devoted to aspects of the sources of habitat modification. In the case of predation, the sources of increased coyote abundance were potentially numerous and unclear (because coyotes were counted but not studied), so a formal analysis of sources could not be performed.

Adapt the SI and CADDIS methodology as needed. Although the essential features of the methodology (comparison of multiple candidate causes by weighing multiple types of evidence using a formal scoring system) must be retained, the details should be adapted to fit the case at hand. Two modifications were used in this case. (1) The demographic modeling results did not fit any of the standard types of evidence, so a new type (mechanistic sufficiency) was developed for this case. This type of evidence is used when causal mechanisms can be identified and quantified and differ among the candidate causes. (2) In addition, a new explanation of inconsistent evidence was developed. The SI and CADDIS guidance allows for the "reasonable explanation of the evidence" to explain how all evidence could be consistent (the cause is true) or inconsistent (the cause is eliminated) if certain suppositions are true. In this case we explain how inconsistent evidence could be shown to be consistently positive or negative if the candidate cause were a contributor to the true cause. For example, it could be part of the causal pathway to the true cause or it could act additively with the true cause through a common mode of action.

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